TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
MECHANICS | MECHANIKA

3-M/2016

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FORMATION OF MICROSTRUCTURE AND PROPERTIES OF SINTERED STEEL THROUGH REMELTING OF SURFACE LAYER

KSZTAŁTOWANIE MIKROSTRUKTURY I WŁAŚCIWOŚCI STALI SPIEKANYCH POPRZEZ PRZETOPIENIOWĄ OBRÓBKĘ WARSTWY WIERZCHNIEJ

Abstract

This study presents the findings concerning the effect of remelting on microstructure and selected properties of sintered duplex steel. It was demonstrated that the methods of processing lead to homogenization and elimination of porosity in the surface layer of sinters, which substantially affects their properties (surface roughness, microhardness and resistance to friction wear). It was found that the degree of tribological wear in the steel used in the study depends primarily on the microstructure and phase composition and less on porosity.

Keywords: duplex sintered steel, *surface layer remelting*

Streszczenie

W artykule przedstawiono wyniki badań mających na celu określenie wpływu obróbki przetopieniowej na mikrostrukturę oraz wybrane właściwości warstwy wierzchniej spiekanych stali duplex. Wykazano, że zastosowana obróbka prowadzi do ujednorodnienia mikrostruktury oraz wyeliminowania porowatości w warstwie wierzchniej spieków, co istotnie wpływa m.in. na ich mikrotwardość oraz odporność na zużycie ścierne. Dowiedziono, że stopień zużycia tribologicznego badanych spieków zależy głównie od mikrostruktury oraz składu fazowego warstwy wierzchniej, natomiast w mniejszym stopniu od porowatości.

Słowa kluczowe: spiekane stale duplex, *przetapianie warstwy wierzchniej*

DOI: 10.4467/2353737XCT.16.128.5739

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1. Introduction

In the period of high demand on technologies and both cheap and ecological products, the increased interest in powder metallurgy and sintered goods in e.g. automotive industry seems to be justified. Although costs of the operation of production line for manufacturing sinters are high, the unit product price in serial production might be several times lower than in the case of a product manufactured with conventional methods [1–3]. In the case of stainless steel, mechanical properties can be considered as secondary, especially because porosity seems to be desirable in order to obtain a product with reduced mass. Porosity also substantially affects tribological properties of sintered steel [4]. This study proposes remelting processing by means of the GTAW welding methodology. The effects obtained were compared to the results of pulsed laser remelting. The idea and description of the method have been contained in e.g. [3]. The previous method of formation of surface layers has been used extremely rarely to develop surface layers on sintered duplex steel. Therefore, the authors aimed to describe microstructural changes in the surface layer of stainless steel, with particular focus on the evaluation of functional properties of sinters after remelting.

2. Materials and Methods

We used corrosion-resistant stainless steel obtained from water-atomized powders of 316L austenitic steel (16.7% Cr, 12.3% Ni, 0.9% Si, 0.1% Mn, 2.20% Mo, 0.025% C) and ferritic 434L steel (16.2% Cr, 0.98% Mo, 0.8% Si, 0.1% Mn, 0.015% C). The powders were mixed with the following proportions: 80% 316L + 20% 434L, 50% 316L + 50% 434L and 20% 316L + 80% 434L. The names of the sinters were adopted with regard to the proportions of powders: 80A-20F, 50A-50F, 20A-80F. The procedure of sinters preparation was described in detail in the study [3].

The microstructure of sinters revealed through etching in aqua regia was represented by a multi-phase structure, different than in the case of conventional duplex steel. The metallographic cross-sections showed light areas of austenite, grey areas of acicular component and dark cross-sections of pores. The percentage of the acicular component was approximately proportional to the percentage of ferritic steel 434 L. Porosity of the steel was examined by means of a quantitative method by means of Image Pro Plus software. Ten microscopic images of non-etched metallographic cross-sections were analyzed. Porosity of individual sinters was around 8%, 11% and 5%, respectively.

The sinters were subjected to arc surface remelting with the following parameters: current intensity from 30 A to 40 A, voltage ~10 V, feed rate 340 mm/min. Selection of the parameters was described in the study [3]. Pulsed laser remelting was carried out by means of impulse laser NdYAG according to the parameters chosen experimentally. Impulses with the power of 3.5 kW, 5 kW and 7.5 kW were generated by changing the degree of laser spot overlapping (from 50% to 90%). The laser spot diameter was 1.5 mm. This publication analyzed the examinations conducted for 50A-50F sinters after remelting with pulses with the power of 5 kW with overlapping of ~85%.

