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STAT

Powder Metallurgy

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Chapter V

BAKING

(A) EQUIPMENT AND TECHNOLOGY

Pressed semifinished products do not possess sufficient strength to be put into use directly. The operation of baking consists of annealing compacts at a temperature below the melting point of the basic component and has for its purpose an improvement in the mechanical properties of products. Sometimes, as has been pointed out in Chapter VI, it is necessary to resort to a supplementary processing after baking in order to obtain the desired properties.

Furnaces

In the baking of metalloceramic products, furnaces of the most varied type are used both with respect to design and to the method of heating. The type of furnace depends on many factors -- the manner of baking on the protective atmosphere, temperature and length of exposure), the manner of cooling, the composition of the product, the number, sizes and shapes of products, etc. The selection of the manner of baking depends in its turn very much on the equipment being used at an enterprise.

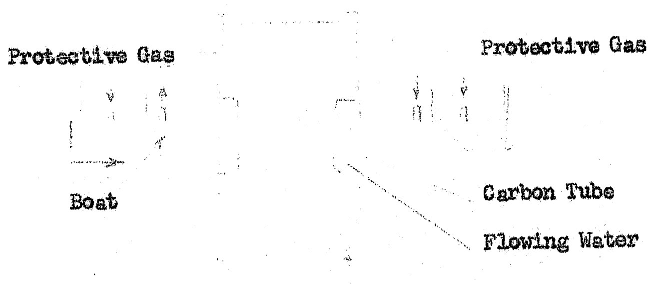


Figure 85. Tammann's Furnace.

Electrical resistance furnaces with Nichrome or "Fekhral" coils are suited for baking at a temperature of 1050-1100 degrees, gas and oil up to 1200 degrees, a electrical furnaces with Silit resistors up to 1350 degrees, and molybdenum furnaces up to 1400 degrees. The so-called Tamman furnaces used in the manufacture of hard alloys (Figure 85), which are heated by having an electrical current pass through a carbon tube, produce a temperature up to 2000 degrees. High-quality furnaces (Figures 86, 87) can operate at a temperature of 2000-3000 degrees. Finally, in order to obtain the highest temperatures ranging up to 3200 degrees for baking refractory metals, heating is done by passing electrical current directly through the object being baked in so-called welding hoods (Figure 88).

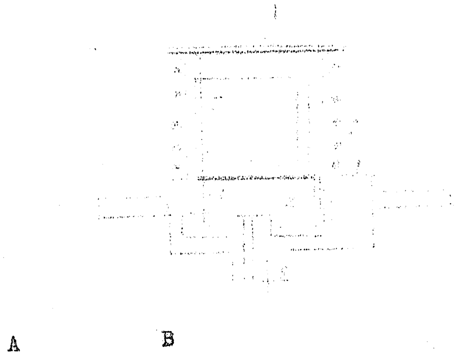
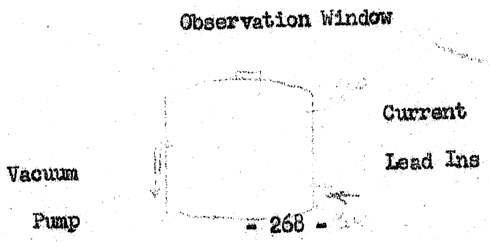


Figure 86. High Frequency Furnace.

1 - fireproof base; 2 - water compression; 3 - quartz pipe; 4 - mica cover; 5 - product being baked; 6 - iron disk; 7 - quartz pipe; 8 - connecting pipe for introducing protective atmosphere.



Box or tunnel furnaces of the ordinary type may be used when loading products to be baked in a closed-in box. If there is used as a protective medium a packing (such as a packing of petroleum coke when baking bronze-graphite bearings), then the same compartments may also be used for the comentation of products. When the protective medium is a gas, the compartment is provided with pipes (Figure 89) for the circulation of the protective atmosphere.

Metalloceramic products because of their porosity are especially inclined to oxidize and, when air is being forced through, they are apt to oxidize not only on the outside but throughout the entire mass. For this reason it is necessary to carry on not only baking but also cooling in a protective medium. In this connection the more improved models of furnaces are designed with a view to decreasing loss of heat and cutting down the expenditure of protective gas in cooling. This is achieved in furnaces of two types -- bell-type and tubular with cooling devices.

The bell-type furnace is shown in Furnace is shown in Figure 90. It has two shells -- an inner case with a lead-in for the circulation of the protective atmosphere which shields the products being baked and an outer heating case with electrical coils. When baking is over, the outer case is removed and placed over another inner case previously prepared for baking. In this way, on the one hand, there is achieved an economy of electricity for preliminary heating of the outer case, and on the other hand, the cooling of products is speeded up, resulting in a decreased expenditure of protective gas.

The most effective type of apparatus is to be found in the

The most effective type of apparatus is to be found in the tubular furnaces provided with cooling devices (Figures 91 and 92). The cooling device consists of a chamber with double walls in between which flowing water circulates and in which products cool rapidly (in about 30 minutes) down to room temperature in a protective atmosphere. Tubular furnaces are frequently supplied with push rods or conveyers for passing the product through the furnace. The protective gas enters the furnace on the principle of a countercurrent passing from the refrigerating chamber to the loading end. Losses of heat and protective gas in cooling are reduced to a minimum in tubular furnaces. Tubular furnaces that provide for the automatic moving of baked objects assure the obtaining of the most standardized production.

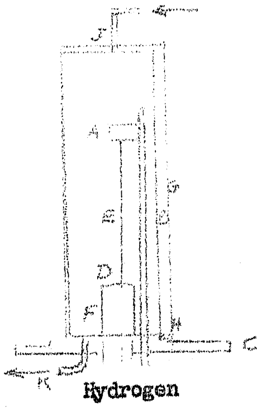


Figure 88. Apparatus for Sintering Bars.

A - upper clamp; B - hollow copper pipe; C - base; D - lower clamp; E - bar being baked; F - mercury contact; G - belljar with water jacket; J and K - hydrogen inlet and outlet.

Figure 89. Baking Box.

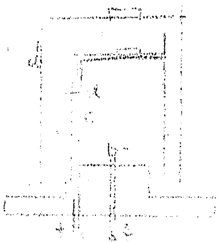


Figure 90. Hood Furnace.

a - inner case; b - base for furnace; c - coil; d - outer case; e and f - inlet and outlet for gas.

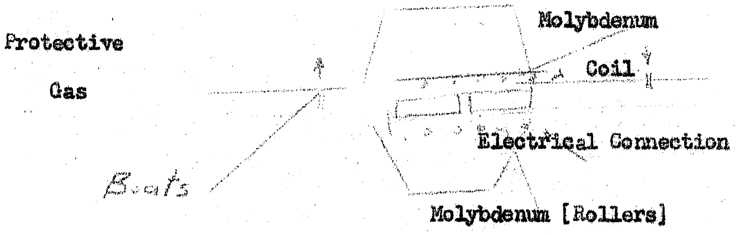


Figure 91. Tubular Molybdenum Furnace.

[Illustration]

Figure 92. Tubular Furnace.

Protective Medium

In baking the following diverse demands are made of a protective medium:

(1) to provide for the reduction of oxides;

(2) to prevent undesirable contamination of products (by soot, formation of carbides, nitrides, etc.);

(3) to prevent undesirable combustion during baking of individual components (such as of carbon in hard alloys);

(4) to serve as a safety factor during the baking process;

(5) to be as economical as possible.

In this connection, the selection of a protective medium strongly depends on the composition of products, the type of furnace, economic considerations, etc. Thus, pure oxygen may be used in small furnaces, but its use in large furnaces is connected with the possibility and danger of an explosion.

All kinds of packs are used as a protective medium -- coal, graphite, metal shavings; reducing and protective gases -- oxygen, generator gas, products of incomplete combustion from illuminating or natural gas, ammonia gas, etc.; combinations of a protective atmosphere with a protective filler, etc.

In baking, hydrocarbons are decomposed with the formation of soot on products. For this reason, gases with a considerable content of hydrocarbons, such as illuminating or natural gas, methane, propane, should be subjected to partial combustion. Figure 93 shows the relation of the composition of a partially combusted natural gas to the composition of air in the mixture, Figures 94 and 95 equipment for partial combustion.

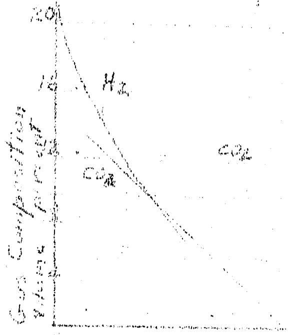


Figure 93. Relation of the Composition of a Partially Burned Natural Gas to the Composition of Air in the Mixture [194].

Figure 94. Apparatus for the Incomplete Combustion of Illuminating or Natural Gas.

Figure 95. Apparatus for the Partial Combustion of Illuminating or Natural Gas.

1 - cooling chamber; 2 - indicator for showing the speed with which air is being supplied; 3 - indicator for showing with what speed gas is being supplied; 4 - butterfly valve for air; 5 - valve for gas; 6 - gas reduction valve; 7 - motor; 8 - water separator; 9 - air pump; 10 - condensing pot; 11 - air pump regulator; 12 - oil separator; 13 - returning gate valve; 14 - manometer; 15 - throttle valve for combustion chamber; 16 - opening for ignition; 17 - dust filtering of air; 18 - reduction air valve; 19 - combustion chamber; 20 - pyrometer.

When baking metals which do not combine with carbon and form easily reduced oxides, such as copper, tin bronze, etc., one may use any kind of protective atmosphere, - coal filler, generator gas, partially burned natural gas, etc.

When baking iron or its alloys it is necessary to take into consideration the possibility of the formation of combined carbon through reaction to the protective medium. It is necessary for this reason to control the CO and CO_2 content of the protective gas in such a way as to avoid both oxidation and carbonization of the iron. The curves of Figures 96 and 97 aid in the selection of the necessary concentration of protective gas for the baking of iron.

When baking tungsten and refractory metals, which easily form carbides, pure oxygen is used as a protective atmosphere. The oxygen upon leaving the baking furnace is freed of water vapor by being passed through water-cooled condensers and columns containing drying agents ($CaCl_2$, NaOH, H_2SO_4, etc.), after which it is reused in the baking process. The diagram showing the circulation of oxygen is given in Figure 98.

When baking hard alloys, it is necessary on the other hand to take special measures to prevent the combustion of carbon (by using carburizing packs, especially when baking in molybdenum furnaces).

If the material being baked contains metals which form oxides difficult to reduce (such as chromium, aluminum, etc.), the presence of CO_2 and H_2O should be avoided in the protective gas. Baking is usually carried on in such cases in a very dry oxygen which is let in through columns containing water absorbing agents (calcium chloride, caustic soda, H_2SO_4) into a furnace containing metal shavings.

Baking should be carried on in a vacuum of such metals as tantalum which show a marked affinity towards all gases except inert gases.

In baking, it is practical to use for a protective atmosphere in baking by-products and waste from manufactures (such as waste oxygen from the electrolysis of sodium chloride).

(B) PROCESSES WHICH TAKE PLACE IN BAKING

The following fundamental processes take place when baking pressed or unpressed powders:

(1) Increased atomic activity due to increased temperature.

(2) Change in the size of contact surface of particles. In baking the size of contact surface quite frequently increases. Even where the absolute size of contact surface decreases because of an increase in grain size, the proportion of contact sectors in relation to the total surface of particles increases in a number of cases.

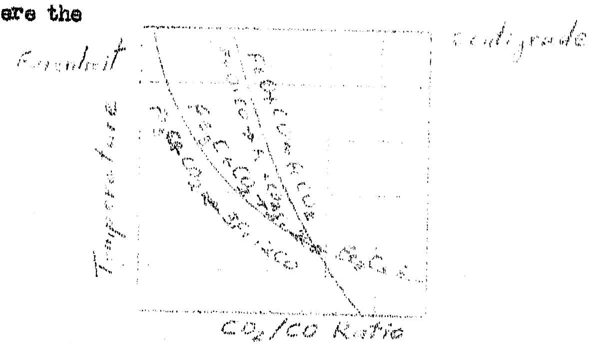


Figure 96. Effect of CO/CO_2 Mixture on Iron [194].

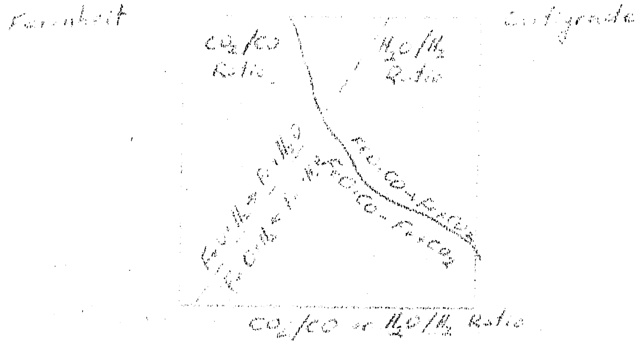


Figure 97. Effect of H_2/H_2O Mixture on Iron [194].

(3) Absorption of residual stresses localized places of contact. As a result of baking, the contact sufrace is transformed from one with [residual] stresses to one without [residual] stresses.

(4) Recrystallization. Grain growth takes place through

contact sectors and thus is a manifestation of the process of change in contact surface.

(5) Change of the entire surface of particles. This also occurs in connection with change in the size of contact surface since the growth of contact sectors always takes place as a result of a transfer of atoms both from other (free) surface sectors and from within particles.

(6) Shifting of position of particles connected with a change in the volume and porosity of powder bodies. It also depends on the size and character of contact.

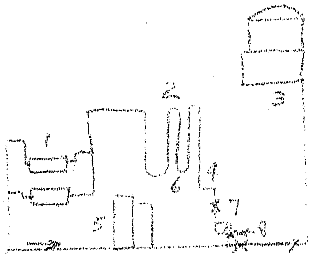


Figure 98. Arrangement for Introducing Protective Gas.

1 - furnaces; 2 - drying of gas; 3 - gas source; 4 - contact furnace; 5 - washing; 6 - condensate; 7 - pressure regulator; 8 - pump.

(7) Reduction of oxides and removal of absorbed and connected liquids and gases. This process is connected with a qualitative change in contact. Non-metallic contact between particles through a layer of admixture becomes a metallic one.

(8) Change in physical and mechanical properties resulting

from a change in the size and character of contact between the structural elements of a metal powder. The cohesion of compacts is due principally to the mechanical interlocking of powder particles. The cohesion of a baked material is due to adhesion due to the action of electrical force among grain atoms. The particle, an individual and isolated body, is the basic structural unit for non-baked powders and compacts. A baked metal is no longer a conglomerate of isolated bodies and is a conglomerate of grains (crystallites) in the same way as a cast metal.

In this way all manifestations observed in baking powders are directly or indirectly connected with quantitative and qualitative changes in contact among particles. For this reason it is expedient to give the term "baking" the following definition:

Baking refers to the quantitative and qualitative change of contact among particles (bodies) caused by the mobility of atoms due to temperature. (A distinction should be made between baking as a process and as an operation. The definition in the text refers to baking as a process. The operation of baking would be best defined as the thermal treatment below the melting point of the basic component of the material which has for its purpose a change along a desired direction of physical and mechanical properties of the powder material being baked). As a result of the quantitative change of contact during baking, the size and disposition of contact sectors as well as the relation of free to contact surfaces of particles also changes; as a result of the qualitative change, non-metallic contact becomes metallic and stress contact changes to one without stress.

Atoms are not stationary but oscillate in relation to a position of equilibrium. The amplitude of such oscillations increases with temperature. For this reason the position of atoms in a lattice becomes less stable with an increase in temperature so that the number of atoms increases which crosses from one knot of a lattice to another of the same or of a neighboring crystal. It would be more practicable to select as a measure of the mobility of an atom the rate of its displacement from a given position of equilibrium. The average "speed" v ("mobility") with which an atom leaves a particular position of equilibrium (120, 121, 5) is expressed by the formula

$$v = ae^{\frac{-Q}{RT}},$$

where "a" is the constant coefficient, "e" the foundation of natural logarithms, "Q" the energy of activation necessary for displacing an atom from a particular position of equilibrium, "R" a gaseous constant, and "T" the absolute temperature.

The different atoms of a crystal possess varying mobility. As Table 16 shows, the atoms on the surface are surrounded by a smaller number of attracting neighboring atoms than those inside the crystal. The smaller the quantity of neighboring atoms the less is the energy of activation and the greater is the mobility of atoms.

[see following page for Table 16]

For this reason the less mobile atoms are those lying within the crystal and within the sectors of contact surface; then there are disposed in order of decreasing mobility: atoms along the junctions

Table 16

NUMBER OF NEIGHBORING ATOMS SURROUNDING ATOMS LYING IN DIFFERENT PARTS OF A CRYSTAL WITH A SIMPLE CUBIC LATTICE

		Number of Neighboring Atoms A	
No. in Order	Position of Atoms	At a Distance Equal to a Parameter of Lattice	At a Distance Less than 2 Parameters of Lattice
1	Within a Crystal or within the contact surface of two identically oriented crystals	6	26
2	In the vertexes of internal angles or at the point of contact of three identically oriented crystals	6	25
3	On the sides of internal angles or on the boundary of the contact surface of two identically oriented crystals	6	23
4	On the surface of a crystal	5	17
5	On the sides of external angles	4	11
6	In the vertexes of external angles	3	7

of several contact sectors and in the vertexes of internal angles, atoms on the boundaries of two contact sectors and on the sidesof internal angles, atoms in surface depressions, atoms on surface protrusions and elevations and along sides of external angles; atoms in the vertexes of external angles (with the condition that the smaller the angle the greater the mobility of atoms).

[see following page for Table 17]

As Table 17 shows, with an increase in the size of crystals there is a decrease in the number of mobile surface atoms (approximately in inverse proportion to linear dimensions). The number of the more mobile atoms along the sides ("linear" atoms) and in the vertexes of angles ("point" atoms) decreases even more rapidly. Their number decreases in inverse proportion to the square and cube of the linear dimensions of the crystal.

At first glance an examination of Table 17 would create the impression that the number of the more mobile atoms, especially along the sides and in the vertexes of angles, is most insignificant (even when the fact is taken into consideration that thanks to surface unevenness their actual number is considerably greater than when computed for the proper geometric form) and that they could not exert a perceptible influence on the baking process. However, an insignificant number of the more active atoms is in many cases more than compensated by their great mobility. Thus, at room temperature the mobility of copper atoms on a free surface is 10^{21}-10^{36} times, at 727 degrees 4 million to 100 billion times, and near melting point at 1077 degrees 80 thousand to 100 million times greater than for of several contact sectors and in the vertexes of internal angles, atoms on the boundaries of two contact sectors and on the sidesof internal angles, atoms in surface depressions, atoms on surface protrusions and elevations and along sides of external angles; atoms in the vertexes of external angles (with the condition that the smaller the angle the greater the mobility of atoms).

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RELATIVE NUMBER OF DIFFERENT ATOMS IN RELATION TO THE DIMENSIONS OF A CRYSTAL WITH A SIMPLE CUBIC LATTICE

Number of Atoms for the Side of a Cube	Total Number of Atoms	Percentage of Surface Atoms (in Relation to Sum Total of Atoms	Percentage of Atoms along Sides		Percentage of Atoms in Vertexes of Angles	
			In Terms of All Atoms	In Terms of Surface Atoms	In Terms of All Atoms	In Terms of Surface Atoms
2	8	100	100	100	100	100
10	10^3	48.8	10.4	21.5	0.7	1.6
100	10^6	5.9	0.12	2	$0.8,10^{-3}$	$1.4,10^{-2}$
1000	10^9	0.6	$0.12,10^{-2}$	0.2	$0.8,10^{-6}$	$1.3,10^{-4}$
10000	10^{12}	0.06	$0.12,10^{-4}$	0.02	$0.8,10^{-9}$	$1.3,10^{-6}$
100000	10^{15}	0.006	$0.12,10^{-6}$	0.002	$0.8,10^{-12}$	$1.3,10^{-8}$

copper atoms within a crystal.

Thus one can posit from these examples and from formula (46) that on increase in temperature tends to neutralize the difference in the mobility of different atoms.

Increased mobility on the part of atoms is due not only to baking but also to the manifestations of recovery (rest), recrystallization, etc. At increased temperatures, a metal after prolonged compression by a load is deformed ("flows") as a very viscous liquid. This manifestation has been given the name of creep ("polzuchest'", viscous flow).

If the properties of a metal with respect to its entire volume tend to take on the properties of a liquid with increased temperature, the same action would apply even to a greater degree to the surface layers of particles and grains with the more mobile atoms. One may consider that during baking the sectors of free surface of particles are, as it were, in a liquid state.

The Process of Baking Powders from a Single Metal Group

In baking one group of processes helps increase the size of contact surface of particles, while another group of processes conversely helps decrease the size of contact sectors.

The principal process which contributes to a growth in the size of contact surface during baking is the displacement of atoms in the direction of contact sectors created by differences in the mobility of atoms. This process is accomplished by a drawing closer of particles or shrinkage.

To the opposite group of processes, to those which decrease the size of contact surface belong principally the absorption of residual stresses, the irregular localization of the shrinking process, and individual changes in particles. This group of processes leads to a separation of particles and to an increase in size during baking.

Finally, there are processes which in relation to the conditions of their occurrence in some cases are connected to an increase in the size of contact surface and to a drawing together of particles, and in other cases to a decrease in contact surface and drawing apart of particles.

The final results of baking an increase or decrease in contact surface, drawing together or moving apart of particles responsible for determining all the properties of the baked metal, depends on which group of processes predominates.

Each process contributing to an increase in contact surface is always connected to a drawing together of particles. On the other hand, each of the processes leading to a decrease in contact surface consists in drawing apart of particles. However, included in the sum total affect by different groups of processes there may be observed cases of decrease of contact surface accompanied by a drawing together of particles. On the basis of studying the effects of compacting and baking one may estimate that in shrinkage, which is connected to the process of drawing together of particles, a 1 percent of volumetric shrinkage corresponds to an increase of contact surface of approximately 5 percent; with a drawing apart of particles, however, caused by the absorption of residual stresses of compacting, a 1 percent increase (growth of volume) corresponds to a decrease of contact surface in the order of 20 percent or more. Let us suppose, by way of example, that the processes of drawing together during baking caused a shrinkage of 3 volumetric percent, while the drawing apart 1 volumetric percent of increase. Corresponding changes of contact surface would be an increase of 3x5 = 15 percent. Measurements of the size of contact cross section prior to and after baking showed that as a result of baking there is usually a decrease in the size of contact surface of particles even where a shrinkage of 1-2 percent occurs. On the basis of these observations one may say that a decrease and not an increase of contact surface of particles is observed to have taken place after baking.

The processes of deformation of a metal powder occurring during baking may be broken down into several groups in a way other than by the results of their action (drawing together or moving apart of particles). For example, it is possible to differentiate between deformations due to stresses distributed over a large number of particles and deformations due to the mobility of atoms localized within the limits of one or two particles. Displacements and changes in the volume and shape of particles caused by the movement of atoms may be considered as a special type of deformation due to atom mobility. This type of deformation may be broken down in turn into:

(1) "individual" or "internal" changes of particles in which atoms change their position within the limits of individual particles (change in the shape of particles);

(2) "external" "collective" change of particles in which atoms move from some particles to others (change in the shape and volume of particles).

(a) Increase of Contact Surface and Shrinkage as of the Mobility of Atoms

The mechanism for increasing the contact surface and drawing together of particles during baking is similar to the process of displacement of atoms and of change in their mobility as during recrystallization. The only difference between recrystallization and baking is that during the first period of baking which is accompanied by lower temperature, atoms are displaced principally within individual particles and along their surface, while during recrystallization they are displaced from one grain to another and across contact sectors. However, in recovery (rest), which precedes recrystallization, atoms also are displaced within individual structural elements. On the whole there is no fundamental difference even in the actual definitions of the terms "baking" and "recrystallization". Recrystallization, just as baking, is in essence due to a change in contact surface between the structural elements of a metal.

Atoms along contact sectors are less mobile than in other surface sectors.

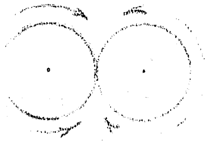


Figure 99. Drawing of Atom Surfaces Toward Places of Contact (194).

As a result of atoms drawing toward the places of contact there takes place a shrinkage and growth of contact surface of particles. One can picture shrinkage as a transition of the mobile, almost liquid, creeping matter from a free surface to places of contact and as being due to a decrease in mobility and a hardening of this matter. This process is to a certain degree similar to the drawing of ink from a blot into the capillaries of the blotting paper. Figure 99 shows a diagram of shrinkage according to Wretblad and Wulff.

The process of shrinkage, i. e., the drawing of metal to places of contact may be considered as being caused by a difference in the mobility of the atoms of free and contact sectors of surface and as being due to the action of surface tension.

Many authors (194, 18) are inclined to explain shrinkage of metal powders by surface tension. This point of view has had wide credence for the longest time in explaining the reasons for shrinkage of non-metallic powders. Thus, Tertsagi, Gersevanov, and others consider that shrinkage and increased durability in drying clay are due to the purely mechanical action of water surface tensions.

However, it should be emphasized that surface tensions may cause a displacement of only mobile and not stationary atoms and molecules. The action of surface tension is closely connected with the mobility of material. Thus, clay reacts with water and becomes viscous and mobile. If one were to add water to gold or resin powder, neither of which react to water (i. e., the mobility of their atoms or molecules would not increase as a result of this), the surface tension of the water does not cause shrinkage or increase of contact surface. Frenkel in one of his articles (120) tries to explain surface phenomena in baking as being due to surface tension and in another (121) to the mobility of atoms. Frenkel makes no final conclusions as to which point of view should be preferred.

We consider that both explanations do not so much exclude as supplement each other. (It should be pointed out, however, that in his article (120) Frenkel wrongly thinks that surface tension would cause a creep over the entire volume of the powder as in the case of amorphous bodies. In reality creep in a metal powder due to the action of surface tension is very different from the viscous flow of amorphous bodies and deforms not so much the volume as the surface of particles).

It should be remembered that certain laws of the equilibrium of forces for an absolutely solid body known to us in mechanics do not always apply to a baked metal powder. For example, let us assume that a baked metal powder is being subjected to the action of contracting and expanding forces, which according to the laws of mechanics for an absolutely solid body should be equal to zero. With respect to metal powders, however, it is much easier to decrease than to increase the action of contracting forces of the same size, so that a metal powder would expand in banking. For this reason explanations originating with the movement of atoms would be connected with smaller risk of error than those based on the action of forces.

Together with an increase in the size of contact surface there proceeds a decrease in the size of free surface of particles. This decrease is due not only to the growth of contact sectors of surface but even to a greater degree to the flowing over of the more mobile atoms from elevations into depressions. The surface profile levels out in such case. As a result of these processes the shape of particles change during heating. There was recently made public a most interesting work of Lukirskiy (71). Balls made from salt crystals changed during heating into flat-grained polyhedrals. It might appear that heating resulted in an increase in the number of mobile atoms inasmuch as the surface of a polyhedron is larger than the surface of a ball. However, one should not forget that the more mobile linear and angular atoms for such a polyhedron are fewer than in the case of a ball and that the total kinetic energy of the surfaces of atoms probably decreased during heating. (One can also conclude from Lukirskiy's work that the more mobile surface atoms are to be found not in an amorphous but in a crystalline state).

The temperature at the beginning of baking is lower than the temperature at the beginning of recrystallization (page 127 of original text) because the atoms of non-contact sectors of surface are more mobile than at places of contact. With higher temperatures during baking the processes of shrinkage and recrystallization take place concomitantly. The speed of shrinkage is approximately the same as that of recrystallization. The size of linear shrinkage may sometimes reach 20 percent of the initial size.

(b) Absorption of Residual Stresses

The absorption of residual stresses during the baking of a metal powder is a manifestation similar to recovery (rest) which takes place during the annealing of a solid metal. It is one of the more important processes leading to a decrease in contact surface and an increase in the dimensions of the metal powder. External stresses during pressing decrease the volume of a compact, while internal, on the other hand, try to increase its dimensions. A partial absorption of internal stresses takes place even at room temperature (the elastic aftereffect, Chapter IV).

The absorption of residual stresses localized at places of contact increases with an increase in temperature and in the mobility of atoms. An irreversible decrease of these stresses may proceed basically along the following channels.

(1) Reduction of residual stresses as a result of a decrease in or a total severance of contact sectors.

(2) Reduction of residual stresses at places of contact as a result of an increase in contact sectors.

(3) Reduction as a result of a heat-indiced expansion of sectors with and without stresses unaccompanied by any particularly significant change in the size of contact surface.

Where the tensile strength of compacts and the specific surface of particles are small, absorption of stresses proceeds according to the first way. But with sufficient size of tensile strength specific surface, the process of drawing matter to places of contact quickly increases strength, decreases contact stresses, and makes severance of contact impossible.

The total linear increase as indiced by the entire group of processes contributing to the drawing apart of particles rarely exceeds 5-6 percent, although, when cracks occur, it sometimes may reach 15 percent.

(c) Zonal Separation of Shrinkage

If one does not include the earlier works of the author (4), the literature of powder metallurgy up to the present time has considered manifestations of shrinkage without reference to structure.

Moreover, cases are generally known where the processes of shrinkage (drawing together of particles) indiced the formation of local ruptures and cracks, i. e., local drawing apart of particles. For example, in the drying of bread, cheese, clay, soil, etc., shrinkage is frequently accompanied by the formation of cracks. In practice, in order to prevent cracks occurring in clay, sand is frequently added, which decreases shrinkage and thereby decreases the tendency for cracks to form. Figure 120 shows characteristic cracks from shrinkage forming in asphalt, clay soil, plaster, etc. The cracks break up the material into large isolated areas (zones) reminding one in their configuration of the grains of cast metal. The formation of such separated areas may be explained only by the fact that in each of them the direction of shrinkage of particles (molecules for asphalt) was oriented as shown by arrows in Figure 100 toward the inside of the zone, as if towards its geometric center.

The boundaries of these areas of separated shrinkage are formed by cracks caused by the movement of marginal particles of neighboring zones in opposite directions.

Figure 100. Formation of Isolated Areas and Cracks during Shrinkage (Bal'shin).

a b c

Figure 101. Modification of Form.

a - original cube; b - after shrinkage; c - after expansion.

Let us consider this question in greater detail. We shall start with the simplest case where an entire baked body, such as that of a cube, shrinks as a single unit. If for each individual place of shrinkage stresses and displacements are directed towards the center, then the middle part has greater pressure than along the edges. For this reason shrinkage in the center of the cube has a maximum value, while grains which had been straight-edged become bent (Figure 101b).

The opposite manifestation is observed in the drawing apart of particles. Stresses in this case are directed from the center to the periphery, so that the center has the maximum separation of particles. For this reason the grains of a cube tend to bulge out (Figure 101c).

Let us now turn to a consideration of various cases where there are observed the formation of several or even many areas of separated shrinkage. Sometimes the reason for such a separation is to be found in the internal stresses caused by compacting. Let us assume (Figure 102) that there have been formed in a compact, which is being subjected to the action of internal stresses trying to stretch the body in a vertical direction, hidden laminated microscopic and even submicroscopic transverse cracks. These cracks break up the body into a number of transverse layers. The internal stresses try to break the connections existing between these layers. These stresses in their turn help to set up the same orientation for the stresses due to shrinkage in each separate layer (Figure 102). As a result the process of shrinkage divides even more the individual layers so that the hidden laminations of the compact are transformed during baking into clear visible cracks.

In other cases a compact may be broken up into agglutinations of particles. Each such agglutination generally becomes through baking an individual area of shrinkage. There is frequently observed the fact that, in spite of the considerable shrinkage taking place within individual agglutinations, shrinkage for the entire product is negligible and sometimes there is even an increase in its dimensions.

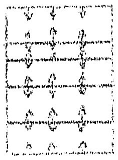


Figure 102. Diagram Showing the Formation of Hidden Layers.

Figure 103. Formation of a Hollow Core. Xr.

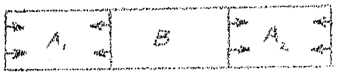


Figure 104. Drawing Explaining Increase in Size Due to Zonal Shrinkage.

Separation can take place as a result of uneven heating. Figure 103 shows a cube where the temperature had been lower in the center than at the edges. Because of considerable shrinkage in the heated edges and small shrinkage in the cold center spoilage of the so-called hollow-core type took place. Such type of damage cannot be corrected inasmuch as leveling out the temperature will not cause the hardened periphery to change but only would interfere with shrinkage in the hollow core.

From what has been said above it follows that the drawing together of particles in some places is accompanied by their separation in others. Moreover, even though at first glance it may seem to be completely impossible, the process of shrinkage may lead to an increase in the dimensions of the overall body as a result of the formation of separated zones. Let us assume (Figure 104) that for a piece of metal there are three areas of shrinkage. In the outer areas A_1 and A_2 an intensive shrinkage takes place, while in the middle area B no shrinkage occurs. The resolving forces of shrinkage are shown in Figure 104 by means of arrows. Thus, shrinkage in areas A_1 and A_2 may be considered as a creep of a porous metal indiced by, what happens to be in this case, compressive forces. But area B is being subjected to forces of the same strength as A_1 and A_2, except that they are stretching the metal. For this reason creep also occurs in it. The tensile strength of a porous metal is considerably smaller during stretching than during compression. For this reason the size of the expansion in area B may exceed the size of compression in zones A_1 and A_2 and thus there may occur a certain overall increase in the total volume of the metal. The zonal character of shrinkage may result in cracks and in the formation of very large pores which considerably exceed the dimensions of the original pores of the compact.

Let us note that there are to be observed cases in other branches of technology where there is a decrease of density through uneven shrinkage. Thus, irregular drawing together of atoms during the cooling of a molten metal results in a porous and non-dense

(d) Individual Separation of Particles

The processes of separation during baking may take place not only within areas (zones) composed of a large quantity of individual particles (grains) but may be localized within individual particles. Aside from the drawing of atoms toward contact sectors and zonal separation, there also takes place, as has been mentioned earlier, a number of processes related to individual changes, irregularly localized within individual particles. Thus, the shape of particles changes as a result of surface tension, residual stresses, recrystallization of subdivisions of particles, etc.

Irregularly localized individual modifications of particles are related to the appearance of compressive forces, a compacting of metal powder in some places, and the appearance stretching stresses and decompacting of the powder body in other places. At first glance it would appear that under such circumstances the magnitude of stretching and compressive stresses should be identical and the total volumetric change of the metal powder equal zero. However, we have already pointed out (page 119 of original text) that the laws pertaining to equilibrium of forces applicable to the mechanics of an absolutely solid body cannot always be applied to metal in a powder state. The drawing together of particles in a metal powder (decrease of porosity) always demands greater force than the drawing apart of particles (increase of porosity). For this reason an increase in porosity caused by a definite stretching force may be greater than the decrease in porosity due to a compressive force of the same magnitude. In this connection, the sum total of activity of irregularly localized individual modifications of particles may be reduced to an increase of porosity -- to individual separation.

(e) Heat Expansion and Contraction

Expansion of particles caused by heating in a number of cases leads to filling in of the pores and to an increase of contact surface. A contact renewed during contraction caused by cooling does not often break. There takes place as a result an irreversible increase of contact surface and a decrease in porosity. This process is particularly important in connection with an increase in contact surface for powders with medium- and large-sized particles (of several tens of microns and more).

However, in certain cases thermal expansion is connected with an increase of porosity and a decrease in the size of contact surface (such as when baking compacts packed to full density).

The cooling process may help increase porosity in metals with separated zones of shrinkage.

For temperatures of practical application in baking, the irreversible linear shrinkage due to expansion caused by heating ("thermal" shrinkage) may not exceed 1-2 percent of the original length and the volumetric shrinkage 4-6 percent of the initial volume of the compact.

It should be pointed out that thermal shrinkage accompanied by a relatively small decrease in volume is usually connected to a relatively large increase of contact surface. "Contact" shrinkage, however, which is caused by a displacement of atoms from a free surface to contact sectors although accompanied by a relatively large decrease in volume is usually connected to a relatively small increase in contact surface.

(f) Influence of Admixtures

The content of primarily surface admixtures in metal powders sometimes reaches 5-10 volumetric percent. The principal ones are metal oxides, water, and gases adsorbed and in solution (page 32 of original text).

The majority of admixtures disappear during baking. Evaporation of water begins at close to room temperatures and stops at 150-200 degrees (the temperature of boiling water which is confined within the capillaries of surface oxides goes up to 200 degrees, while the removal of chemical confined water demands even higher temperature). The main part of adsorbed gases evaporates at 100-200 degrees. The final disappearance of dissolved and chemically confined gases during heating in a vacuum occurs at considerably higher temperatures -- higher than recrystallization temperature. Baking in a protective medium (hydrogen, carbon packing, etc.) may sometimes lead to an increase in the content of certain admistures. The oxygen of oxides disappears either during reduction in a protective medium or in vacuum baking as a result of breaking down of oxides into gas and metal. Depending on the type of metal and the physical characteristics of the powder, reduction temperature varies within wide limits, from 25 to more than 75 percent of the absolute boiling point of the metal. The oxides of certain metals such as aluminum are not generally reduced during the ordinary conditions prevailing during baking.

However, it is more probable that gases as well as air offer during baking a passive harmful influence on the properties of baked products rather than an active expanding effect. Increase in size in the majority of cases is observed when baking coarse powders, the expanding action of whose gases is eliminated by the excellent gas permeability of the material. Liberation of gases may produce the effect of decreasing the shrinkage of fine powders through the formation of closed pores during the later stages of baking which, as Frenkel has pointed out (120), hinders their being filled in.

The negative role of oxides in a powder may be considered to be the following: first of all, oxides lower the tensile strength of compacts. However, a decrease in the tensile strength of compacts makes it easier to break the contact during baking between particles and decreases the density and durability of the baked metal. Besides, during the baking process the reduction of oxides proceeds unevenly in different zones of a compact, which in turn leads to zonal differences in shrinkage (page 120 of original text). Finally, the gaseous products of oxide reduction (H_2O, CO_2) may interfere with shrinkage in the later stages of baking through the formation of closed pores. The oxidation of metal during baking also quite frequently produces a harmful effect on its properties.

The reduction of oxides proceeds as a reversible reaction of the type of $MeO+H_2$ $Me+H_2O$. If the baking atmosphere contains volatile products of reduction (H_2O, CO_2), then together with a reduction of oxides in some places of the surface of particles there will also take place an uninterrupted oxidation of metal in other places of the surface of particles. The atoms of the metal in a lattice of oxides are disposed differently than in a lattice of the metal. For this reason the atoms of the metal are even more mobile and active at the moment of reduction than linear and angle atoms. The presence of oxidizing agents in the atmosphere may activate the baking process creating an intensified shrinkage and grain growth. As a result of good permeability possessed by compacts made of coarse powders, the oxidizing products of reduction (H_2O, CO_2) are very quickly excluded from pores and cannot in consequence exert any marked effect. But permeability is small for dense compacts made of fine powders so that the products of reduction remain for a long time in the pores where they can exert a marked positive effect on shrinkage and grain growth. In technology oxides are sometimes especially added which are volatilized and reduced at high temperatures (Na_2O, SiO_2, etc.) and other compounds which initiate oxidation (NaCl, KCl) to tungsten powders in order to obtain monocrystals and long crystalline threads of tungsten. However, in the majority of cases the unfavorable action of oxides overbalances their favorable effect.

Admixtures in the majority of cases exert an unfavorable effect on the properties of a metal powder. The greater part of admixtures entering into a solid solution with the basic metal decreases its compressiveness and by the same token the properties of the baked metal. Admixtures which do not melt at baking temperatures usually hinder the baking process (pages 145 and 148 of the original text). Admixtures which do not form solid solutions and inter-metallic compounds hinder the contact of particles of the basic metal. Particularly harmful is the action of admixtures of metals which form oxides difficult to reduce and in the same way the admixtures of oxides difficult to reduce as Mes'kin, Shipulin, Vaynshteyn, and Mitrenin have shown (81).

Figure 105. Changes of Structure and Density (d) Occurring during the Baking of Carbonyl Iron. X 1000 [185]. [Photo]

Certain admixtures with which the basic metal reacts form a second phase by melting during baking and may considerably increase the properties and density of baked materials (such as admixtures of phosphorous added to brass).

(g) Recrystallization

As a result of recrystallization and growth of contact during baking a metal powder is transformed from a conglomerate of particles into a conglomerate of crystallites (grains).

Basically, the rules applying to the recrystallization of metal powders may be reduced to the following: (See /5/ for an explanation of these rules).

Figure 106. Modification of Structure Occurring during the Baking of Electrolytic Copper (Bal'shin). X500. [Photo]

(1) Particle growth of metal powders (external recrystallization) begins at much higher temperatures than grain growth of solid metals. According to Sauerwald (184), the temperature at which particle growth for metals powders begins is equal to 66-75 percent of the absolute melting point.

(2) Internal recrystallization of structural subdivisions of particles (in particular submicroscopic) often begins at considerably lower temperatures than external. In the same way internal recrystallization of particles which do not have structural subdivisions (change of shape) begins at considerably lower temperatures than the growth of particles.

(3) The temperature existing at the beginning of growth generally decreases with dispersion of particles and the presence of internal subdivisions within them.

(4) For the majority of powders, the temperature at the beginning of particle growth and the final size of the grain do not depend, as Sauerwald pointed out (184), on the compacting pressure.

(5) The presence of oxides in the original powders and baking in a reducing atmosphere with an insignificant admixture of oxygen lower the temperature for the beginning of recrystallization and increases grain growth.

(6) With respect to fine powders, the temperature existing at the beginning of external recrystallization sometimes decreases with compacting pressure. There is sometimes observed in such cases a strong dependence of the temperature of recrystallization and of grain size on previous processing of powder prior to compacting.

(7) In the deformation of baked metals the same rules of recrystallization as for deformed cast metals.

Modification of structure of carbonyl iron powders by baking temperature is shown in Figure 105 and for compacts of electrolytic copper in Figure 106.

Recrystallization is closely connected with change in volume and contact surface during baking. Such changes may be considered to be the result of creep due to the action of two groups of forces -- stretching and contracting.

It is known that recrystallization is connected with a considerable increase in the speed of creep. For this reason recrystallization, both external and internal, increases the activity both of the processes of drawing together of particles and increasing contact surface and of processes of drawing apart of particles and decreasing of contact. It should be kept in mind that grain growth leads to the formation of intracrystallite pores which may not be covered up in baking. For this reason recrystallization prevents obtaining baked products that have a 100 hundred percent density.

INFLUENCE OF CONDITIONS ON BAKING PROCESSES AND THE PROPERTIES OF BAKED MATERIALS

The size and condition of contact surface of powder particles changes during the course of baking. Corresponding to this all the other properties of the metal powder also change -- structure, porosity, hardness, electrical conductivity, etc. An investigation of these properties makes it possible to make an approximate evaluation of the processes taking place during baking.

The electrical conductivity of a metal powder grows in proportion to a certain degree of contact surface. The size of the index for this degree lies between 1 and 2 for a purely metallic contact. The transition of a contact from a non-metallic to a purely metallic state also increases conductivity.

Resistance to rupture change approximately in proportion to the contact surface of a single layer of particles (contact cross section). However, this depends not only on the size but also on the condition of contact surface. During baking the contact changes gradually from a non-metallic to a metallic one, from one without strain to one with strain, and from cohesion to interlocking. All these factors increase resistance to rupture.

Resistance to compression on the part of baked metals is usually 2-15 times greater than resistance to rupture. This is explained by the fact that during the stretching of a porous metal the contact surface decreases while porosity increases; during compression the opposite takes place. During the course of baking differences between tensile strength in connection with stretching and in connection with compression are usually evened out somewhat. Resistance to compression increases with the size of contact surface and usually also with a decrease in oxide content.

Hardness changes during the course of baking in a somewhat complex manner. The removal of cold hardening and decreasing the oxide content during baking decreases its size, while growth of contact surface and density, on the other hand, increase.

Plasticity increases very much as a result of baking. Increase in length of powder compacts during stretching is equal to zero;

after baking there is to observed sometimes a considerable increase in length.

Changes in linear and volumetric dimensions are not reflected during the course of baking so much as changes in electrical conductivity and tensile strength. In baked metals decrease in porosity of 1 percent usually corresponds to an increase in tensile strength and contact surface of 3-10 percent. In spite of this, estimation of the progress of baking on the basis of linear or volumetric shrinkage is widely used because of the simplicity and accuracy of such determination. Usually (but not always) an increase in density during baking is connected with an increase for all mechanical properties.

The size and condition of contact surface and the correspondence of mechanical properties characterizes the condition existing between the structural elements of a metal powder. Sometimes this combination of properties is designated by the term "adhesion", for which it would be harder to give a more exact definition. One can obtain an understanding of such cohesion on the basis of such qualitative tests as showing the absence of crumbling of particles when scratching the metal, the appearance of a cross-sectional view, etc.

