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The Surface Treatment of Sintered Stainless Steel

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Abstract. Sintered duplex stainless steels are characterized by a two–phase structure consisting of approximately equal content of ferrite and austenite, which makes them very interesting materials for numerous applications. This study proposes a method to improve functional properties by means of alloying the surface of the SDSSs by the gas tungsten arc welding (GTAW) process, which it is an efficient method of surface modification in engineering materials. The results of a SEM/EDX optical metallographic microscope, XRD analysis and hardness are presented. The main assumption of this study was to analyze the microstructure and hardness of a surface layer of SDSS with different proportions of individual powders subjected to the alloying process by means of the GTAW method.

Introduction

Sintered duplex stainless steels (SDSSs) manufactured using the powder metallurgy technology (PM) belong to the most dynamically growing class of engineering materials and they are relatively widely used in many sectors, mainly in highly industrialized countries. The automotive industry is the biggest consumer of sintered products (ca. 73% of all sinters). In the case of SDSS, it is possible to obtain a sintered structure with different proportions of two basic structural components, austenite and ferrite. Consequently, SDSSs are distinguished by very good mechanical strength as well as corrosion resistance, which results mainly from their chemical composition, contribution of individual phases of powders and distribution of the main alloying elements (Cr/Ni) between these phases [1–5].

Surface treatment technology is used to obtain a surface layer with appropriate properties [6–7]. Many times it happens that properties of the surface layer are independent of properties required from the native material (base material). Increasing development of materials, which should be adequately dependent on more and more new technologies of surface treatment is an extremely important challenge. Therefore, it is possible to obtain elements that are characterized by both good volume and surface properties [8].

The purpose of a surface alloying treatment and rapid solidification process is to induce favourable structural changes in the surface layer [9]. Appropriate selection of a treatment method and process parameters affects the achievement of structural changes of the surface, which will lead to the improvement of functional properties of SDSSs [10]. The interest in various welding techniques using concentrated sources of thermal energy has increased, which allows for modifying the surface layer not only of conventional corrosion–resistant steels, but also of sintered duplex stainless steels [11–13].

Laser technologies are the most widespread method used in surface alloying treatments. They are characterized by high precision, ease in automation, but for economic reasons (e.g. high cost of equipment), they belong to expensive processes. Furthermore, it is also imperative to maintain additional EU–OSHA (European Agency for Safety and Health at Work) requirements due to the presence of a characteristic laser radiation. The use of a gas tungsten arc welding (GTAW) is a promising proposal for hardening the surface layer of SDSSs, which they are showing porosity. The ability to modify the surface in terms of hardness and coefficient of friction is a valuable advantage which encourages to use this method. Low costs of equipment and ease of use are significant advantages of using the gas tungsten arc welding (GTAW) method [14–15].

The gas tungsten arc welding (GTAW) method consists in melting and joining the surface of a welded metal by heating it with an electric arc. The electric arc is established between two poles of the current: a non–consumable tungsten electrode (cathode) and a melted metal (anode). The shielding gas (argon) protects a non–consumable electrode and a weld pool and it affects arc voltage and the shape of a weld. Moreover, the current type and intensity, arc voltage and surface scanning rate significantly affect the final properties of the modified surface layer [16–17].

Materials and Methods

The specimens of sintered steels were made of water–atomized powders of 316 L steel and ferritic 409 L steel manufactured by Höganäs (Sweden). The chemical composition of steel powders was presented in Table 1. Both powders selected nominal particle size of 150 μm.

Table 1. Chemical composition of steel powders (% wt.)

Powder grade	Cr	Ni	Mo	Si	Mn	C	S	Fe
316 L	16.80	12.00	2.00	0.90	0.10	0.022	0.005	Balance
409 L	11.86	0.14	0.02	0.82	0.14	0.020	0.010	Balance

Powders mixed at different proportions of ferritic and austenitic steel powders were used in the investigations to give three different series of samples (see Table 2). The powders were compacted uniaxially with the addition of 1% Acrawax C lubricant at 720 MPa. The molded pieces were sintered at the temperature of 1250°C for 30 minutes and then cooled down with a cooling rate of 0.5°C/s. The whole process was carried out in a reducing atmosphere using hydrogen in order to significantly limit oxidation of the batch and protect the chromium content from reduction.

