RESERVES OF RESOURCE SAVING IN THE MANUFACTURE OF BRAKE DRUMS OF CARGO VEHICLES

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ABSTRACT

The object of this research: cast iron grade DSTU EN 1561 (EN-GJL-200), used for the manufacture of brake drums for KrAZ trucks.
Investigated problem: obtaining the effect of resource saving by minimizing the consumption of alloying elements, while maintaining a given level of mechanical properties of cast iron.
The main scientific results: experimental and theoretical confirmation of the possibility of reducing the content of Cr introduced into the alloy to increase its strength, as part of the Cr:Ni alloying complex, was obtained. It is shown that a decrease in the Cr content from the upper range (0.34–0.48) % to the lower one (0.21–0.33) % does not affect the ultimate strength of cast iron (σ_b). The obtained values of σ_b for both ranges are statistically equal: σ_b=234 MPa, $S_{\sigma b}$=16.22 MPa for the upper range of Cr content and σ_b=240 MPa, $S_{\sigma b}$=19.86 MPa for the lower range of Cr content, where $S_{\sigma b}$ is the standard deviation of the tensile strength value. It is established that the hardness (HB) is also unchanged: the obtained values of HB for both ranges are statistically equal: HB213, S_{HB}=9.1 for the upper range of Cr content and HB212, S_{HB}=12 for the lower range of Cr content, where SNB is the standard deviation of hardness. At the same time, it has been statistically proven that the Cr:Ni ratio can be shifted towards lower Cr values – from Cr:Ni=2.2:1 in the existing technology to Cr:Ni=1.76:1 in the ones proposed in this study.
The area of practical use of the results of the study: the results obtained can be used in machine-building enterprises specializing in the manufacture of hull cast iron parts with a foundry cycle. The adaptation of the proposed results to the actual conditions of the foundry production of implementing organizations will be minimal if they comply with the following criteria: cast iron grade, predominant or minimum casting wall thickness, temperature regime of melting and out-of-furnace treatment, ferroalloys and modifiers used.
Innovative technological product: iron smelting technology for commercial vehicle brake drum castings that reduces production costs while maintaining a given level of mechanical properties
The scope of the technological innovative product: technological regimes for producing cast iron for the production of cast brake drums for trucks.

1. Introduction

1. 1. The object of research

Cast iron grade DIN 1691-GG-20 (ASTN A48 Class 30), used for the manufacture of brake drums for KrAZ trucks.

1. 2. Problem description

The struggle for the quality of cast parts in the automotive industry involves diverse approaches to the design and technological preparation of production. The most promising is the use of computer-integrated solutions at the design stage of foundry equipment using CAD/CAM/CAE tools and systems. The first step in the implementation of this approach is, as a rule, the construction of a solid model using Solid Works (SolidWorks Corporation, Dassault Systemes, France) followed by computer simulation of the processes of filling molds with metal [1, 2], crystallization processes [3] and predicting the formation of internal defects in castings [4]. Such approaches require the correct setting of all technology parameters, including the properties of both the casting mold itself and the materials used, as well as the technological regimes of the process. Considering that all these parameters are mostly either random or fuzzy values, the simulation results are not always adequate and require adaptation. This, in turn, requires additional experimental and industrial research to clarify the process parameters to make adjustments to the design and technological preparation of production. However, this is not the only problem if the quality of castings of automotive parts is considered not only by the criterion of the absence of internal defects caused by casting and crystallization processes. An important factor is the quality of the alloy, which requires technological solutions that are not directly related to the design of tooling. Solutions are needed that allow choosing rational modes of melting and out-of-furnace processing of alloys. Such solutions should provide control over the processes of structure formation that affect the formation of mechanical properties. As a rule, this is carried out either by modifying the melt when it is discharged from the furnace [5], or by selecting the ratios of graphitizing elements in combination with alloying [6, 7]. Sometimes the influence of the chemical composition of the alloy on the formation of the structure and properties is studied taking into account the cooling rate of the casting in the mold [8]. Finished castings inevitably contain internal defects, therefore, sometimes the formation of mechanical properties is considered not only from the point of view of the influence of the microstructure on them, but also from the point of view of the influence of internal defects: cavities, porosity, etc. [9]. Such approaches require knowledge of the quantitative influence of technological process factors on the properties being formed, which is impossible without the construction of appropriate mathematical models [10–12]. In this case, a reasonable choice of the range of variation of the input variables is required, which in the majority is either the amount of the introduced modifier or ferroalloy, or the content of elements of the chemical composition, or the ratio of carbide-forming and graphitizing elements. However, choosing in this case any of the optimization criteria, they often do not operate with the concept of costs for obtaining an alloy of a given or optimal value, according to the selected quality criterion. Therefore, the question arises whether it is possible to provide a given, optimal, or at least acceptable level of mechanical properties, with a minimum cost for the alloying or modification process.