(a) Influence of Baking Temperature on Contact, Shrinkage, and Properties

The effect of baking temperature may be divided into several stages.

The first state is characterized by non-metallic contact between particles. Increase of contact, growth of tensile strength, and an insignificant shrinkage during this period may be explained principally by evaporation of water from the surface layer of oxides. In the given instance shrinkage and increase of contact have the same character as when drying out clay.

Shrinkage during this stage may take place because of thermal expansion of particles. This type of shrinkage may reach for a temperature of 100 degrees 0.1-0.2 percent of length and up to 0.3-0.6 percent of volume.

In all probability, shrinkage and growth of contact during heating at this stage would have been greater if the stretching action of residual compacting stresses had been absent, as a result of which there is to be observed quite frequently at this stage a slight increase in dimensions.

Table 18 (155) show changes in electrical resistance of a nickel compact varying with heating temperature. There is to be observed that up to 60 degrees there is a considerable increase in resistance; at 80 degrees it decreases markedly and it drops considerably at 100 degrees (boiling point of water under normal conditions). A decrease in resistance continues up to 140 degrees (the boiling point of water in fine capillaries). The first stage of baking ends at approximately this temperature. In our opinion electrical conductivity of unbaked compacts is due to a considerable extent to the contact of water films surrounding powder particles. In heating up to 60 degrees these films as a result of evaporation are modified very much and thus cause a growth in resistance. At 80 degrees water evaporates even more but resistance on the other hand falls. This is explained by the beginning of shrinkage and growth of contact between oxidized layers of particles (similar to shrinkage during the drying of clay). It is natural that such a growth of contact must reach its maximum proportions at a temperature of 100-150 degrees.

Table 18

RESISTANCE OF CARBONYL NICKEL COMPRESSED AT A PRESSURE OF 6000 KILOGRAMS PER SQUARE CENTIMETER WHEN HEATED AND COOLED IN HYDROGEN (155)

Temperature in Centrigrade	Resistance 10^6 Ohms Heating	Resistance 10^6 Ohms Cooling	Temperature in Centrigrade	Resistance 10^6 Ohms Heating	Resistance 10^6 Ohms Cooling
20	101.0	11.3	200	34.6	24.6
40	105.5		300	46.0	33.8
60	108.0		400	57.7	41.0
80	90.0		500	61.0	44.8
100	55.0	17.0	600	64.0	48.3
120	34.0		700	66.5	52.3
140	33.0		800	67.25	56.0
160	33.0		900	67.6	59.6
180	33.2		1000	68.0	63.4
200	34.6	24.6	1140	68.0	68.0

The author carried out experiments relating to the absorption of solutions of methylene blue with metal powders that had been heated in hydrogen and oxides burned in air and cooled at 20 degrees. After heating to 150 degrees the adsorbing ability increased both for metal and non-metal powders. Here one can again draw an analogy between an increase of permeability of dry, cracked earth as compared with wet clay and that of gases and liquids.

Figure 107 presents data of the author relating to changes in the volumetric characteristic of powders after heating and cooling to room temperature. After being heated to 150-200 degrees powders of both metals and non-metals showed a decrease in poured weight. A decrease in poured weight was due in all probability to an increase of "structural strength" (Chapters II and IV) caused by an increase in the tensile strength of the clayey layer of oxides during the evaporation of water.

The second stage is characterized by a reduction of oxides during baking, i. e., by a qualitative change of contact. It can take place during a certain temperature interval concomitantly with the first stage. Furthermore, contact is transformed from a non-metallic to a metallic one, in which connection the resistance of the metal decreases considerably upon cooling. When in a heated state resistance increases somewhat inasmuch as a pure metal has a considerably higher temperature coefficient than oxides. This stage, just as the previous one, is not accompanied by any considerable shrinkage; in fact, it sometimes results in a certain amount of growth.

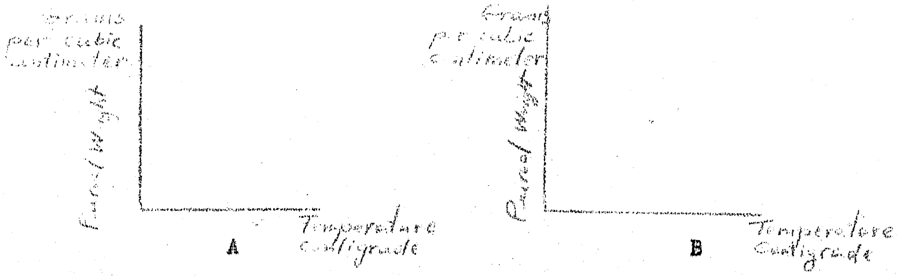


Figure 107. Modification of Volumetric Characteristics of Powders through Changes of Heating Temperature (Bal'shin):

1 - electrolytic copper, poured weight 1.5 grams per cubic centimeter; 2 - the same compacted; 3 - copper composed of flat particles; 4 - restored iron, poured weight 0.67; 5 - electrolytic iron, poured weight 2.11; 6 - the same compacted 7 - electrolytic iron, poured weight 3.66; 8 - the same compacted.

Measurements of absorption show for this stage an occasional increase for the following reasons:

(1) Metals have a higher adsorbing capacity than oxides.

(2) Specific surface may actually increase. It is commonly known that subsequent oxidation and reduction at low temperatures greatly increases the surface of powder.

Poured weight (Figure 107) at this stage clearly drops (increase in tensile strength through reduction of oxidized layer).

The third stage is characterized by a marked quantitative growth of metallic contact caused by the mobility of metal atoms and a modification of particle shape (individual recrystallization). It proceeds for almost the entire interval of temperature concomitantly with the second stage (reduction of oxides), the role of which, however, is not particularly prominent. The third stage, depending on the degree of dispersion of the powder, begins at a temperature of 20-40 percent of the melting point. Fine powders at this stage are characterized by a marked speed of shrinkage which cannot be explained solely in terms of temperature expansion. On the otherhand there is observed an expansion of metal as a result of absorption of residual stresses for corase and strongly compacted powders. Absorption of residual stresses and softening (reversion) probably ends at the beginning of the fourth stage.

Most temperatures for the beginning of baking, as determined by different authors, relate to the beginning of the third stage. However, it is difficult to speak of a precise determination of temperature for the beginning of the actual baking of a metal because shrinkages and increase in contact are observed even during the first and second stages. For this reason, the determination of sufficiently marked shrinkage and growth of contact has to be to a certain extent arbitrary.

There is an increase during the third stage in the specific surface of particles without any growth of particles being observed.

Thus, manifestations of recrystallization at this stage are expressed in individual recrystallization and rectification of particle surface.

At the beginning of the third stage the poured weights of fine powders (Figure 107) at first decrease somewhat and at 40-60 percent of the absolute melting point reach a minimum, whereupon they begin to increase, reaching towards the end of the third stage approximately the initital values of the original powders. Reduction progresses with increased temperature, and surface protrusions, although becoming stronger and not breaking during brittle deformation, yield more easily to plastic deformation. For this reason, the poured weight at the end of the third stage is already more minimal, although not yet markedly exceeding the original value. With time baking of fragments and protrusions increases so that the surface layer of particle becomes less porous and more strong. An increase in the strength of this layer leads to a decrease in poured weight as heating is prolonged (Figure 108).

The fourth stage is characterized by a marked increase in the speed of processes of diffusion. It is for this reason that oxides are completely reduced during the fourth stage and growth of particles commences. Depending on the dispersion of a powder, it begins at 50-75 percent of the absolute melting point and continues right up to melting temperature. During the third stage creep encompasses a relatively narrow strip of atoms near the surface, while deformation (shrinkage) during creep is limited under the influence of atomic forces to a rectification of the surface of particles. During the fourth stage creep according to the degree of grain growth and the shifting of their boundaries takes in significant layers of atoms which previously had remained within the depth of particles. Because a large quantity of atoms is involved in the growth process, the speed of creep sharply increases during the fourth stage. For this reason there is an increase in the activity of processes relating to both the drawing together and moving apart of particles. With respect to compacts that are inclined to expand the beginning of the fourth stage is quite frequently characterized by a marked increase, and for those inclined to contract there is a considerable decrease in volume. The difference in shrinkage for coarse and fine powders is very considerable (Figure 109). There are frequently characteristic for this stage the very prominent role of zonal separation due to shrinkage (page 120 of original text) and irregularly localized modifications of particles, especially for very fine powders. For this reason, when the optimum baking temperature has been exceeded, there ensues a decrease in density and tensile strength with further increase in temperature. This decrease continues to progress, following which there is noticed a buckling and finally a cracking of the material (overheating). Separation through shrinkage may lead as well to a decrease in grain growth (when the optimum temperature has been exceeded (Figure 110). This optimum baking temperature is quite frequently 66-75 percent of the melting temperature for very fine powders, while for the majority of the coarser powders it sometimes lies close to the actual melting point (Figure 109).

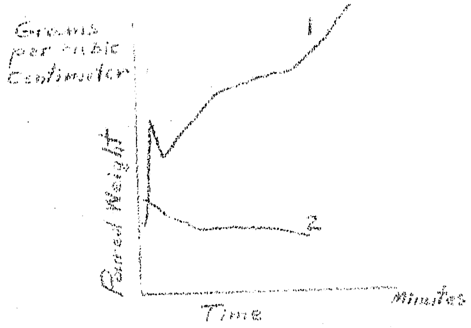


Figure 108. Change in Volumetric Characteristics in Relation to Length of Heating.

1 - electrolytic copper, poured weight 1.41, heated at 700 degrees; 2 - electrolytic copper, poured weight 1.58, heated at 600 degrees (Bal'shin).

Heating at temperatures of the fourth stage increases the poured weight. It increases very much for fine powders (Figure 109). This is explained by the fact that there is a considerable smoothening out of protrusions and depressions and a softening of the surface layer of particles as a result of the complete disappearance of oxides. The decrease in roughness and hardness increases with exposure, while the poured weight continues to increase without interruption throughout the duration of the heating.

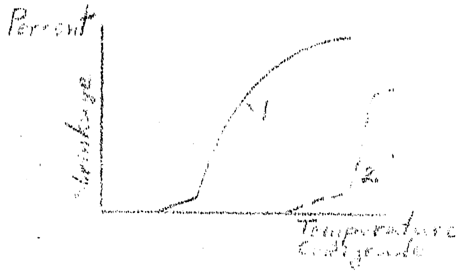


Figure 109. Dependence of Shrinkage on Temperature for Fine and Coarse Iron Powders (Davil').

1 - fine; 2 - coarse.

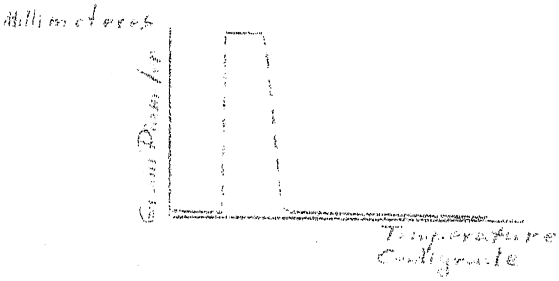


Figure 110. Dependence of Grain Growth of Tungsten on Temperature (Jeffries).

There is also characteristic for the fourth stage the formation of closed pores (Figures 105, 106), explained by the formation of pores during grain growth. The appearance of closed pores is not observed for coarse powders which do not have grain growth during baking. During zonal shrinkage taking place in fine powders there may appear very large pores, the size of which exceeds by many times the original pores of the compact.

A relatively clear subdivision of the action of temperature is observed during the fourth stage for relatively fine powders.

Tensile strength, just as density, usually increases with an increase in baking temperature. The indexes of deformation increase with an increase in temperature even where there is a drop in density and tensile strength.

Change in hardness (as well as the limit of yield during contraction) is distinguished from changes in the indexes of tensile strength during stretching and in the indexes of deformation. With an increase of temperature there is a decrease in the size of residual stresses caused by compacting (this factor lowers hardness), while there is an increase in density and cohesion of the metal powder (this factor, conversely, increases hardness). For this reason change in hardness caused by temperature varies for compacts of different densities (Figure 111). Compacts of slight density compressed under lowppressure possess insignificant residual stresses and shrink a great deal during pressing. It is for these reasons that for such compacts hardness grows uninterruptedly with temperature.

However, very dense compacts compressed under high pressures continue to possess considerable residual stresses and have only slight shrinkage during baking. The hardness of such compacts decreases within a certain temperature interval.

Rate of shrinkage is a good index of the process of baking, inasmuch as it is proportional to the number of atoms shifting during a unit of time from free sectors to contact sectors. However, this rate depends not only on temperature but also on the moment of time during which it is being measured, because with time the number of the more active atoms decreases quickly and so consequently the rate of shrinkage. For this reason rates for different baking temperatures have to be compared with equivalent intervals of time, i. e., with moments that correspond to a similar total shrinkage. Instead of comparing equivalent rates of shrinkage, it would be simpler to compare intervals of time required to attain identical shrinkage at different temperatures (the ratio of these intervals of time is approximately equal to the ratio for identical rates of shrinkage). Determination of the action of temperature on the baking process according to the time required for attaining identical shrinkage is more practicable than the frequent practice of estimating it on the basis of shrinkage attained for an identical interval of time (Figure 109).

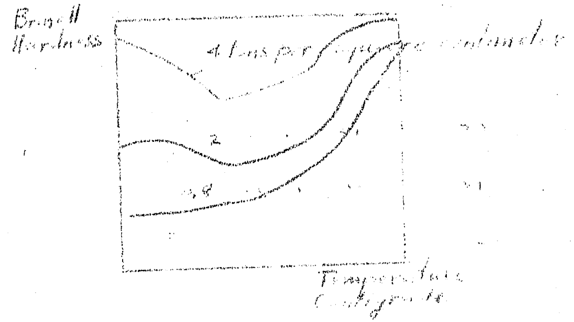


Figure 111. Changes of Hardness during Baking for Carbonyl from Compacted at Different Pressures (55).

Increase in the rate of shrinkage with temperature in accordance with formula (46) is proportional to the expression $e^{-\frac{Q}{RT}}$ where "e" is the base for natural logarithms, "Q" the activating energy, "R" the gaseous constant, and "T" the absolute temperature. In baking iron or copper an increase of baking temperature in practical use equal up to 100 degrees corresponds to an increase in the rate of shrinkage of 2-10 times (this increase grows with the coarseness of the original powder).

which it is being measured, because with time the number of the more active atoms decreases quickly and so consequently the rate of shrinkage. For this reason rates for different baking temperatures have to be compared with equivalent intervals of time, i. e., with moments that correspond to a similar total shrinkage. Instead of comparing equivalent rates of shrinkage, it would be simpler to compare intervals of time required to attain identical shrinkage at different temperatures (the ratio of these intervals of time is approximately equal to the ratio for identical rates of shrinkage). Determination of the action of temperature on the baking process according to the time required for attaining identical shrinkage is more practicable than the frequent practice of estimating it on the basis of shrinkage attained for an identical interval of time (Figure 109).

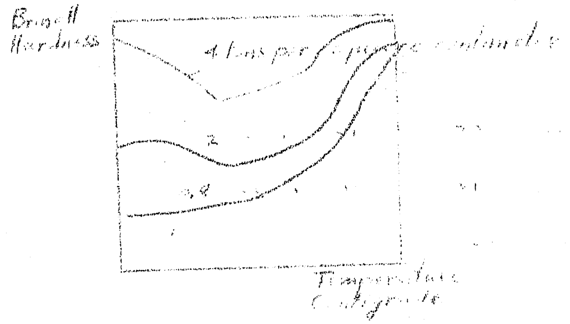


Figure 111. Changes of Hardness during Baking for Carbonyl from Compacted at Different Pressures (55).

Increase in the rate of shrinkage with temperature in accordance with formula (46) is proportional to the expression $e^{-\frac{Q}{RT}}$ where "e" is the base for natural logarithms, "Q" the activating energy; "R" the gaseous constant, and "T" the absolute temperature. In baking iron or copper an increase of baking temperature in practical use equal up to 100 degrees corresponds to an increase in the rate of shrinkage of 2-10 times (this increase grows with the coarseness of the original powder).

It should be pointed out that with an increase of baking temperature there is not only an increase in the speed of the process but also a change in the relationship of atoms with different mobilities which take part in the baking process. At low temperatures the more active atoms along the sides and vertexes of angles are the principal participants in the baking process. At high temperatures close to the melting point, there participate in the baking process not only atoms on the surface of particles but also those which lie within the particles. For this reason the time and temperature of baking do not completely interchange and it is not possible to completely compensate for a decrease in baking temperature by an increase in its duration.

For the majority of pure metals baking temperature practically coincides with the temperature of perceptible growth of particles. Below it adequate porosity is difficult to attain. Above it there is observed an excessive grain growth (at the beginning of the fourth stage). With respect to metals which form oxides difficult to reduce and which interfere with the growth of particles (such as aluminum), the baking temperature is higher and approaches the melting point.

(b) Influence of Baking Time

Figure 112 shows two typical cases showing the relation of volumetric shrinkage and instantaneous speed of volumetric deformation (i. e., the relative change in the volume of an infinitely small interval of time) to baking exposure. In the one case the overall shrinkage at first grows rapidly and then slows down. At the expiration of some time the overall shrinkage reaches its highest level and no longer changes with further exposure. The rate of shrinkage in this case drops to zero and with further exposure remains at zero level. In the second case the overall shrinkage reaches a maximum after the lapse of some time and then decreases with further exposure. The rate of shrinkage in the second case upon dropping down to zero does not stay at that level, but decreases further and changes its sign. In this way the powder metal in the second case begins to expand at that moment with a certain speed.

One may think of the rate of shrinkage as the result of creep under the influence of two groups of forces -- expanding and contracting.

The contraction of a metal powder is principally caused by the action of surface interatomic forces and likewise by the filling in of pores during the thermal expansion of particles. Contraction as a result of thermal expansion drops down to zero very quickly, -- immediately upon becoming thoroughly heated to the temperature of exposure.

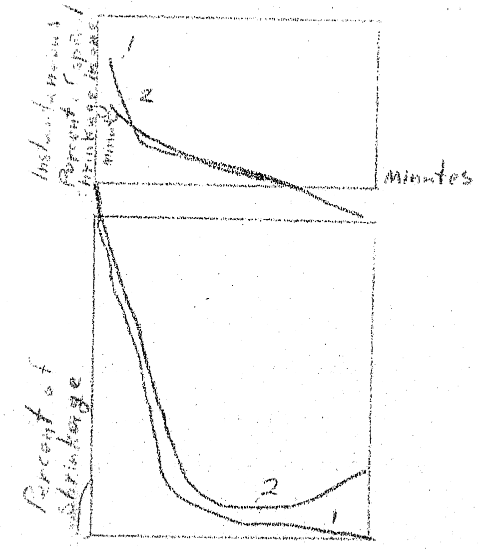


Figure 112. Relation of Shrinkage and Rate of Shrinkage to exposure (Bal'shin).

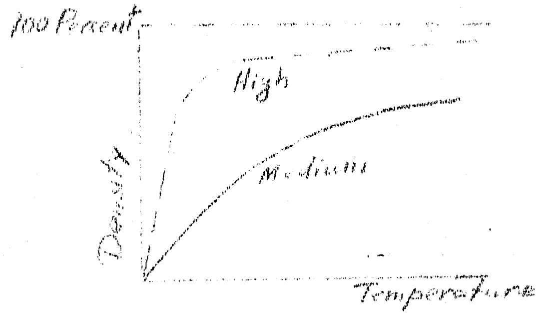


Figure 113. Relation of Shrinkage to Exposure for Medium and High Temperatures (167).

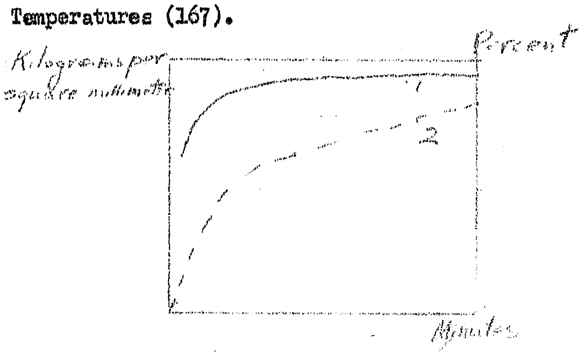


Figure 114. Relation of Resistance to Fracture to Baking Time at 800 Degrees (150).

The rate of contraction due to the action of interatomic forces decreases with exposure as a result of diminution in the specific surface of particles. For this reason the rate of contraction decreases after a certain time to practically an insignificant size.

Expansion is due to the absorption of residual stresses from compacting, to local separation of the shrinking processes, and to varying irregularly-localized individual changes of particles. The rate of expansion also decreases with time because of a diminution in residual stresses and in the rate of processes of local division of shrinkage (which decreases with the rate of shrinkage). However, certain processes relating to the individual modification of particles which cause expansion preserve their rate upon further exposure at a certain rather constant level. Thus, local unevenness in heating, local oxidation and reduction of particles do not radically change with exposure.

When the rate of contraction is compared with the rate of expansion the resultant rate of shrinkage drops to zero. If with further exposure the rates of expansion and contraction decrease equally, the rate of shrinkage remains at zero level. However, if contraction decreases more rapidly than expansion, then the rate of shrinkage during exposure becomes negative and there occurs a growth of porosity.

Figure 113 shows the relation of shrinkage to exposure time at middle and high temperatures. At high temperatures shrinkage very quickly reaches its maximum value, while with lower temperatures, it takes considerably more time. This is explained by the more rapid decrease in specific surface of particles due to increase in temperature.

The properties of a metal powder change during exposure to approximately the same extent as shrinkage and density. The tensile strength of a metal powder (Figure 114) usually reaches its highest level in a relatively short period. With further exposure it continues to remain at that level or may even decrease somewhat. The properties characteristic of plasticity, such as elongation, increase for the most part over the course of a considerably longer period of time (Figure 114). This is explained by the fact that complete elimination of oxygen (Figure 115), as Offerman's studies show (175),

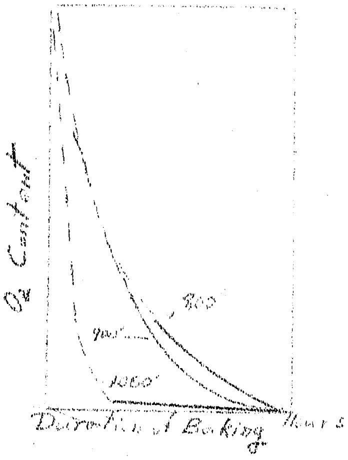


Figure 115. Effect of Baking Time and Temperature on the Oxygen Content of Carbonyl Iron (175).

In practice exposure to baking varies from 10 minutes to 24 hours (sometimes even more) according to the composition and density of the material, the dimensions of product, the amount of the charge, protective medium, and design of furnace.

The rate of cooling (where it is not accompanied by phase transformations) plays a certain role only in case of short exposure to maximum baking temperature. Where this happens slow cooling may sometimes considerable increase density and other properties.

(c) Influence of the Original Properties of Powders

In increasing the size of powder particles from 10 to 50 microns, surface tension which causes shrinkage decreases by 5 times. The rate of creep (shrinkage), moreover, decreases even more. For this reason, when baking at the usual industrial temperatures (2/3 - 3/4 of the absolute melting point) the rate of shrinkage for metal compacted from fine powders with particles about 10 microns in size is about 0.1-1 percent per minute, while with particles about 50 microns in size it is practically equal to zero. With an increase in temperature, the rate of creep increases. For this reason, in temperatures close to the melting point, even powders that are rather coarse have considerable shrinkage (see Figure 109).

The tensile strength of compacts usually either decreases with an increase in the size of particles or remains at the former level. It is for this reason that in the majority of cases the activity of processes contributing to severance of contact either remains at the former level or even increases somewhat with a drop in dispersion. As in such circumstances there is a simultaneous decrease in the activity of processes contributing to a drawing together of particles, compacts of coarse powder often undergo an increase in size after baking.

Compacts made of fine powders subject to considerable shrinkage show a tendency to uneven localized shrinkages during high temperatures (page 120 of original text).

When baking dispersible powders the contact surface of particls greatly increases. In the case of coarse powders contact formed during pressing quite frequently even decreases somewhat during baking. In such instances, the part played by baking resolves principally to a qualitative change of contact (transition from a state of stress to one of non-stress and from metallic to a non-metallic condition).

The mechanical properties of baked products vary directly with density and increase, as Figure 116 shows with the dispersion of the original powders.

Kg/mm^2 Kg/mm^2

Figure 116. Relation of the Mechanical Properties of Iron to the Size of the Original Powder.

I - particle size up to 0.075 millimeters, specific gravity 6.94;
II - the same 0.75-0.1 millimeters, specific gravity 6.99;
III - the same 0.1-0.5 millimeters, specific gravity 7.10;
IV - the same up to 0.5 millimeters, specific gravity 7.16;
resistance to rupture limit of yield; Brinell hardness; elongation (150).

Percent

Relative Volume
for Iron of 1.55

Change in linear Dimensions

Grams per Centimeter

Poured Weight
in Grams per
Cubic Centimeter

Dispersion

Figure 117. Relation of Linear Modification of Dimensions after baking to the Poured Weight of Iron Powders (Bal'shin).

1 - in a direction parallel to compression at a temperature of 1000 degrees; 2 - in a direction perpendicular to compression at a temperature of 1000 degrees; 3 - in a direction parallel to compression at a temperature of 1100 degrees; 4 - in a direction perpendicular to compression at a temperature of 1100 degrees.

The tensile strength of compacts drops with an increase of poured weight, which helps to break contact among particles. For this reason an increase in poured weight of powder is accompanied by a decrease in shrinkage (Figure 117) and mechanical properties (Figure 118).

Temporary Resistance to Bending

Kg/mm^2

Dispersion

Poured Weight

Grams per Cubic Centimeter

Figure 118. Relation of Resistance to Depending to the Poured Weight of Copper Powders (Bal'shin).

1 - Copper, the relative density of the compact being 0.6 in the direction parallel to compression; 2 - the same in

a direction perpendicular to compression; 3 - iron, the relative density of the compact being 0.55 in a direction parallel to compression; 4 - the same in a direction perpendicular to compression.

All structural factors which increase the tensile strength of compacts contribute thereby to producing a more durable and dense baked material. For this reason powders with rough particles give more satisfactory results than with smooth particles, with dendrite and with angular particles than with round and smooth particles. Particularly unsatisfactory results are obtained with powders composed of flat particles.

The structure of a baked metal powder (secondary structure) strongly depends on the structure of the compact (primary structure). Materials which have been compressed from coarse powders quite frequently preserve after baking their primary structure (size and shape of particles, preservation of the compacting orientation). This is explained by the fact that grain growth shows up much less in coarse powders than for fine powders. All factors hindering shrinkage and contact among particles, the action of which is greater for coarse powders, also serve to decrease grain growth. Moreover, the absolute size of individual pores is proportional to the size of particles. The shifting of atoms during shrinkage and grain growth (36) may fill up only the small and not the large pores. For this reason powders with particles of rather large original dimensions yield after baking, on the other hand, a smaller grain than indicated by the work of Agarkova and Korol'kov (1).

The secondary structure of fine powders, on the other hand, is very different from the primary as a result of significant grain growth, decrease in porosity, and the formation of closed intracrystallite pores (Figures 105 and 106). However in such cases baking sometimes may not be completely able to destroy the special features caused by compacting (see point "d").

(d) Influence of Compacting.

The following relation is observed of the shrinkage and properties of baked materials to the conditions of compacting.

(1) Volumetric and linear shrinkages decrease with density of compacts. At low densities there is usually observed a decrease and at high an increase in porosity after baking. At low densities longitudinal shrinkage is generally greater than transverse, at high densities -- contrariwise. For this reason the curves of longitudinal and transverse shrinkages cross each other (Figures 119, 120).

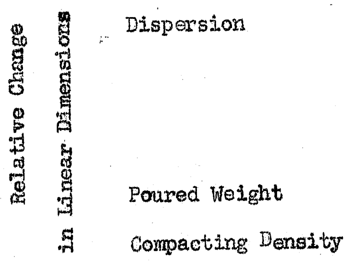


Figure 119. Diagram of the course of changes in linear dimensions following baking in relation to the dispersion of the initial powders and the density of compacting; ---- change of linear dimensions parallel to compacting; ---- the same perpendicular to compression.

Relative Density

Change in Linear Dimensions

Percent

Figure 120. Relation of the Linear Shrinkage of Electrolytic Copper (Poured Weight 1.50 Grams per Cubic Centimeter) to Compacting Density (Baked for 45 Minutes at 80 Degrees). 1 - in longitudinal direction; 2 - in transverse direction (Bal'shin).

Percent

Change in volume

Relative Compacting Density

Figure 121. Relation of Volumetric Shrinkage of Electrolytic Copper to density (Bal'shin)

Porosity before Baking

Relative Density after Baking

Porosity after Baking

Relative Density before Baking

Figure 122. Relation of Porosity and Density after Baking to Porosity and Density before Baking of Electrolytic Copper, Poured Weight 1.50 Grams per Cubic Centimeter (Bal'shin).

(2) The relation of shrinkage to compacting density (porosity) usually has practically a rectilinear character (Figure 121).

(3) With an increase of temperature there is an increase in the degree of shrinkage decrease caused by a growth of compacting density. Thus, at 700 degrees (Figure 121A) shrinkage hardly changes with an increase in density, but at 850 degrees shrinkage drops considerably with an increase in density (Figure 121B).

(4) For powders which are subject to considerable shrinkage, baking evens out to a large degree differences in porosity not only in the case of products compressed to different degrees of density but also for spots of varying density in the same compact (Figure 122). This equalizing action increases with growth of temperature. Differences in shrinkage cause a distortion of the shape of compacts (Figure 123). One may approximately figure that a decrease in porosity caused by baking (Figure 124) and, consequently the final porosity are roughly proportional to the compacting porosity (Figure 122). Exceptions to this rule are observed for compacts both of very high densities and of very low densities, and also for those subjected to very high baking temperatures.

Low Density

High Density

Figure 123. Distortion after Baking of the Shape of Compacts with Uneven Densities: Left - Shape Prior to Baking; Right - after Baking.

(5) Although final densities of baked products usually increase somewhat with an increase in density caused by compacting, however, the densities of products may decrease to a certain extent for very high densities obtained during compacting. This decrease in density is sometimes accompanied by cracking.

Decrease in

Porosity After Baking

Percent

Porosity of Compact

Figure 124. Decrease of Density in Relation to Compacting Porosity (Bal'shin).

1 - electrolytic copper, poured weight 1.50 grams per cubic centimeter, 800 degrees for 45 minutes; 2 - 90 percent, electrolytic iron, 10 percent electrolytic copper, 1150 degrees for one hour.

Kg/mm^2

Kg/mm^2

Temperature Centigrade

Figure 125. Relation of Resistance to Rupture on the Part of Carbonyl Nickel to Compacting Pressure and Baking Temperature (2-Hour Exposure (155)

(6) With an increase of compacting pressure there is an increase in the index of the properties of products (see Figure 125). For powders subject to large shrinkage, the equalizing action of baking leads to an equalizing of properties, an action which progresses with temperatures as shown in Figure 125 (155). There is to be even observed for certain cases a drop in properties with compacting density (especially where excessive pressures caused damage to the compact. However, in the majority of cases the properties of highly compressed products are higher than those which have been subjected to weak compacting even though such products have a somewhat lower density after baking. An increase in pressure caused a specially marked growth of contact surface, density and properties of powders. These show after baking insignificant volumetric modifications.

Rules pertaining to the relation of shrinkage to porosity may be evolved from the following elementary considerations:

(1) The number of atoms found in contact sectors and in gaps which are closed without perceptible shrinkage is proportional to the relative compacting density ϑ, while the number of atoms on the free surface of particles is proportional to its porosity P.

(2) A decrease due to baking of the number of atoms on the free surface of particles (proportional to decrease in porosity ΔP) is proportional to the original amount of atoms on the free surface of particles and, consequently, to the original compact porosity P where

$$\Delta P = cP, \qquad 47$$

where c is the constant coefficient of proportionality.

(3) In a certain number of cases formula (47) calls for a certain modification inasmuch as shrinkage due to baking is proportional not only to the number of atoms in the free sectors but also to the number of places of contact. Through making such adjustments it is possible to obtain a formula of the type:

$$\frac{\Delta\beta}{\beta} = cP, \qquad 48$$

where $\frac{\Delta\beta}{\beta}$ is volumetric shrinkage and c the constant coefficient of proportionality. In some cases (such as when baking involves the creation of a liquid stage) the number of places of contact shows little relationship to initial porosity so that formula (47) may be used without any corrections.

(4) The drawing apart of particles and processes of growth occuring during baking are due to different processes: to absorption of residual stresses, to removal of gases, to zonal and individual separation. However, one may suppose it to be true of all cases that tensions resulting in drawing apart (of particles) have a constant value regardless of original porosity when referred to a unit of contact surface.

For this reason deformation (growth in size) caused by such stresses has a constant value S regardless of initial porosity for specific baking conditions. In summarizing the action of the processes of drawing together and drawing apart we obtain linear relations of the type:

$$\Delta P = c P - S \qquad (47a)$$

and

$$\frac{\Delta \beta}{\beta} = c P - S \qquad (48a)$$

The linear relation according to formula (47a) is whown in Figure 124 and for formula (48a) in Figure 121.

Deviations from the linear relation for compacts having high densities are explained by the action of residual stresses, for those having low densities by the marked decrease in contact points which serve as centers of shrinkage. We should try to obtain compacts which are as dense as possible, inasmuch as the density which is attained during compacting is connected with a number of beneficial structural results. This propensity is limited, on the one hand, by the wearing out of the press mold, and on the other hand, by unfavorable structural changes in the case of certain powders due to exessive pressure (laminated cracks which may not be rectified during baking and an undue orientation of flat particles).

(e) Influence of the Kind of Metal and of Phase Changes

Differences in metals show themselves indirectly when they are being subjected to their respective baking temperatures to the extent that they create differences in the tensile strength of compacts (high melting point and hard metals produce compacts with relatively small tensile strength) and in ease of reducing oxides (for example, oxides of aluminum and of zinc are difficult to reduce) and may be also responsible for the presence of phase changes.

Iron undergoes at 910 degrees an $\alpha\gamma$ transformation which permits an increase in density upon heating the solid metal and a decrease to its former size upon cooling it.

Density in Grams
per Cubic Centimeter

Centigrade

Figure 126. Effect of $\alpha\gamma$ Transformation on the Density of Baked Iron (184).

The density of porous iron upon being cooled after being baked at a temperature somewhat higher than point A_{c3} to room temperature decreases somewhat as a result of the $\alpha\gamma$ transformation (see Figure 126). There is a lowering of the mechanical properties of porous iron parallel to the decrease in density. This decrease in density and [mechanical] properties continues sometimes to exist even at higher temperatures ranging up to 1100 degrees. A diminution in the properties at the actual point of transformation may be explained (36) by the staggered process of transformation in different particles, as a result of which contact is broken between them, so that density decreases. However, a further decrease in density with still higher temperatures, where transformation by all rights should have stopped may be explained only by the intensified action of the processes of irregularly localized individual changes and separations of shrinkage caused by phase recrystallization (perekristallizatsiya). This point of view of the author can be supported by Bryukhanov's work (27) which, based on investigations carried out with respect to grain recrystallization (recrystallizatsiya) shows that further recrystallization (perekristallizatsiya) and a marked change in grain orientation takes place only with relatively prolonged heating above point A_{c3}.

(f) Influence of Atmosphere on Baking

Table 19 presents the results of baking (137) of burnished surfaces of solid metals in a vacuum and in hydrogen (the specimens used in testing for fracture were cut into two halves; the surfaces that had been cut were polished; the halves were pressed together in a special vice and baked).

[For table see following page]

It can be seen from Table 19 that baking in a vacuum in the majority of cases began at relatively lower temperatures and produced a more durable contact.

It has been established (153) that copper compacts that were not dense showed after baking in a vacuum relatively high shrinkage and density than when baked in hydrogen.

Shrinkage and final density of dense copper compacts were almost the same after baking either in a vacuum or in hydrogen.

The process of the formation of a new contact surface and shrinkage may be thought of as the impregnation of metal pores by

Table 19. INFLUENCE OF ATMOSPHERE ON THE TEMPERATURE AT THE BEGINNING OF BAKING AND ON THE MAXIMUM TENSILE STRENGTH ACHIEVED (137)

Metal	Temperature at the Beginning of Baking in Degrees Centigrade		Maximum Tensile Strength Attained in Kilograms per Square Millimeter		
	Vacuum	Hydrogen	Baking Temperature in degrees centigrade	Vacuum	Hydrogen
Al-Al	310	450	600	4.0	2.0
Cu-Cu	500	600	900	14.5	10.0
Cu-Ni	540	410	900	8.5	10.0
Steel-Iron	550	600	1000	15.0	12.0
Cu-Fe	540	410	900	17.0	19.0
Ni-Ni	550	600	1000	23.0	19.0
Steel-Steel	550	600	1000	20.0	25.0
Fe-Fe	550	600	1000	20.0	28.0
Fe-Ni	550	600	1000	19.0	22.0

the mobile, semi-liquid surface layer of particles. The presence of air hinders this impregnation, while a vacuum helps the filling up of capillaries which are difficult of access. In the same way intraparticle pores which contain gases, as Frenkel pointed out (120), may not be completely filled up by metal. This is the reason that, although the removal of oxides proceeds more quickly in hydrogen, shrinkage and the formation of a new contact surface usually begins in a vacuum at a lower temperature and has wider scope. In poorly compressed copper specimens the formation of a new contact surface plays a most important role, while vacuum produces better results than hydrogen. In greatly compressed specimens, the formation of a new contact surface during baking plays no part so that hydrogen does not give an inferior density.

In some cases an important role is played in baking in a vacuum by the freeness of a metal from admixtures (by improving density and [mechanical] properties) and by a slower and more difficult removal of oxides in a vacuum (by decreasing density and [mechanical] properties).

Baking of Multi-Component Systems

In baking metal powders composed of several components, the following cases may take place.

(1) Components do not form in given baking temperatures solid solutions or chemical compounds in sufficiently large quantities.

(2) Components are mutually dissolved during baking. No liquid phase takes place during baking.

(3) Components are mutually soluble during baking. A liquid phase occurs during baking.

Copper-graphite and bronze-graphite compositions may serve as examples of the first case. (In such a case bronze would be considered as a group of components -- copper, tin -- which are inert in relation to graphite). Copper-nickel, iron-nickel and other alloys serve as examples of baking during the solid phase with the existence of mutual solubility of components. Hard alloys (WC--Co, etc.), so-called heavy alloys (W--Cu-Ni), etc., serve as typical examples of baking during which there occurs a liquid phase under conditions of mutual solubility of components.

Certain cases do not fall within the framework of this classification. Thus, the system of iron-graphite may be looked upon as a case of mutual insolubility of components because graphite does not react with iron during baking. However, cementation frequently occurs during the baking of iron-graphite compacts since carbon is dissolved, such a system must be considered as a case of mutual solubility. The same thing may be said with respect to the system of copper-lead. In some cases copper reacts with lead, For other cases this system may be considered as a case of mutual insolubility.

(a) Cases of Mutual Insolubility of Components

The characteristics of a metal powder that is completely mutually insoluble are determined principally by the component that comprises the greatest part of the mixture (volumetrically). For this reason mechanical properties and density in accordance with exposition of data made earlier increase with the dispersion of the basic metal. The system of copper-graphite is a typical example of complete mutual insolubility. The influence of the inert component (in this case graphite) comprising the smaller part may be reduced to the following (Figure 127).

(1) Graphite insulates to a certain degree the particles of metal from mutual contact, interferes with the drawing together of atoms toward the places of contact during shrinkage, and weakens the mechanical strength of the metal powder. For this reason, by introducing graphite shrinkage is reduced (in fact there is frequently observed an increase in size after baking). In this connection longitudinal shrinkages decrease considerably more than transverse ones.

(2) The insulation of metal particles from contact increases with the amount and dispersion of graphite. For this reason decrease in shrinkage progresses with the amount and dispersion of graphite.

(3) In the majority of cases graphite decreases mechanical properties and plasticity, the decrease of properties increases with the quantity of graphite.

Kg/mm^2

Linear Change Temporary Resis-

in Dimensions tance to Rupture

Millimeters

Graphite
in percent

Figure 127. Relation of Shrinkage and Resistance to Bending to Graphite Content on the Part of Copper-Graphite Products (Bal'shin)

1- shrinkage parallel to compression; 2 - perpendicular to compression; resistance to bending; 3 - fine copper, poured weight 0.64; 4 - the same, medium poured weight 1.50; 5 - coarse, poured weight 2.47; depth of survature; 6 - fine copper; 7 - medium; 8 - coarse. Baking for 45 minutes at 800 degrees

(4) In some cases the inclusion of graphite (in a small quantity with sufficient dispersion of the basic metal) causes besides a lowering of shrinkage and density what seems to be on first glance a paradoxical increase in mechanical strength and capacity for deformation. This is explained by an increase in the equability of density distribution in the compact caused by the inclusion of graphite (Figure 70), thanks to which there is a decrease in distortion of shape, buckling, and internal stresses after baking. Sometimes graphite also exerts a favorable deoxidizing action.

(5) With a decrease in the dispersion of the basic metal, there is an increase in the insulating action of graphite on the surface of particles and in its unfavorable influence on [mechanical] properties. For this reason the metalloceramic industry in practice avoids including graphite in mixtures composed of coarse powders.

(6) The relationship of mechanical properties to dispersion of graphite is rather complex. When the basic metal is in the form of fine powder the best results are usually obtained by graphite that is more dispersed even though it considerably decreases shrinkage. Fine graphite lodging in the pores existing between individual particles does not interfere with their contact. Coarse graphite results in

considerable local isolation of a number of particles. On the other hand, with respect to the coarser powders, best results are obtained from larger graphite articles which find their way into interparticle pores. Small-particle graphite completely insulates the surface of particles, exercising a most unfavorable action on their properties. Thus it is necessary for a certain compatibility to exist between the sizes of iron and graphite particles.

(7) Graphite does not exert any significant influence on the temperature for the beginning of shrinkage and the beginning of particle growth. In those cases where the inclusion of graphite resulted in a strong growth of porosity during baking, there was observed a certain decrease in grain size. For the remaining cases there was not observed any perceptible increase in grain size.

(8) A part of the graphite is burned out in baking. The rate of such burning up increases with general porosity and the size of individual pores.

(9) Copper-graphite mixtures should be mixed in drums and not in ball mills so as to avoid total insulation of particles.

The conclusions reached with respect to copper-graphite compositions may be applied to other systems, such as iron-graphite.

It is possible to apply to a certain degree the results obtained from the study of copper-graphite composition to the action of admixtures which do not react with the basic metal and which are to be found on the surface of particles or of mechanically contaminated powders.

Figure 128. Structure of Copper-Lead Specimens. X500 (Bal'shin)

Insoluble components which do not melt during baking exert a somewhat different action. In compacts of slight density the melted component may be transferred in its entirety from contact fissures to large pores without offering any obstacle to the contact of the particles of the metal with the high melting point. In certain cases there may also occur an increase in shrinkage because of an increase in actual porosity due to the volume of the liquid component (the greater the porosity, the greater the shrinkage) or due to a certain amount of surface tension created by the liquid phase. With high densities for the compact, the liquid component insulates contact and greatly decreases shrinkage. Thus, one of the methods for obtaining iron fillings with very high porosity consists in a dense compacting of a mixture of iron and soda powders followed by later baking at 1000-1100 degrees. The melted soda hinders the drawing together of the iron particles. After baking the soda is washed out of the pores. The temperature for the onset of particle growth does not rise, although there is a considerably smaller particle growth. A system of copper-lead shows a strong increase in shrinkage in comparison with the original copper for compacts with slight density and, conversely, a marked decrease for high density. However, it is not quite clear to what extent a copper-lead system may be depended on in baking conditions when it is practically mutually insoluble. Intensified growth and characteristic shape of the grain observed in certain cases (Figure 128) may be explained by the action of a certain amount of solubility of copper in the melted lead. The baking of such system is also often complicated by the manifestation of liquidation on the part of the melted component.

(b) Systems of Mutual Solubility of Components

In the baking of powder mixtures, a marked formation of solid solutions or chemical compounds begins below the lowest melting temperature of the original components or their compounds and solid solutions.

The rate of mutual diffusion for two non-homogeneous metals is always considerably higher than for "selfdiffusion" of the atoms of one and the same metal. For this reason there may be created at first glance the false impression that one may expect a considerably greater shrinkage and growth of contact surface than for pure metals. However, Sauerwald (184) showed that in reality shrinkages and properties of specimens baked from a mixture of Fe-Ni, Cu-Fe, and Cu-Ni powders were always lower than the computations on the basis of additiveness for shrinkages and properties of the original components.

