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"Improvement of Corrosion Resistance of Dental Alloys in oral environment at different temperatures by laser irradiation"

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ABSTRACT

The objective of this study is to demonstrate the corrosion behavior of dental alloys in artificial saliva with pH=5.7 at saliva temperature 37ºC and 40ºC respectively. The Tafel and cyclic polarizations have been investigated by electrochemical measurements. Surface modification by a Q-switched pulsed Nd:YAG Laser with energy 300mJ was achieved for this dental alloy to improve corrosion resistance. The results show that corrosion resistance of dental alloys were increased after laser treatment due to the fact that laser radiation has caused a smoother surface, in addition to the decrement in corrosion current densities (icorr) for this alloy can be seen the improved corrosion resistance of this alloy was attributed to the refinement of its grain sizes and homogenization of its surface elements by laser heating.

INTRODUCTION

Austenitic stainless steels have the appropriate mechanical properties, such as a high ultimate tensile strength and good corrosion resistance, that enable their use on a wide range of technological applications, including orthodontic treatments. (Xiao-Yan ZHANG, *et al.*, 2016) Where Stainless Steel (SS) grade 316L has found numerous and diverse applications in different industries such as automotive, aerospace or many other manufacturing technologies. (Sepehr Razi, *et al.*, 2015) AISI 316L stainless steel is widely used in the medical field as implant materials due to its good corrosion resistance and biocompatibility. Although 316L stainless steel shows extremely good general corrosion resistance, it is nevertheless prone to pitting in the presence of halide ions, particularly the chloride ion. (Kemin Zhang, Jianxin Zou and Thierry Grosdidier, 2006) Where corrosion is the surface disintegration of metals/alloys within specific medium. Some metals basically exhibit high corrosion resistance than others and this can be attributed to several factors like their chemical constituents, the nature of electrochemical reactions itself and others. The corrosion resistance of metals can be defined in terms of its ability to withstand aggressive conditions. This determines to a large extent the operational lifetime of components in service. (Api Popoola, O.E., Olorunniwo and OO Ige, 2014)

Surface heat treatment using laser beam is based on the characteristics of self-quenching that cools rapidly into inside of materials without using cooling medium unlike conventional surface heat treatment. Laser beam provides localized heat input, negligible distortion, ability to treat specific areas, access to confined areas and short cycle times. (Abdel-Monem El-Batahgy *et al.*, 2013) One of the major advantages of the laser as a tool for material processing is the ability to precisely control where in the material and at what rate energy is deposited. This control is exercised through the proper selection of laser processing parameters to achieve the desired material modification. In this section, we discuss the principles and equations that describe the propagation and

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absorption of laser energy and heat flow. (Matthew, S., *et al.*, 2010) There are many authors studied the behavior of dental alloys in artificial saliva to measure the resistance of these alloys toward many materials. (Ataiwi, A.H. *et al*., 2013)

This study aimed to determine the effect of laser surface modification on the corrosion resistance of austenitic stainless steels in artificial saliva.

MATERIALS AND METHODS

Sample Preperation:

316L SS samples with dimensions of 1cm x 1cm x 4mm and then mounting them into epoxy base, thus leaving only one side of specimen area into contact to the test electrolyte. Samples were grinded with successively finer grade of emery papers (up to 1200 grit) and polished using cloth and diamond paste. Then cleaned with ethanol (5min), rinsed with distilled water (3min) and dried have been used for the investigation. Compositions of the samples are investigated by XRF test and tabulated in table (1).

Table 1: Elemental composition of the 316L SS sample

316L SS											
Element	Cr	Ni	Mo	Si	Co	S	P	C	N	Mn	Fe
Wt%	16.82	10.14	2.03	0.55	0.88	0.03	0.03	0.03	0.061	1.51	68.72

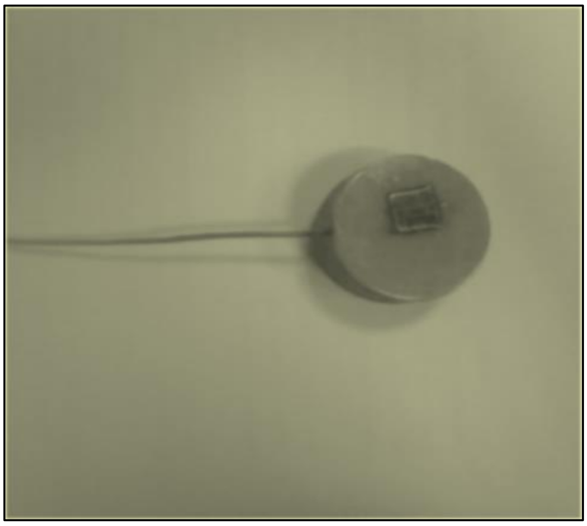

Fig. 1: Shows the photograph of the prepared mounted 316L SS samples.

