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REGULARITIES IN THE FORMATION OF THE STRUCTURE AND MECHANICAL PROPERTIES OF GRAY CAST IRON DEPENDING ON THE COOLING CONDITIONS AND CROSS-SECTION OF CASTINGS

Abstract. Gray cast iron is one of the basic casting materials in industry, widely used for the manufacture of parts for automotive, machine-building and railway equipment due to the combination of high casting properties, satisfactory mechanical characteristics and relatively low cost. In the context of increasing costs of primary raw materials and increased requirements for resource efficiency, the technology of smelting synthetic gray cast iron using steel scrap in induction furnaces is becoming increasingly widespread. Along with technological advantages, this approach determines the specific features of the formation of the microstructure of castings, especially in the presence of variable cooling conditions. One of the key factors determining the structure and properties of synthetic gray cast iron is the cross-section of castings, which directly affects the rate of heat removal during crystallization and subsequent cooling. Non-uniformity of thermal conditions can lead to changes in the dispersion of the pearlite matrix, the morphology of graphite inclusions and, as a result, to variations in the mechanical properties of the material. The complex of studies included Brinell hardness control, determination of tensile strength, and metallographic analysis. It was established that the microstructure of the studied material is represented by a pearlite matrix with lamellar graphite and finely dispersed phosphide eutectic. It was shown that an increase in the cross-section of the casting is accompanied by a decrease in the cooling rate, which is manifested in a decrease in the homogeneity of the pearlite matrix and an increase in the size of graphite cells. It was found that larger graphite inclusions contribute to a decrease in the tensile strength due to stress concentration, while the hardness level is determined mainly by the state of the pearlite matrix and the chemical composition of the alloy. The results obtained are of practical importance for optimizing the technological modes of casting synthetic gray cast iron, in particular when designing parts of different cross-sections and selecting cooling conditions in order to ensure a given set of mechanical properties.

Key words: gray cast iron, mechanical properties, carbon, hardness, tensile, microstructure.

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Introduction

Gray cast iron is one of the most common materials in modern metallurgy and metallurgy and is widely used for the manufacture of castings in the automotive, mechanical engineering, railway and civil engineering industries [1-5]. Typical areas of its use are diesel engine parts, brake elements, piston rings, grates, pipes, casting molds and elements of heat engineering equipment. Such popularity is due to the combination of good casting properties, sufficient strength, wear resistance and relatively low cost.

Traditionally, iron was the main raw material for the production of cast iron, however, today manufacturers are increasingly using steel scrap to reduce production costs for the production of cast iron. Such cast iron is now commonly called synthetic cast iron [6].

This method has been used for about 60 years and has already achieved significant progress. First of all, this allowed smelting to be carried out in coreless electric induction furnaces. Another advantage is the possibility of casting a liquid material of a given composition using almost 100% scrap [6]. At the beginning of the production of synthetic cast iron, it was observed that this material demonstrates higher hardness compared to cast iron produced by the traditional method, provided that the same alloying and addition of carburizers [7-10]. The obtained hardness had a number of advantages and disadvantages in certain areas of application, for example, it created difficulties during mechanical processing at the stages of finishing castings. In addition, synthetic cast iron is prone to increased internal stresses, which is explained by the nitrogen content due to the use of steel scrap [11-12]. Solidification of the melt in the mold, caused by cooling, leads to the production of castings of certain shapes and sizes; however, this process also introduces a number of disadvantages associated with natural settling in the mold, uneven cooling rates at different cross-sections and volume changes during phase transformations [13]. Given this, this work will focus on studying the impact of one of the above-mentioned shortcomings encountered today, which is associated with uneven cooling rates depending on the cross-section.

Purpose

The purpose of this work is to establish the influence of the cross-section of castings, as a factor determining the cooling rate during crystallization, on the features of the formation of the microstructure, the morphology of graphite inclusions and the level of mechanical properties of gray cast iron smelted in an induction furnace using steel scrap.

Materials and research methods

In the work, the object of the study was the experimental samples of gray cast iron with the chemical composition presented in Table 1. The experimental samples were melted in an induction furnace and cast into sand molds as control samples (cylindrical shape). These samples were cast with different cross-sections (No. 1 -24 mm, No. 2- 48 mm) to analyze the influence of the cross-section on the level of mechanical properties and microstructure. This approach allowed us to analyze the influence of the casting cross-section on the level of mechanical properties and microstructure features.

