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Microstructure Characteristic of TiC-Reinforced Cast Steel after GTAW Remelting

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Abstract

In this study, low-carbon cast steel was reinforced with TiC by SHS-B method, also known as combustion synthesis during casting method. The composite zone was then subjected to surface remelting by Gas Tungsten Arc Welding (GTAW) method. The remelting operation was realized manually, at 150 A current magnitude. Microstructure, phase composition and hardness of remelted zone were investigated. XRD results reveal that the phases of the composite zone in initial state consist of TiC and Feα. Surface remelting resulted in formation of thick layers containing TiC carbides, Feα and Feγ. Microstructural examination has shown strong refinement of titanium carbides in remelted zone and complete dissolution of primary titanium carbides synthetized during casting. The average diameter of carbides was below 2 µm. The structural changes are induced by fast cooling which affects crystallization rate. The hardness (HV30) of the remelted layer was in the range between 250 HV and 425 HV, and was lower than hardness in initial state.

Keywords: Composite steel casting, TiC-reinforced cast steel, GTAW surface remelting

1. Introduction

Metal-matrix composites reinforced with ceramic particles (MMCs) are the alternative for high-alloy cast steel, in applications requiring high wear resistance. They are artificially manufactured and consist of metallic matrix and reinforcing phase of carbide, boride or oxide particles in the form of powders, fibres, lamellae as well as carbon microspheres. These materials are often manufactured by mixing ceramic particles with aluminium, magnesium, copper and nickel casting alloys [1,2] or by infiltration of porous preform [3]. The materials fabricated in this way exhibit good wear resistance while showing low impact strength resulting from a lack of coherence between ceramic particles and the matrix. Significant group are metal-matrix composites in which both the matrix and reinforcing phase are being formed in the crystallization process, or, just before crystallization, through chemical reaction. Since the process involves alloying components, there are no limitations resulting from surface phenomena, the phase boundary is highly coherent and free from undesirable impurities, e.g. oxides. At present, the composites of this type, also known as in situ composites, are produced with application of Self Propagating High Temperature Synthesis in Bath (SHSB) method, from the mixtures of pressed metallic and non-metallic powders placed in a casting mould. This method makes it possible to obtain composite layers in selected regions of castings, exposed to environmental influence.

The microstructure of composite layers obtained in situ in castings, is being developed as a result of chemical composition of powders, being the substrates of a reaction of formation of selected carbide type, as well as influenced by the pressure applied to compaction. One of the most commonly used materials reinforcing the cast steel matrix is titanium carbide. Composite layers made from this carbide show high hardness, resulting in good wear resistance. In the case of application of powder metallurgy (PM) compacts containing powders of substrates of a reaction of TiC formation, compacted under the pressure of 300 MPa, to the manufacturing of composite layers, the microstructure of conglomerates is obtained. It is characterized by coagulated TiC particles, often in a form of cellular structure. The size of conglomerates arranged in the matrix may range from 10 to 200 µm. The regions in the matrix located between individual conglomerates are of similar size. The cellular structure of composite layers shows relatively low abrasion resistance, when compared with a structure of dispersed composite. The structure of dispersed composite may be developed within a composite zone by applying suitable additives [4-6] or by means of surface heat treatment such as laser remelting, plasma-arc remelting, vacuum arc remelting and other methods [7-10]. The application of these techniques leads to obtaining strongly defected, very fine microstructure showing high hardness and wear resistance. In order to homogenize and refine the microstructure of composite zones, manufactured without the application of adding powders of substrates of a reaction of TiC formation, an attempt was made to apply surface treatment using GTAW method.

2. Experimental procedures

Cast carbon steel of chemical composition given in Table 1 was selected for the study. The cast steel was melted in a laboratory medium-frequency induction furnace. After melting down the steel was deoxidized with metallic aluminium and alloying components were supplemented. Before tapping, the steel was Al-deoxidized again and then metallic titanium and FeB18 ferroboron were introduced. During tapping into a ladle, FeSiCa30 calcium silicon was introduced.

Table 1.
Chemical composition of cast steel, wt. %

C	Si	Mn	P	S	Ti	B	Al
0.18	0.32	1.01	0.012	0.013	0.08	0.002	0.026

The castings were made in sand moulds with furan resin, coated with zirconium coating. The dimensions of PM compacts containing titanium and carbon powders in 1:1 ratio were 10x15x100 mm. The pressure of 300 MPa was applied during pressing. Three green bodies of this type were placed in a mould cavity having the dimensions of 150x150x20 mm, and liquid steel was then poured into mould. After knocking out, the casting was normalized from the temperature of 920 °C. In the next step, composite zones were exposed by grinding and then remelted using MAGNUM Viper 335 AC/DC device. The remelting operation was realized manually, at 150 A current intensity and with application of tungsten electrode WL15, 2.4 mm in diameter. The shielding gas was argon (99.995 purity) with 8-12 dm3/min flow rate. The specimens for microscopic examination were cut out in parallel with remelting line. Microstructure examination was performed with application of Hitachi S-3400 N scanning electron microscope equipped with EDS detector (Thermo Scientific™). X-ray analysis was carried out using Kristallflex 4HX-ray diffractometer by Siemens.