The laser surface modification was conducted by using a Q-switched pulsed Nd:YAG laser with energy 300mJ. Experimental parameters that were considered for the processing are summarized in this table (2).

Table 2: laser parameters employed during surface processing.

Parameter	Value
Wavelength (nm)	1064
Pulse width (ns)	10
Pulse repetition rate (HZ)	3
Spot diameter (mm)	1
Laser energy (mJ)	300

Corrosion Measurement:

Corrosion tests were carried out using the conventional three-electrode cell containing the work electrode a standard calomel electrode (SCE) as the reference electrode, a platinum sheet as the counter electrode. The standard potentiostatic polarization test was performed in the Artificial Saliva (AS) with pH=5.7 at the saliva temperature of 37°C and 40°C. The samples were immersed in as under open circuit conditions for 0.25h and 0.5h.

Table 3: Composition of artificial saliva.[8]

Composition	Conc.(g/L)
Methyl-p-hydroxybenzoate	2.00
Sodium carboxymethyl cellulose	10.00
KCl	0.625
$MgCl_2.6H2O$	0.059
$CaCl_2.2\ H2O$	0.166

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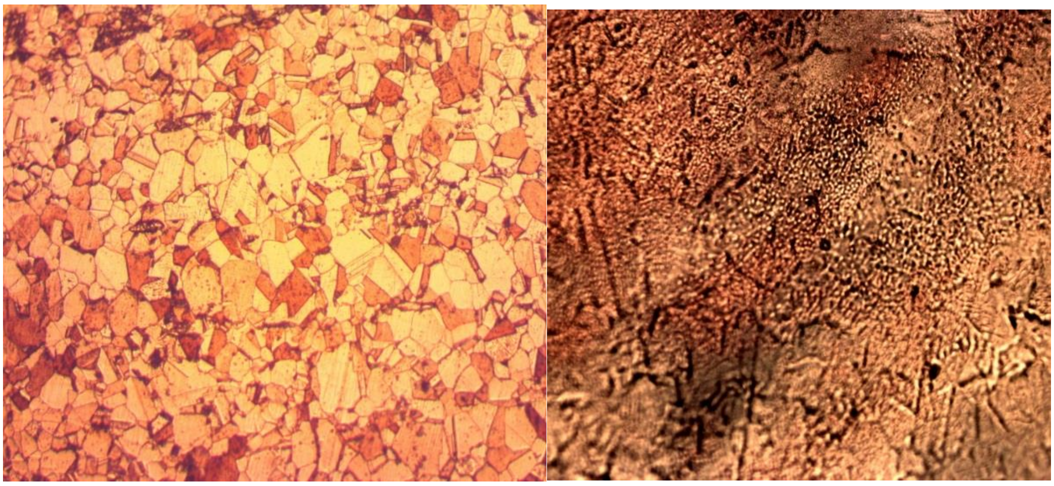
K_2HPO_4	0.804
KH_2PO_4	0.326

After 0.25h and 0.5h in artificial saliva a fairly stable potential could be achieved, and then potentiostatic polarization was carried out at a scan rate of 10 mV/s. The initial scan potential was 3mV/s. The corrosion current density was estimated by tafel extrapolation to the cathodic part of the polarization curve.

