Kufa Journal of Engineering
Vol. 9, No. 2, April 2018, PP. 201-214
Received 3 June 2017, accepted 30 August 2017

ENHANCEMENT OF THE CORROSION RESISTANCE FOR 6009 ALUMINUM ALLOY BY LASER TREATMENT

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http://dx.doi.org/10.30572/2018/kje/090215

ABSTRACT

Using laser in modifying the surfaces of various materials is an important topic in the present time. The type of alloy used in this investigation was 6009Al alloy. Laser has been used as inhibitor to reduce the corrosion rate by using Q-switching Nd: YAG Laser (with changing energy of laser and fixing other parameters) under laser shock peening (LSP) technique for 6009 AA in hydrochloric acid with concentration of 1 M and the immersion time of 30 minutes at room temperature. The corrosion rate was calculated by using the polarization method. The corrosion rate decreased from (0.366 to 0.016) mm/yr before and after using LSP, respectively. Therefore, this study aims to reduce the corrosion rate that occurs in 6009 Al alloy.

KEYWORDS: laser; corrosion; polarization method; laser shock peening

1. INTRODUCTION

The changes that occur in the metal properties from the physical interaction between a metal and its environment were defined as corrosion (Peter, 2011). There are two kinds of corrosion interaction according to the nature of corrosive environments: wet and dry corrosion (Dieter, 2007). These types of corrosion can be classified into: general corrosion; pitting corrosion; crevice corrosion; Inter-granular corrosion; environmentally induced fracture; de-alloying; galvanic, and erosion corrosion; this depends on the morphology of metal's damage (Davies, 2011). Several techniques, such as coating, alloying, cathodic protection, anodic protection, and laser treatment are used to protect metals from corrosion (Grum, 2007). Recently, the laser has been used for surface treatment of metal and considered as the way to improve the properties of metals like roughness, hardness, resistance of corrosion, etc. (Brown and Arnold, 2010; Gujba and Medraj, 2014; Grum et al., 2005; Zhang and Yao, 2002). The surface treatment was based on plasma technology in which increases the hardness of metal surface. Generally, plasma was generated by LSP when front part of the laser pulse interacts with the solid target; it induces plasma plume on the surface of the target, which is suddenly expanded after absorbing rest part of the laser pulse and increasing pressure induced by shock wave. Plasma plume gets cool and hence condense in the form of nanoparticles after losing its energy by expanding against pressure induced by shock wave. Plume also gets condensed on the surface of target and applicable for surface coating of the material. The plasma plume, which dependents on LSP parameters and nature of liquid media (Xiong, 2013, Kubsad, 2012; Al-Amiery et al., 2016; Hussein et al., 2014; Kadhim et al., 2014; Yousif et al., 2015).

2. EXPERIMENTAL WORK

2.1. Sample Preparation

Shape of samples was circular with diameter 20 mm and thickness of 4 mm followed by grinding with different metallographic paper as SiC and Al_4C_3. Additionally, it is refined by polishing paper assistance of Al_2O_3 to polish the surface of samples by using processor polisher machine type (Mopao 160E) to achieve the same surface roughness. Lastly, we cleaned and washed the samples with de-ionized water and ethanol.

2.2. Chemical Compositions

The chemical compositions examination achieved to 6009 AA by using oxford instruments product of Foundry Master Xpert Company.

2.3. Hardness Test

The hardness of all samples measured by utilizing of Vickers hardness testing machine model (HVS-1000) made in Germany. The measurements were made with 4.9N load and 30 sec as a hold time. Three measurements were taken at the impact center of laser spot and averaged to one value.

2.4. Roughness Test

The measurement of surface roughness R_a was made for all samples by using surface roughness measurement instrument type (TR200). Surface roughness measurement was conducted for specimens with and without LSP treatment. Three measurements were taken at the center of laser spot and averaged to one value.