1. 3. Suggested solution to the problem

Verification of the possibility of reducing the costs of the melt treatment process can be performed on the basis of experimental industrial studies directly in the production process using a specific casting as an example. The research hypothesis in this case is as follows. The results of the statistical analysis of the mechanical properties of the alloy obtained in serial heats should confirm or disprove the possibility of obtaining a given level of mechanical properties with a Cr content in the minimum range of values. Chromium was chosen as a priority element, since it is the most common element used to increase the strength of the alloy. However, Cr is an expensive alloying element, and it is introduced, as a rule, in combination with Ni, in the recommended ratio Cr:Ni=3:1.

The aim of the study: to test the hypothesis about the possibility of maintaining a given level of mechanical properties of cast iron used for the manufacture of castings of brake drums, while reducing the consumption of chromium introduced into cast iron as part of the Cr-Ni alloying complex.

2. Materials and Methods

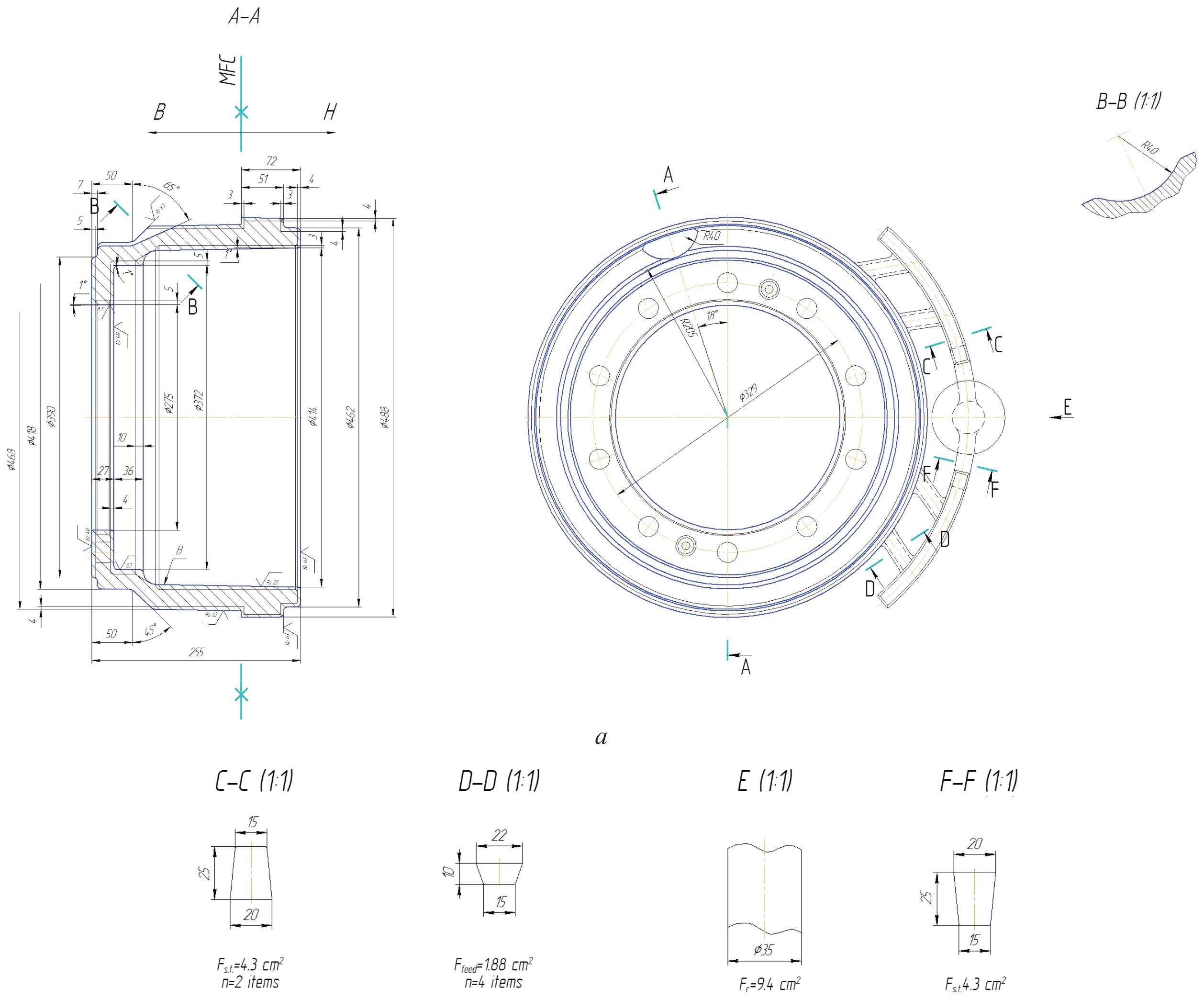
The basic technology for manufacturing brake drums based on disposable sand molds using metal model equipment are used (**Fig. 1**).

