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CORROSION RESISTANCE OF HSLA STEEL AFTER VARIOUS SURFACE TREATMENTS IN CHLORIDE ENVIRONMENT

The effect of mechanical and chemical surface treatment of high-strength low alloy steel S355J2 on its electrochemical characteristics was investigated by voltamperic tests in corrosive environment of 0.1M NaCl solution simulating sea atmosphere. Mechanical surface treatment was done by grinding on 1200 grit paper and by sandblasting. Chemical surface treatment was performed by iron phosphating in aqueous solution of H_3PO_4 and $FeCl_3.6H_2O$. Thermodynamic and kinetic corrosion characteristics including corrosion potentials and corrosion current densities were measured and analysed by potentiodynamic polarisation curves and Tafel analyses respectively. The positive combination of these two techniques on corrosion properties of S355J2 steel surface was reported.

Keywords: S355J steel, corrosion properties, iron phosphating, surface treatment.

1. Introduction

There are two main grades of High Performance Steels (HPS), namely High Strength Low Alloyed (HSLA) and High Strength Steels (HSS). A major feature of these grades is low level of carbon and additions of micro alloying elements resulting in low value of Carbon Equivalent (CE) and improved weldability [1, 2, 3 and 4]. High strength low alloyed (HSLA) steels were primarily developed to replace low-carbon steels for the automotive industry in order to improve the strength-to-weight ratio and meet the need for higher-strength construction grade materials. HSLA steels demonstrate unique properties, such as high strength, excellent ductility, good weldability and also exhibit outstanding low temperature impact toughness superior to that of high yield strength (HY) steels. HSLA steels have much improved weldability compared to HY steels [4]. HSLA steels become an indispensable class for different applications like construction of large ships, oil and gas transmission lines, offshore oil drilling platforms, pressure vessels, building construction, bridges and storage tanks [5]. S355J2 steel is one of the most commonly used member of HSLA steel grade. However for many applications, proper surface pretreatment and painting has to be used to improve its surface quality.

Sandblasting, as a surface treatment method, is commonly used for surface modification [6], surface strengthening [7], surface clearing and rust removal [8]. Compared with shot peening, it has smaller abrasive particles and lower pressure of compressed air. Therefore, a smoother surface can be obtained by sandblasting in general. During the sandblasting process, the surface of specimens is blasted repeatedly by sand or other hard particles with high speed, which leads to the removal of oxide scale and generation of local plastic deformation in the surface layer. However, Wang et al. [9] observed decrease of corrosion resistance of steel after sandblasting, which limits the application possibilities of this technique [10 and 11].

Problems with lower corrosion resistance of sandblasted surface could be solved by application of chemical phosphating. Phosphate coatings are produced on ferrous and nonferrous metal surfaces and are composed of tiny crystals of iron, zinc, or manganese phosphates. These inorganic coatings produced on metal surfaces retard corrosion and promote better paint bonding. Iron phosphating is the workhorse of the general finishing industry because of the quality delivered with regards to the newer coatings, its ease of control, non-sludge characteristics, and economics [12].

For these reasons, the aim of this study is to compare these two techniques for surface treatment of steels applied individually and in mutual combination from the corrosion point of view.

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2. Experimental material and methods

S355J2 steel was used as an experimental material. The chemical composition is listed in Table 1.

The samples for metallographic observation were prepared by conventional metallographic procedures. 3% Nital was used as an etchant for visualisation of the S355J2 steel microstructure (Fig. 1). The microstructure is created by ferrite-pearlite matrix with a low pearlite content (local pearlite occurrence) and with the grain size of about 10 microns. The microstructure was observed by the CARL ZEISS AXIO Imager.A1m (equipment financed by the project ITMS 26220220121) light metallographic microscope in the laboratories of Department of Materials Engineering, University of Zilina.
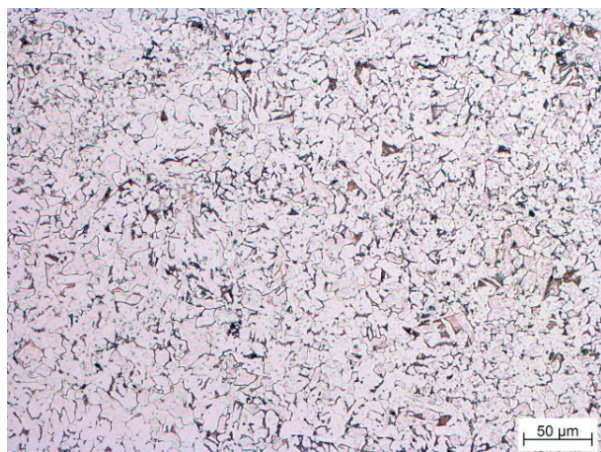

Fig. 1 Microstructure of S355J2 steel

S355J2 steel samples with surface area of 15 cm² were ground with 500 and 1200 grit SiC paper to ensure the same surface roughness, then rinsed with demineralised water and ethanol, and dried using a stream of hot air. The first pretreated samples were further sandblasted. Sandblasting was performed by sand particles on a mobile pressure sandblasting machine with a nozzle diameter 6 mm and pressure of 0.6 MPa. The second samples were treated chemically by iron phosphating. Composition of phosphating bath was 300 ml of demineralised water, 0.42 ml of H_3PO_4 and 0.999 g of $FeCl_3.6H_2O$. Phosphating process was performed for 5 minutes at the temperature of 90-95 °C. Third samples were treated by the combination of these techniques at defined parameters. Sandblasting was followed by iron phosphating in this case. All the samples were rinsed with demineralised water and ethanol, and dried using a stream of hot air after final surface treatment in order to remove chemical and mechanical residues.