2.5. Experimental Setup

In Fig. 1, the sample (6009 Al alloy) in which had been treated inglorious in deionized water. The Q-switching Nd: YAG laser was used with changing values of laser energy and fixing values of other parameters. The focused laser beam passes through deionized water (as a rather transparent overlay) and reaches the sample surface. When a laser pulse with sufficient intensity collides the surface, the material vaporizes and converts to plasma. The plasma absorbs most of the laser energy, so the fast expanding plasma is trapped between the surface of work piece and the transparent overlay, which both are confining the generated plasma, causes a high plasma pressure that propagates into the material as a shockwave (Mohammad et al., 2017).

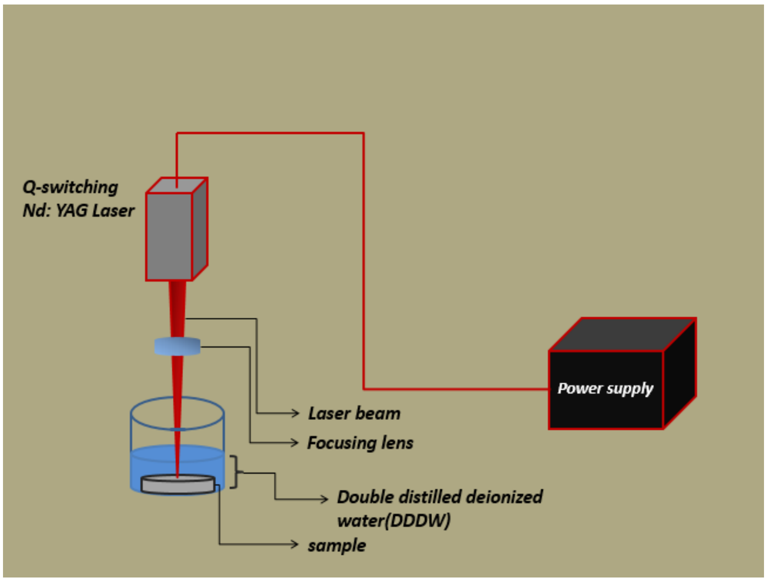

Fig. 1. Experimental Setup of Laser Shock peening.

2.6. Corrosion Test

When inundation the sample in solution of hydrochloric acid of 1 M to 30 min (time) nearly, it will suffer corrosion. The corrosion rate was calculated through the polarization method by using equation (1) (Junaedi et al., 2013; Alobaidy et al., 2015; Al-Amiery et al., 2014a; Al-Amiery et al., 2014b; Lim et al., 2012) as shown.

$$CR(mm/yr) = K1\ icorr.EW/\rho \qquad 1$$

Where K1 is proportionality constant (3.27*10-3 mm g/μA cm yr), CR is the corrosion rate (mm/yr), ρ is the density of metal (g/cm3), icorr is the corrosion current density (μA/cm2) and EW represented the equivalent weight; the equivalent weight and density of 6009 Al alloy were 9.4g and 2.7 g/cm3, respectively (Dean et al., 1971).

In addition, the corrosion current density was calculated from (Dean et al., 1977):

$$icorr. = Icorr./A \qquad 2$$

Where Icorr. is total anodic current (μA) and A is exposed specimen area (cm2) = πr2 , $r(Radius\ of\ exposed\ epcimen\ surface) \cong 0.55\ cm \qquad \therefore A \approx 1cm^2$

Then the efficiency of inhibitor (used laser efficiency) (η) was evaluated from (Lim et al., 2012):

$$\eta(\%) = \frac{CR^O - CR}{CR^O} * 100\% \qquad 3$$

Where CRO is the corrosion rate without inhibitor and CR is the corrosion rate with inhibitor.

2.7. Scanning Electron Microscopy (SEM)

This technique was used to note changes of the internal structure of samples, which were exposed to corrosion in 1 M of HCl solution before and after laser shock peening (LSP) technique by (Inspect S50 FEI Scanning Electron Microscopic).

3. RESULTS AND DISCUSSION

3.1. Chemical Compositions

Chemical compositions examination achieved to know percentages of elements, which make the used alloy. These percentages were compared with standard and concluded that the sample is 6009 Al alloy as shown in table below.

Table 1. Chemical composition of alloy used in this work.