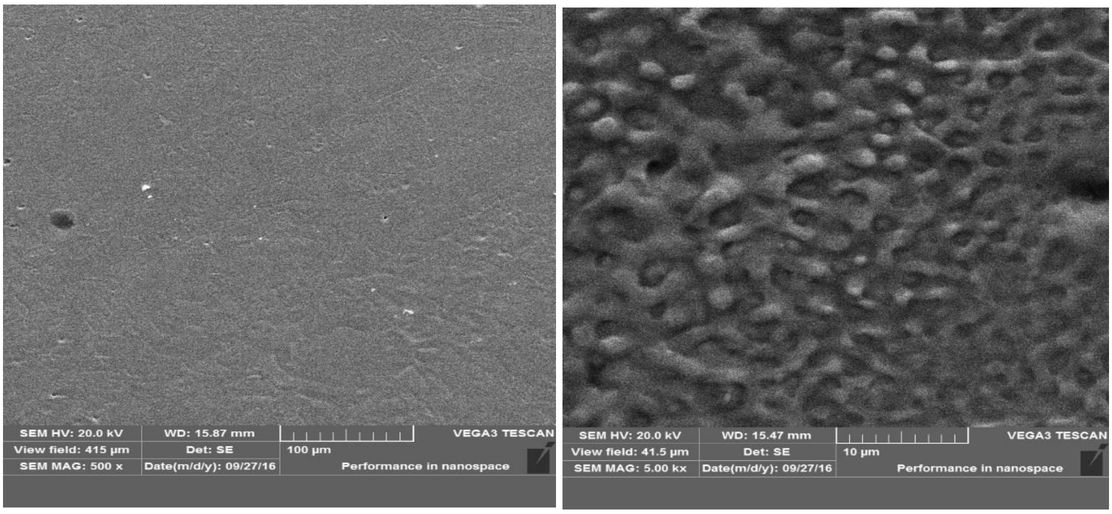
RESULTS AND DISCUSSIONS

This alloy was subjected to optical microscope showed through imaging the dendritic of microstructure for treated alloy was finer than the untreated alloy. Fig (2a) and Fig (2b) represent the surface of the alloy and laser treated layer respectively before electrochemical corrosion tests.



(a) **(b)**

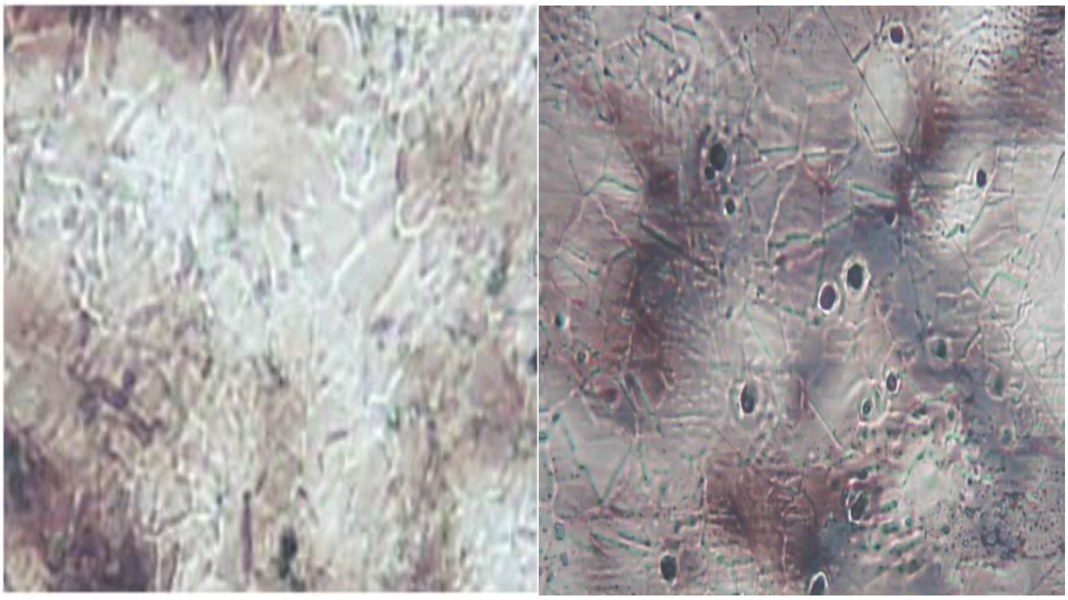
Fig. 2: (a) As its microstructure of 316L SS (20x). (b) Microstructure for treated alloy(20x).



