https://doi.org/10.46813/2024-149-145

UDC 620.175.2:669.15

MULTIFRACTAL ANALYSIS OF THE INFLUENCE OF CHROMIUM-NICKEL CAST IRON STRUCTURE ON ITS QUALITY CRITERIA

D.B. Hlushkova[1], *V.M. Volchuk*[2]
[1]*Kharkiv National Automobile and Highway University, Kharkiv, Ukraine;*
[2]*Prydniprovska State Academy of Civil Engineering and Architecture, Dnipro, Ukraine*
E-mail: diana.borisovna@gmail.com

The influence of the structure of cast irons on their hardness was studied using multifractal analysis. The spectrum of statistical dimensions of the cast iron microstructure was calculated using the Renyi formula. The hardness of chromium-nickel cast iron was determined at three points of the sample. It was found that the pairwise correlation coefficients for predicting hardness by traditional structure characteristics (length, diameter, area) were R^2 = 0.73...0.87. When assessing hardness indicators by multifractal characteristics, the correlation coefficients are 0.78...0.88 for the pearlite structure with flake graphite and 0.81...0.93 for the pearlite structure with spherical graphite. The sensitivity coefficients of the hardness indicators of СПХН-43 rolls to the information and correlation dimensions of carbides, as well as to the fractal and statistical D_{-100} dimensions of flake graphite were determined. The sensitivity of hardness indicators to the fractal and statistical D_{100} dimensions of carbides and to the fractal and correlation dimensions of flake graphite was determined for СПХНФ-47 rolls. Based on the results obtained, an approach to assessing the hardness of СПХН-43 and СПХНФ-47 rolls was developed, which includes: 1). Determination of the statistical dimension spectrum of the cast iron structure elements. 2). Determination of the sensitivity coefficients of hardness indicators to the spectrum of dimensions of structural elements. 3). Creation of a mathematical model for predicting the hardness of rolls. The considered approach can be interpreted as an alternative method for assessing the quality criteria of cast irons based on the analysis of their structure.

INTRODUCTION

The technology for the production of most metal castings is multi-parameter [1, 2] and multi-criteria [3, 4]. It follows that the prediction of quality criteria for chromium-nickel cast iron materials is complicated by the influence of various technological factors, some of which can vary in a relatively wide range of values. On the other hand, conducting full-scale tests on the target product is not always possible, as this can lead to a violation of its integrity [5–7]. Therefore, in materials science, various types of modeling are widely used to control and predict the quality criteria materials [8–10]. Models based on the analysis of the influence of the chemical composition are especially common (see, for example, [11–14]). There are also many models based on the influence of structure on properties, for example [15–17]. Most models are based on the study of the influence of Euclidean characteristics of structural elements (area, length, diameter) on mechanical properties [18, 19]. However, the results of property prediction based on Euclidean characteristics do not always satisfy the objectives. The relationship between the structure and properties of materials is one of the main tasks of materials science, since the choice of metrics in the identification of the object of study plays an important role in the evaluation of structural elements with a complex geometric configuration [20, 21]. The incompleteness of the formal axiomatics that arises when assessing the structure of materials using Euclidean geometry can be compensated for by using various approaches: fractal analysis [22]; multifractal analysis [23], wavelet theory [24], estimation of the region of property compromise, etc.

PROBLEM STATEMENT

Since the structure of chromium-nickel cast iron materials is mostly heterogeneous, it makes sense to use multifractal analysis to identify it. Multifractals used to study heterogeneous objects are characterized by a spectrum of statistical Renyi dimensions [25]. The existing methods for predicting the mechanical properties of metals were analyzed, where the pairwise correlation coefficients in the equations for predicting hardness indicators were R^2 = 0.71 and R^2 = 0.85 for cast iron with an austenitic matrix and R^2 = 0.95 and R^2 = 0.89 for chromium carbides. The results obtained in these studies indicate the prospects of applying the theory of multifractals to the prediction of quality criteria for cast iron rolls based on the analysis of the spectrum of dimensions of their structure elements.

MATERIALS AND METHODS OF THE STUDY

The paper investigates the effect of the structure elements of the chromium-nickel cast iron rolls (СПХН-43 and СШХНФ-47) on the hardness of materials from chromium-nickel cast iron, which was evaluated using traditional methods of quantitative metallography and existing standards and multifractal analysis. These rolls are used in roughing mills, light and medium-gauge mills and pipe rolling mills in the manufacture of critical pipes for the nuclear industry, so their quality also depends on the quality of the equipment on which they are manufactured.

Rolls made of СПХН-43 cast iron are classified as section rolls (С), with flake graphite (П) inclusions in the structure, and the surface of the working layer is alloyed with chromium (Х) and nickel (Н).

Rolls made of СШХНФ-47 cast iron also belong to the sectional rolls (С), the structure of graphite inclusions is characterized by spheroidal (Ш) graphite, the surface of the working layer is alloyed with chromium (Х), nickel (Н) and vanadium (Ф).

Table 1 shows the chemical composition of cast irons after two melts without heat treatment (cast iron rolls СПХН-43 and СШХНФ-47) of their structure elements, which was evaluated using traditional methods of quantitative metallography and existing standards and multifractal analysis. Rolls for roughing mills, light and medium sections, and pipe rolling mills are made from СПХН-43 cast iron; rolls for break-down and roughing mills of section rolling mills are made from СШХНФ-47 cast iron.

Rolls made of СПХН-43 cast iron are classified as section rolls (С), with flake graphite (П) inclusions in the structure, and the surface of the working layer is alloyed with chromium (Х) and nickel (Н).

