THE EFFECT OF ALLOYING METHOD ON THE MICROSTRUCTURE AND PROPERTIES OF THE PM STAINLESS STEEL

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Abstract

Stainless steel products have been developed extensively, especially those made of duplex stainless steel, which is one of the most modern modifications of this material. They are characterized by a two-phase structure consisting of approximately equal content of ferrite and austenite. Such combination of properties makes the duplex stainless steels a very attractive material for numerous applications. The purpose of this study was to investigate the effect of surface layer alloying with chromium carbide on the microstructure and properties of the PM stainless steel. The multiphase sinters investigated in the study were prepared from two types of water-atomized steel powders: 316L and 409L. The technique of plasma spraying was used to deposit Cr_3C_2 on duplex stainless steel surface. Electric arc (GTAW method) was used for surface alloying. Optical and scanning microscopy, X-ray phase analysis and examinations of microhardness and coefficient of friction were performed in order to determine the microstructure and basic properties of sintered duplex steel after alloying. The surface alloying with Cr_3C_2 is a productive method of surface layer hardening in sintered stainless steels and modification of surface layer properties such as hardness and coefficient friction.

Keywords: Surface alloying, sintered duplex stainless steel, chromium carbide

1. INTRODUCTION

Duplex stainless steels are a significant class of engineering materials that have been widely used in a variety of industries. Their name comes from the microstructure that is roughly a 50% mix of ferrite and austenite. Consequently, duplex stainless steels are used due to their improved corrosion resistance, high mechanical strength and superior weldability in different atmospheres [1-2].

Powder metallurgy of stainless steel components represents an important and dynamically growing sector of the PM industry. This method is a very interesting alternative to manufacturing of sintered duplex stainless steel. The duplex steel can be manufactured in different ways, for example by mixing ferritic powder with austenite stabilizer element powder [3-4]. Sintered duplex stainless steels could be used in a number of industrial sectors due to their good corrosion resistance, high toughness, high plastic properties and mechanical resistance within one material [5-9]. In austenitic-ferritic steels, it is possible to obtain the structure with different content of the two basic structural components. The Shaeffler diagram is often used to determine the microstructure of the sinter based on

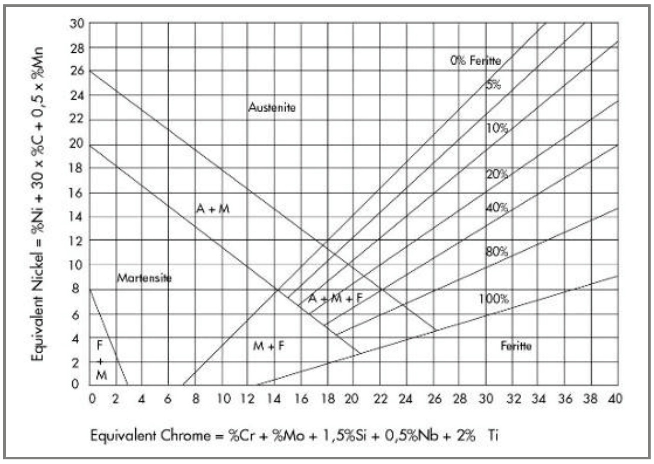

Figure 1 Schaeffler constitution diagram for stainless steel based on [12]

its chemical composition (see **Figure 1**). Although the chart was developed to predict the microstructure of welds in stainless steel, it has also been used in powder metallurgy [10-11].

Properties of sintered steels are closely related to the parameters of compaction and sintering. Reduction atmospheres are used for sintering of moulded pieces made of stainless steel powders (pure H_2) which allows for a significant limitation of oxidation and protects from reduction in chromium content [13]. Sintering time has an essential effect on the microstructure of sintered austenitic-ferritic steels. Longer sintering time is conductive to formation of a balanced two-phase microstructure, which is connected with diffusion processes that occur during sintering. A parameter which finally affects the microstructure of sintered steel is cooling rate from the sintering temperature [14].

