

HIGH-STRENGTH BAINITIC CAST IRON WITH SPHEROIDAL GRAPHITE

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The results of experiments concerning the effect of austenitizing and isothermal hardening conditions on the strength and ductile characteristics of bainitic cast iron with spheroidal graphite showed [1, 2] its advantage over cast iron with a pearlitic structure and also structures that may be obtained after quenching to martensite and high-temperature tempering. For logical applications of cast iron with a bainitic matrix and spheroidal graphite it is necessary to know the conditions of transformation in which the highest mechanical properties of castings are achieved. This work concerns the changes in the basic mechanical properties of cast iron with spheroidal graphite in relation to the time and temperature of the isothermal bainitic transformation (300, 350, and 400°C).

We investigated cast iron with spheroidal graphite with the following chemical composition: 3.3% C, 2.7% Si, 0.24% Mn, 0.062% P, 0.01% S, 0.01% Cr, 0.01% Cu, 0.055% Mg. The cast iron was melted in a 100-kg induction furnace employing current of commercial frequency. The charge consisted of LK1-A-1 cast iron, Armco scrap iron, and SI 75. From the alloy modified by means of a bell with 1% Mg and 0.5% SI 75 we cast standard keel ingots in cured molds with dimensions of 50 × 50 × 300 mm in the lower part. The lower sections of the ingots were cut into prisms 11 × 11 × 95 mm, which were annealed at 900° for 1 h. From the prisms we prepared samples for tensile tests with a reduced section 6 mm in diameter and 30 mm long, with an allowance for machining (0.5 mm in radius). After isothermal hardening the reduced section was ground to obtain the finished dimension. The isothermal treatment was conducted in salt baths - austenitizing at 900° for 30 min, isothermal decomposition at 300, 350, and 400°. The temperature was maintained with an accuracy of ±5° (austenitizing) and ±3° (isothermal decomposition). The isothermal holding time was selected so that it included the range of the bainitic transformation at the given temperature (from several seconds to 55 h). After isothermal holding, the samples were cooled in water. For determining σ_b and δ we used the universal Zwick machine with a constant pull rate of 1 mm/min. The percentage of retained austenite (A_{RE}) was determined after complete cooling by x-ray analysis with the Chirana-II apparatus and the percentage of austenite decomposing in the process of the bainitic transformation (A_{TR}) by the magnetic induction method [3] on samples 10 mm in diameter and 1 mm thick.

The results of the mechanical tests and determination of the amount of retained austenite are shown in Fig. 1, and the decomposition of austenite in Fig. 2 (it should be noted, however, that these curves were obtained for samples differing in size from the samples used for mechanical tests and determining A_{RE}).

It can be seen that increasing the isothermal transformation time leads to an increase of the ultimate strength, the amount of retained austenite, and the relative elongation, and a reduction of the hardness. The low values of σ_b and δ corresponding to the initial period of the transformation can be explained by the premature (brittle) fracture of the samples due to the elevated percentage of martensite with defects in the final structure, which also agrees with the hardness values obtained. The formation of a large quantity of martensite during brief isothermal holding is characteristic of all transformation temperatures tested. A favorable combination of mechanical properties was obtained only with more than ~20% retained austenite, when the amount of martensite in the final structure is small; the highest values of δ and σ_b were obtained with 25-38% retained austenite.

With increasing holding time the mechanical properties generally decline. The ductility decreases most after transformation at 400°. It is accompanied by a reduction in the percentage of A_{RE} to zero. Isothermal transformation at 300 and 350° is accompanied by a slower reduction of δ and A_{RE} with increasing holding times; there is less change in these values after transformation at 300°. Evidently, the quantity of carbon-rich retained austenite has a considerable effect on the ductile characteristics of bainitic cast iron with spheroidal graphite. The substantial amount of A_{RE} (~38%) and the ductility of upper bainite (Fig. 3a) are responsible for the high ductility (up to 12%) of cast iron with spheroidal graphite after transformation at 400°. The subsequent reduction of δ , accompanied by a reduction of A_{RE} , can be explained by the precipitation of carbides,

