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Gradient Structure and Wear Resistance of Steel Castings

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The influences of temperature-kinetic parameters on the morphology, dispersion, and gradient of their cast structure are studied using the example of castings of 30ХГС and У7Л steels obtained under the condition of directional cooling of their end surfaces during crystallization with different intensity of heat removal (5°C/s and 300°C/s), as well as on the length of the transcrystallization zone and its influence on the wear resistance in various sections of castings during abrasive wear. A regular increase in the length of the transcrystallization zone (zone of columnar crystals) is established, corresponding to an increase in the superheat temperature of the steel melt in the range of 50°C–150°C above the liquidus temperature and the cooling rate during the crystallization of castings. As shown, the maximum resistance to abrasive wear is observed during high-rate crystallization of castings and corresponds to an increase in the length of the transcrystallization zone in the cross-sections of samples oriented across the direction of heat removal and advancement of the crystallization front. Such anisotropy of the structure of the transcrystallization zone makes it possible to increase additionally the wear resistance by 13–18% and opens up new prospects for the engineering of cast products to improve their operational properties.

Key words: steel, castings, crystallization, structure, overheating, cooling rate, wear resistance.

На прикладі виливків криць 30ХГСЛ і У7Л, одержаних за умов спрямованого охолодження їхньої іверової поверхні під час кристалізації з різ-

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ною інтенсивністю тепловідбору (5°C/с і 300°C/с), досліджено вплив температурно-кінетичних параметрів на морфологію, дисперсність і ґрадієнтність їхньої литої структури, а також на протяжність зони транскристалізації та її вплив на зносостійкість у різних перерізах виливків за умов абразивного зношування. Встановлено закономірне збільшення протяжности зони транскристалізації (зони стовбчастих кристалів) відповідно до підвищення температури перегріву розтопу криць в інтервалі температур на 50°C–150°C вище температури ліквідусу та швидкости охолодження під час кристалізації виливків. Показано, що максимальна стійкість до абразивного зношення спостерігається за умов швидкісної кристалізації виливків і відповідає збільшенню водночас протяжности зони транскристалізації у перерізах зразків, орієнтованих поперек напрямку тепловідбору та просування фронту кристалізації. Така анізотропність структури зони транскристалізації уможливлює додатково підвищити зносостійкість на 13–18%, відкриває нові перспективи інженерії литих виробів для підвищення їхніх експлуатаційних властивостей.

Ключові слова: криця, виливок, зносостійкість, перегрів, кристалізація, структурні зони, ґрадієнтність.

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1. INTRODUCTION

In the production of castings using traditional casting technologies, a certain inhomogeneity (gradient) of the morphology and dispersion of the cast structure is observed as well as the corresponding change in the mechanical and operational properties of steel products. Metallographically, the possibility of the formation of different macrostructural zones, the structure and length of which is determined by changes in the temperature and time conditions of melt crystallization in the temperature range of the solid–liquid state, is shown [1]. Usually, four main macrostructural zones are distinguished in the cross-section of castings: a chill zone of small equiaxed grains (I); transcrystallization zone of columnar grains oriented in the direction of the main prevailing heat removal (II); a transition zone of branched dendritic-like grains (III); a zone of large equiaxed grains in the central volumes of the castings (IV). The wider the temperature range of steel crystallization, the larger the dimensions and weight of the cast product, the higher the probability of structural heterogeneity inside it. The wider the temperature interval of steel crystallization, the larger the dimensions and mass of the cast product, the higher the probability of structural inhomogeneity in it. In most cases, casters try to ensure the formation of a homogeneous fine-crystalline structure across the entire cross-section of the castings, similar to castings from rolled steel. However, providing such a structure in cast products is a complex technological task.

Modern casting technologies make it possible to effectively use the specified features of the structure in castings and create conditions for the formation of certain directional and gradient structures in them, to realize additional reserves for increasing special properties, in particular, the wear resistance of cast products in accordance with the conditions of their operation [2–9].

Based on the above and in the absence of systematic research in this direction, the purpose of this work was to establish the regularities of the influence of thermokinetic crystallization parameters (melt temperature and cooling rate) on the gradient structure of steel castings and the associated change in wear resistance in various macrojet zones along the depth of the castings in the conditions abrasive wear. The study of the relationship between the presence and length of the transcrystallization zone (II) and the wear resistance of steel castings is of particular interest.

