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FATIGUE BEHAVIOUR OF SYNTHETIC NODULAR CAST IRONS

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The paper shows the influence of charge composition on microstructure, fatigue properties and failure micromechanisms of nodular cast irons. The additive of metallurgical silicon carbide (SiC) in analysed specimens increases the content of ferrite in the matrix, decreases the size of graphite and increases the average count of graphitic nodules per unit of area. Consequently, the mechanical and fatigue properties of nodular cast iron are improved. The best fatigue properties (fatigue strength) were reached in the melt which was created by 60 % of steel scrap and 40 % of pig iron in the basic charge with SiC additive.

Key words: nodular cast iron, synthetic melts, microstructure, mechanical properties, failure micromechanisms

INTRODUCTION

Nodular cast iron is a group of cast structural materials with a wide application in engineering practice (especially in the automotive industry). It combines high tensile strength and plasticity with high fatigue strength. Nodular cast iron can be produced according to the classical or synthetic casting procedure (Figure 1) which is more economical [1, 2].

In recent years, the production of nodular cast iron is from an economic point of view orientated to synthetic melts where a part of more expensive pig iron in a metal charge is substituted for cheaper steel scrap. The transition from the traditional use of pig iron (classical melts) to synthetic nodular cast iron prepared from steel scrap requires the regulation of chemical composition of melt. Steel scrap has low content of silicon therefore increasing of content of silicon to eutectic composition (S_C ~ 1) is reached by using of ferrosilicon (FeSi) or metallurgical silicon carbide (SiC) additive. Nowadays, there is the tendency to use metallurgical silicon carbide as a siliconizing as well as carburizing additive instead of ferrosilicon. SiC additive increases the count of crystallisation nuclei of graphite in the melt, consequently the count of graphitic nodules per unit of area is increased (the size of graphitic nodules is decreased) and at the same time the susceptibility to occurrence of carbide in the structure is decreased. Next influence of SiC additive is its ferritizing effect when the content of ferrite in the matrix is increased [3, 4].

The contribution deals with the influence of charge composition on the microstructure, fatigue properties and failure micromechanisms of nodular cast irons. The basic charge of experimental melts was formed by a different ratio of pig iron and steel scrap. Chemical composition of individual melts was regulated alternatively by metallurgical silicon carbide or ferrosilicon and carburizer.

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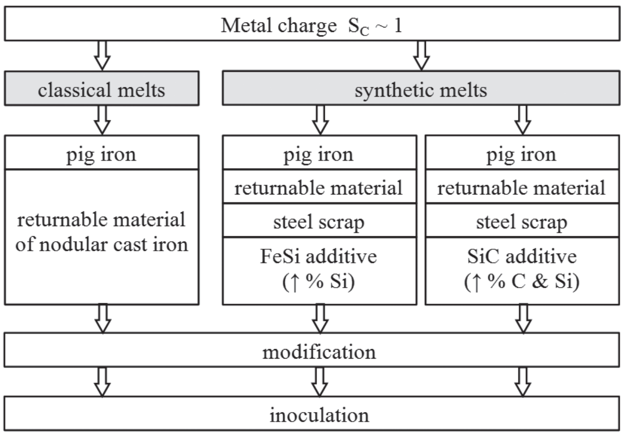


Figure 1 Scheme of the production of nodular cast iron

EXPERIMENTAL METHODS

The specimens from four melts of nodular cast iron were used for experiments. The melts were different by charge composition (Table 1). The basic charge of individual melts was formed by different ratio of pig iron and steel scrap and by different additive for the regulation of chemical composition (metallurgical silicon carbide or ferrosilicon). The content of these additives was chosen to achieve approximately the same resultant chemical composition of the melts. For modification the FeSiMg7 modifier was used and for inoculation the FeSi75 inoculant was used.

Experimental bars (diameter 32 mm and length 350 mm) were cast from all the melts.

