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Mechanical properties and corrosion resistance of burnished X5CrNi 18-9 stainless steel

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Properties

ABSTRACT

Purpose: In this paper there were presented the burnishing process and obtained mechanical properties and the structure of burnished stainless steel and its corrosion resistance.

Design/methodology/approach: Burnishing was conducted in standard milling machine equipped with the 2-ball rotation head. The structural and mechanical researches were carried out by optical microscopy and the X-ray diffraction patterns. The corrosion research was performed using the potentiodynamic anodic polarization. The scope of this study was to achieve the correlations between mechanical and structural properties and corrosion resistance of burnished stainless steel.

Findings: Results shown increasing of the open circuit potential (EOCP) and decreasing of breakdown (Eb) and repassivation potentials (Erp) with increasing of burnishing load. The breakdown potential and the repassivation potential changes were influenced by structural changes in surface layer and it indicated of slightly decreasing of corrosion resistance. It might be caused by martensitic transformation induced by the plastic deformation. The X-ray diffraction analysis showed increasing of Fe-α contain with the burnishing load.

Research limitations/implications: There's need to conduct future research on susceptibility to stress corrosion cracking and fatigue corrosion. The main difference between presented research and the future is necessity of double-sided burnishing of specimens.

Practical implications: Burnishing increases the strength and the rigidity of elements, especially stream plates of heat exchangers which may have lower thickness to improve the heat transfer. Some of elements, such as homogenized valves achieving better erosion and wear resistance by higher surface hardness.

Originality/value: Presented researches contain a lot of quantitative results which may be useful for design engineers in wide space of application.

Keywords: Stainless steel; Burnishing; Strengthening; Corrosion; Martensitic transformation

1. Introduction

Type X5CrNi18-9 austenitic stainless steel is widely used for many applications as a result of its good corrosion resistance and low price. This type of steel, as almost all austenitic type steels, is characterized by low yield stress (about 200 MPa) and tensile strength (about 600 MPa) [4,6]. The advantageous method of strengthening of stainless steel is a cold work, especially ball-burnishing.

Burnishing is considered as a cold working finishing process, using local plastic deformation in surface layer by the interaction of the hard and smooth tool (e.g. ball) on the treated surface [4, 8]. This method differing from other cold-working, surface treatment processes, such as shot peening and sand blasting in that it produces a good surface finish and also induces residual compressive stresses at the metallic surface layers [2]. Burnishing allows obtaining advantageous properties of surface [4-7], such as smooth surface, strengthening and increasing of dimensional and shape accuracy with low costs of process [4, 8]. The strengthening in the surface layer of the stainless steel enables increasing of yield stress from 230 MPa to 450 MPa for the whole element [6]. The cold work in whole volume of element is senseless and too expensive.

The burnishing process can be achieved by applying a polished and hardened ball (or roller) onto a metallic surface under pressure. This will cause the peaks of the metallic surface to spread out permanently, when the applied burnishing pressure exceeds the yield strength of the steel, to fill the valleys (Fig. 1) [2].

The surface of the metallic material will be smoothed out and because of the plastic deformation the surface becomes work hardened, the material being left with a residual stress distribution (Fig. 2) that is comprehensive in the surface [2].

Moreover, burnishing of stainless steels is advantageous in strengthening with minimal geometrical and dimensional changes [4,8]. Applications of stainless steels in many industry branches, especially in the food processing industries, are conditioned by corrosion resistance influenced by state of surface layer [9, 10].

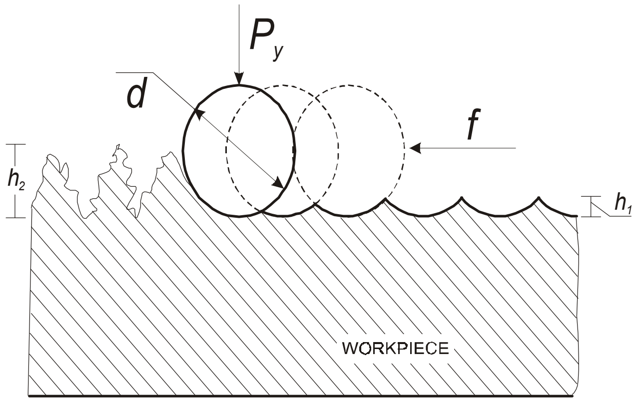

Fig. 1. The burnishing process [2]