(a) **(b)**

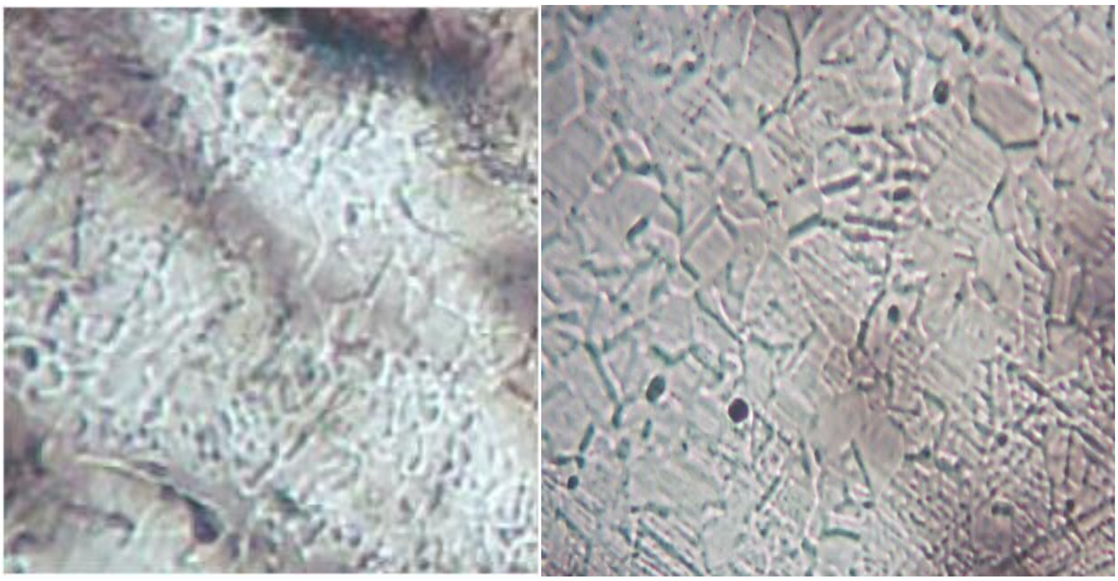
Fig. 3: (a) SEM before laser surface treatment. (b) SEM after laser surface treatment with energy 300mJ.

From fig (3a) and (3b) the morphology of the base material and of the laser treatment was observed. The result was pointed out the spot size of the laser on the surface of stainless steel which is less than 0.5mm after polishing.



(a) (b)

Fig. 4: Micrographs of specimens of stainless steel 316L (40x)
(a): Specimen surface before laser treatment at 37^{o}C.
(b): Specimen surface before laser treatment at 40^{o}C.



(a) **(b)**

Fig. 5: Micrographs of specimens of stainless steel 316L (40x):
(a): Specimen surface after laser treatment at 37^{o}C.
(b): Specimen surface after laser treatment at 40^{o}C.

From fig (4b) and fig (5b) noticed there are Pits different in shape and size, are seen on the surface of all samples after electrochemical tests. It should be mentioned that the number of the pits observed on the untreated samples was greater than treated alloy.

The Tafel plot shows the electrochemical reactions of this alloy in artificial saliva, at cathodic site, the reduction of hydrogen take place according to the following equation due to the acidity of medium:

$2H^+ + 2e \rightarrow H_2$

While at anodic sites, the dissolution of metals can occurs according to their activity as follow:

$Ni \rightarrow Ni^{+2} + 2e$

$Cr \rightarrow Cr^{+2} + 3e$

$Mo \rightarrow Mo^{+3} + 3e$

Corrosion Rate (CR) can be calculated by using the following equation:

CR (mpy) = 0.13 × icorr × [e/ρ] (1)

Where:

icorr: corrosion current density (μA/cm2).

e: atomic weight.

ρ: density (gm/cm^3).

The polarization resistance (Rp) can be determined from the tafel slopes and according to Stern- Geary equation [9].

$$Rp = \frac{bc*ba}{2.3*icorr\,(bc+ba)} \quad (2)$$

Where :

