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The Burnishing Process of the Duplex Cast Steel in Aspect of Improving the Tribological Properties

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Abstract

Duplex cast steel it is a material with great potential. The properties of this material have contributed to its wide application in many industrial sectors, for example: oil extraction, printing, petrochemical industry, energy - flue gas desulphurization systems, seawater desalination plants, shipbuilding industry. The article presents the results of tribological tests following the static pressure roller burnishing (SPRB) process of GX2CrNiMoN22-5-3 duplex cast steel. The tests provided a basis for assessing the effect of the burnishing parameters on tribological properties of that material. The issue is important because the authors focused their research on duplex cast steels grade that are not containing copper. The article presents part of the research concerning the influence of the burnishing process on the properties of the duplex steel surface layer. Copper in duplex steels affects many areas one of them is the plastic properties. Its absence also reduces castability. Because of that it is reasonable to determine to what extent the properties of the surface layer of copper-free duplex cast steel grades can be shaped in burnishing process.

Keywords: Tribology, Duplex cast steel, Static pressure roller burnishing (SPRB)

1. Introduction

The issues of surface engineering are one of the subjects of material engineering research. There is a need for the development of science in the field of shaping the properties of the material through the processes of shaping the surface layer (SL) because the literature emphasizes strong relationships between functional features and the methods and conditions of surface treatment [1-5]. One of the methods that allows to shape the properties of the surface layer of materials is burnishing [6]. Although this method has been known for 100 years and for a certain period it was replaced by physical (PVD) and chemical (CVD) methods of coating deposition, currently research teams appreciate it again and are intensively working on its development [7-10]. Also in terms of the possibility of applying it to materials that have not been burnished so far, as in the case of austenitic-ferritic cast steels. In view of the above, it is reasonable to take up the subject related to the possibility of shaping specific properties of duplex cast steel in the GX2CrNiMoN22-5-3 grade. Duplex cast steel is a material with good corrosion resistance, high strength and ease of fabrication [11].

The burnishing processes are indicated for the surface treatment of rotationally symmetrical elements. A large part of the research work concerns the polishing of various alloys, while the information on the burnishing process is relatively limited. As an introduction, see the 2014 alloy ball burnishing example described in the work of El-Axir et al. [12]. A hardened steel ball with a diameter of 8 mm was used for the tests. During the tests, it was shown that the surface roughness was significantly reduced. It has also been shown that multiple burnishing passes should be used at low speeds. For higher speeds, greater surface degradation is observed after multiple burnishing. The next paper [13] presents tests of burnishing 6061 alloy balls with hardened steel balls. On the basis of the obtained test results, a significant influence of burnishing forces and burnishing speed on the surface roughness of the tested materials was demonstrated. In the case of optimal process conditions, the average arithmetic roughness of surface the Ra was 0.09 µm. The burnishing process is well known as one of method of shaping the properties of the surface layer. There are publications, which refers to technology of burnishing process of duplex cast steels, for example [14-16], however this topic is still not well analyzed [17]. Bouzid Saï and Lebrun [18] described that the burnishing process produces the best quality of the surface when compared with turning or grinding. Moreover even earlier author’s work aimed this technology used in duplex cast steel concerned materials with addiction of copper [19, 20]. In this study authors focuse on the evaluation of the tribological properties of copper free duplex cast steel before and after the static pressure rolling burnishing process.

2. Materials and Methods

The subject of the research was cast steel in the GX2CrNiMoN22-5-3 grade - according to PN-EN 10283:2019, as samples taken from cylindrical castings with a diameter of ⌀ 45 mm. The castings were made in remelting process, which was carried out in the metal melting laboratory of the Department of Metallurgy and Metal Technology of the Czestochowa University of Technology using the Leybold Heraeus IS1 / III crucible induction furnace. Before the burnishing process, the material was heat treated and machining process. The supersaturation process was carried out at a temperature of approx. 1150ºC for 2 hours, which was to eliminate stresses, homogenize the microstructure and dissolve intermetallic phases. The chemical composition of the tested cast steel, summarized in Table 1, was obtained with use of the spectral method using the SPECTROLAB K2 spark spectrometer from Spectro (Germany).