Element	*Mg*	*Al*	*Ti*	*Si*	*Mn*	*Fe*	*Ni*	*Cu*	*Zn*
Wt.%	*0.82*	*97.36*	*0.01*	*0.71*	*0.01*	0.33	0.19	0.29	0.28
Standard values	*≤0.9*	*97.3*	__	*0.7-1.0*	*≤0.03*	__	__	*≤0.35*	__

3.2. Micro-Hardness Results

Vickers hardness method was used to measuring the micro-hardness for all samples before and after laser treatment. The average micro-hardness value before laser treatment about 143.6 Hv for 6009 Al alloy. The measurements after laser processing were varied from 152 Hv to 176.2 Hv according to laser pulse energy. The increasing of laser shock processing pulse energy leads to further refined grain. Therefore, after LSP, the surface micro hardness increases mainly due to dislocation strengthening and grain refinement; this behavior agrees with (Xiong, 2013).

3.3. Surface roughness results

Surface roughness was achieved for all samples before and after laser shock wave treatment. The average of Surface roughness value before laser treatment 0.072 µm for 6009 Al alloy and these the measurements after laser shock wave processing were varied from 0.14 µm to 0.32 µm according to laser pulse energy. This behavior due to the ablation processes which are associated with laser shock wave processing at the samples surface caused by the increasing of laser pulse energy, which agrees with (Veiko et al., 2015).

3.4. Corrosion Rate Results

The corrosion rate results were found at several cases according to different laser energies and what can be noticed through these results that the minimum value of corrosion current (Icorr.) and corrosion potential (Ecorr.) are 1.48 µA/cm2 and -533.1 mV respectively at energy of laser = 1200 mJ.

The three values of energy of Nd: YAG laser were used with fixing other parameters, these conditions listed in Table 2. Figs. 3–5 illustrate the polarization curves that were applied to the sample and the obtained results are demonstrate in Table 3. From these results, we noticed that the reduction occurred in the corrosion current density and the shifting in the potential of corrosion. These results give us index about the corrosion rate and the inhibition efficiency of LSP. Where it caused increasing the pressure generated by the shock wave during laser ablation process, as well as the exposed surface to the laser pulses lead to increase the surface hardness of the sample, so that corrosion resistance will be increased.

