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HIGH-STRENGTH CASTINGS IN HUNGARY

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The physical properties and the strength of a casting are influenced not only by the configuration of the graphite, but by the construction of the matrix as well. It was believed for a long time that in the case of flake-graphite castings it was the presence, in large quantities, of the matrix containing pearlite which produced great strength. It has been found recently that it is not the matrix containing pearlite, but the so-called dendritic matrix which results in best strength in case of flake-graphite distribution. The dendritic casting belongs to that type of castings in which increased strength and physical properties are achieved by the influence of metallic matrices.

Alloys are involved in this type of cast iron. It is necessary that the quantity of alloys be less than that in the preparation of cast iron containing martensite or austenite, but more than that required in the preparation of cast iron of a pearlitic matrix.

The alloy elements are added so that at the given speed of cooling the transformation of austenite into the desired dendritic structure will take place below 500 degrees centigrade. Thus, a basic structure can be achieved which is similar to the structure of martensite, but is in reality bainite, a transitional structure, composed of dendritic, needle-shaped crystals. This structure, as opposed to martensite, is easy to work with and has a much greater strength than pearlite. The tensile strength of this type of cast iron is not greater than that of ordinary castings, but after 5-6 hours of annealing at a temperature of 260-370 degrees centigrade, strength is increased significantly.

If the austenite is left in the structure, it will favorably influence the wear resistance. For this reason, it is used in the manufacture of drive shafts, plowshares, cold and hot pistons, fluted axles, gears, and lathe parts. According to Soviet data, tensile strength is 40-50 kilograms per square meter and transverse bending strength is 70-80 kilograms per square millimeter.

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Dendritic castings of high carbon content may be manufactured in cupola furnaces. It is more practical to manufacture castings of lower carbon content in induction or arc furnaces. The composition of castings produced in cupola furnaces is as follows (in percent): carbon, 2.7-3.1; silicon, 1.6-2.6; manganese, 0.6-0.9; sulphur, maximum, 0.15. Necessary additions are carried out in the cauldron. Ordinarily, 75-percent ferrosilicon is used for this purpose, and 0.3-0.6 percent of it is used. The alloying elements are as follows: molybdenum, 0.7-1.0 percent, is added in the form of powder or lumps during annealing. Nickel is added according to the following chart:

Casting Wall Thickness (mm)	Percent
0-40	0.5-1.5
40-75	1.5-2.5
75-100	2.5-3.0
100-200	3.0-4.0
200 plus	4.0

Nickel may be added in the furnaces or in the cauldron in the form of grains. If the nickel to be added is under one percent, it is added cold. If it is over one percent, it is added warm.

Up to a wall thickness of 40 millimeters, the nickel may be replaced by copper, but in a quantity not exceeding 1.5 percent. In case of a thickness where more than 1.5 percent nickel is required, copper may be substituted for the first 1.5 percent, but nickel should be added to make up the difference. The copper may be added in the furnace or, if it has been preheated, in the cauldron.

The amount of chromium to be added is to be kept under 0.3 percent. The material consists of hematite, raw iron, and steel scrap. The scrap is to be such that it will add the least possible amount of phosphorus. The amount of silicon and manganese can be regulated in the form of ferrosilicon and ferromanganese. The castings are removed from the mold when cold, at a temperature not higher than 300 degrees centigrade.

The castings have to be heat treated by keeping them at a temperature of 300-350 degrees centigrade for 5 hours and then slowly cooling them. For every 25 millimeters of wall thickness, the casting has to be heated an additional hour, if the thickness is not over 250 millimeters. Heat treatment renders the castings more ductile, without changing their Brinell hardness of approximately 300. Heat treatment will result, however, in the above-mentioned high strength. These castings are used in the manufacture of drive shafts. The metal does not wear easily.

A revolutionary change was brought about in the field of high-strength cast iron when castings with spheroidal graphite were introduced. The graphite totals 3 percent by weight and 10 percent by volume. In the case of cast iron, the shape of the graphite is important. If the graphite is spheroidal, it least disrupts the continuity of the matrix. The great strength of this type of cast iron is to be attributed to the spheroidal graphite and the matrix containing pearlite. The spheroidal graphite is formed only in case of a definite chemical composition. It is important that the sulfur content be less than 0.02 percent. Magnesium alloy, used to bring about the formation of spheroidal graphite, has a strong desulfurizing action, so that the sulfur content may be reduced to less than 0.02 percent. Magnesium also has a strong degassing influence. It is not known what role the degassing action plays in the creation of spheroidal graphite. On the basis of Professor Guillemot's experiments, it can be stated that without the use of magnesium it is impossible to carry out the removal of sulfur and gases. Opinions vary as to whether the spheroidal graphite particles are formed during the liquid or solid phase.