Rolls made of СШХНФ-47 cast iron also belong to the section rolling (С), the structure of graphite inclusions is characterized by spheroidal (Ш) graphite, the surface of the working layer is alloyed with chromium (Х), nickel (Н) and vanadium (Ф).

Table 1 shows the chemical composition of cast irons after two melts without heat treatment.

Table 1

Chemical composition of cast irons

Grade of chromium-nickel cast iron	C	Si	Mn	P	S	Cr	Ni	V	Cu
СПХН-43	3.50	0.95	0.54	0.070	0.012	0.63	1.22	–	0.27
СШХНФ-47	3.00	1.40	0.50	0.051	0.012	0.57	1.05	0.10	–

The dimensions of the cast iron rolls of СПХН-43 grade are as follows: body diameter 520 with a length of 1,000 mm (520×1,000 mm); the dimensions of the rolls of СШХНФ-47 grade are as follows: body diameter 680 with a length of 1,000 mm (680×1,000 mm).

Table 2 shows the hardness values of the samples determined by the Shore method. When determining the hardness of rolls using the Shore method, control measurements were made at three points evenly spaced along the length of the roll body.

Table 2

Roll hardness

СПХН-43		СШХНФ-47	
Sample No.	Hardness of the working surface, HSD	Sample No.	Hardness of the working surface, HSD
1	48	1	54
2	49	2	53
3	50	3	53
4	50	4	52
5	49	5	52

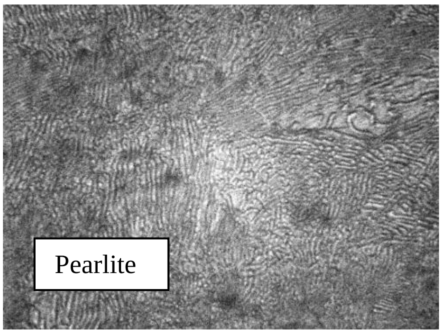
Ten samples were selected for the study: one sample of 5 cast iron rolls of СПХН-43 design and one sample of 5 cast iron rolls of СШХНФ-47 design according to TU U 14-2-1188-97. The samples were made from body chips taken from cast sections. The mass fraction of chemical elements was also determined from these chips.

Fig. 1 shows the structure of cast iron rolls of СПХН-43 design at magnifications of 500 and 1,000. The microstructure analysis showed that the cast iron has a pearlite matrix (see Fig. 1, a,b,c), microalloyed with chromium and nickel with an average content of carbides (Fe_3C) (see Fig. 1,b). The shape of graphite inclusions is flake (see Fig. 1,c).

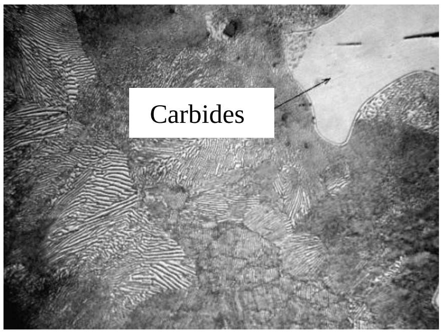
No chill layer was found on the surface of the СПХН-43 roll cast iron (see Fig. 1,d).

Fig. 2 shows the structure of cast iron rolls of СШХНФ-47 at magnifications ×500 and ×1,000. In the structure of pearlite cast iron of different dispersion (see Fig. 2,a,c), spherical graphite (see Fig. 2,e), carbides of different shapes (Fe_3C) (see Fig. 2,b) were found. No chill layer was found on the working surface of the cast iron rolls (see Fig. 2,d).

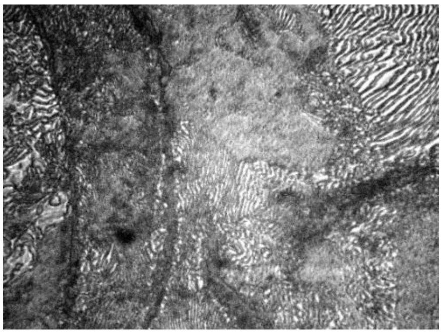
For the multifractal analysis of digital photographs of cast iron, a statistical sum $\sum_{i=1}^{N} p_i^q$ consisting of fractal subsets of variable dimensions was introduced, where the degree index q can take any value in the range from $-\infty$ to $+\infty$. Using this sum, the main multifractal Renyi spectrum *D(q)* is calculated for each microstructure image.