Outer cylindrical surfaces were prepared for the burnishing process by machining on a universal lathe CDS 500x1000 with the following parameters: feed rate f = 0.08 mm/rev, depth of cut a_p = 0.5 mm, cutting speed v_c = 140 m/min. During the process there was no cooling used, dry work was done. The technological parameters were selected on the basis of own research and literature review [21-24]. The burnishing process was carried out on a laboratory stand, on a universal lathe, CDS 500x1000. Burner element was a roller burner (NK-01) with a discshaped and diameter of ⌀50 mm and a rounding radius equal to 3 mm, made of 145CR6 tool steel with a hardness of 66 HRC. The selection of parameters for the technological process of burnishing was determined on the basis of preliminary experimental tests of materials with similar properties and preliminary tests. The pressure force of the NK-01 burner was measured using a static method using the FT-5304M / A / 16 strain gauge force sensor. It was determined that the depth of cut of a burner equal to 1 mm is equivalent to the application of a force equal to 3 kN. To the process, machine oil was used for lubrication and cooling. The tests were carried out on three rollers, process parameters for variants are shown in the Table 2, feed rate - f_n, burnishing depth - an, total burnishing depth - a_{nc}, number of passes - i, and burnishing speed - v_n.

Table 1.
Chemical composition of the examined cast steel grade, weight %

	C	Mn	Si	S	P	Cr	Ni	Mo	N	Fe
tested material	0.028	1.45	0.551	0.001*	0.005*	21.95	5.61	3.24	above 0.108	ballance
according to the standard	0.03*	2.0*	1.0*	0.025*	0.035*	21.0 to 23.0	4.5 to 6.5	2.5 to 3.5	0.12 to 0.2	ballance

* maximum content

Table 2.
SPRB process parameters for tested variants

Variants	f_n, mm/rev	a_n, mm	a_{nc}, mm	i	v_n, m/min
1	0.1	1	1	1	100
2	0.5	1	1	1	100
3	reference sample for the assessment of changes				

The tribological tests were carried out using a tribotester (Fig. 1) using the T-05 method (block-on-ring). The test was carried out with a linear contact, and the countersample was a ring with a diameter of 35 mm made of 100Cr6 bearing steel with a hardness of 58 HRC. The following test parameters were used: constant load = 5N, total friction distance of 7500 km, rotational speed of 500 rpm. In order to determine the kinetics of abrasive wear, the total friction distance was divided into 15 sections, 500 m each. The material loss after each test cycle, was recorded using an OHAUS PX125D analytical balance with a measuring accuracy of 0.00001 g. The weight loss of the samples after the abrasion cycle was a measure of abrasion resistance.

During the test, the friction force was recorded, enabling the determination of the friction coefficient, the average values of which together with the results of tribological wear are presented in Table 3. Before and after the test, the surfaces of the samples were observed using the S neox 3D profiler, which allows for automatic 3D measurements in specific positions in confocal technology, which allows the measurement of surfaces of any type of roughness, from extremely rough to highly reflective, e.g. a diamond mirror surface. The following roughness parameters were measured: Ra - arithmetical mean roughness value; Rt - total height of the roughness profile; Rz - mean roughness depth; RSm - mean value of the width of the profile elements, also 3D surface image was done. The measurement was made along the designated straight which were across to traces lines of burnishing. Measuring line length was compiled with the requirements of the standard PN-EN ISO 4288, and was 4 mm. Microstructural studies were performed using a Nikon MA-200 optical microscope and the material was etched with use of the Mi21Fe reagent. The sample surface were determined using a Phenom XL scanning microscope in magnification 10000x (Fig. 3a).

