

Influence of SiC Additive on Microstructure and Mechanical Properties of Nodular Cast Iron

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The contribution deals with comparing of microstructure, mechanical properties and micromechanisms of failure of synthetic nodular cast irons with graded amount of steel scrap in a charge. Chemical composition of individual meltages was regulated alternatively by ferrosilicon (FeSi) and carburizer or metallurgical silicon carbide (SiC). The paper shows that SiC additive positively influences the microstructure, mechanical properties and micromechanisms of failure of nodular cast iron, especially in the meltages with higher ratio of steel scrap in the charge.

Keywords: nodular cast iron, silicon carbide, microstructure, mechanical properties.

1. INTRODUCTION

Nowadays it is actual from an economic point of view to deal with the possibility to substitute a part of more expensive pig iron for cheaper steel scrap in the charge of graphitic cast irons. The transition from the traditional use of pig iron (claimed to be rich in nuclei) to synthetic cast iron prepared from steel scrap (generally believed to contain only few graphitic nuclei) requires the regulation of chemical composition of melt. It is closely linked with the introduction of metallurgical silicon carbide SiC as a siliconizing and carburizing additive (SiC additive is believed to supply the synthetic pure melts with nuclei) [1]. SiC additive positively influences the count of crystallisation nuclei of graphite in the cast iron melt (it increases the count of nuclei), consequently the count of graphitic nodules is increased and at the same time the susceptibility to occurrence of carbide in the structure is decreased.

The technological foundry literature describes the addition of SiC to the cast iron melt frequently as having a special pre-inoculating effect. This influence is well documented in the case of grey cast iron and has also been observed to some extent at industrial as well as at laboratory experiments in the case of nodular cast iron [2].

The paper deals with the influence FeSi and SiC additive on microstructure, mechanical properties and micromechanisms of failure of synthetic nodular cast irons with graded amount of steel scrap in the charge.

2. EXPERIMENTAL

Two series of five meltages of nodular cast iron were used for the experiments. The resultant meltages have approximately the same chemical composition but this was achieved by different charge composition (Table 1). The basic charge of individual meltages was formed by different ratio of pig iron and steel scrap and for the regulation of chemical composition the additive of carburizer and silicon carbide (in meltages 1 to 5) or ferrosilicon (in meltages 6 to 10) was used [3].

Specimens for chemical composition, experimental bars and experimental bodies with a graded wall thickness were cast from all the meltages [4].

The metallographic analysis of specimens was made by the light metallographic microscope Neophot 32. The microstructure was evaluated by STN EN ISO 945 (STN 42 0461) and by coherent test grids [5, 6].

The mechanical tests (i.e. static tensile test, impact bending test and hardness test) were realized on specimens made from cast experimental bars.

3. EXPERIMENTAL RESULTS

3.1. Metallographic analysis

From microstructural point of view all the meltages are ferrite-pearlitic nodular cast irons with different content of ferrite and pearlite in a matrix, different size of graphite and count of graphitic nodules per mm² (Fig. 1). Graphite occurs only in a perfectly-nodular and imperfectly-nodular shape in all the specimens. The results of evaluation of microstructure of chosen specimens from the experimental bars by STN 42 0461 and by coherent test grids (content of ferrite and count of graphitic nodules per mm²) are presented in Table 2.