Chemical composition, percentage of individual powders and sintering conditions have a significant effect on transitions that are observed during sintering. Therefore, they play an essential role in formation of the final microstructure of austenitic-ferritic sinters and their mechanical and functional properties. The studies available in the literature have demonstrated that remelting of steel allows for improvement of properties of the surface layer such as tribological and fatigue properties through fragmentation and homogenization of the structure or stimulation of other favourable changes without affecting core properties [15-17].

The authors of the present study proposed to improve functional properties (e.g. hardness and wear resistance) by means of alloying the surface of the sintered duplex steel with Cr_3C_2 + 10% NiAl powder. The first step was to deposit the coating with thickness of 60 µm on the steel surface using the plasma spraying method. Furthermore, GTAW (TIG) welding method was used to remelt the coating with the steel base material. The source of heat was electric arc, which was initiated between the tip of the non-consumable electrode and the remelted part in the inert shielding gas. The shielding gas (argon) protected the non-consumable electrode and the weld pool and it had an effect on arc voltage and the shape of the weld. The main aim of the study was to evaluate the effect of atmospheric plasma spraying (APS) and surface alloying with Cr_3C_2 on the microstructure and functional properties of sintered duplex stainless steel.

2. MATERIALS AND METHODS

The specimens for the examinations were obtained from water-atomized powders of 316L steel (16.8 % Cr, 12.0 % Ni, 2.0 % Mo, 0.9 % Si, 0.1 % Mn, 0.022 % C) and ferritic 409L steel (11.86 % Cr, 0.82 % Si, 0.14 % Ni, 0.02 % Mo, 0.14 % Mn, 0.02 % C). Powders were mixed with 50:50 ratio with addition of 1% of Acrawax C lubricant and compacted uniaxially at 720 MPa. The molded pieces were sintered at the temperature of 1250 °C for 30 minutes in the dissociated hydrogen medium and cooled down with cooling rate of 0.5 °C / s. Sinters in the initial state were characterized by a non-uniform microstructure composed of austenite and multi-phase acicular component.

The alloying treatment of sintered steel was performed by means of GTAW arc method with constant surface scanning rate of 340 mm / min and changing welding current intensity, with its values ranging from 35 to 50 A. The shielding gas was argon, with the flow set at ~ 14 l / min.

Analysis of microstructure after application of Cr_3C_2 and surface alloying was conducted using the stereo microscope, optical microscope Axiovert 25 and scanning microscope Jeol JSM 5400. The Vickers method (with the load of 980.7 mN) was employed to measure microhardness of sintered steel, coating and remelted surface layers.

Identification of phase composition of alloyed surface and sintered steel without treatment was carried out using Seifert 3003 T-T X-ray diffractometer with a cobalt lamp with characteristic radiation wavelength of $\lambda_{CoK\alpha}$ = 0.17902 nm. The measurements were carried out for angle range of 2θ = 10÷120°.

Scratch resistance test (Revetest XPress Plus using Rockwell indented tip) were performed in order to determine the coefficient of friction of the sintered duplex stainless steel obtained in the study. The following parameters were maintained during the test: permanent load of 10 N, scratch length 5 mm, scratch rate 5 mm / min.

3. RESULTS AND DISCUSSION

The microstructure of the Cr_3C_2 + 10% NiAl coating deposited using the APS method on the sintered steel surface is presented in **Figure 2**, obtained by the stereo microscope (a - microstructure of the coating surface) and optical microscope Axiovert 25 (b - cross-section). Plasma spraying yielded the coating with the thickness of around 60 µm, which on another stage of the study was alloyed with the base material.

