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NUMERICAL AND EXPERIMENTAL ANALYSES OF THE CHEMICAL HETEROGENEITY OF A SOLIDIFYING HEAVY DUCTILE-CAST-IRON ROLLER

NUMERIČNA IN EKSPERIMENTALNA ANALIZA KEMIJSKE HETEROGENOSTI STRJEVANJA LITEGA TEŽKO GNETLJIVEGA ŽELEZNEGA VALJA

Karel Stransky[1], Frantisek Kavicka[1], Bohumil Sekanina[1], Jana Dobrovska[2], Vasilij Gontarev[3]

[1]Brno University of Technology, Technická 2, 616 69 Brno, Czech Republic
[2]VSB TU Ostrava, 17.listopadu 15, 708 33 Ostrava, Czech Republic
[3]University of Ljubljana, Aškerčeva 12, 1000 Ljubljana, Slovenia
stransky@fme.vutbr.cz

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The quality of the working rollers used for rolling rails is determined by the chemical and structural compositions of the material of the rollers and the production technology. It is necessary to cast rollers with significantly improved utility properties, i.e., mainly a high wear resistance and optimal mechanical and structural properties. It is, therefore, necessary to find and ensure the optimal relationships between the matrix structure and the resulting values of the mechanical properties of the rollers in order to maximize their life time. The requirements introduced here cannot be ensured without a knowledge of the kinetics of the solidification. Therefore, numerical and experimental investigations of the temperature field of the solidifying roller were conducted. The kinetics of the solidification has a measurable and non-negligible influence on the chemical and structural heterogeneity of the investigated type of ductile cast-iron. Linking to the results of the model of the temperature field of the cast rollers, an original methodology was developed for the measurement of chemical micro-heterogeneity. The structure of this cast-iron is created by a large amount of the transition form of graphite and a small amount of globular graphite, and also the lamellar graphite and cementite, whereas the structure of the metal matrix is perlitic. The volume amounts of the structural components were determined using a quantitative metallographic analysis, according to which the places for the analysis of the element composition using X-ray energy-dispersive spectral micro-analysis were selected. The chemical and structural heterogeneity of the cast roller is, therefore, a significant function of the method of melting, modification and inoculation and the successive procedures of risering, casting and crystallization after cooling.

Keywords: spheroidal graphite cast iron, roller, solidification, chemical and structural heterogeneity, methodology for measurement

Kakovost delovnih valjev za valjanje tirnic je določena s kemijsko in strukturno sestavo materiala za valje in s tehnologijo proizvodnje. Potrebno je ulivati valje z znatno povečanimi koristnimi lastnostmi, kot so obrabna odpornost in optimalne mehanske in strukturne lastnosti. Tako je treba ugotoviti in zagotoviti optimalne odnose med strukturo matrice in rezultirajočimi vrednostmi mehanskih lastnosti valjev za maksimiranje trajnostne dobe. Zahteve, ki so tu predstavljene, ne morejo biti zagotovljene brez znanja kinetike strjevanja. Zato je bila vpeljana numerična in eksperimentalna raziskava temperaturnega polja valja pri strjevanju. Kinetika strjevanja ima merljiv in ne brezpomemben vpliv na kemijsko in strukturno heterogenost raziskovanega gnetljivega litega železa. Glede na rezultate modela temperaturnega polja ulitih valjev je bila razvita originalna metodologija za merjenje kemijske mikroheterogenosti. Struktura tega ulitega železa je bila ustvarjena z veliko količino prehodnih oblik grafita in manjših količin kroglastega grafita in cementita, medtem ko je struktura kovinske osnove perlitna. Volumenska količina strukturnih komponent je bila določena s kvantitativno metalografsko analizo, po kateri so bila izbrana mesta za rentgensko analizo sestave ter spektrografsko mikroanalizo. Kemijska in strukturna heterogenost ulitih valjev je pomembna funkcija pri taljenju in modificiranju ter za uspešno ulivanje in kristalizacijo po ohlajevanju.

Ključne besede: siva litina s kroglastim grafitom, valj, strjevanje, kemijska in strukturna heterogenost, metodologija meritev

1 INTRODUCTION

The kinetics of solidification has a non-negligible influence on the chemical and structural heterogeneity of the cast-iron in question[1]. An original methodology for the measurement of the micro-heterogeneity was developed, based on the results of the model of the temperature field of the cast rollers. The chemical and structural heterogeneity of the cast roller has proven to be a significant function of the method of melting, modification and inoculation and the successive procedures of risering, casting and crystallization after cooling.