Two basic reasons exist which are responsible for such a decrease.

(1) If in diffusion the mobility of atoms of two mutually soluble metals is greater than the mobility of atoms of the same metal, then a completely reciprocal relationship is observed for the products of this action -- the hard solids and chemical compounds. The mobility of atoms in the more complex lattices of solid solutions and compounds is almost always less than for pure metals.

A decrease of mobility is reflected in an essential increase of recrystallization temperature with the introduction of admixture into solid solutions (in spite of the lowered melting point). This decrease in mobility slows down the rate of creep for the majority of solid solutions im comparison with pure metals. In this way in the baking of powders in which solid solutions were formed even prior to baking shrinkages and grain growth must be less than for pure metals because of the decrease of surface forces (surface tension) and the increase in the stability of creep as compared to pure metals. When baking, however, mixtures of metal powders in which a reaction has not yet taken place, the speed of shrinkage decrease very rapidly to the level of the lesser than for pure metals because the more active atoms on the surface of particles form solid solutions during the initial stage of baking.

(2) If not more, at least not less important is the process of separation that takes place in the shrinkage of multi-component systems. Let there be baked a compact composed of a mixture of copper and nickel powders. With insufficiently ideal mixing in different parts of the product the following combinations may take place: (1) copper-copper contact, (2) nickel-nickel contact, (3) copper-nickel contact, (4) solid solution - solid solution contact, (5) solid solution-nickel contact, and (6) solid solution-copper contact. We have listed only six types of different contacts. Actually there are considerably more because solid solutions are of different concentrations. All these types of contact give a different shrinkage. There should also be taken into consideration that not only does the chemical composition influence shrinkage, but also shrinkage influences the composition. Let us suppose that there begins in some spot of the product an intensified shrinkage and growth of contact among the copper and nickel particles. This leads to a speeding up of diffusion

in that spot inasmuch as diffusion can take place only through contact sectors. The formation of a solid solution in its turn will modify subsequent rate of shrinkage. Difference in shrinkage for individual spots leads not only to the formation of sectors of varying density but also to a general decrease in density for the entire volume of the metal. As can be seen from what has been described, the process of uneven shrinkage plays in the case of powder alloys a much more harmful role than for pure metals, in particular when the mixing has not been sufficiently good. This is why it is necessary in certain cases to resort to a five-day long mixing of powders in ball mills.

In connection with what has been said there arises the cardinal question as to whether it is practicable to homogenize by means of preliminary heating a powder mixture composed of several metals and to resort to compacting and baking the already homogenized particles or whether to compact and bake a powder mixture of pure metals.

Each of these methods has its advantages and disadvantages

The advantages in homogenizing a mixture lie in the uniformity of shrinkage and composition. The disadvantages of this method lie in the difficulty of obtaining durable compacts (the hardness of a homogenized solid solution is greater than the hardness of the original components) and the using up of a considerable part of atomic mobility in obtaining a prelininary diffusion.

Where it is necessary to obtain a porous sintering, it might prove practicable to use unheated powder mixtures. Where it is necessary to obtain almost solid materials (without later processing after baking), it is frequently preferable to use a homogenized mixture. Thus, when fabricating tungstentitanium hard alloys preliminary heating of the mixture of tungsten carbide and titanium carbide is resorted to.

The basic rules for baking multi-component systems in the absence of a liquid phase may be reduced to the following.

(1) Shrinkage and change of contact surface and of properties of powders is generally subject to the same rules as for single-component systems, i. e., there are changes with dispersion of powders for each of the components, compacting density, temperature, and length of exposure, etc. If powders which have been subjected to preliminary homogenization are used, than the baking of even the system [sic].

(2) The speed and completeness in the formation of solid solutions and intermetallic combinations increases with the dispersion of each component.

(3) The method of mixing the composition plays an important role. Mixing in ball mills helps achieve a closer contact among particles and to a large extent assists the process of diffusion than mixing in drums.

(4) An increase in compacting density increases the contact surface of particles and speeds up the course of diffusion processes (Figure 129).

Percent

Percent

Combined

Figure 129. Relation of the Content of Combined Carbon in Iron-Graphite to Compacting Porosity (Bal'shin).

(5) Shrinkage and modification of contact surface during baking affects the course of diffusion processes. In the case of shrinkage of large products during the course of baking, the largest stresses of shrinkage, density and size of contact surface take place in the central zone. In consequence the formation of solid solutions and intermetallic combinations occurs there with the greatest degree of completeness.

Sometimes the greatest degree of activity among components is also observed in the central zone during the expansion of products from baking when expanding stresses achieve their greatest size in this zone. It is possible that under such conditions diffusion is intensified both as a result of the presence of stresses and as a result of considerable displacement of contact points during baking.

(6) The number of reacted components increases with temperature and length of baking.

(7) Some admixtures interfere with diffusion. According to

the author's findings carburization of iron begins only at 1000-1100 degrees after an adequately complete reduction of oxides contained in the original powders. Rapid reduction of residual oxides takes place at a temperature 2/3-3/4 of the absolute melting point of the metal. In this way such a temperature is not only the temperature marking the onset of perceptible grain growth but in some cases the onset of perceptible diffusion.

(8) Certain admixtures considerably speed up diffusion. Thus according to Offerman (175) slight admixtures of sulphur and phosphorus help carbon to react with iron in the fabrication of carbonyl steel. In all probability this effect may be explained by the formation of eutectics which melt at baking temperature and increase contact between particles and mobility of iron atoms which are on the surface and have entered into solution, as a result of which diffusion is intensified.

(9) If diffusion processes pass through a gaseous phase, then its composition plays an important role. For example iron-graphite products are carburized more if they are baked in dry hydrogen than in wet hydrogen. Of great importance is gas permeability, which increases with total porosity and the size of individual pores. Gas cementation of products made from coarse powders which are very porous takes place more completely and quickly than for products made from fine powders with slight porosity. The burning out of carbon is also more considerable when baking compacts made from coarse-particle powders.

The factors mentioned above may cause an unevenness in structure density, composition, and properties even where mixing and compacting has been ideally uniform and even. In actual practice, unevenness of mixing and compacting play a significant role.

(c) Baking of Multi-Component Systems and the Formation of a Liquid Phase

The baking of a hard homogenous metal powder at a temperature below the melting point may be considered as a special kind of borderline case in the baking of a two-phase system at a temperature above the melting point of the more fusible phase.

The obtaining of complete contact among particle and a 100 - percent solidity for baked products in such a borderline case is hindered by the inadequate quantity and mobility of atoms of the "liquid phase".

Such defects do not occur in baking powder mixtures of two or more components where the smaller part melts and dissolves a part of the less fusible metal.

Two cases may be considered.

(1) Solubility of the liquid phase in the hard phase is relatively small. For this reason the system remains heterogeneous regardless of the time of exposure for a given temperature.

(2) The solubility of the liquid phase in the hard phase at baking temperature is so considerable that after a certain time the system becomes homogeneous.

Let us begin by considering the first possibility. Let us assume that there is baked a powder mixture of two metals. -- basic component A with the higher melting point and a more readily fusible, so-called cementing component B -- at a temperature above the melting point of dissolving. A in B. For the sake of simplicity let us propose that the cementing component B is completely insoluble in A at baking temperature, although, as Jones correctly points out, nothing of any importance happens if some B dissolves in A (under conditions where heterogenity of structure is preserved). An inevitable consequence of the solubility of A in B is a process of interchange of atoms between the solid and liquid phase, even after the formation of a saturated solution. The saturated solution contains a dynamic equilibrium between atoms which are being dissolved and those which are coming out of solution. In this connection, the first to be dissolved are the more mobile atoms, while the first to separate from a solution are the less mobile atoms.

a b

Figure 130. a- Faceted and b - Oval Shape of Crystallites in Powder Alloys.
a- hard alloy WC-Co; X1000 (167); b - heavy alloy W-Cu-Ni (178).

For this reason the atoms which are dissolved come primarily from the sides and corners of particles, while the places of contact where the less mobile atoms are located tend to separate A atoms from the solution. In this way there is an uninterrupted drawing of A atoms through the liquid phase to the places of contact of particles accompanied by an intense shrinkage during baking. Grain growth takes place parallel to the shrinkage process because the number of mobile atoms is greater in smaller particles than in larger ones. For this reason the number of atoms dissolved during a unit of time is smaller and the number separating from the solution greater for smaller than for larger atoms, while there continues to take place an uninterrupted growth of large particles at the expense of small ones. Furthermore, considerable grain growth of component A begins to take place at very low temperatures, sometimes at less than 40 percent of its absolute melting point. The shape of crystallites during this recrystallization, which may even be qualified as a further recrystallization (perekristallizatsya) through liquid phase, being identical to the one taking place during crystallization from a fusion of the original crystals of cast alloys. Bochvar (23) points out the existence of two basic shapes for the original crystals of cast alloys -- faceted and oval. Bochvar explains differences in shapes being due to variations in the surface tension of hard metals, the latter being relatively great in oval and insignificant in faceted crystals. In powder alloys baked in the presence of a liquid phase these two shapes are also observed for the grains of the basic component (and probably for the same reasons). Figure 130a shows WC faceted crystallites in hard alloys (WC-Co), Figure 130b oval tungsten grains in tungsten-copper-nickel powder alloys. In the final analysis, increase in contact surface of particles and grain growth during baking in the presence of a liquid phase may be reduced to the same growth of the number of less mobile atoms at the expense of more mobile ones that takes place in the baking of pure metals. However baking during which a liquid phase occurs enables one to achieve greater contact among particles, density (almost theoretical) and tensile strength. This is explained by the following reasons.

(1) The number of mobile atoms of the basic component is considerably larger than when baking pure metals. In pure metals the number of the more mobile surface atoms reaches one percent at the most (Table 17) and as baking progresses it drops to an insignificant part of one percent. In baking in which a liquid phase occurs, the number of the more mobile atoms (surface and dissolved) comprises several percent and decreases much more slowly with exposure. For this reason the speed of creep (shrinkage) strongly increases during baking.

(2) The flow of the liquid phase (and consequently the mobility of the dissolved atoms) is considerably greater than the flow of the surface semi-liquid layer of pure metal (consequently the mobility of the corresponding atoms). For this reason capillary pores, which are hard to reach, are more quickly filled up.

(3) The area of initial contact among particles in the mixture increases considerably because of the spreading of the liquid phase over the surface (contact through the liquid phase).

(4) Shrinkage increases at the expense of an increase in effective porosity. Thus for an alloy with 30 percent pores and 20 volumetric percent of liquid phase, shrinkage should be the same as for a pure metal with 50 percent pores. Furthermore, the greater the porosity, the greater is the shrinkage (Figures 120, 112, 124).

(5) The filling up of larger interparticle pores is eased because the liquid phase is squeezed into these pores during shrinkage.

(6) During grain growth there is no such tendency to form intraparticle pores which are hard to fill when baking without a

liquid phase because recrystallization takes place through the cementing phase and not through direct contact.

This factor makes it easier when baking with a liquid phase to obtain alloys with 100 percent density. Alloys without pores are hard to obtain in those cases where, aside from an overcrystallization through a liquid phase, there may also take place grain growth because of direct contact among particles of the basic metal with the higher melting point, which is connected with the creation of intracrystallite pores. For example, it is difficult to fabricate non-porous iron- copper alloys because the melting point of the cementing metal (copper) is higher than the temperature of particle growth of the basic metal (iron), they being in direct contact.

In investigations of the nature of contact existing among grains of baked hard alloys (WC-Co) the cementing phase was removed by the dissolving of cobalt in reagent which would not act upon the basic component, tungsten carbide (148). Strength (resistance to bending) of the non-dissolved carbide skeleton (Table 20) is to a certain extent a measure of direct contact between grains of the basic component.

[See following page for table 20]

In this way, at any rate when the content of the cementing metal is not very high contact and strength are determined to a considerable extent directly by the basic component. A decrease in strength when cobalt is dissolved is to be explained by the harmful effect of porosity. However, it is quite probable that direct contact among the grains of the basic component is quite considerable even when there is a high content of the cementing metal. Let us assume that for each

Table 20. STRENGTH OF A CARBIDE SKELETON IN ALLOYS WITH VARYING COBALT CONTENT (BAKING TEMPERATURE OF 1450 DEGREES FOR ONE HOUR [148]

Amount of Cobalt in Percent		Resistance to Bending in Kilograms per square millimeter		Volumetric Percent of Cementing Phase
In Original Alloy	After Dissolving	By Original Alloy	By Skeleton	
3.0	0.04	126	54	6.1
6.0	0.04	165	45	12
11.0	0.03	185	0	22

three grains of carbide two are joined by direct contact and the third by the cementing phase. In such a case the alloy breaks up upon cobalt being dissolved and thus acquires zero strength. However, this does not serve as a proof of the absence of direct contact among the grains of carbide. Moreover, such experiments proved that in increasing the baking of the alloy with 11 percent carbide to 120 hours at 1450 degrees with the dissolving of carbide strength grew to 18 kilograms per square millimeter, i. e., direct contact among the grains of carbide became quite significant.

The cementing metal is added in the quantity of 5-30 volumetric percent, usually 10-20 percent. Too slight a quantity of the cementing metal does not sufficiently activate baking, too large a quantity results in liquidation which causes distortion and other defects.

In practice such alloys are usually baked at a temperature somewhat higher than the melting point of the cementing phase (moreover, the higher it is, the larger can the size be for the original powders of the basic component).

Hard alloys (WC-Co, WC-TiC-Co), heavy alloys (W-Cu-Ni), iron-copper alloys (Fe-Cu), copper-silver alloys (Cu-Ag), a number of alloys to which phosphorus has been added to a copper or iron base, etc., may serve as examples for this type of alloys. Sometimes it is sufficient for only a slight dissolving of the basic component in the cementing phase to take place in order to obtain this type of alloy. Thus, the author obtained in some cases (4) for copper-lead powder alloys a characteristic grain growth through the liquid phase, despite the slight solubility of copper in lead at baking temperature (Figure 128).

[redacted]

There may serve as practical examples of the second variant of baking during which a liquid phase occurs the systems Cu-Sn, Fe-Al-Ni-Co (alnico), and other systems. For such cases the liquid phase diffuses after a while into the basic component and results in the formation of a homogeneous solid solution. The first stage may thus be considered as an instance of baking in the presence of a liquid phase and the second stage as baking without a liquid stage. In such a case it is possible to frequently acquire considerable strength and almost the full theoretic density.

The dependence of the properties of alloys baked in the presence of a liquid phase upon different factors (dispersion of powders, compacting pressure, temperature and duration of baking) is basically the same as for pure metals.

Spoilage in Baking

Baking is one of the last operations in which there can occur not only damage due to improper conducting of baking but also damage resulting from the earlier operations of compacting, mixing, and fabrication of powders.

The most important reasons for damage are the following:

(1) Hidden lamination. Compacting improperly conducted may result in the formation of small laminated cracks not visible to the unaided eye which may considerably increase during baking. The measures for dealing with them are the same as for visible lamination.

(2) Buckling and distortion of shape. This type of damage is especially frequently observed for flat products, the thickness of

which is insignificant in comparison with its length manufactured from fine powders which are subject to considerable shrinkage. This type of damage is promoted by poor mixing, uneven compacting density due to imperfect construction of the press mold or poor compacting operations, too rapid an increase in temperature, surface oxides or the burning up of the protective medium because of improper selection, or an excessively high baking temperature. Protective measures include the elimination of the defects just mentioned, using for some cases powders which are less prone to buckling, and baking under pressure. Damage may be rectified by subsequent hot or cold pressure treatment (calibration, baking under pressure).

(3) Overheating -- products cracking in baking temperatures which are too high for a given mixture. This type of spoilage is induced by the same factors as buckling.

(4) Formation of macropores due to shrinking. Observed in baking products compacted from a powder mixture of two or more components. Caused by uneven shrinkage which is especially favored by the uneven mixing of components. Measures to avoid this include a more scrupulous mixing, and a preliminary heating mixture. Such spoilage may sometimes be rectified by subsequent cold or hot pressure treatment.

(5) Formation of a loose, poorly baked core. This is primarily observed when baking mixtures of powders which become very dense because of considerable shrinkage due to the presence of a liquid phase. It takes place when the outside of products becomes heated too quickly through oven-rapid raising of temperature to baking level. Furthermore, shrinkage in the external zones ceases prior to the beginning of shrinkage in the central zone. A premature formation of a dense external zone

interferes with the shrinkage of internal layers and with the circulation of gases. This type of spoilage is also aided by the formation of differences in chemical composition between external and internal zones due to incorrect selection of a protective medium. The measures for dealing with this include a more gradual reheating of products and a proper selection of the protective medium.

Chapter VI

HOT PRESSING

The operation of hot pressing combines the operations of pressing and baking into one. One actual distinction can be made between pressing and baking under pressure. This distinction between them consists in the fact that the term "hot pressing" should be applied primarily to pressing at high speeds. When pressing at high speeds there is only a slight manifestation of creep. Diffusion, recrystallization, and reduction also do not occur to the fullest extent. In this connection a second heating is required for evening out composition and structure. At the present time hot pressing of powders of non-ferrous and ferrous metals is not economically feasible for the following reasons.

1. Hot pressing is connected with considerable wear of the press mold and also partly with the difficulty of selecting a material for the press mold which can be used at high temperatures. For the hot pressing of the majority of powders press molds are required which have a more complex design for avoiding oxidation of products during pressing or ejection.

2. Hot in contrast to cold pressing is not very productive.

3. In the majority of cases hot pressing does not eliminate the necessity either for later heating (for evening out composition and structure) or for a preliminary cold pressing (to make pressing easier).

However, on the qualitative side hot pressing is connected with important advantages. Table 21 presents comparative data of of Sauerwald and Gunchek (184) relating to resistance to rupture on the part of iron and copper specimens.

TABLE 21

Temperature in Degrees Centigrade for Hot Pressing or Baking	in Kilograms per Square Millimeter for Baked Specimens		in Kilograms per Square Millimeter for Hot Pressed Specimens	
	Cu	Fe	Cu	Fe
610	14.2	-	26.3	19.7
715	13.2	6.6	24.1	29.3
810	10.3	11.5	23.5	39.6
920	-	14.7	-	-

As can be seen from Table 21 mechanical properties are considerably higher with hot pressing. Pressure in hot pressing is considerably lower than for cold pressing (Table 22). The advantages mentioned make it possible to apply hot pressing for the obtaining of materials and products the fabrication of which by cold pressing and baking is limited by the composition or structure of the powder or the size and shape of product.

At the present time (127), hot pressing is used on an industrial scale only for the production of metalloceramic hard alloys and diamond-metal materials (Chapter XII). In connection with its being less economical than cold pressing, hot pressing is used either in the production of hard-alloy products of very large size weighing several tens of kilograms or of thin plates, disks, etc., which buckle in baking. During the war hot pressing was used in the production of substitutes for hard alloys (142) with vanadium carbide, etc., for a base. The manufacture of such materials so that they have the requisite qualities by cold pressing and baking is difficult and sometimes impossible. Hot pressing of hard alloys is carried on either in graphite or carbon molds which are capable of pressing only a very limited number of details (from one to several pieces). In the hot pressing of hard alloys there is no need for a special protective atmosphere inasmuch as one is created by a slight combustion of the graphite of the press mold. In some cases hot pressing is carried on in a reducing atmosphere which cuts down the burning of the graphite and is used for lengthening the life of the press mold. The design of press molds used in hot pressing is no different in principle from the design of press molds for cold pressing.

[Figure 131. Press for Hot Pressing (194).]

For purposes of increasing the length of service of graphite press molds it is possible to use replaceable graphite lining. Parts of press molds are fabricated from graphite rods and tubes, the inner diameter of which is made exact by pulling through brushes. In spite of all such measures, the cost of press molds used in the hot pressing of other non-ferrous and ferrous metals turns out to be too high.

The poured mixture in the press mold is subjected to a preliminary cold compression at no very high pressures. Heating in hot pressing is achieved by passing an electric current through the press mold. Figure 131 shows an industrial press for hot pressing according to Engle [194]. The hot pressing of hard alloys may also be done in apparatuses used for welding under pressure (127) or with a press according to Vasil'yev's system (17).

In hot pressing of hard alloys pressures have been used varying from 80 to 300 kilograms per square centimeter depending on the tempe ature and composition (161). At 1350-1400 degrees there was used a pressure of 105 kilograms per square centimeter, above 1400 degrees a pressure of 70 kilograms per square centimeter. In other experiments pressure varied from 30 to 180 kilograms per square centimeter (194). There are indications that, besides heating by passing a current through the press mold, it would be possible to employ a high-frequency heating. The pressing of hard alloys (tungsten carbide, cemented with cobalt) usually takes place in a temperature which is somewhat lower than that used in the baking of cold pressed compacts of a comparable composition. With extremely high temperatures it is possible to squeeze out the liquid phase. Control over temperature is achieved by means of an optical pyrometer, in which connection it should be kept in mind that, because of heat loss, the temperature of the walls of the press mold is 150-200 degrees higher than that of the compact. Compression under pressure varied from a fraction of a minute to ten minutes. The total duration for the entire cycle of pouring, cold prepressing and the cooling off of the compact is commensurably longer.

a

b

c

[Figure 132. Porosity of Hard Alloys]

a - hot pressing, b and c - cold pressing and baking; without pickling. X100 (167)

Hot pressing increases density, hardness, strength, and the cutting properties of hard alloys (167, 194). Figure 132 shows that in hot pressing in distinction to cold, hard alloys have practically a non-porous structure. The maximum hardness of alloys made by cold pressing and baking (161) is 92 and with hot pressing is 95.6 according to Rockwell. The advantage of hot pressing for producing diamond-metal alloys lies in the fact that less diamond is burned out because of the shorter heating period.

The processes of hot pressing and the properties of materials obtained by this method have been studied by a number of investigators, including Vasil'yev (17), Borok and Zarubin (22), Mol'kov, Gruzdov, Trzhyebyatovskiy (192), and others (144, 184). The hot pressing of different powders of copper and its alloys, iron and its alloys, gold, hard alloys, and others were investigated. However, the material obtained experimentally is not yet sufficient for establishing a satisfactory theory of hot pressing. The fundamental facts as known at the present time may be reduced to the following.

(1) In hot pressing increase of contact among powder particles is achieved through deformation by external forces and by the mobility of atoms activated by temperature. For this reason it establishes the possibility of obtaining material with a density approaching the theoretical and with properties not lower than those for cast metals treated by pressure.

(2) With an increase in temperature (194), as Table 22 shows, lowers the size both of the specific pressure necessary for attaining a certain density for the powder and of the maximum specific pressure for attaining 100-per cent density. Certain exceptions to the relationship just given may be explained by phase transformations.

TABLE 22

RELATION OF PRESSURE TO TEMPERATURE FOR POROUS IRON POWDER WHOSE PARTICLE SIZE IS 150 MICRONS (194)

in Kilograms per Square Millimeter

Relative Density of Briquet in Percent	Compacting Pressure/at a Temperature of							
	20°	500°	600°	700°	800°	900°	1000°	1100°
90	160	30	16	95	5	4	6	3
95	240	55	30	16	8	6	9	6
100	350	95	47	32	16	12	14	11

(3) The considerable increase of tensile strength for hot pressings in comparison with unbaked cold pressings cannot be explained by growth in density through increased temperature alone. An important role is also played by the following factors:

(a) An increase in the coefficient of lateral pressure ξ as a result of growth of Poisson's coefficient due to temperature; (b) a decrease in the elastic aftereffect after ejection, inasmuch as the elasticity modulus decreases with temperature to a lesser degree than hardness; (c) the tensile strength of hot pressings is due not only to the interlocking but also to the cohesion of particles.

(4) At a given pressure an increase in temperature in pressings causes the indexes of tensile strength (resistance to rupture, compression, and bending) to grow and to achieve a maximum at some mixed temperature. Beyond this temperature either continues to stay at its highest level or sometimes even decreases. For example (Table 23),

the resistance of iron to rupture at different temperatures which had been compressed at a pressure of 7 kilograms per square centimeter at 780 degrees in a reducing medium (duration, 150 and 450 seconds) was somewhat lower than iron compressed at 700 degrees.

TABLE 23

MECHANICAL STRENGTH OF IRON COMPRESSED UNDER DIFFERENT CONDITIONS AT A PRESSURE 7 KILOGRAMS PER SQUARE MILLIMETER (144)

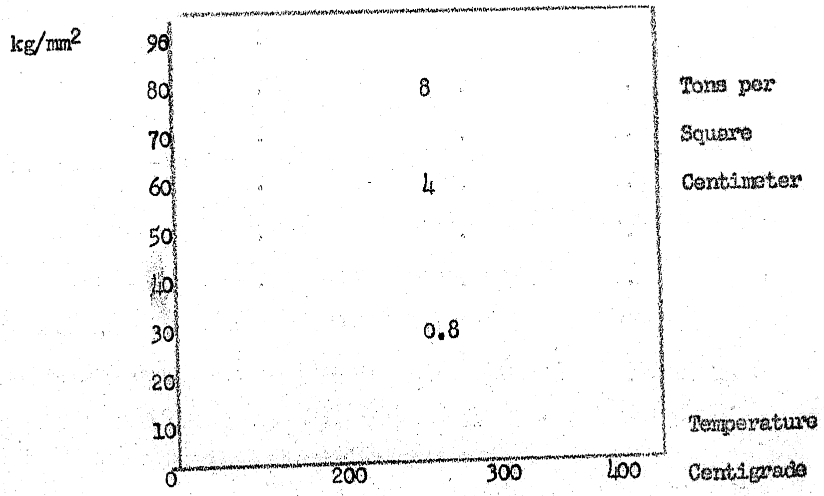
Temperature in Degrees Centigrade	Time in Seconds	Specific Weight in Kilograms Per Sq			ell iness
500	50	6.31	18.4	0	50
	150	6.38	22.8	0	51
	450	6.71	28.0	1.0	63
600	50	6.70	25.9	0.5	62
	150	6.89	28.6	1.0	77
	450	7.05	34.2	2.0	80
700	50	7.32	33.5	1.0	90
	150	7.52	40.1	12.0	95
	450	7.58	40.3	27.0	100
780	50	7.59	37.9	22.0	101
	150	7.71	36.7	32.0	93
	450	7.76	37.0	37.0	96

This relationship is explained in the following way. Tensile strength depends basically on three factors -- density of material

(The influence of the factors given above - the coefficient of lateral pressure and elastic aftereffect - changes with temperature in one direction with density. For this reason we do not give any data concerning them in the given case), hardening, and contents of admixtures and oxides. An increase in density accompanied by an increase in temperature helps to increase tensile strength. It is for this reason that a decrease in tensile strength induced by the last two factors begins at some given temperature. From what has been said above it is clear that the crest temperature drops with an increase of oxide content and compacting pressure. With slight oxide content and compacting pressure the crest point (tochka peregiba) may be entirely absent.

The crest point is most clearly evident for hardness at high compacting pressures (Figure 133).

Indexes of plasticity (elongation, neck reduction, increase of transverse cross section during compression) show an unbroken increase with compacting temperature (Figure 134) because the action of all three above-mentioned factors is in the direction of increasing properties.



[Figure 133. Brinell Hardness of Copper in Relation to Compacting Temperature (194)]

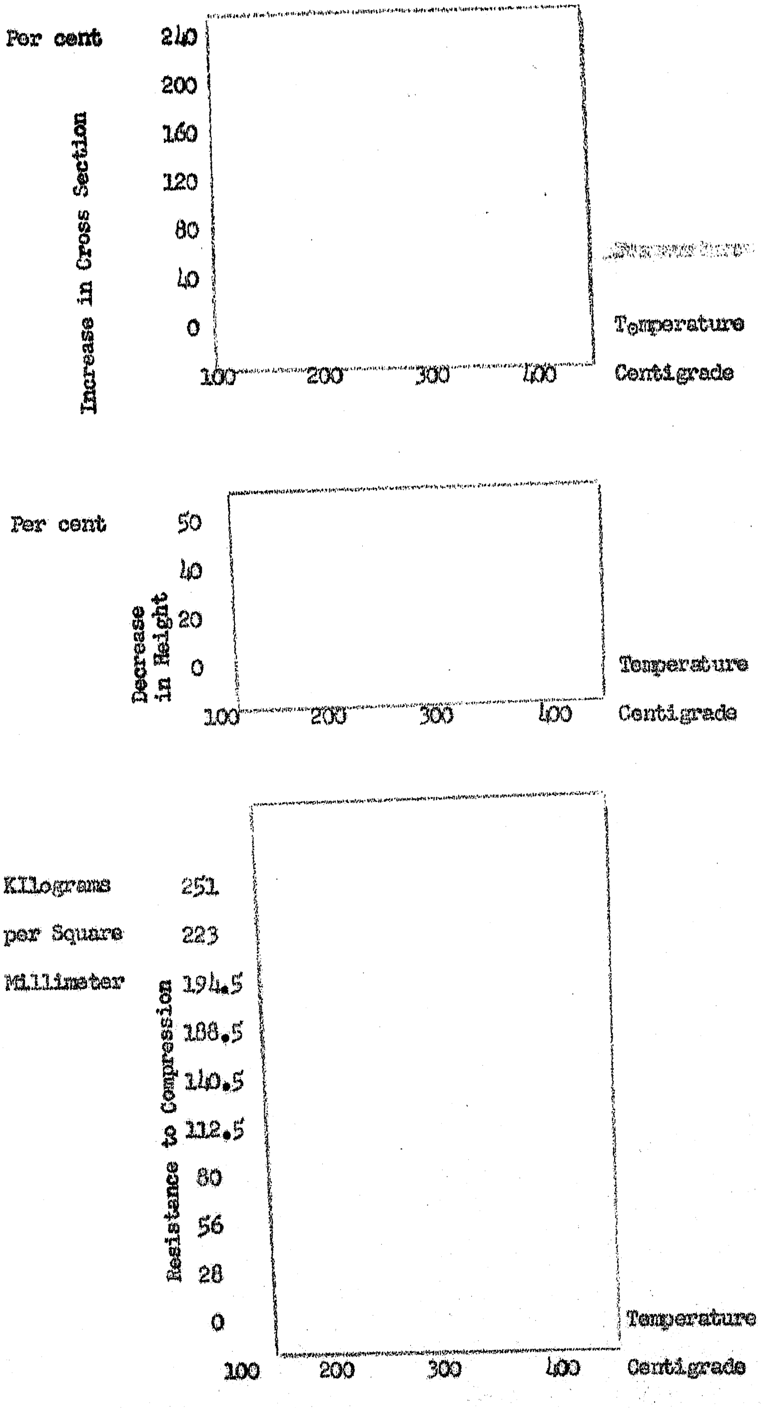


Figure 134. Relation of Mechanical Properties to Compacting Pressure When Compressing Copper (194).

(5) All properties increase with growth in compacting pressure, but only to a certain point, which is reached when there is 100 per cent density. They remain practically the same with additional increases in pressure, especially with higher compacting temperatures. The pressure at which properties become constant (corresponding to low critical pressure in specimens) varies inversely with the temperature.

(6) The duration of hot pressing is a very important factor as a very significant role is played by manifestations of creep at high temperatures. The slower the pressing the lower is the pressure required for attaining certain densities and properties, or, the greater are properties and density for a given compacting pressure (Table 23). Aside from manifestations of creep, prolonged pressing is connected with a greater reduction of oxides, recrystallization, and breakening down of cold hardening. All these considerations result in an increase of plasticity and, in the majority of cases, of properties (except hardness and tensible strength at higher temperatures which may decrease somewhat for reasons given in paragraph 4.

[Figure 135. Furnace for Baking Friction Disks Under Pressure]

(7) Manifestations of recrystallization are observed in hot pressing. Observable symptoms of recrystallization have been noted (194) in the hot pressing of copper even at 500 degrees (approximately 60 degrees below the melting point). It is characteristic that recrystallization is markedly expressed in the case of coarse, and not fine, powders. This is obviously connected with a relatively smaller oxide content and because of this with a more rapid reduction of coarse particles in rela-

tively short periods of hot pressing.

(8) Annealing by hot pressing is connected with further recrystallization, correcting structure and changes in density. Compacts of slight density show a certain shrinkage, large ones increase in size (194). The concurrence of shrinkage and growth in their case should be explained in the say way as for cold compacts, i. e., growth by the elimination of gases during reduction of oxides and absorption of residual stresses.

Baking under pressure is not done with high compression speed. Its features are prolonged exposure to the baking temperature and, what is related to this, a complete transaction of the processes of diffusion, recrystallization, and a marked occurrence of creep in relation to which pressures are insignificant.

The process of baking under pressure is used in present-day metalloceramic technology for metalloceramic friction disks (Chapter XI), which in the opposite case would have buckled and separated from the steel lining. Baking under pressure, as Gardin points out, is carried on in bell-type furnaces (Figure 135). Steel stamped disks and friction linings compressed from powders of copper, tin, lead, and graphite are loaded into the furnace with a reamer, after which the dome is put on and pressure applied, with baking taking place in a protective atmosphere. Pressure on the shell is achieved with compressed air through a damper. The size of the specific pressure applied to the surface of the baking disks is 10-40 kilograms per square centimeter. Temperature and exposure are the same as for baking alloys of this type without pressure, being 700-860 degrees from 30 minutes to several hours. When baking under pressure, there are obtained considerably higher properties and a stronger cohesion of the metalloceramic layer to the steel disk.

CHAPTER VII

DIFFERENT METHODS OF METALLOCERAMIC TECHNOLOGY. SUPPLEMENTARY HEAT AND MECHANICAL FINISHING OF BAKED OBJECTS

The production of objects by employing the operations of mixing, pressing, and baking of metal powders is basically the most widespread method of the metalloceramic industry.

Other, quite numerous methods (Figure 1) may be broken down into the following groups.

(1) Methods distinguished by specific differences in conducting the above-mentioned fundamental operations and also by the inclusion of supplementary intermediate processes between pressing and baking.

(2) Exclusion of the pressing operation.

(3) Exclusion of the baking operation.

(4) Combination of the operations of pressing and baking into one - so-called hot pressing (see Chapter VI).

(5) Supplementary and/or heat finishing of baked objects.

(6) Special kinds of finishing baked objects.

The above-listed supplementary operations are used in factories which contract for metalloceramic products. Moreover, supplementary finishing sometimes, especially machine finishing, is also carried by consumers of metalloceramic materials.

SPECIFIC VARIATIONS IN MIXING, PRESSING, AND BAKING OPERATIONS

The following specific variations in carrying out mixing, pressing, and baking operations may be listed.

(a) The pressing and baking of mixutres composed partially or completely of metal oxides or combintions which are reduced in baking. This method of technology is used in some cases in order to improve and make easier the mixing of powders (such as in the production of hard alloys), in others - in order to obtain high porous products, and still other cases - for the purpose of lowering the cost of production through combining the operations of obtaining the powder (reduction) and baking.

(b) The pressing and baking of mixtures with special additives in order to obtain highly porous products (higher than 40 per cent). Such additives are either burned out and volatilized during baking (aluminum carbide) or are washed out of the pores of products after baking (soda).

(c) Some baked materials, such as hard alloys (Chapter XII) and magnetic materials which contain aluminum, nickel and cobalt (alnico, Chapter XVI) do not lend themselves to mechanical finishing. In such cases recourse is had to the processing of semifinished products on polishing wheels prior to baking or directly after pressing or after an initial baking at a lower temperature than that of the final (second) baking. The processing of both hard alloys and of magnetic alloys (101) directly after pressing is more productive and pickles an instrument less than processing after a preliminary baking. Powders of hard alloys must be compacted with adhesive agents for mechanical processing without a preliminary baking. In the processing of hard alloys there are usually used thin carborundum disks on a vulcanite binding which rotate with a speed of about 2000 revolutions per minute. According to Rakovskiy (101) satisfactory results can be achieved with carbide-tungsten wheels on a bakelite binding.

Sometimes preliminary baking is done with a lower temperature, even where there is no necessity for a mechanical finishing of objects. Preliminary baking in such cases is recommended either for detecting spoilage which had not been discovered in compacts (such a semifinished product may be easily reduced to powder) or for obtaining a homogeneous composition prior to final baking (reduction of oxides, extraction of admixtures, burning out of additives used for easing pressing, etc.).

(d) In some cases a layer of metalloceramic material is on a superimposed metal sheet, plate, or disk, or as an insert in a metal socket. At other times, a core or insert made of a solid metal is inserted into a metalloceramic socket. Steel is usually used as a metal base to which the powder metal is fused. The fusing of the power metal is done either in pressing or in baking, sometimes baking under pressure (Chapter VI). Bimetals are used in the following instances: (1) when strength of the metalloceramic material is inadequate and must be reinforced; (2) for decreasing the cost of products made from a very expensive powder metal; (3) to make for easier assembly when it is either impossible or difficult to process metalloceramic materials directly; (4) the combination of the above-mentioned considerations. Examples of such bimetals may be found in friction disks (Chapter XI), lead bronze on a steel ribbon and triple-layer antifriction material (Chapter X). In a number of cases there are fabricated bimetal permanent magnetic (Chapter XVI) and contact materials, filters with metal washers (Chapter XIV), etc.

It is possible to produce bimetals not only from a powder and a solid metal but also from several powder metals.

EXCLUSION OF THE PRESSING OPERATION

There have been produced on an industrial scale ingots weighing up to 2 tons of slivhtly shaken down carbonyl iron or nickel baked in sealed containers. These powders have a high poured weight (relative density of a pouring is about 40 per cent) and a spherical shape for their particles. The baked ingots are later subjected to forging and rolling.

Filters which have considerable porosity are produced by baking in mold powders with high poured weight (density of pouring about 50 per cent) composed of spherical particles.

EXCLUSION OF BAKING OPERATION

Magnetic cores for induction coils (magneto-dielectrics) and also permanent press magnets are made by compacting a mixture of ferro-magnetic materials and plastic (Chapter XVI). Pressing is generally done at a pressure of 8-15 tons per square centimeter at room temperature or at 150 degrees for polymerization of the plastic. Where a material has been compacted at room temperature, it is later heated to 150 degrees to harden the plastic.

Porous iron for calking pipes (72) is produced by compacting bituminized iron grit (Chapter XIV).

SUPPLEMENTARY MECHANICAL AND HEAT FINISHING

In many cases supplementary mechanical and/or heat finishing is necessary for attaining precise measurements or improvement density and properties of a material.

To give precise dimensions to porous metalloceramic products recourse is usually had to so-called calibration, that is, cold compression in press molds. Calibrating press molds differ from compacting ones principally by their smaller height (no reserves are necessary for compacting the powder) and, quite frequently, by a less complex design.

A calibrating press mold of TsNIITMASh for calibrating only the diameter of bushings is depicted in Figure 136. A calibrating press mold for bushings on which it is also possible to calibrate height is shown in Figure 137 (194).

The dimensions of calibrating press molds are such as to include an allowance for an elastic a fftereffect (expansion up to 0.1 per cent) in the final dimensions of details. The ratio between the dimensions of compacting and calibrating press molds that is chosen is such as to permit changes in baking which would give them a diameter prior to being subjected to calibrating 0.5-1 per cent greater than the final one.

[Figure 136. A TsNIITMASh Calibrating Press Mold]

[Figure 137. A Calibrating Press Mold]

1 - punch; 2 - stopping device in calibrating face; 3 - die; 4 - ejector; 5 - press table; 6 - product.

[Figure 138. Calibrating Press Mold with Receiving Container (186)]

In baking residual stresses from compacting are eliminated, while the hardness of the grains of the metal is reduced very much, quite frequently by several times, because of the removal of cold hardening and the reduction of oxides. For this reason compacting pressure (net pressure) is many times less for a baked material than for later compacting of a briquet of the same porosity. This pressure is also considerably less than for processing a cast solid metal of the same composition. The pressure used in calibration is usually 10-30 per cent of compacting pressure. In order to use less pressure it is better to do the calibrating after a partial impregnation of the product with oil. Calibration is best done with crank presses. In industry calibration is done successfully with removable containers (Figure 138), which considerably increases labor productivity. Thus (186), calibration speed without a container is 4-6 pieces a minute, with a container 10 pieces a minute (up to 5,000 pieces during a shift).

Differences in density of material are evened out in calibration (the more porous places are easier to solidify). Here is also an increase of contact among grains and an improvement in the quality of outside surface. For this reason even with an insignificant increase in density of about 1 per cent, the strength of articles increases considerably (up to 20 per cent).

Subsequent processing by pressure, either hot or cold, as well as an additional thermal finishing is done not only to achieve precise measurements, but also for increasing density and properties of the material. Thus, in obtaining dense and strong materials with an iron or copper base, recourse is had to cold compressing in press molds, sometimes with later annealing.

Table 24 shows changes in properties and density of iron with different working according to Mes'kin, Shipulin, Mitrenin, and Vaynshteyn.

Upon increasing density to its theoretical level, the properties of a powder metal approach the properties of cast iron treated by pressure.

[See Table 24 on next page]

As has been mentioned, baked carbonyl iron ingots are subjected to not forging and rolling before being allowed to cool off. Data has been published concerning the fabrication by pressing in a reducing atmosphere from hot, baked billets (194) of round, rectangular, and irregularly shaped bars of oxygen-free copper having a cross-section of 3 to 30 square centimeters. There has also been described the production of thrust collars from coarsely ground shavings of austenitic steel (avtomatnaya stal') by being pressed at a pressure of about 4500 kilograms per square centimeter. Compressed briquets are baked at a temperature of 1000-1100 degrees in tubular furnace with the use of a push rod. The billets are picked up with special tongs at the unloading end of the furnace and are drop forged before they can cool off in a press in a special die.

TABLE 24. INFLUENCE OF PRECOMPRESSING AND SECOND BAKING ON THE PROPERTIES OF METAL-CERAMIC IRON (81)

Technology of Manufacture						Specimen Properties (Average Figures)								
	First Baking			Second Baking					Results of Stretching Tests					
Compacting Pressure of First Pressing in Tons per Square Centimeter	**Temperature in Degrees Centigrade**	**Duration in hours**	**Prepressing Pressure in Tons per Square Centimeters**	Temperature in Degrees Centigrade	**Duration in Hours**	Specific Gravity in Grams Per Cubic Centimeter	Brinell Hardness in Kilograms per Square Millimeter	Impact Toughness In Kilograms Meter Per Square Centimeter	in Kilograms per Square Millimeter	in Kilograms per Square Millimeter	in Kilograms per Square Millimeter	**in Per cent**	**in Per cent**	**Maximum Compressive Strength in Kilograms per Square Millimeter**
8	1200	1.5	-	-	-	6.7	75	0.74	17.0	13.0	12.3	3.8	-	165
10	1200	1.5	-	-	-	6.8	85	0.84	22.0	13.5	12.2	3.9	-	171
8	1200	1.5	8	-	-	7.1	134	0.46	26.3	22.4	21.2	-	-	-
8	1200	1.3	8	1200	1.5	7.0	103	1.51	26.0	16.5	16.1	7.0	-	186
10	1200	1.5	10	1200	1.5	7.4	121	2.50	29.9	17.5	15.1	16.8	120	186

The die (shtamp) has a central mandrel which is inserted in an opening in the baked billet held from the side by eight radial clamps. The press plunger exerts simultaneously a vertical pressure. Pressure in drop forging varies from 4500 to 8000 kilograms per square centimeter. The productivity of this operation is 500 pieces an hour. After drop forging the details are cooled off in water and then processed for the removal of lateral protrusions, Figure 139 shows a drawing of a detail and its appearance following different stages of finishing.

Asymmetrical
Protrusions

Figure 139. Drawing of a Detail Made from Steel Shavings and its Appearance Following Different Stages of Finishing.

I - after baking; II - after drop forging; III - after final finishing.

Bars baked from metals with a high melting point (tungsten, molybdenum, tantalum) are subjected to drop forging in rotating forging machines (Figure 140). A bar this way receives approximately 10,000 blows a minute from forging hammers (shlagbaken) (40,167). In forging, the original square bars have a cross section of 9X9 millimeters, but are transformed in several stages into round rods with a diameter of approximately 2 millimeters. After this the rods are subjected to a hot pulling on a straight chain machine (pyramolineynyy tsepny stanok) until they acquire a diameter of 1 millimeter and to a further hot drawing on a draw bench (blochnyy stan - sic) to a diameter of 0.5 millimeters, and from a diameter of 0.5 millimeters to 12 microns on medium, fine, and very fine wire-drawing machines.

[Figure 140. Rotational Forging Machine]

In order to improve the properties of baked products they may be subjected to the same heat and chemical-heat finishing as solid metals. Use is made of tempering of metalloceramic steel, aging of copper-nickel-silicon alloys, cementation and nitration of iron, chrome, cadmium, - and zinc - plating for improving corrosion resistance of powder metals, annealing for removing cold hardening, etc.