The effects of the remelting were initially evaluated based on macroscopic observations. Microstructural examinations were carried out on etched metallurgical cross-sections by means of Axiovert 25 metallurgical microscope.

Microhardness measurements used the Vicker's method with the load of 490 mN.

Examinations of friction wear resistance were carried out by means of T-05 block-on-ring wear tester in dry sliding contact. Test parameters were selected experimentally: $F_N \approx 49.05$ N, rotational speed of the roll: 3.55 rps. Test duration was 120 minutes (8 cycles for 15 minutes). Total friction distance was ~2809 m.

3. Results and Discussion

Microscopic observations were employed after remelting to examine specimen surface. In the case of sinters after GTAW method, further examinations involved remelting of samples with arc with intensity of 35 A and linear speed of 240 mm/min, for which no defects were found (i.e. craters, excessive penetration or lack of penetration). For pulsed laser remelting, the best surface quality was found for the specimen remelted with pulses with the power of 5 kW with overlapping of 85%. However, the surface of the specimen was characterized by substantially higher degree of surface development compared to arc remelting. The overlapping of individual laser spots on the sinter surface caused formation of flash, exhibiting a characteristic relief. This effect does not occur for arc remelting due to a continuous mode of tool operation, ensuring even the distribution of liquid metal across the remelted volume.

Microscopic observations revealed uniform microstructure in the surface layers of sinters after arc remelting (Fig. 1). The treatment was accompanied by the fast heat transfer and high gradient of temperature, which resulted in formation of the primary structure with columnar crystals oriented according to the direction of heat transfer (in sinters 80A-20F and 50A-50F). Microscopic examinations showed also epitaxial character of nucleation and growth of primary structure cells, initiated in the transition zone formed as a result of base material remelting. A cellular-dendritic structure was formed in the microstructure of surface

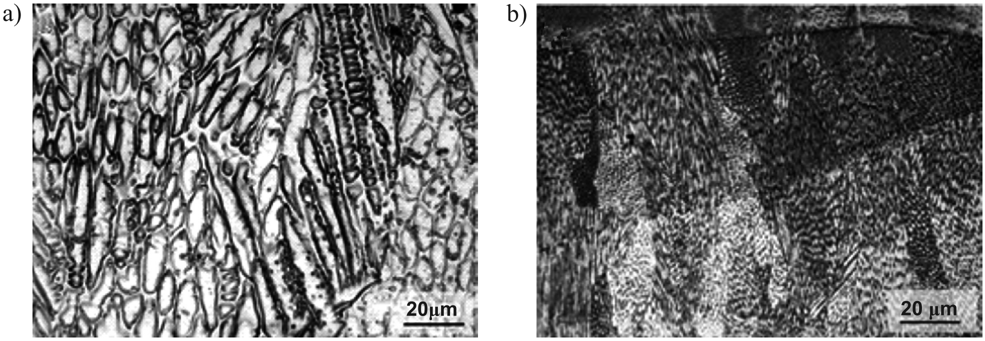

Fig. 1. Microstructure of surface layer for 50A-50F sintered steel after remelting: a) GTAW method, b) laser method

layer of 20A-80F sinter after arc remelting. Complete description of the microstructure of surface layer of the sinters after remelting was contained in the study [3].

In the case of 50A-50F sintered steel after laser remelting, a cellular-dendritic structure was formed on the surface layer. Cooling rate for laser treatment was by several orders of magnitude higher compared to the arc method, which consequently led to the formation of a much finer structure (Fig. 1b). Similar as in GTAW method, nucleation and growth of cells had also an epitaxial character. A clear transient zone was not observed. It was found that both methods ensured the development of a homogeneous surface layer without voids. Figures 1a, b show example images of microstructure of sinter surface layers (50A-50F) after remelting.

Measurements of microhardness (Fig. 2) supported the results obtained from the microscopic observations. Substantial variation in hardness, resulting from presence of various phases and structural components and pores was observed in the area of core material. Furthermore, an insignificant increase in hardness with respect to mean hardness of sinters in the initial state was observed for remelted layers, regardless of the method used. Insignificant deviations from mean values of microhardness (Fig. 2) suggest a substantial homogenization of the microstructure.