Table 2. Percentage contribution of individual powders

Powder grade	Series number		
	1	2	3
316 L	100%	80%	20%
409 L	0%	20%	80%

The surface layers alloying treatment of the SDSS coating was performed by means of the GTAW technology (gas tungsten arc welding). The electric arc established between a non–consumable electrode of tungsten and work–pieces to be joined was the source of the heat. The alloying treatment of the sintered steel was carried out with a constant surface scanning rate of 340 mm/min and changing welding current intensity, with its values ranging from 30 to 60 A. Argon was the shielding gas, with the flow set at ~ 14 l/min.

The analysis of the microstructure was performed using an Olympus GX41 optical microscope and a Jeol JSM–6610LV scanning microscope. The macroscopic evaluation of sintered duplex

stainless steels after alloying process was carried out using an Olympus SZ61 stereo microscope. The Vickers methodology (with the load of 980.7 mN) was employed to measure the microhardness of SDSS obtained by Shimadzu HMV–G Series.

The identification of phase composition of the alloyed surface of SDSS was carried out using an X–ray diffractometer (Seifert 3003 T–T) with a cobalt lamp with a characteristic radiation wavelength of $\lambda_{cok\alpha} = 0.17902$ nm. Other parameters were the following: supply voltage: $U_r = 30 \div 40$ kV, current intensity $I_r = 30 \div 40$ mA, angle range: $2\theta = 10 \div 120°$, measurement step: 0.1°, pulse integration time $t_r = 10$ s.

Results and Discussion

Macroscopic examinations were used to evaluate how the alloying process affects the surface quality of sintered duplex stainless steel. The morphology of the surface after the alloying process for each SDSS with changing welding current intensity obtained by the GTAW method are presented in Figure 2.

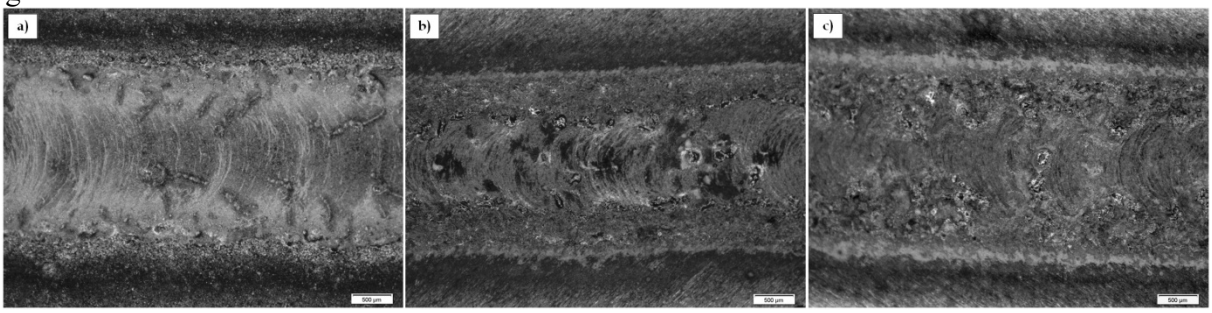

Fig. 2. Morphology of the surface of SDSS after alloying 50 A:
a) 100% 316 L; b) 80% 316 L + 20% 409 L; c) 20% 409 L + 80% 316 L

The microstructures obtained for SDSS after the surface alloying treatment were observed using metallographic sections etched with aqua regia. Figure 3 illustrates the microstructure of the surface after alloying at 30 A obtained for 100% 316 L steel by the Olympus GX41 optical microscope. Microstructural examinations revealed a homogeneous cellular–dendritic structure in the surface layers after the alloying treatment. The occurrence of columnar crystals oriented according to the direction of heat transfer was caused by the fast heat transfer and high gradient of temperature. The transient zone obtained by the contact of the alloyed layer with base material was the location of nucleation and growth of primary structure crystals.

