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Corrosion Inhibitor for St-37 Alloy by Laser Shock Peening Technique

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ABSTRACT

This study aims to reduce the corrosion that occurring in mild steel (st-37). Laser has been used as inhibitor to reduce corrosion rate by using Laser shock peening (LSP) technique for st-37 submerged in hydrochloric acid with concentration of 1 M and the immersion time of 30 minutes at room temperature. The corrosion rate was evaluated by two method; weight loss method and polarization method. The results were observed that the values of corrosion rate are decreased after using the laser shock peening from 7.7210 mm/y to 1.0716 mm/y.

1. Introduction

Corrosion defined as the damage of metals and alloys through chemical or electrochemical interaction with its surrounding environment [1]. The classification of corrosion reactions According to the nature of corrosive environments are divided into wet and dry corrosion [2]. Depending on the morphology of metal's damage the corrosion can be classified into: general corrosion, pitting corrosion, crevice corrosion, Inter-granular corrosion, environmentally induced fracture, de-alloying; galvanic and erosion corrosion [3]. There are certain ways to protect the metal from corrosion such as coating, alloying, cathodic protection, anodic protection and recently been using the laser for this purpose by surface treatment of metal it considered as the way to improve the properties of metals like roughness, hardness, resistance of corrosion, etc. [2, 4]. The laser is characterized by the provision of large amounts of energy in confined regions from materials in order to reach the desired reaction, this energy will be absorbed by nearby surface of metal and the surface chemistry will be processed [5-8]. LSP represent a modern way used for the surface treatment and it can be defined as a mechanical process based on introduce deep compressive residual stresses by shock waves that generating through shedding laser pulses with high power intensity on the surface target [9-11]. In continuous to or work [12-17], herein we try to reduce corrosion rate by using Laser shock peening (LSP) technique for st-37 submerged in hydrochloric acid with concentration of 1 M and the immersion time of 30 minutes at room temperature.

2. Experimental Methods

2.1 Sample Preparation

The samples were prepared by cutting into circular shape with diameter 14 mm and thickness of 2 mm followed by grinding with different metallographic paper as SiC and AlC and additionally it has been refined by polishing paper assistance of Al_2O_3 to polish the surface of samples and to have same evaluation of roughness procedure was completed by processor polisher machine type (Mopao 160E). Finally cleaning and washing by de-ionized water and ethanol has been utilized to uproot the sullying and metal oxidation.

2.2 Chemical Compositions

The chemical composition of mild steel alloy was carried out by using oxford instruments product of Foundry Master Xpert Company.

2.3 Roughness Test

Surface Roughness R_a was measured for all samples possession the same roughness by using surface roughness measurement instrument type (TR200), the average value of the roughness was about R_a = 0.047 µm.

2.4 Experimental Setup

Experimental setup shown in Fig. 1 and it represented by using Q-switch Nd-YaG laser with different parameters listed in Table 1. The St-37 sample is to be immersed in deionized water. When the laser pulse is directed into surface to be treated, it passes through the confinement layer (deionized water) and strikes the sample plasma formed and absorbs the energy of laser. The expanding plasma create high pressure on sample surface and it has been improved the surface characteristics this technique is called Laser Shock peening.

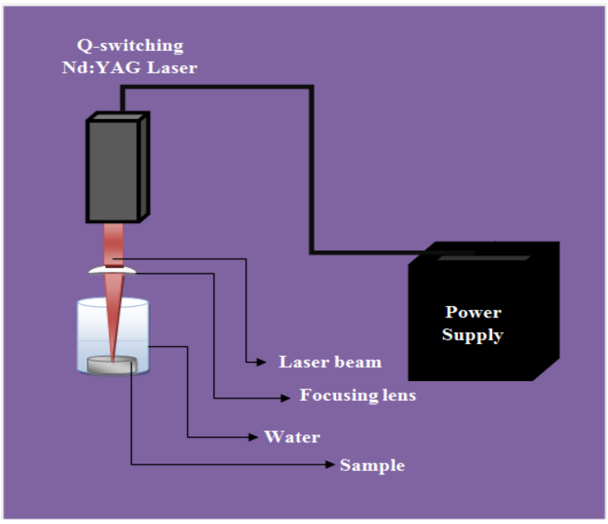

Fig. 1 Experimental Setup of Laser Shock peening

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Table 1 laser shock peening parameters

Temperature	25 °C
Laser wavelength	1064 nm
Repetition rate	1 Hz
Pulse duration	10 ns
Energy	400 mJ
Number of pulses	90 pulse
Beam spot size	1.2 mm
Focal length of lens	10 cm