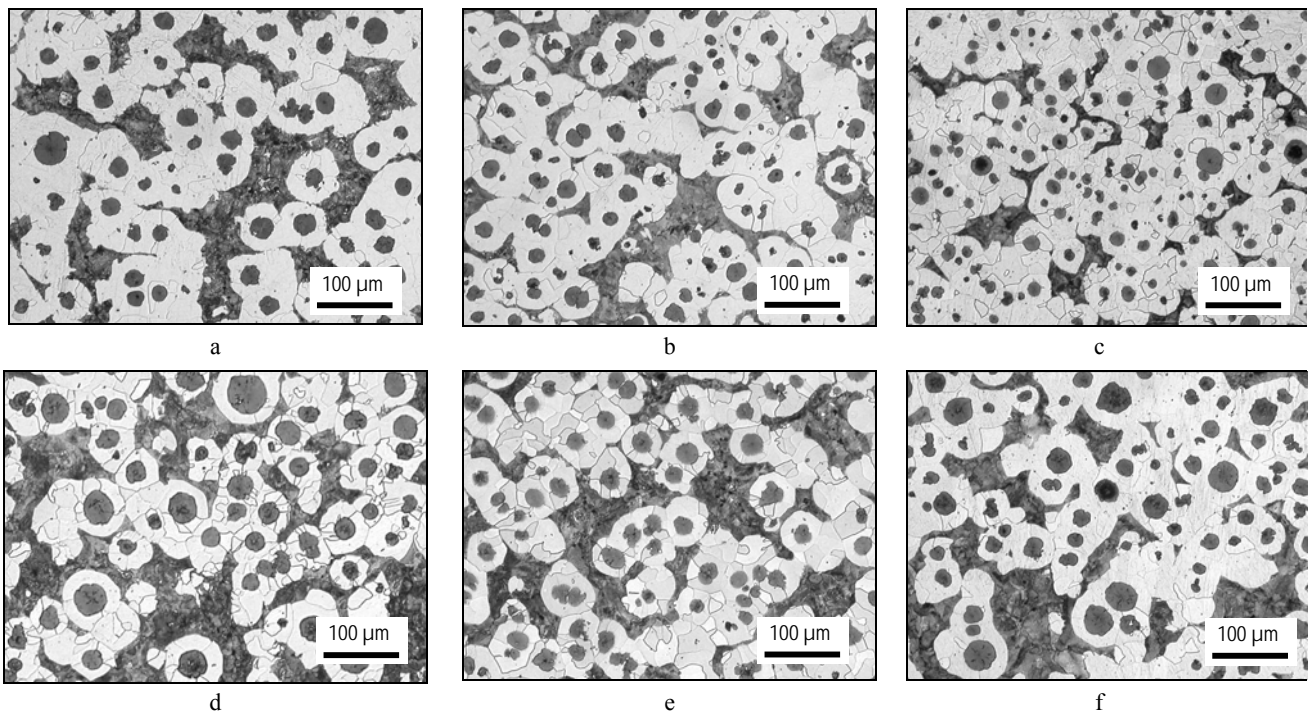
The changes of microstructure in dependence on a wall thickness of cast (i.e. cooling rate) are presented in Fig. 2. It shows the microstructure of specimens from the experimental bodies with a graded wall thickness from the meltage 3 (with SiC additive) and the meltage 8 (with FeSi additive) with the same ratio of pig iron and steel scrap in the charge.

The content of ferrite in the matrix is being decreased with a decreasing wall thickness. The content of ferrite in the meltages with SiC additive (i.e. meltages 1 to 5) is generally higher than in the meltages with FeSi additive (i.e. meltages 6 to 10). In some of the specimens with a thinner wall thickness also cementite, which is an undesirable structural part in the matrix of graphitic cast iron, occurs. In the meltages with SiC additive cementite occurs rarely only in the specimens with a thinner wall thickness whereas in the meltages with FeSi additive cementite occurs also in the specimens with a thicker wall

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Table 1. Charge composition of experimental meltages

Number of meltage	Charge composition (kg)						
	pig iron	steel scrap	carburizer	SiC90	FeSi75	modifier FeSiMg7	inoculant FeSi75
1	24	6	0.27	0.09		0.5	0.2
2	18	12	0.48	0.23		0.5	0.2
3	12	18	0.69	0.37		0.5	0.2
4	6	24	0.90	0.70		0.5	0.2
5	0	30	1.00	0.90		0.5	0.2
6	24	6	0.27		0.08	0.5	0.2
7	18	12	0.40		0.69	0.5	0.2
8	12	18	0.65		0.74	0.5	0.2
9	6	24	0.90		0.80	0.5	0.2
10	0	30	1.25		0.92	0.5	0.2