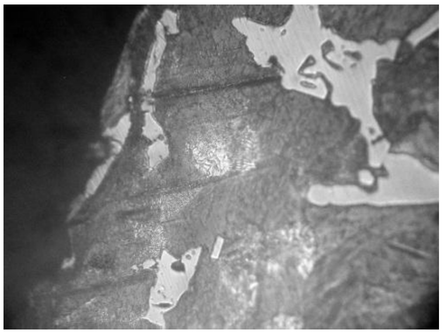
a, ×1,000



b, ×500

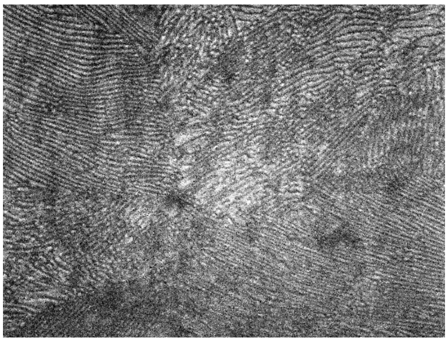


c, ×1,000

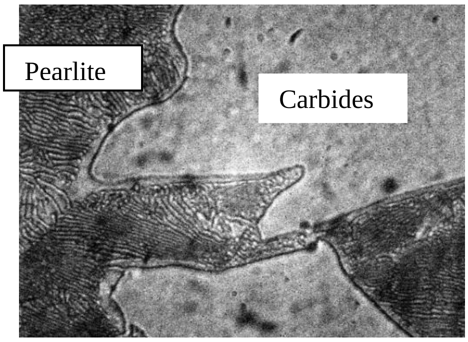


d, ×500

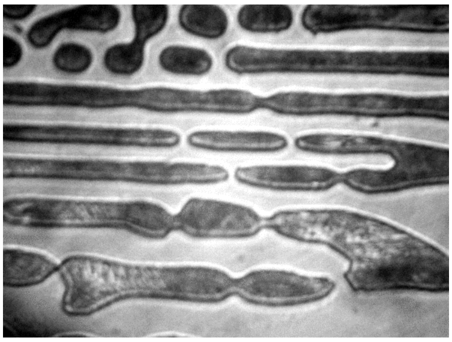
Fig. 1. Microstructure of cast iron rolls СПХН-43



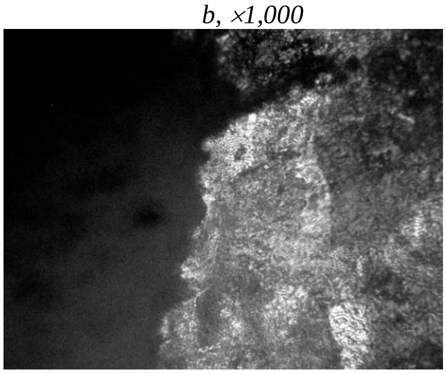
a, ×1000



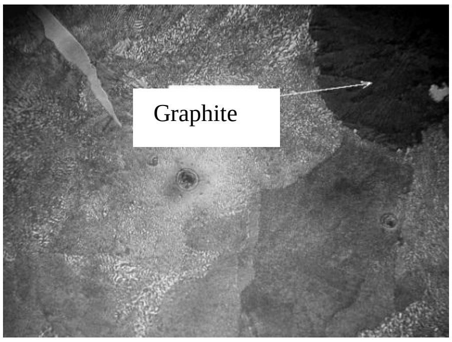
b, ×1,000



c, ×500



d, ×500



e, ×500

Fig. 2. Microstructure of cast iron rolls СШХНФ-47

The Renyi spectrum is a set of dimensions, each of which has its own physical meaning and is introduced by the following relation [25]:

$$D(q) = \frac{1}{q-1} \cdot \lim_{\delta \to \infty} \frac{\ln \sum_{i=1}^{N} p_i^q}{\ln \delta}, \qquad (1)$$

where δ – are the dimensions of a cell, which is a unit element of a square grid that covers the object under study (in this case, photographs of the microstructure of roll cast iron) to calculate the dimensional spectrum; p_i is the probability of a point (pixel for a computer) located on the object under study falling into the *i*-th cell of a square grid with linear size δ.

The defined dimensions have the following physical meaning:

– D_0 – is a fractal dimension at $q=0$;

– D_1 – is an information dimension (entropy) at $q=1$;

– D_1 describes the rate of growth of the information amount and shows how the information required to determine the location of a point in the cell covering the object of study increases with the size of the cell $\delta \to 0$;

– D_2 – is a correlation dimension that characterizes the probability of finding two points of an object in the same cell;

– D_∞ – is a dimension that characterizes the sparsest space on the object (the lightest elements of the structure) and the most concentrated space;

– $D_{-\infty}$ – is the dimension of the darkest elements of the structure. For the calculations, the limits of q values from -100 to 100 were taken.

RESULTS AND DISCUSSION

The pearlite matrix of СПХН-43 rolls is about 62...70% (P70); the share of carbides (in this case, it is mainly cementite of ledeburite eutectic) accounts for 25...35% (C25) and the share of flake graphite (FG4) varies within the range of 3...5%. For СШХНФ-47 rolls, the share of pearlite matrix is 64...76%; the share of carbides is 20...31%, and the share of nodular graphite is 4...7%.

An increase in the amount of cementite and a decrease in the amount of pearlite leads to an increase in hardness (Fig. 3,a,b) due to the fact that cementite has a higher hardness compared to pearlite. This can also explain the increase in hardness with an increase in the average area of the largest cementite inclusions (see Fig. 3,c,d). Graphite, compared to carbides and pearlite, has lower mechanical properties because its presence in the structure weakens the metal matrix, in this case, pearlite. Reducing the amount of flake graphite (see Fig. 3,a), as well as the linear dimensions of its inclusions (see Fig. 3,e), leads to an increase in hardness due to the fact that the ends of its plates serve as concentrators of microcracks and therefore reduce tensile strength. The content of flake graphite is reduced by heat treatment, such as annealing. On the contrary, cast irons with nodular graphite have higher tensile strength and hardness (see Fig. 3,f) due to its spherical shape, which has a more suitable configuration for preventing microcrack propagation. Therefore, the smaller the diameters of nodular graphite inclusions, the higher the mechanical properties of cast iron, in particular, the hardness.

Based on the analysis of the data obtained, the relationship between the structure and hardness of roll cast irons of СПХН-43 and СШХНФ-47 was(2) established. Regression equations (2)–(11) were obtained that describe the dependence of hardness on structure parameters: the percentage of its elements, the area of the largest cementite inclusions, and the linear dimensions of graphite inclusions.

The analysis of the obtained equations shows that a relatively high correlation $R^2 = 0.73...0.87$ for linear models is observed between the percentage of pearlite, cementite, and flake graphite [3–6]. In other cases, the pairwise correlation coefficients are relatively low and range from 0.4 to 0.7. This confirms the existing incompleteness of the formal axiomatics in identifying the structure and properties of roll cast iron using traditional methods. The multifractal analysis apparatus was used to partially compensate for the existing incompleteness.