2.5 Corrosion Test

Two methods have been used to calculate the corrosion rate of mild steel in hydrochloric acid of 1 M; the first method is weight loss and the second is a polarization method. The immersion time of sample was 30 minutes. Equations (1) and (2) were used to calculate the corrosion rate by weight loss and polarization methods respectively [18, 19] as follows:

$$CR(mm/y)=87.6 \times \Delta w/(\rho.A.t) \quad (1)$$
$$CR(mm/y)=(3.27 \times 10^{-3}\, I_{corr}\, W_e)/\rho \quad (2)$$

Where CR is the corrosion rate, Δw is the weight loss, ρ is the density of metal, A is the area, t is the immersion time, I_{corr} is the corrosion current density and W_e represented the equivalent weight.

Then the efficiency of inhibitor (η) was evaluated from [20-23]:

$$\eta\%=\frac{CR^0-CR}{CR^0} \times 100\% \quad (3)$$

Where CR^0 is the corrosion rate without inhibitor and CR is the corrosion rate with inhibitor.

2.6 Scanning Electron Microscopy (SEM)

SEM technique was used to observation the changes that occurring in the samples exposed to corrosion with a solution of HCl of (1 M) before and after laser shock peening (LSP) technique by (Inspect S50 FEI Scanning Electron Microscopic).

3. Results and Discussion

3.1 Chemical Composition

Table 2 represent the chemical composition of samples which were used in this investigation, and by comparing these percentages with standard we can conclude that the sample is mild steel type st-37.

Table 2 Chemical composition of sample used in this work

Sample	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Co%
	0.121	0.195	0.578	0.003	0.033	0.013	0.001	0.002
Sample	Cu%	Ta%	Zr%	As%	Sb%	Ni%	Fe%	
	0.070	0.013	0.002	0.035	0.012	0.022	98.900	

3.2 Corrosion Rate Results

Table 3 represent the parameters determined by using weight loss method such as initial weight (before corrosion) the final weight (after corrosion) and the net weight reduction. While Table 4 represent the factors that we got from the polarization curves shown in various Figs. 2-6 at different confinement thickness and can be noticed that the minimum value of corrosion current (I_{corr}) and corrosion potential (E_{corr}) are 138.17 μA/cm² and -504.6 mv respectively at confinement layer = 4 mm. All measurements of corrosion current and corrosion potential which got from polarization curves (Figs. 2-6) are listed in Table 4. These results give us index about the corrosion rate and the inhibition efficiency of LSP. Fig. 7 shows the relation between the corrosion rate values (calculated by two methods) and the thickness of confinement layer (DDDW depth). It can be reasoning from this figure that the results of corrosion rate extracted from the weight loss method equivalent to almost the results extracted from the polarization curves. The second deduction from this figure that the corrosion rate decreases with increasing of confinement layer thickness up to 4 mm due to increase the pressure that generated by the shock wave as well as the exposed surface to the laser pulses lead to increase the surface hardness of the sample. After this value (4 mm) the corrosion rate starts to increase this behavior may be due to the increase in thickness lead to the absorption of laser energy by DDDW and therefore lack adequate access of energy to sample. Fig. 8 shows the results of LSP efficiency to the inhibition of corrosion which determined by two method and the thickness of confining layer (DDDW depth). The maximum laser inhibition efficiency determined by weight loss was η = 84.80% and form polarization curves is η = 85.59% at the optimum result of confinement layer (DDDW = 4 mm).

Table 3 weight loss method measurement

d (mm)	W_1 (g)	W_2 (g)	ΔW (g)
0	2.8441	2.7989	0.0452
2	5.5392	5.5043	0.0349
4	3.5225	3.4961	0.0264
6	2.9107	2.8662	0.0445

Table 4 potentiodynamic polarization measurement

d (mm)	I_{corr} (μA/cm²)	$-E_{corr}$ (mV)	ba (mV.dec⁻¹)	-bc (mV.dec⁻¹)	Rp (KΩ.cm²)
0	230.00	518.12	73.4	159.32	0.095
2	195.00	512.3	75.3	91.1	0.092
4	138.17	504.6	79.9	99.1	0.139
6	264.45	520.9	91.4	173.4	0.098