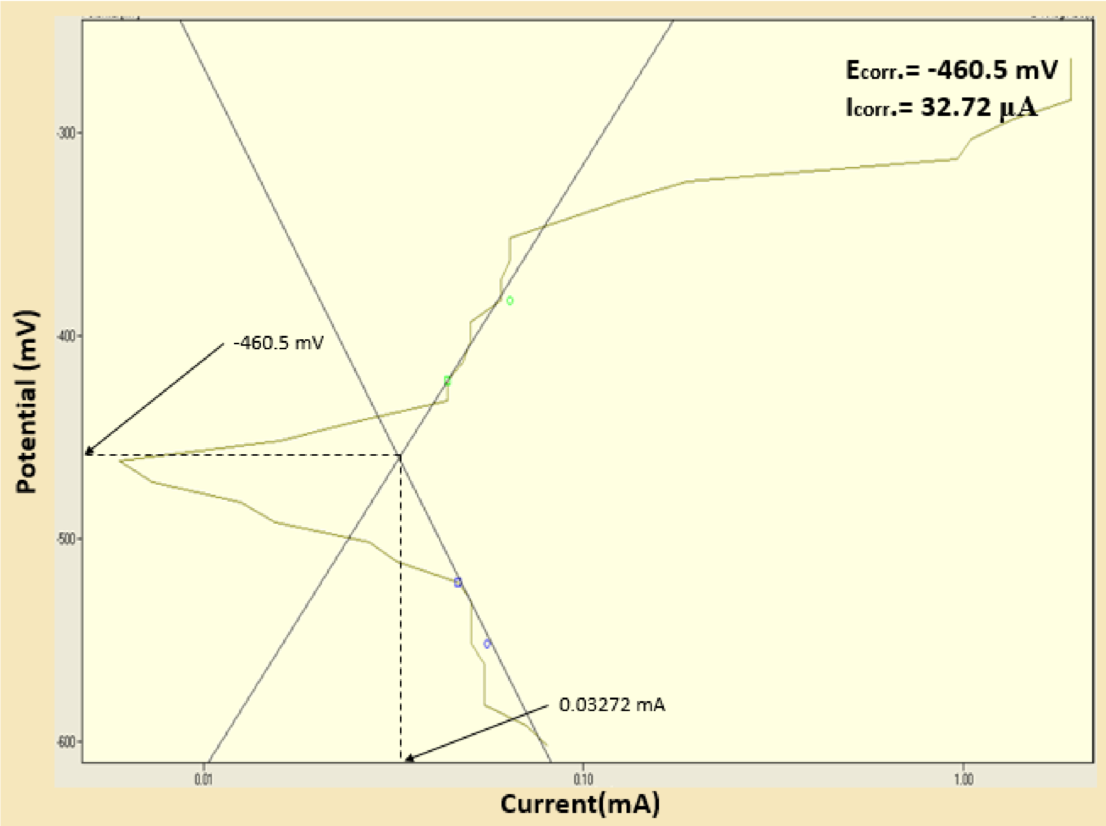

Fig. 2. Polarization curve of sample before LSP.

The corrosion rate decreased from 0.366 to 0.016 mm/yr and efficiency of inhibitor increases from 65.41 to 95.47 % with rise of laser energy as shown in Fig. 6 and 7.

Table 2. LSP conditions with different laser energy at the following fixed parameters.

conditions	values
laser wavelength	1064 nm
pulse repetition rate	1 Hz
No. of pulses	80
spot size	1.2 mm
confining layer	3 mm
Pulse duration	10 ns
Focal length of lens	10 cm
Temperature	25 C^{o}

Table 3. The values of polarization measurement at different laser energy for exposure to 1M of HCl (30 min).

energy of laser (mJ)	icorr ($\mu A/cm^2$)	Ecorr (mV)	ba (mV/dec)	-bc (mV/dec)	Rp ($k\Omega.cm^2$)
800	11.31	-520.7	139.9	33.6	1.040
1000	4.92	-508.4	87.5	58.8	3.103
1200	1.48	-533.1	47.3	58.2	7.655