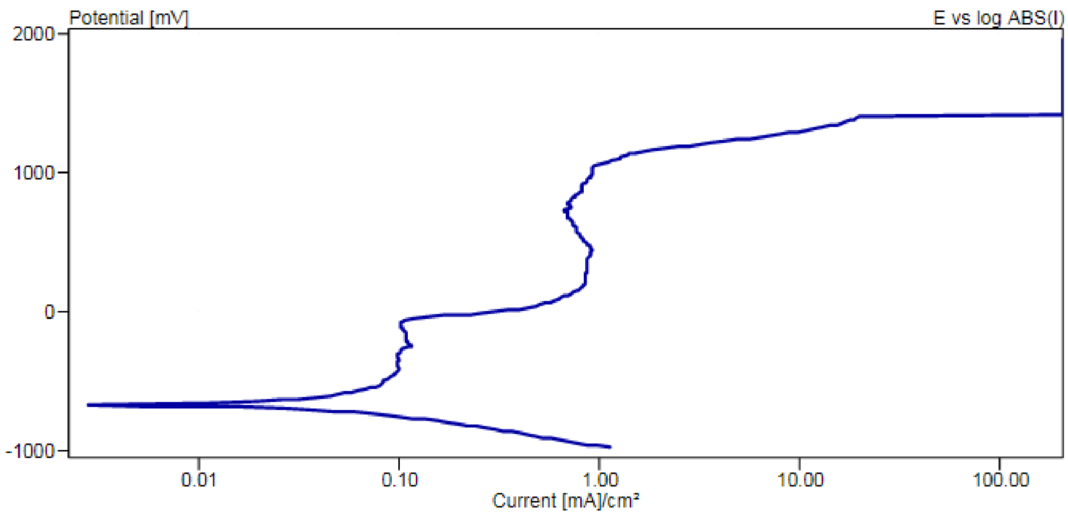
Rp: polarization resistance (Ω.cm^2).

bc and ba: cathodic and anodic Tafel slopes respectively.

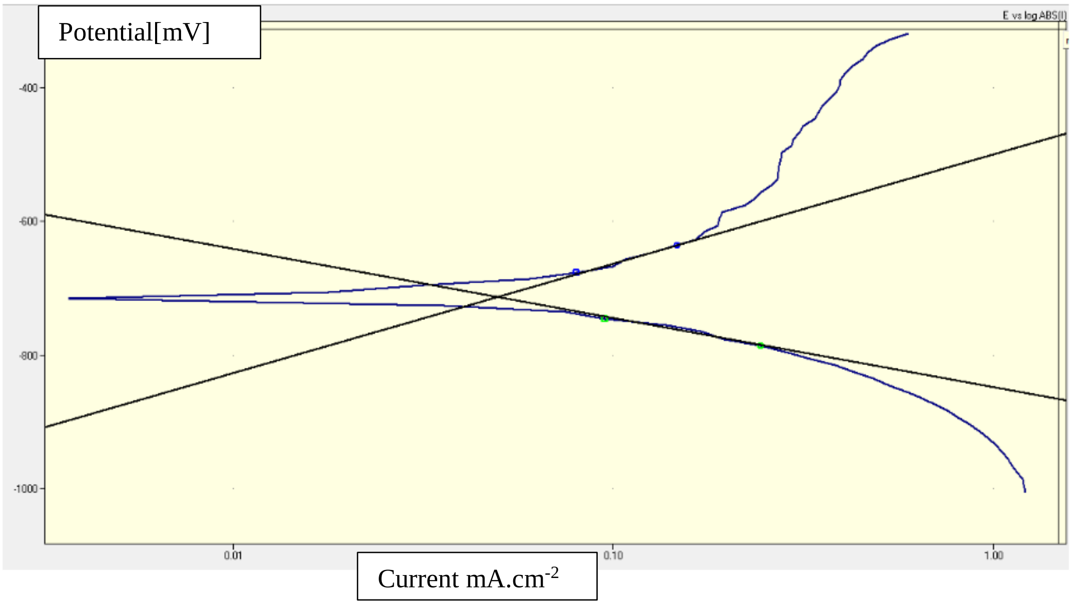
Table 4: Corrosion parameters of dental alloys in artificial saliva at pH=5.7.

Alloys (316L)	Temp	-Ecorr (mV)	icorr (μA.cm^{-2})	Rp x10^3 (Ω.cm^2)	CR (mpy)
Sample As its	37ºC	666.2	18.8	1.6475	7.8
	40ºC	713	49.7	0.5547	20.6
Treated alloys with energy 300mJ					
Sample treated	37ºC	563	3.27	0.1329	1.3567
	40ºC	346	1.23	23.478	0.5476

The presence of Cr improves the corrosion resistance of alloys in a corrosive environment due to the formation of a Cr-rich, passive oxide film which is highly resistant to acid attack. Similarly, presence of molybdenum in the Ni-Cr based alloy increases the resistance to localized corrosion in the chloride containing environment. Therefore for Ni-Cr based dental alloys the addition of 12% Cr (minimum value) and 2-5% Mo to the alloy bulk is well recommended from the corrosion resistance point of view. (Haitham Alobaidi and Muna Abbass, 2014; Mohit Sharma, A.V., *et al*., 2008).

