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Electrolytic Plasma Surface Cleaning of Industrial Metallic Components

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Electrolytic plasma is an emerging, environmentally friendly surface engineering technology that can be used for cleaning of metal surfaces and removing several coating. The present work was concerned with cleaning of corrosion products (oxides and contamination) on steel surfaces for corrosion protection. The effects of processing parameters on cleaning steel surfaces were investigated. The results show that electrolytic plasma can effectively produce clean surfaces and remove iron oxides. Also the arc spray coatings deposited on steel was removed by electrolytic plasma.

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1. Introduction

Coating performance of metals is directly related to the surface properties like cleanliness, morphology and roughness. Additionally, the cleaning is important for removing of mill-scales (originated from the hot-rolling mill), pigmented films, environmental contaminations (oil, grease) and rust spots [1–3]. For the structural steels "using in a wide range of applications such as pipes, wires, bridge supports and industrial structures, etc." surface cleaning is essential pre-treatment to form an "anchor or crater" surface profile providing sound mechanical interlocking prior to coating [1, 2]. Conventional cleaning applications include both mechanical and chemical techniques such as abrasive blasting and acid etching or pickling. However, these methods have major difficulties such as high economical cost, ecologically unfriendly, waste-disposal problems, unfavorable surface profile, embedded abrasive particles onto cleaning metal, etc. [1]. Electrolytic plasma (EP) is a process that uses the cathodic hydrogen glow discharge on the surface of the substrate to be treated [4, 5]. Compared with the conventional chemical and mechanical method, the electrolytic plasma is more ecologic and combines surface cleaning and micro-crater formation in one process.

The present study emphases the methodology of surface cleaning and mechanism involved in EP cleaning. This study also summarizes the surface characteristics acquired after EP.

2. Experimental studies

Research has been carried out on several grade steels rectangular bar shape samples with a dimension of 150×25 mm^2 and 10 mm. The samples have been collected from the out of closed area that waited at least 2 years without protection. Also different kinds of heavily corroded machine components like gear, saw, blade have been also tested. The roughness of the surface (Ra) with the corroded samples is 10–15 μm. The plasma electrolytic cleaning has been carried out by using a 24 kW DC power supply and in an instrument rig consists metallic anode torch, electrolyte container and dynamic electrolyte circulation system (pump, filter, flow meter, thermometer) shown in Fig. 1. Electrolyte has been pumped from close circulation system into the anode torch then onto the cathodic substrate; the flow of electrolyte was vertically downwards. Larger specimens have been cleaned in similar but larger rig system with the help of lathe and CNC router. The electrolyte temperature has been increased from 15 to 25, 35, 45, 55, 65 and 75 °C; the flow rate of electrolyte has been arranged to several flow rates from 2 l/min to 10 l/min. The distance between anode and cathode that was termed as "gap" has been determined from 1, 2, 3, 4, 5 mm to 10 mm. The electrolyte has been prepared solving a sodium carbonate in water solution; the sodium carbonate concentration has been altered between 0%, 5%, 10% and 15%.

3. Results

Initially, the process parameters such as flow rate, electrolyte temperature, gap and sodium carbonate have been optimized and the effect of each parameter on the other has been revealed. During the optimization the main target was both cleaning performance and type of plasma that was generated between cathode and electrolyte. Detailed studies have been written about the scientific backgrounds of plasma types that were observed in overall electrolytic plasma process [1–7]. To recognize the parameters effect, samples have been investigated by optical microscopy, scanning electron microscopy (SEM)

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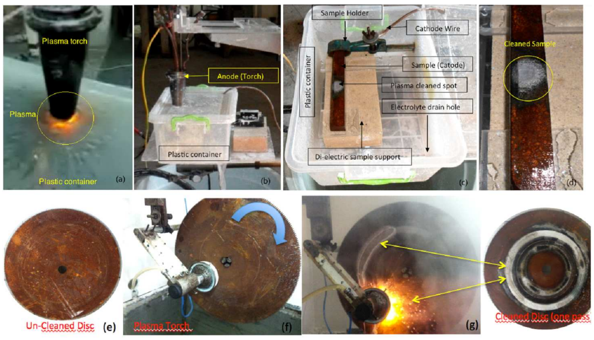


Fig. 1. Vertical type plasma torch (a), assembly of torch onto plastic container (b), plasma reactor components (c), a cleaned spot (d), corroded uncleaned disc (e), horizontal assembly (f), plasma cleaning (g), partially circular cleaned disc.

with energy dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD), and corrosion immersion test.