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After several experiments with materials such as copper, it was decided that $SiMg$ would be most advantageous for the preparation of the additive. There were serious difficulties in the beginning because magnesium burned out and two explosions took place.

It was found, finally, that if a very small quantity of copper is put into the alloy and melting is carried out under certain definite conditions, the explosions and the burning out of the magnesium can be prevented. Other difficulties arose because of the introduction of silicon. When the quantity of silicon rose above 3 percent, ferrite, not pearlite, was obtained. Silicon ferrite is a hard and brittle substance. When the amount of silicon was reduced to 0.5-0.7 percent, the experiment met with success and a tensile strength of 45-50 kilograms per square millimeter was obtained. No constant results could be obtained, however. At times, flake-graphite castings were obtained, while at other times the spheroidal variety was formed. It was found that the quantity of magnesium was an important factor. The magnesium quantity has now been established and a constant variety is obtained.

Up to now, only tensile strength, transverse bending strength, Brinell hardness, and resistance to wear have been examined. The tensile strength is 45-60 kilograms per square millimeter, transverse bending strength is 75-100 kilograms per square millimeter, and the Brinell hardness is 270-310.

Despite the high Brinell hardness, the castings are ductile. The resistance to wear was tested by preparing a brake block for a freight locomotive. While an ordinary brake block loses 18 millimeters /in use?/, a spheroidal one loses only 2-3 millimeters. Other data regarding strength can be obtained only from the foreign press.

The resistance to heat of spheroidal graphite castings compared to that of other gray castings is shown in the following table:

Casting	Temp (deg C)	Elongation (mm)	Thickness of Oxide (mm)
Gray casting	870	12.1	12
Chrome-alloy gray casting	870	2.8	1
Magnesium treated spheroidal graphite casting	870	2.1	0.5

The stress on spheroidal graphite castings at various loads, as compared to other gray castings is as follows:

Casting	Tensile Strength (kg/sq mm)	Fatigue Strength for Repeated Bending (kg/sq mm)
Flake graphite	23.5	18
Modified casting	34.0	23.5
Spheroidal graphite castings with ferrite and pearlite	55.5	25
Spheroidal graphite and pearlite	60.0	29

The resiliency under impact of spheroidal graphite castings is as follows:

Casting	Tensile Strength (kg/sq mm)	Elongation %	Impact Strength (acc to Izod test)
Flake graphite	21.0	0.2	3
Spheroidal graphite	82.0	3.0	13.4

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The modulus of elasticity of ordinary cast iron is 4,000-13,000 kilograms per square millimeter.

The modulus of elasticity of spheroidal graphite castings is 18,000 kilograms per square millimeter.

Steel has a modulus of elasticity of 20,000-21,500 kilograms per square millimeter.

The compressive strength of spheroidal graphite castings is two or three times that of the tensile strength. The quenching characteristics of spheroidal graphite castings lie between the ordinary gray castings and steel.

In the case of spheroidal castings where the silicon content is over 3 percent, there is no elasticity. This is also true when the manganese or phosphorus content is over 0.1 percent. The reason for this is that the spheroidal graphite appears in these cases in a pure pearlite or cementite bed. To render the casting ductile, the cementite has to be dissolved. This can be effected by the introduction of 0.4 percent of silicon if the wall of the casting is not thicker than 12 millimeters.

If the wall thickness is less than 12 millimeters, the cementite network can be destroyed by subjecting the casting to a temperature of 970 degrees centigrade for half an hour.

To achieve elasticity, the pearlite matrix has to be destroyed as well. This can be achieved by a heat treatment at 720 degrees centigrade.

Up to now, a maximum of 6-percent elasticity has been achieved. In foreign literature, references to 15-percent elasticity can be found. In these casting alloys, nickel-magnesium and not silicon-magnesium was used. Nickel probably causes great elasticity. Nickel-magnesium alloys were tried in Hungary, but they were found to have no advantages over silicon-magnesium. On the contrary, disadvantages were experienced. Nickel-magnesium makes the iron flow less fluid. No definite opinions can be expressed on this topic, because relatively few experiments have been conducted with nickel-magnesium alloys.