**Fig. 1.** Microstructure of chosen meltages from experimental bars, etched 1 % Nital: a – meltage 1, b – meltage 3, c – meltage 5, d – meltage 6, e – meltage 8, f – meltage 10**Table 2.** Microstructure and mechanical properties of chosen meltages

Number of meltage	Microstructure			Mechanical properties		
	STN EN ISO 945 (STN 42 0461)	content of ferrite (%)	count of graphitic nodules (mm^{-2})	tensile strength R_m (MPa)	impact toughness $KC0$ (Jcm^{-2})	Brinell hardness HB
1	60 %VI5/6 + 40 %V6 – Fe80	61.6	104.3	500.8	6.4	210.0
3	80 %VI6 + 20 %V6 – Fe94	74.0	199.8	539.0	30.6	192.3
5	70 %VI5/6 + 30 %V6 – Fe94	78.0	179.8	515.7	17.2	182.3
6	70 %VI5/6 + 30 %V6 – Fe55	50.8	126.5	367.1	8.4	190.0
8	70 %VI5/6 + 30 %V6 – Fe80	65.2	151.0	462.6	24.0	181.3
10	70 %VI5/6 + 30 %V6 – Fe80	56.0	157.6	462.6	19.2	183.0

thickness. The content of cementite in the meltages with SiC additive is generally lower than in the meltages with FeSi additive.

Graphite occurs only in a perfectly-nodular shape and imperfectly-nodular shape in all the specimens. The proportion of perfectly-nodular graphite is being increased with a decreasing wall thickness. The size of graphite is

being decreased with a decreasing wall thickness, on the other hand, the count of graphitic nodules per mm^2 is being increased with a decreasing wall thickness. The count of graphitic nodules per unit area in the meltages with SiC additive is generally higher than in the meltages with FeSi additive.

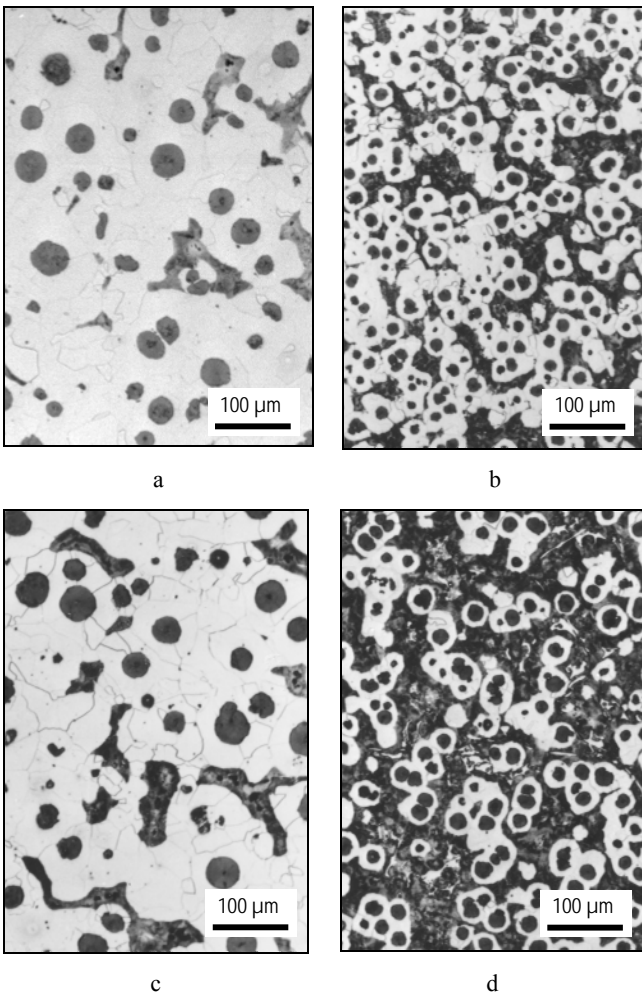


Fig. 2. Microstructure of experimental bodies etched 1% Nital:
a – meltage 3 with a graded wall thickness of 26 mm,
b – meltage 3 with a graded wall thickness of 3 mm,
c – meltage 8 with a graded wall thickness of 26 mm,
d – meltage 8 with a graded wall thickness of 3 mm

3.2. Mechanical properties

The results of mechanical tests, that are tensile strength R_m , impact toughness $KC0$ and hardness HB , are given in Table 2. Their course depends especially on the character of matrix (content of ferrite and pearlite) and also on the size and count of graphitic nodules.