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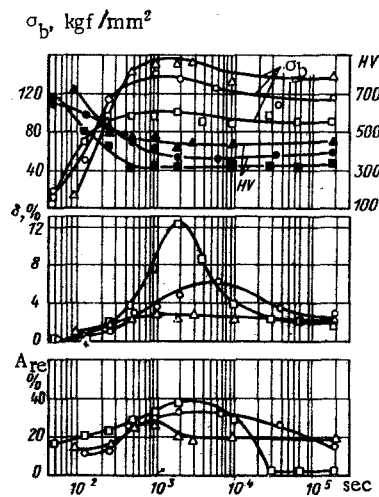


Fig. 1

Fig. 1. Variation of the mechanical properties and amount of retained austenite with isothermal holding time at 300 (Δ), 350 (\circ), and 400° (\square).

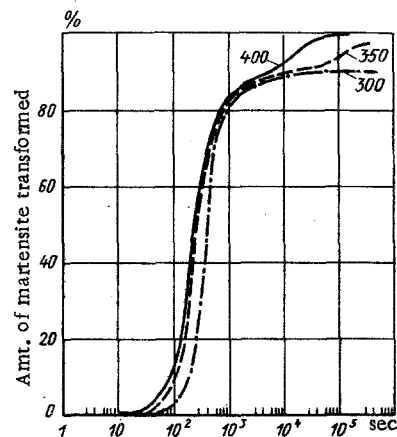


Fig. 2

Fig. 2. Decomposition of austenite in relation to isothermal holding time (at temperatures given on the curves).

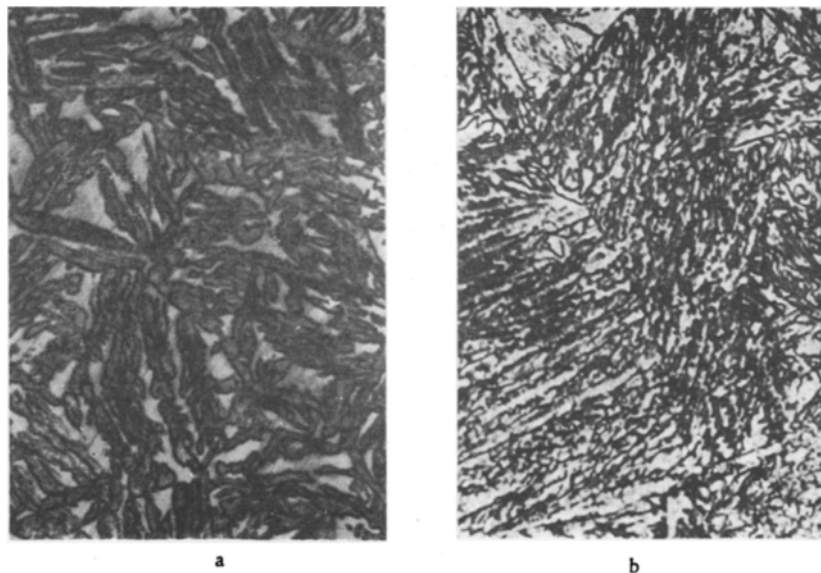


Fig. 3. Microstructure of high-strength cast iron after isothermal hardening. 2000 \times . a) 1920 sec at 400° (upper bainite); b) 200,000 sec at 300° (lower bainite).

due to which the carbon concentration in austenite at the transformation temperature decreases and further transformation of austenite at this temperature becomes possible (Fig. 3b) or the martensitic transformation during subsequent cooling. Precipitation of carbides may occur in a similar manner to the process in silicon steel [4] – preferentially in the γ/α interphase boundary. The carbide particles precipitated in austenite grain boundaries are larger than the particles precipitated in the bulk of the grains and in the boundaries of bainitic ferrite platelets. Longer holding times at 400° lead to completion of the transformation. The percentage of decomposed austenite (A_{de}) reaches 100% in this case (Fig. 2).

