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STRUCTURE AND PROPERTIES OF CAST IRON PREFORMS OF PISTON RINGS

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A brief description of the technology of piston ring castings made of gray cast iron with spheroidal graphite is presented. Special attention is paid to the melting regimes and modification of the melt as the most important factors that determine the structure and properties of the metal in the cast preforms. Methods for controlling the quality of the preforms are considered.

Before 1986 piston rings for VAZ engines were manufactured by the Michurinsk Plant of Automatic Equipment. Upper compression rings were produced from high-strength cast iron with spheroidal graphite, and oil-control rings and lower compression rings were produced from gray cast iron. In both cases individual preforms were used for each ring.

The central zone of the cross section of upper compression rings often exhibited a streak loose shrinkage structure. The structure of the rings was nonuniform with a variable content of ledeburite, pearlite, and ferrite. The structure of oil-control and lower compression rings contained coarse rosette graphite and often an elevated amount of ferrite. Thus, the rings had unstable micro- and macrostructures and mechanical properties. Over 20% of the cast preforms did not correspond to the standard requirements on the quality of the material and the parts. The use of such piston rings caused scoring, increased the consumption of oil, and ultimately decreased the service life of the parts.

In 1986 VAZ bought a licence for the production of piston rings from the Riken firm (Japan). However, experience has shown that this technology required considerable correction due to the specific features of the plant.

In order to improve the quality of piston rings VAZ specialists developed a technology for melting, casting, and modifying a metal based on domestic materials. At present, cast irons for upper compression rings are melted in induction crucible furnaces of normal frequency with a crucible capacity of 5 tons. Similar materials are melted by the Riken firm in high-frequency induction furnaces in a 1-ton crucible.

Gray cast iron for castings of piston rings is melted in induction furnaces of elevated frequency in a 0.5-ton crucible (Riken uses cupola melting).

Although the charge materials and the modifiers have changed and the melting is conducted by different methods, the requirements on the quality of the microstructure and the properties of the castings and the parts correspond to the Riken standards.

A preform for an upper compression ring is a ring pot for 9 parts. The pot is manufactured by the principle of directed hardening (the slope inside the preform is $\alpha = 40'$, a ring head for the feeder is envisaged). This technique provides dense rings, while shrinkage blisters and looseness form in the head. The molds are produced in a Dizamatic installation.

The melt is prepared in an acid-lined induction furnace of normal frequency in a 5-ton crucible. The initial content of the elements is as follows: 3.7 – 4.1% C, 1.8 – 2.0% Si, 0.6 – 0.8% Mn, < 0.010% P, 0.015% S, < 0.07% Cr, 0.65 – 0.85% Cu. Before tapping, the melt is heated to 1550 – 1570°C and poured into a ladle heated to about 750°C. Then it is moved onto the Dizamatic line for modification and casting into molds.

The Dizamatic line is equipped with another ladle with a capacity of 200 kg, also heated to 750°C. On the bottom the ladle has a pocket for modifiers. The FSMg6K2R modifier is sucked into the pocket through a pipe in an amount of 0.8 – 1.05% and ferrosilicon of grade FS75 of the sixth class of coarseness is poured from the top in an amount of 0.8 – 0.85%.

The first modifier promotes the formation of spheroidal graphite in the cast iron and the second plays the role of a cover material that prevents early reaction with magnesium. In addition, the FS75 ferrosilicon causes graphitization in the course of the crystallization process. The temperature of the cast iron is measured in each ladle before pouring and is maintained at the level of 1470 – 1490°C. The duration of the casting in the line does not exceed 7 min. A cylindrical specimen 20 mm in diameter is taken from each ladle. The quality of the modification is estimated from a fracture of this specimen. In addition, the microstructure is controlled for the amount of spheroidal inclusions in the metal melted in the first ladle. Only if the results of the check are positive, is the
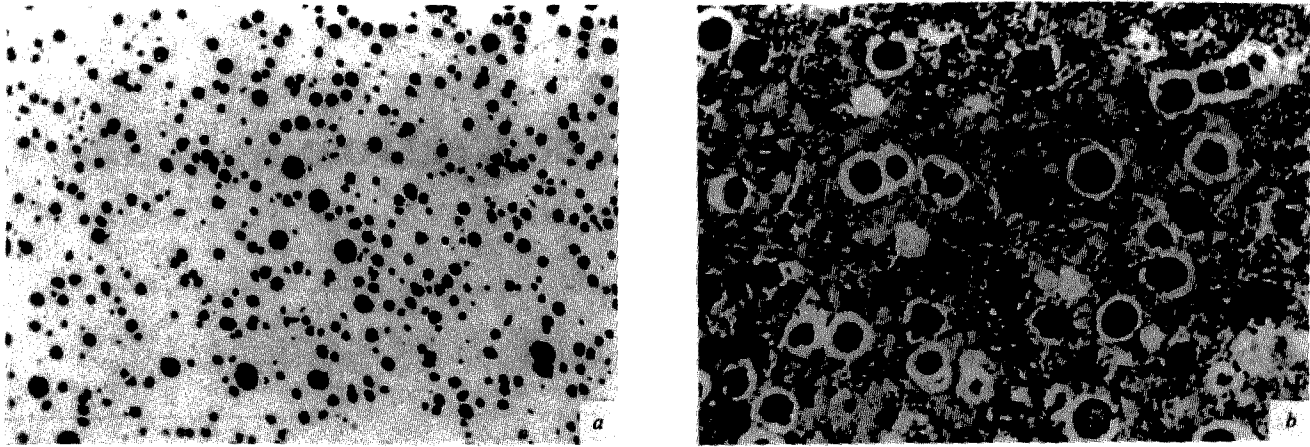
Fig. 1. Microstructure of preforms made of high-strength cast iron: a) graphite (without etching), $\times$ 100; b) metallic matrix and graphite (etched in a solution of HNO_3 in alcohol), $\times$ 200.