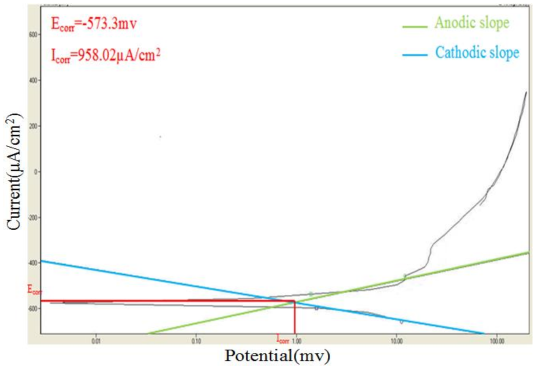

Fig. 2 Polarization curve of Mild steel before LSP

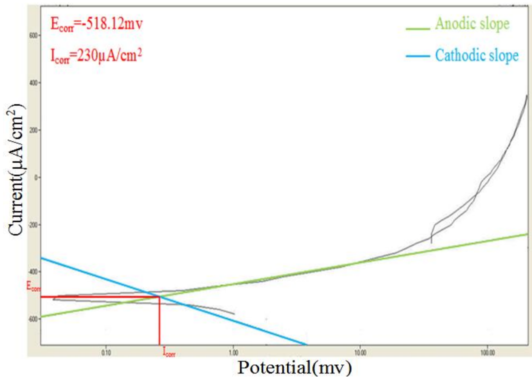

Fig. 3 Polarization curve of Mild steel after LSP with thickness of DDDW = 0

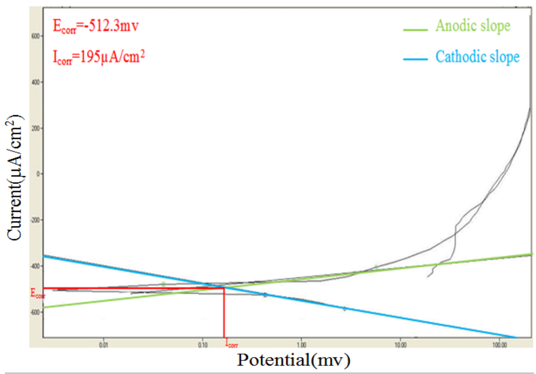

Fig. 4 Polarization curve of Mild steel after LSP with thickness of DDDW = 2 mm

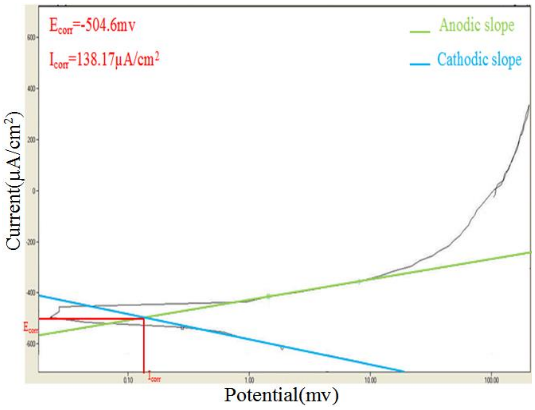

Fig. 5 Polarization curve of Mild steel after LSP with thickness of DDDW = 4 mm

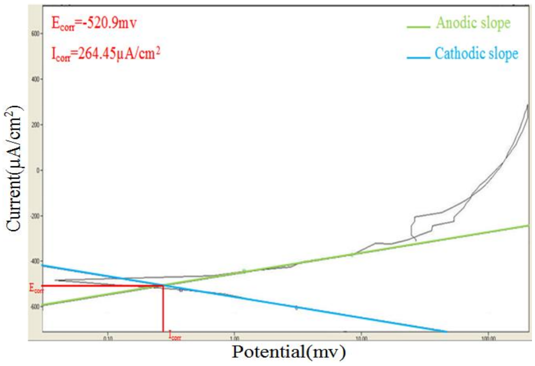

Fig. 6 Polarization curve of Mild steel after LSP with thickness of DDDW = 6 mm

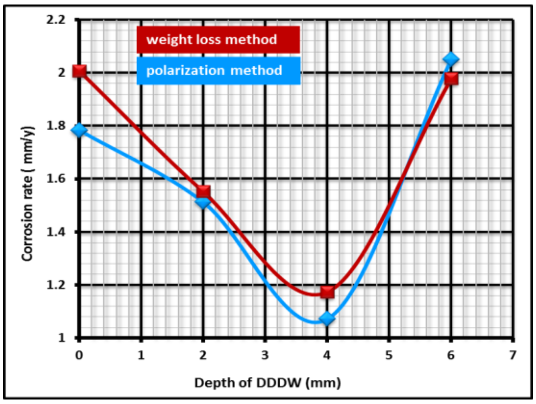

Fig. 7 Corrosion rate as a function of depth of DDDW

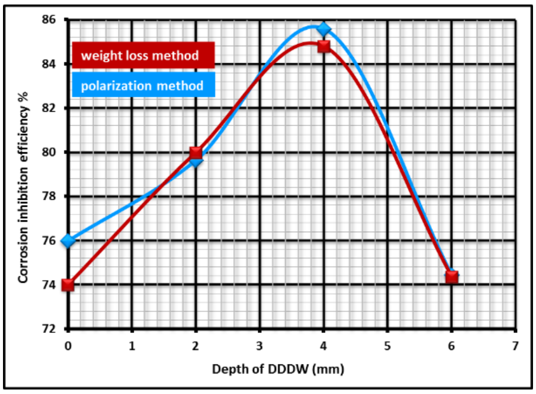

Fig. 8 Corrosion inhibition efficiency as a function of depth of DDDW

3.3 SEM Results

Sample surface suffer from corrosive solutions, The corrosion was carried out by 1 molar HCl. Figs. 9, 10 and 11 represented the samples before corrosion test, samples after corrosion test without LSP and samples after corrosion test with LSP respectively. One can be demonstrated that the pitting corrosion in Fig. 10 is higher than that in Fig. 11. This behavior due to the effect of laser shock peening on the surface of samples.