SPECIAL KINDS OF FINISHING

Later impregnation of the baked skeleton made of a more difficultly fusible metal by an easily fusible metal is used in obtaining antifriction materials (Chapter X) -- iron-lead, lead-bronze, "triple-layer" material, contact materials (Chapter XV) -- tungsten-copper, tungsten-silver, molybdenum-copper, molybdenum-silver, etc. Powders composed of coarse particles which assure a high penetrability are to be preferred for such impregnation. In impregnating a thin layer of porous metal finer powders of the difficultly fusible components may be used. An important consideration is to have the least possible mutual dissolving of the basic components of the solid and liquid phase during impregnation.

At the present time there are being produced very interesting alloys which have a resistance to rupture of 35-85 kilograms per square millimeter, an elongation of 3-35 per cent, a neck reduction of 3-35 per cent, impact strength (Izod specimens) up to 2 kilogram-meters (143,177). They are produced by impregnating a steel skeleton with copper (25-45) per cent) and admixtures of silicon, phosphorus, chromium, etc. An important advantage of such types of alloys is "self-welding", the possibility of soldering and welding without any solder or flux, inasmuch as the "solder" (copper penetration of the steel skeleton) is to be found in the actual material. This enables one to obtain complex structures from individual details of simple shape. The optimum weight of details fabricated from such alloys varies from 125 grams to 10 kilograms. When it is necessary to include very large quantities of the low-melting component (more than 30-40 per cent), it is done by impregnating non-compressed powders of the high-melting metal which have been deposited in a crucible (167). In this way alloys of tungsten or molybdenum are obtained which contain 35-60 per cent copper or silver.

Impregnated alloys may be subjected to hot or cold compacting to improve their properties.

A metal skeleton may be saturated also with non-metallic materials such as plastics.

In order to improve hardness and resistance to corrosion of porous iron materials, baked products are treated (194) by superheated steam (Chapter XVIII).

Porous bearings are saturated with oil at a temperature of about 100 degrees.

FINISHING OF METALLOCERAMIC PRODUCTS BY THEIR USERS

In the majority of cases producing plants release metalloceramic products in their final shape and size which do not require any further finishing by machining. The latter, however, is necessary for metalloceramic products of a given dimension which are little used when it is not fesible to make special press molds. In order to make holes and notches perpendicular to the axis of compression, holes with a diameter varying for the length of a screw, products with very complicated shape, etc.

The method of cutting solid metalloceramic materials is the same as for cast allows of similar composition. The method of machining porous powder metals, however, is somewhat different from the finishing of solid metals, the difference increasing with porosity.

18 - 20°

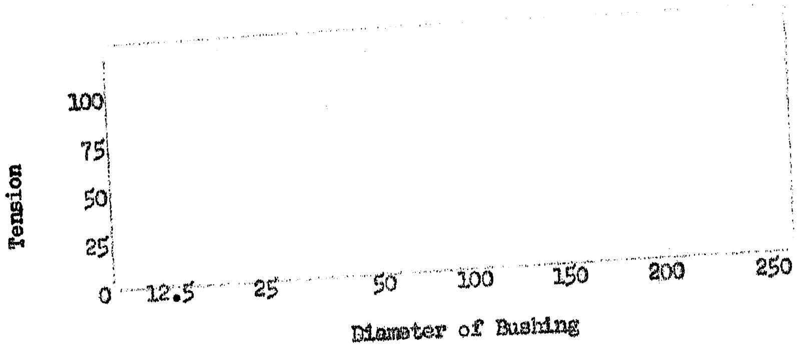
5 - 8°

[Figure 141. Geometry of Cutting Tools]
Left - for Finishing, Right - for Rough Cutting.

[Figure 142. Punch for Pressing Bushings into Sockets]
A - External Diameter of Bushing; B - Inner Diameter Minus 0.13 Millimeters; C - Length of Bushing Plus 6 Millimeters; D - Free Length

TsNIITMASh in its data (6, 7, 58) recommends hard tungsten-cobalt alloys of VK8 type for use in machining porous iron. Attention should be given to a more careful grinding of cutting tools. TsNIITMASh recommends cutters with a small principal angle in plane for rough cutting.

The profiles of cutters for rough cutting and finishing and also angles of the blades are shown in Figure 141. It is possible to have smaller angles than those shown in Figure 141 - the rear angle of blades for porous iron alloys to be 8 degrees and the front angle for iron alloys and bronze to be 0 degrees.



[Figure 143. Tensions for Pressing in Bushings]

The bracing of thin-walled details having a high porosity and decreased strength should be done carefully with chucks. A rough grip by cam chucks may cause a detail to disintegrate. When machining the inner diameter, it is necessary to unscrew the steel socket and then insert in it the detail. When finishing the external diameter, the detail is placed on a mandrel screwed into the chuck. Thicker-walled details are finished after the ordinary fastening in a chuck.

TsNIITMASh recommends that final machining of iron having 25 per cent porosity be done with a speed not exceeding 110 meters a minute, a cutting depth not greater than 0.8 millimeters and a maximum feed of no more than 0.8 millimeters per revolution. For iron with higher porosity (more than 25 per cent) a maximum speed of 60 meters is recommended per minute, a maximum cutting depth of 0.5 millimeters and a maximum feed of 0.4 millimeters per revolution. A minimum feed should be used for maximum depth in both cases.

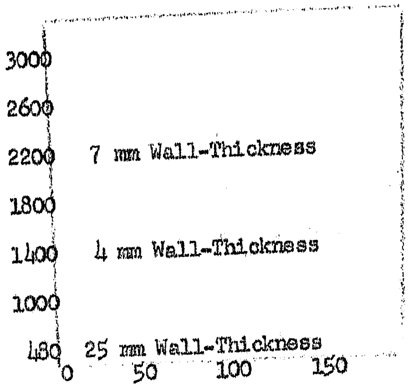
Cooling emulsions should not be used to avoid having them get into the pores of the material.

Drilling should be avoided where possible. Where it cannot be avoided, there should be left a slight allowance for later turning or reaming. With an allowance of 0.05-0.07 millimeters the smoothing out of unevennesses with an expanding mandrel. The drill should be sharpened to an angle of 70 degrees.

It is not permitted to finish the working surface of porous details (inside surface of bearings, filtering surface of filters) with grinding materials to prevent abrasives getting into the pores. It is permitted to use a sharp scraper with light pressure in order to remove small unevennesses not exceeding 0.01-0.02 millimeter.

It is recommended that final lapping in machining by cutting should be done by broaching. The layer of material should not exceed 0.25 millimeters.

After machining by cutting, shavings should be removed by washing with oil followed by drying with pure polishing materials. If through improper machining pores are closed up, the porosity of iron and bronze materials, according to literature, may be restored by a half-minute pickling in a 50 per cent solution of HNO_3 followed by neutralization by a soda solution, washing in hot water and saturation in oil at a temperature above the boiling point of water.



[Figure 144. Relation of Force of Pressing in to Magnitude of Tension (Bebnev)]

In mass use of porous details (bushings), their setting into sockets is best of all done with a screw press with the help of a special mandrel (Figure 142). In the absence of a press and mandrel, porous bushing may be inserted with a hammer and a wooden lining. When pressing in, it is necessary that there be bevel edges both in the socket and on the bushing. Pressing in of porous iron bushings into sockets of class III accuracy calls for a recommendation of third class accuracy, third and second press settings, and for sockets with second class accuracy for a recommendation of second class accuracy, first press setting. Figure 143 shows the tensions sometimes recommended depending on the diameter of the shaft for pressing when inserting porous bushing. Figure 144, according to Bebnev, shows the relation of the pressing force to the magnitude of tension for different thicknesses of iron bushings with 25 per cent porosity. A decrease of the inside diameter depends on the instrument being used for setting, the thickness of the walls of the bushing, the materials used for the socket and the bushing, etc. Shrinkage of the internal diameter is somewhat less for thick-walled bushings. A decrease of the inside diameter of bushing in setting comprises from 60 to 75 per cent of the magnitude of tension.

TABLE 25

RELATIONSHIP BETWEEN PRESSURE AND RESIDUAL DEFORMATION FOR POROUS BRONZE

Magnitude of Residual Deformation in Millimeters	Pressure in Kilograms per Square Millimeter when Porosity is		
	about 30 Percent	about 20 Percent	about 4 Percent
0.03	8	14	21
0.13	11	18	25
0.88	13	28	-

Table 25 shows the relationship existing between the magnitude of residual deformation in compression and the pressure needed for bronze with 10 per cent tin and varying porosity.

As can be seen from the table, pressure decreased considerably with increase in porosity.

[See Figure 145 on next page]

28.795 ± 0.125

18.948 + 0.005 - 0.000

18.974 + 0.005 - 0.000

18.999 + 0.005 - 0.000

19.024 + 0.005 - 0.000

19.050 + 0.005 - 0.000

19.075 + 0.005 - 0.000

19.091 + 0.003 - 0.000

19.091 + 0.003 - 0.000

18.795 ± 0.125

Directing

Holder

[Figure 145. Instrument for Machining Metalloceramic Details]

a - Calibrating mandrel, b - broach for ø 19.079 + 0.012 of R_C 62-63 steel

[Figure 146. Devices for Finishing Metalloceramic Details]
a - spiral braoch bits for ∅ 19.079+0.012, and b,c,d, - cylindrical

When it is necessary to slightly augment the diameter for a porous bushing after it has been pressed in, calibrating mandrels (Figure 145a) broaches (Figure 146 b,c, and d) may be used.

The machining of metalloceramic hard alloys is very laborious because of their exceptional hardness and is only done for lapping, pointing, grinding, and polishing. Grinding is done with carborundum wheels of the "extra" type, diamond-metal disks, and polishing by boron carbide and diamond dust.

In all probability the electroerosion method recently developed by N. and B. Lazarenko (67) would be useful for finishing hard alloys. Electro-erosion finishing makes it possible to produce in hard-alloy blades holes with exact dimensions and complex shape, etc.

When mounting metalloceramic details it is possible to also use soldering and welding.

Chapter VIII

PROPERTIES OF METALLOCERAMIC MATERIALS

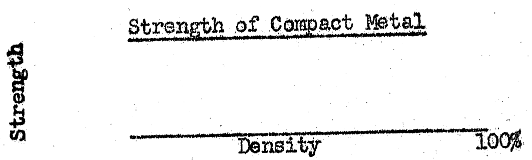
PROPERTIES OF POROUS METALS

The properties of baked porous metals may be considered as being in a way intermediate to the properties of compacts and solid metals.

Table 26 lists certain properties of porous iron. Mechanical properties strongly depend on the way incomplete contact among grains changes during testing - whether it decreases (stretching) or increases (compression). In accordance with this there is in the case of cast metals an absence of a normal correlation between resistance to rupture, bending, and compression. For porous metalloceramic materials sometimes resistance to compression is no lower than for solid cast metals and may exceed two or even more than two times resistance to bending, while the latter in its turn is considerably greater than resistance to rupture. The yield point in stretching for porous metals is often almost exactly even to resistance to rupture, while the yield point in compression is considerably smaller (by several times) than resistance to compression. In the same way there is absent for porous metals a normal relationship between hardness and resistance to rupture.

Even more than for indexes of strength, porous metals differ from cast with respect to the indexes of deformation (plasticity) and the relationship existing among the different indexes of deformation. Thus elongation for metalloceramic iron with 30 per cent porosity is usually equal to zero, while contraction during compression may be considerably larger than for soft solid iron, reaching up to 50-60 per cent. Thus, porous metals are very brittle in stretching and to a lesser extent in bending. In this connection, their impact strength is very small. On the other hand, with respect to compression, porous metals are to be distinguished by their exclusively high deformation (and with considerably smaller pressure than for cast metals, inasmuch as their yield point is several times smaller). This last consideration is very important in two respects. First, it is thanks to this that porous metals may be reduced to necessary dimensions much more easily by the use of pressure (calibration) than cast metals (see Table 25). Second, porous details used in friction can be worked in much better than cast metals. Thus, upon working in, porous iron had unevennesses with crests of 0.5 microns, while cast bronze after a similar working in 5-6 microns. Exceptional working in is one of the reasons for the high resistance to wear for porous metals in work involving friction. Another reason is the constant presence of lubrication which does away with dry friction.

The dependence of mechanical properties of baked porous metals on pressing and baking conditions has already been considered in Chapter V. For this reason we shall only add the following few features of the relation of the properties of porous metals to porosity and composition.



[Figure 147. Schematic Curves of the Relation of Mechanical Properties to Porosity]

(1) Mechanical (and other) properties of porous metals are determined directly not by the actual porosity but by the degree of contact among grains of baked metals (contact cross section), which porosity reflects only indirectly.

Indexes of strength of baked porous metals in terms of a unit of original (prior to the testing of mechanical properties) contact cross section are constants of the material within certain limits independent of its porosity in the same way as compressed metals.

However, inasmuch as the testing of mechanical properties is usually connected with strengthening of the metal for contact cross section, the contact strength depends to a certain extent on the porosity (or, more precisely, on the size of contact cross section) of the baked metal (especially for wide intervals of porosity). With marked porosity (approximately more than 15-20 per cent) and insignificant contact cross section (less than 20-30 per cent of nominal cross section for a specimen) a baked metal in stretching may become considerably harder in places of contact without any perceptible deformation either for the entire specimen or the contact sectors. For this reason the yield point in stretching for a baked metal of such porosity when referred to the original contact cross section is significantly greater than the corresponding yield point for a solid metal. The yield point in stretching for porous copper when referred to a unit of contact cross section has a value of about 40 kilograms per square millimeter, for porous iron 60-100 kilograms per square millimeter, i. e., considerably higher than for solid metal. With respect to iron and copper with marked porosity there is an approximate correspondence of values for the limits of yield for streching and compression, the limit of tensile strength in stretching, critical stress σ_K (page 67 of original text), and the micro-hardness of the material. Such a correspondence is not accidental, inasmuch as the hardness of the metal corresponds to the stress creater per unit of contact surface, and the yield point to the stress at which contact surface begins to break up. There is practically no elongation of such materials when testing for rupture; furthermore, fracture takes place without the formation of a neck. When porosity decreases below 15-25 per cent (with an increase of contact cross to above 20-30 per cent of nominal) specimens show marked elongation during stretching. Furthermore, the progress of the transition of the metal towards a compact state is marked by a gradual decrease in the values for the limits of yield as referred to contact cross section approaching the value for the limit of yield of ordinary solid metal (15-20 kilograms per square millimeter for iron) and an increase in the ratio of the limit of tensile strength in stretching to the limit of yield and index of deformation. In contradiction to the indexes of strength as referred to an original contact section, the limits of strength referred to a nominal section increase with decreasing porosity (paragraph 2).

The moduli of elasticity of porous baked metal as referred to a unit of contact section are equal to the elasticity moduli of the corresponding solid metal. This relationship is expressed by the formula:

$$\frac{E^1}{\qquad} = E_1 \qquad (49)$$

where E^1 is the elasticity modulus of the baked metal as referred to a nominal section, E the elasticity modulus of the corresponding solid metal, and α the relation of contact to nominal section.

Formula (49) makes it possible to determine the size of contact section of a baked metal.

The strength of baked metals in contrasts with compacts is determined by grain fusion resulting from interatomic force and not to the mechanical interlocking of particles. For this reason the limits of strength and yield in stretching for baked metals are considerably greater than for compacts (approximately 10 times and more). The limit of yield in compression for baked metals may be either greater or smaller than for compacts depending upon the fact whether the size of contact section increases or decreases during baking. Hardness and resitance to compression for baked metals are frequently less than for briquets.

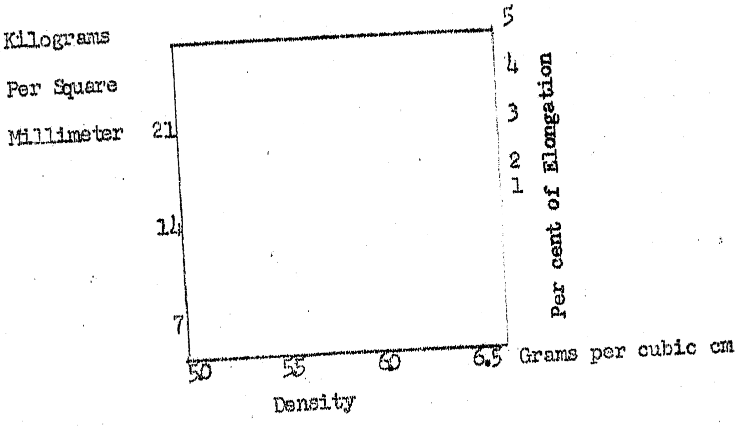
(2) Analysis of phenomena related to pressing (Chapter IV) showed that contact surface between particles grows considerably faster than with the first stage of density. This is also true in a number of cases in relation to baked products. For this reason mechanical properties, especially elongation and impact thoughness, sometimes increase faster than for the first stage of density, while density (porosity) curves bulge out downwards (Figure 147a). However, there often exists for baked metal a linear dependence of the size of contact corss section to porosity. It was proved on page 142 (of original text) that initial contact surface of a compact together with contact sectors formed during baking is often proportional to the density of compacts as a result of heat expansion and that the surface of contact established during shrinkage

in linear dependence to porosity. In such cases, the contact cross section and, consequently, the properties of porous metal change with increased density change according to the straight line shown in Figure 147c. This linear dependence, first established for a number of mechanical properties by the investigations of the author (4, 10, 11), was recently confirmed in an article by Federchenko, Filimonova, and Brabino (119). Sometimes a dependence exists of properties to density (porosity) according to the curve shown in Figure 147c. Figure 148 shows the dependence of a number of mechanical properties on density (169) and Figure 149 the same thing according to Bal'shin and Korolenko (6). There is always observed for metals with a considerable degree of porosity an intercrystal breakage and for those which are less porous fracture of crystal faces.

(3) With a decrease in porosity, the degree of contact for compacts increases from 2 to 10 per cent, most frequently 3-5 per cent. Quite similarly, mechanical properties of baked materials change 2-10 per cent, in the majority of cases 3-5 per cent, with a modification of porosity of 1 per cent.

[See Figure 148 on following page]

(4) Materials with identical porosity and baked from coarse powders usually have a smaller degree of contact among grains, a greater number of inter-particle pores, and larger pores than those baked from fine powders. For this reason the mechanical properties of products from coarse powders (Table 26) with the same degree of porosity are usually fewer and increase more rapidly with a lowering of porosity.



[Figure 148. Dependence of Mechanical Properties on Density for Metalloceramic Iron (169)] 1 - σ_b ; 2 - σ_s ; 3 - δ

Thus, with a decrease in porosity there is an evening out of differences in properties for materials fabricated from fine and coarse powders (as compared with the properties of briquets).

Sometimes materials made from fine powders have, contrariwise, lower properties. Such exceptions are explained most frequently by an increase in the contents of oxides for such materials.

(5) With identical porosity, the degree of contact among grains is less in the case of hard and brittle materials than for soft and plastic ones. For this reason, without going on to speak of indexes of deformation, the strength of hard porous metals comprises a smaller fraction with respect to the strength of solid materials than that of soft materials with identical porosity. In this connection, the mechanical properties of porous metals with different chemical composition varies much less than for corresponding solid metals. There is sometimes even observed an inverse relationship of properties in comparison with compact metals. For example

with an identical degree of porosity, porous steel may be less strong than porous iron, and porous iron than porous copper (as compared with the properties of compacts). It should also be pointed out that the properties of hard metals increase with a decrease in porosity more than soft metals.

TABLE 26

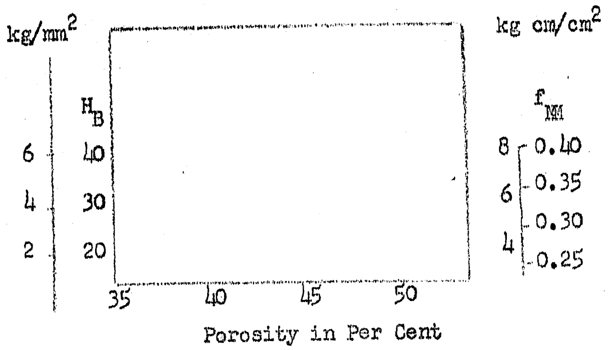
PROPERTIES OF BAKED POROUS IRON WITH 25 PER CENT POROSITY

	Fine Powder	Medium Powder	Coarse Powder
Resistance to Fracture in kg per mm^2	8 - 11	4 - 10	to 4
Yield Point in Stretching in kg per mm^2	8 - 10	-	-
Resistance to Bending in kg per mm^2	15-25	8 - 16	to 8
Resistance to Compression in kg per mm^2	50-70	40- 60	30-45
Yield Point in Compression in kg per mm^2	to 12	-	-
Elongation in Stretching in per cent	0 - 1	0	0
Shrinkage Compression in per cent	about 50	about 40	about 30
Impact Strength in kg-cm per square cm	12-40	8 - 12	to 8
Brinell Hardness in kg per square mm	40-60	30- 45	to 35

[See Figure 149 on following page]

(6) Porous alloys baked in the presence of a liquid cementing phase have a higher degree of contact among grains, more intercrystallite pores, and relatively higher mechanical properties than other metals and alloys of the same porosity.

(7) Porous alloys containing components whose oxides are difficult to reduce or components which lower weldability when baked with-



[Figure 149. Mechanical Properties of Iron-Graphite in Relation to Porosity (Poured Weight of Iron Powder 1.6 grams per Cubic Centimeter, 98 Per Cent Iron, 2 Per cent Graphite, Baked for 1 Hour at 1100 Degrees Centigrade, According to Bal'shin and Korolenko);] H_B - Brinell Hardness, σ Resistance to Bending, a_K Impact Toughness; ρ Depth of Curvature.

out the formation of a liquid phase have lower mechanical properties (such as iron-silicon containing more than 1.5 per cent silicon).

(8) The properties of porous alloys usually decrease as the number of components of which they are comprised increases, especially when baking without the formation of a liquid phase.

(9) Machine finishing of porous metals decreases their mechanical properties. This decrease in properties becomes more sharply expressed with increase in porosity and brittleness of the metal. For this reason specimen to be used in mechanical testing should not be finished by machining.

(10) The properties of porous specimens depend on the design of press molds. Thus, specimens pressed in non-dismountable press

molds are often stronger (sometimes by 10-20 percent) than those produced in dismountable press molds.

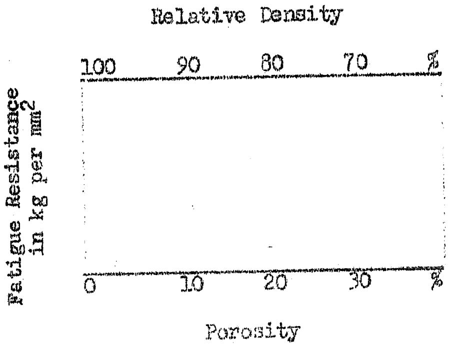
Fatigue endurance of porous iron and copper (153) is shown in Figure 150. Fatigue endurance and the value of its relation to the value of resistance to fracture increase with the fineness of initial powders and decrease in porosity. Antifriction characteristics of porous metals are considered in Chapter X.

The electrical conductivity of porous metals as the function of the degree of porosity and conditions of fabrication varies from 20-30 to almost 100 percent of the electrical conductivity of solid metals of the same composition. Heat conductivity also decreases with increase in porosity.

The coefficient of heat expansion of baked metals is a property which practically does not depend on porosity. A metal with 30 percent porosity has almost the same coefficient of expansion as one that has been cast (sometimes 1-5 percent less).

The surface of porous metals which is subject to the corrosive action of a medium is greater than in the case of solid metals. For this reason resistance to corrosion decreases with growing porosity. However, it should be kept in mind that saturation with oil usually is sufficient to protect porous products from corrosion. In many production experiments it has been observed that although rusting of rollers and other steel parts of machines occurred, iron bushings, which had been saturated with oil, were not subject to corrosion. Corrosion resistance of porous metals, aside from other well-known means, may be increased by the method proposed by Michelson (82). According to this, porous metal which has been saturated with oil is stored for a considerable length of time in a drying cabinet at a temperature of approximately 150 degrees.

Porosity is characterized by the proportion of volume occupied by pores, by the relation between open pores and total porosity as determined by oil permeability, and by penetrability of liquids and gases. The proportion of open pores and penetrability grows with the size of particles comprising the initial powders and the size of the pores of the baked metal.



[Figure 150. Fatigue Endurance of Porous Iron and Copper (153)].

1 - copper, 200 mesh; 2 - copper, 325 mesh; 3 - iron, 100-200 mesh; 4 - iron, 32 mesh.

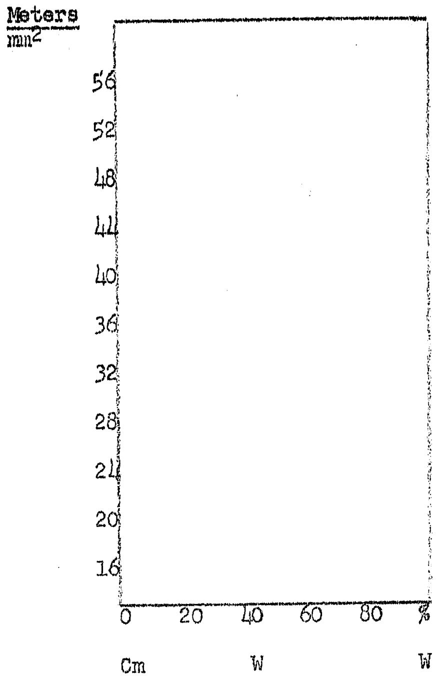
PROPERTIES OF DENSE BAKED METALS AND ALLOYS

In the majority of cases metalloceramic metals and alloys which have become completely compact through the necessary finishing after baking have the same mechanical and physico-chemical properties as cast compact metals of the same composition after being treated by compression (Tables 27 and 30, page 194 of original text).

Sometimes certain properties of dense metalloceramic materials for one reason or another are higher than for cast metals treated by compression. Thus metalloceramic carbonyl steels, due to a lesser content of silicon, manganese, phosphorus, and sulphur, have better weldability than regular steels. It can be seen from Table 27 that electrical conductivity of solid metalloceramic copper is higher than for ordinary electrolytic copper, which is to be explained by the smaller oxygen content. Metalloceramic beryllium has higher properties than cast beryllium, which is to be explained by the greater amount of close grain structure of baked beryllium (166).

The properties of certain solid metalloceramic materials may be lower than for cast metals, especially in the presence of components which lower weldability of form oxides which are difficult to reduce.

[Figure 151. Structure of Alloys containing 60 Percent Iron, 27 Percent Nickel, 13 Percent Aluminum. Below - Cast, Above - Metalloceramic. X150 (167)]



[Figure 152. Relation of Specific Electrical Conductivity of Tungsten-Copper on Composition (167)]

Compact metalloceramic alloys obtained by baking in the presence of a liquid cementing phase have properties without being subsequently treated by compression which not only are not lower but frequently even higher than for corresponding cast alloys. Thus resistance to rupture (167) on the part of metalloceramic hard alloys WC-CO (120-180 kilograms per square millimeter) is 5-6 times higher than for them when cast (20-30 kilograms per square millimeter). This is explained primarily by the fact that tungsten carbide WC in cast alloys breaks down into tungsten and graphite. In exactly the same way mechanical properties of baked magnetic alloys of the type of alni (Fe, Al, Ni) and alnico (Fe, Al, Ni, Co) are 2-3 times higher than for cast of the exact same composition (167) due to the close-grained nature of metalloceramic materials (Figure 151). Resistance to fracture of baked alloys of the type of alni is 100-140 kilograms per square millimeter, of cast alloys 30-50 kilograms per square millimeter, (167).

A special type of compact metalloceramic alloys is to be found in compositions whose components are not soluble nor form chemical compounds either in liquid or solid form (for example, copper-graphite brushes and copper-tungsten contacts). Such compositions are used in electrical engineering thanks to the additiveness of their properties. For example, copper-tungsten compositions combine the hardness, strength and high melting point of tungsten with the high electrical conductivity of copper. In distinction to solid solutions and compounds, electrical conductivity of compositions does not decrease but is additive to the properties of the original components (Figure 152).

[See Table 27 on next page]

TECHNICAL CONTROL OVER METALLOCERAMIC PRODUCTS

The properties which are of interest to us from the point of view of the finished product are: chemical composition, structure, porosity, mechanical properties, correspondence between necessary dimensions and density, and absence of external flaws.

There are no specific differences in determining the chemical composition of metalloceramic products from that of ordinary metals, just as there are none when determining dimensions and weight. However, special difficulties are to be met with when determining den-

TABLE 27

PROPERTIES OF COPPER AS RELATED TO THE METHOD OF PRODUCTION (167, 194)

Method of Production [1]	Brinell Hardness in kg/cm^2 [2]	Resistance to Rupture in kg Per Square cm [3]	Elongation in Percent [4]	Specific Gravity in Grams per cm^3 [5]	Specific Electrical Conductivity [6]
Cast	40 - 50	15 - 20	15 - 25	8.9	55 - 57
Cast After Forging Rolling, and Annealing	50	20 - 24	38	8.93	57 - 59
Cast After Rolling for 80 Percent	100 - 110	44	10 - 12	8.93	55 - 57
Cold Pressing in Tons Per Square Centimeter, Baking Temperature 300 Degrees	45	14 - 16	3 - 4	7.6	32 - 36

[1]	[2]	[3]	[4]	[5]	[6]
Hot Pressing in Tons Per Square Centimeter, 300 Degrees	100 - 110	25 - 30	10 - 20	8.9	-
Hot Pressing 15 Tons per Square Centimeter, 400 Degrees	120-150	30 - 35	-	8.9	57-59
Cold Pressing (3 Tons Per Square Centimeter), Baking Temperature 900 Degrees, 90 Percent by Hot Finishing Annealing	40 - 50	20 - 25	35	8.9-8.93	59-62
Cold Pressing After Hot Rolling, 50 Percent Cold Deformation	100 - 110	35 - 40	10 - 12	8.9-8.93	55-57

sity. Density is usually determined by the difference in the weight of the body in water and in air. When determining the weight of porous products in water, water gets into the pores and thus distorts such determination. For this reason it is necessary to first fill the pores, as by oil impregnation.

In exactly the same way specific difficulties are met with in determining the structure of porous products. In grinding and polishing the pores draw in. In order to get a true picture, it is necessary for this reason to fill up the pores with a hard material which prevents the deformation of the pores in grinding. With this purpose in mind, it is expedient to fill them with bakelite lacquer and to follow this up with subsequent heat treatment in order to solidify the bakelite (Chapter II, page 37 of original text). No need exists to resort to such preliminary treatment in the case of hard or non-porous materials.

For porous materials it is desirable in the majority of cases to determine both the magnitude and the character of porosity. The total porosity is determined by the difference in the specific gravity of compact and porous materials according to the following formula:

$$P = 100 \left(1 - \frac{\gamma_n}{\gamma_k} \right) \text{ percent,}$$

where P is the volumetric percentage of pores,

γ_n is the specific gravity of the porous material, and

γ_k is the specific gravity of the compact material.

Moreover, porosity is also characterized by the division of pores into open (or more exactly easily-accessible) and closed (or more exactly accessible with difficulty, and also by the size of individual pores.

A qualitative, and to a certain extent even a quantitative, representation may be obtained by examining cross cuts. Thus, intraparticle pores are often closed.

A more accurate quantitave representation may be acquired by special tests, such as determining oil permeability and air penetration.

Only open pores are filled with oil. By knowing the specific gravity of oil, it is easy to determine the volume of pores that have been filled with oil. By dividing this volume by the entire volume of pores we obtain the percentage of open (capillary, accessible) pores.

An idea of the size of individual pores is given by air penetrability. The greater the number of individual pores, the greater is air penetrability. In order to determine penetrability of a metalloceramic bushing, it is pressed from the top and bottom by a special clamp and placed into a measuring graduated cylinder containing water. Air enters into the bushing from one side due to a definite, small pressure (less than atmospheric) and passes through its pores and forcing the water out of the cylinder. Penetrability is determined by the volume of air passing through the pores of the bushing during the course of one minute.

Methods for determining mechanical properties of dense metalloceramic materials do not essentially differ from those used in testing solid metals.

When testing porous metals it should be kept in mind that mechanical properties decrease with machine finishing. For this reason it is necessary either to have special press molds for making specimens or carry out technological tests on finished products.

In accordance with the ideas expressed on page 176 (of the original text) rupture tests give a lowered and with compression a higher representation of the strength of the powder metal. Bending tests give a somewhat smaller distortion of the representation of strength.

It is recommended that impact toughness tests be carried out for porous metal without any notches in view of its small size.

In place of tests for rupture on special specimens, they may be carried out on specimens of any shape and even on pieces of products by the wedge-pressure method (of Lyudvik). This method of testing has been described by I. V. Kudryavtsev. The specimen being tested has a rectangular or round cross section and is compressed between two wedges. Steel wedges having an angle of 90 degrees at their apex are placed in guides so that their edges form one plane. The ultimate strength is computed according to the formula:

$$\sigma_b = \frac{L}{F} \left(1 + 0.02 \frac{L}{F} \right),$$

where σ_b is the ultimate tensile strength,

F is the specimen's cross-sectional area, and

L is the load which shatters the specimen.

[Figure 153. Clamp for Testing a Ring for Rupture].

Inasmuch as the strength of a baked metal is within a certain interval approximately proportional to contact cross section, it is possible in a number of cases to determine contact cross section in place of testing for mechanical properties. Such determination can be made on the basis of formula (49) without destroying the specimens by measuring their elasticity modulus.

Hardness tests carried out on finished products depend on their form and dimensions and on the technical requirements made on them. It is impossible for this reason to give exhaustive indications for all cases. There is employed in the case of bushings crushing by compression in a radial direction, for rings resistance to rupture by stretching in special clamps (Figure 153).

Chapter IX

METALLOCERAMIC MATERIALS

A. SPECIAL FEATURES OF COMPOSITION PECULIAR TO METALLOCERAMIC TECHNOLOGY

At the present time almost all the metals known to technology are used in powder metallurgy. Besides, metalloceramic materials often contain nonmetallic components.

Many of these materials, such as the refractory metals (tungsten, molybdenum), hard alloys, diamond-metallic compositions, etc., cannot be produced by casting.

On the other hand, the fabrication of many commonly known metals and alloys by metalloceramic methods is so cumbersome, that from a practical point of view it is ruled out, even at the present day. For example, the most ordinary cast iron containing 3½ percent silicon cannot be produced by powder metallurgical methods. It is interesting to note that its fabrication is hindered by the same silicon which is of such help in the making of cast iron.

Thus, the specific features of metalloceramic technology in some cases expand and in others limit the composition of metalloceramic materials in comparison with casting.

The composition of any material is determined by a special compromise between the requirements of production and the technological possibilities of its manufacture. A rational selection of the composition of metalloceramic materials is impossible without a clear understanding of technological factors, which either help or hinder or even limit the introduction of some component. Listed below are some basic considerations of the connection existing between technology and composition.

(1) The inclusion of components which form oxides difficult to reduce (such as aluminum, silicon, chromium, zinc) is connected with special measures for preventing the formation of oxides, for reducing them, or neutralizing their action. As examples of such measures there may be cited baking in very pure hydrogen or in a high vacuum, the introduction into the powder mixture of source agents of atomic hydrogen (for example, titanium hydride), the inclusion of a component in the form of powdered alloys, which are less inclined to oxidation than the pure component (for example, aluminum-iron alloys), the inclusion of components in the baked skeleton in melted form, the addition of components which assure the formation of a liquid phase in baking (for example, phosphorus), compact pressing, etc. For this reason the use of components which form oxides difficult to reduce complicate technology and make it more expensive especially where the latter lower weldability (silicon) or undergo considerable evaporation in baking (zinc).

(2) The production of alloys or compositions from several metals in cases where there is no liquid phase in baking is always more difficult than the production of pure metal (Chapter V, page 148 of original text). These difficulties increase with the number of components used. Where such alloys are not subjected to finishing by compression after baking, their density and mechanical properties are low in comparison with the corresponding pure metal powders. This factor essentially limits the number of components in porous materials. It should be emphasized that powder metallurgy in the

given relation is in complete opposition to casting metallurgy. As is known, alloys are usually easier to cast than pure metals.

(3) The addition of a more easily fusible component, such as copper, to iron, which assures the formation of a liquid phase during baking by reacting with the basic metal, makes it easier to obtain alloys with high density and mechanical properties. However, it should be kept in mind that even in such cases difficulties in baking increase with the number of components introduced into the mixture. Thus, the obtaining of hard alloys (Chapter XII) from several carbides (such as WC + TiC + Co) is always more complicated and difficult than with one carbide (WC + Co); in obtaining hard alloys with complex carbides (WC + TiC + Co) it is necessary to resort to an exceptionally careful mixing lasting for several days. In spite of this, the porosity of such alloys is higher, while the mechanical properties (excluding cutting) are lower than for WC + Co alloys. This feature is explained primarily by the variegated localization of shrinkage (Chapter V, page 120 of original text) and limits the number of components in metalloceramic materials.

(4) In the technology of casting the introduction of certain components is due not to production but to technological considerations (including casting properties). In the same way certain components of metalloceramic materials have a purely technological significance, easing baking or pressing and the obtaining of dense and strong materials.

Phosphorus in copper alloys is such a technological component. Phosphorus forms a chemical compound Cu_3P which, with 8.38 percent P, forms with copper a eutectic melting at 707 degrees (below baking temperature). In this way, a small quantity (about 0.8 percent) of phosphorus may assure the creation of a 10-percent low-melting eutectic.

The reaction of phosphorus with other components in copper alloys may sometimes increase even more the formation of a liquid phase during baking. It is expedient to introduce phosphorus into the mixture in the form of powders of preliminary alloys with a large phosphorus content which melt during baking. In alloys of copper with components which form oxides difficult to reduce (zinc and silicon), phosphorus assists reduction and the removal of oxides. In such cases the liquid phase acts as a flux in welding, assisting the cleaning of the surface of particles of oxides. Phosphorus, and also sulphur, can help not only baking but also other operations of metalloceramic technology. Thus, increasing the contents of phosphorus and sulphur in "austenitic" ("avtomatnaya") steel makes it easier to obtain fine shavings which are easily pulverized in hammer mills (page 26 of original text). Graphite, besides increasing antifriction properties, can also play a technological role by making pressing easier, preventing buckling, etc. Copper in antifriction alloys with an iron base is a technological component which assures the formation of a liquid phase in baking and which increases density and mechanical properties. The inclusion of "technological" components may be compensated by a corresponding modification of technology. For example, mechanical properties may be raised instead of by adding copper by modifying pressing or baking procedures, by subsequent treatment by pressure, etc.

5. When there is mutual insolubility on the part of components with a considerable difference in melting points, it is practicable

to impregnate the baked skeleton with a liquid easily-fusible metal.

(6) The addition of such materials as graphite which insulate contact among metal particles is possible only for relatively dispersable powders of the basic metal.

(7) The application of hot pressing, baking under pressure, and subsequent treatment by pressure decreases the difficulty of obtaining alloys and expands the composition of metalloceramic materials.

The factors given above make it easier to understand specific differences in composition between cast and metalloceramic materials. For example, cast antifriction iron contains much while metalloceramic iron contains little silicon. In contradistinction to casting procedure, the purest iron possible is to be preferred for porous bearings. The only alloying element (except carbon) used in the production of porous bearings with an iron base is copper which makes it easier to obtain a strong material by forming a liquid phase in baking.

B. COMPONENTS OF METALLOCERAMIC MATERIALS

Iron and Its Alloys

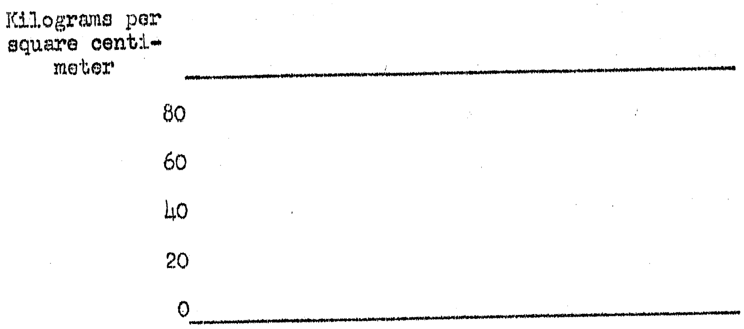
The manufacture of products industrially from iron and its alloys by using the methods of powder metallurgy began later than the application of metalloceramics for nonferrous and rare metals. Powder metallurgy showed an especially rapid development in all countries during the Second World War. According to Frey [152], the manufacture of metalloceramic iron products in Germany exceeded towards the end of the war 30,000 tons per year, including 30,000 tons of shell collars (Chapter XVII), about 500 tons of porous bearings, and up to 200 tons of different details. Most powders for these products were obtained by eddy-mill pulverization, followed by granulation of molten metal and reduction of oxidized matter. Electrolytic powders were also fabricated to some extent. The manufacture of carbonyl powders, primarily for magnetic materials, by the vacuum technique [141] reached 1000 tons a year. In the US there were manufactured primarily bearings, details and magnetic materials having an iron base. In 1946 the US produced about 3000 tons of iron powder.

The principal methods for producing iron powders are reduction (of pulverized oxides, oxidized steel scrap, calcined ferrous sulfate), grinding of steel shavings with subsequent decarburizing heating of powder, granulation, and electrolysis. In particular, there are used iron and steel powders obtained by pouring into water cast iron with slight silicon content (with 4.2 - 4.5 percent C, 0.1 - 1.2 percent Mn, and 0.2 - 0.6 percent Si), then subjecting the granules to decarburization by heating the granules in a rotating furnace containing an atmosphere of $CO-CO_2$. The bigger parts of relatively large granules are remelted for obtaining cast iron and steel.

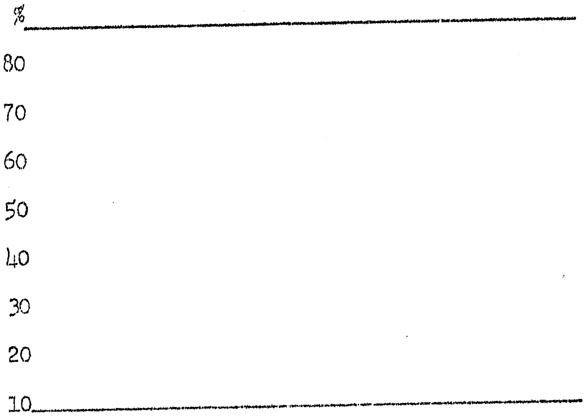
The small particles (up to 40 percent smaller than 0.5 millimeters and up to 8 percent smaller than 0.2 millimeter) may be used successfully in the production of metalloceramic products.

In the majority of metalloceramic porous and dense materials having an iron base, iron is the only component (if one does not include admixtures in powders). There are produced from iron alone porous bearings, shell collars, telephone inductors, pole pieces for small direct-current motors, and other soft magnetic materials, materials for use in vacuum technology, many details, sealing or packing materials, iron sheets (zhest') from carbonyl iron with high stamping qualities, etc. Porous iron for calking pipes is made of iron grit impregnated with bitumen. Iron powders and insulating plastics are used in magnetic cores. In certain materials it is characteristic to find a higher content of phosphorus and sulphur admixtures (bearings from "austenitic" ("avtomatnaya") steel shavings) which assure the production of fine, more easily pulverized and compressed shavings. Recommendations also exist [162] for increasing the content of phosphorus in iron in order to achieve greater strength from hot pressing and baking. Admixtures of phosphorus and sulphur [175] make it easier to hold carbon when introducing it in free form into a powder mixture (graphite, etc.). This positive action of phosphorus is explained by the formation of eutectic melting at baking temperature and by deoxidizing action. Products made from reduced oxidized particles (okalina) contain a considerable quantity of oxides (SiO_2 and MaO) which cannot be reduced in baking (to the order of 1 percent).

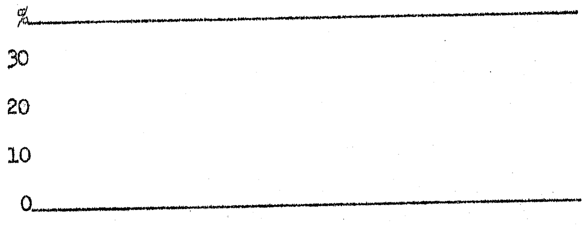
Carbon in free (iron-graphite) or combined (metalloceramic steel) form contains many powder materials with an iron base. Graphite in the quantity of 2 percent is introduced sometimes into the powder mixture in the manufacture of porous bearings, steel gears, and other details.