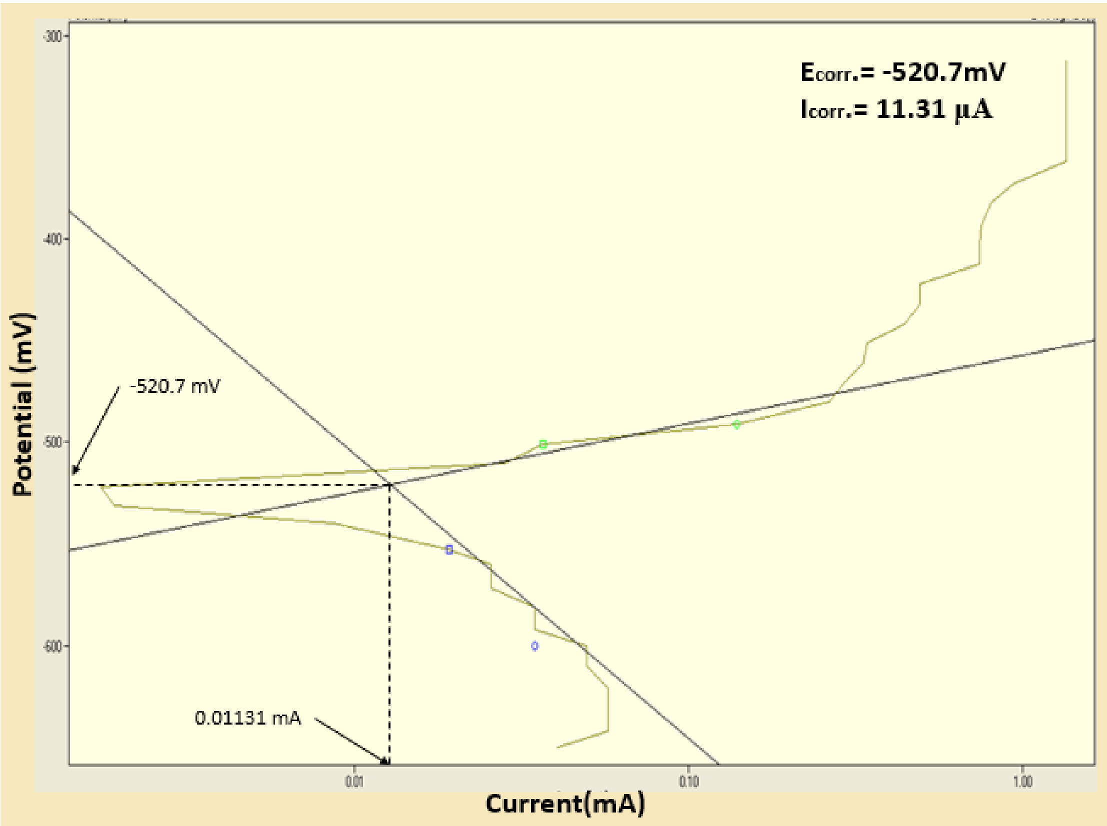

Fig. 3. Polarization curve of sample at energy 800 mJ.

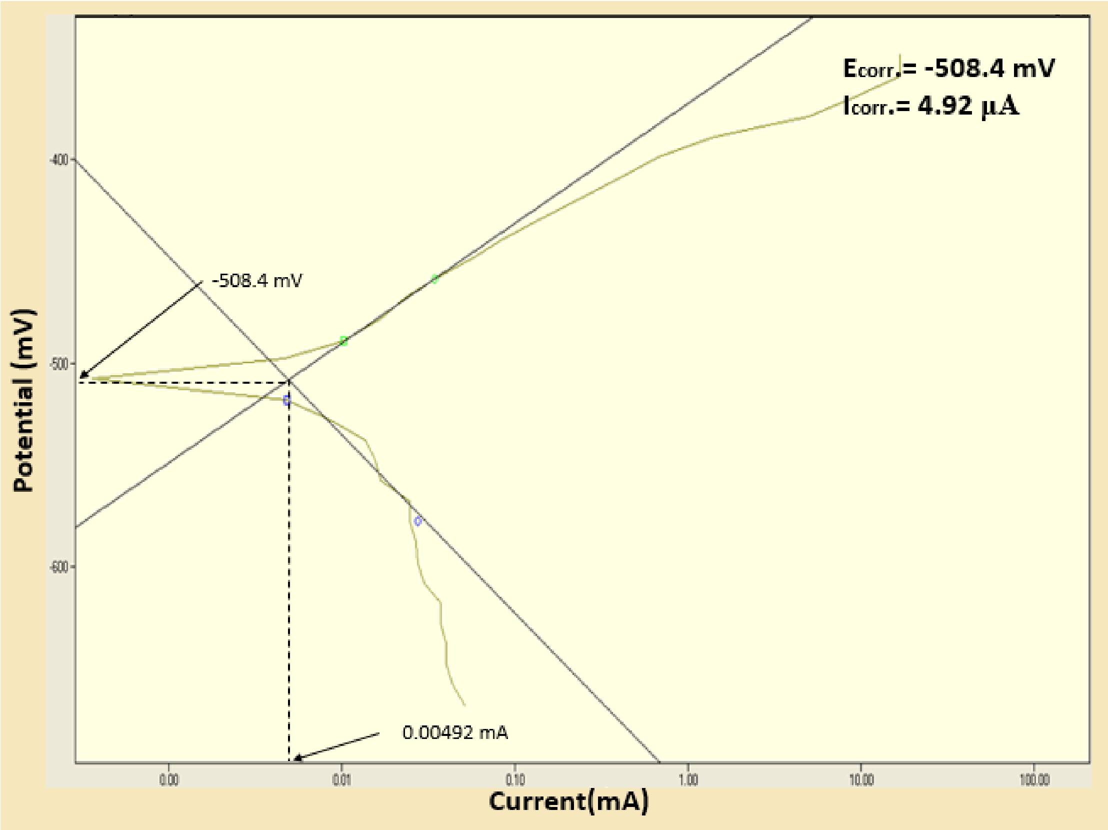

Fig. 4. Polarization curve of sample at energy 1000 mJ.