3. Results

Fig. 1 presents the cross-section of composite zone made in parallel with remelting line. Three zones can be distinguished: remelted zone, heat affected zone (HAZ) and base composite. In the remelted zone, when using low magnification, no carbides can be observed practically, except fine conglomerates which were not dissolved during remelting. Some dark regions are also visible, in which shrinkage microporosity occurs (Figs. 1 and 2a).

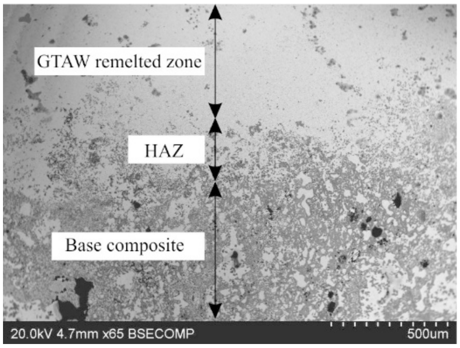

Fig. 1. Cross-section of remelted zone

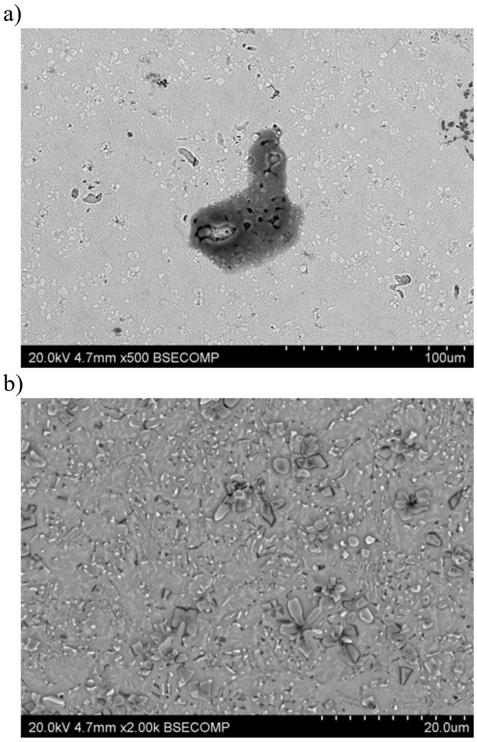

Fig. 2. Microstructure in GTAW-remelted zone, magn. 500x (a), magn. 2000x (b)

The remelted zone is shown in Fig. 2 at the magnification of 500x and 2000x. Besides very fine carbides of size not exceeding 4 µm, shrinkage microporosity can be observed here. Primary titanium carbides which were not dissolved are practically not visible.

As the observation focuses on the HAZ, more and more primary carbides formed during synthesis are visible (Fig. 3a). They are characterized by the size between a few micrometers and 20-30 µm and by oval shape.

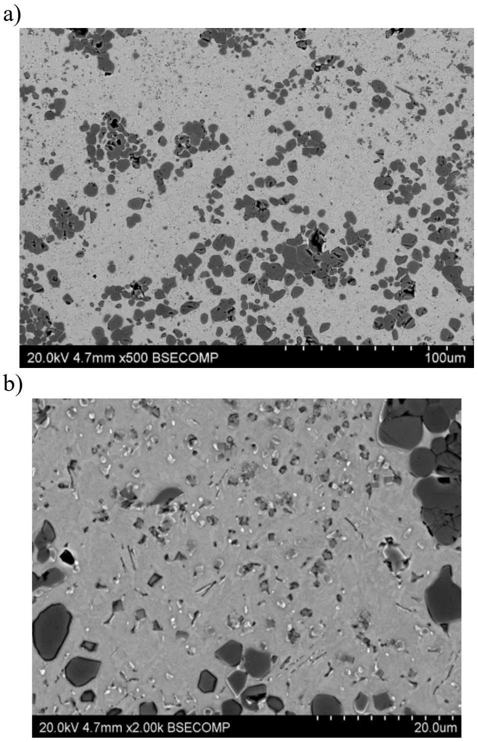

Fig. 3. Microstructure in HAZ (a) and (b) and in base composite (c)

There are also very fine carbides formed during remelting visible in the HAZ, the size of which does not exceed 2 µm (Fig. 3a and b).In base composite, the carbides form a continuous ceramic skeleton and are characterized by very large size and oval shape (Fig. 3c).