Contraction



Elongation



Impact Toughness

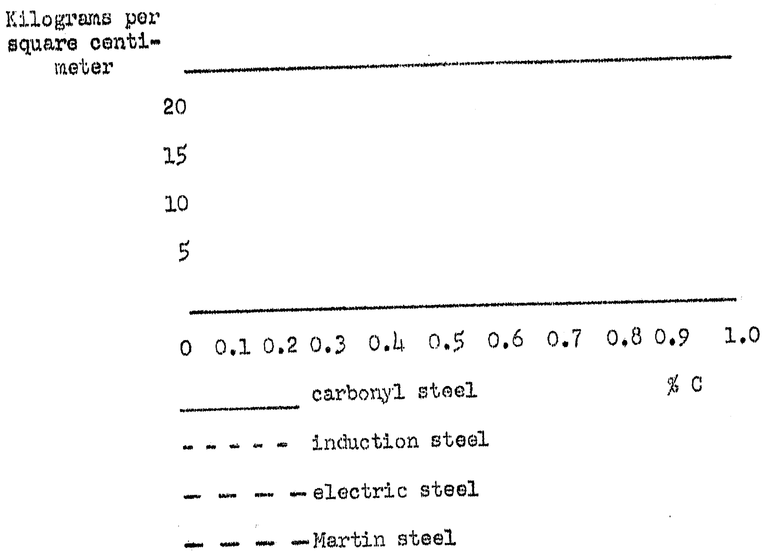


Figure 154. Properties of Metalloceramic Carbonyl Steels in Comparison with the Ordinary Steels Produced in Martin, Arc, and Induction Furnaces [175]

Carbon metalloceramic steels may contain the usual or smaller quantity of ordinary admixtures (Si, Mn, P, S). The properties of compact metalloceramic carbon steels do not differ markedly from the properties of cast steels of corresponding composition. Steels prepared from carbonyl iron as compared with the usual steels (Figure 154) have the same or even slightly greater elongation, reduction of area, and impact toughness and a somewhat smaller resistance to rupture and yield point. With metalloceramic steels made from other powders [186], resistance to fracture is almost the same, while elongation and reduction in area are smaller than for cast steels. Carbon in metalloceramic steels may be introduced by adding to the powder mixture graphite or cast iron powders or is already contained in the original steel powders.

The widespread application of cast iron powders in metalloceramics is hindered by the lowering of properties caused by the considerable content of graphite and silicon which form oxides difficult to reduce and lower weldability. According to the data of Bal'shin and Korolenko [11, 12], it is undesirable to use cast iron containing more than 1.3 - 1.5 percent silicon. Cast iron containing a smaller content of silicon may be used to produce bearings with somewhat lower but still acceptable properties. For this reason, cast iron is used in powder metallurgy only on a limited scale. Thus, steel powders are obtained from decarburized slightly-silicon cast-iron shot produced by atomizing. Cast iron powder is used which has been treated to decarburizing heating with iron oxides [162]. Cast iron powders are added to a powder mixture used in the manufacture of metalloceramic steels. In producing cast iron powders, it is possible to use waste shavings and iron shot from casting ("steel" sand).

The methods of powder metallurgy make it possible to obtain alloyed and special steels and alloys with an iron base with a smaller content of carbon and other admixtures. Alloys made from carbonyl powders with 35 - 36 percent Ni have a lower coefficient of heat expansion than cast metals because of their greater purity [167]. It is easier to regulate the composition and size of the coefficient of expansion for metalloceramic materials of this type. For this reason they are used [167] in the fabrication of bimetals and in electrical control instruments (heat regulators, instruments for automatically turning on the current). Alloys containing aluminum and nickel (alni) and aluminum, nickel, and cobalt (alnico) are used in making permanent magnets (Chapter XVI).

Alsifer powders used in making magnetic cores contain 7.5 percent Al and 10 percent Si. It is also known [194] that metalloceramic stainless steel containing 18 percent Cr and 8 percent Ni is being manufactured. Iron alloys with 5 - 20 percent Mo and 1 percent Cu [194] are recommended for soldering in glass.

Materials specifically intended for metalloceramics are iron alloys containing copper and lead. Copper (5 - 25 percent) used in porous bearings and steel details is a "technological" component which raises density and strength because it creates a liquid phase during baking. However, this effect may be obtained without introducing copper by the proper modification of technology. Alloys are prepared whose steel skeleton is impregnated with molten copper and additions of silicon, chromium, etc. They have the faculty of fusing without the addition of flux at the melting temperature of the copper alloy impregnated in the skeleton. Lead in small content may be added to the powder mixture in the form of oxides in large content through impregnation of the iron skeleton. According to data existing in literature [167], the addition of lead improves the ability to be treated by pressure. At one time it was recommended that lead be added to antifriction alloys with an iron base. However, according to more recent data, lead when in quantity above 3.5 percent lowers antifriction and mechanical properties. Its addition in quantities up to 3.5 percent is not connected with any particular advantages [158].

Superheated steam is used in the finishing of porous iron or steel [194]. The oxidized film that is thus formed in the boundaries between grains and pores increases hardness and resistance to corrosion on the part of the material.

Iron is also used as an additive or admixture in metalloceramic alloys with nonferrous metals as a base. The magnetic alloy permalloy which has a nickel base contains 17 - 21 percent Fe, friction materials with a copper base contain up to 10 percent Fe, hard alloys up to 1.5 percent Fe.

Copper and Its Alloys

Copper is one of the materials most widespread in powder metallurgy. The use of copper in powder metallurgy is favored by its low melting point in baking, its plasticity, easy reducibility of oxides, and the ease with which its powder can be fabricated.

The most widespread method for obtaining powder is electrolysis. This is followed by atomizing of melted copper, reduction, and eddy-mill comminution.

Copper-alloy powders are usually obtained by atomizing the liquid metal.

Hot pressing of baked billets (page 169 of original text) results in metalloceramic oxygen-free copper. The electrical conductivity of such copper [194] is 0.3 percent higher than for the best electrolytic copper made from the same raw product.

Copper is used as the basic component in the following metalloceramic materials:

(a) copper-graphite brushes (graphite, from several to 75 percent, with occasional addition of tin or lead, the rest being copper);

(b) friction materials (60 - 75 percent Cu, 5 - 10 percent Sn, occasionally 6 - 15 percent Pb, 5 - 8 percent graphite, 0 - 4 percent SiO_2, 0 - 10 percent Fe);

(c) filters (92 percent Cu, 8 percent Sn);

(d) tin bronze for details and porous bearings (about 10 percent Sn, sometimes several percent Pb, and 0 - 4 percent graphite, the rest being Cu);

(e) special bronzes. They include the recently-developed antifriction bronze with 2.4 percent Ni; 0.8 percent Si and 0.3 percent P, adapted to aging -- to dispersion hardening (Chapter X), also metalloceramic bronzes [159], capable of aging, the properties of which are given in Table 28;

(f) brass with 10 or 30 percent zinc. Metalloceramic brass characteristically has a content of 0.3 - 0.8 percent of the "technological" component phosphorus (page 166 of original text). The properties of metalloceramic brasses are given in Table 29;

(g) copper-nickel skeleton in triple-layer antifriction material Durex-100 impregnated with lead babbit contains about 60 percent Cu and 40 percent Ni. Copper-nickel porous materials are used in England to prevent icing of airplanes (page 251 of original text).

A large quantity of copper (10 - 40 percent) is contained in copper-tungsten contacts. The use of copper in alloys having an iron base was mentioned above. Several percent of copper and nickel are contained in so-called heavy alloys having a tungsten base (3 - 20 percent Cu, 3 - 16 percent Ni); 0.5 - 5 percent copper is contained in dental fillings.

TABLE 28

PROPERTIES OF SPECIAL BRONZES CAPABLE OF AGING [159]

Composition in Percent					Maximum Strength in Stretching in Kilograms per Square Millimeter	Elongation in Percent	Electrical Conductivity in Percent of Copper		Rockwell Hardness		
Ni	Cr	P	Be	Other Elements			Solid Solution	After Aging	Upon Being Produced	Solid Solution	After Aging
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
1.00	--	0.25	--	--	--	--	23.3	30.0	22B	25F	20B
2.00	--	0.50	--	--	32	4	21.0	40.0	19B	36F	23B
--	--	0.25	--	0.75Mn	--	--	24.4	44.1	33B	45F	14B
--	--	0.15	--	0.50Mn	--	--	32.2	55.6	44B	26F	44
4.00	--	--	--	4.00Sn	--	--	11.7	12.8	42B	30B	35B
5.00	--	--	--	8.00Sn	--	--	7.25	8.4	46B	15B	40B
--	3.0	0.50	--	--	--	--	--	--	--	38F	53F
--	3.0	0.10	--	--	34	7	32.2	64.3	35B	38F	51B
--	3.0	0.10	--	0.5TiH_2	36	8	33.5	69.1	38B	42F	68B

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
--	--	0.50	--	2.0Co	26	15	28.5	43.4	30B	28F	39B
2.5	--	0.5	0.5	--	36	7	--	61.0	35	--	72B
2.5	--	0.5	0.5	--	39.4	5	--	52.0	35B	--	60B
2.5	--	0.5	0.5	0.5Si	43	2.5	--	35.5	35B	--	80B
--	--	--	0.5	2.5Co	55	3.1	--	41.6	35B	--	85B

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
--	--	0.50	--	2.0Co	26	15	28.5	43.4	30B	28F	39B
2.5	--	0.5	0.5	--	36	7	--	61.0	35	--	72B
2.5	--	0.5	0.5	--	39.4	5	--	52.0	35B	--	60B
2.5	--	0.5	0.5	0.5Si	43	2.5	--	35.5	35B	--	80B
--	--	--	0.5	2.5Co	55	3.1	--	41.6	35B	--	85B

TABLE 29

PROPERTIES OF BRASSES

Composition in Percent			Specific Gravity in Grams Per Cubic Centimeter	Maximum Tensile Strength	Elongation in Percent
Cu	Zn	P			
70	30	--	7.88	23.0	14
70	30	0.3	7.80	24.0	48
90	10	--	8.25	22.0	18
90	10	0.7	7.64	16.5	26

EASILY-FUSIBLE METALS (MERCURY, LEAD, TIN, ANTIMONY, CADMIUM, ZINC)

Easily-fusible metals sometimes do not enter into the composition of metalloceramic materials as a basic component. Tin and lead powders are primarily obtained by atomizing of the liquid metal and zinc by atomizing and volatilization.

Mercury was first used in the preparation of pastes for the nozzle-extrusion method of pressing tungsten (page 61 of original text). At the present time mercury is only used for producing pastes (amalgams) for the fabrication of metalloceramical dental fillings (Chapter XVIII).

Aside from iron and copper alloys, lead is used in the impregnation of the copper-nickel skeleton of triple-layer material (an alloy of lead with 3 percent antimony and 4 percent tin). Patent literature speaks of impregnating tungsten with lead used in X-ray screens.

Cadmium is used in contacts in the form of an oxide on a silver base. Furthermore, it is used in electrolytic cadmium surface plating of metalloceramic materials for the purpose of increasing resistance to corrosion.

Zinc, besides copper alloys, is used in precipitating cobalt and nickel from ammonia solution on powder particles of tungsten carbide. The properties of aluminum alloys containing 10 percent Zn are given in Table 30. Zinc is also used as an anticorrosion coating of metalloceramic products.

TABLE 30

PROPERTIES OF ALUMINUM ALLOYS [194]

Composition in Percent	Pressure in Tons per Square Centimeter	Baking Temperature in Degrees Centigrade	Resistance to Fracture in Kilograms per Square Millimeter	Density in Grams per Cubic Centimeter	Porosity in Percent
90% Al +	3.1	430	3.75	2.266	13.0
+ 10% Mg	4.7	430	12.5	2.409	7.5
	9.1	430	17.5	2.519	3.3
90% Al +	6.3	370	7.6	--	--
+ 10% Zn	6.3	430	10.6	--	--
	6.3	510	10.9	--	--
90% Al +	6.3	370	15.2	--	--
+ 7% Zn +	6.3	430	23.2	--	--
+ 3% Mg	6.3	510	28.2	--	--

LIGHT METALS (ALUMINUM, MAGNESIUM, BERYLLIUM)

Aluminum is used as the main component in porous bearings produced on an industrial scale. The exact composition and properties of these porous bearings have not been made public.

The relationship of the properties of metalloceramic aluminum to the conditions of fabrication [144] is given in Figure 155.

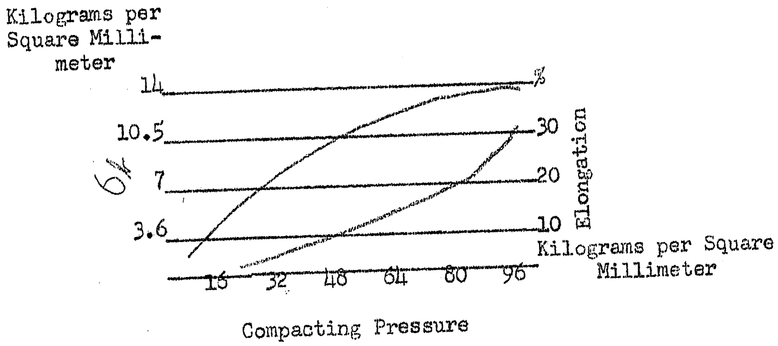


Figure 155. Properties of Metalloceramic Aluminum [144]

The properties of aluminum to which 10 percent of magnesium or zinc or both of these metals has been added [194] have been given in Table 30. Aluminum carbide has come to be used as a substitute in hard alloys.

Beryllium [166] is used in the manufacture of windows for X-ray tubes. Metalloceramic beryllium is superior to cast for the manufacture of thick X-ray windows because of its greater close-grained quality. See above for the use of beryllium in bronze.

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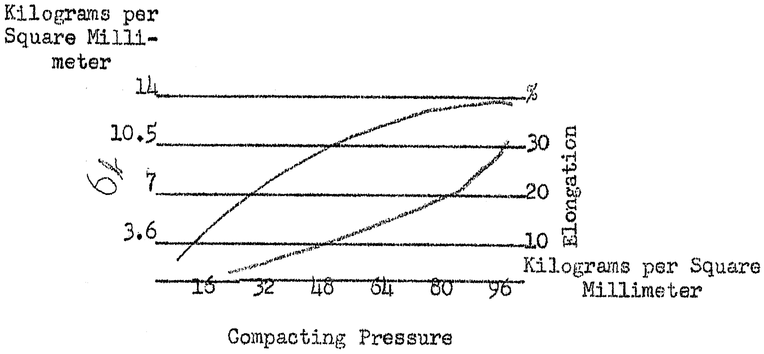

Figure 155. Properties of Metalloceramic Aluminum [144]

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METALS OF THE IRON GROUP (NICKEL AND COBALT)

Nickel powders are obtained by reduction or heat dissociation of carbonyl $Ni(CO)_4$.

Nickel is used in limited quantities as an only component in vacuum technology and in the production of bimetals and filters.

As a principal component, nickel is used in the magnetic alloy Permalloy for pressing of cores (78.5 percent Ni and 21.5 percent Fe or 81 percent Ni, 17 percent Fe, and 2 percent Mo).

Alloys of nickel with iron and copper have already been referred to above.

Nickel is used as a cementing metal in certain hard alloys (as an alloy for the cores of armor-piercing shells with 97 percent WC and 3 percent Ni, the German wartime substitute containing 45 percent VC, 45 percent TiC, and 10 percent Ni, titanite with 8 - 15 percent Ni, tantalum carbide alloy Ramet with 8 - 13 percent Ni).

Cobalt powders are obtained by reduction. Cobalt is used principally as a cementing metal inthe majority of hard alloys (from 3 to 20 percent Co).

PRECIOUS METALS (SILVER, GOLD, METALS OF THE PLATINUM GROUP)

Silver is obtained either by reduction of salt solutions or atomizing of the liquid metal.

Silver in pure form is used in the fabrication of filters. It is used as a main component in contact materials (silver-graphite, silver-nickel, silver-cadmium oxide). A considerable quantity of silver (10 - 40 percent) is contained in contacts with a tungsten or molybdenum base. Silver is the principal component in metalloceramic dental fillings (about 50 percent).

Gold is used in so-called electrostatic eliminators for eliminating static charges from telegraph ribbons [177].

Platinum was the first industrial metal to be obtained by the methods of metalloceramics 120 years ago. Metalloceramic platinum is softer and more plastic than cast because of smaller admixture content [167]. The Brinell hardness of cast platinum is 40 - 44, that of metalloceramic 38 - 42.

About 1900 osmium was used in the production of incandescent filaments for electric lamps. Osmium at the present time, as well as palladium, rhodium, and iridium, is used in concentrations of 1.5 - 10 percent in place of cobalt in hard-alloy contacts for telegraph relays.

REFRACTORY METALS (TUNGSTEN, MOLYBDENUM, TANTALUM, NIOBIUM)

Refractory metals in pure form and alloys in which they are the basic components are produced at the present time almost exclusively by the methods of powder metallurgy. (Tantalum is also produced on an industrial scale by means of vacuum arc smelting.)

The properties of refractory metals [167] are given in Table 31.

Tungsten powders are obtained by reduction.

TABLE 31

PROPERTIES OF REFRACTORY METALS

Property	Metal			
	Tungsten	Molybdenum	Tantalum	Niobium
[1]	[2]	[3]	[4]	[5]
Specific gravity				
in grams per cubic centimeter	19.0 - 19.3	10.0 - 10.3	16.6 ± 0.1	8.57
Melting Point				
in degrees Centigrade	3400 ± 50	2630 ± 50	2900 ± 100	2415
Resistance to Rupture				
in kilograms per square millimeter				
Cold-hardened metal	180 - 400	100 - 250	90 - 120	60 - 90
Annealed metal	-	80 - 120	35 - 50	30 - 40
Monocrystal, not hardened	110	35	-	-
Elongation in percent				
Cold-hardened metal	1 - 4	2 - 5	2 - 3	2
Annealed metal	-	10 - 30	25 - 40	10
Monocrystal, not hardened	20	30	-	-
Yield point				

[1]	[2]	[3]	[4]	[5]
in kilograms per square millimeter				
Cold-hardened	150			
Annealed	72 - 83	40 - 60	-	-
Elasticity modulus in kilograms per square millimeter	41,500	33,600	18,800	-
Brinell hardness in kilograms per square millimeter				
Cold-hardened	350 - 400	240 - 255	150 - 200	200 - 250
Annealed	-	-	70 - 120	-
Coefficient of linear expansion at 25 degrees	$4.41 \cdot 10^{-6}$	$5.2 \cdot 10^{-6}$	-	$7.2 \cdot 10^{-6}$
Heat conductivity at 20 degrees in calories per centimeter/second/degree	0.4	0.35	-	-
Specific electrical resistance at 20 degrees in ohms square millimeter/meter	0.055	0.058	-	-

[1]	[2]	[3]	[4]	[5]
Vapor pressure in millimeters of mercury column	1530° - $- 1.93 \cdot 10^{-15}$ 2130 - $7.9 \cdot 10^{-9}$ 3230° - $- 4.68 \cdot 10^{-3}$	1530° - $6.4 \cdot 10^{-9}$ 1730° - $8 \cdot 10^{-7}$ 1930° - $4 \cdot 10^{-5}$	-	-

Tungsten is used principally for incandescent filaments for electric lamps, parts of cathode lamps in vacuum technology, X-ray tubes, rectifiers and transformers, discharge tubes, electrodes, spark plugs, etc., contacts and electrodes for atomic-arc welding, hard alloys, heavy alloys for radium shields, etc. (see Chapters XII, XV, XVII, XVIII). Molybdenum powders are obtained by reduction.

Molybdenum is used principally in the electric-lamp and electric-vacuum industries, for attaching tungsten connecting filaments to glass, for anodes in vacuum tubes, in X-ray tubes, for heating elements in high-temperature furnaces, in contacts, and in obsolete brands of hard alloys (for greater detail see Chapter XV).

Tantalum powder is obtained by the reduction of alkali metals and by the electrolysis of melted media. Tantalum is baked in a vacuum.

Tantalum is used in vacuum technology (Chapter XV), in hard alloys (Chapter XII), in military surgery (Chapter XVII). Thanks to its high resistance to corrosion, tantalum is widely used in chemical machine-building, in apparatuses for the production of hydrochloric acid, etc.

Niobium powder is obtained primarily by electrolysis of melted media.

The industrial application of niobium in vacuum technology and for hard alloys is still small.

OTHER METALS

Manganese is used as an admixture and sometimes as an additive to metalloceramic steels.

Chromium is used in alloys of iron and copper. Chromium carbide is contained in certain kinds of hard alloys.

Vanadium is used in hard alloys as a substitute, as in Germany during the war (45 percent VC, 45 percent TiC, 10 percent Ni).

Titanium is one of the ten most widely used elements contained in the earth's crust. Titanium is used in the form of a carbide TiC in powder metallurgy for present-day hard alloys used in cutting steel. Additions of titanium hydride TiH_2 may be used [194] as a source for atomic hydrogen for the reduction of difficult-to-reduce oxides (such as aluminum).

Titanium in its pure form or as a basic component in alloys has not yet come to be used either in casting metallurgy or in powder metallurgy. Moreover, the mechanical properties of titanium have not been well known. The reason for this lies in its exceptional affinity to gases (oxygen, azote, hydrogen) and to carbon, thus making it difficult to obtain. Only recently has ductile titanium [149] been obtained by the methods of powder metallurgy. The initial powders were prepared by the reduction of titanium tetrachloride with metallic magnesium. Compacting was done at a pressure of 6000 kilograms per square centimeter, baking -- in a vacuum with a rarefaction of $2 \cdot 10^{-4}$ millimeters of mercury column at a temperature of 950 - 1000 degrees over a period of 16 hours. The properties of titanium are given in Table 32.

In its resistance to corrosion titanium is close to Steel 18-8. Concentrated H_2SO_4 and HCl quickly erodes titanium, but 5 percent H_2SO_4 causes a loss of only 0.40 milligrams per square decimeter in 24 hours. Diluted solutions of Na_2SO_4 do not act on titanium. Specimens of titanium showed no change after a 30-day stay in a salt chamber. Titanium will not burn in air when heated up to 800 degrees.

Titanium possesses exceptionally valuable properties. Its melting point is only 190 degrees above that of iron, but it is stronger and considerably lighter (by 43 percent) than iron and has a very high resistance to corrosion. A phase transformation at 880 degrees (910 degrees for iron) permits the treatment of titanium alloys by heat and tempering. In this way, powder metallurgy opens up the prospects of industrial utilization of a new important metal.

Zirconium is used in the vacuum technique as a getter (gas absorbent).

Thorium is introduced into tungsten in the form of ThO_2 to regulate recrystallization and increase emission capability.

Radium compounds are used in electrostatic eliminators [177] for the purpose of removing electrostatic charges from the ribbons of telegraph apparatuses (Chapter XV).

TABLE 32

PROPERTIES OF TITANIUM

Property [1]	Value [2]
Lattice Construction	Hexagonal dense packing a = 2.95, c = 4.73 Cubical above 880 degrees a = 3.32 A
Specific gravity in grams per cubic centimeter	4.5
Melting point in degrees centigrade	1725
Resistance to rupture in kilograms per square millimeter	
Cold-hardened	88
Annealed	57
Yield point in kilograms per square millimeter	
Cold-hardened	70
Annealed	43
Limit of proportionality in kilograms per square millimeter	
Cold-hardened	50
Annealed	39
Elongation in percent	
Cold-hardened	4
Annealed	28

[1]	[2]
Young's modulus in kilograms per square millimeter	
Cold-hardened	10,800
Annealed	11,300
Hardness	
Cold-hardened	65
Rockwell "A"	
Annealed	75
Rockwell "B"	
Electrical conductivity in ohms per cubic centimeter	56

NONMETALLIC COMPONENTS

Carbon in the form of diamond dust is used in diamond-metallic compositions (Chapter XII). Mention has already been made above of graphite and combined carbon in iron, copper, and hard alloys, etc. Organic compounds of carbon enter as plastics primarily into the composition of cores.

Silicon ordinarily exerts a harmful influence in view of the difficulty of reducing its oxides and because it decreases weldability (sintering) of metal. For this reason silicon in the majority of cases is used in materials that are produced without recourse to baking. Thus magnetic cores pressed with plastics utilize the alloy alsifer with 10 percent Si. Silicon in the form of SiO_2 is introduced into friction materials for raising the coefficient of friction.

Mention has also been made above of the role of sulphur and phosphorus in metalloceramic materials. Phosphorus plays more frequently a positive than a negative role in powder metals.

Oxygen appears in the great majority of cases as an undesirable admixture. Reference has been made above to the special oxidation of porous iron by superheated steam.

Chapter X

METALLOCERAMIC ANTIFRICTION MATERIALS

A. POROUS BEARINGS

Porous bearings were introduced to industrial use relatively recently -- about 25 years ago. This branch of industry has developed rapidly since then. At the present time industry in the US employs more than 1 billion porous bearings. The output of porous antifriction materials in terms of total metalloceramic production is quite significant.

As is known, pure cast iron having a homogeneous structure cannot be used as an antifriction material. Figure 156 shows that porous metalloceramic iron has an irregular structure (ferrite grains and pores). The macrohardness of porous iron containing 25-percent pores is about 30-40, while the microhardness of ferrite grains is about 70, with zero hardness for pores. Thus, antifriction lead bronze (where lead takes up about 25 volumetric percent) has a macrohardness of 35, with a microhardness of 56 for the copper and 8 for the lead. As can be seen, porous iron is quite comparable to lead bronze in hardness -- for the collective and individual structural composites. The presence of pores, which contain a supply of oil against accident and which provide an excellent working-in quality, makes it possible to utilize successfully materials for bearings which do not possess antifriction qualities in the compact state, such as iron.

Figure 156. Porous Metalloceramic iron. X 500 (Bal'shin) [Photo]

Porous metalloceramic bearings have the following advantages over other sliding bearings:

(1) Thanks to the presence of an emergency supply of oil in the pores and to the possibility of simplifying the introduction of lubricants there is a decrease in many cases of the danger of bearings going out of order, in wear on bearings and shaft, and in expenditure of oil, eliminating the necessity of frequent lubrication and consequent damage to products from lubricants, and simplifying the design of assemblies, etc.

(2) Excellent accommodation due to the presence of pores.

(3) Possibility of working not only with tempered but also with plain shafts [syryye].

(4) The possibility of obtaining finished details with desired dimensions and requiring no machining.

(5) Simplicity of installation and operation of porous bearings.

(6) Possibility of manufacture from non-deficit meterials (iron).

In contrast to roller bearings, the advantage of porous bearings lies in their cheapness and quietness of operation.

Porous bearings have forced out from many branches of technology cast tin bronze. In some they have replaced roller bearings and have given better performance.

However, it would be incorrect to consider porous iron as solely a substitute for tin bronze. Porous metals are new technical materials and surpass bronze with respect to a number of properties.

Composition, Structure, and Density of Porous Bearings

At the present time the following varieties of porous antifriction materials are being produced on an industrial scale.

(a) Bronze and bronze-graphite with a porosity of about 20-30 percent (87-90 percent Cu, 9-10 percent Sn, 0-4 percent graphite, sometimes with additions of lead). Fabricated primarily from fine and medium powders. Used in work under conditions where lubrication is difficult and which call for low loads and speeds (product of specific load "p" and velocity "v" up to 20 kilograms per square centimeter-meters per second). (Sometimes porous bearings have several percent of lead).

(b) Porous iron with 10-30 percent pores. Prepared mainly from medium and coarse powders. With a satisfactory lubricant it may work at values of pv = 100 and, with an unsatisfactory one, up to 25 kilograms per square centimeter-meters per second. When working with tempered rollers, one may use carbonization from bearings during caking or afterwards.

(c) Porous iron-graphite with 20-30 pores (97-98 percent Fe, up to 2 percent graphite, including up to 1 percent combined carbon). The structure is ferrite, ferrite-pearlite, or pearlite. When working with tempered rollers, pearlite structure is preferable. Fabricated from fine and medium powders. Intended for the same conditions of work as porous iron.

(d) Iron-copper and iron-copper-graphite with 20-30 percent porosity (83-97 percent Fe, 3-15 percent Cu, 0-2 percent graphite, 0-1 percent combined carbon). Intended for the same conditions of work as compositions listed under paragraphs b and c.

(e) Lead-iron and iron-graphite (167). At first contained up to 18 percent Pb. At the present time iron is used with no higher than 3.5 percent Pb content. An opinion exists (158) that the introduction of lead does not add any advantages but even exerts an unfavorable action.

(f) Porous bearings with an aluminum base. Only fragmentary data exists concerning them (specific gravity about 23 percent that of cast bronze, high resistance to corrosion, and approximately the same maximum loads and speeds as for porous bronze).

The following porous antifriction materials are also deserving of attention although they have not yet found their way into industry.

(a) A special bronze (159), which contains 2.4 percent Ni, 0.8 percent Si, 0.3 percent P, the rest being copper. After being chilled in water from 850 degrees, it can be improved by aging at 450 degrees. A material with approximately 12 percent porosity, it has a resistance to fracture of about 35 kilograms per square millimeter, an elongation of about 1 percent, and a 35-40 Rockwell B hardness. Bearings from this bronze, after a preliminary working in for a period of 2 hours with a load of 38 kilograms per square centimeter and a speed of 4.5 meters per second and for another period of 3 hours with 59 kilograms per square centimeter and 5.9 meters per second, were then tested for 50 hours at 160 kilograms per square centimeter and 9.4 meters per second (pv = 1500). Following this no perceptible wear or defects were observed on the surface of the bearings or the roller.

(b) Metalloceramic cast iron with 96-97 percent Fe, up to 3 percent C, up to 1 percent of which was combined. Fabricated basically from iron shavings or cast iron powders with slight silicon content; 10-20 percent porosity. Mechanical properties and maximum loads are smaller than for porous iron. However, they can do work with pv = about 50 kilograms per square centimeter-meters per second and even somewhat greater.

The tendencies observed during the course of development of powder antifriction materials may be reduced to the following.

(1) Porous tin bronze is being forced out by porous iron. Porous iron, which is not a deficit material, has higher antifriction properties and may be used to work with more sizeable loads than porous bronze.

(2) A transition from finer to coarser powders. Bearings made from powders of coarser particles are cheaper, contain fewer closed pores and are more permeable with reference to lubrication.

(3) Decrease in porosity. Initially porous antifriction materials had approximately 35-40 percent porosity. In recent times the fabrication of bearings with 15-30 percent porosity has come to be preferred. Denser bearings have higher mechanical properties and may be used in work with more sizeable loads. Practice cannot yet

give decisive indications of the optimum magnitude of porosity for different materials and conditions of performance. It may be pointed out, however, that the coarser the original powder the smaller is the magnitude of optimum porosity.

(4) Refusal to introduce components which lower mechanical properties even where they increase antifriction properties (graphite, lead in iron). Thus the firm of Chrysler has turned down graphite because it believes that bearings containing graphite can give satisfactory performance, but only as long as nothing unforeseen happens. Graphite in particular should not be added to coarse powders. For such cases colloidal graphite may be introduced into baked bearings with the lubricant.

According to Geydebrok (158) bearings of eddy-mill iron have considerably higher antifriction properties than those made from reduced iron.

Physicomechanical Properties of Porous Antifriction Materials

Table 33 presents the indexes (135) of physicochemical properties of porous antifriction materials manufactured by different American firms. Favorable hardness values of porous metals make it possible to use them in work with both non-tempered and tempered shafts. A decrease in mechanical properties accompanied by an increase in the size of particles (Figure 116) caused by the inclusion of graphite (Figure 127) and growth in porosity (Figures 148, 149) was noted even earlier.

Upon being heated to 200 degrees, the properties of porous metals having an iron base change only insignificantly.

Table 33. PHYSICOMECHANICAL CHARACTERISTICS OF BEARINGS MADE BY AMERICAN FIRMS

(values of pv with slight lubrication)

Firm [1]	Brand Name of Material [2]	Composition in % [3]	Specific Gravity in grams per cu. cm. [4]	Porosity in % [5]	Resistance to Fracture in kgs. per sq. mm. [6]	Resistance to Compression, kgs. per sq. mm. [7]	Elongation in Percent [8]	Brinell Hardness [9]	Maximum Load in kgs. per sq. mm. [10]	Produced pv in kgs. per sq. mm. [11]	Pressure for Lateral Thrust in kgs. per sq. mm. At 0.025 per mm. [12]	Pressure for Lateral Thrust in kgs. per sq. mm. At 0.13 per mm. [13]	Coefficient of Linear Expansion
Bound Brook Co.	Compo	88.5 Cu 10 Sn	6.3	27	7.6	45	-	25-35	470	16	7	-	17.6
	Powdiron 55-p	96 Fe 5 Cu	5.5	32	7.6	88	-	25-35	950	16	10	-	13.0
										20	11	-	
	Powdiron 61-1C	Up to 10 CU	6.1	25	19.0	88	-	60-90	1250				13.9
	Powdiron 51-1	100 Fe	5.9	25	7.6	82	-	35-50	1250	16	14	-	12.2

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14)
Chrysler	Oilite	90 Cu 10 Sn	6.1	27	7.9	76	5	30	500	25	7-10	-	18.9 ~~[illegible]~~
	Super-Oilite	75 Fe 25 Cu	6.4	25	19.0	125	1	45	2000	16	19-30	-	13.9
	Iron-Oilite	100 Fe	7.1	30	9.5	82	1	40	1250	16	14-25	-	10.8
Keystone Carbon Co.	Selflube Bronze	90 Cu 10 Sn	6.1	24	8.8	-	-	-	-	15	7	-	-
	Selflube Iron	96 Fe 5 Cu	5.5	29	11.0	-	-	-	-	16	19	-	-
General Motors	Durex Iron	98 Fe 2 Cu	55-6.0	20-30	22.0	-	-	60-90	950	16	12-16	-	11.7-12.6
	Durex Bronze	89 Cu 10 Sn	6.0-7.0	20-30	7.6	-	-	25-40	470	16	7	-	18.0
United States Graphite Co.	61	90 Cu 10 Sn	6.6	20-25	13.0	-	-	-	450	16	9	11	17.5
	81	90 Cu, 10 Sn and slight graphite addition	6.0	20-30	11.0	-	-	-	400	16	6	8	17.5

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
	86	85 Fe, 15 Cu and slight graphite addition	5.8	15-20	6.0	-	-	-	000[?]	16	11	17	12.8
	139	100 Fe	5.5	20-25	6.0	-	-	-	000[?]	16	9	11	12.2

The size of the coefficient of thermal expansion for porous and compact materials of the same composition is approximately the same. Heat conductivity and electrical conductivity of porous materials is lower than for corresponding compact materials.

Resistance to corrosion of porous materials, including iron, impregnated with oil is entirely satisfactory. Where so desired it can be increased by finishing with Michelson's method (82), bonderizing, etc.

Antifriction Properties of Porous Materials

(a) Coefficient of Friction and Expenditure of Energy

Comparative tests carried out by Sushkina and Korolenko for Ts TsNIITMASh showed that with ample lubrication the coefficient of friction for porous iron-graphite (2 percent graphite, 25-30 percent porosity) is somewhat smaller than for cast tin bronze. It was also established that calibrated porous bearings have a smaller coefficient of friction than those machine finished. This should be explained by deterioration in the quality of surface and decrease in strength and binding of porous metal when machine finished. Figure 157 shows, according to the data of ENIMS, the relation of the coefficient of friction and the temperature to load for iron with 25 porosity and 2 percent graphite and with additional lubrication (6). With increase in load, the coefficient of friction decreases while temperature increases. Figure 158 shows the relation of the coefficient of friction to speed for eddy-mill iron with 19 percent porosity when lubricated by forced circulation at a pressure of 1 $\overset{\text{aru}}{\text{atmosphere}}$ (158). As can be seen, with an increase in speed the coefficient of friction μ at first drops very rapidly to its minimum value of about 0.001 and then again grows so that it achieves its maximum value at a speed of about 2 meters per second, after which it once more drops somewhat. The decrease in the coefficient of friction for speeds above 2 meters per second is explained by Geydebrok as due to the heating of the oil.

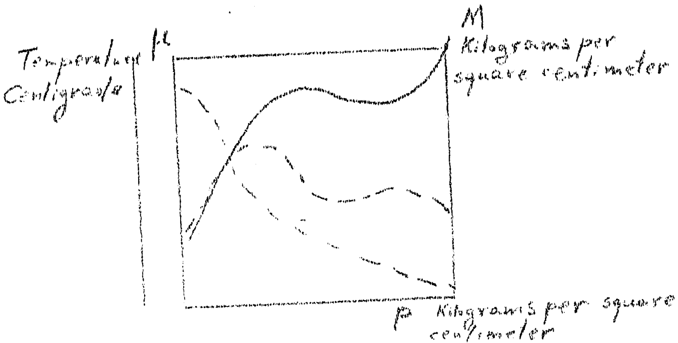

Figure 157. Relation of the Coefficient of Expansion (μ), Moment of Friction (M) and Temperature (t) to Specific Pressure (p) (Ginsburg)

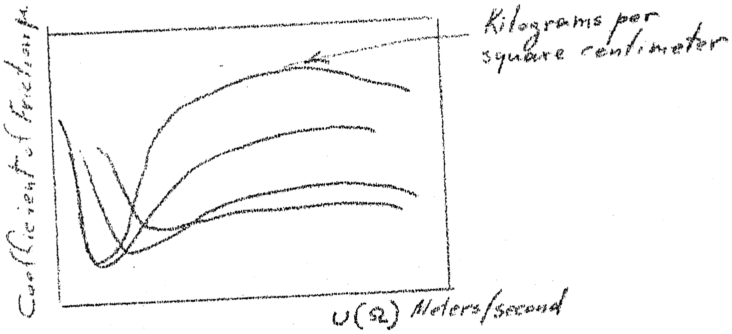

Figure 158. Relation of Coefficient of Friction to Peripheral Speed (158).

If the coefficient of expansion for cast bronze is larger even with copious lubrication than that for porous iron, then with scanty lubrication this discrepancy would increase still more. Comparative tests at one plant (6) showed that with scanty lubrication porous iron is from the point of energy 2-3 times more economical than cast tin bronze. With small loads the expended energy (in watts) was 3.14-3.39 when grease was used, a.65-2.74 with grease and 50 percent oil, 4.9-5.1 upon removing lubricant from neck of shaft, 2.06-2.16 with uninterrupted application of oil (20 drops per minute), and 5.6-5.5 with lubrication discontinued. For iron-graphite it was 1.47-1.57 with periodic applications of oil, 2.92 with continued application of oil (20 drops per minute), and 1.47 after discontinuing lubrication.

It can also be seen from the data presented that supplying oil from an outside source for porous materials did not lower expenditure of energy but, quite the opposite, increased it considerably (twice) as compared to lubrication with the supply of oil contained in the pores (capillary lubrication). This interesting phenomenon of a growth in the coefficient of friction through application of supplementary lubrication has been observed more than once in the performance of porous bearings with small loads.

The constant presence of adsorptive (capillary) lubrication in porous bearings lowers the actuating coefficient of friction and eliminates manifestations of dry friction.

(b) Wear

Wear from operation both of the porous bearings and of the shaft is less than for cast antifriction materials, such as tin bronze and babbitt. This is explained by the absence of dry friction, thanks to the constant presence of oil in pores, the insignificant value for the coefficient of friction, and to good accommodative ability of porous material.

Table 34 shows the sesults of relative tests on porous materials (25-30 percent porosity) and babbitt alloys carried out by Professor Saytsev. They show that wear of the bushing, shaft (ring), and the coefficient of friction were considerably smaller for porous materials than for cast babbitt alloys (6).

[See following page for Table 34]

Numerous performance tests on porous iron carried out by TsNIITMASh (6) showed that in the majority of cases wear on porous bearings was smaller (larger only in very rare cases) than for cast antifriction materials. Thus, in comparative tests of porous iron and graphite on electric motors having a capacity of 15 kilowatts lasting 300 hours, the results obtained were as follows. Slack at the beginning of the test was 0.05 millimeters for both babbitt and iron-graphite. At the end of the experiment it was 0.10 to 0.37 for babbitt and 0.05 to 0.07 for iron-graphite.

Such insignificant wear assures a prolonged preservation of exactness in dimensions and a long life for porous bearings.

(c) Accommodation

The experiments of TsNIITMASh on relative accommodation showed that iron-graphite has better accommodation than bronze, considerably

Table 34. RESULTS OF RELATIVE TESTS OF POROUS MATERIALS ON AN "AE" MACHINE CARRIED OUT BY PROFESSOR ZAYTSEV

(Speed of 10 Meters per Second, Lubrication with No 3 Spindle Oil)

Material	2-hour Test with p = 25 kilograms per square centimeter		10-hour Test with p = 50 Kilograms per square centimeter		Weare after 12 hours' operation in millimeters	
	Increase in Temperature in Degrees Centigrade	Coefficient of Friction	Increase in Temperature in Degrees Centigrade	Coefficient of Friction	Bushing	Friction Ring
Porous Iron	24.5	0.018	40.7	0.013	0.41	0.6
Porous Iron-Graphite with 1.5 Percent Graphite	26.6	0.026	36.2	0.014	0.34	0.4
Porous Iron-Graphite with 1.75 Percent Graphite	25.6	0.026	33.8	0.016	0.37	0.4
Porous Iron-Graphite with 2 Percent Graphite and 7 Percent Copper	32.3	0.016	39.8	0.010	0.30	0.0
Babbitt B-83	26.8	0.057	33.1	0.033	9.0	2.5
Babbitt BM	28.7	0.042	35.7	0.024	11.0	0.0

better than its substitutes, and approximately the same as for Babbitt B-83. For example, when testing bushings at a peripheral speed of 2.2 meters per second with copious lubrication and stepped increase in load (by 3 kilograms per square centimeter) up to 16.7 kilograms per square centimeter, the time of accommodation for achieving a stable heat temperature was 6 hours and 45 minutes for Babbitt B-83, 8 hours and 20 minutes for cast tin bronze, 7 hours and 20 minutes for iron-graphite with 25 percent porosity on a non-tempered shaft and 6 hours for a tempered shaft. The good accommodation of porous bearings is to be explained by plastic deformation caused by change in the volume of pores.

It should not be thought, however, that the accommodation of metalloceramic materials increases without interruption with growth of porosity. Tests carried out by Sushkina and Korolenko at TsNIITMASh showed quite the opposite, that accommodation for iron-graphite with 30 percent porosity is worse than with 20 percent porosity. Thus material with 20 percent porosity was accommodated at the end of 7 hours and 40 minutes and with 30 percent porosity only after 9 hours and 35 minutes. This manifestation should be explained by the drop in adhesion and strength of material with growth of porosity leading to disintegration of the metal at the surface of friction, crumbling of the particles, and prolonged accommodation. Thus, there exists an optimum porosity which probably depends on the kind of material and on test conditions.

Materials from coarse powders have worse accommodation than those from fine powders. This is to be explained by the smaller adhesion and strength of such materials and also by the fact that in such cases deformation occurs to larger sized unevennesses.

The good accommodation of porous metal increases the quality of surface. Thus investigations carried out by TsNIITMASh showed the size of unevennesses on the surface of tin bronze to be 5-6 [?] and of porous iron 0.5-1 μ.

Good accommodation and quality of surface in their turn exert a beneficial influence on other antifriction properties of porous materials, such as lowering the coefficient of friction, wear on bushing and shaft, and increasing permissible maximum loads.

(d) Maximum Loads

Figure 159 shows relative curves of the relation of permissible loads to the rotating speed for cast and porous bronze (167). It can be seen from these curves that with low speeds permissible loads are greater for porous bronzes, especially those fabricated from fine powders with small pores, than for cast. This feature holds true for work either with supplementary lubrication or with lubricants existing in the pores. The magnitude of permissible loads of porous bearings at low speeds does not change with the addition of supplementary lubrication. With increased speeds, supplementary lubrication increases the size of permissible loads. Moreover, at high speeds loads for cast bronze are higher than for porous bronze.

Mann explains this discrepancy from the point of view of the hydrodynamic theory of lubrication. An unbroken oil film cannot be formed at low rotating speeds. For this reason porous bearings whose lubrication reaches the surface by way of numerous capillaries are capable of working with greater loads. Especially good results in this connection have been obtained with bearings made from fine powders and with a greater number of small pores. With increased speeds an unbroken film forms on the surface of cast bronze. Pores in metallo-ceramic bearings break up continuous surface and interfere with the formation of a continuous film. Moreover, a porous surface from the purely mechanical point of view can support a smaller weight than a solid surface. It is for this reason that at high speeds the values for permissible loads are smaller for porous bearings than for cast.

Hydrodynamic theory without doubt can explain only a portion of the manifestations observed in working with porous bearings. There should also be taken into consideration differences in heat conductivity, accommodation, and other properties of porous and cast bearings.

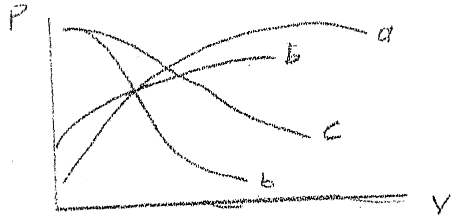

Figure 159. pv Curves

a. cast bronze; b. baked bronze without supplementary lubrication; c. and d. baked bronze with supplementary lubrication (167).

