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The Impact of Selected Geometry Parameter of Titanium Spatial Insert on the Surface Layer Formation on Grey Cast Iron

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Abstract

The paper presents a method of producing a grey cast iron casting locally reinforced with a titanium insert printed using SLM method (Selective Laser Melting). This article attempts to examine the impact of the selected geometry of titanium spatial insert on the surface layer formation on grey cast iron. The scope of the research focuses on metallographic examination - observation and analysis of the structure of the reinforced surface layer on a light and scanning microscope and a hardness measurement of the titanium layer area. Based on the obtained results, it was concluded that the reaction between titanium insert and metal (grey cast iron) locally develops numerous carbides precipitation (mainly TiC particles), which increases the hardness of the reinforced surface layer and local strengthening of the material. The ratio between the thickness of the support part (grey cast iron) and the working part (titanium insert) affects the resulting layers connection structure. The properties of the obtained reinforced surface layer depend mainly on the geometry of the insert (primarily on the internal dimensions of the connector) and the volume of the casting affecting the re-melting of the insert. A more concentrated structure of carbides precipitation occurs in castings with a full connector insert.

Keywords: Grey cast iron, Titanium, Carbides, Insert, Layered casting

1. Introduction

Dynamic technological progress in the past century has caused rapid development of industry and manufacturing techniques [1]. Among the traditional methods of manufacturing processes such as: casting, moulding, joining and machining, new technologies began to appear. One of them is additive manufacturing which consists of processes of applying subsequent layers of material through sintering, melting, extruding, laser irradiation etc. [2-7]. The process involves the use of a computer and special CAD software. The use of modern additive manufacturing techniques became possible due to development of special materials and methods of their processing [8,9]. The following stage of technological change is the combination of traditional and modern manufacturing processes that allows the production of elements with high mechanical and physicochemical properties that meet contemporary technological requirements [10,11]. One of the examples of combining traditional and modern production methods are layered castings, which are locally reinforced with 3D printed inserts. This method deserves a special attention because it brings about many advantages for the production process and high properties of the connection of obtained materials. The technique is simple, it does not require use of additional devices and is economical because the whole method takes place in a single process. It is possible to regulate the thickness of the layers, and they can be placed on any casting area inside the mould. In addition, the formation of cracks in the heat affected zone is eliminated. The layered castings consist of two main elements: the working part (layer) and the supporting part. The insert form may occur as granular particles, monolithic plaques or spatial inserts. The spatial inserts are made using the 3D printing method - SLM (selective laser melting). It allows to make inserts with a complicated geometric shape, duplicate the mould cavity area where different properties are required, for example: higher abrasion resistance or increased hardness of the casting working part [12].

2. The aim of the research

The aim of the research was to create a grey cast iron material with titanium reinforcement and to determine the influence of insert geometry (connector thickness) and casting volume ratio on the layer structure. The layered castings were produced using a eutectic grey cast iron (supporting part) and a titanium insert (working part). The pouring temperature was 1450°C. The spatial insert was printed via SLM method (Selective Laser Melting), using titanium powder with granulation up to 50 µm. The inserts shown in Figure 1 were used in the experiment. Their total dimensions were 80x24x24 mm, the outer diameter of the connector was 3 mm, and the internal diameter of the connector was 2.25 mm (Fig. 1a - "empty connector") or 0 mm (Fig. 1b - "full connector").

a) b)

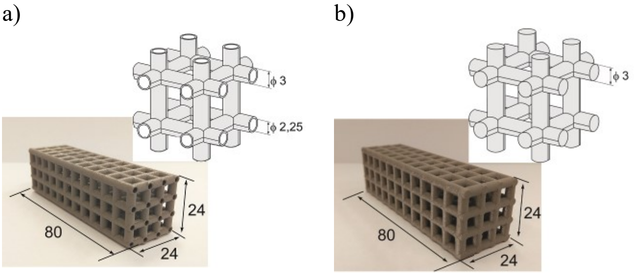


Fig. 1. 3D printed insert; a) with an empty connector; b) with a full connector

The shape of the casting along with the location of the insert is shown in the Figure 2.

The research included microstructure observation via light microscopy using NIKON microscope and scanning electron microscopy (SEM) with point and surface EDS microanalysis f the chemical composition using PHENOM scanning microscope. Samples were digested in 3% Mi1Fe (containing 3 cm^3 of nitrous acid and 100 cm^3 of ethanol). The micro-hardness tester FM 700 by FUTURE-TECH was used to measure the hardness.