The following figure (Fig.4) present the analysis of chemical composition of precipitates in the remelted zone. Very fine carbides of irregular or polyhedral shape can be observed, characterized by increased percentage of titanium (Table 2 – point 1, 3).

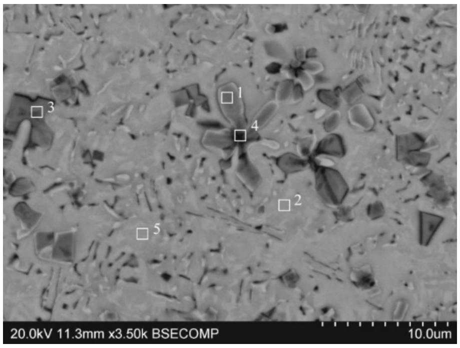

Fig. 4. EDS analysis of precipitates in remelted zone.

The occurrence of tungsten was also identified in these precipitates (it was not introduced on purpose and probably comes from the electrode of remelting device). The EDS analysis of such fine precipitates is susceptible to error, therefore X-ray analysis was also performed in order to identify the crystalline structure of detected phases.

Table 2.
Chemical composition of precipitates from Fig. 5, wt. %

Point	C	S	Si	Mn	Ti	W	Fe
1	20.61	-	-	-	26.2	7.79	45.9
2	3.88	-	0.53	1.20	5.50	-	88.8
3	15.61	-	-	-	43.4	10.2	30.8
4	5.96	-	0.92	0.87	8.76	-	83.5
5	5.64	0.52	1.35	1.58	3.02	-	87.9

In the Fig. 5 the X-ray pattern obtained for the investigated case of remelting is presented. The application of an X-ray diffractometer confirmed the occurrence of TiC in both remelted zone and composite layer.

In the case of composite layer, Feα is identified as the matrix, while in remelted layer additional small Feγ peak was observed. The occurrence of retained austenite after GTAW remelting can result from dissolution of titanium carbides and their repeated fast crystallization. During this process, a part of carbon and titanium remains dissolved in the matrix (austenite) and it will not precipitate again in the form of carbides, as a result of very fast cooling rate, which impede diffusion of alloying elements and lead to formation of Feγ in matrix.

It is confirmed in EDS analysis, which showed higher percentage of titanium in the matrix (Fig. 4 – points 2 and 5), in remelted layer.

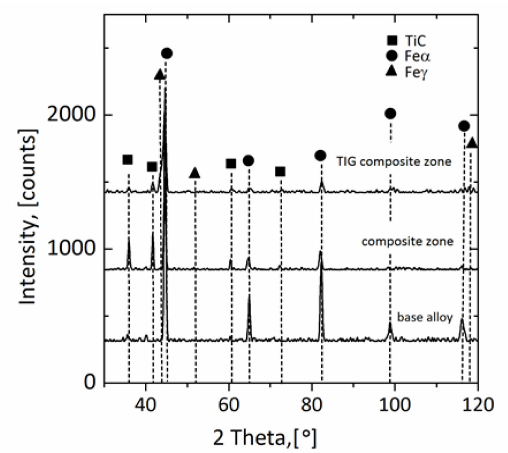

Fig. 5. Diffraction pattern of composite zone

The effect of GTAW remelting on the hardness of composite layer is shown in Fig. 6. Significant decrease of hardness is observed at both 9.81 N (HV1) and 294.3 N (HV30) loads.

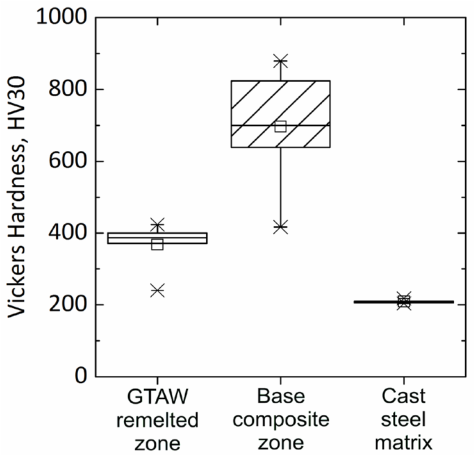

Fig. 6. Results of hardness measurements

The hardness of non-remelted composite zones is at the level of about 700 HV30. The application of remelting results in hardness lowering to the level of 400 HV30. It should be noticed that the positive effect of GTAW treatment is a significant homogenization of hardness, which is caused by more uniform distribution of carbide particles in the cast steel matrix.

4. Conclusions

Based on investigation of the application of GTAW method to the modification of surface of a casting with composite layer the following conclusion can be summarized:

1. Microscopic observations in GTAW remelted zone revealed strong refinement of titanium carbides.
2. Supersaturation of a matrix with titanium and carbon, leads to formation of retained austenite in remelted zone.
3. The hardness of the GTAW treated layers is decreased to a level ranged between 250 and 500 HV and was lower than hardness in initial state.

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