metal poured. If the amount of spheroidal inclusions is low, the fraction of the spheroidizing modifier is increased in the next heat. Castings from each ladle are stored separately. After a positive conclusion on microstructure control they are combined into one batch. Castings from different ladles can be rejected if their microstructure contains less than 85% spheroidal inclusions (the evaluation is conducted by comparison with a standard).

After shotblasting and control of the appearance the castings are subjected to heat treatment in a through-type furnace with a bogle mesh hearth. A nitrogen-base protective atmosphere is maintained in its functional space. The functional space of the furnace consists of zones with different temperatures, namely,

Zone	t, °C
I	890 – 920
II	920
III	920
IV	900

The total holding time of the castings is 3.5 h. Then they are cooled by a gas with a temperature of 100 ± 20°C. The gas flow is directed from the top and from the bottom of the castings placed in a single row, which provides efficient and uniform cooling. After a second shotblast cleaning one casting in a batch is tested for microstructure and hardness. An annular specimen is cut from the functional zone of the casting at a distance of 3 mm from the edge. The cast iron should have an optimum structure consisting of a pearlite-ferrite metallic matrix (2 – 3% ferrite, the maximum admissible value is 15%) without structurally free cementite (the maximum admissible value is 5%) and spheroidal graphite with a fraction of vermicular inclusions of at most 15% as evaluated by a standard scale. The microstructure of a final casting is presented in Fig. 1.

The hardness of the cast iron commonly fluctuates within 104 – 108 *HRB* (the admissible range is 100 – 110 *HRB*).

Castings made of gray iron have the form of annular preforms for one article with a cross section of 4 $\times$ 4 mm for lower compression rings and 4 $\times$ 5 mm for oil-control rings. The final rings can have a diameter from 76 to 82 mm.

In accordance with the Riken standards the mechanical properties of the annular preforms should be maintained at the following level: 95 – 107 *HRB*, normal modulus of elasticity $E = 91{,}140 – 124{,}460$ N/mm^2. These requirements are met if the structure of the castings contains a comparatively small amount of fine and uniformly distributed graphite. The carbon concentration in the melt before modification should range within 3.35 – 3.50%. The concentration of the elements in the initial cast iron (before modification) should be as follows: 3.35 – 3.50% C, 2.25 – 2.40% Si, 0.55 – 0.75% Mn, 0.35 – 0.50% P, 0.06 – 0.08% S, < 0.05% Cr, < 0.20 – 0.50% Cu. In order to maintain a stable content of excess manganese, ferrosulfur is introduced into the melt in the requisite amount, which provides stable graphitization of the metal in hardening. When the ladle is filled by the melt from the furnace, several graphitization modifiers are introduced into it in order to control the formation of the microstructure (graphite and metallic matrix). A 120-kg portion of the metal is determined by a mark on the wall of the ladle. The temperature of the metal before tapping is maintained at 1550 – 1560°C in the beginning and at 1540 – 1560°C in subsequent pourings. The lining of the ladle before tapping from the furnace is heated to 1000°C. A mixture of three modifiers (0.25 – 0.40% mixed modifier FS30U60, 0.26 – 0.40% ferrosilicon FS65Ba1, 0.20 – 0.40% ferrosilicon FS75St1 or superferrosilicon) is gradually introduced into the stream of the tapped metal.