Melting was carried out by the "cupola - mixer" duplex process in accordance with the Regulations described in [13]. Technical characteristics of furnaces are given in **Tables 1, 2**.

The chemical composition was corrected by introducing ferroalloys into the electric furnace after its control in the melt issued from the cupola (**Tables 3, 4**).

Chromium and nickel were initially introduced with a charge into a cupola in the composition of chromium-nickel cast iron with a ratio of elements Cr:Ni=2.2:1–2.4:1.

Modification was carried out on the furnace chute with the release of the melt with ferrosilicon (FeSi75) at a temperature of about 1400 °C. The modifier was introduced in an amount of 0.3 % by weight of the liquid metal with a fraction of 1–10 mm.



a

b

Fig. 1. Casting technology and gating system: *a* – casting technology; *b* – sections of the elements of the gating system

Tensile strength testing was carried out in accordance with DSTU EN 10002-1 (DSTU EN 10002-5), hardness testing was carried out in accordance with DSTU ISO 6506-1.

The boundary value of the Cr content separating the upper range from the lower one was 0.33 %, as accepted in practice in the basic technological process in accordance with the recommendations [7, 14]. The upper range for chromium content was (0.34–0.48) %, and the lower range was (0.21–0.33) %. The number of serial heats with the upper range was 51, the number of experimental industrial heats with the lower range was 38.

The mathematical expectation of the content of the element and the value of mechanical properties in each of the series of heats – for the upper and lower ranges of the Cr content, and the value of the standard deviation – were calculated by formulas (1) and (2), respectively:

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} X_i, \quad (1)$$

$$S_X = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(X_i - \overline{X}\right)^2}, \quad (2)$$

where X_i – the content of an element of chemical composition, %, or mechanical properties (σ_b, MPa and HB), S_x – the standard deviation of the content of an element of chemical composition or mechanical property, N – the number of experimental points for which the calculation of statistical characteristics is carried out. According to the total data sample N=89, for the upper range of chromium content N=51, for the lower range of chromium content N=38.

Table 1

Technical characteristics of the cupola

No.	Name	Dimension	Characteristic
1	Performance	t/h	5
2	Download method	–	skip lift
3	Diameter in the light	mm	900
4	Cross-sectional area	mm^2	0.636
5	Useful height (from the axis of the lower row of tuyeres to the level of the filling window)	mm	4234
6	The number of the I row tuyeres	–	6
7	The number of the II row tuyeres	–	6
8	The number of the III row tuyeres	–	6
9	I row tuyere size	mm×mm	200×125
10	II row tuyere size	mm×mm	70×50
11	III row tuyere size	mm×mm	70×50
12	Receiver diameter	mm	820
13	Working capacity of a receiver	m^3	0.283
14	Height from the hearth to the slag tap hole of the receiver	mm	450
15	Height from the hearth to the axis of the I row tuyeres	mm	400
16	Diameter of the slag tap hole	mm	50
17	Diameter of metal tap holes	mm	25
18	Number of metal tap holes	–	2
19	Transition window section	mm×mm	120×90
20	The mass of the loaded metal charges	kg	500
21	The mass of idle charges	kg	900–930
22	The height of the idle charge above the upper edge of the III row of tuyeres	mm	550–600
23	Air pressure in the tuyere box	mm wc	600–650
24	Fan type	–	A-72-2 No. 725766
25	Fan aperture diameter	mm	220