The bainite formed at 350° has a higher strength and lower ductility. Even with the maximum amount of retained austenite in the finished structure, the relative elongation of this cast iron is low. It can be assumed that the precipitation of carbides has some effect on the ductility after the transformation, as at 400°.

After transformation at 300° the cast iron has a higher strength and hardness and lower ductility. The amount of retained austenite remains almost unchanged with long isothermal holding times (Fig. 1), and the change in the mechanical properties is also slight. It can be assumed that relatively little diffusion occurs at this temperature even with substantial holding times. Under these conditions carbides are precipitated within platelets of the ferritic component of bainite [4], which has no essential effect on the mechanical properties of A_{Fe} .

The change in hardness after partial transformation in the bainitic range does not correspond to the change in strength. The ductility of the structural mixture of bainite, martensite, and retained austenite, in which martensite predominates, is inadequate and does not make it possible to utilize the maximum strength of the matrix due to the premature (brittle) fracture of the samples. Premature fracture is characteristic of high-strength steels after quenching or low-temperature tempering and is explained by the presence of defects (microcracks) in martensite. Microcracks have been associated mainly with the elevated carbon content of the solid solution, the austenite grain size [5], aging processes in martensite [6], etc. Therefore, the structural mixture obtained in the incomplete bainitic transformation of the matrix of cast iron with spheroidal graphite in which martensite predominates is susceptible to premature fracture similar to steel quenched to martensite. Since bainitic ferrite occurs preferentially in regions of the matrix with a low carbon content [7] (as a consequence of direct segregation), the martensitic transformation occurs in areas richer in carbon. The product of the transformation is lamellar martensite with low ductile characteristics. The high carbon content of the solid solution in cast iron with spheroidal graphite is evidently the most probable reason for premature failure. Also, due to chemical heterogeneity, the martensitic component of the structural mixture is located in the boundaries of eutectic cells where casting defects are concentrated (microporosities, inclusions, etc.). Their unfavorable effect on the mechanical properties of cast iron is aggravated by defects in martensite. Premature failure may also be affected to some extent by aging of martensite at room temperature, limiting its capacity for relaxation. The grain size evidently has a smaller effect, since even at high austenitizing temperatures there is no substantial grain growth [8]. The cast iron investigated in this work had a grain size of $\sim 30 \mu$.

It follows from the results presented that prolonged isothermal holding times reduce the ductile characteristics of cast iron with spheroidal graphite to values near those of cast iron with a pearlitic matrix. The results also indicate that cast iron with spheroidal graphite quenched to bainite can be used for machine parts operating at lower temperatures than the transformation temperature.

The isothermal bainitic transformation of cast iron with spheroidal graphite can be divided into three stages on the basis of the results obtained (Figs. 1 and 2) and on the basis of data for silicon steel [9].

In the first stage (high average rate of the transformation) bainitic ferrite is formed and grows, accompanied by enrichment of the surrounding austenite in carbon. The precipitation of carbides can be regarded as a secondary process not having an essential effect on the transformation process. The first stage ends when the maximum concentration of carbon in untransformed austenite is reached.

In the second stage (very low rate of the transformation) the transformation continues very slowly in the remaining austenite with a relatively low carbon content. Formation of carbides continues in the second stage, the amount of carbide formed depending on the transformation temperature. Two stages in the transformation of austenite were observed at all bainitic transformation temperatures investigated (see Fig. 2).

In the third stage, characterized by a high rate of the transformation, the basic process is the precipitation of carbides and the associated reduction of the carbon concentration in enriched austenite, due to which the transformation continues.

The third stage is observed at isothermal holding temperatures of 400–350° (see Fig. 2). At 400° the transformation ends with the decomposition of all the austenite; at 350° the rate of the transformation increases but complete decomposition of austenite does not occur. At 300° the third stage is absent, but it can be assumed that with longer holding times the amount of austenite transformed increases. The results indicate that present day concepts of the incomplete bainitic transformation [10] are not always correct.