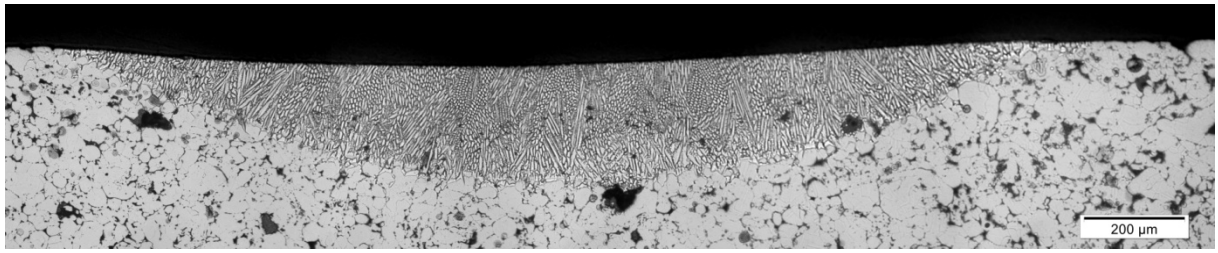

Fig. 3. Microstructure of the entire alloyed zone of 100% 316 L after alloying 30 A

Figure 4 are presents the microstructure of the surface after the alloying process for SDSS obtained by the Jeol JSM–6610LV scanning microscope.

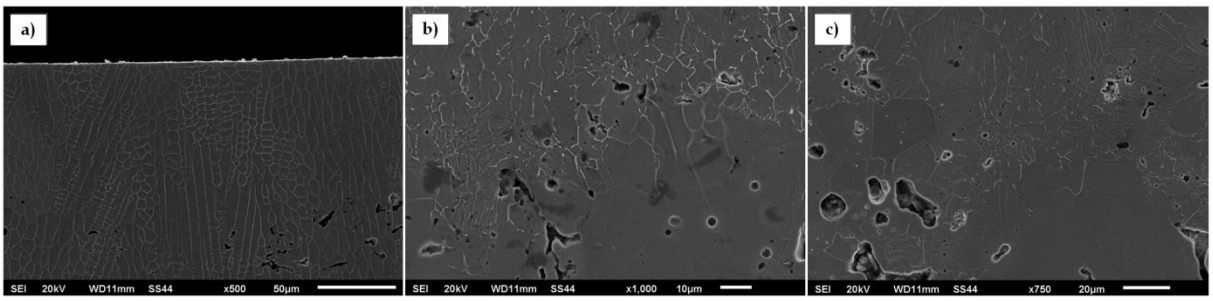

Fig. 4. Microstructure of the surface of SDSS after alloying at current intensity of 40 A: a) 100% 316 L; b) 80% 316 L + 20% 409 L; c) 20% 409 L + 80% 316 L

The analysis of chemical composition for each SDSS after the surface layer alloying treatment is presented in Table 3. The aim of the analysis was to compare areas obtained for SDSS after the surface alloying treatment, determination of the migration process of the alloying elements (Cr, Ni) during the crystallization process and determination of the degree of homogeneity of the chemical composition in the surface layers.

The examination of the surface layer alloying demonstrated migration of Cr and Ni during sintering caused by the diffusion process. The effect of diffusion was a creation of mutual diffusion areas between the ferritic and austenitic phases. The formation of the intermediate zone is a result of Ni diffusing to austenite, which leads to different phase transformations.

The remelting pathway for the alloying parameters was non–homogeneous in terms of chemical and phase compositions. Furthermore, the surface revealed oxide phases, likely to have been created at the stage of solidification of the alloyed mass. The oxide phases were confirmed by the investigation of the analysis of phase composition.