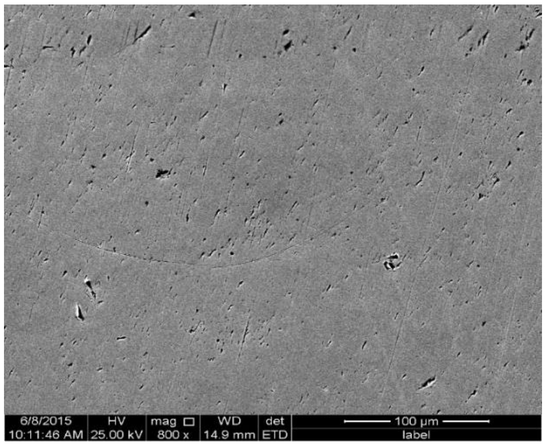

Fig. 9 SEM micrographs of st-37 alloy surface

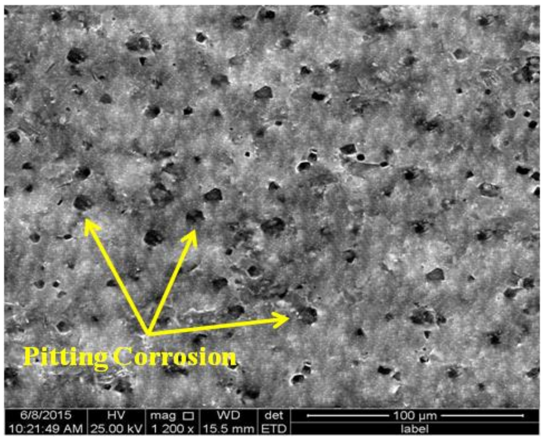

Fig. 10 SEM micrographs of st-37 alloy surface after corrosion without LSP

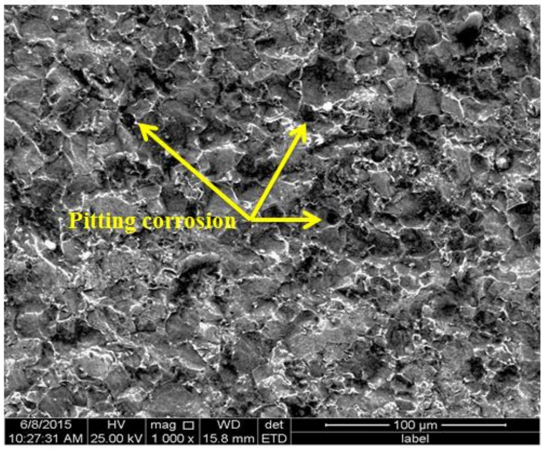

Fig. 11 SEM micrographs of st-37 alloy surface after corrosion with LSP at optimum thickness of DDDW

4. Conclusion

Laser Shock Peening technique is a good technique to modify the surface properties and improve the corrosion resistance thus the corrosion rate decreased from 7.7210 mm/y before LSP treatment to 1.0716 mm/y after LSP treatment at the optimum thickness of confining layer (4 mm). Q-switching Nd:YAG laser is an efficient corrosion inhibitor for st-37 alloy that immersion in HCl of 1 M, the maximum inhibitor efficiency is 85.59%. From polarization curve results show the shifting that occurs in the potential to more positive region after applying LSP as well as the corrosion current is reduced from 958.02 µA/cm^2 to 138.17 µA/cm^2 after using Nd:Yag laser as a corrosion inhibitor.

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