Earlier literature states that the use of magnesium alloys poses the difficulty of having to pour the pieces 2-3 minutes after magnesium alloying, or the spheroidal graphite is transformed into flake graphite. This assertion has not been proved in practice. Pieces have been poured 15 minutes after magnesium alloying. The major danger seems to be that the cementite network, broken up by the addition of silicon, will reappear if more than 3 minutes elapse between the addition of silicon and the pouring of the piece. Even then, the cementite network may be eliminated by a repeated addition of silicon. To eliminate the need for a repeated addition of silicon, the piece should be poured within 3 minutes after adding silicon for the first time.

Magnesium-silicon may be used in the manufacture of spheroidal graphite castings as well as in that of modified castings. It is required that the castings have a cementite structure in addition to the given wall thickness and rate of cooling. If the matrix is primed with a special additive containing 0.2-0.3 percent of magnesium, a modified casting is obtained which contains graphite in its pearlite matrix, finely distributed in the form of small bars. In this case, the strength of the casting falls between 26-32 kilograms per square millimeter. The additive is very useful in the field of desulfurizing. The following chart shows the desulfurizing action of the magnesium-silicon additive in the case of good-quality gray castings (in percent):

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Sulfur at Start	Magnesium Added	Final Sulfur	Decrease in Sulfur Content
0.082	0.066	0.074	9.8
0.082	0.149	0.047	42.7
0.082	0.257	0.021	74.4
0.082	0.445	0.014	82.9

It should be noted that the price per kilogram of a spheroidal graphite casting is about a forint higher than that of a good-quality gray casting.

During the last few years, malleable cast-iron castings have gone through considerable changes. While before the war, during the 1930's, the tensile strength of malleable castings was 35-43 kilograms per square millimeter, yield strength was 16-21 kilograms per square meter, elongation was 3-4 percent, today tensile strength is 50-60 kilograms per square meter, yield strength is 35-45 kilograms per meter, and elongation is now 5.5-8 percent.

Attempts have been made to reduce the cost of heat treatments and tempering processes. This is important for Hungary because capacity for heat treatment is relatively small, when considered in the light of the malleable cast-iron casting requirements of the Five-Year Plan. To increase production, the time required for heat treatment will have to be reduced. Experiments have been conducted in the past with this end in view. Attempts have been made to achieve the best chemical composition of the castings, and tempering methods have been put into effect which reduced the 140-170 hour tempering time through the use of induction furnaces. Under present Hungarian conditions, and if the castings have the most favorable composition, tempering time can be reduced to 90-100 hours in continuous furnaces and to 140 hours in muffle furnaces. Further reduction could be obtained only through the gas-phase process. Furnaces used for this process are manufactured in England only and, since the process is patented, its application involves the payment of royalties. The purchase of these furnaces would require expensive foreign exchange. In addition, it is quite expensive to operate these furnaces, since the fuel used is electricity. The idea of using this type of furnace has been abandoned, therefore.

After preparing the silicon-magnesium additive for the spheroidal-graphite castings, there are two possibilities for the manufacture of castings which can be heat treated rapidly. One involves the manufacture of malleable cast-iron castings with a low silicon content at the start. It can be raised later by the addition of the silicon-magnesium additive. This additive does not cool malleable cast-iron castings, even the thinnest pieces flow out, and the added silicon assures the separation of the cementite from the numerous temper-carbon seeds. This process is facilitated by the fact that through the application of silicon magnesium, the magnesium exerts a strong desulfurizing action. Through the application of this process, favorable results have been achieved from 12-17 hours of heat treatment.

The other possibility is the manufacture of spheroidal-graphite castings, but silicon priming is not used and the spheroidal particles appear in a cementite, not pearlite, bed. The cementite composition can then be broken up after a few hours of heat treatment.

Spheroidal-graphite castings are malleable. If the iron, flowing from the smelting furnace and poor in sulphur content, is treated with silicon magnesium in addition to phosphorus and manganese, an alloy will be obtained which does not have to be transformed to steel in Martin and induction furnaces to render it malleable. Thus, malleable castings can be obtained in one step. On the one hand, this would free to a certain extent Hungarian induction and Martin furnaces and, on the other hand, this process renders the production less expensive. Hungary is not at all backward in this type of research, but is on a level equal to that reached by industrially advanced countries. The deficiency is that industry takes a very long time to put the described processes into practice. Difficulties will be encountered in the production of ordinary iron castings although this field of manufacture has a background of several hundred years.

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