The metallographic analysis of specimens from experimental melts was made by the light metallographic microscope Neophot 32. The specimens for metallographic analysis were taken out from the cast bars and prepared by usual metallographic procedure. The mi-

Table 1 **Charge composition of experimental melts**

Melt number	pig iron/ %	steel scrap/ %	additive
3	40	60	SiC
5	0	100	
8	40	60	FeSi
10	0	100	

crostructure of specimens was evaluated according to STN EN ISO 945 (STN 42 0461) and by automatical image analysis (using NIS Elements software) [5-7]. The image analysis was used for the evaluation of count of graphitic nodules per unit of area and content of ferrite in the matrix.

The tensile test was made according to STN EN 10002-1 by means of the testing equipment ZDM 30 with a loading range F = 0 to 50 kN. The impact bending test was made according to STN EN 10045-1 by means of the Charpy hammer PSW 300 with a nominal energy of 300 J. The Brinell hardness test was made according to STN EN ISO 6506-1 by means of the testing equipment CV-3000 LDB with a hardmetal ball of diameter D = 10 mm forced into specimens under the load F = 29 430 N (3000 kp).

The fatigue tests were made according to STN 42 0362 at high-frequency sinusoidal cyclic push-pull loading (frequency $f \approx$ 20 kHz, stress ratio R = –1, temperature T = 20 ± 5 °C) using the ultrasonic testing equipment KAUP-ZU [8, 9].

The microfractographic analysis was made by the scanning electron microscope VEGA II LMU on fracture surfaces of the specimens from experimental bars fractured by fatigue tests [10].

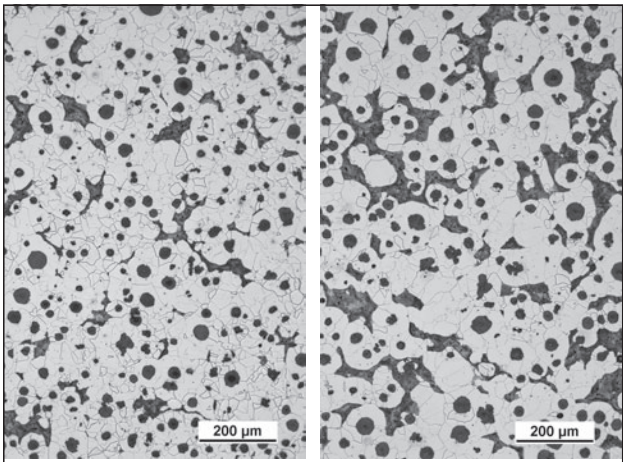
RESULTS AND DISCUSSION

From a microstructural point of view, the specimens from all the melts are ferrite-pearlitic nodular cast irons with different content of ferrite and pearlite in the matrix, different size of graphite and count of graphitic nodules (Figure 2). Different content of ferrite and pearlite in the matrix as well as different size of graphite and count of graphitic nodules in the individual specimens are caused by different ratio of steel scrap in the charge and kind of additive for the regulation of chemical composition (SiC or FeSi).

The results of the evaluation of the microstructure of the specimens from the cast bars by STN EN ISO 945 (STN 42 0461) and by image analysis (content of ferrite and count of graphitic nodules) are presented in Tables 2 and 3.

Table 2 **Results of evaluation of the microstructure by norm**

Melt number	microstructure by STN EN ISO 945
3	80 % VI6 + 20 % V6 – Fe94
5	70 % VI5/6 + 30 % V6 – Fe94
8	70 % VI5/6 + 30 % V6 – Fe80
10	70 % VI5/6 + 30 % V6 – Fe80



a) melt 3 (with SiC additive) b) melt 8 (with FeSi additive)

Figure 2 Microstructure of the specimens from cast bars, etched 1 % Nital

Table 3 **Results of evaluation of the microstructure by image analysis**

Melt number	content of ferrite/ %	count of graphitic nodules/ mm^{-2}
3	74,0	199,8
5	78,0	179,8
8	65,2	151,0
10	56,0	157,6