The mechanical properties in the meltages with SiC additive (i. e. meltages 1 to 5) are generally better than in the meltages with FeSi additive (i. e. meltages 6 to 10), especially in the meltages with higher amount of steel scrap in the charge.

3.3. Microfractographic analysis

The microfractographic analysis was made by the scanning electron microscope Tesla BS 343 on fracture surfaces of specimens from experimental bars fractured by the static tensile test (Fig. 3) and the impact bending test (Fig. 4). Fracture surfaces of analysed specimens from both series of meltages are characteristic of mixed mode of fracture.

In the specimens from the meltages with low amount of steel scrap in the charge, transcrystalline cleavage of ferrite with an inclination to intercrystalline cleavage

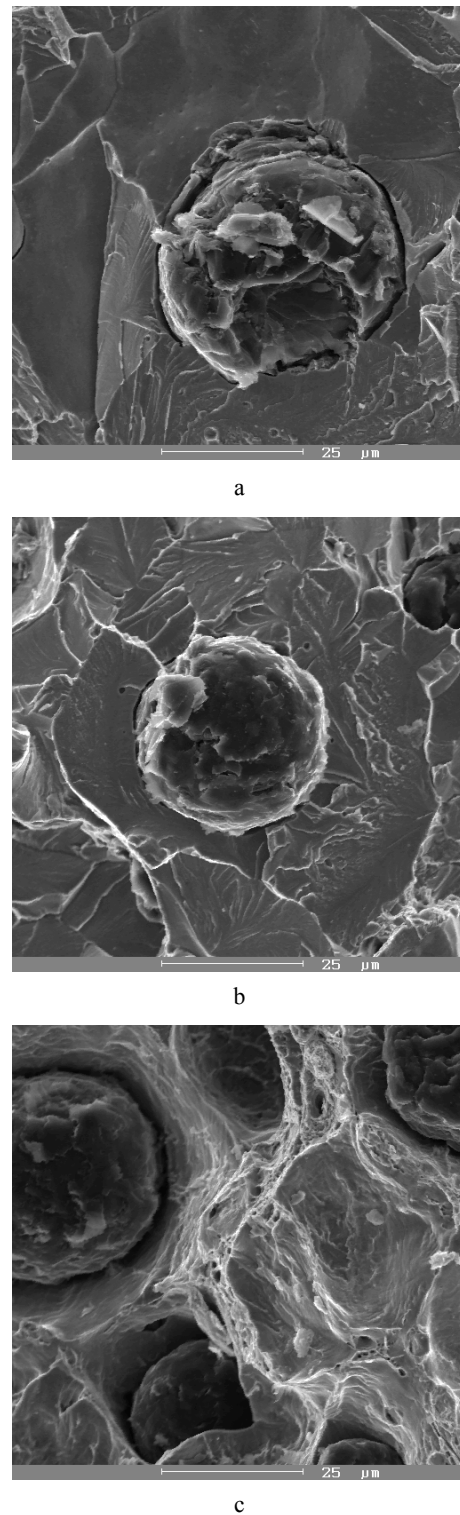
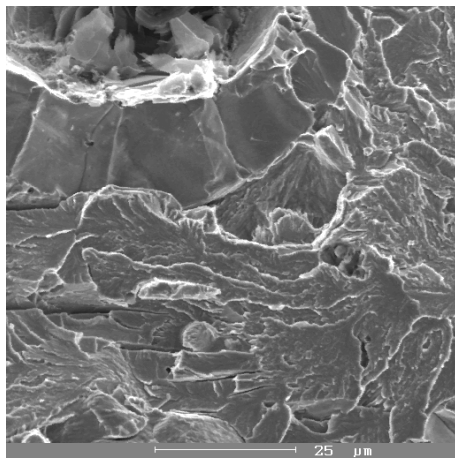