Table 3. EDX–analysis of chemical composition of the surface in sintered duplex stainless steels after alloying at current intensity of 40 A

SDSSs	Element	Weight %		
		Alloying zone	Heat affected zone	Native material
100% 316 L	Cr	17.23	16.26	14.57
	Fe	65.07	63.98	57.35
	Ni	12.09	13.13	10.63
80% 316 L + 20% 409 L	Cr	15.26	15.72	16.88
	Fe	68.73	70.07	66.96
	Ni	9.60	7.67	11.28
20% 409 L + 80% 316 L	Cr	15.07	14.88	14.43
	Fe	75.49	73.37	69.96
	Ni	6.11	7.35	7.10

Hardness measurements by the Vickers method were performed in order to evaluate mechanical properties. The results represent the mean of three measurements to the alloying zone, heat affected zone and native material obtained after alloying at current intensity of 40 A (see Table 4). The contribution of individual phases has a direct effect on mechanical properties of the whole sinter. The hardness results obtained in the study directly show improvement in strength properties after the surface alloying treatment.

X–ray phase analysis was conducted to identify the phase composition of the alloying surface layer. The results of the analysis are presented in Figure 6. The phase analysis for individual

specimens showed the austenitic and ferritic phases with the content proportional to the powders used.

Table 4. Hardness of sintered stainless steel

SDSSs	Hardness [HV 0.1]		
	Alloying zone	Heat affected zone	Native material
100% 316 L	185.0	172.7	90.4
80% 316 L + 20% 409 L	196.3	173.0	107.0
20% 316 L + 20% 409 L	353.8	334.0	284.0

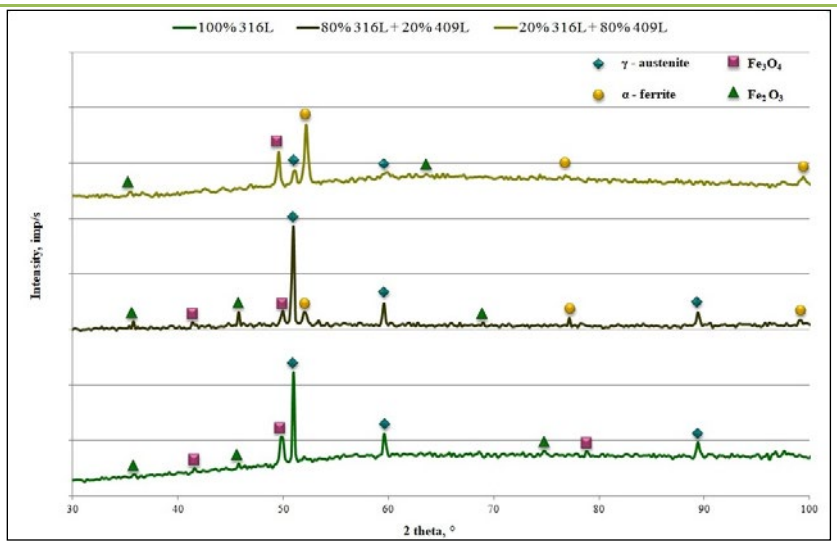

Fig. 7. Diffractograms of the sintered stainless steels

The phase composition analysis for individual specimens revealed the presence of the ferritic phase (cell parameters: a = b = c = 0.286 nm, $\alpha = \beta = \gamma = 90°$) and the austenitic phase (cell parameters: a = b = c = 0.359 nm, $\alpha = \beta = \gamma = 90°$), which crystallized in a cubic cell. Additionally, the analysis revealed the presence of iron oxides: Fe_3O_4 phase crystallizes in a cubic cell (cell parameters: a = b = c = 0.840 nm, $\alpha = \beta = \gamma = 90°$) and Fe_2O_3 phase crystallizes in a cubic cell (cell parameters: a = b = c = 0.835 nm, $\alpha = \beta = \gamma = 90°$). The peak intensities obtained on the diffractogram depend on the amount of individual phases in sintered steels.

Conclusions

The gas tungsten arc welding (GTAW) method proposed in the study represents an alternative solution compared to the laser technique. A modification of surface layers of SDSSs leads to an increase in mechanical properties of sintered steels and their wear resistance. The study shows that the increase in current intensity causes an increase in hardness, which leads to the increased wear resistance. Additionally, studies have shown that the wear resistance of SDSSs depends on the microstructure and hardness of the alloying surface layer. Consequently, this allows for a wider use of these materials, mainly in terms of their use in industry.

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