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ARCHIVES
of
FOUNDRY ENGINEERING

DOI: 10.24425/118819

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (2299-2944)
Volume 18
Issue 1/2018

99 – 102

18/1

Grey Cast Iron Locally Reinforced Using 3D Printing Scaffold Insert

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Received 03.04.2017; accepted in revised form 23.06.2017

Abstract

The paper presents an innovative method of creating the layered castings. The innovation relies on application the 3D printing insert obtaining in SLM (selective laser melting) method. This type of scaffold insert made from pure Ti powder, was placed into mould cavity directly before pouring by grey cast iron. In result of used method was obtained grey cast iron casting with surface layer reinforced by titanium carbides. In range of studies were carried out metallographic researches using light microscope and scanning electron microscope, microhardness measurements and abrasive wear resistance. On the basis of obtaining results was stated that there is a possibility of reinforcing surface layer of the grey cast iron casting by using 3D printing scaffold insert in the method of mould cavity preparation. Moreover there was a local increase in hardness and abrasive wear resistance in spite of the precipitation of titanium carbides in surface layer of grey cast iron. While the usable properties of composite surface layer obtained in result of use of the method presented in the paper, strongly depend of dimensions of scaffold insert, mainly parameters R_e and R_i.

Keywords: Grey cast iron; 3D printing insert; Titanium; Hardness; Abrasive wear resistance

1. Introduction

Composites represent one of four groups of engineering materials. They are made from at least two constituent materials which have significantly different properties. The product of that combination is a material characterizing by different, better features from the individual components. The unique features of composites entail intensive research on the development of manufacturing technology and continued improvement of their properties [1-4].

The important manufacturing technique of layered materials, also composites is method of mould cavity preparation. In this method the working surface layer characterized by high usable properties, is produced by placing the insert in the mould cavity directly before pouring molten metal. This technology is a very economical way to enrich the surface of castings directly in cast process. Moreover, does not generate cracks in a heat affected zone what is possible when surface is modified in other processes i.e. using welding methods [4-11].

In the method of mould cavity preparation usually were used granular inserts in form of metallic or ceramics powder and binder mixture or monolithic inserts in form of steel plates. These type of insert often were poured by cast steel or cast iron [6-8].

Whereas in paper is presented new method of insert manufacturing i.e. 3D printing based on SLM (selective laser melting) method. Selective Laser Melting is an additive manufacturing method that uses a laser in an inert atmosphere to selectively melt layers of loose metal powder into a solid, building a part layer by layer from the bottom up.

In presented studies was analyzed scaffold shape of insert with clearly defined shape and overall dimensions [12,13,17,18].

2. Range of studies

The aim of studies was to manufacture the layered casting using method of mould cavity preparation by insert carry out in SLM method. Applied scaffold insert made from pure Ti powder is presented in Fig. 1. The scaffold structure of the insert was made by connecting rods of circular cross-section, arranged vertically and horizontally. The dimensions of external diameter (R_e) of rods is 1-5 mm and internal diameter(R_i) of rods is 50-90% R_e (Fig. 2). The distance (P) between connecting rods is from 100 to 150% of R_e and the weight of insert do not exceed 5% of the weight of whole layered casting (Fig. 3) [14].

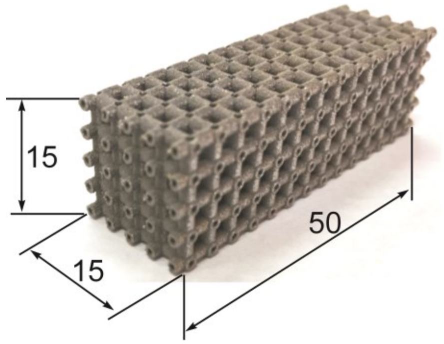

Fig. 1. Scaffold insert made from pure Ti powder

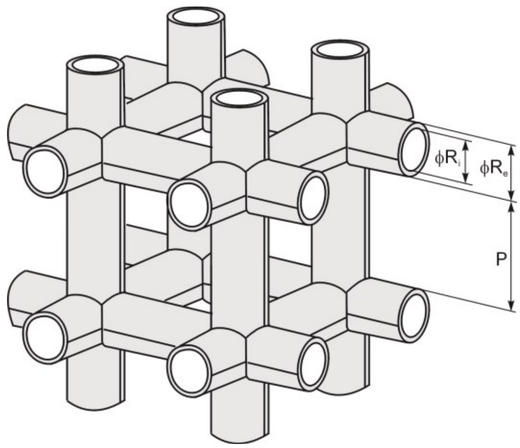

Fig. 2. Scheme of example cell of scaffold insert

The mould with insert was poured by pearlitic grey cast iron with flake graphite. The pouring temperature was set of 1500°C. Next were made metallographic researches using light microscope Nikon and scanning electron microscope PhenomProX with analysis EDS, microhardness measurements with load 10N using of microhardness tester FUTURE-TECH. Moreover, was carried out researches of abrasive wear resistance using pin-on-disk method according to [15,16]. In this method the speed of disk with the sample was 150rpm, while speed of rotation of counterspecimen with SiC (abrasive paper) was 400rpm.