Elimination of heat is most important at high speeds. Heat conductivity is smaller for porous materials than for cast. This factor must result in a decrease in the size of maximum loads for high speeds. Accommodation of porous bearings is greater than for cast, even at high rotating speeds. In this connection it should also be taken into consideration, as pointed out above in point c, that excessive porosity does not increase but decreases accommodation. For this reason with a sufficiently adequate lubrication carrying away the heat and a proper degree of porosity should cause maximum loads of porous bearings to be undoubtedly higher than for cast even at very high speeds. Figure 160 shows functional curves of loads p and rotational speed v for porous iron (158). These tests were carried out without supplementary lubrication and with drop lubrication and a forced circulation at a pressure of 1 atmosphere ( ). It can be seen from the curves that the values for pv were very high (up to 700 kilograms per square centimeter-meters per second) with forced circulation of lubrication.

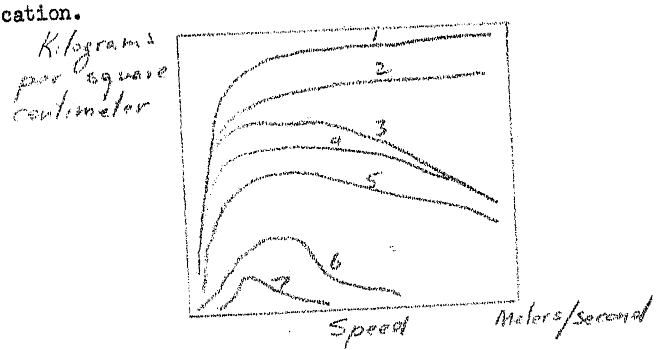

Figure 160. pv Curves for Porous Iron (158).

1. eddy-mill iron, medium-sized powders; specific gravity 6.4 grams per cubic centimeter, calibrated, complete lubrication after prolonged accommodation; 2. the same, after accommodation of 3 hours; 3. the same, drop lubrication; 4. the same, without added lubrication; 5. eddy-mill iron, fine, specific gravity 5.8 grams per cubic centimeter, machine-finished, without added lubrication; 6. eddy-mill iron, coarse, specific gravity 5.8 grams per cubic centimeter, machine-finished, without added lubrication; 7. reduced iron, specific gravity 5.5 grams per cubic centimeter, machine-finished, without added lubrication.

With drop lubrication (10 drops per minute) and capillary lubrication (from supply contained in pores) p values were smaller. It should be pointed out that these experiments did not disclose any particularly large differences between the action of capillary or drop lubrication. In the case of the densest specimen which had 19 percent porosity, pv values rose up to 400 grams per square centimeter-meter per second (p being approximately 135 kilograms per square centimeter and v in the vicinity of 3.1 meters per second). Coarse powders gave considerably lower value for maximum loads than fine or medium powders. Load magnitudes were greater for calibrated than for machine-finished bearings. Bearings from eddy-mill iron gave better results than those from reduced iron; values for pv decreased with increase in porosity. This behavior may be explained by differences in accommodation and adhesion (accommodation and adhesion are lower for bearings from coarse powders obtain by reduction and for bearings which were machine finished and had greater porosity).

The comparative tests carried out at TsNITTMASh on porous iron-graphite (about 25 percent porosity) made from powders of restored iron and electrolytic porous bronze, on cast tin bronze OTs-10-2, and on Babbitt B-83 with a lubrication of 80 drops per minute and a speed of 2.2 meters per second gave the following results: For Babbitt B-83 pv was 222, for bronze OTs-10-2 pv was 53, for iron graphite from electrolytic iron with 1 percent graphite content pv was 84 and with 3 percent graphite content it was 109, for reduced iron with 2 percent graphite content, and for porous bronze Oilite pv was 39 kilograms per square centimeter-meters per second. Thus pv values were larger for porous bearings with an iron base than for cast tin bronze.

On the basis of the agreement existing between laboratory and production experiments it may be said that pv is 20-25 kilograms per square centimeter-meters per second for materials with an iron base and and 25 percent porosity getting poor lubrication, while pv equaled 70-100 when there was copious lubrication. With further improvement in material and decrease in porosity, pv values, as Geydebrok's experiments have shown, should increase even more under conditions of copious lubrication.

Maximum load at very low speeds may exceed 1000 kilograms per square centimeter by a significant margin (Table 36). Speeds at which bearings may operate under conditions of poor lubrication should not exceed 5 meters per second (6).

Installation and Use of Porous Bearings

Porous bearings are fabricated as details with precise measurements whose tolerances for diameter and length usually fall into third or second class of accuracy (Chapter XIII). The finishing and installation of porous bushings into sockets was described in Chapter VII (page 171).

With respect to the size of tolerances certain contradictions exist in data.

Together with indications that tolerances for porous materials should be smaller than for cast bronze (6) there also exist indications that they should be larger (162), inasmuch as the special mechanism of lubrication for porous materials demands a sufficiently great thickness for the oil film making it desirable to have large clearances. To all appearances (6, 7), clearance norms depend also on the size of grain and on the products of wear. They should be larger for coarse powders than for fine. Furthermore, the amount of tolerance should probably be increased for large values of pv.

The following tolerances have been recommended: porous bronze -- 16 μ + 0.08 percent d; porous iron -- 20 μ + 0.1 d; and porous iron-copper -- 35 μ + 0.17 percent d, where d is the diameter of the shaft. Geydebrok recommends a tolerance of not less than 0.2-0.25 percent of the diameter of the shaft for porous iron. In our opinion, the norms recommended by Geydebrok are best stuited for the more heavily loaded bearings.

With insignificantly small pv (up to 6 kilograms per square centimeter-meter per second) it is not necessary to build in within the bodies of bearings slots and supplementary oil reservoirs. Lubricants included in the pores of a bearing are sufficient for several months of operation. With heavier loads it is necessary to have regular feeding of lubrication. Oil reservoirs may be built in the body of the actual bearing as shown in Figure 161.

Figure 161. Left -- Ordinary Porous Bearing; Right -- With Lubricant Reservoirs.

Figure 162 shows model designs of friction joints with lubricant reservoirs. The lubricant is supplied through the outer wall of the bearing and passes through pores to the inner wall (capillary lubricant feeding). For values of pv above 25 kilograms per square centimeter-meter per second there should be used the regular methods of supplying supplementary lubrication. There is also attained for such cases economy of lubrication, although it is less effective. In capillary lubrication economy is quite considerable (Several tens of times).

Figure 162. Different Types of Capillary Lubrication for Porous Bearings.

A and B -- with upper oil reservoirs; C -- feeding by means of an oiled wick; D, E and F -- ring reservoirs.

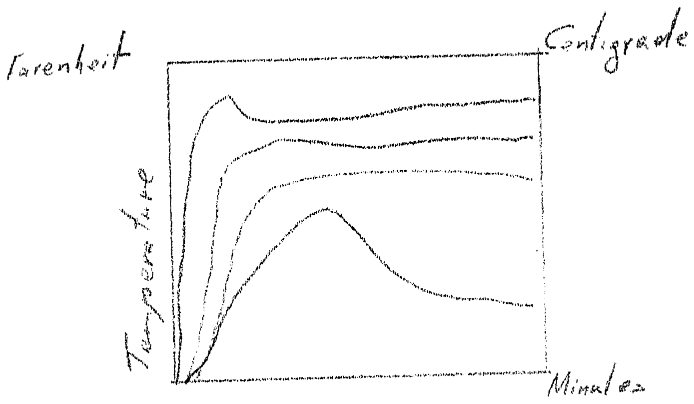

Figure 163. Testing Curves for Porous Bronze Impregnated with Different Lubricants

1 - oil with 1650 viscosity at 38 degrees Centigrade, according to Seybolt; 2 - 660 viscosity; 3 - 102 viscosity; 4 - 53 viscosity (191).

Figure 163 shows the results of tests on bronze with 27 porosity and pv of about 18 kilograms per square centimeter-meter per second, saturated with oils of different viscosity, without a supplementary supply of lubricant. Viscosity gave the same effects as for ordinary materials, i.e., the coefficient of friction and temperature decreased with lowered viscosity. However, it should be kept in mind that with lower oil viscosity there is a decrease in the maximum size of permissible loads (in Figure 163 the bearing with the least viscous lubricant, No 4, went out of commission after 220 minutes).

Tests carried out by TsNIITMASh showed that with small and medium values for pv it is preferable to use somewhat less viscous lubricants than for the ordinary cast materials.

According to data existing in literature, oils used abroad include SAE 20 (viscosity at 98.9 degrees according to Engle being 1.8, at 54.4 degrees 4.7 and at 37.8 degrees 7.5) and SAE 30 (viscosity at 98.9 degrees according to Engle being 2.0, at 54.4 degrees 7.5, at 37.8 degrees 15.8).

Application of Porous Bearings in Industry

Porous bearings with an iron base may be used with adequate lubrication in all joints whose values of pv do not exceed 70-100 kilograms per square centimeter-meter per second, in the absence of acute shock loads. With inadequate lubrication pv values drop to 20-25 kilograms per square centimeter-meter per second. The use of porous bearings should be avoided under conditions where there is direct contact with water. Porous bearings give good performance under conditions of both increased and decreased temperature.

For example, bearings are used in the conveyer of a bread-baking cradle [lyuliko-podikovaya] oven with a load of 50 kilograms per square centimeter and a speed of 0.01 meters per second at a temperature of 250-300 degrees and in a steam atmosphere. No bearing made from cast antifriction material could work under such conditions. Bearings made from porous iron-graphite perform satisfactorily in such ovens and have a life length exceeding six months (6). Bearings of textolite and bronze for roller conveyers of a large-sheet mill would not work because of the high temperature and scales. Bearings of porous iron gave satisfactory service exceeding 7 months on the same roller conveyers.

It is especially desirable to use porous bearings in the following instances:

(1) Where it is difficult to provide regular lubrication;

(2) Where a lubricant must not get into a product (textile and food industries);

(3) Presence of dust in surrounding atmosphere;

(4) Frequent starting and stopping:

(5) Considerable loads at low speed (directing bushings, bearings for shafts with reversible rotation, etc);

(6) Mass production of bearings with specific dimensions.

Below is given a condensed listing of the application of porous antifriction details in different branches of industry.

Automobiles: sleeve pieces, spring lining, brake shoes, transmission shaft, cam shaft, ventilator fan, water pump, throttle, steering gear, pedals, coupling, universal joint, electrical equipment, shock absorbers, bumpers, windshield wipers.

Tractors: ventilator fan, water pump, oil pump, dynamo drive gear.

Aircraft: control bearings of auxiliary instruments, etc. Up to 4000 details are used in present-day four-motor bombers.

Machine building: auxiliary bearings for lathes, shavers, cutters, drillers, woodworking lathes, and presses.

Agricultural machine building: bearings for straw cutters, binders, mowers, straw presses, etc.

Lift-transport machine building: in cranes, hoists, conveyers, lifts, etc. The operational life of porous iron bearings was eight times longer than for ball bearings in conveyers of the coal industry.

Textile industry: in weaving looms -- bearings for crank and blade shafts, cylinder stands for ringspinning frames, spindle footstep bearings, feed cylinders, printing machines, wringer, ribbon machines, etc.

Electrical industry: generators and electric motors (0.05-15 kilowatts), fans, etc.

Transport machine building: yard locomotives, pit locomotives, cars for carrying slag, inserts for steel supports of cars with tilting platforms, etc.

Metallurgy: bearings for roller conveyers of rolling mills, large-sheet mills, blooming mills, bearing inserts for rollers of steel-casting cranes, cars, etc.

Other branches of industry: food industry, gas engine pumps, motion picture apparatus, precision machine building, consumers' goods instruments (vacuum cleaners, washing machines), etc.

Use of Porous Details as Elements in the Construction of Bearings

Recently porous metalloceramic separators (Figure 2) have come to be widely used for ball and roller bearings. The use of these separators, which are impregnated with a lubricant, has made it possible to produce enclosed sealed-type, free-play bearings containing a lubricant supply intended to last for their entire length of service. Such bearings are widely used in aircraft, automobiles, etc.

These separators are prepared from porous bronze and iron. Very favorable results are being attained with porous iron with 12-20 percent porosity, 30-50 Brinell hardness, resistance to fracture up to 20 kilograms per square millimeter, and an elongation of 2.5-4.5 percent.

The dn output (d being the diameter of a shaft in millimeters, n the number of revolutions per minute) for ball and roller bearings with porous separators can reach 300,000-700,000 millimeters revolutions per minute.

The advantages of porous separators become particularly noticeable with frequent starting and stopping. The ball bearings with ordinary separators in the pressure mechanism of the clutch of a passenger automobile were not able to exceed more than 178,000 clutching operations. Ball bearings with porous separators stood up for 2.5 million operations -- 14 times more.

At the present time there is a tendency to replace free-rolling bearings with sliding bearings in a series of points. There are being used for this purpose short bushings with a 0.3-0.5 ratio of length to diameter and with smooth inner walls without lubricating slots (151). It is recommended that lubrication be applied to such bearings (151) by removing the outer porous-iron ring (Figure 164).

The porous material in such a case operates as a sort of wick or filter. We list one more example: The surface of a complex form for a special design was not accessible to lubrication. As a result, porous rivets weighting 0.05 grams were used that had been impregnated with oil.

Figure 165. Use of Porous Iron for Introducing a Lubricant to Slide Bearings.

1 - bushing; 2 - porous iron.

B. COMPACT ANTIFRICTION MATERIALS

The most important of compact metalloceramic antifriction alloys consists of a steel band with copper-nickel and babbitt layers (170-194), the so-called "triple-layer" material. Figure 165 shows the structure of such material. There is pressed onto the surface of the steel band a powder mixture of copper and nickel (about 60 percent Cu, 100-200 mesh size, and 40 percent Ni, 80-100 mesh size).

The nickel in subsequent sintering increases the adhesion of copper particles to the steel base. The thickness of the metalloceramic layer is about 0.5 millimeters. After sintering the pores of the metalloceramic sublayer are impregnated in a vacuum with melted lead babbitt, the surplus of which forms the third surface antifriction layer with a thickness after machine finishing not exceeding 75 (for certain uses even 20 μ).

Figure 165. Triple-layer Material.

1 - steel layer; 2 - copper-nickel layer, impregnated with lead babbitt; 3 - lead babbitt layer (194). [Photo]

The antimony and tin content of the impregnated alloy should be considerably smaller than for ordinary lead babbittt (in order to decrease the reaction of antimony and tin with the copper-nickel skeleton). According to published materials (170), the alloy for purposes of impregnation contains 93 percent Pb, 4 percent Sn, and 3 percent Sb.

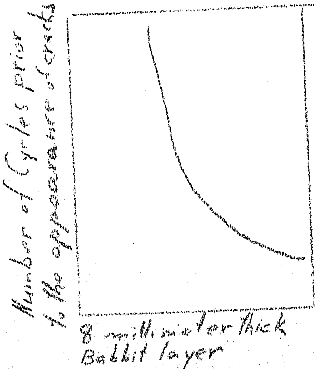

Figure 166. Relation of Resistance to Fatigue to the Layer of BMN Babbitt at a Computed Stress of $\sigma_{nep\chi H}$ = 5 Kilograms per Square Millimeter (Krushchov).

Such an alloy has considerable advantages over regular babbitts with a high tin content or a lead content. The principal defect which prevents babbitts from being used in crank or connecting rod bearings of modern engines is that they crumble as a result of the formation of fatigue cracks. Different measures for dealing with fatigue in babbitts are brought together in a book of Khrushchov's (125) entitled Fatigue in Babbitts. One of the principal measures consists in decreasing the thickness of the babbitt layer, which in turn increases its fatigue resistance (Figure 166). However, a number of considerations go against any considerable decrease in the thickness of the babbitt layer below 500 μ when using the usual way of lining the steel or cast-iron base (125). Babbitt does not adhere with sufficient strength to the smooth surface of the steel base. Shafts often bend with high loads and speeds. A certain thickness is required for the babbitt layer so that it can adjust itself to deformations caused by the sagging of the shaft without laying bare the steel base of the lining. Finally, when the thin layer of babbitt wears out it lays bare the steel base and the bearing thus goes out of order.

Such defects are eliminated in triple-layer bearings due to the presence of the metalloceramic sublayer. In their case the adhesion of babbitt to the metalloceramic skeleton is considerably greater than for a comparable steel surface with ordinary lining. Surface unevennesses of a copper-nickel skeleton hinder the spreading of fatigue cracks. The metalloceramic sublayer (lead bronze) is in itself a material with exceptionally high antifriction properties.

For this reason it is possible to greatly decrease the thickness of the babbitt layer (up to 20-75 μ), inasmuch as the baring of the metalloceramic layer through wear or as a consequence of bending of the shaft is not connected with harmful after-effects. This factor makes it possible to considerably decrease the thickness of the babbitt layer and at the same time considerably increases its fatigue resistance.

This triple-layer material has been in production since 1940 and is used for crank and connecting rod bearings of automobiles and aircraft engines and diesels. Its fitness was put to a severe tests during the war. It has been shown that this material can work with loads that are 15-20 percent higher than for the best babbitts of high tin and lead content. The rated load for this material is about 140 kilograms per square centimeter under normal conditions. To give precise limiting values for pv is very difficult for this material. It has performed excellently in many joints at pv values exceeding 2600 kilograms per square centimeter per meter per second. Triple-layer material has not given satisfactory results in some joints with pv below 1000 kilograms per square centimeter-meter per second.

Several research works have been devoted to metalloceramic lead bronze (167). It is quite probable that powder metallurgy will be able to decrease the difficulties of its fabrication as compared with cast lead bronze. Certain data has already been given above relating to the properties of special bronze having 12 percent porosity, with 2.4 percent Ni, 0.8 percent Si, 0.3 percent P, the rest being copper. With a specific gravity of 8.4 grams per cubic centimeter, it has a 75-80 Rockwell B hardness, a resistance to rupture of about 40 kilograms per square millimeter, and gave the same results in antifriction tests as the bronzes with 12 percent porosity (page 202).

At the present time there are being produced guide bushings for valves of internal combustion engines made of brass with a large quantity of graphite. These give better than 500 hours of performance at 430 degrees without lubrication. Guide bushings of cast materials could not operate under the same conditions in excess of 50-75 hours.

Compact bearings of steel shavings (194) are being used in the automobile industry in place of antifriction iron. They are less expensive and superior in quality (show less wear). The technology of producing these materials has been described on page 169. The properties of compact alloys on an iron base as produced by this method (194) are given in Table 35.

Most interesting is the wide industrial use of metalloceramic alloys with a tungsten carbide base as an antifriction material (172) for bearings operating under very aggravated conditions. Thus, in machines used for grinding hard alloys with diamond disks working at a speed of 10,000 revolutions per minute ordinary ball bearings last about a week (172). Bearings from hard alloys coupled to the shaft with a hard alloy nozzle (Figure 167) operate for more than a year with a wear of 1.0

Figure 167. Bearings Made from Hard Alloys [Photo].

See following page for Table 35.

Table 35. MECHANICAL PROPERTIES OF COMPACT ALLOYS WITH AN IRON BASE (194)

Original Material	Specific Gravity in Grams per Cubic Centimeter	Resistance to Rupture in Kilograms per Square Millimeter	Yield Point in Kilograms per Square Millimeter	Elongation in Percent	Reduction in Neck Area in Percent	Rockwell B Hardness
Roughly granulated Steel Shavings	7.79	38	26	11	13	59-74
Fine Iron Powder from Carburized Steel Shavings	7.78	39	26	14	13	61-68
The Same, with 0.25-0.35 Percent Graphite	7.81	52	36	23	32	74-85
Iron Powder from Reduced Scales (Okalina)	7.39	78	23	3	3	67-82
The Same, with 0.25-0.35 Percent Graphite	7.40	39	31	4	5	66-74

A careful polishing of the surface of such bearings with diamond paste or alloys is necessary. Kerosine with colloidal graphite is used as a lubricant.

Copper-tungsten alloys (page 259) are used on a limited scale in bearings through which electrical current is conducted.

C. ANTIFRICTION MATERIALS CONTAINING NON-METALLIC COMPONENTS

There is no doubt that the combination of plastics with metal powders in antifriction materials presents a certain interest (7). Such a union makes it possible to combine heat conductivity and accommodation of metals with resistance to binding on the parts of plastics. Two possible ways exist for producing such materials: impregnation of the sintered metal skeleton with plastic and using metal powders or shavings as a filler for the plastic. The future should demonstrate the possibility of their industrial application.

In finishing (194) porous materials with an iron base by means of steam at 500-600 degrees, iron oxide forms on the surface of particles according to the reaction

$$3Fe + 4H_2O = Fe_3O_4 + 4H_2$$

Steam treatment considerably increases resistance to corrosion, hardness (up to 100 Rockwell B hardness), resistance to deformation and rupture, and the yield point. Resistance to rupture and compression decreases somewhat during steam treatment.

Porous iron treated with steam is used as an antifriction material in those cases where there is required great hardness and an increased resistance to deformation, corrosion, and wear for work in high temperatures, in a moist atmosphere, in sharp variations of temperature, etc. (for conveyer rollers of furnaces, rollers for refrigerators, etc).

Chapter XI

FRICTION MATERIALS

The steady progress of technology in the field of aviation, auto-tractor industry, tank building, etc., is connected with the speed and cargo-carrying ability of machines and for this reason makes continually heavier demands on braking materials. It may be mentioned by way of illustration that when testing metalloceramic friction materials for use in airplanes braking must reduce a rotation of 20,000 revolutions per minute to zero in less than 0.1 second. Friction disks sometimes heat up to 550 degrees and more, while specific pressure reaches 70 kilograms per square centimeter. For this reason purely metallic materials (such as iron) and non-metallic materials are not suitable for severe conditions of work. High-quality friction materials must be necessarily composed both of metals with high heat-conductivity and accommodation and of non-metals which would increase resistance to seizing during friction (graphite, silicic acid). Such materials, sometimes including up to 30 volumetric percent of non-metallic components, may be obtained only by the methods of metalloceramics. The inclusion of non-metallic components necessarily lowers the strength of the material. Metalloceramic friction materials for this reason are used in the form of a layer or lining on a steel supporting layer (disks, bands, shoes, etc.). The combination of a metalloceramic layer with a steel support is usually done during the fabrication of the material -- during sintering under pressure (Chapter VII, page 164 of original text). For better adhesion to the layer of metalloceramic bronze the steel supports (disks) are subjected to a preliminary electrolytic copper plating. Sometimes there is also used a mechanical joining (riveting) of metalloceramic facing to the steel support.

Figure 168 shows the design of "bimetallic" friction details for brakes and clutches.

A rather large number of articles have been published on the fabrication and application of metalloceramic friction materials, including the works of Rybal'chenko (107), Rostarchuk (105), Krasnokutskiy (63), Gardin (32), and others (191). These articles, however, hardly mentioned the quantitative characteristics of the properties of metalloceramic friction materials. This factor is due on the one hand, to the use of such materials in bimetallic form (a metalloceramic layer on a steel support), and, on the other hand, to their military value.

Figure 168

Brake and Clutch Bimetallic Friction Details.

The following demands are made of high-quality metalloceramic friction materials:

Sufficient magnitude of the coefficient of friction and its constancy during temperature variations;

Low wear and very long length of service;

Smooth braking without jerking;

Adequate strength to withstand centrifugal, shearing, and other forces in braking;

preliminary electrolytic copper plating. Sometimes there is also used a mechanical joining (riveting) of metalloceramic facing to the steel support.

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Adequate strength to withstand centrifugal, shearing, and other forces in braking;

(In Rybal'chenko's article (107) it is pointed out that resistance to rupture of the metalloceramic layer when isolated from its steel support is about 3.5 kilograms per cubic [sic] millimeters.)

Temperature and corrosion resistance;

High heat conductivity;

Good accomodation;

High resistance to "seizing".

Present-day high-quality friction metalloceramic materials include 60-75 percent Cu, 5-10 percent Sn, 6-15 percent Fe, 0-7 percent Zn. One composition of this kind contains 73 percent Cu, 14 percent Pb, 7 percent Sn, and 6 percent graphite.

The basic component of a composition for assuring adequate heat conductivity is copper (60-75 percent). Tin (5-10 percent) is an alloying component which increases the strength of copper alloys and provides for the formation of a liquid phase during baking. Sometimes it is possible to partially replace tin with zinc. Lead (6-15 percent) increases accommodation, resistance to wear and seizing and contributes to smooth braking without jerks. When there is considerable heat developed during braking, the lead melts and serves as a kind of metallic lubricant (191). Graphite (5-8 percent) hinders adhesion, seizing and wearing of friction surfaces and increases smoothness of braking. Silicic acid, which sometimes is included to the extent of several percent, just as graphite, lowers adhesion and seizing of friction surfaces, but in distinction to it, it is an abrasive component and thus increases rather than decreases the coefficient of friction. In this way SiO_2 neutralizes the decrease in the coefficient of friction caused by the presence of graphite. Iron (191) raises the coefficient of friction and decreases wear.

The thickness of the metalloceramic layer on disks used in aircraft usually varies between 0.25 to 2 millimeters and in automobiles, tractors, tanks, etc., between 2 and 10 millimeters.

The thickness of the supporting steel disk with a metalloceramic layer on one side only of up to 5 millimeters is 1.6 millimeters and for a metalloceramic layer of 5 to 10 millimeters it is 3.2 millimeters. Disks which have a metalloceramic layer on both sides have a thinner steel support, but one which is not less than 0.8 millimeters. In the case of large segmented disks (with a diameter up to 900 millimeters) the distance between individual sections should not be less than 3 millimeters.

Friction metalloceramic materials started being manufactured in 1932. The first branch of industry to use these materials was that of aviation. Metalloceramic friction materials are being used for driving and driven disks of clutches for aircraft engines, disks of superchargers, airplane braking disks. At the present time such friction disks are installed in all American airplanes. These metalloceramic friction materials have come to be used in the autotractor industry since 1940. At the present time these materials are being used for autobuses, trucks (from 1/4 to 10 tons), and occasionally in passenger machines. Metalloceramic braking materials have performed in automobiles faultlessly up to 160,000 kilometers. In the caterpillar tractor the length of service of main and side friction disks with a metalloceramic facing has increased 3 times in comparison with former materials. Metalloceramic materials are being used in tanks in the brakes of rotating towers, in clutches, braking cones, plates for automatic transmission boxes. The use of metalloceramic friction materials is also increasing in other branches of industry (in machines for excavation work, in industrial gas-engine locomotives, locomotives, lifting cranes, shapers, revolving lathes, friction presses, etc.). Metalloceramic materials in forging friction presses with a capacity of 1,000 tons have sometimes lasted several tens of times longer than former braking materials.

Metalloceramics can also be used in the fabrication of friction materials on an iron base for lighter conditions of work (instead of iron shoes, etc.). Their use in industry is connected with a greater decrease in the price of metal powders.

Chapter XII

HARD ALLOYS AND DIAMOND-METALIC COMPOSITIONS

A. HARD ALLOYS

The production of metalloceramic hard alloys, begun about 20 years ago, is at the present time one of the most important branches of powder metallurgy. One may state without any exaggeration that the introduction of metalloceramic hard alloys has caused a genuine revolution in metal working. It is sufficient to point out that thanks to these alloys it was possible during the Fatherland War to finish by machining artillery shells ten times faster than in 1914-1918. Up to 1941 alloy steels were milled at a speed of 18 meters per minute. The transition during the war to cutting with plates made of metalloceramic titanium-tungsten hard alloys made it possible to "supermill" alloy steels at a speed of 110-300 meters per minute, i. e., 6-16 times faster than formerly (3, 28, 97).

Metalloceramic hard alloys made it possible to machine iron with a Brinell hardness of 200 at a cutting speed in excess of 100 meters per minute, medium-hard steel at a speed of 500 meters per minute, and light alloys in excess of 2,500 meters per minute (28).

The use of hard alloys is very effective in working metals by pressure, in drilling rock, and in the munitions industry as cores for armor-piercing shells.

Composition and Properties of Metalloceramic Hard Alloys

The following varieties of metalloceramic hard alloys are in existence.

(1) Alloys containing 80-97 percent tungsten carbide WC and 3-20 percent of cobalt (tungsten-cobalt alloys "VK" are better than "RE", etc.).

(2) Alloys containing about 97 percent tungsten carbide and 3 percent nickel.

(3) Alloys having a base of complex tungsten carbides WC and titanium carbides TiC with 5-13 percent Co, 5-60 percent TiC, the rest being WC (superior to "Moskva", "TVK", etc.).

(4) Alloys with 97-92 percent tantalum carbide TaC and 8-13 percent Ramet nickel are at the present time already obsolete.

(5) Alloys with a base of complex carbides of tungsten, titanium, tantalum, niobium and vandium with cobalt, in which the principal component is tungsten carbide (German alloy H2 containing 91.5 percent WC, 1 percent TaC, 0.5 percent VC and NbC, and 7 percent Co; Kennametal KH containing 62.9 percent W, 9 percent Ta, 9.4 percent Ti, and 10.1 percent Co; Kennametal KM containing 55.5 percent W, 13.6 percent Ta, 10.2 percent Ti, and 10.7 percent Co; Kennametal KS containing 62.2 percent W, 14.3 percent Ta, 4 percent Ti, and 10.8 percent Co; etc.).

(6) Alloys with a base of complex carbides of molybdenum and tantalum with nickel (Sergonite, containing 39 percent Mo, 37 percent Ti, 1 percent Cr, 15 percent Ni, and 8 percent C; Titanite, Containing 34 percent Mo, 38 percent Ti, 1 percent Cr, 13.4 percent Ni, and 13.6 percent C).

(7) Alloys with a base of complex carbides of vanadium and titanium with nickel or cobalt as developed in the USSR (101).

During the war there were used in Germany as substitutes for hard alloys having for their tungsten carbide and carbides of tungsten and titanium (Alloy V 814, containing 45 percent TiC, 45 percent VC, and 3 percent Co).

(8) Alloys having a base of complex carbides of chromium Cr_3C_2, and titanium TiC with nickel.

(9) There was used during the war in Germany as a substitute a metalloceramic alloy having for its base aluminum carbide. This alloy, however, did not give satisfactory results. Besides the components indicated, hard alloys sometimes contain rather a considerable quantity of admixtures. Among them may be included iron (0.2-1.5 percent) and chromium (0.0-0.14 percent) which find their way into the powder mixture as a result of the wear of balls and lining of ball mills.

When baking in furnaces with carbon tubes (Tammann's furnaces), admixtures of sulphur find their way into hard alloys. Titanium alloys have considerable admixtures of nitrogen (Alloy F2 with 60 percent TiC contains 1.4 percent of H_2 [N_2 ?]).

Refractory carbides (WC, TiC, TaC, etc.) in metalloceramic hard alloys create high cutting properties, hardness, resistance to wear, and an ability to function at high temperatures. Cobalt and nickel are cementing metals which melt during baking (Chapter V). The presence of a cementing metal makes it possible to obtain a dense, non-porous alloy; it increases adhesion and the mechanical strength of a material and lowers the baking temperature. Cobalt as a cementing metal gives better results for alloys whose basic component is tungsten carbide. Nickel is to be preferred for alloys whose basic high content of other carbides (Ramet, Sergonite, Titanite, V 814). Nickel is used in place of cobalt because it is less deficient in alloys with a tungsten carbide base used for armor-piercing cores (Chapter XVII). Various other cementing metals and alloys have been proposed (iron, ferrochrome, additions to cobalt, copper, tungsten, molybdenum), but they have not received industrial application.

Tungsten-cobalt alloys are baked at a temperature of about 1,400 degrees. The baking temperature decreases with an increase in the content of a cementing metal (about 1,380 degrees with 15 percent Co and 1,420 with 6 percent Co). Exposure to baking varies from 15 minutes for small products to 1 ½ hours for large ones.

The baking temperature for titanium, tungsten alloys is higher. It grows with an increase in the content of titanium carbide (from 1,500 degrees for Alloy S3 with 5 percent TiC and 7 percent Co up to 1,700 degrees for Alloy F2 with 60 percent Tic and 5.5 percent Co). Exposure also increases with the amount of titanium carbide and goes up to 3 ½ hours for large products containing 25-60 percent TiC.

Titanium-vanadium hard alloys are baked, according to Rakovskiy (101), at relatively low temperatures (1,200-1,250 degrees).

Hot pressing gives better results than cold pressing for substitute alloys having for their base vanadium and titanium carbides, chromium and titanium carbides, or aluminum carbide.

Figure 169

Structure of the Hard Alloy with 87 Percent WC 13 Percent Co (161).

[Photo]

Figure 170

Structure of a Hard Alloy Containing 86 Percent WC, 5 Percent TiC, and 9 Percent Co (167). [Photo]

Figure 169 shows the typical structure of tungsten-cobalt alloys and Figure 170 titanium-tungsten hard alloys.

The properties of certain native hard alloys as presented by Rakovskiy (101) are given in Table 36, German, according to Kieffer and Hotop (167), and Comstock (142) in Table 37, and American, according to Engle and Schwarzkopf (194), in Table 38.

Titanium-vanadium alloys having aratio of TiC:VC = 50:50 or 30:70 have, according to Rakovskiy (101), a specific gravity of 5.5-5.7, a resistance to bending of 60-75 kilograms per square millimeter, and a Rockwell "A" hardness of 89.5-90.

Alloys having for their base carbides of molybdenum and titanium possess less strength than alloys having for their base complex carbides of tungsten and titanium, and for this reason they are no longer used.

The properties of metalloceramic hard alloys are remarkable in many respect. They are inferior in hardness only to diamonds, boron carbide, carborundum and corundum. But they are not as brittle as these materials. The size of their modulus of elasticity exceeds that of all known metals and alloys and for this reason they show the smallest degree of deformation under a load. Resistance to compression is very high for hard alloys, resistance to rupture and bending adequate, while plasticity and impact toughness are most insignificant.

Table 36

PROPERTIES OF CERTAIN NATIVE HARD ALLOYS, ACCORDING TO RAKOVSKIY (101)

Trademark of Alloy	Composition in Percent				Specific Gravity in Grams per Cubic Centimeter	R_A Hardness	Resistance to Bending in Kilograms per Square Millimeter	Heat Conductivity in Relation to Heat Conductivity of Fast-Cutting Steel
	WC	TiC	Co	Ni				
VK3	97	--	3	--	14.9	89.5	105	1.0 - 1.2
VK6	94	--	6	--	14.5	87.5	140	1.2 - 1.4
VK8	92	--	8	--	14.3	87	150	1.4 - 1.5
VN6	94	--	-	6	14.7	89	125	1.2 - 1.3
T10VK10	80	10	10	--	10.9 - 11	89	125 - 120	-
T15 VK7	78	15	7	--	11.2 - 11.3	88	125	0.3 - 0.4
T21VK7	72	21	7	--	10.5	89	110	0.2 - 0.25

Table 37

PROPERTIES OF GERMAN HARD ALLOYS (142, 167)

Trademark of Alloy	Composition in Percent				Specific Gravity in Grams per Cubic Centimeter	Hardness		Resistance to Bending in Kilograms per Square Millimeter	Elasticity Modulus in Kilograms per Square Millimeter	Heat Conductivity in Calories per Centimeter per second Degrees Centigrade	Mean Coefficient of Expansion 20-800 Degrees	Specific Electrical Resistance Ohms. Square Millimeter/meter	Specific Thermal Capacity
	WC	TiC	Co	Others		Vickers	Rockwell "A"						
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
--	100	-	-	-	15.60	-	91-94	30-45	72,200	-	-	-	-
G2	89	-	11	-	14.2	1400	88.5	185	58,000	0.16	5.5• 10-6	0.18	0.05
G3	85	-	15	-	13.7	-	87	205	-	-	-	-	-
--	80	-	20	-	12.54	-	83-84	-	42,700	-	-	0.30	-
H1	94	-	6	-	14.7	1600	91	150	64,000	0.19	5•10-6	0.21	0.05

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
H2	91.5	-	7	1% TaC									
					VC								
				0.5%	NbC								
					14.4	-	91.5	120	-	-	-	0.25	-
S3	88	5	7	-	13.3	-	90	150	59,000	0.15	5.5·10-6	0.26	-
S2	78	14	8	-	11.25	-	90.5	140	-	0.08	6.2·10-6	0.44	-
S1	78	16	6	-	11.15	1600	91	115	54,000	0.09	6·10-6	0.43	0.06
F1	69	25	6	-	9.9	-	91.5	110	52,000	0.05	-	0.65	-
F2	34.5	60	5.5	-	6.8	-	92.5	80	-	-	-	0.77	-

Note: Alloy H1 differs from G1 by less time of baking.

Table 38

PROPERTIES OF AMERICAN HARD ALLOYS (194)

Composition of Alloy	Specific Gravity in Grams	Rockwell "A" Hardness	Resistance in Kilograms Per Square Millimeter		Impact in Kilogram Centimeters per Square Centimeter	Young's Modulus in Kilograms per Square Millimeter	Heat Conductivity in Calories / Square Centimeter Second	Coefficient of Linear Expansion 20-700 Degrees	Specific Resistance Ohms Square Millimeter / Meters
			To Bending	To Compression					
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
95.5% WC 4.5% Co	15.05	92.3	140	625	-	63,500	-	-	-
91% WC 9% Co	14.56	88.5-91	-	480	-	-	-	-	0.233
89% WC 1% Co	14.0	-	185	380	-	57,500	-	$5.5 \cdot 10^{-6}$	0.18

Table 38

PROPERTIES OF AMERICAN HARD ALLOYS (194)

Composition of Alloy	Specific Gravity in Grams	Rockwell "A" Hardness	Resistance in Kilograms Per Square Millimeter To Bending	Resistance in Kilograms Per Square Millimeter To Compression	Impact in Kilogram Centimeters per Square Centimeter	Young's Modulus in Kilograms per Square Millimeter	Heat Conductivity in Calories / Square Centimeter Second	Coefficient of Linear Expansion 20-700 Degrees	Specific Resistance Ohms Square Millimeter / Meters
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
95.5% WC 4.5% Co	15.05	92.3	140	625	-	63,500	-	-	-
91% WC 9% Co	14.56	88.5-91	-	480	-	-	-	-	0.233
89% WC 1% Co	14.0	-	185	380	-	57,500	-	$5.5 \cdot 10^{-6}$	0.18

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
87% CW 13% Co	14.1-14.15	87-89.5	210	380-440	9	56,000	0.652	$5.9 \cdot 10^{-6}$	0.196
80% WC 20% Co	12.54	85-87	250	385	15	-	-	-	-
Alloy of WC with a Small Quantity of TiC and 8-13 Percent Co	12.80	90-92.5	175	505	5.1	-	-	-	-
Alloy of WC with a Large Quantity of TiC and 7 Percent Co	9.0	92-93	105	510	-	-	-	$7.0 \cdot 10^{-6}$	-
Kennemetal KH With 62.9 Percent W, 9 Percent Ta, 4 Percent Ti, 10.1 Percent Co	-	91	140-200	485	-	-	0.075	-	-

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
Kennametal KM with 55.5 Percent W, 13-6 Percent Ta, 10.2 Percent Ti; 10.7 Percent Co	-	90.3	195-245	-	-	41,000	0.11	-	-
Kennametal KS with 62.2 Percent W, 14.3 Percent Ta 4 Percent Ti, 10.8 Percent Co	-	89.9	220-260	-	-	-	0.12	-	-

Metalloceramic hard alloys have an exceptionally high resistance to heat. As compared with fast-cutting steels, their hardness and strength decreases relatively insignificantly upon being heated to redness. Figure 171 shows that an alloy containing 95 percent WC and 5 percent Co has a greater hardness at 700 degrees than a fast-cutting steel at room temperature (148). Resistance to bending of an alloy containing 87 percent WC and 13 percent Co changes upon being heated in the following manner (167): at 20 degrees -- 174 kilograms per square millimeter, at 800 degrees -- 137, at 850 degrees -- 127, at 900 degrees -- 105 kilograms per square millimeter. With respect to resistance to oxidation at high temperatures hard alloys surpass the best heat-resistant steels.

With respect to wear, hard alloys surpass by many times all other known metals and alloys. In tests involving a jet of steel sand, wear for metalloceramic hard alloys was 58 times less than for fast-cutting steel and 110 less than for carbon steel.

These properties of hard alloys make them exceptionally adaptible for machine and pressure finishing of metals and other materials.

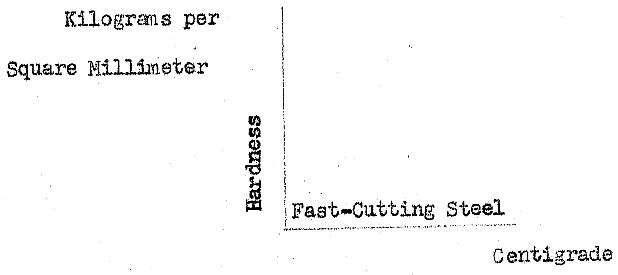

Figure 171. Relation of Vickers Hardness of Hard Alloys to Testing Temperature (148).

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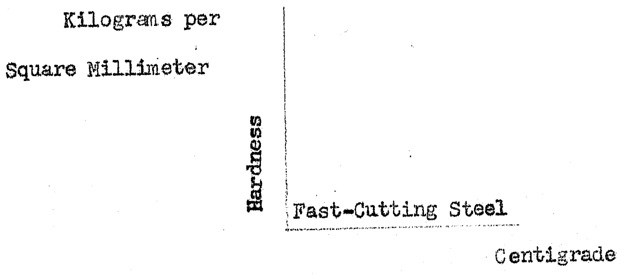

Figure 171. Relation of Vickers Hardness of Hard Alloys to Testing Temperature (148).

With an increase in the quantity of cementing metal there is a drop in ordinary and red hardness and an increase in the adhesion and weldability of hard alloys to the cutting metal. For this reason there is a drop in permissible cutting speed as shown in Figure 172 with an increase in cobalt content. The diagrams of Figure 172 show on a logarithmic scale the relation

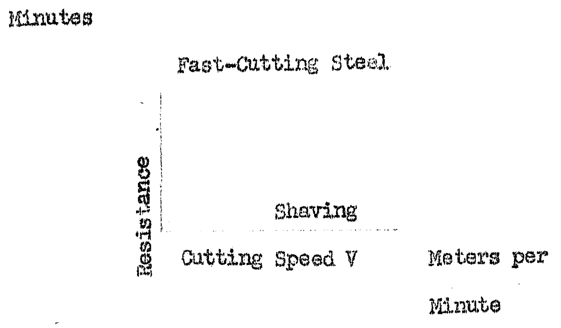

Figure 172. Influence of Cobalt Content on Cutting Diagram (179).

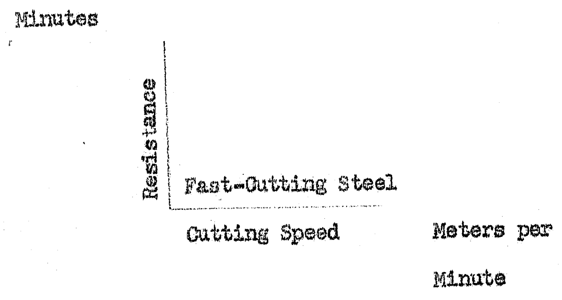

Figure 173. Influence of Titanium Content on Cutting Diagram (179).

of durability (time it takes to dull cutter) to cutting speed when machining steel with σ_b = 80 kilograms per square millimeter. With no change in cutting edge, the cutting speed during 1 hour is almost twice as great for an alloy containing 5 percent Co (120 meters per minute) than for an alloy containing 8 percent Co (58 meters per minute) and 7.7 times as great as for fast-cutting steel. On the other hand, the use of a cementing metal increases strength and toughness of hard alloys. It is for this reason that with an increase in cobalt content there is an increase of permissible speed in feeding and depth of cutting, as well as in the ability of the hard alloy to sustain interrupted cutting, etc.

Titanium carbide decreases mechaical strength and toughness of hard alloys having for their base tunsten carbide. On the other hand, it lowers the coefficient of friction and sticking of the cutter to the steel (Table 39). Moreover, an addition of titanium carbide increases resistance to heat and to oxidation. According to Rakovskiy (101), in the case of hard alloys WC - TiC - Co, the tendency to oxidize is 1.2-2 times less than for alloys WC - Co. Finally, a decrease in heat conductivity through adding TiC 2-4 times is also a beneficial factor in machining steel (The shaving becomes more heated, while the cutter less, which makes for easier machining). For this reason an increase in the content of Ti brings with it an increase of permissible cutting speed for steel. Figure 173 shows that with a 60 minute durability of the cutter, the cutting speed for carbon steel of σ_b = 90 kilograms per square millimeter for an alloy containing 25 percent TiC (200 meters per second) is more than 6 times that of an alloy of WC - CO and more than 10 times greater than for fast-cutting steel. However, permissible feeding and depth of cutting decrease with increases in the quanity of TiC (decrease in strength and toughness).