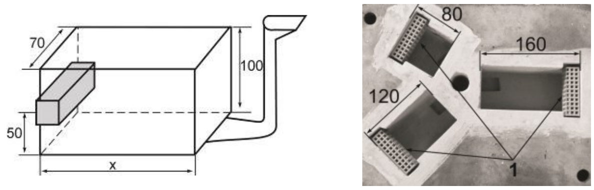


Fig. 2. Shape of the casting with dimensions; 1- titanium insert

3. The results of the research

As a result of combining the two materials, the layered casting of grey cast iron with titanium reinforcement (with numerous carbides precipitates) was obtained. Figures 3 and 4 show the structures of the layers obtained using the insert with a full connector (Fig. 3) and an empty connector (Fig. 4). Pouring liquid iron into the mould, which comes into contact with the titanium insert, triggers a diffusion processes (carbon and titanium) that causes carbides precipitation. The carbides precipitates concentration is dependent on the proximity of the insert. Comparing the influence of the insert geometry (connector shape), we can observe a greater concentration of carbides precipitates in the castings with a full connector insert. In case of a casting of dimensions 70x100x80 mm (for an insert with an empty connector), no titanium layer was observed. It was most probably caused by a high pouring temperature (1450 °C) and small volume of the casting, which caused dissolution of the insert (with an empty connector).

a) b) c)

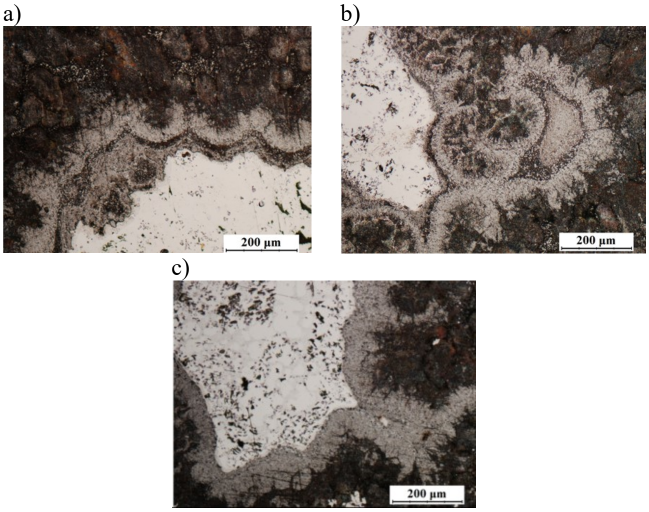


Fig. 3. The area of carbides precipitation in casting with full connector; magnification 100x; casting thickness: a) 160 mm; b) 120 mm; c) 80 mm

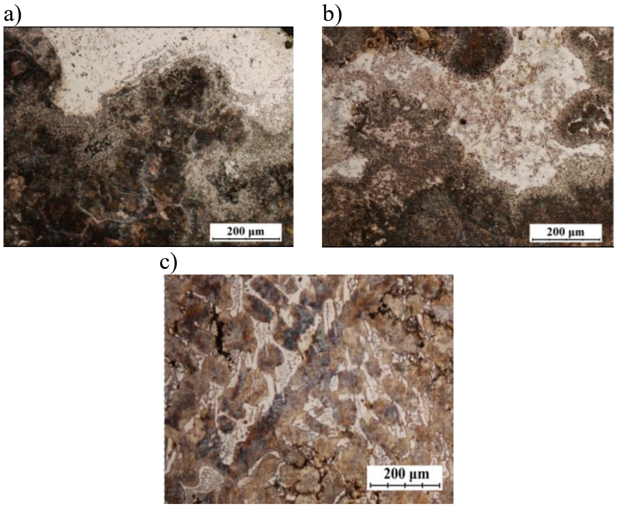
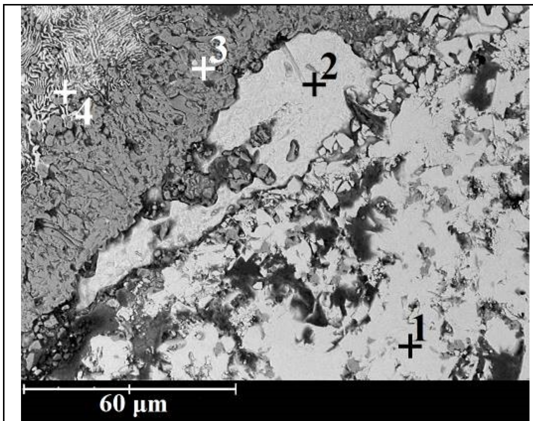


