Under certain conditions sulfur has a spheroidizing influence on graphite in cast iron [1]. However, attempts to obtain high-strength sulfur cast iron with spheroidal graphite have failed — spheroidization of graphite began only after a large proportion of the carbon was combined in ledeburitic cementite.

Aluminum - sulfur cast iron has been produced in the laboratory with spheroids consisting of graphite and sulfur phase, although it is difficult to produce such alloys under commercial conditions.

We propose the following method of obtaining castings of sulfur cast iron with high strength: 1) production of completely chilled castings from cast iron ordinarily hardened with sulfur (containing over 3% C and 1.5% Si) by means of alloying with sulfur; 2) rapid graphitization in the solid state in the process of annealing or self-annealing to obtain cast iron with a preferential pearlitic structure of the matrix and compact graphite inclusions.

The basis of this proposal was used in previous work by P. Ya. Gruzdov, R. P. Todorov, E. A. Vasil'ev, and other investigators in the area of malleable iron with sulfur, A. D. Ushakov in the area of chilled gray cast iron, and also in theoretical work [2-4] in which it was shown that the chilling effect of sulfur can be considered to be the effect of kinetics associated with the surface-active properties of this element. The thermodynamic susceptibility of cast iron to graphitization remains practically unchanged even when the sulfur concentration is raised to 0.5-1%.

One of the characteristic features of the process is the low concentration of manganese. This element, combining with sulfur, weakens its effect and leads to undesirable effects due to formation of MnS.

We investigated sulfur cast iron cast in green and cured sand molds with different total concentrations of carbon and silicon (from 4.6 to 6.2%). It was found that through chilling is obtained in castings with 3.7% C, 2.5% Si, 0.1% Mn, and 0.4% S with a wall thickness not over 8 mm cast in green molds. With thicker walls the structure of the cast iron is half and half, with no zones where no chilling is present. However, with a wall thickness of 16 mm the eutectic graphite is very small and its branched structure sharply reduces the mechanical properties after graphitization annealing; the relative elongation is equal to zero and the ultimate tensile strength drops to 25 kg/mm².

With reduction of the carbon and silicon concentrations to 3 and 1.8%, respectively (with the sulfur and manganese concentrations retained at the same level) the maximum thickness of the wall with through chilling increases to 16 mm. Further lowering of the carbon and silicon concentrations is inadvisable, since it is difficult to melt the metal in the cupola. Also, this composition approaches that of malleable iron, which was not the purpose of this work.

Preliminary studies of cast irons with 1% S and more (Table 1) showed that it is premature to recommend such a high concentration of this element for castings in sand molds due to segregation, which lowers the mechanical properties, the precipitation of large numbers of coarse sulfides, and also due to the fact that the concentration of sulfur approaches that in alloys where sulfurous gases are given off during solidification and blow holes occur in the castings.

The sulfur concentration can be increased for casting in chill molds. In this case complete and through chilling is ensured by alloying with sulfur and also by the rapid solidification.*

*We also investigated the effect of die casting; in this case the susceptibility to chilling increases.

Fig. 1. Microstructure of alloy 1 (×100): a) after casting in chill mold; b) after annealing at 950°C for 2 h and rapid cooling in air.

Fig. 2. Microstructure of alloy 4 after annealing at 950°C for 2 h with furnace cooling (×500).

The metal was melted in a standard acid cold-blast cupola. Sulfur was added in the ladle in the form of iron sulfide. In the laboratory the heats were melted in an acid 50-kg induction furnace. Wedge-shaped samples were cast in chill molds and also crankshafts for household refrigerator compressors. The mold for the crankshafts was cast iron with a surface obtained by the Shoup process.* The diameters of the main and connecting rod journals of the crankshaft were 18 and 20 mm, respectively.

Through chilling of crankshafts made from cast iron with the standard sulfur content (alloy 1, Table 1) occurs with not over 2.0% Si (Fig. 1a). After annealing at 950°C for 0.5–1.5 h the metal is completely graphitized. However, due to the high concentration of carbon and silicon (compared with standard cast iron) it is impossible to prevent precipitation of ferrite even with normalization (Fig. 1b). For the same reason, graphite inclusions have an unfavorable shape and the mechanical properties are low (σb = 36 kg/mm², δ = 2.5%). However, the crankshafts meet the specifications under these conditions (σb = 30 kg/mm²).

To stabilize the pearlitic structure of the castings and increase the wear resistance we investigated alloying with copper (alloy 2, Tables 1 and 2). However, the addition of copper sharply reduces chilling.

The structure of the matrix is pearlitic in cast iron with as little as 0.3% S (alloy 3, Table 1) even with a relatively low rate of cooling on the rolling bed of the annealing furnace. With 0.4–0.5% S the pearlitic structure is retained even with furnace cooling after graphitization annealing. In this case the pearlite is spheroidized (Fig. 2, alloy 4 in Tables 1 and 2) without any special heat treatment, i.e., a structure typical of Z-metal is formed. High mechanical properties are obtained with spheroidal carbon inclusions and a homogeneous structure of the matrix consisting of divorced pearlite and fine sulfides that is difficult to distinguish from eutectoid cementite.

This favorable structure of sulfide inclusions is obtained only with casting in chill molds. In dispersed ledeburite of chill castings there are fine sulfides in austenite (pearlite) and in cementite. With over 0.3% Mn the quantity of sulfide of the MnS type increases, being formed at relatively high melting temperatures and therefore not refined with solidification in a chill mold.

Cooling of the castings in air after graphitization annealing leads to fine lamellar or sorbitic eutectoid instead of divorced pearlite, the cast iron acquiring higher strength and wear characteristics (alloy 5, Tables 1 and 2).

Casting of cast iron with 0.8–1.1% S in a chill mold leads to the same dispersity of the sulfide phase, no segregation of sulfur is observed, and the high strength characteristics are retained, and even slight

---

* A method developed at the N. É. Bauman Moscow Technical College.