Table 39

TEMPERATURE OF ADHESION TO STEEL OF Co, WC, TiC AND THEIR ALLOYS (WITH STATIC CONTACT), ACCORDING TO DAWIHL (148)

Material	Steel $\sigma_b = 60$ Kilograms per Square Millimeter	Steel $\sigma_b = 140$ Kilograms per Square Millimeter
Co	500°	750°
WC	925°	1,000°
TiC	1,125°	1,175°
94% WC; 6% Co (Alloy G1)	650-675°	750°
78% WC, 16% TiC, 6% Co (Alloy S1)	700-875°	800-900°

Industrial Use of Metalloceramic Hard Alloys

About 70 percent of the entire output of metalloceramic hard alloys is used in machining of metals by cutting. About 10 percent is used in treating of metals by pressure, 10 percent for rock drilling, and the remaining 10 percent for measuring instruments and wear-resistant alloys.

At the present time about 50 percent of metal-working by cutting with a single cutting-edge instrument is done with metalloceramic hard alloys.

(a) Machine Finishing

The use of metalloceramic hard alloys for machine finishing metals and other materials (plastics, glass, cardboard, electrode carbon, ceramics, etc.) is connected with the following basic advantages.

(1) A considerable increase in the speed of cutting and in the productivity of labor. According to Meyerson and Pravdyuk (78), the speed of cutting medium-hard steel with a metalloceramic alloy containing 21 percent Tic and the quantity of shavings that are removed are 10 times greater than in cutting fast-cutting steel. Howwever, the increase in labor productivity due to a decrease in the magnitude of feeding and depth of cutting is usually about 10-50 percent.

(2) A higher accuracy in finishing and a better quality of surface. These advantages are connected, on the one hand, with a greater hardness for metalloceramic alloys both at room and high

temperature, and, on the other, finishing with sharp metalloceramic alloys at high speeds causes less damage to the metal and makes it possible to decrease the feed and depth of cutting, which, in turn, considerably increases accuracy of finishing. The so-called diamond boring and turning of non-ferrous metals, iron, and steel with hard alloys is done at cutting speeds of 130-450 meters per minute, a feed of 0.02-0.18 millimeters per revolution, and a cutting depth of 0.05-0.25 millimeters. Diamond finishing makes it possible to obtain details with a mirror surface with unevennesses to the order of 1-4 μ having tolerances up to the first class of accuracy and higher. According to Shakhray the precision of diamond finishing and the quality of surface is higher than in reaming, broaching, grinding, or honing.

(3) The possibility of machining materials with a very high hardness (up to 550 according to Brinell).

(4) In hard alloys the effectiveness of using tungsten (i. e., the amount of shavings removed with each kilogram of tungsten being used) is considerably greater than for fast-cutting steels. This is explained, on the one hand, by the exceptional wear resistance of hard alloys, and, on the other, by the more complete use of material (hard alloys are fabricated in the form of small plates welded onto the cutter, instrumental steel in the form of whole cutters). According to Rakovskiy (101), tungsten is used in hard alloys ten times more effectively than in fast-cutting steels.

Hard alloys are used for turning, milling, drilling, shaving, cutting screw threads, etc.

At the present time there are being fabricated hard-alloy files, hard-alloy tips for scissors used in cutting metal, etc., and lock-smith instruments.

According to Rakovskiy (101), tungsten-cobalt alloys containing 15 percent Co can be more effectively used in finishing iron, with 12 percent Co for rough finishing and rough grinding of iron, with 8 percent Co for rough grinding and semi-rough finishing of iron, for rough finishing and grinding and semi-rough finishing of iron and all possible kinds of finishing of carbons. For finishing steels, Rakovskiy recommends the following titanium-tungsten-cobalt alloys: with 10 percent TiC for rough finishing and grinding of carbon and alloy steels, with 15 percent TiC for semi-rough and clean finishing, and with 21 percent TiC for clean and final finishing.

Tungsten-cobalt alloys (142, 167) with 6 percent Co (G1) are used for finishing iron with 200 H_B, iron with a hard skin, glass, marble, hard cardboard, stones, etc.; with 11 percent Co (G2) for machine finishing of iron, non-ferrous metals, synthetic wood with increased depth of cutting and finishing; with 15 percent Co (G3) for a still greater depth of cutting and feeding in interrupted cutting and finishing of electrode carbons. An alloy with 6 percent Co and 1.5 percent TaC, VC, and NbC (H2) is used for casting with hardness exceeding 100 according to Shore as well as for final finishing of iron and non-ferrous metals. Machining of steels is done with alloys which contain titanium carbide. An alloy with 60 percent TiC (F2) is recommended for diamond drilling and turning, with 25 percent TiC (F1) for very precise drilling and turning with a very small cross section of shaving and high cutting speed. An alloy with 16 percent TiC (S1) is used for finishing steel at high cutting speeds and feeds up to 1 millimeter per revolution, an alloy with 14 percent TiC (S2) for finishing steel with a cutting depth 130 percent greater than for S1 with feeds up to 2 millimeters per revolution, for interrupted cutting and work on old machines. Cutting speeds for S2 alloys are about 30-40 percent lower than for S1. Alloys S3 with 5 percent TiC is used under even more severe conditions of work, in roughing and rough finishing of steel at feeds up to 3 millimeters per revolutions and at cutting speeds about 50-60 percent lower than for S1.

American alloys with tantalum and titanium carbides (Kennametal, Table 38) give rather high index in finishing steel.

Titanium-vanadium alloys with a ratio TiC: VC=50:50, according to Rakovskiy (101) and others (171), are good for final finishing and clean finishing of ferrous and non-ferrous metals with an insignificant cross section of shaving. With larger cross sections of shaving these alloys have a tendency to chip.

These alloys have been used in Germany (142) under the same conditions as Alloy S1, i. e., for machining steel at a feed of 1 millimeter per revolution. Alloys having for their base aluminum carbide are useful only for machining non-ferrous metals at an insignificant feed and cutting depth.

During the war effective methods were developed for milling and turning which are being very successfully used by us at the present time (28, 97). The method is based on the use of metalloceramic hard-alloy cutters with a negative face angle of about minus 10 percent. Negative face angles make it possible to avoid defects connected with the brittleness of metalloceramic hard alloys. The cutting speed for steel reaches 250 meters per minute and for non-ferrous metals it exceeds the speed of wood working. A very graphic example of effective utilization of hard alloys is given by Kaplan (53). The milling of steel gears with gear cutters with metalloceramic hard-alloy replaceable teeth made it possible to increase the milling speed from 23 hours with ordinary cutters to 2 hours per gear. At the same time the wear of the instrument increased so that instead of being in need of resharpening after 280 gears as with ordinary cutters it did not have to be resharpened ones until after 9,000-10,000 gears had been cut.

(b) Pressure Working

Metalloceramic hard alloys for pressure working metals have the following advantages over other materials used for instruments.

(1) Considerably less wear and longer period of service (10-1,000 times).

(2) Higher precision of dimensions and better quality of surface.

(3) The possibility of working materials which have a greater thickness (sheets more than 10 millimeters in thickness).

(4) The possibility of greater deformation in one operation.

(5) Faster working.

Because of the above, metalloceramic hard alloys are being widely used in pressure working of metals and other materials (plastics, cardboard, etc.) for wire drawplates, dies, punches, rollers, etc. In view of the high cost and brittleness of hard alloys they are used in the form of caps and inserts. Figure 174 shows a hard-alloy die firmly set in a bushing made of heat-resistant steel.

Figure 174

A Hard-Alloy Die. [Photo]

The tougher varieties of hard alloys are used in pressure working. Rakovskiy (101) recommends for stamping hard non-ferrous metals alloys of WC with 12 percent Co, for stamping soft non-ferrous metals Wc with 8 percent Co, for drawing non-ferrous metals WC with 6-8 percent Co. In Germany there was used for pressure working the alloy G2 (WC with 11 percent Co), and much less frequently an alloy with 5 percent TiC and 9 percent Co (167).

The following examples show the effectiveness of hard alloys in pressure working of metals.

According to Rakovskiy (101), when drawing through a steel drawplate it is possible to produce 80 kilograms of iron wire before it wears out and through a hard alloy one up to 50 tons (600 times more). The period of service of a drawplate made from metalloceramic hard alloys in comparison with fast-cutting steel in drawing beryllium bronze increased by 75 times. Punches from hard alloys used in stamping steel details gave 50-60 million stampings (183) before they had to be re-sharpened. This is 550-650 times more than by high-alloy steel. When stamping rings from steel used for transformers having a diameter of 100 millimeters and a thickness of 0.6 millimeter, the hard alloy punch performed more than half a billion operations before it had to be reground. The working speed was doubled as compared to previous punches.

A number of examples of the application of metalloceramic hard alloys for pressure working of metals is cited in numerous articles (183). Thus one factory used metalloceramic dies for deep drawing in 95 percent of the instances of pressure working. Punches are used with an inner diameter ranging up to 350 millimeters and weighing up to 50 kilograms. The use of metalloceramic punches by this plant made it possible to increase annual output by not less than 30 percent, to decrease waste by 50 percent, to decrease the number of operations (strokes) 15 percent on the average accompanied by an increase in the magnitude of deformation for one stroke, and to increase the stamping speed. The length of period of service for dies increased by not less than 20 times.

Metalloceramic punches for safety razors give more of metalloceramic hard alloys (length up to 1 meter and diameter up to 150 millimeters) for cold rolling of steel. Hard-alloy roller have a length of service which exceeds by 50-100 times those of steel. Their use makes it possible to produce products of higher quality -- with a more homogeneous thickness for the sheet and a better quality of surface.

There has recently been proposed the use of hard alloys with a porous surface which are impregnated with oil for pressure working of metals (177).

(c) Mining

Metalloceramic hard alloys are widely used in mining for perforation drilling with ~~by~~ shot-hole drilling and cutting machines. Recommended for this purposes are alloys of WC with 11-15 percent Co.

According to Rakovskiy (100), steel drills in perforation drilling penetrate about 1 meter per hour. Drills suppled with a hard alloy with 15 percent Co penetrate under the same conditions 2.5 meters. The cost of drilling with steel instruments is 210-218 rubles per 100 meters, with hard-alloy instruments 100-106 rubles. The expendability of steel teeth for a cutting machine (100) per 1 square meter of cutting is 10-12 and 40-120 times less for hard-alloy ones -- 0.10-0.25 units.

(d) Other Fields of Application

In view of their high wear-resistance, hardness, corrosion resistance, and large elasticity modulus, hard alloys with 94 percent WC and 6 percent Co are successfully used as tips of micrometers and calipers, Rockwell instrument bores, and other measuring instruments.

The high resistance to wear and corrosion and low deformation of these alloys make it possible to resolve the most varied technological problems. Alloys containing 94 percent WC and 6 percent Co are generally used for such purposes. Figure 175 shows hard-alloy centers and a driving bushing. Hard alloys are also used for roller bearings, for balls and lining of ball mills, for polishing disks in the watch industry (167), for nozzles of sand jets, for valves in the chemical industry, for slide bearings, etc. (146).

Figure 175

Hard-Alloy Centers and a Driving Bushing (167). [Photo]

Metalloceramic hard alloys are used (53) for tips of measuring instruments and for terminal Johanson disks (the length of service is 30-40 times that of steel plates). Hard-alloy sprays for paint spray guns perform 100 times longer than sprays made of stainless steel. Hard-alloy valves, nozzles, sprays and other details are being used with great success in petroleum oil pumps, apparatuses for dehydration of fruit juices, milk, preparation of blood plasma, for refrigerating machines, etc.

Metalloceramic hard alloys have achieved widespread distribuition in the fabrication of hand tools: files, tips, scissors for cutting metals and strips, details of manual vises, etc. Thus, pieces with hard-alloy tips for steel tempered springs made two million cuts in comparison with 20,000 with steel tips. The use of hard-alloy linings and punches in experimental apparatuses made it possible (25) to achieve a pressure of 100,000 kilograms per square centimeter.

The use of hard alloys under high temperatures is also increasing. Hard-alloy details cooled inside by water are used for tempering safety razors under pressure. Hard alloys are used by one American observatory which, for photographing the sun's spectrum, uses details which are exposed to the rays of the sun after undergoing a tenfold magnification through an optical system.

B. Diamond Metallic Compositions

Diamond metallic compositions are made from diamond borts and splinters and metal powders. Cold pressing and baking or hot pressing of the same mixture are used in their manufacture. There are usually used in the preparation of these compositions grains varying in size from 50 μ to 2.5 millimeters (weighing about 0.2 carat). (A carat equals 0.205 gram). There are cases where diamonds weighing more than 0.5 carat are used (167).

Diamonds usually comprise 5-20 percent of the total weight of a composition (167). The following compositions are used as a cementing metal material (167):

(1) Tough hard alloys containing 60-90 percent tungsten carbide and 10-40 percent cobalt or nickel.

(2) Heavy alloys of tungsten, copper, and nickel (Chapter XVIII).

(3) Alloys with copper or iron as a base.

(4) Hard alloys.

In the last instance diamonds used in the composition last longer. However, in some cases it is desirable to increase the rate of diamond wear. Then recourse is had to least resistant hard alloys W - Ni - Cu and even to alloys with iron or copper as a base.

Figure 176

Structure of a Diamond-Metallic Composition. X6 (167). [Photo]

Figure 176 shows the structure of a diamond-metallic composition with diamond grains about 0.1 millimeter in size (167). Sometimes diamonds (such as in diamond-metallic pencils) are not distributed throughout the entire product but as a chain.

Diamond-metallic compositions are used in the following fields.

(1) For trimming grinding rings. Diamond-metallic pencils are fabricated for this purpose from diamonds 0.03-0.5 carat in size (2, 167) with a binder from a hard or heavy alloy (Figure 177). The pencil is welded onto the steel stock with a brass solder. When used the pencil is set through the center of the grinding ring at an angle of 15-20 degrees from the horizontal in the direction of the rotation of the ring (358). Diamond-metallic rings are considerably cheaper than whole diamonds (1-3 carats), less brittle, and permit a more complete use of the diamond.

Figure 177

A Diamond-Metallic Pencil (167). [Photo]

(2) For grinding and working hard alloys, glass, and hard ceramics. There are used for this purpose grinding rings with diamonds varying from 50 μ to 2.5 millimeters mostly in a hard-alloy binder.

(3) For drilling rock. For this purpose there are used drilling crowns (Figure 178) equipped with diamond-metallic compositions. Diamond-metallic compositions used in rock drilling possess the following advantages over whole diamonds.

(a) A longer period of service for the crowns.

(b) A more complete utilization of the diamonds (not less than 75 percent).

(c) Higher drilling productivity.

Figure 178. Diamond-Metallic Crown (194). [Photo]

Chapter XIII

METALLOCERAMIC DETAILS

GENERAL INFORMATION

In its initial period of development, the metalloceramic industry produced only those materials that were in essence a monopoly of powder metallurgy. By way of example there may be cited hard alloys, refractory metals, copper-graphite brushes, porous materials, pressed cores of induction coils, etc. Later on, as technology improved and production decreased in cost, the methods of metalloceramics began to compete with the regular methods in the manufacture of a number of details from ferrous and non-ferrous metals.

In resolving the question of the competitiveness of powder metallurgy with respect to the usual methods of fabricating details, it is necessary to take into consideration the following factors.

(a) Scale of production. In the production of metalloceramic details with definite measurements and form, it is necessary that there be fabricated two press molds -- compressing and calibrating. Expenditures for press molds may be justified only in mass or large-series production. According to published data (193), such justification calls for an output of not less than 500 pieces of large or complex details ranging up to 50,000 pieces of small ones. According to other information, a minimum figure of 5,000 pieces is given for non-complex details and 50,000 for complex (187).

(b) Size of details. At the present time the methods of metalloceramics can fabricate details of most varying size from pins weighing 0.05 grams to bearings weighing 100 kilograms. The diameter of friction disks often exceeds 900 millimeters. At the present time plates are being produced which have dimensions of 3600 X 750 X 50 millimeters. However, in the majority of cases "economic" dimensions of details with which powder metallurgy may compete with the usual methods are considerably smaller. These economic dimensions have a wide fluctuation depending on the scale of output, complexity of design, material of detail, etc. Moreover, powder metallurgy can compete successfully in the fabrication of details which for the most part do not weigh more than 1 kilogram, are not longer than 75 millimeters, and do not have a cross-sectional area exceeding 50 square centimeters. It may be figured that the most satisfactory details for metalloceramic production have a cross-sectional area ranging up to 25 square centimeters.

(c) Precision of manufacture. The methods of powder metallurgy (pressing, baking, calibration) usually allow for fabricated details to have tolerances for the diameter within the second class of accuracy. For example, at the present time bearings are being manufactured with the following tolerances with respect to the inner and external diameter: for rated dimensions up to 40 millimeters plus 0 minus 25μ; from 40 to 65 millimeters plus zero minus 50μ; above 65 millimeters plus zero minus 50μ. Tolerances in industry with respect to inner and outer diameters for the fabrication of metalloceramic details are, according to data published by Arata (135), for rated dimensions up to 50 millimeters

± 13μ, from 50 to 125 millimeters ± 25μ. Tolerances are possible which are even more rigid, within the first class of accuracy, but they are accompanied by higher production cost.

Figure 179. Metalloceramic Detail (187) [PHOTO]

For example, Figure 179 shows a bronze detail in which the slot width and hole diameter are kept to an accuracy up to 8μ. Tolerances for height correspond usually to the fourth and sometimes to the fifth class of accuracy. It is possible to observe tolerance for height (length) for dimensions up to 40 millimeters ± 125μ, from 40 to 75 millimeters ± 190μ, and above 75 millimeters ± 250μ. The obtaining of tolerances with greater precision calls for additional expenditures. When fabricating products by using only pressing and baking (without calibration), it is possible to produce details with tolerances for the diameter of fourth class and for height (length) of 4th-5th class of accuracy. Usually allowances for eccentricity between outer and inner diameter are where the outer diameter ranges up to 40 millimeters 75μ, from 40 to 75 millimeters 100μ, and above 75 millimeters 125μ. More rigid tolerances of up to 25μ for a diameter up to 40 millimeters are possible only with additional expenditures. The quality of surface even for metalloceramic details which are not calibrated is generally higher than for ordinary machine-finished details (Figure 180).

Cast Gear

Metalloceramic Gear

Metalloceramic Gear after burnishing
1000 microinches (microdyumy)

Figure 180. Quality of Surface for Gears

(d) Designing considerations. In designing metalloceramic details it is recommended that there be avoided narrow protrusions, longer and narrow notches, sharp angles, and similar aspects of design which weaken the press mold, large and abrupt changes in the thickness of details, which cause the appearance of strains during baking, notches and protrusions in directions perpendicular to compression, and configurations which hinder even solidification and the removal of compacts from press molds (Figure 181). For details which have a length greater than 18-20 millimeters, the flange diameter should not exceed the outer diameter of the bushing by more than 1-1/2 times. In order to make it easier to remove details from press molds an angle of taper should be observed for the flange allowing 0.0004 millimeter for each millimeter of flange thickness (193). The length (height) of a bushing may sometimes exceed its diameter, sometimes by 13 times, and the thickness of the walls by 25 times (193).

Figure 181. Metalloceramic Detail Designs.
a - undesirable; b - permissible

However, it is desirable in the majority of cases to have a ratio of height to diameter not larger than 2-2-1/2 and height to wall thickness not more than 15-17. Langhammer (191) recommends a wall thickness of not less than 1.2 millimeters and preferably 1.6 millimeters. In certain cases the permissible thickness may be 0.8 millimeter, but it is usually connected with an increase in spoilage norms. In linking surfaces it is necessary to adhere to a radius of curvature (193) of not less than 0.25 millimeters. According to other data, the following radii of curvature are observed for bushings having a flange; with a diameter up to 12 millimeters 0.8 millimeter, from 12 to 25 millimeters 1.2 millimeter, from 25 to 50 millimeters 1.6 millimeters, from 50 to 65 millimeters 2.4 millimeters, and above 65 millimeters 3.2 millimeters. It is recommended that all external angles for very thin walls (thickness up to 2.4 millimeters) be rounded off, and for those with considerable thickness to be supplied with bevel edges having an angle of 45 degrees (of 0.4 millimeters for walls which have a thickness exceeding 2.4 millimeters and of 0.8 millimeters for very large parts). Bevel edges may be formed without recourse to machining through pressing and calibration. Machining should be used for obtaining holes of different diameters for height (length), notches perpendicular to the axis of compression, screw threads and other configurations which would hinder ejection in pressing. Various metalloceramic parts are shown in Figures 2, 179, 181, 182, 183, 184, 185, 186. Powder metallurgy methods are very suitable for manufacturing grooved parts, gears and parts with teeth, graduations on the surface, parts with a single flange, etc.

It is difficult to give general indications applying for all cases inasmuch as modifications are required for adaptation to metalloceramic manufacture. Figure 187 shows several examples of such changes in design (a - former design, b - new design of metalloceramic parts). Detail 1 was first fabricated and then subjected to machining along three of its sides. The metalloceramic design makes it completely possible to avoid machining; it does away with the angularity of the top surface caused by forging. The metalloceramic variation of Detail 2 replaces the radii of curvature bevel edges.

Figure 182. Metalloceramic Parts of an Aviation Control Instrument. [PHOTO]

Figure 183. Metalloceramic Parts for Measuring Instruments. [PHOTO]

Detail 3 is rather of a complex design. The metalloceramic variant requires a small subsequent machine finishing (drilling of a transverse hole and a screw thread for the longitudinal hole). The groove in Detail 4 with the flange is used for fixing it in place. The same end is achieved by a notch in the metalloceramic design. The metalloceramic variant of Detail 5 (magnetic pole piece) made it possible to decrease expenditure of material and improve operating properties. Detail 6 shows the former and the metalloceramic variant of a level mechanism. The former design of Detail 7 may be attained metalloceramically

Figure 184, 185, 186. Different metalloceramic Parts.

[PHOTO]

However, it would be better to replace the protruding cams by indentations in the metalloceramic design, transferring the cams to the design of the adjoining detail. An investigation of the conditions of operation of the link shown as Detail 8 showed that the rounded surfaces were necessary only for one side. This made possible a simplification in the design of the metalloceramic variant of the detail, with allowance for later drilling of the holes. At first glance the variants of Detail 9 seem to be of completely different design, yet both variants fulfill identical functions. Details 10, 11, 12, 13 show how much a design may be simplified when metalloceramic technology is applied.

Figure 187. Examples of Changes in Detail Design (187): 1-7. a - ordinary detail; b - metalloceramic detail.

Figure 187. 8-13. a - former detail; b - metalloceramic detail (187).

The metalloceramic variant of Detail 10 replaces three details by one. The detail eliminates the making of the connecting-piece slots and the connecting pieces. The metalloceramic variant of Detail 12 replaces three details by one. The former variant of Detail 13 provided for its attachment to an adjacent plastic detail by means of two screws. The metalloceramic variant makes it possible for it to be pressed directly into the plastic detail.

(e) Materials. At the present time various metalloceramic details are made for the most part from iron, steel (primarily carbon), tin bronze, special bronzes, brasses, iron-copper alloys. There are also used special steels for magnetic details and alloy steels to a small degree. Stainless steels and alloys with an aluminum base are in the development stage.

(f) Properties. It is possible to obtain completely dense details from metalloceramic materials with the same mechanical properties as corresponding cast alloys which have been pressure worked. However, at the present time it is economically more feasible to produce details from iron, steel, and copper alloys with a certain amount of porosity ranging from 5 to 20 percent. The mechanical properties of such details are usually 20-40 percent lower by comparison with details produced by pressure working of cast materials, but they are often no lower than for cast details from alloys of corresponding composition. Metalloceramic details from certain special alloys (such as the magnetic alloys alni and alnico, Chapter XVI) have considerably higher properties than cast. Porosity in ordinary details is in the majority of cases not connected with any considerable advantages. Nevertheless, the presence of a certain percentage of pores impregnated with oil is often useful, such as in sealing linings and gears, because it cuts down friction and wear, improves accommodation, and decreases noise during operation. The tensile strength of metalloceramic details with slight porosity decreases much less, than impact strength, elongation, and decrease in neck area. In addition to the properties of metalloceramic materials given in Tables 24, 26, 27, 28, 29, we present certain additional data for steel materials and copper alloys usually applying to details. According to Frey (152), German steel details with 0.7-0.9 C have a resistance to rupture of 45-65 kilograms per square millimeter and an impact toughness of 200-300 kilogram centimeters per square centimeter. Metalloceramic steel made from powders containing 0.4-0.8 percent C has a resistance to rupture of 55-85 kilograms per square millimeter. The impact toughness of metalloceramic brasses fluctuates in the bracket of 24-56 kilogram centimeters per square centimeter. The properties of metalloceramic details with a porosity in the order of 10 percent are given in Table 40 (187).

[See next page for Table 40]

Table 40

Properties Of Certain American Materials Used In Details

(With Approximately 10 Percent Porosity)

[1] Composition and State of Alloy	[2] Specific Gravity in Grams per Cubic Centimeter	[3] Resistance to Rupture in Kilograms per Square Millimeter	[4] Yield Point in Kilograms per Square Millimeter	[5] Elongation in Percent	[6] Brinell Hardness
Carbon Steel with 0.2-0.3 Percent C					
Annealed	7.0	27	20	8.0	60
Cold Hardened		31	-	2.5	80
Tempered		39	-	1	250
Copper-Graphite 95 Percent CU, 5 Percent C					
Annealed	8.0	25	13	17.0	54
Cold Hardened		26	21	4.5	71

[1]	[2]	[3]	[4]	[5]	[6]
Bronze, 90 Percent Cu, 10 Percent Sn					
Annealed	7.9	25	16	12.0	62
Cold Hardened		27	23	3.5	72
Bronze, 90 Percent Cu, 10 Percent Sn	8.0	28	-	20	60

Metalloceramic steel has a 60-65 Rockwell "O" hardness after heat treatment.

The properties of the majority of metalloceramic steels is in any case higher than for cast iron.

Details made from iron-copper alloys (steel skeleton impregnated with a copper alloy) can be welded without the use of flux (page 171).

Corrosion resistance of many metalloceramic materials, especially those with a copper base, is entirely satisfactory.

COMPARISON OF METALLOCERAMIC TECHNOLOGY WITH ORDINARY METHODS OF FABRICATING DETAILS

The advantages of metalloceramic methods for producing details as compared with the usual methods consist in economy of metal, high productivity, absence of expenditures connected with subsequent machine finishing, high dimensional precision, good quality of surface, high accommodation in a number of cases, wear resistance, and quiet operation of details. Losses of metal in metalloceramic technology for the fabrication of details are usually considerably less than 1 percent (shaking down of powder in mixing, weighing, and pressing). Losses of metal with the usual methods of fabricating details range in the majority of cases from 20 to 80 percent. Moreover, metalloceramic details because of their porosity are frequently 10-20 percent lighter than ordinary ones. Thus, in the fabrication of gears for an oil pump from cast iron billets (194) losses of metal through the removal of shavings constituted 64 percent. Metalloceramic gears had 25 percent porosity and were fabricated almost without any metal loss. Thus, in this case there was an economy of metal amounting to almost 80 percent. Moreover, the porous metalloceramic gears had a better quality of surface (Figure 180) and shape of teeth, deviated less from a true evolvent (evol'venta), had better accommodation, showed better wear, and were quiet in operation. In fabricating a valve disk for the gasoline fuel system of airplanes by means of metalloceramics it was possible to decrease expenditure of time by three times in the fabrication of the part, considerably decrease costs, and increase production output. Table 41 presents according to Chikhachev (130) a comparison of the degree of accuracy for different methods of obtaining details.

Thus, metalloceramic technology surpasses in the degree of accuracy all other methods for fabricating details (except machining). The methods of powder metallurgy are also more precise in the rapidly developing precision casting. Tolerances in precision casting of small parts may only be obtained in the neighborhood of ± 80 microns.

[See next page for Table 41]

The drawbacks of metalloceramic technology are to be found in the high cost of original powders, the necessity for large-series or mass production of details to justify expenditures on press molds, the specific limitations on form and size of details mentioned above, and lower mechanical properties in some cases. Problems of cost of

Table 41

A Comparison According To The Degree Of Accuracy Of The Production Of Details By Different Methods (According To Chikhachev)

Number According to Porosity	Method	Class of Accuracy	Number According to Porosity	Method	Class of Accuracy
1	Casting according to Metallic Models with Machine Molding	7	6	Stamping in Closed Dies	7
2	Chill Casting	4	7	Cold Stamping	6
3	Centrifugal Casting	4	8	Cold Forging	4
4	Die Casting	3	9	Coining with a Punching Machine	3
5	Free Forging	9	10	Metalloceramic Technology	2

metalloceramic details are considered in Chapter XIX. It should be pointed out that the competitive value of metalloceramic technology as compared with other methods of fabricating details has been decreasing to some extent with the spread of metalloceramic hard alloys which make machine finishing easier and lower its cost.

The comparative competitiveness of metalloceramic technology with other methods for fabricating details may be shown to be as follows. Ordinary methods of casting are relatively inadequate for obtaining precise details because of the necessity of designing heads for shrinkage blisters and for lowered mechanical properties of the material. In centrifugal casting and die casting it is possible to obtain less precise tolerances but a considerably greater variety in the shape of details than by the methods of powder metallurgy. Die casting is most economical in the production of details from zinc alloys, but its difficulties grow with an increase in the melting temperature. The production of steel details by die casting is very difficult in practice. Precision casting can produce details with small dimensional accuracy but with considerably more complex form than by means of metalloceramics. Precision casting is good for the obtaining of alloys of very varied composition and with high mechanical properties. The defects of precision casting which limit the possibility of its competing with porous metallurgy are to be found in the very high cost of details.

The weight of precision casts ranges from 1 gram to two kilograms, their size for the longer measurement up to 200 millimeters. Powder metallurgy can compete in a number of instances with machine finishing of shaped bars and pipes. The advantages of powder metallurgy lie in the possibility of obtaining internal holes with more complex contours and details with a dissimilar cross section as to height (details with a flange, conical products, etc.). At the present time it is relatively difficult for powder metallurgy to compete with stamping and coining. Although the cost of dies is relatively high, the cost of initial materials and work and loss of metal is low. The advantages of powder metallurgy over stamping lies in higher dimensional precision (Figure 179), the possibility of fabricating details with greater thickness of walls and frequently with considerably more variation in form. Hot forging of details by stamping machines gives higher mechanical properties but yields to powder metallurgy in permissible tolerances, productivity, and is connected with greater wear for the dies. Powder metallurgy in a number of cases makes it possible to obtain details, especially from non-ferrous metals (Chapter XIX), which are cheaper than those produced by other methods. This competitiveness increases with the complexity of details, decrease in their dimensions, and increase in the scale of output.

DETAILS PRODUCED BY THE METHODS OF POWDER METALLURGY

At the present time there are being produced a large number of metalloceramic details with precise measurements.

A very large quantity of metalloceramic details, about 100, are being used in present-day passenger automobiles and trucks. Aside from bearings, friction disks, and filters for automobiles, there are being produced cams, washers, lining door hinges, gears for the oil pump, etc. There have also been developed porous metalloceramic piston rings.

Considerable development has been achieved in the production of metalloceramic sealing rings and lining, porous and non-porous, rivets, etc.

Powder metallurgy is being applied with success to the production of details for measuring instruments (Figure 183) — clamps for micrometers, measuring blocks, plates and calibers, details for sliding calipers.

At the present time a number of magnetic details for electric motors, telephones, etc., which originally were being produced from cast materials are now being made by metalloceramics.

Metalloceramics details are being used to a considerable extent in the defense industry (Chapter XVII). In the production of armaments there are a large number of details which are not called upon to possess great durability but which must possess exceptional precision of form and dimensions. Taking into consideration the mass production of such details, powder metallurgy, because it is capable of achieving high tempos of production, becomes one of the most feasible methods for their manufacture.

Chapter XIV

DIFFERENT POROUS MATERIALS AND DETAILS

FILTERS

At the present time filters together with bearings (Chapter X) are one of the most important representatives of the class of porous metalloceramic materials.

Porous metalloceramic filters are fabricated primarily from powders made from corrosion resistant materials, usually bronze (92 percent Cu, 8 percent Sn), but also nickel, silver, brass, and sometimes iron, steel, etc. The original powders have spherical particles of more or less the same size, which makes for better permeability on the part of filters by filtering liquids and gases. Such powders are produced by shotting of melted metal and, less frequently, by decomposition of carbonyls (nickels). Filters are produced in the majority of cases by the baking of non-compressed powders poured in special forms. Certain characteristics of bronze filters (180) are presented in Table 42.

[See Table 42 on following page]

An increase in wall thickness above the dimensions given in the table is not recommended because it increases resistance to filtering. A decrease in thickness is permitted where it is not required that complete removal of the smallest particles be effected.

Bronze filters with 47.5 percent porosity have a resistance to rupture of 3.5 kilograms per square millimeters, and an elongation of 3 percent.

TABLE 42

CHARACTERISTICS OF FILTERS (180)

Brand	Size of Filtering Particles in Millimeters	Volumetric Percentage of Pores	Chemical Composition in Percent		Permissible Temperature in Degrees Centigrade		Resistance to Rupture in Kilograms per Square Milli- meter	Minimum Wall Thickness in Millimeters
			Cu	Sn	With Protection against Oxidation	Without Protection against Oxidation		
1	0.05 - 0.13	50	92	8	500	180	3 - 4	3
2	0.03 - 0.05	50	92	8	500	180	3 - 4	2.3
3	0.01 - 0.03	50	92	8	500	180	3 - 4	1.5
4	0.002 - 0.01	50	92	8	500	180	3 - 4	1.5

Figure 188 shows the relation between rate of filtering (penetrability) of a liquid (water) and pressure loss for Brand 2 filters having varying wall thickness. Figure 189 shows the relation in the case of air. Resistance to filtering increases with the wall thickness of a filter (approximately in proportion to the thickness) and decreases with the size and number of pores (penetrability increases when pores are homogeneous in size approximately in direct proportion to the square of their diameter).

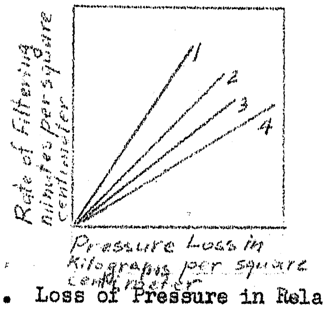

Figure 188. Loss of Pressure in Relation to Wall Thickness when Filtering Water (180).

1 - wall thickness 1.5 millimeters; 2 - 2.25 millimeters; 3 - 3 millimeters; 4 - 3.75 millimeters.

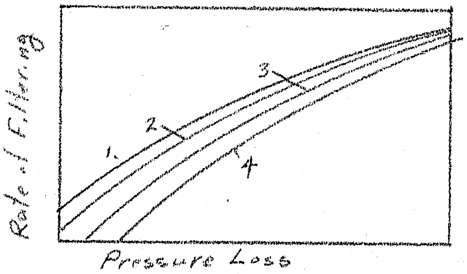

Figure 189. Drop in Pressure with the Passage of Air through Filters with Varying Wall Thickness.

1 - wall thickness 1.5 millimeters; 2 - 2.25 millimeters; 3 - 3 millimeters; 4 - 3.75 millimeters (180).

Porous filters are fabricated as cups, cylinders, bushings, cones, candles, disks, plates, etc. The size varies from disks 1½ millimeters in diameter and cups smaller than a thimble to hollow cylinders with a diameter of 300 millimeters and plates 450 by 1200 millimeters. Tolerances are usually about 1.5 percent of the dimensions of a filter. More rigid tolerances, should they be required, may be attained by calibration.

When installing porous filters, in view of the good deformation nature of porous metal, to use pressure fitting is expedient. In a number of cases filters are soldered on to a copper-plated steel plate (in such an instance overheating of the porous metal should be avoided). The attaching of a filter to a steel plate may also be done during baking. A screw thread may also be cut in the porous metal or it may be joined by means of lining or rings of solid metal. Machine finishing of filters (turning, drilling, threading) is permissible. However, it is not recommended that the surface of filters be machined. Removal of edges may be done with a sand wheel.

Figures 190 and 191 show ways of installing porous filters.

The cleaning of porous filters from sediments is done by blowing a jet of air or steam (in a direction opposite to that of filtering), washing with a liquid, burning out (of organic sediments), etc. However, in view of the cheapness of filters, it is often most feasible to simply replace them.

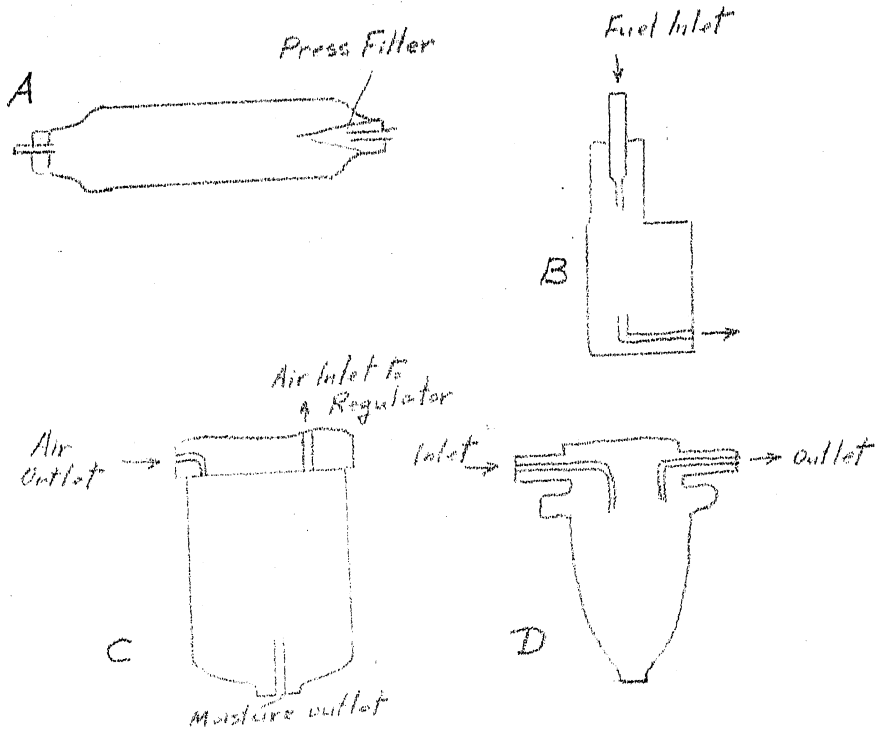

Figure 190. Installation of Porous Filters.

A - porous filters in a drying unit of a refrigerating installation: 1 - porous filters, 2 - silica gel; B - fuel filter for a diesel engine: 1 - porous filter, 2 - steel lining plated with copper (connected to the porous filter during manufacture); C - porous filter combining purification of air of moisture and dusting and regulating pressure in a device for spraying paint: 1 - porous filter, 2 - screen; D - filtering and centrifugal device for purifying liquids and gases: 1 - porous filter.

Metalloceramic filters hold back small hard particles better than tissue filters because of the winding and multi-layered disposition of pores and because of the rigidly fixed, unmovable disposition of metal particles. In distinction to cloth, paper, etc, filters, in metalloceramic filter the filtered liquid or gas is not contaminated with material from the filter. Metalloceramic filters have a greater durability than other filters and can operate under high temperatures (Table 43).

[See Table 43 in Chapter XV]

Metalloceramic filters are most feasible for use as a "precision" filter for removing very slight quantities of hard particles which contaminate a large quantity of liquids and gases. Metalloceramic filters simultaneously unite high penetrability for filtering liquids and gases with excellent retention of small hard particles.

Porous metalloceramic filters are used in filtering liquid fuel and lubricating materials for diesel and gasoline engines, - stationary, ship, automobile and aircraft (Figures 190B and 191B). Such filters make possible the efficient operation of such engines, a factor which is particularly important say in bomber aircraft. Present-day heavy bombers are supplied with such filters. Metalloceramic filters may be very small for precision filtering (in a number of cases no larger than a thimble -- 8 to 15 millimeters) (Figure 190B).

For filtering solutions with a higher content of sediment in the chemical industry, the size of filters is considerably larger.

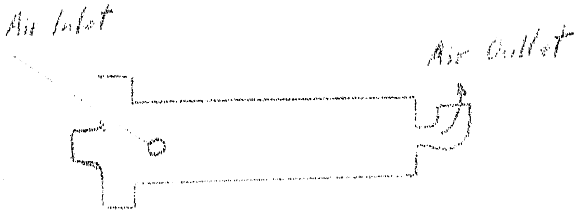

Figure 191. Installation of Porous Filters.

A - explosion-proof instrument for circulating air in explosion-proof motors: 1 - porous filter, 2 - steel bushing; B - filter for filtering liquid fuel for locomobile diesels. The installation makes is possible for filtering to take place with the diesel in operation thanks to the presence of two filters (1 and 2); C - filter for drying air: 1 - large-pore filter regulating the flow and pressure of air, 2 - small-pore filter purifying the air of silica gel, 3 - stainless-steel bushing, 4 - insert retaining the porous filter with bent edges, 5 - observation glass, 6 - silica gel.

Metalloceramic filters are also used for purifying air and gases (Figures 190C and 191C) of dust in appliances for condensing air, pneumatic hammers, etc.

Besides performing essentially filtering jobs, metalloceramic filters are also used for the following purposes.

(1) Separation of a mixture of liquid materials with different viscosity and soaking qualities, etc, through the use of filters with varying penetrability. Thus, metalloceramic filters are used for separating water from oil in emulsions, etc. It is also possible to effect similar separation of gases.

(2) Regulating the quantity of a flowing liquid or gas in measuring and distributing apparatuses, and also for softening shocks in releasing compressed gas.

(3) For stopping sparks, as in explosion-free motors. Figure 191A shows an instrument for circulating air used in explosion-free motors. The porous filter through which the air circulates serves in such a case as a barrier against the igniting action of sparks.

OTHER POROUS MATERIALS AND DETAILS

Porous metals possess a number of properties which make it possible to use them as sealing materials and in sealing details. In the hermetic sealing of stationary apparatuses (such as joints of watermains) it is important to have exceptionally good plasticity and softness in porous materials. Iron with a considerable percentage of pores is closer to lead than to compact iron in softness and deformation (Figure 192).

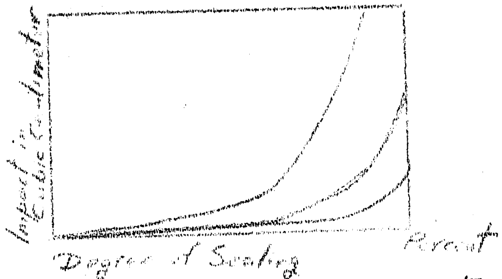

Figure 192. Sealing Ability of Porous Iron (Vogt).

The sealing ability of porous iron is shown in Figure 192. The external appearance of this material (strips composed of individual segments fastened together by iron wire passing through them) and the calking of pipe joints are shown in Figure 193.

Figure 193. External View of Iron Used in Calking (Above) and Calking of Steel Pipes (Below). [photo]

According to Vogt, the calking of porous iron is capable of withstanding a pressure of 50 atmospheres. Pipes, which have been thus calked, can withstand dislodgement when bent as when calked with lead, while resistance to vibration and corrosion for such iron is even greater.

It is important that details intended to serve as sealing agents but located between movable and stationary parts in mechanisms have good antifriction properties, slight wear, and accomodation of porous materials. Penetrability of metals with fine pores, impregnated with oil, is insignificant and does not interfere in a number of cases with their use for sealing details. Porous lining and rings are rather widely used as sealing details. Mention has been made of piston rings in Chapter XIII.

Jones describes an interesting device for preventing icing of airplanes. The edges of wings which are subject to dangerous icing are covered with a copper-nickel porous strip. A liquid circulates through the pores hindering icing (anti-freeze). Such a device increases the effectiveness of anti-freeze by five times. The entire weight of the installation, including the pump and supply of anti-freeze, is 0.6 percent of the weight of the airplane and of this 50 percent belongs to the anti-freeze.

As has already been pointed out in Chapter XIII, porosity with respect to many metalloceramic details, such as gears and other movable parts of mechanisms, is an important feature (decrease in wear and friction, increase in accomodation). Porous iron seals with 60 percent porosity have been proposed by Bal'shin, Borok, and Ol'khov (15). Prior to compression these seals have a Brinell hardness of 3.5 to 4, i.e., the same as lead ones. After compression in a "plombir", the hardness goes up to 60 as for ordinary lead. This factor interferes with the forging of seals as compared with those made from lead.

Moreover, there have been proposed many other interesting applications for porous materials. Among their number may be included circuit breakers, electrodes for accumulators and secondary elements, metalloceramic wicks and lighters, and lightning arresters.