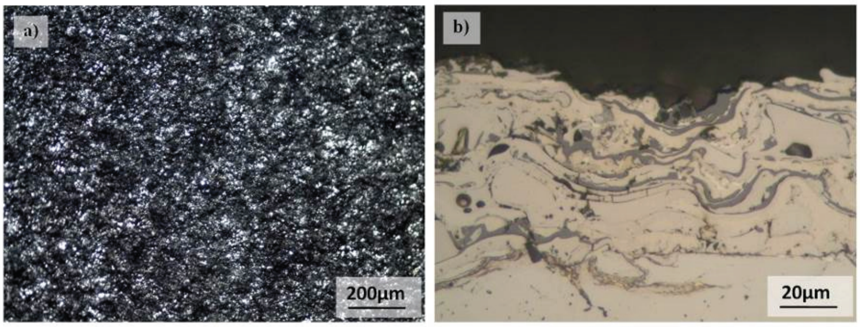

Figure 2 Microstructure of the sintered duplex stainless steel

The alloyed surface was then used for macroscopic evaluation, with the main criteria including band continuity, comparable width and relatively smooth surface without craters. These requirements were met by the bands remelted using arc method at current intensity 50 A. **Figure 3** illustrates the example of macroscopic image of the surface alloyed at 35 A.

Figure 3 Macroscopic image of the alloyed bands (GTAW method)

Figure 4 presents the microstructure obtained for sintered duplex stainless steel after surface alloying treatment with changing welding current intensity.

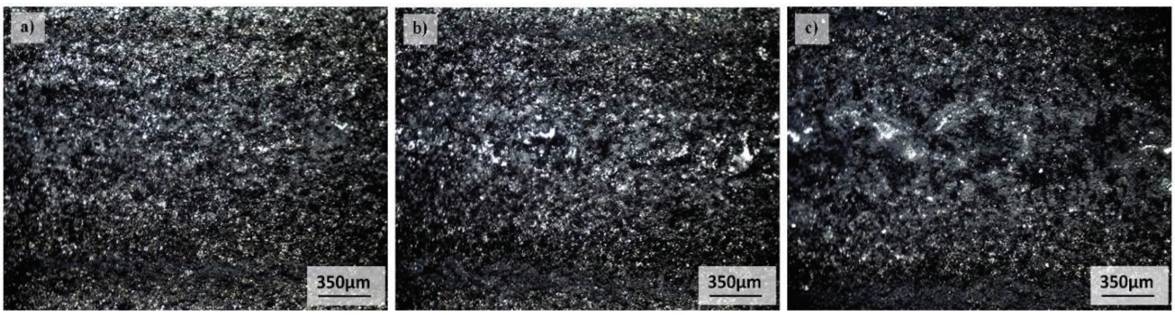

Figure 4 Morphology of specimen's surface after alloying: a) 35 A, b) 40 A, c) 50 A

Figure 5 presents the microstructure obtained for sintered duplex stainless steel after surface alloying treatment (Axiovert 25 optical microscope).