When the ladle is filled to the mark, the melt with retained modifiers is tirred rapidly by a graphite mixer for 2 – 3 sec. Then a slag-forming material (pearlite) is poured onto the surface of the melt in order to protect it from a high loss of temperature. It collects the products of the reaction with the
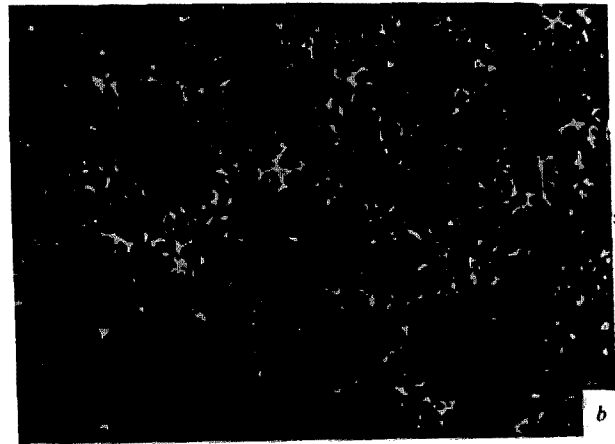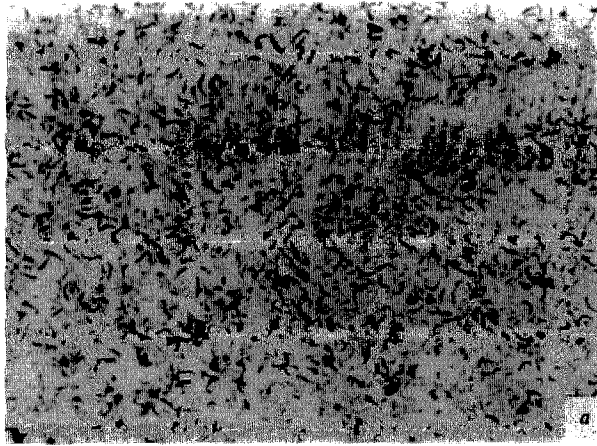
Fig. 2. Microstructure of preforms made of gray cast iron: a) graphite (without etching), × 100; b) steadite (etched in a solution of HNO₃ in alcohol), × 100.

modifiers into a thick slag film, which is easily removed in the line before pouring.

The combination of the three modifiers provides the formation of fine graphite (Fig. 2a) uniformly distributed inside the casting (from the center to the corners). Such a microstructure is stably formed inside each mold, in each pile of one heat, and between the heats.

The time of pouring from each ladle including that spent on transportation does not exceed 5 min. The temperature of the metal at the end of each pouring is at least 1400°C. In order to control the microstructure and the hardness, annular castings are taken from the top of the first pile and from the bottom of the eighth one.

The admissible content of ferrite in the microstructure of the metallic matrix is 5%; a broken steadite network, and structurally free cementite in the corners of the cross section are permitted but no deeper than the level of the process allowance. The metallic matrix of the cast iron is represented by lamellar pearlite. The microstructure of the rings is presented in Figs. 2b and 3.

After knocking out, castings from each ladle are stored separately. If the conclusions on the microstructure and hardness of castings from several ladles of one heat are positive, they are united into a single batch for processing in a batch shotblast drum. After visual monitoring of their appearance 10 castings are taken from a batch. Two of them are tested for hardness (in three zones). The scattering of the hardness values in one ring should not exceed 4 *HRB*, and in a batch it
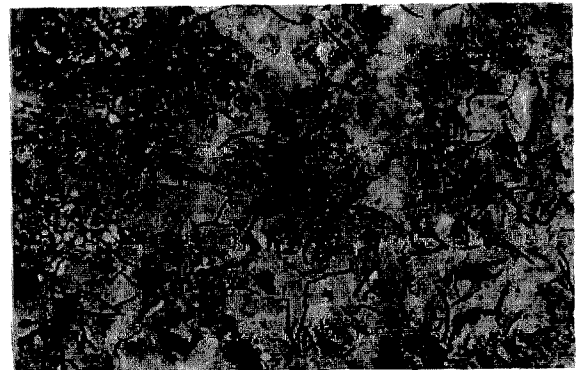

Fig. 3. Microstructure of a preform made of gray cast iron (lamellar pearlite and graphite). Etching in an HNO₃ solution in alcohol, × 400.

should not exceed 6 *HRB*. Each of the remaining 8 rings is broken into 10 – 12 parts in order to determine metallurgical defects in the fractures (blisters, slag inclusions, etc.). After this monitoring, the accepted batches are certified and transported for mechanical processing and chromizing.

CONCLUSION

The developed technology for melting, pouring, and modification cast iron for piston rings makes it possible to control the process of their structure formation and provides high-quality parts.