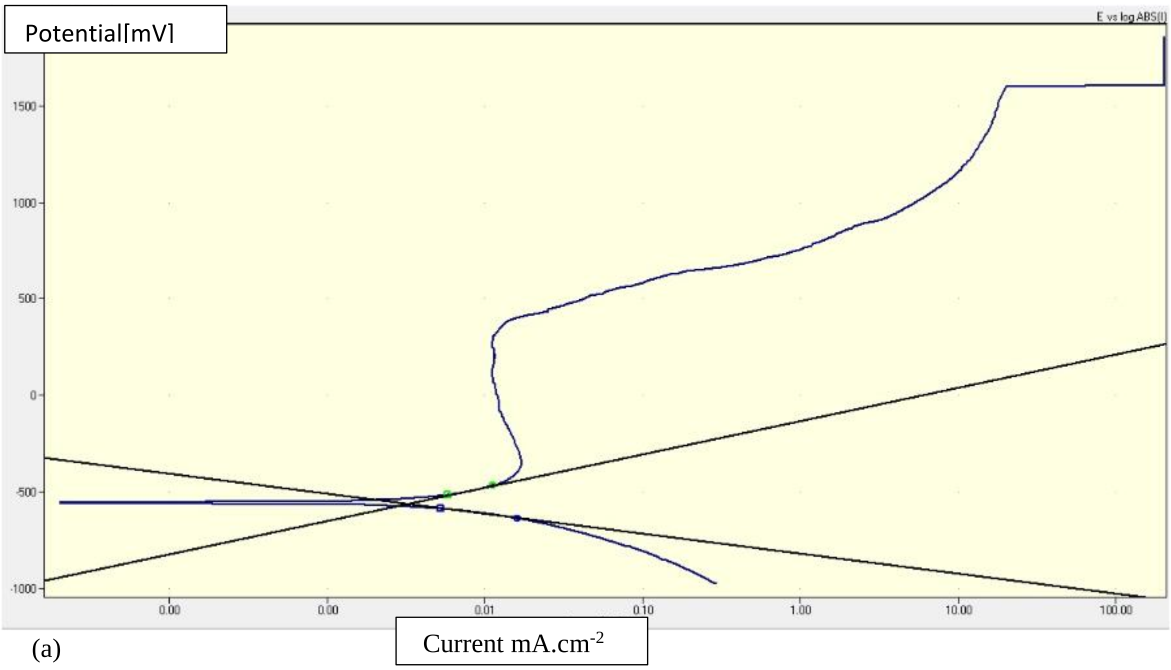


(a)



(b)

Fig. 6: Tafel plots before laser treatment with temperature (a) 37ºC (b) 40ºC



(a)