The surface morphology of the treated samples was assessed by a stereomicroscope Nikon AZ100 (equipment financed by the project ITMS 26220220048) with a digital camera using NIS Elements software. The corrosion characteristics of S355J2 steel samples after various surface treatment were evaluated by potentiodynamic polarisation using a potentiostat/galvanostat/frequency response analyser VSP from BioLogic SAS France. All the corrosion experiments were performed in 0.1M NaCl at 22±1 °C. A saturated calomel electrode and a platinum electrode served as the reference and auxiliary electrodes, respectively. Treated S355J2 samples formed the working electrode in such a way that only 1 cm² area of the working electrode surface was exposed to the electrolyte solution in corrosion cell.

Potentiodynamic polarisation tests were carried out from -200 to + 300 mV vs SCE with respect to the OCP at a scan rate of 1 mV.s^{-1}. Measured potentiodynamic curves were analysed using Tafel fit by EC-Lab software (software financed by the project ITMS 26220220183). The potentiodynamic polarisation measurements were repeated at least three times, so that reproducibility of the test results was ensured [13].

3. Results and discussion

Surface 3D morphology of S355J2 steel after sandblasting is shown in Fig. 2. As can be seen, sandblasting caused mild surface deformation up to 10 microns of depth, which is appropriate in terms of surface roughness increase and surface oxide cleaning.
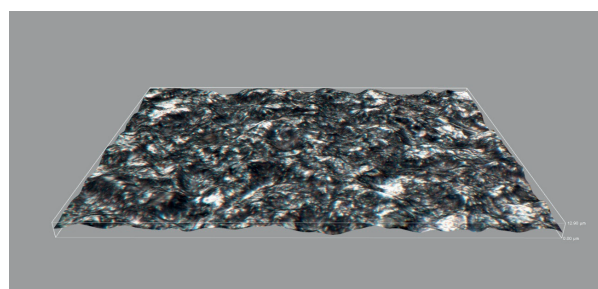

Fig. 2 Surface 3D surface morphology of S355J2 steel after sandblasting

When steel is exposed to the phosphating solution, iron dissolution is initiated at the micro-anodes present on the substrate due to the presence of free phosphoric acid in the bath and hydrogen evolution occurring at the microcathodic sites [14].

Chemical composition of S355J2 steel   Table 1

Component	C	Mn	P	S	Si	Cu	Fe
wt. %	0.200	1.600	0.025	0.025	0.550	0.550	balance

$$Fe + 2H_3PO_4 \Leftrightarrow Fe(H_2PO_4)_2 + H_2$$
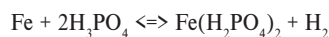
The formation of soluble primary ferrous phosphate leads to a concurrent local depletion of free acid concentration in the solution resulting in a rise in pH at the metal/solution interface. Hence, a certain amount of free phosphoric acid must be present to repress the hydrolysis and to keep the bath stable for effective deposition of phosphate at the microcathodic sites [14 and 15]. The morphology of created iron phosphate is shown in Fig. 3 at maximal magnification of the used microscope. Iron phosphate forms a continuous layer homogeneously covering the entire surface of the base metal in such a way that no evidence of previous grinding process is noticeable on the surface although iron phosphate crystals are of very low size. However, the layer is significantly porous, which is a typical feature of chemically prepared phosphates. This porous character of the layer is beneficial for the further oil or paint preservation of the surface.
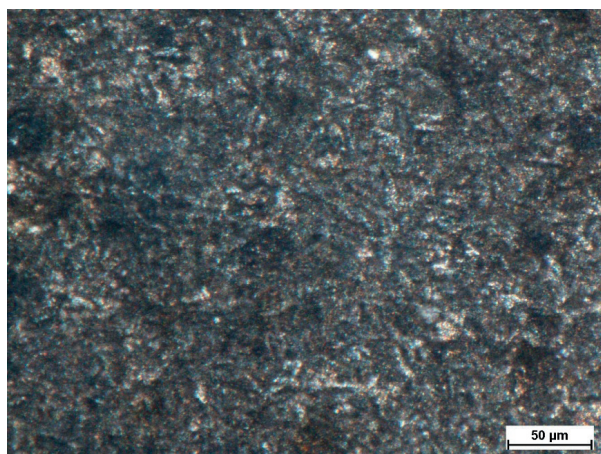