CONCLUSIONS

1. The change in the properties of high-strength cast iron in relation to isothermal holding time is extremal in character.
2. The best mechanical properties of cast iron with spheroidal graphite are obtained at 300–400° with 25–40% retained austenite.

3. Cast iron with spheroidal graphite whose matrix consists of a structural mixture of bainite, martensite, and retained austenite, with a predominance of martensite, is susceptible to premature failure.

4. The reduction of the amount of retained austenite with prolonged isothermal holding times leads to a reduction of the ductility; the strength characteristics decrease negligibly in this case.

5. The isothermal bainitic transformation is divided into three stages that differ in the average rate of the transformation.

LITERATURE CITED

1. E. Dorazil and B. Barta, *Slevarenstvi*, No. 1, 8 (1971).
2. E. Dorazil, B. Barta, and E. Munsterova, *Giessereitechnik*, No. 19, 79 (1973).
3. V. Kraus, *Atlas Diagramu pro Zuslehtovani Konstrukcnich Oceli*, SNTL, Praha (1964), p. 32.
4. L. Hyspecka, *Kovove Mater.*, No. 1, 74 (1966).
5. Ya. M. Potak, *Metalloved. Term. Obrab. Met.*, No. 5 (1961).
6. W. Leslie and J. Sober, *TASM*, 459 (1957).
7. E. Dorazil, *Kovove Mater.*, No. 6, 475 (1971).
8. E. Dorazil and V. Kraus, *Slevarenstvi*, No. 2, 503 (1970).
9. E. Dorazil, J. Crhak, and B. Barta, *Mezinarnodniho Symposia, Svornik II: Kovove Materialy s Vysekymi Mechanicko-Fyzikalnymi Vlastnostami*, Bratislava, zari (1977), p. 5.
10. R. Hehemann and A. Troiano, *J. Metals-Trans. AIME*, 20, No. 3, 707 (1955).

STRUCTURAL STRENGTH OF MALLEABLE IRON WITH DIVORCED PEARLITE

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Ferritic malleable iron with relatively high ductility ($\delta = 6-12\%$) and low strength ($\sigma_b = 30-37 \text{ kgf/mm}^2$) and pearlitic malleable iron with high strength ($\sigma_b = 45-63 \text{ kgf/mm}^2$) and low ductility ($\delta = 2-6\%$) are produced at the present time (GOST 1215-59). Nevertheless, malleable iron with divorced pearlite is not widely used in industry, despite its high strength and ductility ($\sigma_b = 45-60 \text{ kgf/mm}^2$, $\delta = 6-10\%$). This is probably due to the fact that little research has been done on its structural strength.

The structural strength of a material refers to the combination of properties most completely characterizing the working capacity of machine parts (service life in combination with reliability) [1].

Malleable iron is widely used in manufacturing farm machinery. Many parts of such machines operate under conditions of repeated impact loads. The strength of malleable iron subjected to repeated impact loads cannot be judged from the ultimate tensile strength, relative elongation, or hardness. For proper determination of the working capacity of malleable iron under such conditions it must be subjected to repeated impact tests [2].

We tested malleable iron with divorced pearlite and, for comparison, ferritic malleable iron and ferritic-pearlitic malleable iron and lamellar pearlite. All malleable irons were obtained from white cast iron of the same chemical composition and melted under plant conditions to obtain ferritic malleable iron.

The microstructure and mechanical properties of the iron are given in Table 1.

The impact-fatigue strength was tested on a machine of the lever-impact type designed at the Central Scientific-Research Institute of Heavy Machine Construction (TsNIITMASH), with use of unnotched samples $10 \times 10 \times 55 \text{ mm}$. The samples were subjected to one-sided impact bending under repeated loads with a frequency of 194 impacts per minute (distance between supports 50 mm, impact energy $A = 5-20 \text{ kgf-cm}$). The impact energy was determined as the product of the weight of the falling load and the height of the drop. The