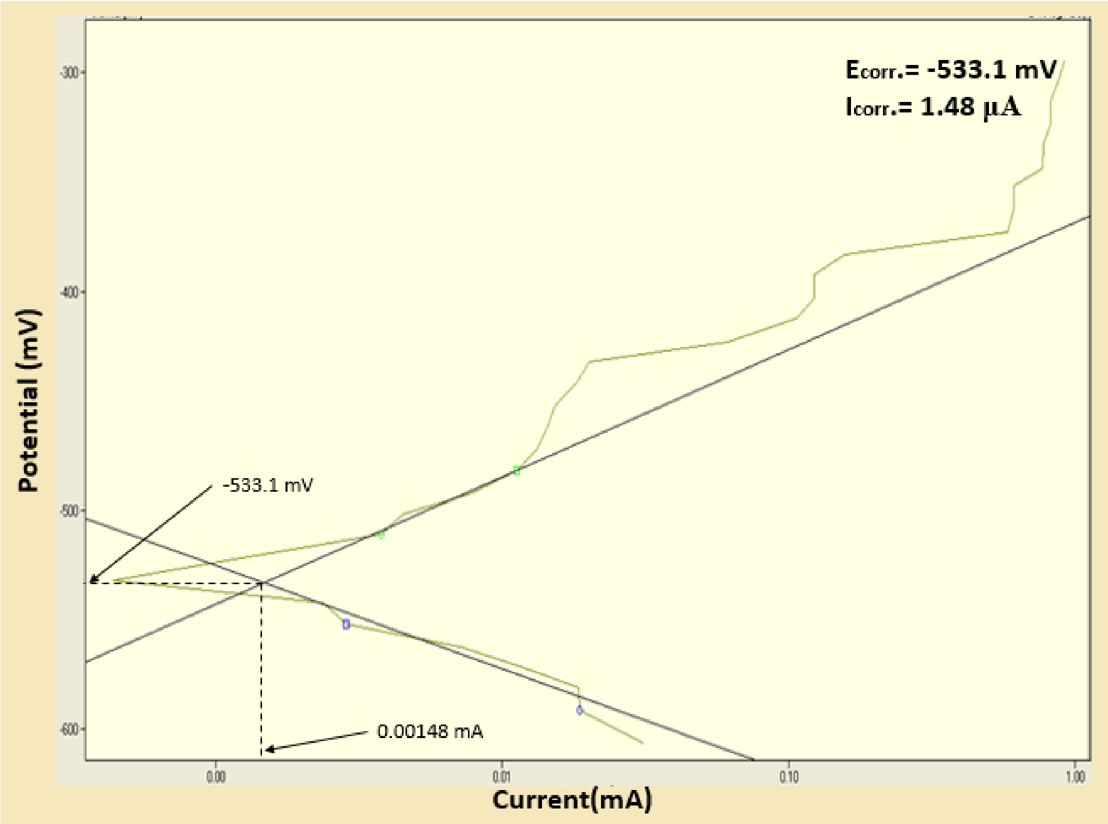

Fig. 5. Polarization curve of sample at energy 1200 mJ.