An example of calculating the multifractal spectrum of the statistical dimensions of flake pearlite (see Fig. 1,a) using formula (1) is shown in Fig. 4.

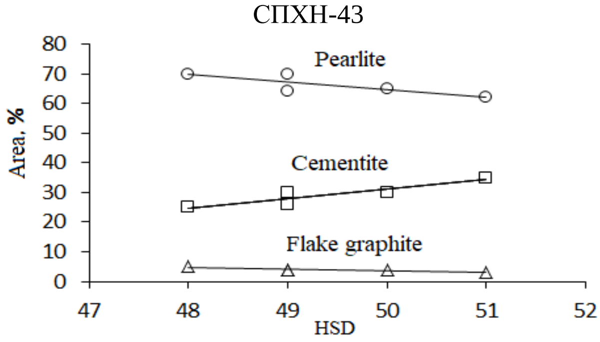
The following relation (12) was used to select the most adequate hardness characteristics and statistical dimensions (12):

$$K = |Y_i - Y_{i+1}| / |X_i - X_{i+1}|, \qquad (2)$$

where X_i i X_{i+1} – values of quality criteria at two reference points (in this case, hardness indicators); Y_i and Y_{i+1} values of the dimensions of the structural elements at these points. The coefficients of sensitivity of the fractal dimensionality of the structure elements of mild steel Ст3пс to its mechanical properties were recorded in the range of 0.2...0.9, which made it possible to increase the accuracy of predicting these properties by up to 10%.

The construction of fractal models for predicting the hardness of rolls was carried out on the basis of studies of the highest sensitivity coefficients, which are shown in Fig. 5. In some cases, despite the relatively high sensitivity values, there was a weak correlation between the hardness indicators and the dimensions of the structure elements. Such cases were recorded for the statistical dimension of carbides D_{100}, when the sensitivity coefficient was 0.68 (see Fig. 5,a), while the pairwise correlation coefficient was 0.57. For the dimensionality of D_{-100} carbides (Fig. 5, c) with $K_i = 0.47$, the correlation coefficient was 0.62, and for the dimensionality of D_{-100} carbides (see Fig. 5,c) with $K_i = 0.47$, the correlation coefficient was 0.62. Due to the relatively low correlation coefficients established, the correlation between these characteristics was not given. This indicates the fact that the use of sensitivity coefficients to establish a relationship between the studied values is in some cases insufficient, which initiates the search for more stable indicators.

Fig. 6 shows the correlation between hardness indicators and dimensions with the highest values of sensitivity coefficients determined by (2), except for the cases described above.



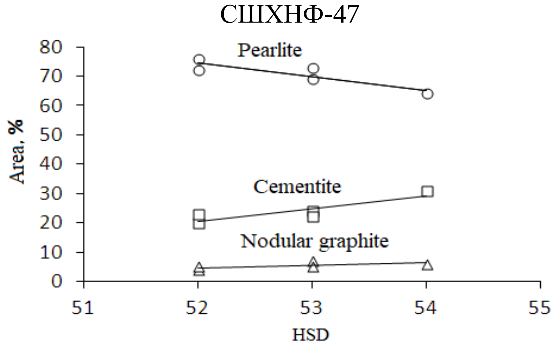
a

pearlite: $HSD = -2.5769 \cdot S_P + 193.5$; $R^2 = 0.65$, (2)

cementite: $HSD = 3.1923 \cdot S_C - 128.5$; $R^2 = 0.84$, (3)

flake graphite:

$HSD = -0.5769 \cdot S_{FG} + 32.5$; $R^2 = 0.87$, (4)



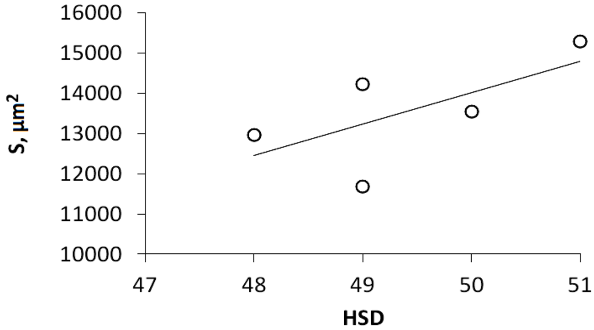
b

pearlite: $HSD = -4.7143 \cdot S_P + 319.71$; $R^2 = 0.75$, (5)

cementite: $HSD = 4.2857 \cdot S_C - 202.29$; $R^2 = 0.73$, (6)

nodular graphite:

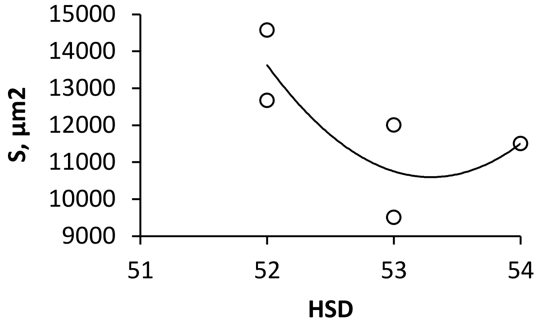
$HSD = 0.8571 \cdot S_{NG} - 39{,}857$; $R^2 = 0.40$, (7)



c

$HSD = 785.77 \cdot S_{Cmax} - 25{,}275$; $R^2 = 0.44$, (8)