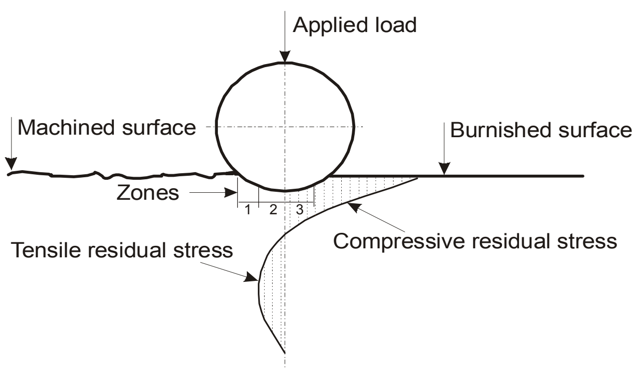

Fig. 2. Schematic representation of the residual stress distribution in the burnishing process [2]

Increasing of mechanical properties obtained as effect of burnishing points at necessity to measure of corrosion resistance changes caused by the treatment. The present work is also an attempt to study the effect of ball-burnishing on the structure, strength and surface roughness and its influence on corrosion resistance.

2. Experimental details

2.1. Materials

The substrate material used for the experiments was type X5CrNi18-9 austenitic steel plate of 4 mm thickness with a chemical composition as shown in Table 1. The steel plate was cut into 150×15 mm rectangular plates. To eliminate plastic deformation occurred during cutting specimens were hyperquenched in 1100°C in 5 min. and cooled in water. The heat treatment was conducted in argon shielding gas.

Microstructural characterization was carried out before and after burnishing by optical microscopy (OPM) following etching with nitrochydrochloric acid.

As a tool there was used a 10 mm ball made of hardened steel. The ball hardness was 64 HRC. The chemical composition of the ball is shown in Tabl. 1.

Table 1.
Chemical compositions of steel (wt. %)

chemical element	X5CrNi 18-9	burnishing ball
C	0,040	0.99
Cr	18.3	1.46
Ni	8.7	0.23
Si	0.44	0.23
Mn	1.55	0.26
P	0.027	0.006
S	0.002	0.005
Fe	bal.	bal.

2.2. The burnishing process

The burnishing process was conducted on milling machine (Fig. 3) with rotation head equipped with 2 balls. Burnishing load was setting by the tension of springs. The main parameters for the burnishing processes were:

– burnishing load 1600N, 1800N, 2000N and 3000 N,
– feed f = 20 mm/min;
– head rotation 60 rpm.

Specimens were burnished twice in reciprocally perpendicular direction.

In the experimental there was used an oil to lubricate the tool and the specimen. Moreover, an oil was used as a cooler and cleaning environment. Lubricating and cleaning of the tool and specimen was carried out continuously in order to prevent any hard particles usually leaving deep scratches, which may damage the burnished surface of the specimen.

Fig. 3. The milling machine with the burnishing rotation head

Parameters of the process were obtained in a preliminary research. These parameters enabled obtaining advantageous surface roughness, which was increased with burnishing load (Fig. 4). In research there was used stainless steel type X5CrNi 18-9 and as a comparison there was used the same steel after hyperquenching.

2.3. The corrosion research

The corrosion research was conducted to obtain susceptibility to pitting corrosion. Corrosion behavior was studied by means of potentiodynamic anodic polarization test in 5 wt.% citric acid solution with 150 ppm chloride ions added in temperature of 20°C. The choice of corroding medium was determined by its similarity to food processing media [1, 5, 6].

The samples prepared for polarization tests were cut from the burnished specimens Only one surface of each sample was exposed to the electrolyte, with an area of 15×15 mm, while the other surfaces were covered with epoxy resin. Corrosion researches were conducted on specimens without any additional treatment –as-received. The boundary between the sample and the epoxy resin was sealed to avoid crevice corrosion. The polarization tests were carried out using a conventional three-electrode cell, comprising the sample, a platinum foil counterelectrode and a saturated calomel reference electrode. A EP-20 transistor potentiostat was used to control the potential at a sweep rate of 0,001V/s from E_{OCP} to about +0,5V. Before polarization the sample was degreased and immersed in the solution for 10 min to stabilize the open circuit potential (E_{OCP}). All potentials are quoted with respect to the saturated calomel electrode scale. For comparison, the same corrosion test was carried out under the same experimental conditions on the hyperquenched sample.

The breakdowndown potential (*Eb*) and the repassivation potential (*Erp*) were evaluated from polarization curves. To obtain reliable results there were conducted several measures and average values of evaluated potentials were calculated. The dispersion was very small, the standard deviation calculated in percentages to average value did not exceed 3%.