Table 1. Chemical composition of the experimental cast irons, wt%.

Number	C	Si	Mn	Cr	Cu	Ni	P	S	Mo
1	2,84	1,8	0,87	0,12	0,2	0,7	0,07	0,03	0,3
2	2,69	1,78	0,93	0,12	0,2	0,7	0,07	0,02	0,3

The control of mechanical properties was performed on pre-cut test samples along the cross-section of the workpiece. All test samples were prepared mechanically using CNC machines - HAAS. As a result of the preparation, test samples were obtained from two ingots measuring Ø22x10 mm (3 samples each) for hardness control, which were taken from the bottom, center and top of the test ingot; a tensile test sample to determine the tensile strength with a working zone diameter of 10 mm (Fig. 1); a microstructure control test sample Ø20x10 mm (3 samples each).

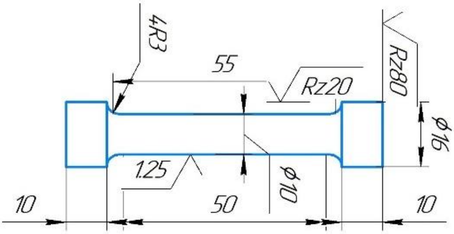


Figure 1 – Tensile test specimen

Test specimens for microstructure control were pre-prepared mechanically on vertical grinding and polishing machines using sandpaper of different grain sizes (P120…P1000) followed by polishing with a cloth. The structure was detected using a solution of nital. The microstructure was analyzed using a Carl Zeiss Axio Vert A1 optical microscope.

Hardness control was performed on a stationary hardness tester TSh-2M, the indenter was a metal sphere with a diameter of 10 mm and a load of

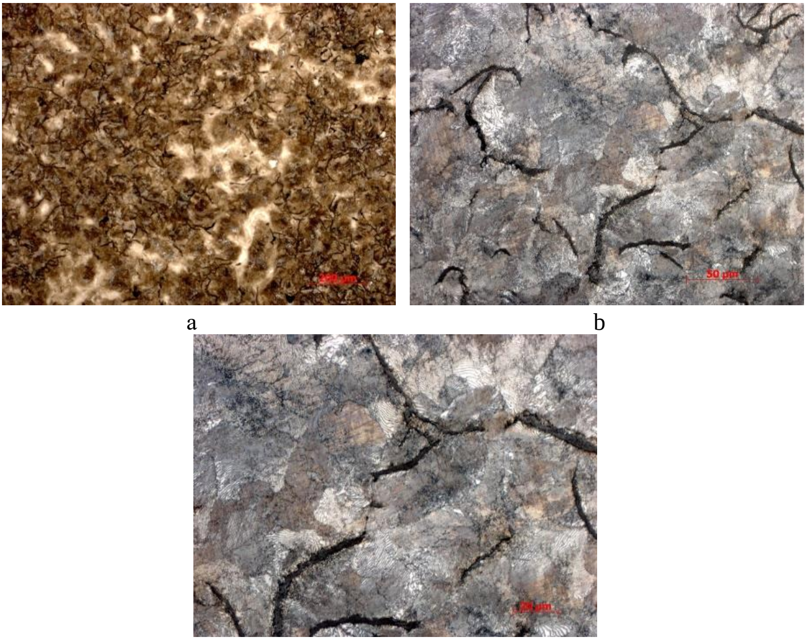
3000 kgf with a holding time of 10 s at this load. The resulting hole was controlled using a specialized MPB-2 reference microscope.

Determination of the tensile strength was performed on an Amsler tensile testing machine with a maximum load of 5 t and a traverse speed of 0.5 mm/s.

Results and discussion

As a result of the conducted research, it was found that the hardness of the test samples of ingot No. 1 during hardness testing showed an average hardness of 285, while ingot No. 2 has an average hardness of 269 HB, which is 16 HB lower than ingot No. 1. When testing the hardness, no fluctuations in hardness were observed along the height of the ingot, and the increased level of hardness is associated not only with the cross-section of the ingot, but with the probable influence of the carbon content, which is higher by 0.15%.