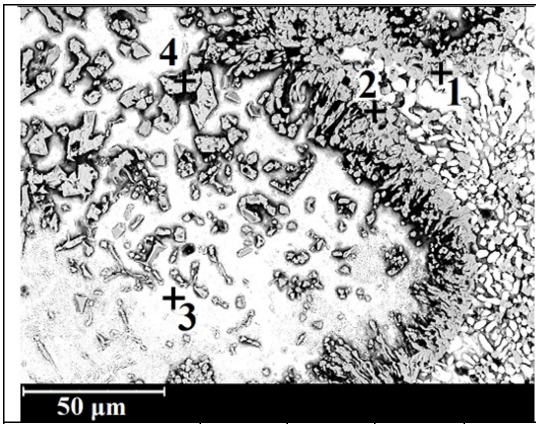
Fig. 4. The area of carbides precipitation in casting with empty connector; magnification 100x; casting thickness: a) 160 mm; b) 120 mm; c) 80 mm

The results of the research conducted using the scanning microscopy are shown in Figures 5 and 6. Point EDS analysis allowed to detect the chemical composition of the material and to measure the weight and atomic content of the elements in the chosen points of the surface layer.



Measurement	Ti%	C%	Fe%	Si%
1	22.6	20.4	54.7	2.3
2	2.1	19	77.8	1.1
3	67.2	32.8	0	0
4	56.5	36.24	7.23	0.03

Fig. 5. Point EDS analysis (%wt.) - casting with an empty insert connector and dimensions 70x100x160 mm



Measurement	Ti%	C%	Fe%	Si%
1	45.5	54.5	0	0
2	45.9	54.1	0	0
3	0	51.9	47.3	0.8
4	49.8	50.2	0	0

Fig. 6. Point EDS analysis (%wt.) - casting with an empty insert onnector and dimensions 70x100x120 mm

Point EDS analysis results showed that the carbon and titanium eight concentration are dominant in the reinforced surface layer.

As a part of the research, a surface analysis (mapping) of the obtained layer for castings with the insert with a full (Fig. 7) and empty connector (Fig. 8) was also performed. Surface analysis allowed to observe the distribution of elements (mainly carbon, titanium and iron) concentration in different areas of the material. It is noticeable that carbon concentration is distributed quite regular among the other elements of analysed areas.

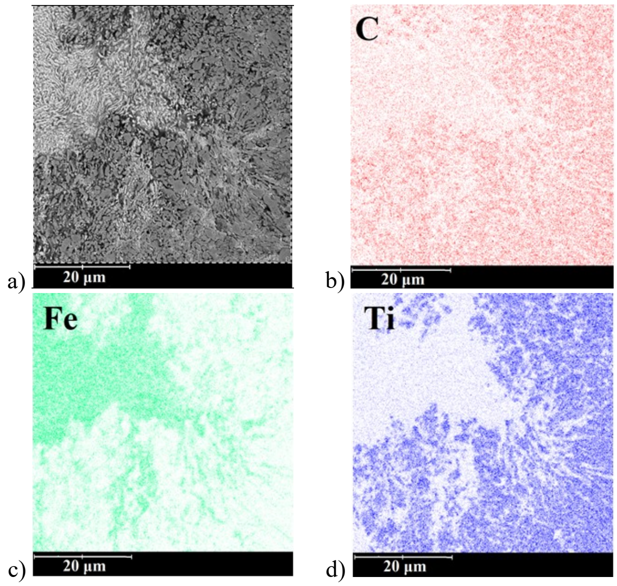


Fig. 7. Surface EDS analysis of the titanium layer - insert with a full connector, casting dimensions: 70x100x160 mm;
a) microstructure of the surface, b) carbon content, c) iron content, d) titanium content