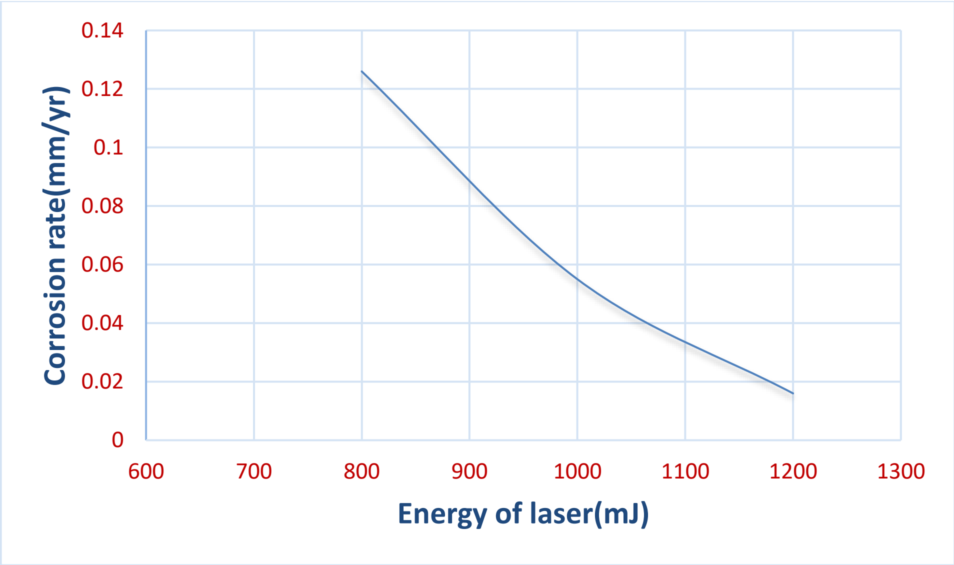

Fig. 6. Corrosion rate as a function of laser energy.

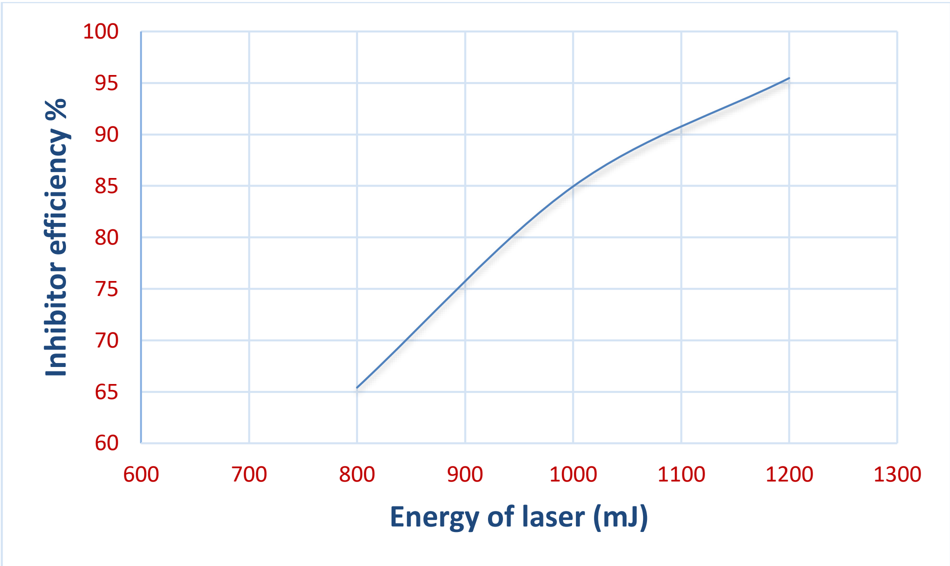

Fig. 7. Inhibitor efficiency as a function of laser energy.

3.5. SEM Results

SEM micrographs of 6009 Al alloy surface before corrosion test, after corrosion without LSP and after corrosion test with LSP were showed in Figs 8, 9 and 10 respectively. One can be demonstrated that the pitting corrosion in Fig. 9 is higher than that in Fig. 10. This is behavior due to the effect of laser shock peening on the surface of samples. After LSP, the corrosion pits seem to be localized mainly in the strongly deformed regions of the surface. The distribution and size of corrosion pits are uniform in surface of LSP treated samples, and the size of corrosion pits is smaller than that without LSP treated. In a word, the electrochemical damage of the surface in 6009 Al alloy with LSP treatment after corrosion test is smaller than that in 6009 Al alloy without LSP treated (Saeed., 2014).