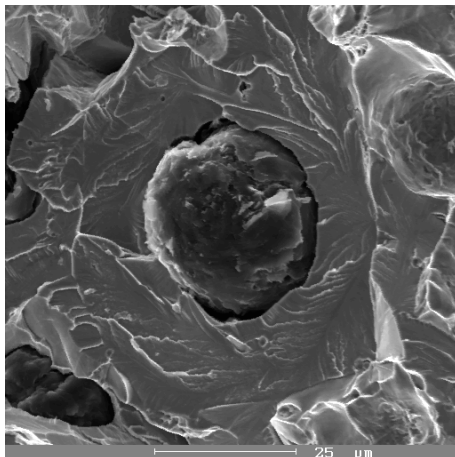
Fig. 3. Micromechanisms of failure of ferrite at static stress, SEM: a – intercrystalline cleavage, b – transcrystalline cleavage, c – transcrystalline ductile failure

(Figs. 3, a; 4, a) was observed. Fracture surfaces of the specimens from the meltages with SiC additive are characteristic of higher ratio of transcrystalline cleavage of ferrite than fracture surfaces of the specimens from the meltages with FeSi additive.

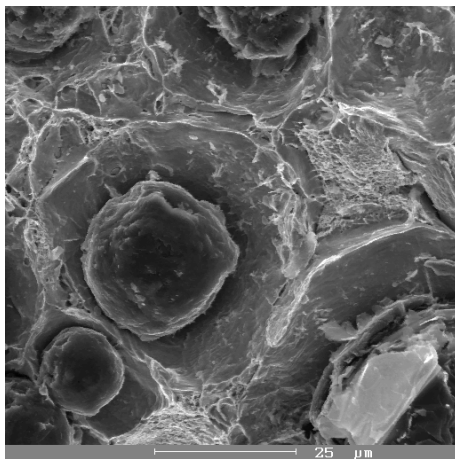
In the specimens from the meltages with high amount of steel scrap in the charge, transcrystalline cleavage with river drawing on facets (Figs. 3, b; 4, b) and transcrystalline ductile failure of ferrite with dimple morphology



a



b



c

Fig. 4. Micromechanisms of failure of ferrite at impact stress, SEM: a – intercrystalline cleavage, b – transcrystalline cleavage, c – transcrystalline ductile failure

(Figs. 3 c; 4 c) was observed. Fracture surfaces of the specimens from the meltages with SiC additive are characteristic of higher ratio of transcrystalline ductile failure than fracture surfaces of the specimens from the meltages with FeSi additive.

Transcrystalline continuous cleavage of pearlite was observed in all the specimens. In the specimens from the meltages with SiC additive with higher amount of steel

scrap also transcrystalline ductile failure of pearlite was observed. The results of microfractographic analysis correspond to the results of metallographic analysis and mechanical tests.

4. CONCLUSIONS

The substitution of a part of pig iron for steel scrap in the charge of nodular cast iron has a considerable economic contribution. For the regulation of chemical composition of melt it is advantageous to use metallurgical SiC additive which has been used in this work as an alternative additive instead of FeSi in meltages with a different ratio of pig iron and steel scrap in the charge.

Increasing amount of steel scrap in the charge decreases total costs of charging raw materials and in consequence of the increasing of SiC or FeSi additive the microstructure is changed (the content of ferrite in the matrix is increased, the count of graphitic nodules per unit area is increased and the occurrence of undesirable cementite is eliminated) and consequently the mechanical properties are improved. This positive influence is more significantly shown in the meltages with SiC additive.

Mode of failure of structural components depends especially on the content of ferrite in matrix and its purity, which has a connection with the charge composition. Failure of ferrite was made from intercrystalline cleavage over transcrystalline cleavage with river drawing on facets to transcrystalline ductile failure with dimple morphology where higher ratio of this micromechanism of failure (transcrystalline ductile failure) has a connection with higher content of ferrite in the matrix. Failure of pearlite was made especially by transcrystalline continuous cleavage with river drawing on facets.

Acknowledgments

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