When determining the strength limit of test ingots No. 1 and No. 2, it was found that the strength limit of test ingot No. 1 has a value of 285.4 MPa. At the same time, the strength limit of test ingot No. 2 is 268.5 MPa, which is probably also related to the carbon content in the test ingots, but this conclusion is preliminary and requires additional analysis of the microstructure.



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c

Figure 2 – Microstructure of test ingot No. 1

At the next stage, the microstructure of the experimental ingot No. 1 was analyzed (Fig. 2). As a result of the microstructure analysis, it was found that the structure consists of pearlite and lamellar graphite (Fig. 2, a). The graphite is lamellar rectilinear (Fig. 2, b, c). The length of the graphite inclusions is approximately 45 µm. The graphite colonies are mainly distributed evenly and correspond to a score of 3 (GOST 3443). The analysis of the number of graphite inclusions is approximately 6%. The dispersion of pearlite is not uniform and mainly has a size of 0.3-1.0 (GOST 3443), the presence of a uniform phosphide eutectic, namely a ternary fine-grained.

As a result of the microstructure analysis of the experimental ingot No. 2 (Fig. 3), it was shown that the structural component consists of pearlite of different dispersion and lamellar graphite (Fig. 3, a). Graphite, as in ingot No. 1, is lamellar rectilinear (Fig. 3, b, c) with a length of 45 µm. Graphite colonies are mainly distributed evenly and correspond to a score of 3 (GOST 3443), by the number of graphite inclusions ~ 6%. Pearlite dispersion is uniform 1.0 (GOST 3443), which indicates the presence of both coarse-plastic cells and fine-dispersed ones. Also, as in ingot No. 1, a finely dispersed phosphide eutectic with a uniform distribution was detected.

Thus, as a result of the analysis of the microstructure and its comparison with standard requirements, it can be concluded that one of the distinguishing elements is the dispersion of pearlite, which can affect the mechanical properties, in addition to the content of the main strengthening element - carbon.

Taking into account minor differences in the microstructure, an additional analysis was carried out, namely, measuring the size of graphite cells and their number (Fig. 4). The analysis showed that in the field of view of the control ingot No. 1, 5 cells with a diameter of 14-40 µm were detected, in ingot No. 2, 4 cells were detected, but with a larger diameter from 25 to 52 µm.

Taking into account the analysis of graphite cells, it was found that the presence of larger cells with a lower carbon content plays a significant role in the indicators of bulk hardness, namely, a decrease in this characteristic. When testing for tensile strength, the tensile strength is lower, probably this is also due to the size of the graphite cells. It should also be noted that the presence of larger graphite cells in ingot No. 2 may be one of the reasons for the smelting conditions and longer dissolution and redistribution of graphite, which had a larger cross-section.