2. EXPERIMENTAL/THEORETICAL DETAILS

The study was conducted on rectangular castings of 30ХГСЛ and У7Л steels, the chemical composition of which is given in Table 1, with dimensions of 60×60×100 mm. The castings were designed to ensure one-sided predominant cooling of the end part of the castings with different intensity of heat removal V during solidification: 5°C/s (sand mold) and 300°C/s (copper water-cooled mold). The steels were melted in an induction furnace with acidic lining using the same technically clean raw materials (ISO 4990:2015). The melts of the investigated steels were poured into moulds at temperatures 50°C, 100°C, and 150°C higher than the liquidus temperature (T_L) of each of the steels. The liquidus temperatures (T_L) were determined by a calculation method based on the chemical composition of the steels and were 1486°C and 1470°C for 30ХГСЛ and У7Л steels, respectively [10, 11]. The investigated castings were removed from the moulds after cooling to room temperature.

The wear resistance test was carried out on samples cut from the casting along and across the direction of heat removal, on the ЛМИ-3М friction machine on an abrasive pad (P120) at a sample movement speed of 0.20 m/s and a specific static load of 1.85 kg/m^2 for 5 min.

TABLE 1. The chemical composition of steels.

Steel	Weight fraction of elements, %					
	C	Mn	Si	Cr	P	S
30ХГСЛ	0.29	0.9	1.1	1.0	0.025–0.030	0.025–0.030
У7Л	0.69	0.45	0.31	0.20	0.025–0.030	0.028–0.032

3. RESULTS AND DISCUSSION

Metallographically, the formation of a cast structure with a systematic decrease in its dispersion along the depth of the castings and the formation of transcrystallization zones (columnar crystals) of various lengths depending on the temperature–kinetic conditions of melt solidification have been established. Thus, with an increase in the melt temperature from $T_L + 50°C$ to $T_L + 100°C$ and $T_L + 150°C$, an increase in the extent of this zone is observed in all modes of external heat removal, reaching maximum values during rapid cooling of the casting surface of steels. Under these cooling conditions (300°C/s), the length of the zone of

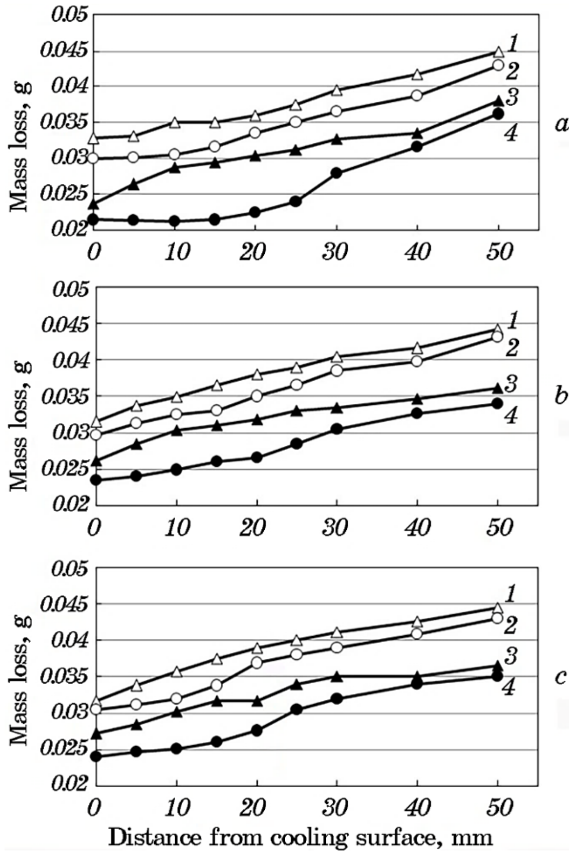

Fig. 1. Wear along the cross-section of 30ХГСЛ steel castings depending on temperature–time conditions and the direction of heat removal during crystallization: melt temperature of 1670°C (*a*), melt temperature of 1620°C (*b*), melt temperature of 1570°C (*c*); *1*, *3*—along the direction of crystallization, *2*, *4*—across the direction of crystallization, *1*, *2*—cooling speed of 5°C/s, *3*, *4*—cooling speed of 300°C/s.

columnar crystals in 30ХГСЛ steel castings is 20 mm, 24 mm and 25 mm, in У7Л steel castings it is 18 mm, 20 mm and 26 mm, respectively. While the melts of the studied steels solidify at a standard cooling rate (5°C/s), with increasing melt temperature, the transcrystallization zone for 30ХГСЛ steel castings reaches 16 mm, 18 mm, and 20 mm, while for У7Л steel, it amounts to 10 mm, 13 mm, and 16 mm, respectively.