In evaluation of corrosion resistance there were also used following indexes:

$$\Delta Ep = Eb - E_{OCP} \tag{1}$$

describing the width of passive area, and:

$$\Delta Eh = Erp\text{-}Eb \tag{2}$$

describing the width of hysteresis loop in repassivation.

Increasing of measured potentials and decreasing of calculated indexes points to the better corrosion resistance.

3. Results and discussion

The microstructure of burnished steel was presented on Fig. 4. In the core there is visible austenite structure with primary precipitates and twins (Fig. 4a). After burnishing there was observed increasing of slip bands, density of dislocations and twinning deformations with approaching to the surface (Fig. 4b and c).

The strengthening in the surface layer enables increasing of yield stress from 230 MPa (hyperquenched steel) to 450 MPa for the burnished element (Fig. 5). Besides, the burnishing process reduces the elongation by 16%. Summarize, it’s a cheap treatment, which gives such a great results. The cold work in whole volume of element is senseless and too expensive. To simplification the yield stress was represented by the proof stress ($Re_{0,2}$).

Changes of surface roughness after burnishing process were presented on Fig. 6. Application of burnishing significantly decreased the roughness of surface. All parameters of roughness were reduced. Burnishing with the load of 1600N caused reduction in the roughness parameters from 40% to 67%, and load of 3000N caused reduction by over 80%.

Smoothness of surface is the first determinant in corrosion resistance. It’s necessary to notice, that the bigger loads may cause formation of lapping, which may induces porosity or corrosion initiators.

Characteristic potentials of pitting corrosion, obtained from polarization curves and measures, were presented on Fig. 7.

The corrosion resistance of the hyperquenched steel is mainly dependent upon such factors as composition and structure. Incorrect heat treatment leads to creation of the chromium carbide precipitation or intermetallic phases, such as the sigma phase. The chromium carbide precipitation and the sigma phase at the grain boundaries leading to chromium depletion in the zones in the immediate vicinity of the grain boundaries is of particular importance for the intergranular corrosion (IC) resistance of the metal. The chromium depleted zones become susceptible to corrosion. Rising carbon contents facilitate chromium carbide precipitation, but the alloying element niobium reduces chromium carbide precipitation and hence limits the susceptibility to IC.

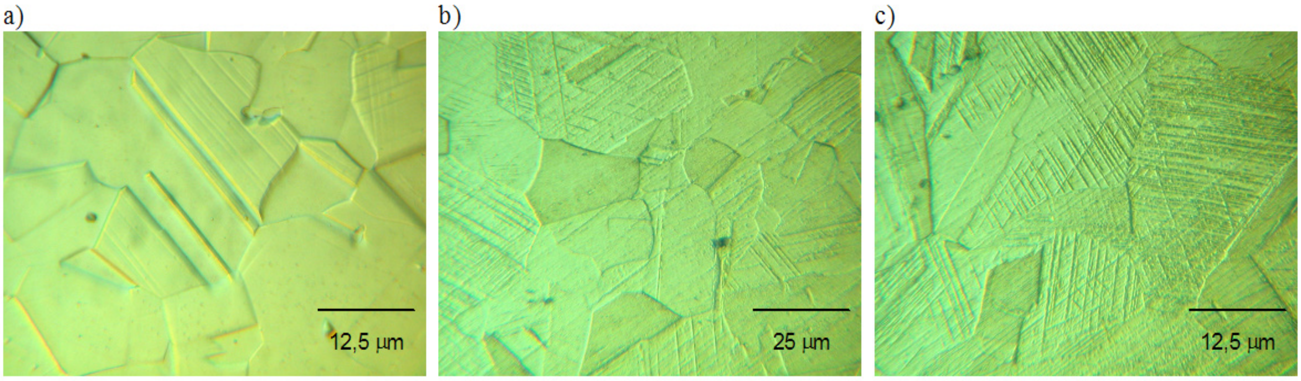

Fig. 4. The microstructure of burnished X5CrNi 18-9 steel: a) the core, b) the intermediate zone, c) the subsurface zone.