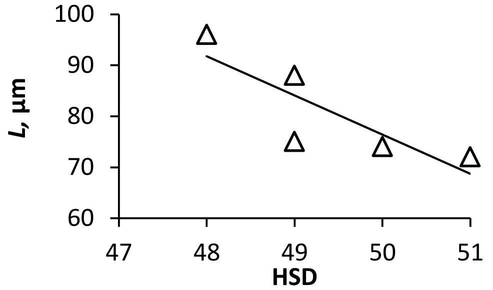
where S_{Cmax} – area of the largest cementite inclusions



d

$HSD = 1{,}810 \cdot S^2_{Cmax} - 192{,}920 \cdot S_{Cmax} + 5E+06$; (9)

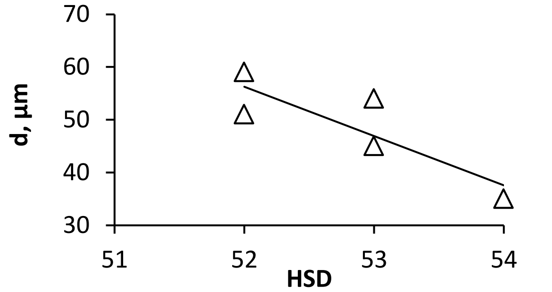
$R^2=0.64$, where S_{Cmax} – area of the largest cementite inclusions



e

$HSD = -7.6923 \cdot L + 461$; $R^2 = 0.70$, (10)

where L is length of flake graphite inclusions



f

$HSD = -9.3571 \cdot d + 542.86$; $R^2 = 0.72$, (11)

where d is the diameter of nodular graphite inclusions.

Fig. 3. Relationship between structure and hardness of roll cast irons

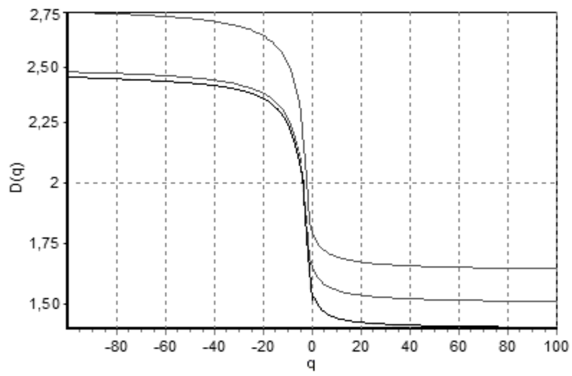


Fig. 4. Spectrum of pearlite dimensions

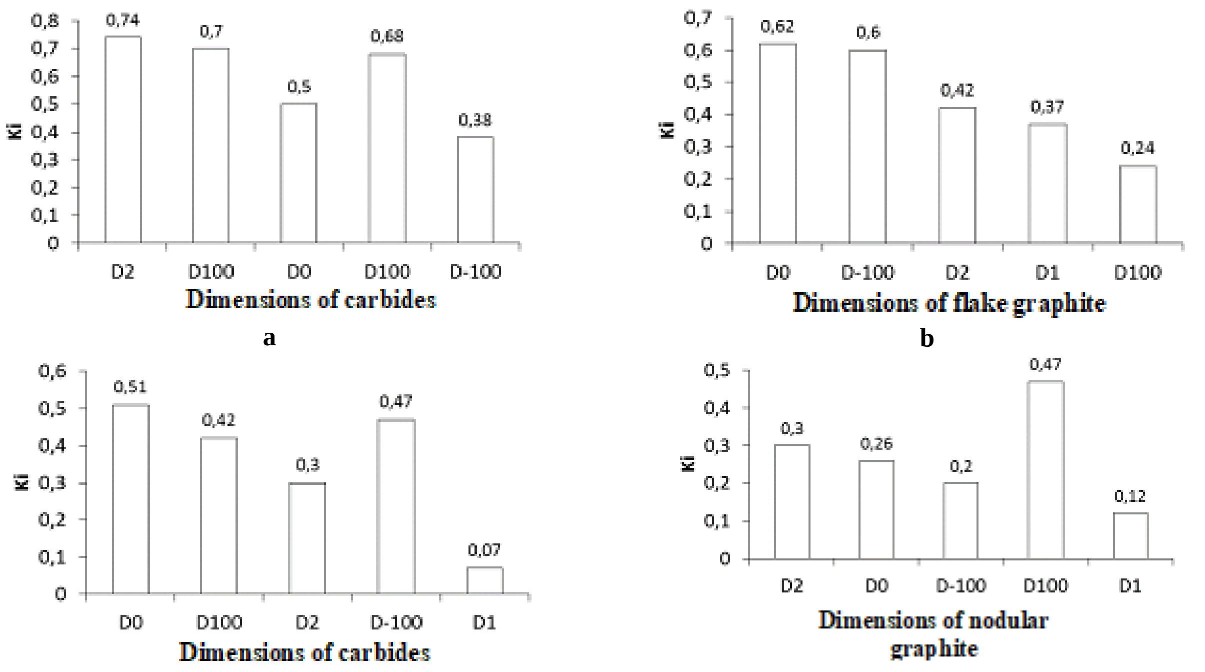
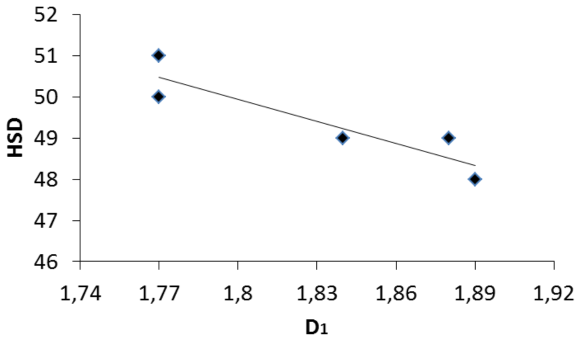