The graph that was plotted from the results of the optimization study has been shown in Fig. 2. The blue continuous line shows the optimum area that the plasma named as continuous plasma envelope [3] or region Ub–Uc that the process again becomes stable and the plasma discharge remains controlled [2]. Red triangles show the unstable electrolysis regimes called gas liberation or spark ignition. The left lower corner and right upper (red triangles) of the graph shows the regions that need high energy (potential) to generate the stable plasma. Process duration and sample dimensions have another effect on plasma cleaning. Continuously applying the voltage (after a while) can increase the temperature of electrolyte, ionic mobility of dissolved salts, and temperature of sample. Also short gap distance is better for the stable plasma. As a result one can achieve the stable plasma at low dissolved Na_2CO_3 (4%), short gap (1 mm) and relatively high electrolyte temperature (65 °C). More than 15% of Na_2CO_3 in water may be crystallized and freezes in electrolyte at lower temperature than the 10 °C. On the other hand, high flow rate has detrimental effect on plasma electrolysis because of the not adequate bubble and hydrogen generation on cathode surface. Briefly, Fig. 2 shows the effective and economic route to produce plasma or glow discharge. From now on the optimum region bordered with blue line will be named as midpoint.

Having optimized the process parameter, the samples have been cleaned in the midpoint region [2]. However, Fig. 3 shows the unprocessed and cleaned sample's optic micrographs.

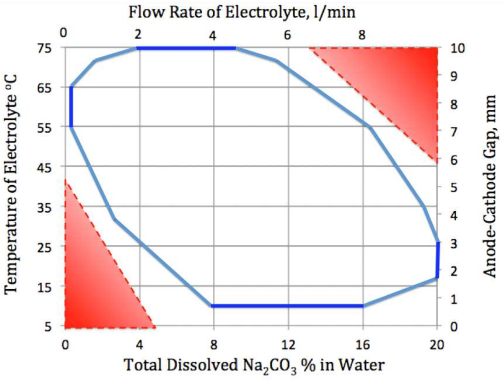


Fig. 2. The optimization map of process parameters of plasma electrolysis.

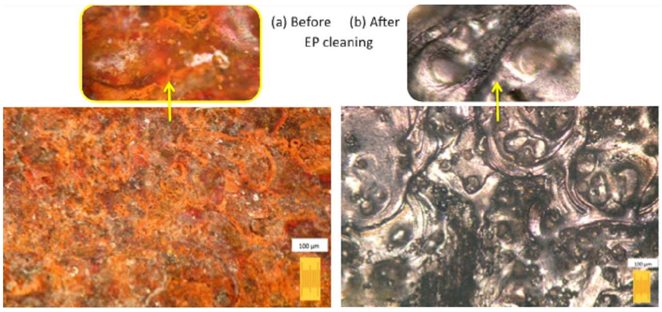
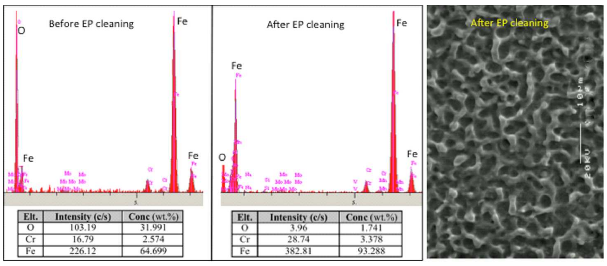


Fig. 3. Initial (unprocessed) (a) and final (EP cleaned) (b) microstructure of the sample.

The elemental analysis of Fe, Cr and O obtained from SEM–EDS analyses on the uncleaned and EP cleaned surfaces have been presented in Fig. 4. The EP cleaned surface has a significantly lower O concentration than the uncleaned sample; this is confirmation that the EP process has effectively removed or reduced surface oxides and contaminations [2]. During the EP cleaning, applied high voltage raises the temperatures in plasma bubbles which leads to micro melting of the surface layer of the sample. The plasma-activated hydrogen is able to reduce iron oxides present at the surface and results in a clean surface [1]. This surface is cooled by the adjacent electrolyte after collapse of the plasma bubble; additionally continuous shockwaves reduces oxide-scale, briefly; thermo-chemical-mechanical process take place at the same time that this kind of effect forms a proper surface microstructure for next treatments such as painting, coating, etc. (Fig. 4). Surface profile test is a proof that the initial Ra has been reduced from 5–10 μm to 0.15–0.5 Ra. XRD patterns have been investigated for