2 STRUCTURAL AND CHEMICAL HETEROGENEITY OF THE ROLLER

The final mechanical properties of the rollers – of the spheroidal graphite cast-iron – are determined, not primarily by the chemical composition, but mainly by their structural and chemical heterogeneity, which occurs during casting, crystallization and successive cooling of the material. Some defects occurring in this way can be corrected by heat treatment; however, the quality of the pouring structure is very important, especially with graphite cast-iron.

The chemical composition is given in **Table 1**.

The samples used for determining the structural and chemical heterogeneity were taken from the spheroidal graphite cast-iron roller with the chemical composition given in **Table 1** from the upper part (Section III) and from the bottom part (Section I). **Figure 1** shows how the four samples were taken, with the upper surfaces – marked "X" – being analyzed. In addition, they were specified as follows:

- The upper part of the roller on the outer surface (*R*1 = 540 mm) marked TR1, TR2
- The upper part of the roller on the inner surface (*R*4 = 400 mm) marked TR3, TR4
- The lower part of the roller on the outer surface marked BR1, BR2
- The lower part of the roller on the inner surface marked BR3, BR4

The actual analyses were conducted at a specialized workplace[2,3]. The structural analysis of the cast-iron samples was conducted using a Neophot 32 metallographic microscope and an Olympus digital camera. The measurements of the metallographic parameters of the graphite and the evaluation of the volume part of the structural components were conducted on the Olympus CUE4 image analyzer. The basic statistical parameters of the graphite particles and also the stereological estimate of certain other parameters[2] were calculated from the data files.

The JSM-840 (JEOL) electron scanning microscope was used for determining the chemical heterogeneity together with the LINK AN 10/85S X-ray energy-dispersive microanalyzer. Based on the results of the metallographic analysis[2], two pairs of graphite grains were selected on the ground surface of every sample in order for the line of measurement between the first pair to pass through the perlite (marked "a") and the cementite (marked "b"). The third line was selected through two boundaries created by particles of lamellar graphite, where the measurement passes through the basic perlite (marked "c"). The individual elements (Si, P, Mo, Cr, Mn, Fe, Ni, and Cu) were analyzed by means of a point X-ray microanalysis in a direct line with a step of 3 μm [3,4]. **Figure 2** illustrates the material around the selected line of the measurement on sample TR1 through the scanning electron microscope and the X-ray energy-dispersive microanalyzer. Following the chemical (elemental) analysis, the samples were etched using 2 % nital in order to make the contamination traces visible and display the line of measured points, including their connection to the sample microstructure.

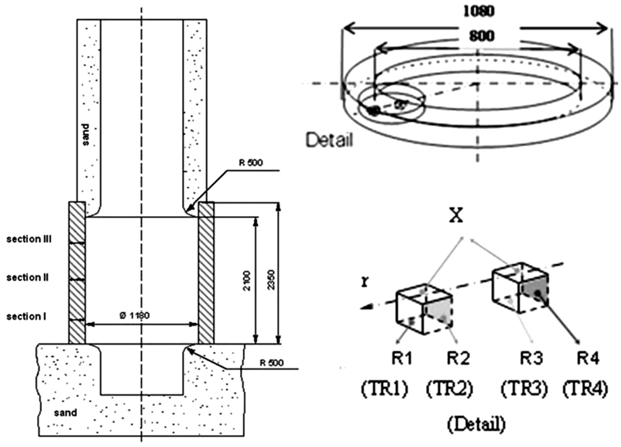

Figure 1: The set-up of a vertically cast roller and sampling
Slika 1: Pogled na navpično ulit valj in vzorčenje

2.1 Structural heterogeneity

Based on experience, it can be assumed that the structure of the material of the casting, spheroidized graphite cast iron (named "ductile cast-iron" for working purposes) will, besides the globular graphite that is characteristic of ductile cast-iron, also contain a mixture of a certain amount of transition forms of graphite and lamellar graphite found between the globular and lamellar graphite. **Table 2** shows the results from the quantitative metallographic analyses of the structures of the samples in **Figure 1**. The procedure of the quantitative structural measurements, including the results, is described in detail in a special report[2].