Chapter XV

ELECTRICAL MATERIALS AND DETAILS

The manufacture of electric incandescent lamps with metal filaments was one of the reasons for the rebirth of metalloceramics at the beginning of the twentieth century. Since then the continued progress of electrotechnology is so closely connected with powder metallurgy that present-day electrotechnology is unthinkable without metalloceramic materials.

Aside from electric bulbs (see Figure 194), details from powder metals are essential to fluorescent and X-ray tubes, cathode lamps, rectifiers and amplifiers, electric motors and dynamos, electric-welding apparatuses, telegraph apparatuses, all manner of electrical instruments, radio location installations, etc. Without the use of metalloceramic materials it would not have been possible to reach the high level of present-day radio technology.

The important role of powder metallurgy in electrotechnology is due to the possibility of producing such materials which are difficult or even impossible to obtain by other methods. The methods of metalloceramic technology make it possible to produce refractory metals (tungsten, molybdenum, tantalum, niobium), very pure metals and alloys, compositions of metals that will not alloy with each other (tungsten-copper, tungsten-silver, etc), compositions of metals and non-metals (copper-graphite, silver-cadmium oxide, iron-plastics, etc).

THE APPLICATION OF POWDER METALLURGY TO THE ELECTRIC BULB INDUSTRY

Metalloceramic materials and details are exceptionally widely used in incandescent lamps and various electrovacuum lamps and tubes -- fluorescent lamps, X-ray tubes, cathode lamps, rectifiers and amplifiers, generator lamps, kenotrones, etc.

Incandescent lamp filaments are fabricated out of the most refractory metal - tungsten.

The high melting point (3400 degrees), low evaporation and significant durability at high temperatures (Table 31) make tungsten an irreplaceable material in electrovacuum technology (167). Tungsten is used in incandescent cathodes of X-ray tubes, radio tubes, generator tubes, rectifiers and amplifying tubes. Tungsten can withstand a temperature of 2000 to 2500 degrees, and for short periods up to 3000 degrees.

The cathodes of industrial lamps are frequently manufactured from tungsten to which thorium oxide has been added.

The addition of 1 to 2 percent ThO_2 increased by several times electronic emission.

Tungsten is also used for making anticathodes for X-ray tubes, regulating and screening grids for X-ray tubes and cathode lamps, ignition tips of high-voltage rectifiers for ignition by immersion or sparking.

Tantalum (Table 31) is used for details in the vacuum technique, operating at temperatures which do not require as high refractoriness as in the case of tungsten. Tantalum is used in the manufacture of anticathodes, anodes, and grids of X-ray tubes, radio tubes, rectifiers, generator tubes, etc. Tantalum is considerably lighter and more plastic than tungsten, thus making it easier to produce from it sheets, wire, form (fasonnyye) details.

Figure 194. Use of Molybdenum and Tungsten in Incandescent Bulbs and Radio Tubes. a - incandescent bulb; b - radio tube.

Molybdenum (Table 31) is used in the electric lamp industry principally as filaments, hooks and loops for retaining tungsten filaments in incandescent lamps (Figure 194) and for joining glass or quartz to metal in incandescent lamps, mercury rectifiers, quartz and mercury lamps, etc. Other metals besides molybdenum are also used for fusing in glass. Depending on the variety of glass and its coefficient of expansion these include tungsten for refractory glass of shortwave transmission radio tubes, an alloy with 54 percent Fe, 27 percent Ni, 18 percent Co, and iron-molybdenum alloys (5 to 20 percent Mo, 1 percent Cu, remainder Fe) (194).

There are also made from molybdenum grids of transmitting radio tubes, spiral grids for tubes of radio receivers, anodes, springs for supporting cathodes in resonator tubes, anode screens and cups in X-ray tubes.

In the vacuum technique there is also used a certain amount of especially pure iron, nickel, and their alloys, obtained from carbonyl powders (167). Metalloceramic iron and nickel contain considerably less gas than cast, which fact is very important for the vacuum technique.

In order to absorb the small quantity of gases which are given by metal details during the operation of vacuum apparatus, powder metals -- so-called "getters" -- are employed. Tantalum and zirconium are used for this purpose because they have an exceptional affinity for all gases - oxygen, hydrogen, nitrogen, CO, CO_2, etc.

Surfaces coated with zirconium have a dark-grey color and radiate heat much better than non-coated metals. For this reason zirconium coating makes it possible to decrease the dimensions of anodes used in the vacuum technique and in some cases even replace the anode material. For anodes of certain power tubes zirconium-coated molybdenum has come to be used instead of tantalum and zirconium-coated nickel instead of molybdenum. Zirconium coating increases diffusion by 30 percent.

Niobium has been used so far in the electric lamp industry experimentally. Niobium is more ductile than tantalum and rather close to it in other properties (Table 31). For this reason the application of tantalum and niobium in this field should overlap rather closely.

Windows of X-ray tubes made from metalloceramic beryllium surpass windows from cast in closeness of grain and mechanical properties (166).

METALLOCERAMIC MATERIALS IN ELECTRICAL RESISTANCE FURNACES

At the present time refractory metals, especially molybdenum, are widely used as heating elements in high-temperature (up to 1700 degrees) electrical resistance furnaces (167). The increasing use of molybdenum in this field is due to its strong durability at high temperatures (Figure 205), good electrical conductivity, and exceptionally high specific loads per unit of conductor surface. For nichrome, permissible loads range up to 5 watts per square centimeter, for semiconductors (Silit) 23 watts per square centimeter, and for molybdenum more than 80 watts per square centimeter. In connection with the character of temperature relation to the electrical resistance of molybdenum, casual fluctuations of tension in the grid cause smaller variations in temperature, than, for example, nickel.

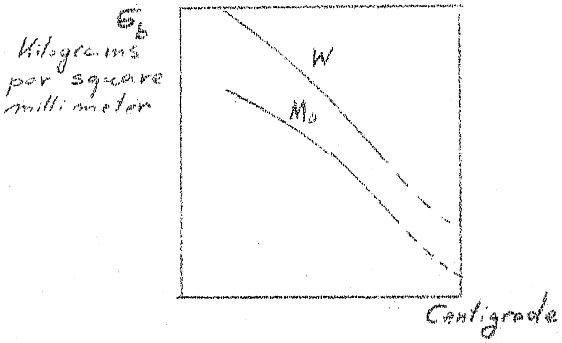

Figure 195. Strength of Tungsten and Molybdenum in Relation to Temperature (167).

The use of molybdenum for heating elements in resistance furnaces is connected with the following features (167).

(1) Because of the fact that molybdenum is highly oxidiaing at high temperatures, the operation of heating elements must take

place in a protective atmosphere (hydrogen, dissociated ammonia gas, generator gas, partially burned illuminating gas, etc).

(2) For the same reason it is desirable to use molybdenum not as wire or ribbon but as heating elements with a large transverse cross section. In this connection there are molybdenum furnaces of a new design which operate at low tension.

(3) Wherever possible, direct contact between molybdenum and the ceramic lining of furnaces should be avoided (alundum, sillimanite, etc). It is therefore recommended that molybdenum elements should either be suspended or have as few a number of contact points as possible.

(4) It is necessary to provide cooling (by water or air) and a hermetic dense-gas (gazoplotnoye) connection of the terminals conducting the current to the furnace.

Tungsten, having a somewhat lower electrical conductivity than molybdenum, is used in heating elements in refractory furnaces with very high temperatures up to 3000 degrees (167).

COPPER-GRAPHITE BRUSHES

Copper-graphite brushes for dynamos and electric motors possess both good contact and antifriction properties. Graphite prevents the adhering and welding of metallic particles to the rotor through sliding contact, decreases the coefficient of friction and wear, and prevents the copper from oxidizing. The copper contributes high strength, electrical conductivity, permissible current density, and a low value for transitional voltage. Copper-graphite brushes contain from 8 to 75 percent graphite and correspondingly 92 to 25 percent copper.

An increase in graphite content lowers electrical conductivity of brushes, increases contact (transitional) drop in current, decreases permissible current density, and increases antifriction properties.

Table 43 shows the composition and properties of Soviet copper-graphite brushes (4).

The composition and characteristics of certain German brushes (167) are to be found in Tables 44 and 45.

[See Tables 44 and 45 on following pages]

In the US brushes are made from copper and graphite and frequently include additions of tin, zinc, and lead (191). Recently they started to produce these in some quantity silver-graphite brushes, distinguished by their higher properties. The specific electrical resistance of American copper-graphite brushes varies from 0.1 ohm square centimeters per meter for a slight content to 13 ohms square centimeters per meter for a considerable graphite content. Resistance to rupture is 1.8 to 17.6 kilograms per square millimeter, hardness according to Shore 5-35, coefficient of friction 0.04-0.13, transitional drop in voltage 0.25-1.50 volts. Pure carbon and graphite brushes allow loads of 5.5-7.5 amperes per square centimeter. Permissible current density for metalloceramic brushes with large copper content is 19 to 23 amperes per square centimeter. However, short overloading up to 70 to 80 amperes per square centimeter are possible.

TABLE 43

CHARACTERISTICS OF SOVIET COPPER-GRAPHITE AND GRAPHITE-COPPER BRUSHES

Characteristic of Brush	Trademark					
	MG	MG-1	MG-2	MG-3	M-1	M-2
Graphite Content in Percent	Slight	10-15	15-20	20-25	About 50	About 75
Brinell Hardness	6-12	5-7	4-6	3-5	—	—
Shore Hardness	—	—	—	—	30-42	28-38
Specific Electrical Resistance in Ohms Square Millimeters per Meter	0.05-0.1	0.1-0.25	0.2-0.4	0.3-0.45	4-10	6-16
Transitional Drop in Voltage	Low	Low	Low	Low	Medium	Medium
Permissible Current Density in Amperes per Square Centimeter	25-30	22-25	22-25	20-22	14	12
Coefficient of Friction	Medium	Low	Low	Low	—	—
Permissible Linear Speed in Meters per Second	20	20	25	25	15	20
Normal Pressure in Grams per Square Centimeter	120-150	120-150	120-150	120-150	160-200	160-200

TABLE 44

COMPOSITION OF GERMAN BRUSHES IN PERCENT (167)

Cu	C	Sn	Pb
85	5	--	10
80	10	--	10
80	10	10	--
70	20	--	10
70	30	--	--
68	12	8	12
30	70	--	--

TABLE 44

COMPOSITION OF GERMAN BRUSHES IN PERCENT (167)

Cu	C	Sn	Pb
85	5	--	10
80	10	--	10
80	10	10	--
70	20	--	10
70	30	--	--
68	12	8	12
30	70	--	--

TABLE 45

CHARACTERISTICS OF GERMAN BRUSHES (67)

Characteristic	Bronze with Slight Graphite Content	With Large Graphite Content	With Very Large Graphite Content
Specific Gravity	5.0	3.5	2.5
Brinnell Hardness	38	32	15
Shore Hardness	10	20	15
Coefficient of Linear Expansion in Longitudinal Direction	12	4	2.9
The Same, Transverse	13	5	5.9
Specific Electrical Resistance in Ohms Square Millimeters per Meter	0.1	0.5	8
Resistance to Rupture in Kilograms per Square Millimeter	3.0	3.5	1.0

TABLE 46

CRITICAL VALUES FOR ARCING CURRENT BETWEEN CONTACTS, IN AMPERES (194)

Material	Voltage			
	25 Volts	50 Volts	110 Volts	220 Volts
Graphite	--	5	0.7	0.1
Copper	--	1.3	0.9	0.5
Molybdenum	18	3	2	1.0
Nickel	--	1.2	1	0.7
Lead	7.5	3	0.85	0.7
Silver	1.7	1	0.6	0.25
Tungsten	12.5	4	1.8	1.4

TABLE 47

WEIGHT LOSSES OF CONTACTS IN SPARKING (194)

Material	Characteristic Sparking Current	Weight Loss in Milligrams per Coulomb
Carbon	18	0.0013
Aluminum	14	0.014
Nickel	14	0.02
Copper	12.3	0.045
Molybdenum	17	0.01
Silver	11.5	0.17
Tungsten	10	0.07
Platinum	16	0.13

CONTACT MATERIALS

Very high demands are made of present-day contact. They must have a considerable hardness and strength and slight deformation at high temperatures, an insignificant tendency for fusing and adhering, low vapor pressure, high resistance to oxidation and electrical erosion, and a combination of good heat conductivity, electrical conductivity, and low transitional resistance. It is very difficult to find all these properties in pure metals. Similarly the usual alloys are little suited for this purpose because there is a decrease in electrical conductivity with the formation of solid solutions and intermetallic combinations.

Metalloceramic compositions, being mechanical mixtures of metals certain metals of which provide, for example, hardness, lack of fusion, or resistance to erosion, and, on the other hand, electrical conductivity and heat conductivity most suitable for contact materials.

At the present time the following metalloceramic contact materials are in use.

(a) Pure tungsten contact. Tungsten remains very hard and strong at high temperatures and has only a slight tendency to sparking and a high resistance to electrical erosion. Table 46 gives the critical values for the strength of current for establishing an electric arc causing contact erosion for different metals. It can be seen from Table 46 that critical values are greater for tungsten than for other materials. Table 47 shows that erosion of tungsten is not very great. At the same time resistance to oxidation at high temperatures is small. Similarly, heat and electrical conductivity are slight in comparison with copper. In accordance with the properties thus given, pure tungsten is suitable for contacts used in very rapid switching with a very considerable density of current, such as in breaking contacts of ignition instruments and alternating-current rectifiers.

(b) Compositions with a tungsten base. Tungsten provides hardness, strength, and resistance to erosion. Silver (10 to 40 percent) or copper (10 to 40 percent) serves as the component for providing electrical and heat conductivity. Such contacts have a specific gravity of 14 to 17, a hardness of 110 to 250 , a specific electrical conductivity 30 to 50 percent of the electrical conductivity of pure copper. Combining electrical conductivity with strength, non-welding and resistance to erosion, they, depending upon the composition, may be used either as main contacts, working at high current densities, or as protective contacts which are meant to protect the main contact from erosion when turning the current on or off. These contacts are being very successfully used in high-voltage switches -- oil (primarily W-Cu) and aerial (preferably W-Ag) and also in low-voltage ones. The following example shows under what severe conditions such contacts can operate. In one aerial high-voltage switch the silver-tungsten contacts are obliged to operate with continuous switching on and off of the current at a current density of 15,000 amperes per square centimeter and a voltage of 600 volts. The period of service of W-Ag and W-Cu contacts is considerably greater than for pure silver or copper under similar conditions (Figure 196). Such contacts can operate briefly at temperatures above the melting point of copper or silver because the capillary forces prevent the extension of the melted copper and lower the pressure of its vapor.

A certain amount of use is made of copper-nickel-tungsten contacts (80 to 95 percent W, 2 to 10 percent Cu, and 2 to 10 percent Ni), which have a lower degree of electrical conductivity than copper-tungsten (about 20 to 25 percent that of the electrical conductivity of copper) but a greater hardness (250 to 300 according to Brinell).

(c) Compositions with a molybdenum base to which additions of silver (10 to 40 percent) or copper (10 to 40 percent) have been added are similar to compositions with a tungsten base, but they are less widespread.

(d) Contacts with a tungsten carbide base. They are especially resistant to the action of erosion during arcing. Besides tungsten carbide they contain as a cementing metal 1.5 to 10 percent cobalt, osmium, or some other noble metal (platinum, rhodium, iridium).

The use of tungsten carbide contacts in telegraph relays made it possible to increase transmission speed from 140 to 700 letters per minute.

(e) Contacts with a silver base -- silver-graphite (4 to 30 percent C), silver-cadmium oxide (2.5 to 10 percent CdO), silver-nickel (10 to 60 percent Ni) (191). These contacts are employed in lighter conditions of work with respect to voltage and frequency of switching than compositions with a tungsten base, as in aircraft relays with direct current. The use of silver-oxide contacts is most interesting. Cadmium oxides break down at high temperatures and volatilize, as a result of which such contacts possess arc-extinguishing properties. The electrical conductivity of silver-oxide contacts is 69 to 95 percent that of pure copper (191).

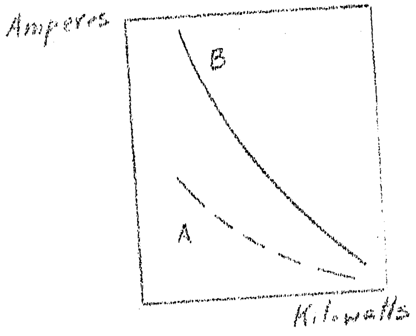

Figure 196. Length of Service of Contacts. A - copper; B - compositions with 60 percent W and 40 percent Cu (140).

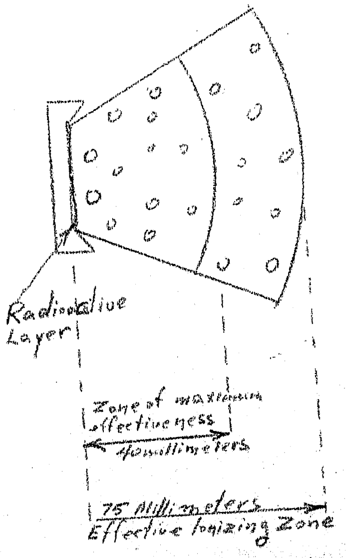

Figure 197. Electrostatic Eliminator.

OTHER ELECTRICAL MATERIALS

The use of metalloceramic materials for arc and contact electric welding is described in Chapter XVIII.

Electrodes for spark plugs are made from tungsten.

Recently there has appeared a description of an instrument for eliminating charges of electrostatic electricity -- the so-called electrostatic eliminator. In manufacturing the eliminator (Figure 197) powders are used which include radioactive compounds and gold. A thin sheet of up to 2.5 millimeters of a compressed and baked material is welded on to a non-radioactive layer of silver. The apparatus is mounted in a case which provides screening. The use of gold powder makes it possible to obtain a durable radioactive layer without interfering with the radium emanations. The concentration of radium in this layer may be up to 240 micrograms per square centimeter; the α radiation comprises 60 to 75 percent of the theoretical. There is an ionization current of 1.4 microamperes per 1 milligram of radium. The eliminator ionizes the air and makes it possible to eliminate electrostatic electricity for a distance up to 75 millimeters from the radioactive surface. It is used for removing electrostatic charges from rapid-operation telegraph apparatuses.

Chapter XVI

MAGNETIC MATERIALS

The methods of powder metallurgy are used in the manufacture of the following magnetic materials.

(1) Magneto-dielectrics -- pressed ferromagnetic powders insulated by dielectrics (plastics).

(2) Production of very pure magnetic materials from carbonyl iron and nickel powders.

(3) Production of finished details from soft and hard magnetic materials.

MAGNETO-DIELECTRICS

In the early stages of the development of radio technology, when long waves were used, induction coils used to be fabricated with a core consisting of a bundle of fine insulated iron wire. The later progress of radio technology was connected with an increase in radio frequency. An increase in radio frequency caused an increase in Foucault current losses. This made it necessary for the core wires of induction coils of short-wave sets to have a diameter of several microns, but this was impossible in view of the current development of radio technology. Because of this there were used for a time coils without any cores.

The use of coils made from insulated dielectrics of pressed ferromagnetic materials sharply decreased the clearances of induction coils (Figure 198). Metalloceramic coils made it possible to design compact radios for tanks, airplanes, etc. The use of cores in airplane direction-location antennas made it possible to decrease

Figure 198. Comparison of the Dimensions of Several Induction Coils. Left - without a core, right-with powder cores. [photo]

the dimensions of a set from 230 to 65 millimeters (145). Moreover, sets that have metalloceramic cores are more sensitive and have much sharper tuning. Compressed cores are being widely used in high-frequency technology for tuning coils, filters, input and output transformers, etc.

Pressed cores are also used in Pupin coils which are employed for compensating capacitance of telephone cable.

For low frequency there are used primarily iron powders reduced with hydrogen (size of particles, 1 to 40 microns), electrolytic iron, and Permalloy (78.5 percent Ni and 2 percent Mo). The effective permeatility of Permalloy cores is 125 gauss per oersted and of iron reduced with hydrogen only 50 (145). For frequencies of 300 to 40,000 kilocycles the best results are obtained with carbonyl iron powders. At the low end the powder particles should have a size of 4 to 10 microns, in the middle 2 to 7 microns, and at the higher end 1 to 5 microns.

We use for pressing cores Alsifer alloy powders with 7.5 percent Al, 10 percent Si, 82.5 percent Fe (38). Magneto-dielectrics for tonal frequencies are made from Alsifer T - 60 with particles about the size of 50 microns and having an effective magnetic permeability of 60 and a coefficient of Foucault-current loss $400 \cdot 10^{-1}$. The properties of Alsifer cores for radiofrequency R_f-9 with particles having a diameter of 15 to 20 microns are given, according to Saymovskiy (35), in Table 48.

In the majority of cases there are used as insulating dielectrics plastics (bakelite, aminoplast, polystirol), less frequently cardboard (ferrokart [88]) or ceramic compositions. Iron powders with phenol plastics are pressed at room temperature with a force of 5 to 12 tons per square centimeter and then heated to 100 to 150 degrees for polymerization and hardening of theplastic. In the case of other plastics pressing is often done at a temperature of 120 to 150 degrees.

TABLE 48

PROPERTIES OF ALSIFER R_f-9, ACCORDING TO SAYMOVSKIY (38)

Property	Value
Specific Gravity in Grams per Cubic Centimeter	4.6-4.8
Shore Hardness	50-55
Specific Electrical Resistance in Meters Ohms Centimeter	$12\text{-}15^{10}$
Dielectric Constant	12-15
Coercive Force H_c in Gauss/Oersteds	8- 9
Residual Induction B_r in Gauss	75
Induction when H = 400 Oersteds B_{400} Gauss	3600
Initial Permeability μ_a in Gauss/Oersteds	9±0.05
Ratio of Maximum to Initial Permeability μ_{max}/μ_a	1.03
Coefficient of Foucault Current Loss δ_f	$4\text{-}5.10^{-9}$
Aging $\frac{\mu_t - \mu_a}{\mu_a}$, where μ_a is the Initial Permeability and μ_t the Permeability after One Year's Operation	$5 \cdot 10^{-3}$

PURE MAGNETIC METALLOCERAMIC MATERIALS

Iron baked from carbonyl powders possesses an exceptionally high purity. Carbonyl iron after annealing in hydrogen contains

0.0018 percent C, 0.002 percent Si, 0.0005 percent S, 0.003 percent N_2, 0.002 percent O_2, 0.0005 percent H_2. The magnetic properties of pure carbonyl iron are given in Table 49.

TABLE 49

Property	Value
Coercive Force in Gauss	0.08
Initial Magnetic Permeability μ_a in Gauss/Oersteds	3000
Maximum Magnetic Permeability μ_{max}	20000
Residual Magnetism B_r in Gauss	6000
Magnetic Saturation in Gauss	22000

Metalloceramic alloys from carbonyl iron and nickel powders are also used as soft magnetic materials because they possess greater magnetic permeability and magnetic saturation than ordinary ones. For this reason they are used in loudspeakers, radio transformers, measuring instruments, etc. The characteristics of carbonyl iron-nickel alloys are shown in Figure 199.

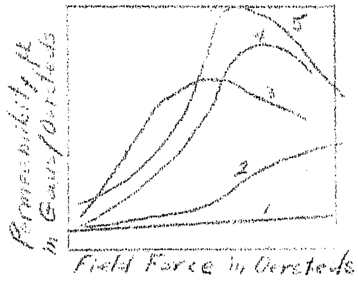

Figure 199. Curves of Permeability for Industrial Iron-Nickel Alloys. 1 - transformer iron; 2 - iron-nickel cast alloy with 48 percent Ni; 3 - metalloceramic iron-nickel alloy with 47 percent Ni; 4 - ditto, with 45 percent Ni; 5 - Permalloy (187).

MAGNETIC METALLOCERAMIC DETAILS

Permanent magnetic materials of the type of alni (5 to 14 percent Al, 12 to 33 percent Ni, the rest iron) and alnico (iron, aluminum, nickel, cobalt, sometimes with additions of copper and titanium) are very brittle and hard. For this reason such cast magnetic alloys cannot bepressure worked or machine finished. The only method by which the magnetic alloys alni and alnico can be finished is by grinding them down to required dimensions.

In this connection there has become rather widespread the fabrication of small permanent magnets of the type of alni and alnico by the methods of powder metallurgy. With a somewhat lesser density (approximately 2 percent) metalloceramic alloys are finer grained, less brittle and stronger than cast. Resistance to rupture of cast alloys of the type of alni is 30 to 50 kilograms per square millimeter and for metalloceramic 100 to 140 kilograms per square millimeter (167).

Figure 200. Details Suitable (a) and (b) Unsuitable for Being Manufactured from Alnico Alloys by Means of Metalloceramics. [photo]

Figure 201a. Ordinary Direct-Current Motor Pole Pieces. [photo]

Resistance to rupture of metalloceramic alnico alloys is 50 kilograms per square millimeter (3 to 5 times more than for cast), Rockwell hardness is 45 to 50 (191). The magnetic properties of metalloceramic alni and alnico alloys are 5 to 10 percent lower than for cast (167). At present only alnico II is being produced by metalloceramics (10 percent Al, 17 percent Ni, 12.5 percent Co, 6 percent Cu, the rest Fe) (182). The properties of metalloceramic alnico II are the following (the figures in parentheses show the characteristics of cast alnico II for purposes of comparison): specific gravity 6.77 (7.04) grams per cubic centimeter, residual magnetism B_r 6900 (7200) gauss, coercive force 520 (540) gauss, magnetic energy BH_{max} 1,430,000 (1,600,000) gauss/oersteds. The maximum weight of details at which it is practicable to produce alnico alloys by means of metalloceramics is usually about 60 grams (167, 191), althouth details weighing almost as much as two kilograms are sometimes produced metalloceramically. Dimensions for alnico details which are economically feasible stay within the following limits: height 2 to 30 millimeters; transverse cross-sectional area 0.6 to 13 square centimeters; weight 0.02 to 60 grams, occasionally up to 20 kilograms (191). Shapes of details which are suitable and unsuitable for manufacture by the methods of powder metallurgy are shown in Figure 200. Magnetic alnico details are not suited for calibration after baking. For this reason their tolerances are greater than for other metalloceramic products (dimensions up to 3 millimeters plus or minus 0.13 millimeters, from 3 to 16 millimeters plus or minus 0.25 millimeters, from 16 to 32 millimeters plus or minus 0.4 millimeters, from 32 to 75 millimeters plus or minus 0.8 millimeters, and above 75 millimeters plus or minus 1.5 millimeters).

Figure 201b. Metalloceramic Direct-Current Motor Pole Pieces. [photo]

Figure 202a. Metalloceramic Magnetic Detail for a Field Telephone. [photo]

Figure 202b. Metalloceramic Magnetic Detail of a Field Telephone. [photo]

Production by means of powder metallurgical methods is already quite widespread of various details from soft magnetic materials, principally ordinary iron (primarily from electrolytic, shotted, and pulverized powders). Thus (61, 191), there are being produced metalloceramic pole pieces for small direct-durrent motors (Figure 201), pole shoes, inductor coils for field telephones (Figure 202), etc. Such details have a density of about 95 percent of theoretical and somewhat lower magnetic properties than ordinary magnetic materials of the same composition. At the same time it is much cheaper to produce, for example, metalloceramic pole pieces for small direct-current motors than by fabricating them from riveted plates of sheet electro steel (Figures 201a and 201b). Moreover it is possible to produce for metalloceramic details rounded pole cores, which simplifies and makes less expensive winding and completely compensates for the lower permeability of powder details. Metalloceramic pole pieces may be used only for small rotors using direct current. Motors using alternate current, as well as large direct-current ones, cannot afford hysteresis and eddy-current losses. For this reason pole shoes for such motors should be made from insulated steel plates.

Chapter XVII

MILITARY APPLICATIONS OF METALLOCERAMIC MATERIALS

Examples of metalloceramic materials used in armaments are: armor-piercing shells, airplane and tank friction disks, porous filters in Flying Fortresses, etc.

CORES OF ARMOR-PIERCING SHELLS AND BULLETS

Metalloceramic armor-piercing cores for bullets and shells played an extraordinarily important role during the Fatherland War and were included in the armaments of all belligerent nations (13, 139, 142). Armor-piercing cores are made from tungsten carbide powders cemented with a small quantity of nickel or cobalt. German armor-piercing shells contained 0.75 to 2.5 percent Ni and 0.5 to 1.25 percent Fe.

The advantages of metalloceramic armor-piercing cores include a combination of great hardness (about 90 Rockwell "A") and a considerable specific gravity (14.7 to 15 grams per cubic centimeter). The use of metalloceramic cores not only raises the armor-piercing ability of shells but also improves their ballistic properties, makes it possible to decrease the caliber of shells and thereby use less expensive rapid-firing and accurate guns of smaller caliber. Figure 203 depicts German armor-piercing cores and shells.

Figure 203. German Armor-Piercing Cores and Shells (139).
[photo]

During the Fatherland War shells and bullets with armor-piercing were widely used for fighting with tanks (13).

METALLOCERAMIC SHELL COLLARS

During the war there was widely used by Germany iron shell collars (snaryadnyye poyaski) (152) in place of brass or copper ones (Figure 204). Copper was replaced by metalloceramic iron in all German shells whose caliber was between 20 and 210 millimeters (152). Collars for shells larger than 210 millimeters were not produced by means of the methods of powder metallurgy because of the lack of sufficiently powerful presses. The porosity of iron for shell collars was about 20 percent, Brinellhardness about 60, resistance to rupture for small calibers 7 to 9 kilograms per square millimeters, for large 12 to 15 kilograms per square millimeter. Pores were impregnated with paraffin to decrease friction and corrosion. At first iron metalloceramic collars gave inferior results to brass ones. The length of service of guns which used the first output of iron collars was only 60 to 70 percent of those which used brass. But the quality of the collars got better as a result of improvements in technology. The latest batches of metalloceramic collars were superior to brass.

The use of iron collars is connected with a very considerable saving in non-ferrous metals.

Chapter XVIII

OTHER TYPES OF METALLOCERAMIC PRODUCTS

USE OF POWDER METALLURGY IN WELDING

The progress of present-day electric welding is closely connected with the use of metalloceramic materials.

The development of atomic hydrogen arc welding is due to the use of refractory tungsten electrodes fabricated by the methods of powder metallurty (126). A drawing of an atomic-hydrogen welding apparatus is shown in Figure 205. When the current reaches the tungsten electrodes (1), an arc (2) is formed between them. The hydrogen is fed through side inlets (3), which, upon issuing through a ringed slot between each nozzle (4) and electrode (1), reaches the heated zone of the arc where the temperature can be as much as several thousand degrees. Then the hydrogen molecules break down into atoms. The process of breaking down the hydrogen molecules is endothermic and is connected with a decrease in temperature at the ends of the electrodes. Upon leaving the arc (the middle section), the hydrogen atoms recombine into molecules, thereby causing a considerable increase in temperature (up to 4000 degrees) at the periphery of the flame. Atomic-hydrogen welding (126) is a most economical way of making pipes from high-alloy, stainless, acid-resistant, and heat-resistant steels. It is also widely used in the building of aircraft and automobiles.

The use of metalloceramic copper-tungsten electrodes in place of copper for contact welding (194) increased the life of electrodes by 10 to 80 times.

Figure 205. Drawing of a Torch for Atomic-Hydrogen Welding.

It is very practical to make wire with a metalloceramic coating for welding stainless steel (147). Steel wire containing 0.3 percent C is covered with a layer of powder mixture of nickel, ferrochrome, ferromanganese, ferrosilicon and flux. Wire produced by this method is 25 to 33 percent cheaper than the usual wire made from stainless steel (147).

A description was given on page 62 [of original text] of nozzle-extrusion pressing of weld rods and wire from stainless steel. Metalloceramic weld rods made from stainless steel which has a certain amount of porosity (up to 25 percent) and an increased content of carbon (because starch is included in the paste for nozzle-extrusion pressing) give welding seams higher quality and demand less current (150 amperes instead of 175 amperes) as compared with rods from the usual stainless steel (166).

CORROSION-RESISTANT MATERIALS

Tantalum (167) is to be included among those materials which are more resistant to the action of different chemical reagents at room or slighter higher temperature (up to 100 to 150 degrees).

Tantalum is actually resistant to the action of diluted or concentrated, cold or heated, sulphuric or hydrochloric acid, organic acids, sulphur-chrome mixture, $HClO_4$, chlorine or brome water, cold mixture of HCl and HNO_3 (aqua regia). Heated aqua regia induces a formation on tantalum of a protective film which prevents further corrosion. Tantalum is not resistant to the action of hydrofluoric acid, caustic and carbonic alkali, and ammonia gas.

Because of this tantalum is used in the manufacture of laboratory ware, in chemical machine building, such as apparatus for producing hydrochloric acid, spinnerets for spinning synthetic wool, for all kinds of covering, nozzles for steam turbines (146), life-long pens, etc. The length of service of tantalum spinnerets, nitrogenized for increasing hardness, is several times longer than of those made from gold.

Metalloceramic hard alloys are to be distinguished by a relatively satisfactory chemical stability and high resistance to oxidation under normal and high-temperature conditions.

Iron treated with superheated steam (page 183) [of original text] possesses considerable resistance to oxidation under ordinary and high-temperature conditions and is very hard. It is consequently used for rollers and bearings of furnaces and in chemical apparatuses (refrigerators).

OTHER METALLOCERAMIC MATERIALS

Important metalloceramic materials consist of so-called heavy alloys with a tungsten base and additions of copper and nickel (80 to 90 percent W, 2.5 percent Cu, and 75 percent Ni) (178). These alloys have a specific gravity of 16.3 to 17 grams per cubic centimeter, a resistance to rupture of 63 kilograms per square millimeter, a limit of proportionality of 58 kilograms per square millimeter, a modulus of elasticity of 23,000 kilograms per square millimeter, an elongation of 4 percent, a Brinnell hardness of approximately 250 kilograms per square millimeter, a coefficient of linear expansion of 5.6 by 10^{-6}, a head conductivity of 0.25 calorie per centimeter second degree, a specific electrical conductivity of about 17 percent of the electricalconductivity of copper. Heavy alloys are used to manufacture containers for storing radium, screens for protecting personnel from radioactive radiations, etc. Moreover, heavy alloys are used in gyroscopes, balance mechanisms, contacts, diamond-metallic compositions, etc.

Because of the refractory quality and considerable strength of certain metalloceramic materials, they may be used as heat-resistant metals. Unfortunately, there have not yet been developed alloys, having for their base refractory metals, which combine strength and resistance to oxidation at high temperatures (except for brittle hard-alloy carbides). For this reason metalloceramic heat-resistant alloys with refractory metals as a base are only being used on a limited scale to serve as protection against oxidation. The use of molybdenum as a heating element comes under this classification (Chapter XV). Metalloceramic alloys of cobalt with 20 to 35 percent W are used for forge sides (dlya kovochnykh bakenov) in machines which forging tungsten at 1400-1700 degrees. Gardi (Hardy) recommends metalloceramic solders pressed from powders of electrolytic copper, phosphor copper, and borax. The rods are baked for strength at low temperature.

Powder metallurgy is used to some extent in jewelry manufacture (articles from tantalum niobium, porous silver, and gold).

Quite widespread is the preparation of dental fillings from powders of silver, copper, tin, zinc, cemented with mercury at room temperature (167). Dental fillings are composed of 67.7 percent A, 26.3 percent Sn, 4.7 percent Cu, and 1.2 percent Zn; also 48 to 50 percent Ag, 45 to 49 percent Sn, 0.52 percent Cu, and 0.1 to .05 percent Zn. There is added to the powder mixtures 85 to 120 percent of mercury. After mixing the paste is inserted into the dental cavity, any excess being removed. The filling achieves its maximum hardness approximately after 8 hours. The process of making dental fillings may be described as hot pressing and baking at room temperatures. The resistance of fillings to compression is 11.5 to 27 kilograms per square millimeter. Brinell hardness 26 to 54. There are expended in the making of fillings (on a world-wide scale) about 80 tons of silver and tin powders annually (167).

Chapter XIX

ECONOMICS AND PROSPECTS OF THE DEVELOPMENT OF POWDER METALLURGY

A. ECONOMICS

The limited literature containing information on the size of production and capital investment, manufacturing cost of powders and products does not give a sufficiently complete picture of the economics of powder metallurgy. The entire output of metalloceramic manufacture comprises less than 0.1 percent of the world production of metals. However, this relatively modest figure does not by any means characterize the totalrole of powder metallurgy in the national economy. Its economic significance is composed of the following factors.

(1) Economy from the use of materials which can be produced only by the methods of powder metallurgy.

(2) The economy of metal and substitution for deficit nonferrous metals.

(3) Lower cost of manufacturing products as compared with the usual methods.

Economy from the Use of Metalloceramic Materials

Savings resulting from the use of materials which may be produced only by the methods of powder metallurgy exceed by many times the cost of these materials and the total sum of capital investment for the entire metalloceramic industry. It is precisely these savings which determine to a large degree the importance of powder metallurgy for the national economy.

For example, according to Balza the replacement of a carbon filament in electric lamps by wire made from sintered tungsten results in an economy in the US of 3 billion dollars a year. One 100-watt electric bulb with a tungsten incandescent filament during the period of its life uses energy to the amount of 40 kilowatt hours less than a carbon lamp of the same brightness. A stillgreater economy is obtained by the use of metalloceramic hard alloys. They make it possible to increase productivity of labor when machine finishing metals by 30 to 60 percent and frequently even more.

Decrease in expenditures connected with servicing and lubrication when changing over to porous bearings is many times greater than their totalcost.

In the majority of cases it is difficult to express in specific figures the economy resulting from the use of metalloceramic materials. These materials have made it possible to produce a number of products of present-day electrical technology, such as radio tubes, magneto-dielectrics, etc.

Economy and Replacement of Metal

The economy of metal resulting from the manufacture of metalloceramic products may be broken down into quantitative (absence of loss from shavings,profits, etc, use of lighter porous metals) and qualitative (substitution for deficit non-ferrous metals).

Quantitative economy of metal arising from the fabrication of details by the methods of powder metallurgy is 20 to 80 percent as compared with ordinary methods.

Porous iron replaces copper alloys (bearings, shell collars, etc), lead (sealing materials, bearings), tin, and other metals.

One ton of porous iron, taking into consideration the smaller specific gravity and absence of loss of metal, is equivalent to 1.5 to 5 tons of copper alloys or 2 to 6 tons of lead.

In 1944 there were produced in Germany (139) about 30,000 tons of shell collars from porous iron, thereby resulting in a replacement and a saving of 45,000 tons of brass, and one to two thousand tons of other materials used in place of 4 to 5 thousand tons of non-ferrous metals. The total output of primary copper from ore comprised in Germany before the war not more than 30,000 tons. This example shows how effective can be the substitution of non-ferrous metals by porous iron.

Decrease in the Cost of Manufacturing Details

The development and scale of powder metallurgy is determined not only by the gains enumerated above but in many cases by lower production cost of finished products. This factor permits metalloceramics to compete with the usual methods for producing details (Chapter XIII).

A decrease in the cost of manufacturing details is due to the following factors.

(a) Economy of metal (see above).

(b) Higher labor productivity in connection with the elimination of machine finishing.

(c) In a number of cases lower expenditures for getting ready for production, shorter periods for going into full production, etc. Sometimes there is required only one twentieth of production area

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(c) In a number of cases lower expenditures for getting ready for production, shorter periods for going into full production, etc. Sometimes there is required only one twentieth of production area used in the fabrication of details by other methods. In order to put into production one splined detail with an inside slot 9 months were needed for preparing broaches and another instrument. In producing this detail from powder it was possible to shorten the period of getting ready for production down to 6 weeks.

Factors which make the cost of metalloceramic details more expensive are a relatively high cost of powders (usually one-half to two-thirds of the total cost of products is composed of the cost of powder) and large expenses for press molds. For this reason powder metallurgy is feasible only for the mass production of such details whose production by ordinary methods is labor-consuming or connected with large losses of metal.

The nomenclature of details which are profitable to make by the methods of metalloceramics depends on the cost of powder.

Table 50 gives the prices of metal powders in the US during 1946.

[See Table 50 on following page]

We can make the following conclusions from Table 50.

(1) With respect to the non-ferrous metals -- copper, tin, aluminum, and nickel, the price of powder is 10 to 90 percent higher than the price of ordinary solid metals and approximately the same as for the price of metalloceramic semifinished products (sheets, wire, rods). In this way by taking into consideration the above-described economic advantages of the methods of powder metallurgy, finished products made from non-ferrous metal powders are in a number of cases less expensive than details manufactured by ordinary

TABLE 50

PRICES OF METAL POWDERS AND ORDINARY METALS IN CENTS PER POUND (5 DECEMBER 1946)

Name of Metal	Powder		Ordinary Metal	
	Type	Price	Type	Price
Iron	Crushed, 200 Mesh, 90 Percent	4	Sheet Iron	4.5
	Sponge Iron	7.4-8	Wire	4.5
	Industrial, 100-200 Mesh, 96 Percent	11-16		
	Electrolytic, Annealed, Plus 100 Mesh, 99 Percent	17		
	Carbonyl, Minus 300 Mesh, 98-99 Percent	90		
Copper	Electrolytic, 150-200 Mesh	23.5-27.5	Electrolytic	19.5
	Reduced, 150-400 Mesh	22 2/3	Sheet	29.21
Aluminum	Atomized, 100 and 200 Mesh	25	Primary Aluminum in Ingots, 99 Percent	15.00
			Sheet	23.7-32.7
Nickel	Reduced, 150 Mesh	51.5	Electrolytic	35.00
Tin	Atomized, 100 Mesh	58.75	Ingot	52.00

Remarks. 1. The method used in producing industrial iron is not given.

2. The percentage given refers to the content of the element in a metal state, not to its total percentage.

means. In one case, the cost of metalloceramic bronze sealing details comprised only 10 percent of the cost of cast. During the second half of 1946 the prices of non-ferrous metal powders (also of cast metals) increased somewhat as compared with 1945., but less than those of cast metals. The prices of certain iron powders, on the other hand, decreased. There appeared less expensive powders made from electrolytic iron (more than two times cheaper) and cheap Swedish sponge iron.

(2) Iron powders in the US at present are considerably more expensive than semifinished products of solid iron (wire, sheets), being approximately 4 times as expensive for industrial iron. Pulverized iron shavings sell for somewhat less than semifinished products of solid iron. However, in spite of the relatively high cost of powder, finished iron products are in a number of cases less expensive. According to Pemfri, gears made of steel powder are 33 percent cheaper than those made from cast iron.

B. PROSPECTS FOR THE DEVELOPMENT OF POWDER METALLURGY

One should expect to see in the near future further and considerable development of powder metallurgy. A considerable development of this kind would be due to the following two factors.

(1) A decrease in the cost of products made from powder because of mastery and further improvement of technology. This factor would make it possible to expand considerably the nomenclature of metalloceramic details manufactured from ferrous and non-ferrous metals.

(2) Expansion of the application of already-known materials, which are produced solely by the methods of powder metallurgy, and

the introduction of new metalloceramic materials.

It seems certain that there will be a considerable surge in the production of metalloceramic products from ferrous metals. The author believes that with further improvement of technology and utilization of waste products (shavings, etc), metalloceramic products should cost only somewhat higher than ceramic (brick, pottery, etc). We can expect that in the relatively near future metalloceramics will produce up to 1 percent of total ferrous metal production and up to 2 to 3 percent of copper and its alloys.

We should also expect a further growth in the use of metalloceramic antifriction materials, both porous and compact. Porous bearings with an iron base will be used in considerably larger volume than up to now for "pv" values up to 100 to 150 kilograms per square centimeter meter per second. The field of higher "pv" values will also be using on a wider scope bearings from porous and compact alloys from special bronzes, triple-layer material, hard-alloy materials (Chapter XI), etc.

The use of porous filters will considerably increase both in machine building and in the chemical industry. One should expect the appearance of new fields for the application of porous metals -- in "automatics" ("avtomatika"), etc.

It is also possible that there may appear cheaper friction materials with an iron base, metal-plastic products, etc.

We should expect further qualitative and quantitative development of the hard alloys by industry. It seems possible that up to 90 percent machine finishing will be done with metalloceramic alloys. There is a large increase in the use of hard alloys for pressure finishing and in wear-resistant parts for machines.

Further progress in electrical engineering would be tied both to a development in the production of existing and in the appearance of new metalloceramic materials.

One can await the development of creep-resistant metalloceramic refractory alloys, standing up against oxidation, and of ways for protecting alloys against corrosion, which tend to oxidise at high temperatures, of cermicometallic materials, etc.

It is possible that a very small part of metalloceramic materials will be replaced by non-metallic (such as pure graphite bearings for light loads). However, this will not effect the general development of metalloceramic production.

An especially significant development of metalloceramic production should be expected in our own country. The Soviet Union can come to occupy and shall come to occupy the leading place in powder metallurgy.