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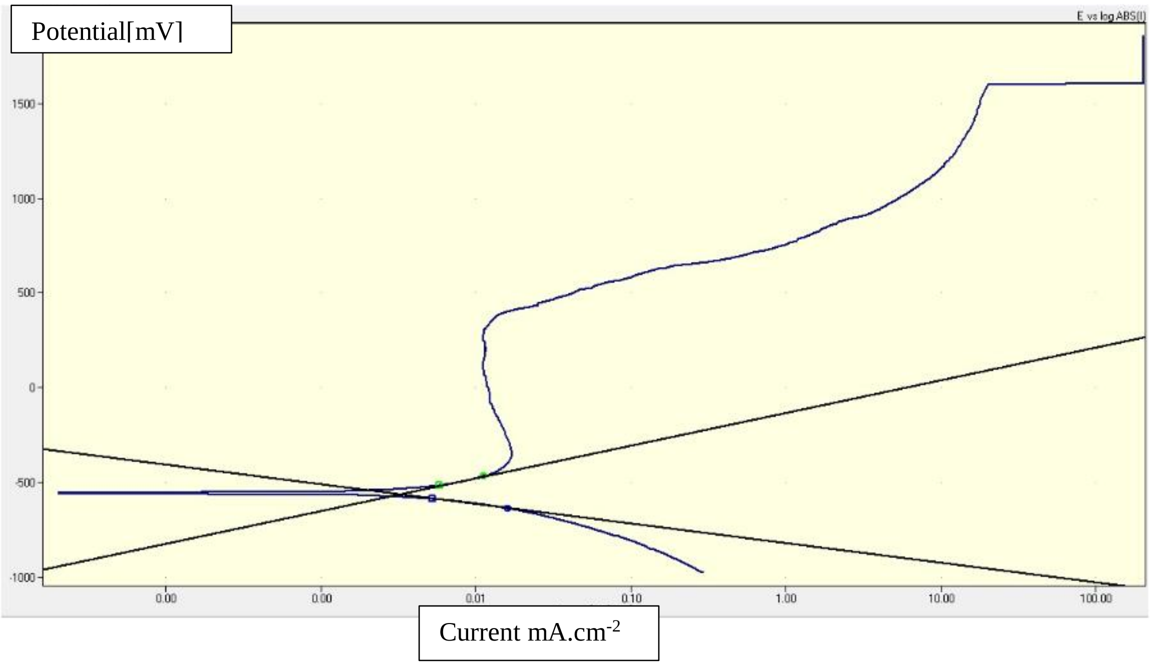
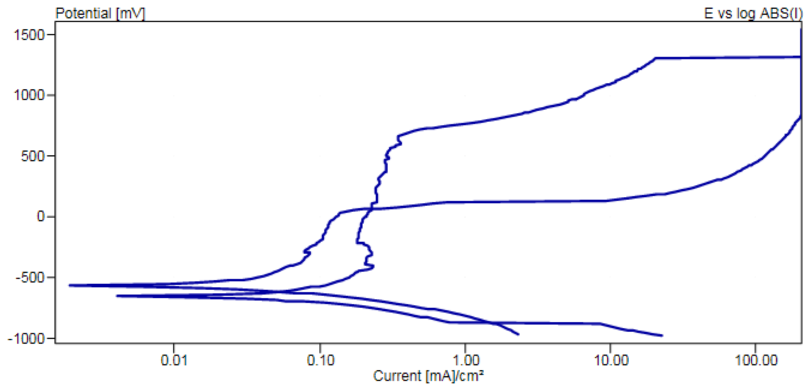


Fig. 7: Tafel plots after laser treatment with 300mJ at temperature (a) 37ºC (b) 40ºC.