Table 2

Technical characteristics of the electric furnace

No.	Name	Dimension	Characteristics	Motes
1	Furnace capacity	t	10	cast iron
2	Power transformer	kW	2250	–
3	Transformer low side voltage	V	150 125 105	with deviations ±5 %
4	Maximum furnace current	A	10400	–
5	Number of phases	–	3	–
6	Current frequency	s^{-1}	50	–
7	Electrode diameter	mm	350	–
8	Electrode decay diameter	mm	900	–
9	Electrode stroke	mm	1200	–
10	Electrode speed	m/min	1.65	–
11	Bath diameter at threshold	mm	2350	–
12	Depth of the bath to the threshold	mm	560	–
13	Working window dimensions	mm×mm	780×460	width×height
14	40° tilt time	S	56	minimal
15	Specific energy consumption for cast iron heating	kW·h/t	105	when heated from 1400 to 1550 °C
16	Cooling water consumption	m^3/h	15	–
17	The total weight of the furnace metal	T	23.6	–

Table 3

The amount and method of introducing additives to reduce the content of elements in cast iron

Name of additives	The amount of additive, kg per 1 ton of molten iron, introduced into the electric furnace					
	Si, %			**Mn, %**		**Cr, %**
	0.1	**0.2**	**0.3**	**0.1**	**0.2**	**0.1**
Steel scrap	12	25	38	42	84	74
Converted cast iron	26	51	76	83	166	148
–	In this case, Mn is introduced, %			In this case, Si is introduced, %		In this case, the following shall be introduced: Mn=0.17 %; Si=0.1 %
	0.018	0.038	0.057	0.06	0.12	–

Table 4

The amount and method of introducing additives to increase the content of elements in cast iron

Name of additives	The amount of additive, kg per 1 ton of molten iron, introduced into the electric furnace					
	Si, %	**Mn, %**	**Cr, %**	**C, %**	**Ti, %**	**Cu, %**
	0.1	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Ferrosilicon FS-25	4.4	–	–	–	–	–
Ferromanganese FMN-70	–	1.3*	–	–	–	–
Ferrochrome	–	–	1.85	–	–	–
Converted cast iron	–	–	–	25	–	–
Titanium copper cast iron	–	–	–	–	13.3	36.3

*Note: * – given to the bottom of the bucket*

3. Results

Fig. 2–5 show circular diagrams of the distribution of the content in melts of elements: C, Mn, Si, Ni. Statistical characteristics calculated according to (1) and (2) for the upper and lower ranges of chromium content are shown in **Tables 5**, **6,** respectively.