Elt.	Intensity (c/s)	Conc (wt.%)
O	103.19	31.991
Cr	16.79	2.574
Fe	226.12	64.699

Elt.	Intensity (c/s)	Conc (wt.%)
O	3.96	1.741
Cr	28.74	3.378
Fe	382.81	93.288

Fig. 4. EDS analysis of uncleaned and SEM–EDS analysis of cleaned steel by EP.

the cleaned at 1, 5, 10, 15, 30 s and uncleaned samples. XRD results have been shown in Fig. 5. As it can be seen, the oxide scales, iron hydrooxides and iron oxides forms have been removed from the surface. Considering the XRD patterns of treated samples the best cleaning performance has been achieved for the sample that was cleaned 30 s.

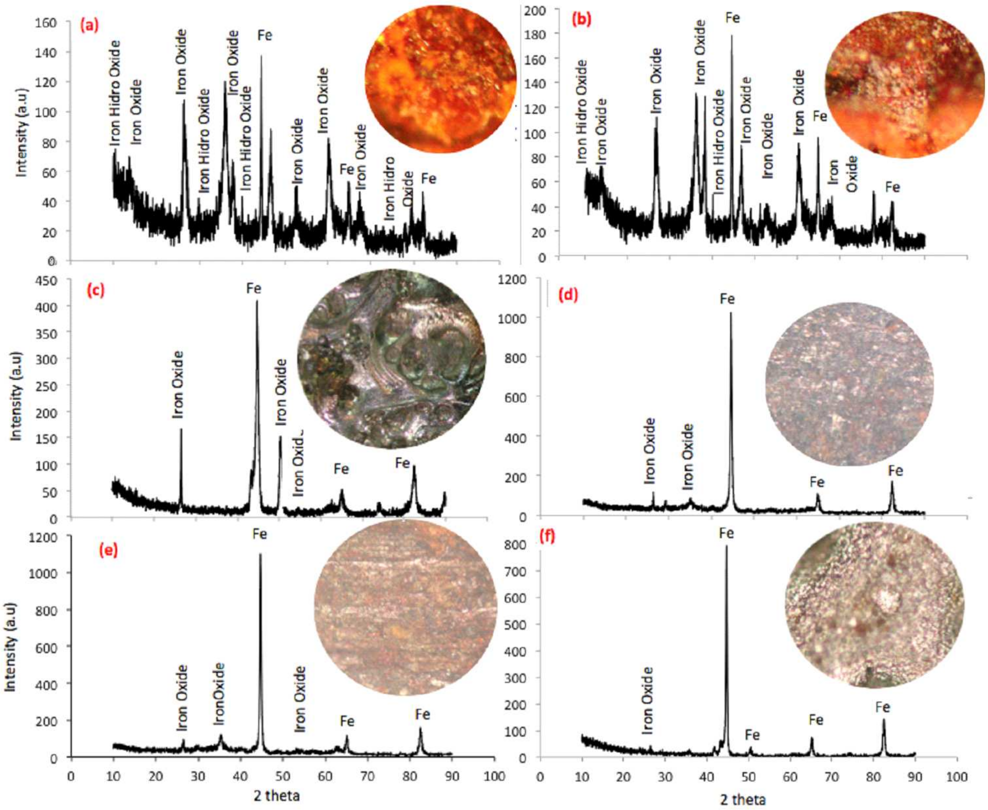


Fig. 5. XRD patterns and optic microstructures of (a) untreated, (b) 1 s, (c) 5 s, (d) 10 s, (e) 15 s, (f) 30 s treated samples.

4. Conclusions

It has been concluded that EP cleaning can remove and reduce iron oxides, rust, and contaminations from the surface of the ferrous metals and EP offers economical and environmental surface cleaning. Arc spray coatings also have been removed from the metallic substrate at the cathodic regime in midpoint region.

Increasing the flow rate and gap distance, increases the required electric potential to generate stable plasma, on the other hand increasing the temperature of electrolyte and ion suppliers, decreases the electric potential which is known as breaking voltage.

Different anode torch shapes can be designed for industrial applications such as disc, saw, blade, pipe, plate, gear, wire, nut, sheet etc. and electrolyte flow can be routed to downward, upwards and vertically.

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