Table 1: The chemical composition of ductile cast-iron B10 (*w*/%)
Tabela 1: Kemijska sestava sive litine B10, z globularnim grafitom (*w*/%)

Cast-iron B10										
Element	C	Mn	Si	P	S	Cr	Ni	Mo	Mg	Cu
Content (%)	3.31	0.65	0.70	0.105	0.005	0.35	2.59	0.59	0.04	1.48

Table 2: The results from the quantitative measurements of the volume part of the components (in volume fractions, φ/%)
Tabela 2: Rezultati kvantitativnih meritev volumenskega dela komponent (volumenski deleži, φ/%)

Sample	All graphite, incl. micro-shrinkages	Globular graphite	Transition forms of graphite and lamellar graphite	Cementite	Perlite
BR1	10.5 ± 2.8	1.3	9.2	2.2 ± 1.7	87.3
BR3	13.0 ± 5.4	1.1	11.9	1.2 ± 1.2	85.8
TR1	13.4 ± 5.6	1.1	12.3	2.2 ± 1.8	84.4
TR3	12.6 ± 5.7	1.1	11.5	1.3 ± 1.4	86.1

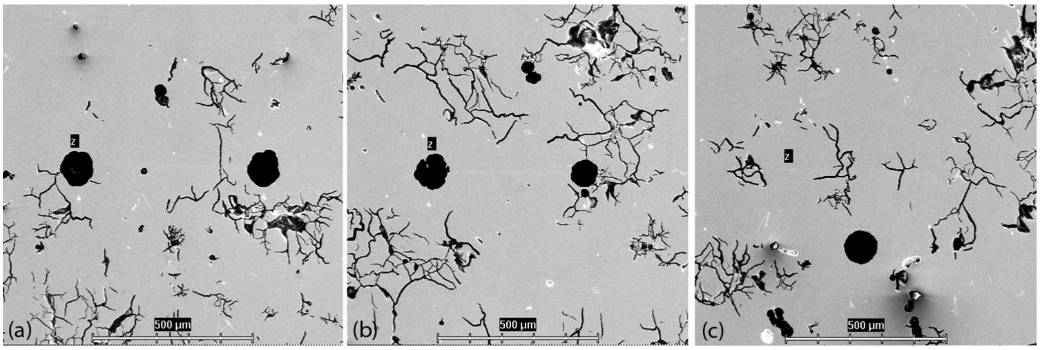

Figure 2: The structures in the area of sample TR1 selected for analysis: a) between two spheres of graphite through perlite, b) between the two spheres of graphite through cementite, c) through lamellar graphite

Slika 2: Strukture v območju vzorca TR1 za analizo: a) med dvema kroglama grafita v perlitu, b) med dvema kroglama grafita v cementitu, c) v lamelnem grafitu

2.2 Chemical heterogeneity

The distribution of the concentration of the eight elements, measured three times in one line for each of the samples (**Figures 2a–c**), was evaluated using statistics: the arithmetic mean of the concentration of the element in the selected interval c_{st}, the standard deviation σ_{n-1} of the measured concentration, the minimum concentration c_{min} and the maximum c_{max} – measured each time in the selected interval of the sample (in mass fractions, w/%). Besides these basic concentration parameters, the segregation index of each measured element was determined and defined as $I_S = c_{max}/c_{st}$, i.e., as the quotient of the maximum concentration of elements measured on the given interval and the arithmetic mean of its concentration in the same interval. The tendency of the element to segregate – based on experience – is expressed in the values of the segregation indexes. A detailed description of the measurement procedure and the corresponding results can be found in the reports[3,4].

Figure 3 illustrates the values of this parameter for individual elements and samples measured in one line across the lamellar graphite – c. Similarly, the segregation index values can be plotted for the area between the globular graphite in a line across perlite – a, and also in the area between the globular graphite in a line across cementite – b. **Figure 4** shows the segregation index values for the elements calculated as the average of the values for all three areas – a, b, c. Furthermore, the graphs in **Figures 3** and **4** also indicate that the segregation indexes of the highest values – from the set of measured elements – belong to phosphorus and molybdenum, and the lowest values refer to nickel and iron, which make up the matrix.