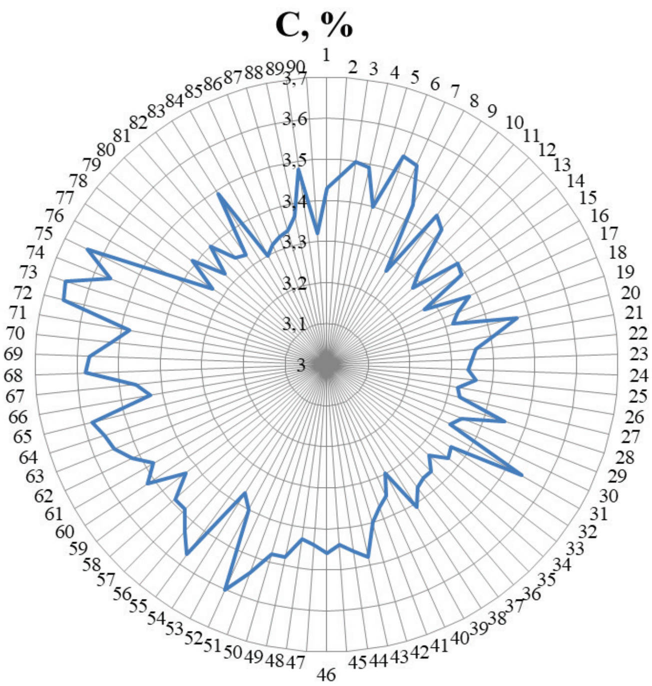


Fig. 2. Diagram of distribution of content in melts C, %

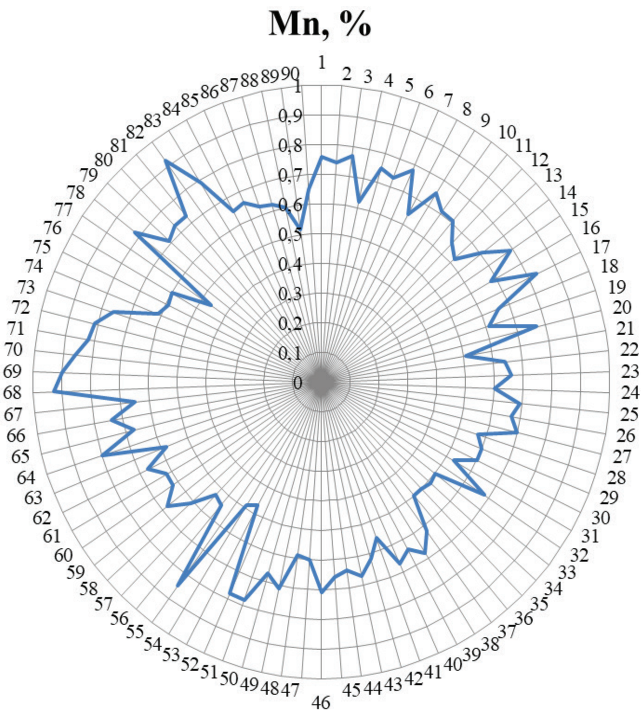


Fig. 3. Diagram of distribution of Mn content in melts, %

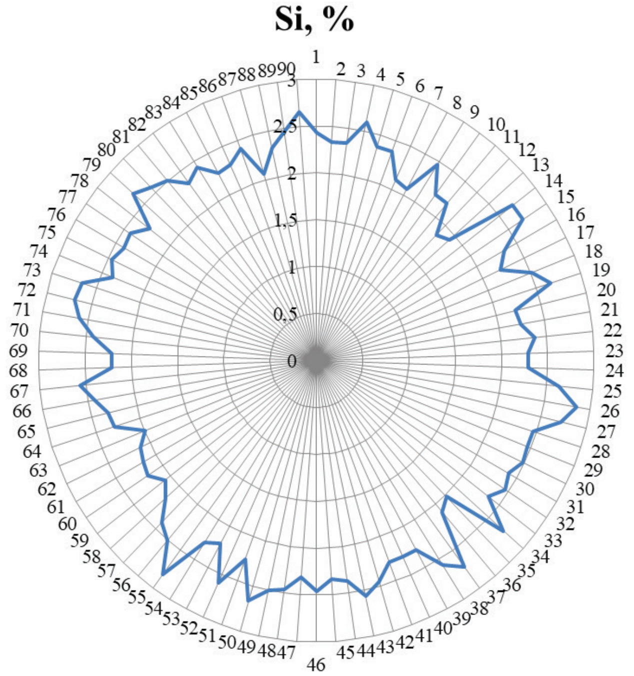


Fig. 4. Diagram of distribution of Si content in melts, %

Table5

Statistical characteristics for the upper range of chromium content

C, %		Mn, %		Si, %		Ni, %		σ_b, MPa		HB	
$\overline{X}_{C}$	S_{C}	$\overline{X}_{Mn}$	S_{Mn}	$\overline{X}_{Si}$	S_{Si}	$\overline{X}_{Ni}$	S_{Ni}	$\overline{X}_{\sigma b}$	$S_{\sigma b}$	$\overline{X}_{HB}$	S_{HB}
3.43	0.09	0.69	0.097	2.42	0.21	0.18	0.01	234	16.2	213	9.1

Note: with the charge, on average, 0.27 % Cu and 0.07 % Ti were also introduced in the composition of titanium-copper cast iron