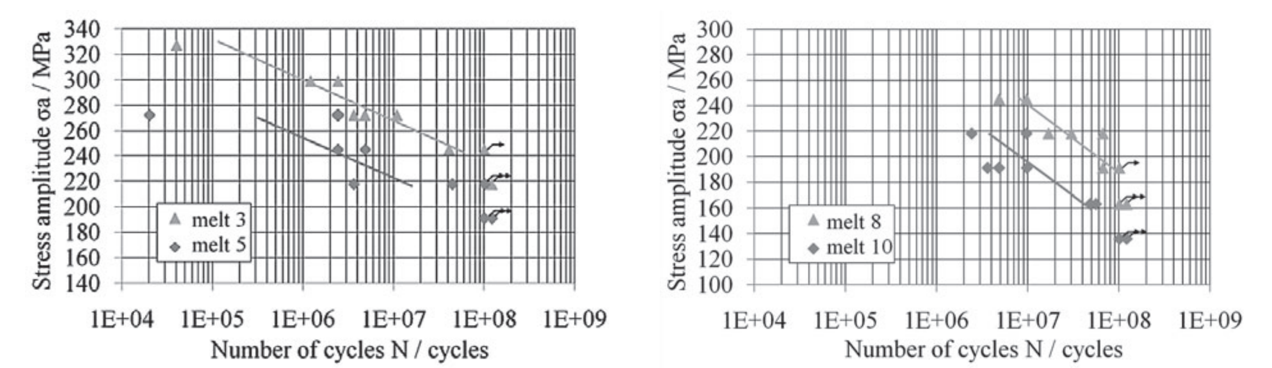
The mechanical tests (i.e. tensile test, impact bending test and Brinell hardness test) were realized on the specimens made from cast bars. The results of mechanical tests, i.e. tensile strength R_m, elongation A, absorbed energy K and Brinell hardness HB, are given in Table 4.

The specimens from the melts with SiC additive have better mechanical properties than the specimens from the melts with FeSi additive. It has connection with the microstructure of the specimens, especially with the character of matrix (content of ferrite and pearlite) and also with the size and count of graphitic nodules. The best mechanical properties were reached in the melt 3 created by 60 % of steel scrap and SiC additive, which has the highest ratio of perfectly-nodular graphite, the smallest size of graphite and the highest count of graphitic nodules.

Table 4 **Mechanical properties**

Melt number	R_m/ MPa	A/ %	K/ J	HBW 10/3000
3	539,0	4,0	30,6	192,3
5	515,7	3,7	17,2	182,3
8	462,6	2,7	24,0	181,3
10	462,6	2,7	19,2	183,0

For the fatigue tests, ten specimens from each melt were used to obtain Wöhler fatigue curves $\sigma_a = f(N)$ and determine fatigue strength σ_c for $N = 10^8$ cycles. The specimens were loaded by high-frequency sinusoidal cyclic push-pull loading (loading frequency $f \approx$ 20 kHz). The results of fatigue tests (relationship between stress amplitude σ_a and number of cycles to failure N_f) are



a) melts 3 and 5 (with SiC additive) b) melts 8 and 10 (with FeSi additive)

Figure 3 Wöhler curves $\sigma_a = f(N)$

shown in Figure 3. Obtained data were approximated by the Basquin function [9] with using of least square method. The number of cycles to failure increases with a decreasing stress amplitude. The values of fatigue strength σ_c are given in Table 5.