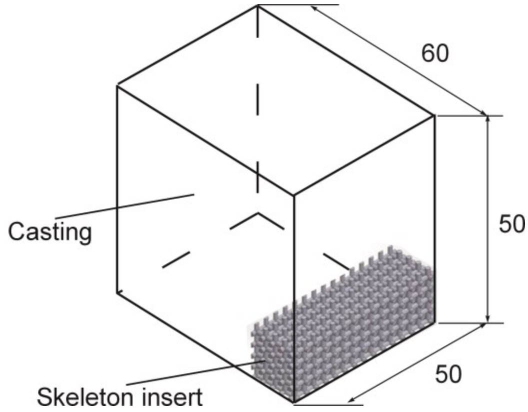

Fig. 3. Shape and dimensions of casting and position of scaffold insert

3. Results of studies

In Fig. 4 is presented example cross-section of obtained grey cast iron casting with surface layer locally reinforced by Ti insert. As shows Fig. 4 in the casting is present surface layer reinforced by the insert partially dissolved in the grey cast iron matrix. The degree of dissolving of insert depends of parameters of cast process, mainly of pouring temperature of grey cast iron. Therefore, thickness of obtained reinforced layer is irregular.

Fig. 4. Macrostructure of obtained layered casting

Whereas in Fig 5. is presented example microstructure of surface layer of casting. As a result of reaction between liquid metal solidified in the mould and Ti scaffold insert, is observed a precipitation of titanium carbides in the microstructure of reinforced surface layer of casting.

The mechanism of the reaction provides that - as a consequence of diffusion process in high temperature zone - the atoms of carbon are set in octahedral interstice of titanium atoms what is accompanied by the precipitations of carbides. The concentration of carbides decreases with increasing distance from the insert.

Moreover, the carbides have different size (from 2 to 7μm) and shapes. Example titanium carbides in pearlitic matrix obtained in surface layer of casting are presented in Fig. 6. On the basis of EDS analysis (Tab. 1) carry out in selected points from Fig. 6 was affirmed that generally in microstructure are carbides of type TiC.

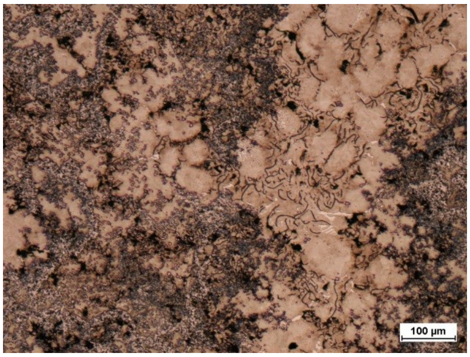

Fig. 5. Microstructure of surface layer of casting reinforced by Ti insert, etch. Nital, mag. 100x., LOM

On the basis of obtained metallographic researches was affirmed also, that in each reinforced layer are two areas i.e. internal with small amount of titanium carbides (Fig. 6a) and external with large amount of titanium carbides (Fig. 6b). The internal area was created in the empty inside of the rod. Whereas the external layer was created in result of reaction between liquid cast iron and wall of rod.

The obtained carbides are very good connected with cast iron matrix as show Fig. 7. Therefore, it can be considered that the studied casting has the reinforcing surface layer in the form of an in situ composite.

a)

b)

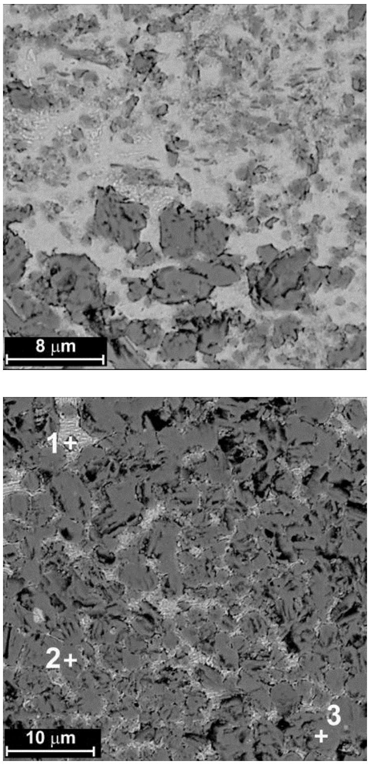

Fig. 6 Microstructure of surface layer of casting reinforced by titanium carbides, SEM