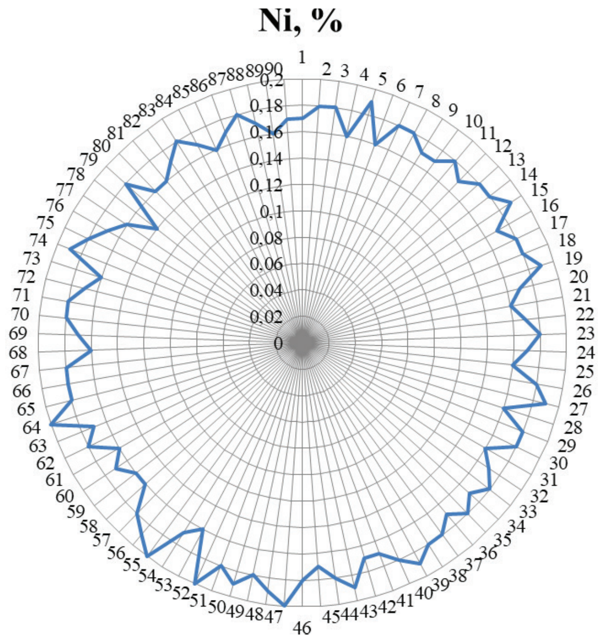
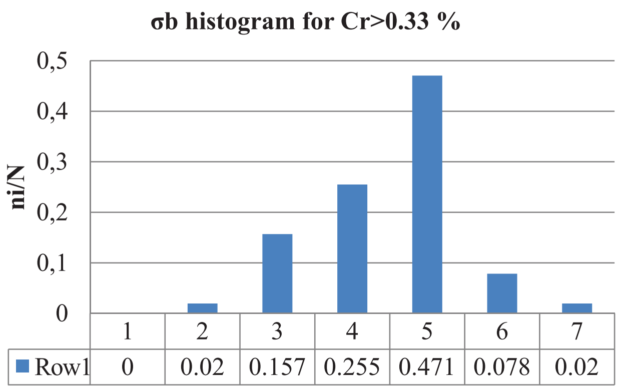


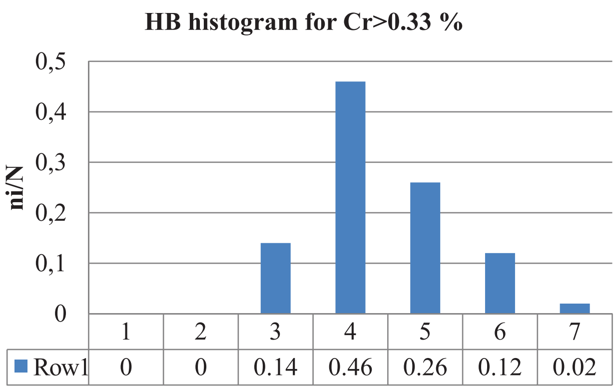
Fig. 5. Diagram of distribution of Ni content in melts, %

The content of sulfur (S) and phosphorus (P) in the alloy did not exceed 0.084 % and 0.137 %, respectively.

Fig. 6, **7** show histograms of the distribution of σ_b and HB for the upper and lower ranges of chromium content, respectively.



a



b

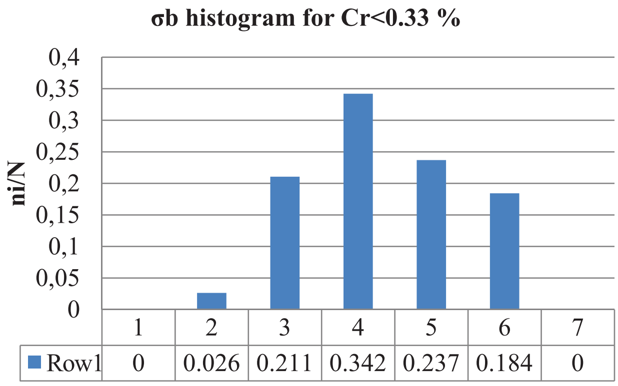
Fig. 6. Distribution histograms of σ_b and HB for the upper range of chromium content: *a* – σ_b distribution; *b* – HB distribution

Table6

Statistical characteristics for the lower range of chromium content

C, %		Mn, %		Si, %		Ni, %		σ_b, MPa		HB	
$\overline{X}_C$	S_C	$\overline{X}_{Mn}$	S_{Mn}	$\overline{X}_{Si}$	S_{Si}	$\overline{X}_{Ni}$	S_{Ni}	$\overline{X}_{\sigma b}$	$S_{\sigma b}$	$\overline{X}_{HB}$	S_{HB}
3.43	0.095	0.64	0.106	2.34	0.18	0.17	0.007	240	19.9	212	12

Note: an average of 0.29 % Cu and 0.06 % Ti was also introduced with the charge in the composition of titanium-copper cast iron