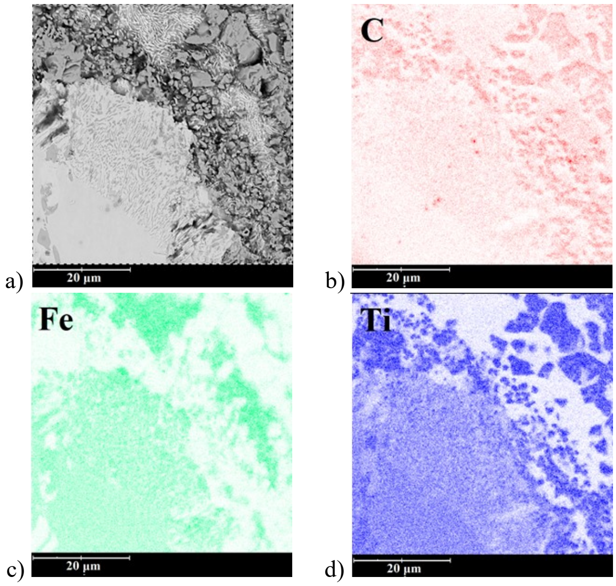


Fig. 8. Surface EDS analysis of the titanium layer - insert with an empty connector, casting dimensions: 70x100x160 mm; a) microstructure of the surface, b) carbon content, c) iron content, d) titanium content

Vickers hardness measurement was carried out using a static load (F = 1kgf ≈ 9.81 N). For each of the castings with an insert with a full connector and an empty connector, a series of measurements were carried out. The average results of the measurements are presented in Table 1.

Table 1.
The average results of the Vickers hardness measurements HV1

insert	empty connector			full connector		
dimensions mm	70x100			70x100		
	160	120	80	160	120	80
grey cast iron layer HV1	326	362	342	324	317	378
titanium layer HV1	602	578	-	646	611	806

The average result of hardness measurements for the titanium layer area is in the range from 600 to 800 HV1, while for the iron area it is 320-370 HV1. The measurement result testifies to the local reinforcement of the grey cast iron by titanium. Comparing the obtained hardness measurement values of the both layered castings (insert with full and with empty connector), it can be noticed that castings with a full insert achieve higher results. Figure 9 shows an example of the indentations left after the measurement with the obtained values.

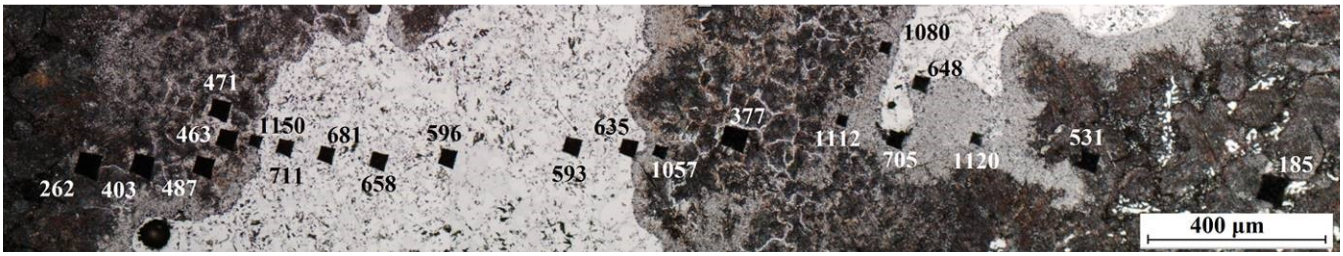


Fig. 9. The area of microhardness measurement – casting with the full insert; dimensions: 70x100x80 mm

4. Conclusions

Based on the results received from the research, the following conclusions were reached:

1. As a result of the reaction: the titanium insert - metal (grey cast iron), numerous carbides precipitates (mainly TiC) are generated, which guarantees an increase of hardness of the material surface (about 650 HV1). Carbides have irregular shape and size.
2. The result of measurement of hardness of the support part material (grey cast iron) area in layered casting shows higher values (about 350 HV1) compared to the standard grey cast iron hardness (about 230 HV1), which proves that the titanium insert provides local strengthening of the material.
3. The thickness ratio of the support part (grey cast iron) to the working part (titanium insert) affects the resulting reinforced surface layer structure. With appropriate pouring temperature, the lower the thickness ratio between the support part and the working part, the more concentrated carbides precipitation is and greater the hardness of the structure becomes.
4. The properties of the obtained reinforced surface layer depend mainly on the geometry of the insert, primarily on the internal dimensions of the connector (thickness) and the volume ratio of the casting affecting re-melting of the insert. More concentrated structure of carbides precipitates occurs in castings with a full connector insert.

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