Fig. 3 Surface morphology of S355J2 steel after iron phosphating

Figure 4 shows the measured potentiodynamic curves of S355J2 steel samples after various surface treatments in 0.1M NaCl corrosive solution. The thermodynamic (corrosion potential) and kinetic (corrosion current density, corrosion rate) characteristics obtained from the measured curves are listed in Table 2.
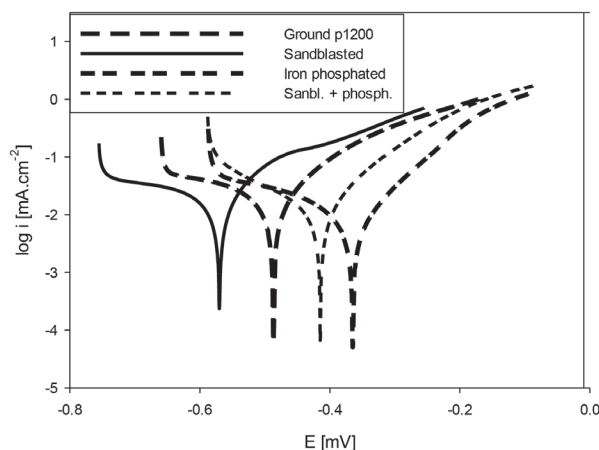

Fig. 4 Potentiodynamic curves of S355J2 steel after various surface treatments in 0.1M NaCl

Used mechanical and chemical surface treatment caused changes in both thermodynamic and kinetic characteristics of the base material. Thermodynamic stability of the surface is represented by the values of corrosion potentials E_{corr} in our case. More positive value of this electrochemical characteristic means that the surface is nobler and thermodynamically more stable. Sandblasting caused intensive destruction of the surface, which is an accompaniment to its cleaning process purpose. Destroyed surface with a higher concentration of structure defects and with larger area of an active surface resulted in lower electrochemical stability, which is reflected in 83 mV decrease of E_{corr} value in comparison with simply ground surface and sandblasted surface. A part of kinetic energy of sandblasting particles transformed into addition of internal energy of the base material, which caused its absolute value increase. As the result of higher surface activity, an increase of corrosion current density i_{corr} value and directly related value of corrosion rate rcorr is observed on sandblasted surface compared to the ground surface. However, this increase is not very significant and represents just 3.2 $\mu A.cm^{-2}$ and 0.07 $mm.y^{-1}$ respectively. It is a beneficial finding that corrosion resistance decrease caused by intensive sandblasting surface cleaning is acceptable.

Iron phosphating creates a stable layer of several microns that forms a mechanical barrier against corrosion process. The higher

Electrochemical characteristics of S355J2 steel after various surface treatments   Table 2

Surface treatment	E_{corr} [mV_{SCE}]	i_{corr} [$\mu A.cm^{-2}$]	r_{corr} [$mm.y^{-1}$]	β_a [$mV.dec^{-1}$]	β_c [$mV.dec^{-1}$]
Grinding (1200 grit paper)	-487	16.3	0.38	124	288
Sandblasting	-570	19.5	0.45	139	477
Iron phosphating	-365	7.7	0.18	108	213
Sandblasting + Iron phosph.	-415	10.4	0.24	102	177

stability of iron phosphate in 0.1M NaCl solution compared to the base metal resulted in more positive value of $E_{corr.}$. E_{corr} of iron phosphated surface is moved by 122 mV to nobler values. Thanks to mechanical barrier of iron phosphate the diffusion of oxygen to base metal active surface is more difficult and concentrated mainly to the more porous areas. This complication for kinetics of corrosion process results in decrease of i_{corr} and r_{corr} values too. Corrosion current density of the surface with iron phosphate represents just 47 % of base metal corrosion current density. These findings prove significant positive effect of iron phosphating on corrosion properties of S355J2 steel surface.

Very interesting combination of mechanical and chemical treatment of steel surface leading to preparation of pure and porous surface ideal for further preservation operations also brings positive effect on corrosion properties of S355J2 steel. In this case, positive effect of iron phosphating is more intensive than negative effect of sandblasting, which finally causes the improvement of both thermodynamic and kinetic electrochemical corrosion characteristics of double treated surface compared to simply ground surface with 1200 grit paper. Generally, two processes occur during iron phosphating in the first stage of this chemical treatment. The formation of iron phosphate on the one hand and the active dissolution of the base metal by phosphoric acid on the other hand. This active dissolution plays an important role in our case of sandblasted surface because at least a part of destroyed active surface layer can be removed in this way. However, the corrosion properties of this double treated surface are not of the same level as the corrosion properties of only iron phosphated surface.

4. Conclusions

On the basis of the measured data and analyses we concluded:
1. Sandblasting of S355J2 steel surface deteriorates corrosion properties of the surface by mild surface destruction.
2. Iron phosphating of S355J2 steel surface forms stable and effective porous barrier against corrosion process, which is proved by the best corrosion protection from tested surface treatment techniques.
3. Combination of surface treatment by sandblasting followed by iron phosphating improved corrosion protection of the base metal so it can be considered to be a suitable process for surface preparation prior to further preservation/painting.

Acknowledgements

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