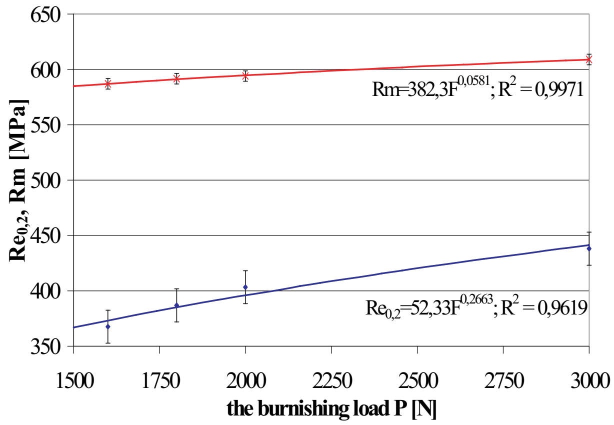

Fig. 5. The yield stress ($Re_{0,2}$) and the tensile strength (Rm) in relation to the burnishing load

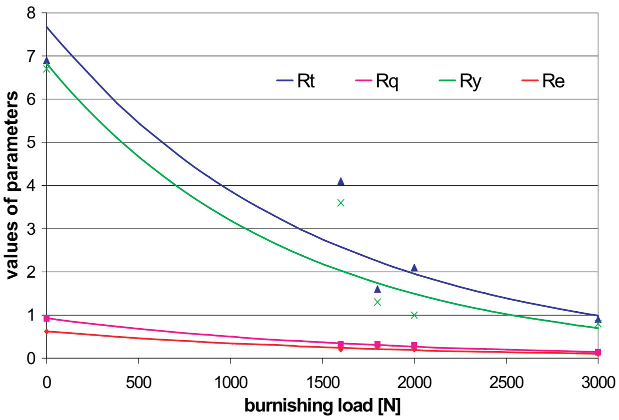

Fig. 6. Changes of surface roughness after burnishing

Moreover, the presence of the carbide precipitation or intermetallic phases creates galvanic cells, which are initiators of pitting corrosion. Summarize, the more single-phase material is the more corrosion resistance of metal.

The main aim of this study was to find an influence of strengthening of the stainless steel by burnishing on its corrosion resistance.

Increasing of burnishing load involved increasing of open circuit potential E_{OCP} and decreasing of both, the breakdownown potential *Eb* and the repassivation potential *Erp* (Fig. 7). All these changes had nearly logarithmical nature. Increasing of E_{OCP} was caused by smoothing surface and reducing of metal activity in corroding medium. Changes of the breakdown potential and the repassivation potential were the result of structural transformation produced in surface layer [9, 10]. The possibility of martensitic transformation appearance and increasing of dislocation density and also forming of extrusions and intrusions – as the pitting corrosion initiators – these contribute to decreasing corrosion resistance. So it's necessary to consider parameters of burnishing to get the proper structure.

Microscopic observations of post-corroded surface indicated of pitting corrosion initiators. Pits were formed primarily on precipitations, but they were also initiated on structure objects such as slip bands and on some undefected grains. It led to conclusion, that the corroded grains had different electrochemical potential than the matrix – it might be a different phase. To obtain the answer the X-ray diffraction analysis there was conducted.

The X-ray diffraction analysis indicates that the main constituent phase of the burnished layer is austenite (Fe-γ) with a small amount of ferrite (Fe-α). The intensity of reflection for Fe-α phase increases together with the burnishing load so it points to increasing of amount of ferrite. Ferrite has a less corrosion resistance so it could be easily attack. The diffraction patterns of the burnished layers are shown in Fig. 9.

The change of breakdown potential is very small, in comparison to value obtained for hyperquenched steel, the value of breakdown potential decreased in range from 10% to 32%. The open circuit potential was changed in wider range from 20% to 46%. The value of *Erp* potential decreased with increasing of burnishing load. It was also the effect of structural changes and difficulty in rebuilding of passive oxide layer.

The width of hysteresis loop in repassivation, described by ΔEh index, slightly increased reflecting the level of material "etching" as a result of corrosion process.