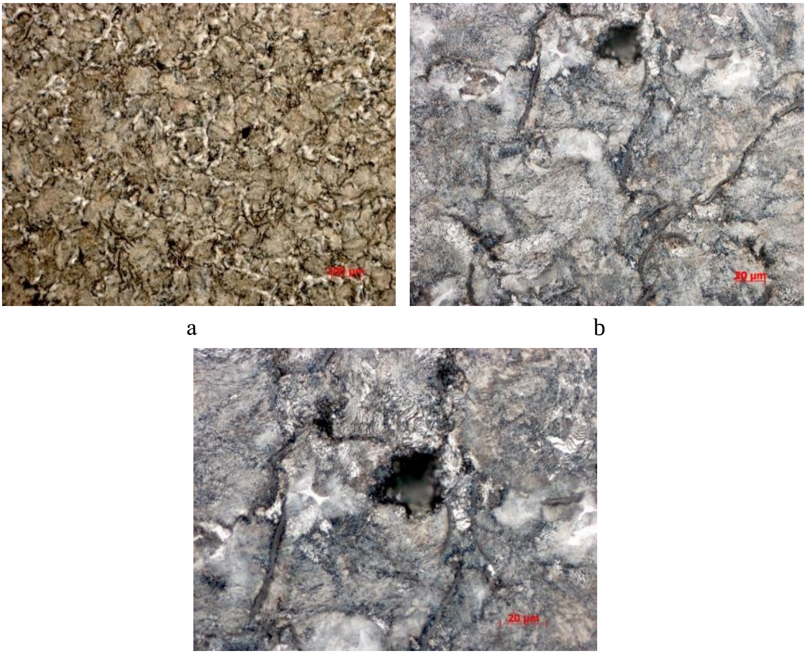

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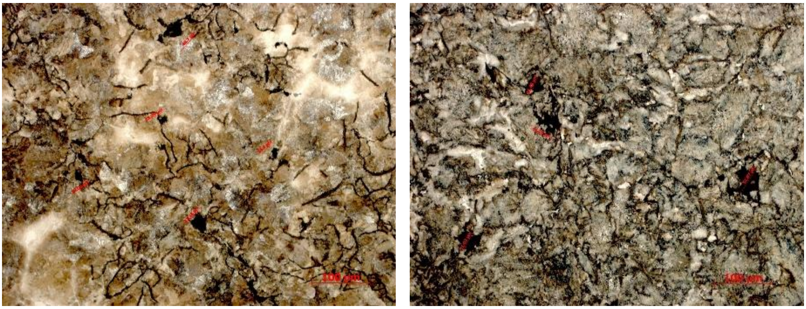
Figure 3 - Microstructure of test ingot No. 2



a b

Figure 4 – Graphite in test samples No. 1 (a) and No. 2 (b)

Conclusions

1. It was established that the microstructure of the studied synthetic gray cast iron is represented by a pearlite matrix with evenly distributed lamellar graphite and phosphide eutectic.

2. An increase in the size of graphite cells contributes to stress

concentration and a decrease in the tensile strength.

3. The level of hardness is determined mainly by the state of the pearlite matrix and the chemical composition of the alloy, while the influence of graphite morphology is secondary.

4. The mechanical properties of gray cast iron are formed under the complex influence of the chemical composition, cooling rate and geometry of castings, which must be taken into account when developing casting technologies for parts of various cross-sections.

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ЗАКОНОМІРНОСТІ ФОРМУВАННЯ СТРУКТУРИ ТА МЕХАНІЧНИХ ВЛАСТИВОСТЕЙ СІРОГО ЧАВУНУ ЗАЛЕЖНО ВІД УМОВ ОХОЛОДЖЕННЯ ТА ПЕРЕРІЗУ ВИЛИВКІВ

Анотація. Сірий чавун є одним із базових ливарних матеріалів в промисловості, що широко застосовується для виготовлення деталей автомобільної, машинобудівної та залізничної техніки завдяки поєднанню високих ливарних властивостей, задовільних механічних характеристик і відносно низької собівартості. В умовах зростання вартості первинної сировини та підвищених вимог до ресурсоефективності все більшого поширення набуває технологія виплавки синтетичного сірого чавуну з використанням сталевого брухту в індукційних печах. Разом із технологічними перевагами такий підхід зумовлює специфічні особливості формування мікроструктури виливків, особливо за наявності змінних умов охолодження. Одним із ключових факторів, що визначає структуру та властивості синтетичного сірого чавуну, є переріз виливків, який безпосередньо впливає на швидкість тепловідведення під час кристалізації та подальшого охолодження. Нерівномірність теплових умов може призводити до зміни дисперсності перлітної матриці, морфології графітових включень і, як наслідок, до варіацій механічних властивостей матеріалу. Комплекс досліджень включав контроль твердості за методом Бринелля, визначення границі міцності при розтягуванні, а також металографічний аналіз. Встановлено, що мікроструктура досліджуваного матеріалу представлена перлітною матрицею з пластинчастим графітом і дрібнодисперсною фосфідною евтектикою. Показано, що збільшення перерізу виливка супроводжується зниженням швидкості охолодження, що проявляється у зменшенні однорідності перлітної матриці та збільшенні розмірів графітових осередків. Виявлено, що більші графітові включення сприяють зниженню границі міцності при розтягуванні внаслідок концентрації напружень, тоді як рівень твердості визначається переважно станом перлітної матриці та хімічним складом сплаву. Отримані результати мають практичне значення для оптимізації технологічних режимів лиття синтетичного сірого чавуну, зокрема при проєктуванні деталей різного перерізу та виборі умов охолодження з метою забезпечення заданого комплексу механічних властивостей.

Ключові слова: сірий чавун, механічні властивості, вуглець, твердість, розтягування, мікроструктура.

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