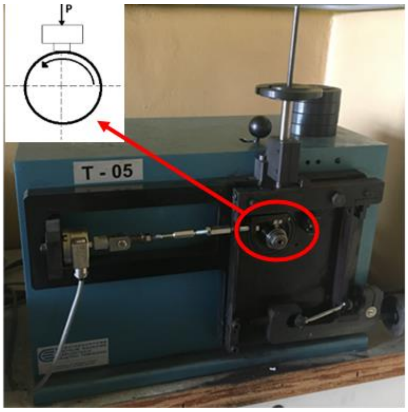

Fig. 1. T-05 tribological tester

3. Results

The physical properties of duplex cast steel are between those of austenitic and ferritic stainless steels [25]. The material is two-phase, it is mixed microstructure of about equal proportions of austenite and ferrite (Fig. 2) but it is generally accepted that expected properties can be achieved if ferrite and austenite are in 30 to 70 % in structures [26]. As it can be seen the microstructure is typical for a cast with dendrites.

Fig. 2. Microstructure of duplex cast steel

In figure 3 is presented an exemplary sample microstructure and surface (optical and scanning microscopy) with view of surface layer (marked area – dashed line). The range of the surface layer for the tested samples was from 0 (sample 3) to 500 µm.

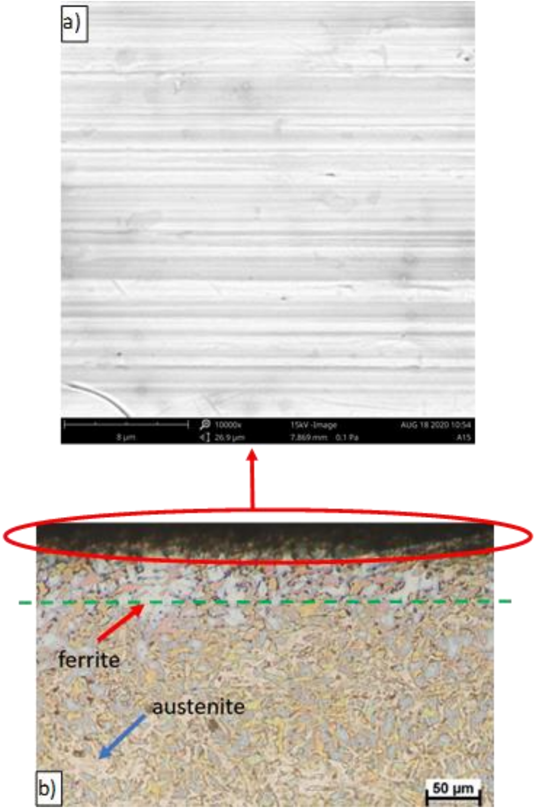

Fig. 3. Surface - view a) and microstructure of duplex cast steel – view b)

The tribological tests were carried out, then the weight loss of the samples and the geometric structure of the surface were assessed. The obtained results are shown below in Figures 4-6. Measurement results of the Ra, Rt, Rz and RSm parameters of the surface roughness of the tested samples are shown in the Table 3. The surface roughness was tested according to the standards PN-EN ISO 4288:2011, PN-EN ISO 25178-1:2016-08.

Table 3.
Parameters of the surface roughness

	1	2	3
Ra, µm	0.31±0.08	1.17±0.04	0.59±0.04
Rt, µm	2.30±0.5	6.73±0.6	4.43±0.6
Rz, µm	1.73±0.6	5.60±0.4	3.35±0.3
RSm, µm	12.24±0.2	63.5±0.4	20.37±0.7

The results of the weight loss of the samples after tribological tests are presented in Figures 4 and 5.

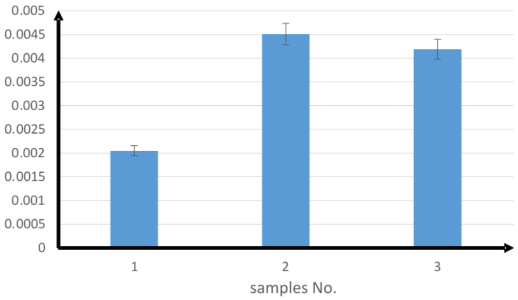

Fig. 4. Weight loss of the samples after tribological tests.

The characteristics of the tested materials in the form of the dependence of the weight loss on the friction path are shown in Figure 5.