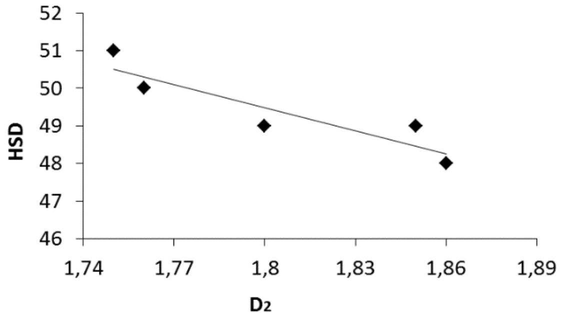
Fig. 5. Sensitivity of hardness to dimensions of roll structure elements of СПХН-43 (a, b) and СШХНФ-47 (b, c)



a

$$HSD = -17.91 \cdot D_1 + 82.176;\ R^2 = 0.83, \quad (13)$$

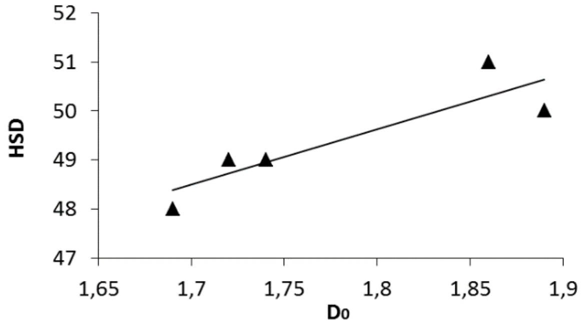
where D_1 – information dimension of carbides



b

$$HSD = -20.553 \cdot D_2 + 86.478;\ R^2 = 0.82, \quad (14)$$

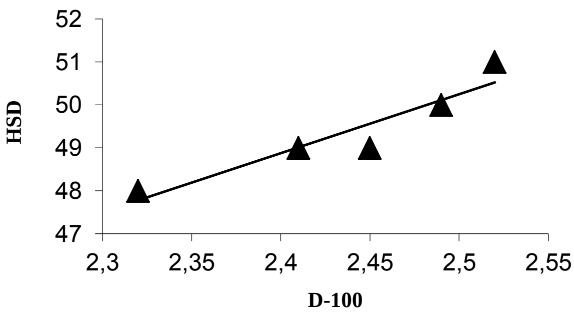
where D_2 – correlation dimension of carbides



c

$$HSD = 11.321 \cdot D_0 + 29.249;\ R^2 = 0.78, \quad (15)$$

where D_0 – fractal dimension of graphite



d

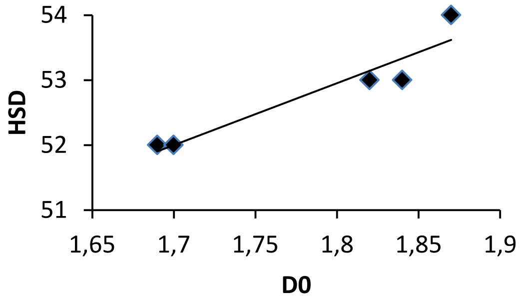
$$HSD = 13.756 \cdot D_{-100} + 15.862;\ R^2 = 0.88, \quad (16)$$

where D_{-100} – dimension of graphite at q = -100

Fig. 6. Correlation between the dimensions of carbides (a, b), graphite (c, d) and hardness of СПХН-43 rolls

The values of the pairwise correlation coefficients R^2 = 0.78...0.88 (13)–(16) in determining the hardness of cast iron rolls of СПХН-43 design indicate a higher degree of prediction compared to traditional methods of quantitative metallography [5–11] and the expediency of using multifractal theory to assess the quality of long-range cast iron rolls. We recorded a decrease in hardness indicators with an increase in the information (see Fig. 6,a) and correlation (see Fig. 6,b) dimensions of carbides, since these dimensions have a greater effect on the distribution of graphite in the volume. An increase in the dimensionality of flake graphite on the studied grinding plane (see Fig. 6,c,d) leads to an increase in hardness, since cast iron with graphite with an equiaxed geometric shape has better mechanical properties than cast iron with a complex flake shape. The flake shape of graphite effectively utilizes only 30-50% of the strength of the metal base of cast iron and there is practically no possibility of using its plastic properties. This is due to the fact that the boundaries of flake graphite inclusions serve as concentrators of microstresses, and an increase in its content weakens the metal matrix of cast iron, which indicates the influence on the mechanical properties of cast iron of both the content, size, and distribution of graphite and the geometric configuration of graphite inclusions. A calculation metric is set to describe the geometric configuration of the structure elements. The accuracy of calculations of the dimension of the object of study depends on the choice of the metric.

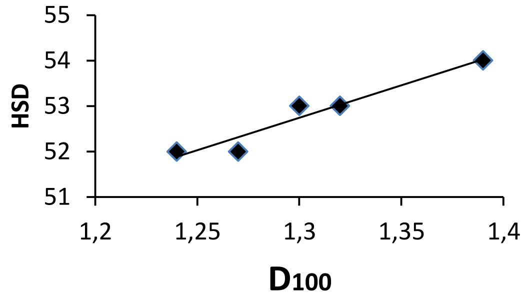
The correlation coefficients for the models for predicting the hardness of rolls with a spheroidal shape of graphite СШХНФ-47 (Fig. 7) varied within the range of 0.81...0.93 [17–20], which also indicates the adequacy of using the fractal geometry language in modeling the structure and properties of metal.