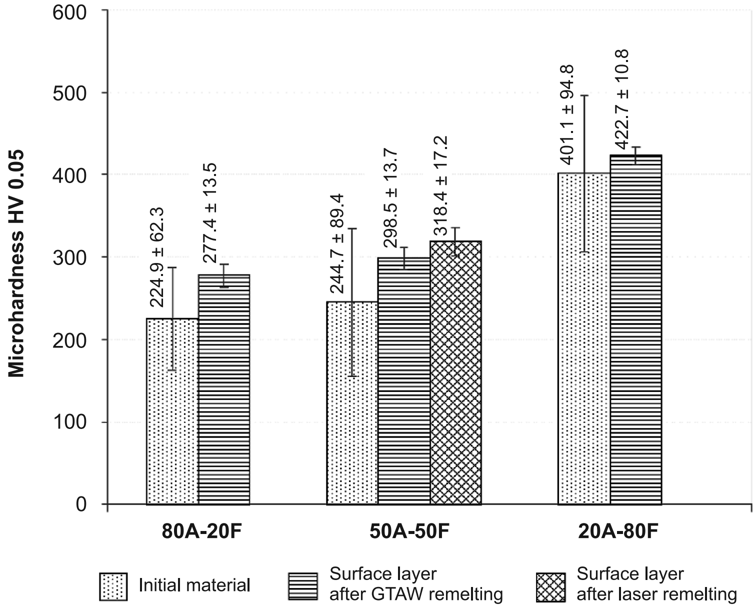

Fig. 2. Microhardness of sintered steel in the initial state and after remelting

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 that improved resistance to friction wear in the group of austenitic-ferritic sinters is observed for steels with non-homogeneous microstructure and higher hardness [2]. Fig. 3 presents the results of measurement of specimen mass reduction after tribological test.

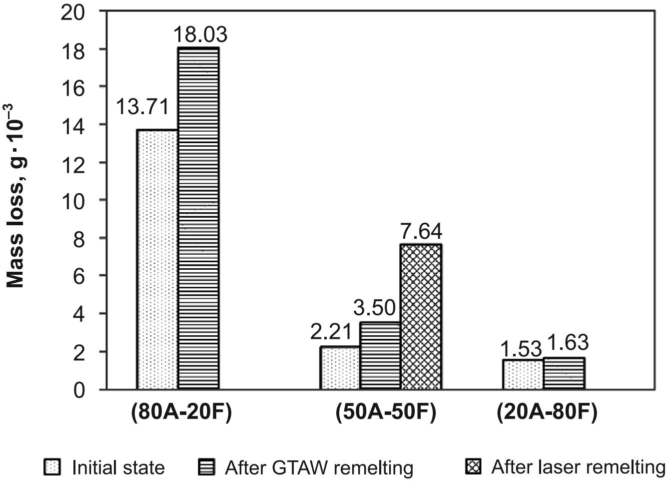

Fig. 3. Decrease in mass of sintered steel after examination of resistance to friction wear

Among the sinters remelted using GTAW method, the best resistance to friction wear was observed for (20A-80F) sinters, for which the reduction in mass after tribological test was 1.63 mg, whereas for sinters in the initial state, this value was 1.53 mg (Fig. 3). Higher reduction in mass was also observed for remelting of (80A-20F) and (50A-50F) sinters. Furthermore, the analysis of diagram in Fig. 3 shows a relationship: the resistance to friction wear was higher for higher percentage of ferritic steel powder in the sinter i.e. for higher hardness. In conclusion of the above observations, the most important factor that determined friction wear of sintered steel was microstructure and hardness of sinter, whereas porosity played the secondary role. The multi-phase acicular component present in the microstructure of sinters, with a relatively high hardness, is likely to have acted as an "inhibitor" of material wear. The substantial loss of mass of the specimen after laser treatment results not only from the homogenization of microstructure but also from the presence of unevenness (relief) on the contact surface of the specimen.

4. Conclusion

The remelting of sintered austenitic-ferritic steels leads to substantial changes in the microstructure of surface layer and, consequently, changes the properties of sinters. The findings presented in the paper, which represent a continuation of the investigations contained in [3], led authors to the following conclusions:

- Remelting is an adequate method for homogenization of microstructure, especially for the elimination of porosity in the surface layer area of sinters. Furthermore, GTAW method allows for the reduction in sinter roughness, whereas using the laser method results in the appearance of relief, which negatively affects tribological properties of sinters. It is recommended to perform additional finishing (e.g. rolling or burnishing) after pulsed laser remelting;

- The treatment used in the study leads to an insignificant increase in hardness in the surface layer of sintered steel;
- In order to improve resistance to friction wear of sintered steel, it is desirable to carry out remelting with the addition of an alloying element or compound.

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