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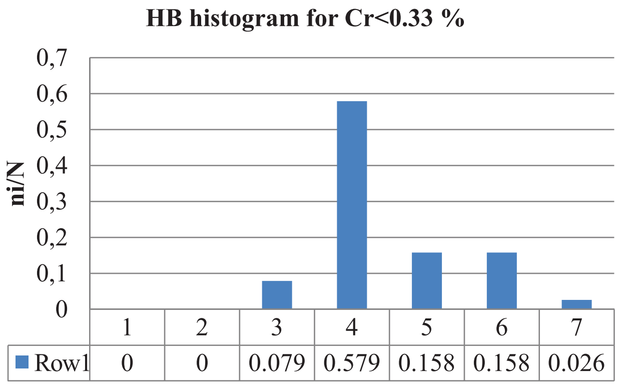

b

Fig. 7. Distribution histograms of σ_b and HB for the lower range of chromium content: *a* – σ_b distribution; *b* – HB distribution

It should be noted that both asymmetry and kurtosis take place, therefore, to check the compliance of the distribution of mechanical property values with the normal law, one of the goodness-of-fit criteria should be used. However, by analyzing the obtained histograms, there is reason to believe that the distribution laws of σ_b and HB are close to normal. Therefore, these results can be taken as initial for the analysis of the possibility of transition from the upper to the lower range of chromium content while maintaining a given level of mechanical properties.

4. Discussion

From **Fig. 6, *a*** and **Fig. 7, *a*** it can be seen that the range of random errors estimated by the three sigma rule (in this case it is 3S) covers both areas of the distribution of σ_b values – both for the upper and lower ranges and is (185–283) MPa and (180–300) MPa, respectively. This indicates that the transition to the region of the lower range of chromium content does not lead to a change in the value of the tensile strength. That is, it is possible in principle to reduce the consumption of Cr to (0.21–0.33) %.

Similar conclusions can be drawn for the hardness of the alloy, which will also not change (**Fig. 6, *b*, 7, b).** With such results, it is possible to assume that the generalized indicator of the quality of the material, estimated by the ratio σ_b/HB, remains constant. Consequently, it becomes possible to save resources and reduce the cost of producing brake drums. This is also confirmed by the fact that in the transition to the lower range of chromium content, the ratio in the Cr-Ni alloying complex decreases – from Cr:Ni=2.2:1–2.4:1 to Cr:Ni=1.76:1.

The results obtained in this way can be explained by the fact that structural transformations do not undergo significant changes in the considered ranges of chromium content. This is facilitated by rationally selected content of graphitizing elements, which compensate for the potential effect of carbide formation with the formation of Fe_3C in the thinner walls of the casting. For the "brake drum" casting, this thickness is 27 mm (**Fig. 1**).

The results obtained are limited by the ranges of variation in the content of elements of the chemical composition (**Fig. 3, 5**), as well as by the technological modes of the process. Therefore, when using the results obtained in practical conditions, one should take into account the need to adapt them according to the following criteria: cast iron grade, the predominant or minimum thickness of the casting wall, the temperature regime of melting and out-of-furnace processing, the ferroalloys and modifiers used.

The study of the mechanisms of formation of mechanical properties, taking into account the variation of the wall thickness of castings, can be considered as a potentially interesting development of this study. This will make it possible in the future to build models of the type "chemical composition – cooling rate – microstructure – mechanical properties" and move on to solving the problem of purposeful control of the properties of the alloy, taking into account possible variations in the process of design and technological preparation of production.

5. Conclusions

It was found that a decrease in the Cr content from the upper range (0.34–0.48) % to the lower range (0.21–0.33) % does not affect the value of σ_b. The obtained σ_b values for both ranges are statistically equal: σ_b=234 MPa, $S_{\sigma b}$=16.22 MPa for the upper Cr content range and σ_b=240 MPa, $S_{\sigma b}$=19.86 MPa for the lower Cr content range. HB is also unchanged: the obtained values of HB for both ranges are statistically equal: HB213, SHB=9.1 for the upper range of Cr content and HB212, SHB=12 for the lower range of Cr content. At the same time, it becomes reasonable to reduce the ratio of Cr:Ni to smaller values of Cr - from Cr:Ni=2.2:1 in the existing technology to Cr:Ni=1.76:1 in those proposed in this study. This opens up opportunities for resource saving in the brake drum manufacturing process, reducing production costs.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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