a

$$HSD = 9.5238 \cdot D_0 + 35.81;\ R^2 = 0.90, \quad (17)$$

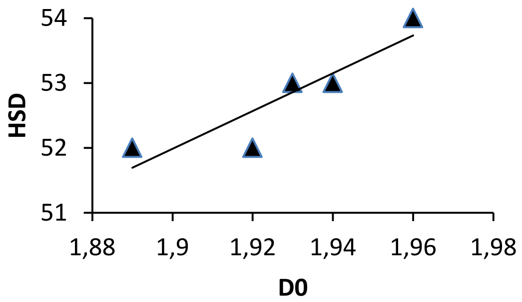
where D_0 – fractal dimension of carbides



b

$$HSD = 14.241 \cdot D_{100} + 34.229;\ R^2 = 0.93, \quad (18)$$

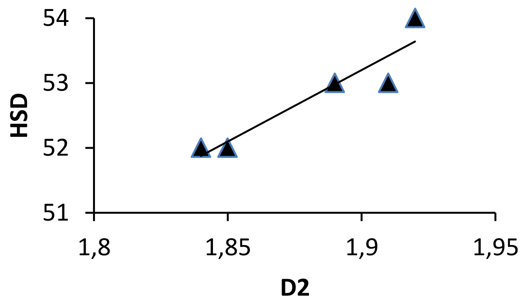
where D_{100} – dimension of carbides at q = 100



c

$$HSD = 29.104 \cdot D_0 - 3.3134;\ R^2 = 0.81, \quad (19)$$

where D_0 – fractal dimension of graphite



d

$$HSD = 22.047 \cdot D_2 + 11.307;\ R^2 = 0.88, \quad (20)$$

where D_2 – correlation dimension of graphite

Fig. 7. Correlation between the dimensions of carbides (a, b), graphite (c, d) and hardness of СШХНФ-47 rolls

The results obtained indicate the possibility of using multifractal analysis in modeling the structure and properties of rolls with flake and spheroidal forms of graphite.

The degree of influence of the multifractal characteristics of the structure elements of cast iron rolls СПХН-43 and СШХНФ-47 (pearlite, carbides, and graphite) on their hardness parameters was determined. The application of the multifractal theory in modeling the structure of section-roll cast iron rolls with flake and spheroidal forms of graphite indicates a higher degree of prediction of their hardness values compared to the prediction values determined by traditional methods of quantitative metallography.

CONCLUSIONS

The paper investigates the influence of multifractal structure characteristics (dimensions D_0, D_1, D_2, D_{-100}, and D_{100}) on the hardness of sectional cast iron rolls with pearlite matrix and flake and nodular graphite. A comparative analysis of the multifractal and traditional approaches to assessing the structure of cast iron was carried out. It has been established that the pairwise correlation coefficients for predicting the hardness of rolls based on traditional structure characteristics (area, diameter, and length) are R^2 = 0.40...0.87, and for predicting hardness by multifractal characteristics for rolls of СПХН-43 design are 0.78...0.88; for rolls of СШХНФ-47 design they are 0.81...0.93.

The obtained results confirm the importance of choosing a metric that is inherent in the state space of the object of identification (in this case, when calculating the dimension of the structure). The correct choice of the metric is reflected in the results of the forecast of cast iron quality criteria using a multifractal spectrum of dimensions.