Experimentally, it has been established that, during abrasive wear, a higher level of wear resistance is observed in the surface layers (zones I, II) of the castings of both investigated steels under all regimes of melt overheating and cooling during crystallization (Fig. 1, Fig. 2),

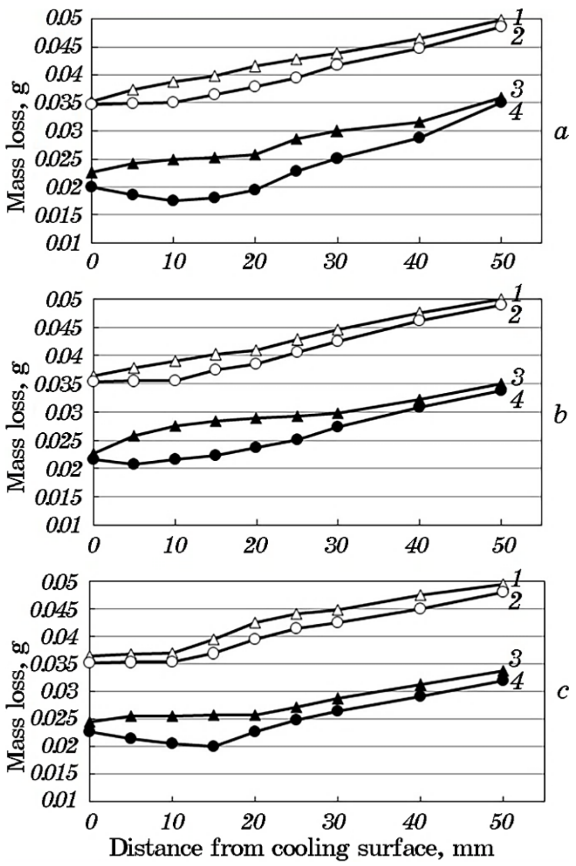

Fig. 2. Wear along the cross-section of У7Л steel castings depending on temperature–time conditions and the direction of heat removal during crystallization: melt temperature of 1670°C (*a*), melt temperature of 1620°C (*b*), melt temperature of 1570°C (*c*); *1*, *3*—along the direction of crystallization, *2*, *4*—across the direction of crystallization, *1*, *2*—cooling speed of 5°C/s, *3*, *4*—cooling speed of 300°C/s.

and the orientation of samples relative to the direction of heat removal.

It should be noted that the overall level of wear resistance in steel castings of high-speed cooling during crystallization is higher than in castings of normal cooling. For example, at maximum overheating of the melt, the mass loss of rapid cooling samples decreases by 17% (steel 30ХГСЛ) and by 35% (steel У7Л), when determining wear resistance along the direction of heat removal during crystallization. The highest rates of resistance to abrasive wear are observed on rapid cooling samples oriented across the direction of heat removal (direction of crystallization) and correspond to the length of the transcrystallization zones. When the samples are oriented across to the direction of heat transfer, the difference in mass loss between rapidly cooled and normal-cooled castings can reach 30% for 30ХГСЛ steel and 48% for У7Л steel.

4. CONCLUSION

A significant part of modern research is devoted to the development of technological processes for the production of castings with surface functional layers, including wear-resistant ones. Most existing methods do not allow obtaining a functional layer with a thickness of more than a few tenths of a millimetre, which is not enough for long-term operation of castings. Methods that make it possible to obtain a functional layer of the required thickness significantly complicate and reduce the profitability of the casting manufacturing process due to the high cost and complexity of the equipment.

Thus, based on the results of the research, the possibility of purposefully changing the gradient of the cast steel structure, controlling the extent and dispersion of macrostructural zones in castings, forming mechanical properties and wear resistance by means of regulating the temperature–time parameters of melt preparation, crystallization and structure formation has been proven. This opens up the prospect of producing cast products with predetermined differentiated properties in the volume of castings for special operating conditions, limited by the minimum quantity and low cost of external equipment.

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