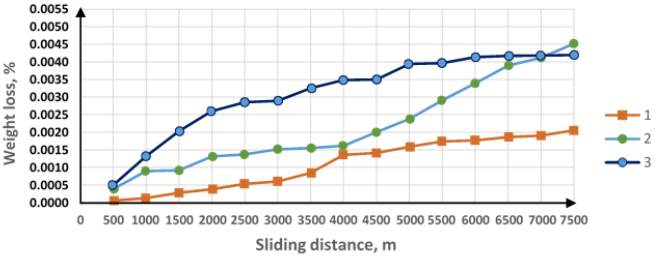

Fig. 5. Chart of weight loss as a function of the sliding distance

Figure 6 presents an example of the macro view of samples before and after tribological tests. Red ellipse mark surface of friction wear.

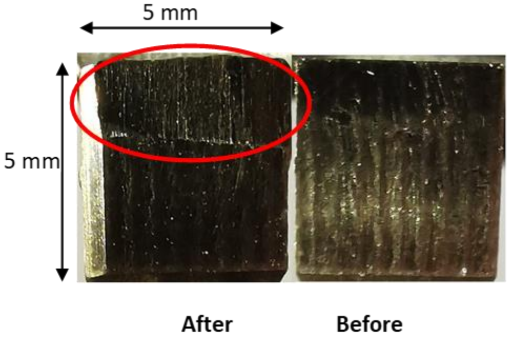

Fig. 6. Exemplary macro view of samples after and before tribological tests

For better analysis were also made surface scan with use of the S neox 3D profiler. Figures 7-9 show obtained images of the surface before and after the tribological tests. The images shows surface changes that occurred during tribological tests. The measurement area was 0,66 mm × 0,89 mm. Measured textures were only leveled without digital filtration. The surface topography parameters were calculated using the MountainsMap software.

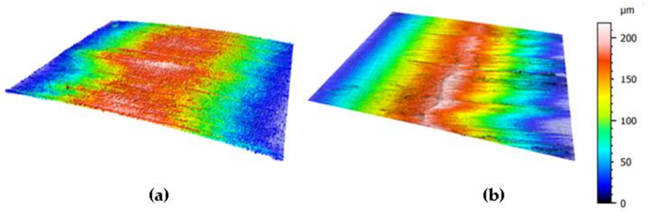

Fig. 7. 3D images of the surface of sample 1, a - before, b - after the tribological test

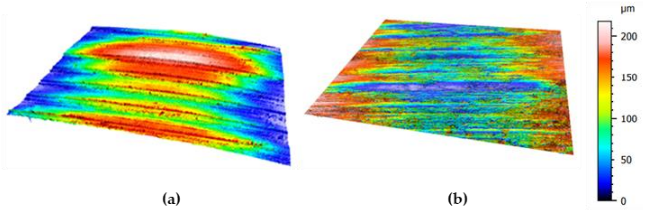

Fig. 8. 3D images of the surface of sample 2, a - before, b - after the tribological test

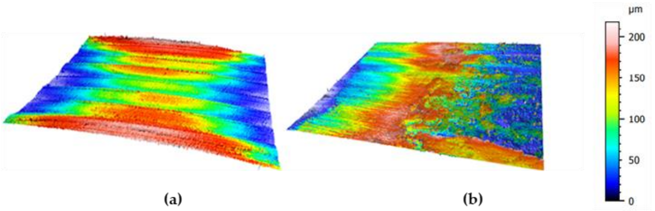

Fig. 9. 3D images of the surface of sample 3, a - before, b - after the tribological test