REFERENCES

1. S.V. Hayduk, O.V. Hnatenko, O.H. Andreyenko, V.V. Smart. Research on structural transformations of heat-resistant nickel alloys under creep conditions // *New materials and technologies in metallurgy and mechanical engineering*. 2012, p. 37-40.
2. N.E. Kalinina, D.B. Hlushkova, O.D. Hrinchenko, V.T. Kalinin, V.A. Voronkov, L.L. Kostina, I.N. Nikitchenko, T.V. Nosova, F.F. Reznikov. Hardening of leading edges of turbine blades by electrospark alloying // *Problems of Atomic Science and Technology*. 2019, N 2(120), p. 151-154.
3. L.I. Gladkikh, S.V. Malykhyn, A.T. Pugache, O.M. Reshetnyak, D.B. Glushkova, S.S. D'Yachenko, G.P. Kovtun. Residual Stresses and Structure of Titanium and Chromium Nitride Coatings Obtained by a Method of an Ion-Plasma-Enhanced Deposition // *Metallofizika i Noveishie Tekhnologii*. 2003, N 6(25), p. 763-776 (in Russian),
4. E.I. Tsyvirko, A.A. Pedash. Grinding the structure of internal surfaces of cooling parts, VMD // *Visnyk dvizhnoboduvaniya*. 2010, N 1, p. 99-103 (in Ukrainian).
5. D.B. Hlushkova, V.A. Bagrov, S.V. Demchenko, V.M. Volchuk, O.V. Kalinin, N.E. Kalinina. Structure and properties of powder gas-plasma coatings based on nickel // *Problems of Atomic Science and Technology*. 2022, N 4(140), p. 125-130; https://doi.org/10.46813/2022-140-125
6. V.S. Vahrusheva, D.B. Hlushkova, V.M. Volchuk, T.V. Nosova, S.I. Mamhur, N.I. Tsokur, V.A. Bagrov, S.V. Demchenko, Yu.V. Ryzhkov, V.O. Scrypnikov. Increasing the corrosion resistance of heat-resistant alloys for parts of power equipment // *Problems of Atomic Science and Technology*. 2022, N 4(140), p. 137-140; https://doi.org/10.46813/2022-140-137
7. O.M. Vynogradov. Reduction of costs for foundry production // *Casting of Ukraine*, 2005, N 3, p. 5-8.
8. M. Hoffman. What you should know o mold steels // *Plast. Technol*. 2005, N 28(4), p. 28-30.
9. H.H. Nersisyan, J.H. Lee, C.W. Wok. Self-propagating high – temperature synthesis of nano – sized titanium carbide powder // *J. Mater. Res*. 2002, N 11(17), p. 2859-2864.
10. O.M. Smirnov, I.V. Leprechaun. *Production of castings.* Donetsk: Donetsk National. technical Univ., Nard-Press, 2005, 244 p.
11. D.B. Hlushkova, O.D. Hrinchenko, L.L. Kostina, A.P. Cholodov. The choice of material for strengthening of leading edges of working blades of steam turbines // *Problems of Atomic Science and Technology*. 2018, N 1(113), p. 181-188.
12. N.E. Kalinina, D.B. Glushkova, A.I. Voronkov, V.T. Kalinin. Influence of nanomodification on structure formation of multicomponent nickel alloys // *Functional Materials*. 2019, N 3(26), p. 514-518; https://doi.org/10.15407/fm26.03.514
13. D.B. Hlushkova, V.A. Bagrov, V.M. Volchuk, U.A. Murzakhmetova. Influence of structure and phase composition on wear resistance of sparingly alloyed alloys // *Functional Materials*. 2023, N 1(30), p. 74-78; https://doi.org/10.15407/fm30.01.74
14. V.A. Kostin, H.M. Grigorenko, V.V. Zhukiv. Modification of the structure of welds of high-strength, low-alloy steels with nanoparticles of refractory metals // *Collection of scientific works "Construction, materials science, mechanical engineering"*. 2016, N 89, p. 93-98.
15. A.M. Petrychenko, O.O. Novyk, V.I. Krylov, et al. Selection of steel for forms of LPD of aluminum alloys // *Foundry production*. 1990, N 3, p. 8-9.
16. V.T. Kalinin, V.A. Fedotov. Synthesis and application of nanodisperse powders – modifiers // *System technologies*. 2002, N 1, p. 67-71.
17. D.B. Hlushkova, A.V. Kalinin, N.E. Kalinina, V.M. Volchuk, V.A. Saenko, A.A. Efimenko. Study of nanomodification of nickel alloy GS3 with titanium carbide // *Problems of Atomic Science and Technology*. 2023, N 2(144), p. 126-129; https://doi.org/10.46813/2023-144-126
18. O.P. Brodyanskyi. Strengthening of the tool on the "Pusk" and "Bulat" installation // *Technology and organization of production*. 2003, N 2, p. 1-25.
19. V.I. Bolshakov, V.E. Vaganov. Carbon containing structural and functional coatings // *Bulletin of Prydniprovs'ka State Academy of Civil Engineering and Architecture*. 2014, N 10, p. 34-43.
20. H.H. Nersisyan, J.H. Lee, C.W. Wok. Self-propagating high – temperature synthesis of nano-sized titanium carbide powder // *J. Mater. Res*. 2002, N 11(17), p. 2859-2864.
21. D.B. Hlushkova, V.A. Bagrov, V.A. Saenko, V.M. Volchuk, A.V. Kalinin, N.E. Kalinina. Study of wear of the building-up zone of martensite-austenitic and secondary hardening steels of the Cr−Mn−Ti system // *Problems of Atomic Science and Technology*. 2023, N 2(144), p. 105-109; https://doi.org/10.46813/2023-144-105
22. D.B. Hlushkova, V.M. Volchuk. Fractal study of the effect of ion plasma coatings on wear resistance // *Functional Materials*. 2023, N 3(30), p. 453-457; https://doi.org/10.15407/fm30.03.453
23. D.B. Hlushkova, V.M. Volchuk, P.M. Polyansky, V.A. Saenko, A.A. Efimenko. Fractal modeling the mechanical properties of the metal surface after ion-plasma chrome plating // *Functional Materials*. 2023, N 2(30), p. 275-281; https://doi.org/10.15407/fm30.02.275
24. I. Daubechies. *Ten lectures on wavelets*: Society for industrial and applied mathematics, 1992, 350 p.
25. A. Rényi. *Probability Theory*. Amsterdam: North-Holland, 1970, 670 p.

Article received 15.11.2023

МУЛЬТИФРАКТАЛЬНИЙ АНАЛІЗ ДОСЛІДЖЕННЯ ВПЛИВУ СТРУКТУРИ ХРОМОНІКЕЛЕВОГО ЧАВУНУ НА ЙОГО КРИТЕРІЇ ЯКОСТІ

Д.Б. Глушкова, В.М. Волчук

Досліджувався вплив структури чавунів на їх твердість з використанням мультифрактального аналізу. Розрахунок спектра статистичних розмірностей мікроструктури чавуну здійснювався за формулою Рень'ї. Показники твердості хромонікелевого чавуну визначалися у трьох точках зразка. Встановлено, що коефіцієнти парної кореляції при прогнозі твердості за традиційними характеристиками структури (довжиною, діаметром, площею) становлять R^2 = 0,73…0,87. При оцінці показників твердості за мультифрактальними характеристиками показники кореляції становлять для перлітної структури з пластинчатим графітом 0,78…0,88, для перлітної структури з шаровидним графітом – 0,81…0,93. Виявлено коефіцієнти чутливості показників твердості валків СПХН-43 до інформаційної і кореляційної розмірностей карбідів, а також до фрактальної і статистичної D_{-100} розмірностей пластинчатого графіту. Для валків СПХНФ-47 встановлена чутливість показників твердості до фрактальної і статистичної D_{100} розмірностей карбідів і до фрактальної і кореляційної розмірностей шаровидного графіту. На підставі отриманих результатів розроблено підхід до оцінки показників твердості валків СПХН-43 і СПХНФ-47, що включає: 1 – визначення спектра статистичних розмірностей елементів структури чавунів; 2 – визначення коефіцієнтів чутливості показників твердості до спектру розмірностей елементів структури; 3 – побудову математичної моделі прогнозу твердості валків. Розглянутий підхід можна трактувати як альтернативний метод оцінки критеріїв якості чавунів на основі аналізу їх структури.