3 CONCLUSION

This article introduces an original methodology for the measurement of the chemical heterogeneity of cast-iron of the composition given in **Table 1**. The structure of this cast-iron is created by a large amount of the transition form of graphite and small amount of

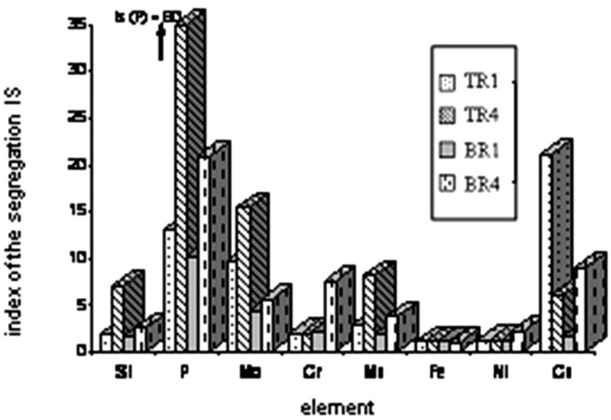

Figure 3: The index of the segregation of elements for individual samples in the area of the transition graphite in the measured area across lamellar graphite

Slika 3: Indeks izcejanja elementov posameznih vzorcev v območju prehoda grafita v merjeno področje lamelnega grafita

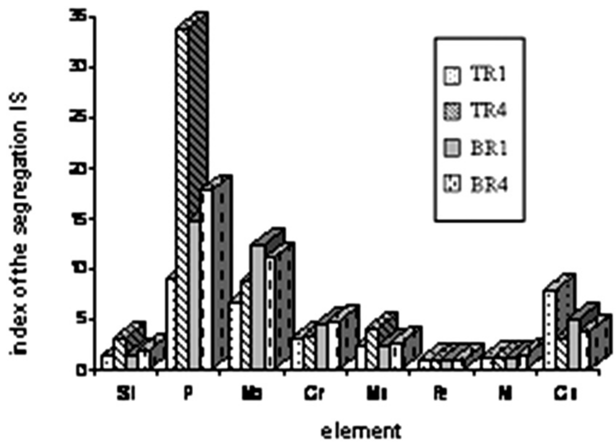

Figure 4: The average index of segregation of the analyzed elements in individual samples

Slika 4: Povprečni indeks izcejanja analiziranih elementov v posameznih vzorcih globular graphite and also lamellar graphite and cementite, whereas the structure of the metal matrix is perlitic. The volume amounts of the structural components were determined using a quantitative metallographic analysis, which was simultaneously the basis for the selection of the places for the analysis of the element composition using an X-ray energy-dispersive spectral microanalysis. Inside the microstructure of four samples, taken from the outer and inner parts of the ring at the top and bottom of the roller (**Figure 1**), in a total of twelve areas, the linear concentration dispersion was measured on the eight elements which make up the basic constitution of the cast-iron: Si, P, Mo, Cr, Mn, Fe, Ni, and Cu. A statistical analysis was used to determine the distribution characteristics of the concentration of the individual elements, including the segregation indexes and the relationships among them. In this way it was possible to assess the influence of the changing kinetics of the temperature field on the resultant structural and chemical heterogeneity of the roller. The kinetics of the solidification of the cast-iron roller had a non-negligible influence on the chemical and structural heterogeneity of the investigated type of cast-iron. It is obvious that the chemical and structural heterogeneity of the cast roller is a significant function of the method of melting, modification and inoculation and the successive procedures of risering, casting and crystallization after cooling.

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4 REFERENCES

[1] F. Kavicka et al.: Numerical optimization of the method of cooling of a massive casting of ductile cast-iron. In: Book of Abstracts and CD ROM of the 13th International Heat Transfer Conference, Sydney, Australia, August 2006, 27

[2] J. Belko, K. Stransky, Structural analysis of cast-iron samples (in Czech). Research report, VTUO Brno, 2005

[3] Z. Winkler, K. Stransky, Microheterogeneity of the composition ductile cast-iron samples alloyed with Mn, Cu, Ni and Mo (in Czech). Research report, VTUO Brno, 2005

[4] R. Kamensky, et al.: The influence of silicon on the thickness of the hardened surface layer of cast-iron castings (in Czech). Slevarenstvi, 16 (**1968**) 1, 35–39