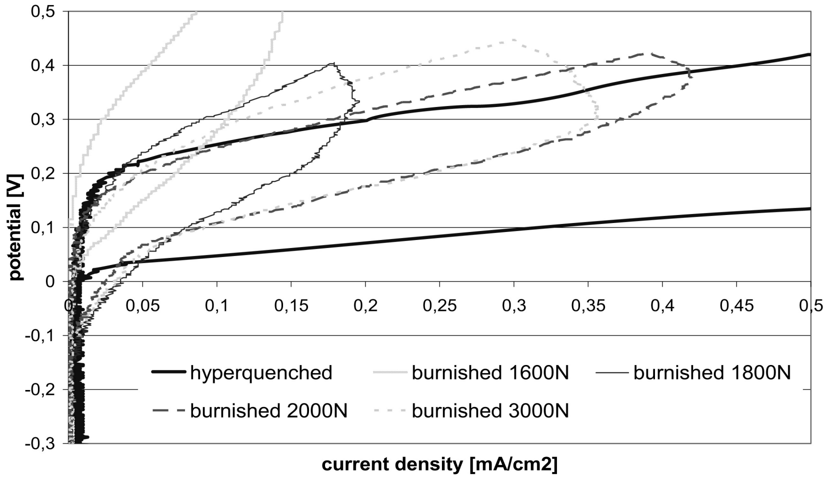

Fig. 7. Anodic polarization curves for the tested steel

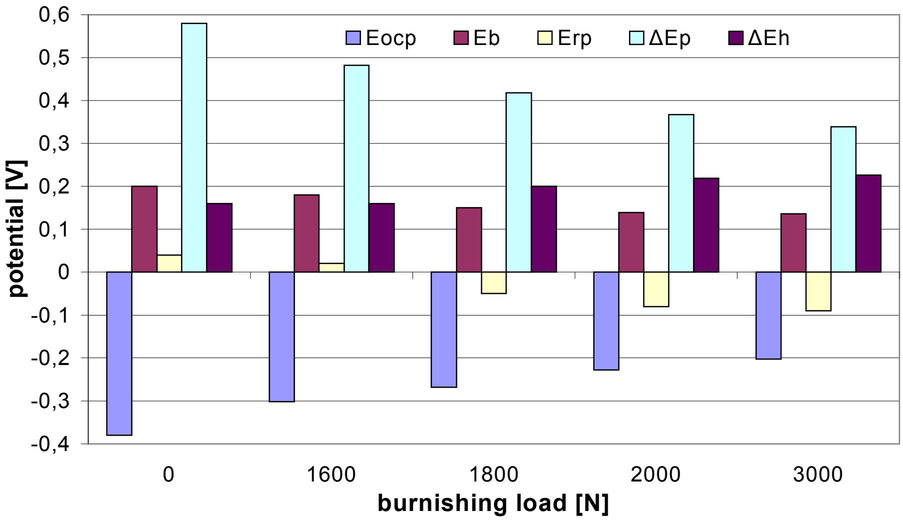

Fig. 8. Characteristic potentials of pitting corrosion in relation to burnishing load; (0N means hyperquenched steel)

4. Conclusions

(1) The strengthening as the result of burnishing enables increasing of yield stress from 230 MPa (hyperquenched steel) to 450 MPa for the burnished element 4 mm thick. The burnishing process reduces the elongation by 16% in this case.

(2) Burnishing with the load of 1600N caused reduction in the roughness parameters from 40% to 67%, and load of 3000N caused reduction by over 80%.

(3) There were observed increasing of the open circuit potential with the burnishing load. It could be interpreted as effect of coarseness decreasing.

(4) Anodic polarization showed that the breakdown potential and the repassivation potential were decreased with the burnishing load. It points at decreasing of corrosion resistance in effect of burnishing.

The burnishing process considerably reduces the surface roughness and improves the yield stress and the tensile and fatigue strength [6, 7]. It's necessary to consider advantages in strength as effect of burnishing in comparison to requirements of corrosion resistance. Because there is always the probability of decreasing of corrosion resistance in case of strengthening surface by cold work it's necessary to make a choice of priority. In case of choice of the strength it's preferable to use the steel with better corrosion resistance, such as X2CrNiMo 17-14-2. There's need to conduct future research to find relations between structure stereology and its influence on corrosion resistance.

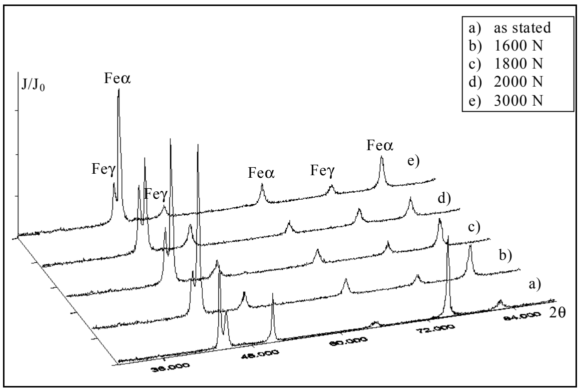

Fig. 9. The X-ray diffraction patterns for tested steel after hyperquenching (a) and burnishing (b÷e)

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