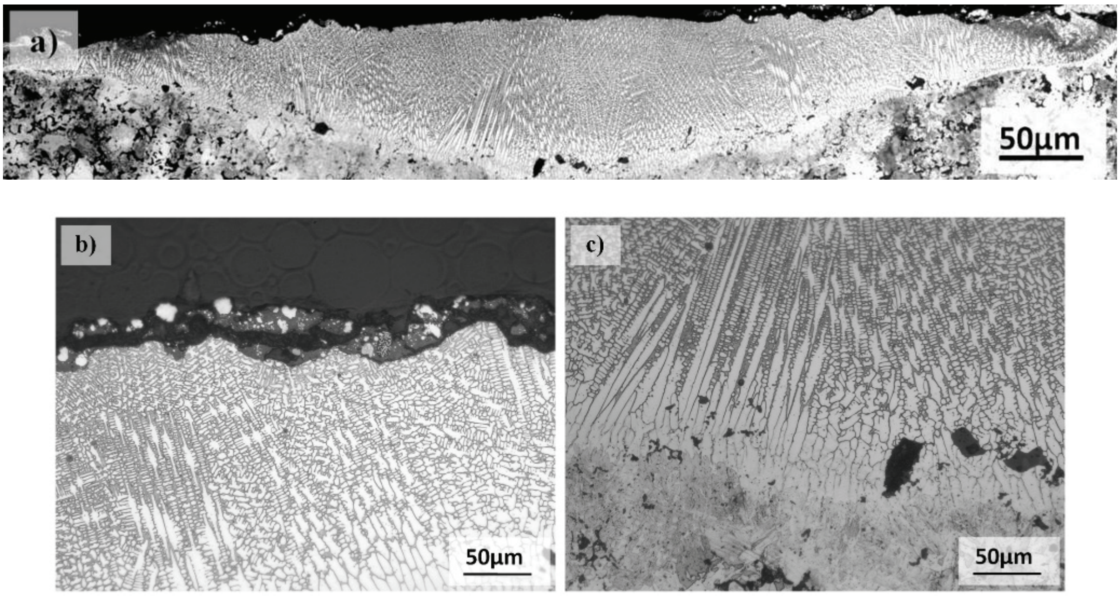

Figure 5 Microstructure of the alloyed layer for remelting current intensity of 50 A,
(a) structure of the entire alloyed zone, (b) upper part of the alloyed zone, (c) boundary of the alloying zone and heat affected zone

Figure 6 presents the microstructure of the surface after alloying process obtained by the scanning microscope Jeol JSM 5400.

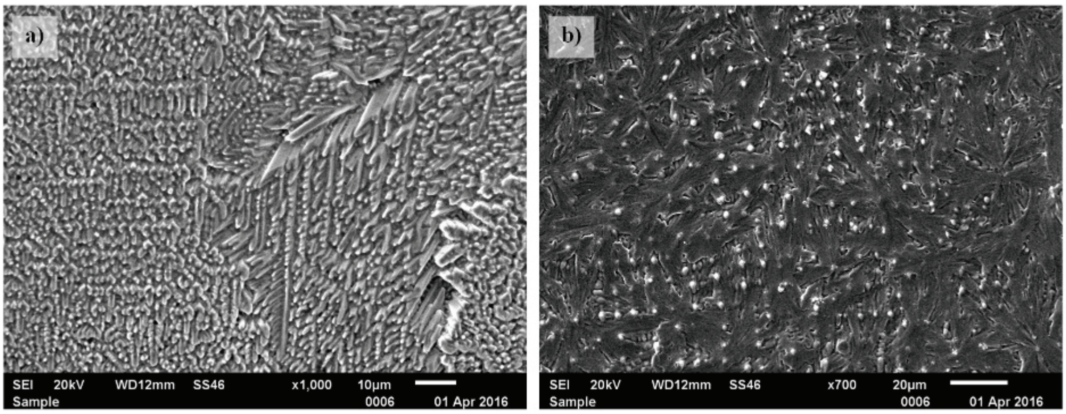

Figure 6 Microstructure of the surface sintered duplex stainless steel: a) after remelting at current intensity of 35 A, b) after remelting at current intensity of 50 A

Microstructural examinations revealed that in the case of alloying treatment, the surface layer showed a homogeneous cellular-dendritic structure. Presence of columnar crystals oriented according to the direction of heat transfer and dendritic crystals was observed. A transient zone was formed at the contact of the remelted layer with core material. This zone (see **Figure 5c**), obtained through melting of the core material, was the location of nucleation of primary structure crystals. It was found that remelting method ensured development of a continuous surface layer without voids.

Results of the analysis of phase composition of the sintered duplex stainless steel are presented in **Figure 7**. **Figure 7a** presents the results for duplex stainless steel sintered with Cr_3C_2, while **Figure 7b** presents the results for surface alloying at current intensity of 40 A. Hardness of the sintered duplex stainless steel, Cr_3C_2 coating and alloyed layer were presented on the **Figure 8**.