Table 5 **Fatigue strength for $N = 10^8$ cycles**

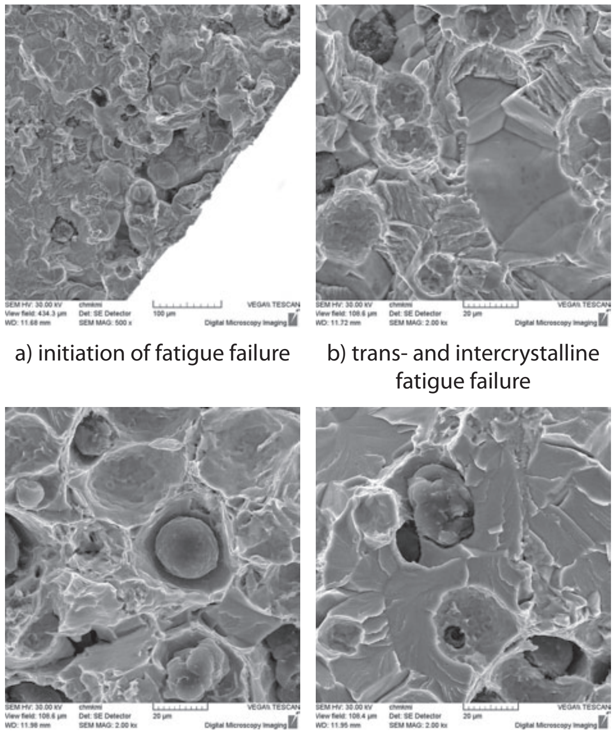
Melt number	σ_c / MPa
3	218
5	191
8	163
10	136

The fatigue strength in analysed specimens of nodular cast iron increases with an increasing tensile strength. The fatigue strength in the specimens from the melts with SiC additive is higher than in the specimens from the melts with FeSi additive. The highest fatigue strength (218 MPa) was reached in the melt 3 created by 60 % of steel scrap and SiC additive, which has the best mechanical properties.

Three specimens from each melt were used for the fractographic analysis of fracture surfaces after fatigue failure. The fracture surfaces of analysed specimens do not show any remarkable differences; they are characteristic of mixed mode of fracture.

The fracture surface of the specimen from the melt 3 (with SiC additive) being loaded by stress amplitude σ_a = 272 MPa (N_f = 1,1 x 10^7 cycles) is shown in Figure 4. The fatigue fracture was initiated by casting defect (Figure 4a). The fatigue fracture is characteristic of intercrystalline fatigue failure of ferrite around graphitic nodules and transcrystalline fatigue failure of ferrite and pearlite in the rest of the area (Figure 4b). The final rupture is characteristic of transcrystalline ductile failure of ferrite with dimple morphology (Figure 4c) and transcrystalline cleavage of ferrite and pearlite with river drawing on facets (Figure 4d).

No significant differences were observed by the comparison of fracture surfaces of the specimens from the analysed melts. The fatigue failure has a mixed character of fracture (intercrystalline and transcrystalline fatigue failure) in all the specimens; the intercrystalline fatigue failure predominates near graphitic nodules and the transcrystalline fatigue failure predominates in the rest of the area.



a) initiation of fatigue failure b) trans- and intercrystalline fatigue failure

c) final rupture – transcrystalline ductile failure d) final rupture – transcrystalline cleavage

Figure 4 Fracture surface of the specimen from the melt 3 (with SiC additive), σ_a = 272 MPa, N_f = 1,1 x 10^7 cycles, SEM

CONCLUSIONS

The results of the experiments show that the charge composition influences the microstructure, mechanical and fatigue properties of nodular cast iron.

The SiC additive positively influences the microstructure, it means the content of ferrite in the matrix is increased, the size of graphite is decreased and the average count of graphitic nodules per unit of area is increased; consequently the mechanical and fatigue properties of nodular cast iron are improved.

The fatigue strength of nodular cast iron is increased with an increasing tensile strength. The best fatigue properties (fatigue strength) from the analysed specimens has the melt 3 created by 60 % of steel scrap and 40 % of pig iron in the basic charge with SiC additive.

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Note: The responsible translator for English language is Gabriela Vašková, Žilina, Slovakia