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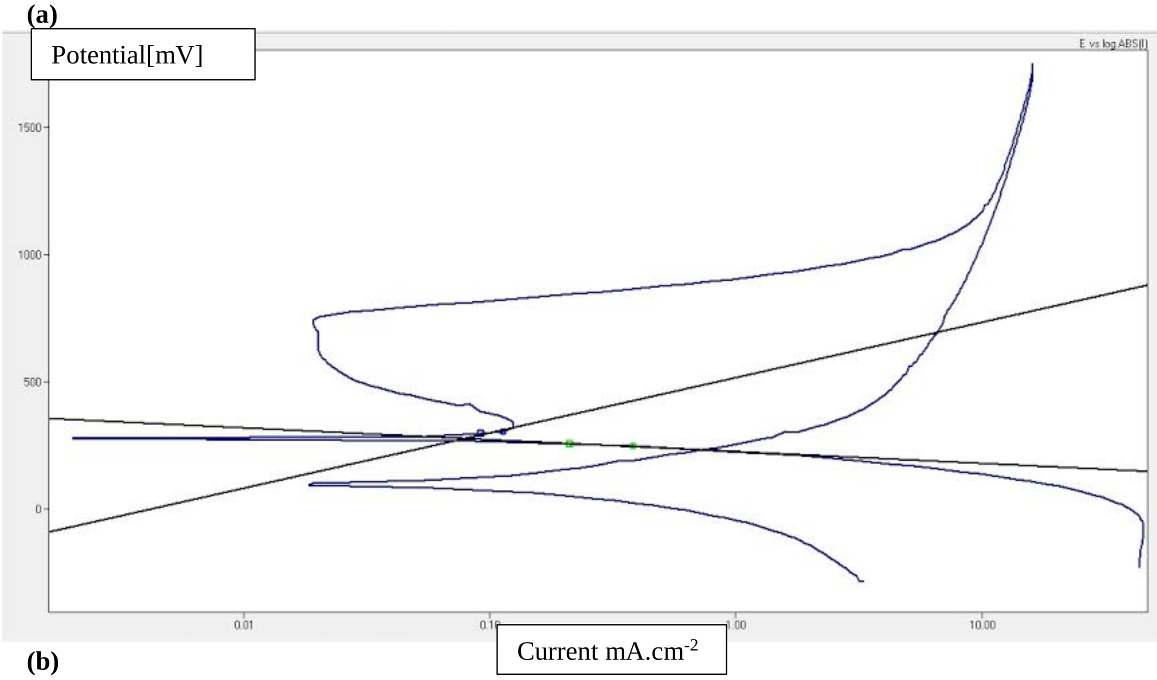
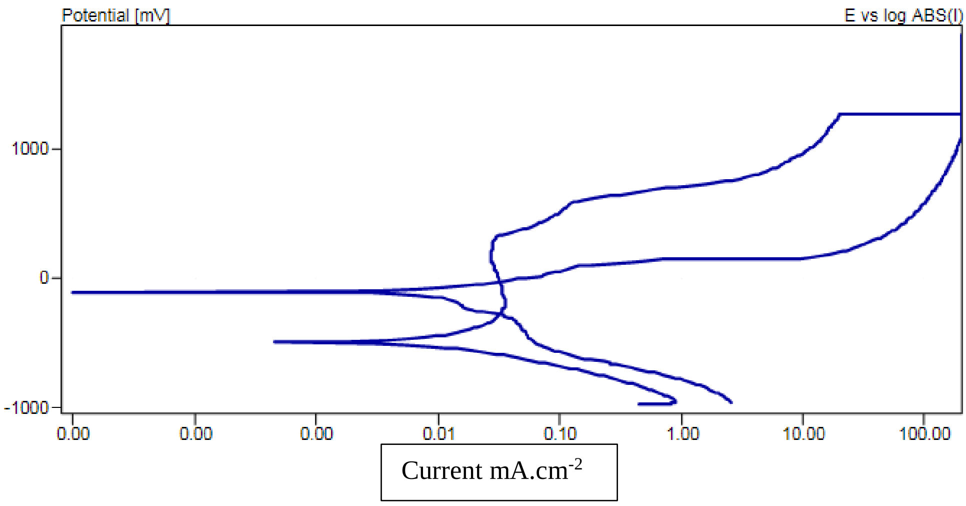
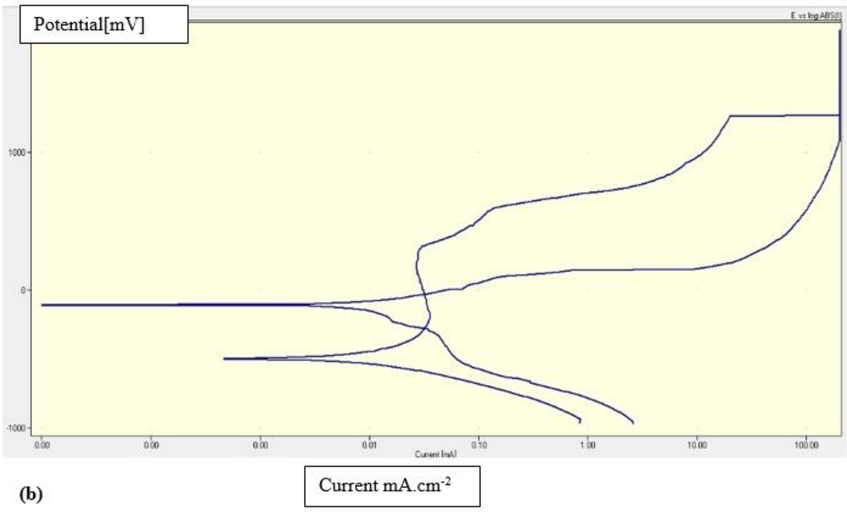


(b)

Fig. 8: Cyclic plots before laser treatment with temperature (a) 37ºC (b) 40ºC.



(a)



(b)

Fig. 9: Cyclic plots after laser treatment with 300mJ at temperature (a) 37ºC (b) 40ºC.

Conclusion:

From the results of corrosion of dental alloy shows an increasing in corrosion with increasing the saliva temperature (from 37 ºC to 40 ºC) for untreated sample, while samples that irradiated by laser have high corrosion resistance even at increasing saliva temperature. This is refer to laser energy used in this work gave agood surface modification for the samples which were decreased the ability of metal for corrosion and also decreased in corrosion rate (CR) and current density (icorr).

The improved corrosion resistance of 316L was attributed to the refinement of its grain sizes and homogenization of its surface elements by laser heating.

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