4. Discussion

The microstructure of the core of the tested material shows a characteristic dendritic structure, typical for cast materials. The Sigma phase precipitation was not observed in the structure, which proves that the supersaturation process was correctly carried out. The percentage share of individual phases in the structure (ferrite-austenite), determined on the basis of computer image analysis, amounted to about 45-55%, which is the expected value. The measurement area was 841x568 µm^2 and was obtained as a mean value of 5 areas. The results of the material wear work in the friction node is adhesive and abrasive, which is confirmed by the 3D images shown in Figures 7-9. As a result of the test, there was a loss of mass and permanent surface changes related to tribological wear. Analysis the weight loss in correlation to the sliding distance shown that variant 3 has a constant loss weight after distance of 6000m that is not found in the other two variants. The analysis of the surface after the tribological test shows that during the deformation and the formation of furrows, cracking also took place and the formation of wear products which, being in the friction zone, caused abrasive wear. It should be pointed out that, the abrasive wear is the most common type of wear in the case of technically dry friction [27-29]. The data presented in Figure 4 indicate that samples 2 and 3 had a comparable percentage loss in mass. The question that needs to be answered is: why the improvement in tribological properties was not achieved in the case of sample No. 2? It is worth paying attention to the value of the friction coefficient, which for samples 1 and 3 remained at a similar level, and its increase is visible for sample no. 2. The feed rate favors an increase in roughness, which in turn causes an increase in the coefficient of friction. Table 3 presents the measurement results of the Ra parameter - arithmetic mean profile deviation and RSm - the average distance between the height of the profile. The values of the measured parameters confirm that the surface formed as a result of burnishing has a different roughness, which depends on the parameters of the process. Moreover, in the range of up to a few millimeters, the material may have a higher hardness and a different character of stress, which in turn determines its behavior during friction [21, 30]. The different nature of changes due to abrasive wear is confirmed by 3D images of the surface before and after the test. The surface condition of the rubbing elements depends mainly on the surface treatment technology and the type of material.

Burnishing leads to formation of compressive residual stresses in the surface layer of workpieces [31, 32]. The burnishing can increase surface layer hardness and reduced surface roughness and lead to reduction in the coefficient of friction [33] – but results of process depends on its parameters. Different conditions of the burnishing process in-fluence the different condition of the surface, which in effect shapes the tribological properties. In all cases, tribological processes were associated with a loss of mass, but for samples 2 and 3, significant chipping is visible in the 3D image, which was not observed for sample 1. The surface wear of samples 2, 3 is greater than that of sample 1, because of material loss in the surface layer caused by particle separation due to microcracks on its surfaces. This process occurs when abrasive particles are present between the surfaces of the friction elements, which are a product of wear. Sample 2 had higher roughness than sample 1, and sample 3 had also less hardness, so this properties determine type of wear. It is known that under test without lubrication a friction force leads to an increase in the maximal tangential stresses of the sample and, as a result, to the formation of periodic microcracks on its surface [34, 35].

5. Conclusions

The article presents part of the research concerning the influence of the burnishing process on the properties of the duplex steel surface layer. The authors carry out research in a broader scope, both in terms of process parameters and other properties, e.g. fatigue resistance and corrosion resistance. The issue is important because the authors focused their research on grade (GX2CrNiMoN22-5-3) that are not containing Cu. Copper in duplex steels affects many areas one of them is the plastic properties of duplex cast steel, its absence also reduces castability and hinders plastic deformation. Because of that it is reasonable to determine to what extent the properties of the surface layer of copper-free duplex cast steel grades can be shaped in burnishing process.

First conclusion is that the heterogeneous, two-phase structure of the tested materials, castings, does not limit the possibility of obtaining a surface free from cracks, discontinuities, tears and other surface defects after the process.

Second, it can be prove that effect of burnishing process depends on its parameters. In general, the burnishing process determines the surface roughness and its direction. It is the result of plastic deformation and crumple zone. Microstructure tests confirmed that as a result of the burnishing process, a surface layer was obtained, which was different from the structure of the material core. As a result of the clamping force, the material deformed plastically, which is evidenced by the change in the directional orientation of the grains.

The topography of surface after tribological tests have been carried with use of the Sensofar microscope. During the test – on samples 2, 3 – have been formed solid particles what increase the surface destruction. Their presence influence the type of wear: adhesive, abrasive or mixed. The nonrecommended amount of feed, which negatively shapes the tribological properties of the tested material is 0.5 mm / rev. Burnishing at a feed rate of 0.5 mm / rev increases roughness, which causes lower tribological properties.

The conducted laboratory tests confirm that the functional properties of the material can be shaped through SPRB of duplex cast steel. Depending on the parameters used, it is possible to improve (sample 1) or worsen (sample 2) the tested properties of the material. In order to obtain favorable treatment results, it is necessary to properly select the parameters of the processes. When designing the technological process of burnishing, the relationship between the parameters of the process and the properties of the surface layer should be taken into account.

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