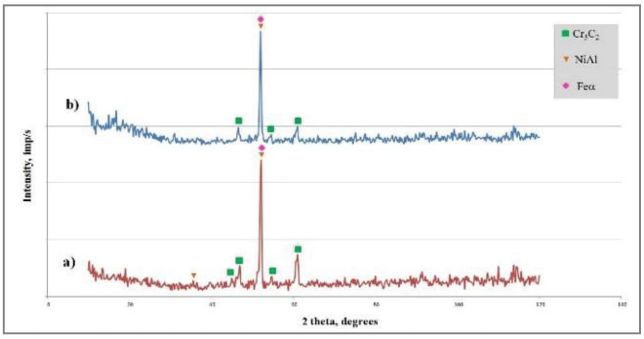

Figure 7 Diffractograms of the sintered duplex stainless steel

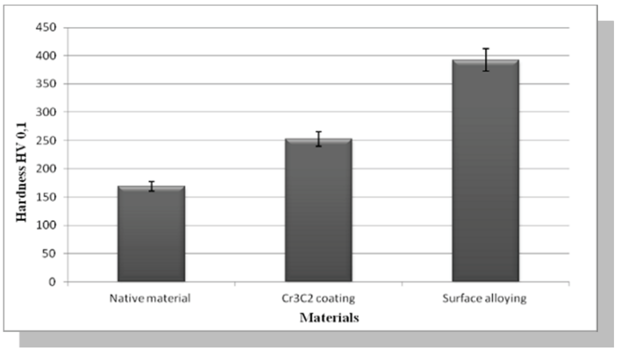

Figure 8 Hardness of the materials

Analysis of phase composition revealed presence of the Cr_3C_2 phase and peaks from Fe core material in the case of ceramic coating α. Alloying of the sintered steel resulted in the reduction in the percentage of the Cr_3C_2 phase and solving of Cr in the crystallographic Feα, which is noticeable in the diffractogram through changes in the values of the parameter d_{hkl} and the parameter of lattice constant for A2 cell of iron modification.

Scratch tests were performed under constant load in order to evaluate the coefficient of friction. The data obtained from the scratch test are presented in the form of a chart with coefficient of friction (**Figure 9**).

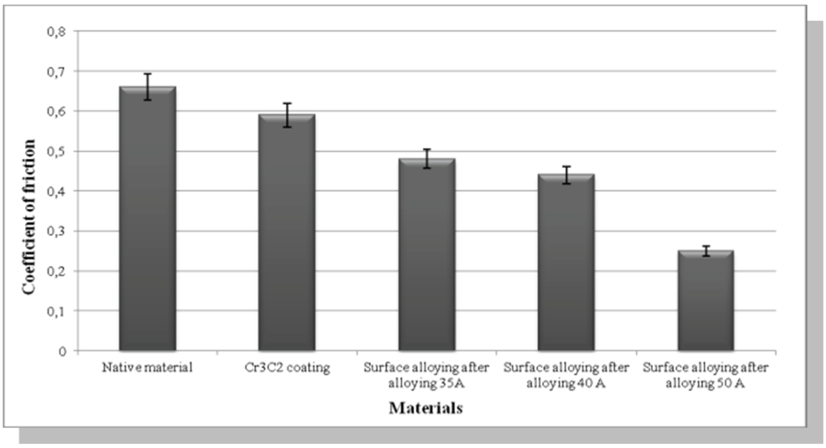

Figure 9 Coefficient of friction for the materials

Resistance to friction wear of sintered steels represents the effect of several factors, e.g. microstructure, hardness, porosity and surface quality. The studies have demonstrated [18] that improved resistance to friction wear in the group of austenitic-ferritic sinters is observed for steels with non-homogeneous microstructure and higher hardness. Due to the alloying process that occurred in the remelted layers, the coefficient of friction in the specimens was changed, which contributed to the improvement in tribological properties.

4. CONCLUSIONS

Remelting treatment used in the study led to the formation of a surface layer with homogeneous cellular-dendritic structure without voids. The alloying method used by the authors represents a promising proposal for hardening of surface layer of sintered duplex steels that show porosity. A valuable benefit of using this method is opportunity for modification of the surface in terms of hardness and coefficient of friction. The results obtained in the study showed that the increase in current intensity causes a decrease in the coefficient of friction and increase in hardness, which consequently leads to the increased wear resistance.

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