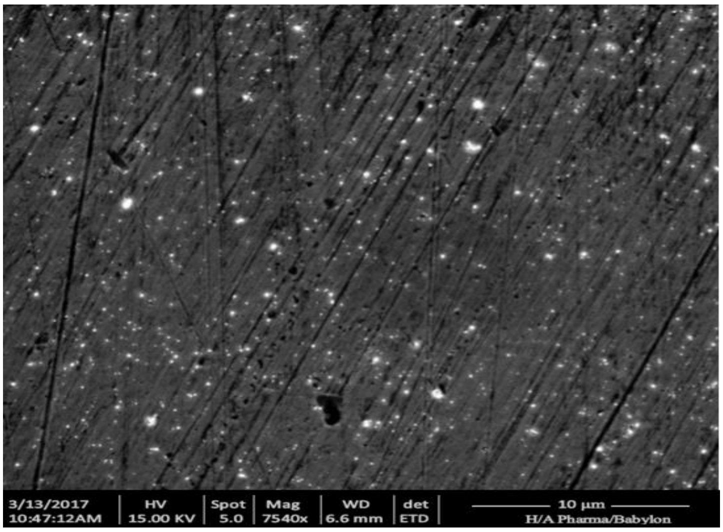

Fig. 8. SEM micrographs of 6009 Al alloy surface.

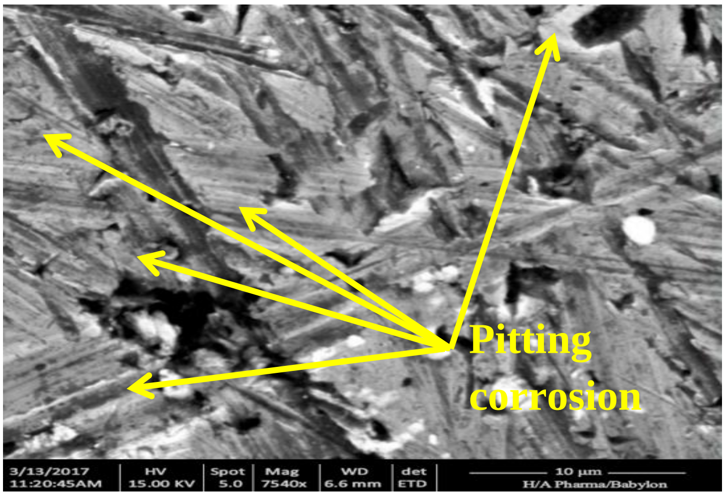

Fig. 9. SEM micrographs of 6009 Al alloy surface after corrosion without LSP.

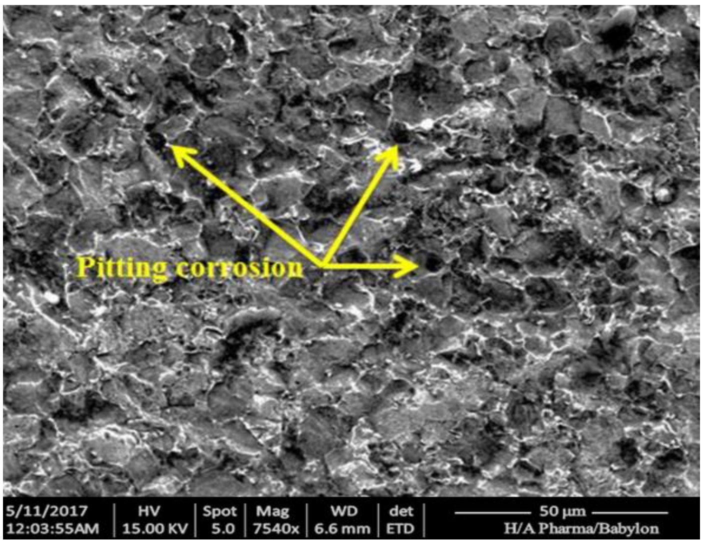

Fig. 10. SEM micrographs of 6009 Al alloy surface after corrosion with LSP.

4. CONCLUSIONS

Laser shock peening technique is a good technique to modify the surface properties and improve the corrosion resistance thus the corrosion rate decreased from 0.366 mm/y to 0.016 mm/y after LSP treatment at the optimum laser energy. Q-switching Nd: YAG laser is an efficient corrosion inhibitor for 6009 Al alloy, which immersed in HCl of 1 M, the maximum inhibitor efficiency, is 95.47%. 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 32.72 $\mu A/cm^2$ to 1.48 $\mu A/cm^2$ after using Nd: YAG laser as a corrosion inhibitor.

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