Table 1.
Pointwise EDS analysis (number of measuring points as in Fig. 6)

No	Ti %		C %		Fe %	
	atomic	weight	atomic	weight	atomic	weight
1	40.25	71.52	58.62	26.13	1.13	2.34
2	43.27	73.27	55.04	23.39	1.70	3.35
3	38.96	69.84	59.39	26.71	1.65	3.44

a)

b)

c)

d)

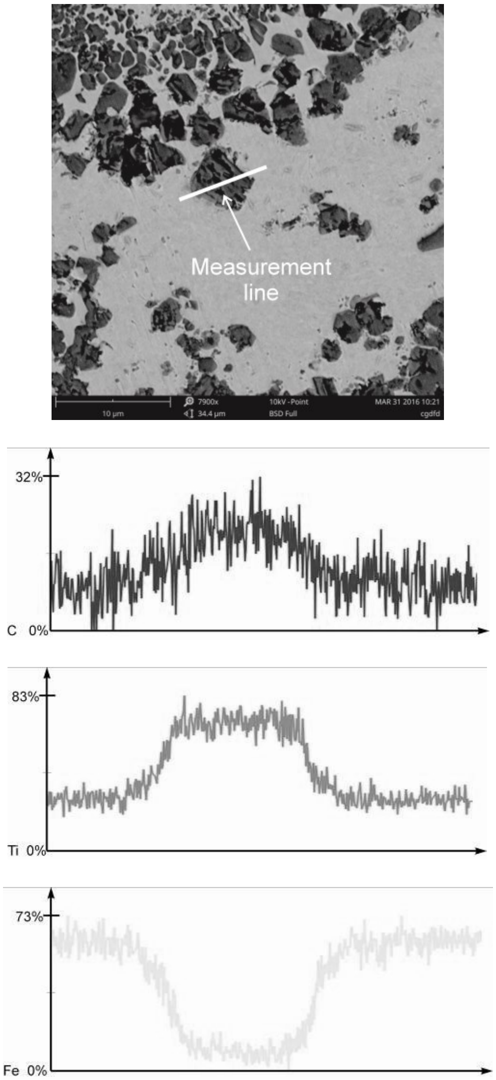

Fig. 7. Linear EDS analysis of selected titanium carbide in pearlitic matrix in surface layer of casting: a) measurement area, b) distribution of C, c) distribution of Ti, d) distribution of Fe.

In Fig. 8 shows example results of microhardness measurements. On the basis of obtained results was affirmed that hardness of reinforced layer of casting depends of titanium carbides concentration. Therefore, internal area with small amount of carbides has hardness approx. 700µHV and external area with large amount of carbides has hardness approx. 900 µHV.

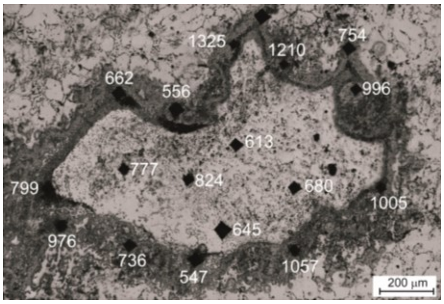

Fig. 8. Microstructure of reinforced surface layer of casting with results of microhardness measurements

Such high hardness guarantees high resistance to abrasive wear of the obtained reinforced surface layer of casting, despite its non-regularity. Wear resistance of studied layered composite is larger than wear resistance of matrix material i.e. pearlitic grey cast iron with flake graphite and chromium cast iron contains 3%wt. of C and 18%wt. of Cr at hardness 597µHV and hardened low-alloyed steel contains 0,3%wt. of C and 2%wt. of Cr at hardness 440µHV (Tab. 2).

Table 2.
The results of wear resistance measurements

Material	mass decrement, g					Average mass decrement, g
casting composite	0.012	0.021	0.013	0.014	0.014	0.012
chromium cast iron	0.043	0.034	0.031	0.061	0.062	0.044
low alloy steel	0.092	0.053	0.061	0.082	0.071	0.070
cast iron	0.262	0.201	0.203	0.192	0.281	0.226

4. Conclusions

Based on the conducted studies the following conclusions have been formulated:

1. There is a possibility of reinforcing surface layer of the grey cast iron casting by using 3D printing scaffold insert in the method of mould cavity preparation.
2. Titanium carbides, mainly TiC, are obtained as a result of reaction between pure Ti and liquid cast iron. Their presence in microstructure of surface layer guarantees a growth of wear resistance and hardness of casting.
3. Dimensions of scaffold insert, mostly parameters R_e and R_i, are the main factor that influence the usable properties of composite surface layer obtained in result of use of the method presented in the paper.

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