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RESEARCH ARTICLE

INVESTIGATION OF SURFACE TREATMENT OF 413 ALUMINUM ALLOY BY HIGH ENERGY ELECTRON BEAM AND ITS EFFECT ON CORROSION BEHAVIOR

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ABSTRACT

Dengue High energy electron beam was used to treat the Al surface. Electron beam irradiation produces an ultra-fast cycle at the surface which results in deep subsurface hardening (about 100 μm) which improves corrosion and wear resistance. Analysis of top surface of Al showed shock hardening and condensation of chemical species. Electrochemical characterization of treated Al surface in 3.5% NaCl solution showed an increase improvement in uniform and pitting corrosion in comparison to untreated samples.

INTRODUCTION

Increasing attention has been paid towards Mg, Al, and Ti-based alloys in the past few decades due to their low density and high strength/ductility ratio. Attempts have been made to replace steels by light alloys in industrial components. However, light alloys suffer some serious surface-related disadvantages like poor wear or corrosion resistance which strongly have been limited their potential for use in specific industrial applications. Therefore, to improve their surface performance from such deficiency, surface treatment techniques must be applied on their surface. One of the new surface modification techniques is by use of high-energy electron beam (HEEB) which first was developed by Russian scientists (Proskurovsky *et al*., 1997; Proskurovsky *et al*., 1998 and Ozur *et al*., 2003). This technique has an advantage over pulsed laser and ion beams due to its high efficiency, simplicity, and reliability. Other advantages of this technique are formation of thermal stress and stress waves (Proskurovsky *et al*., 2000 and Qin *et al*., 2009) which as a result improves surface properties of materials which is unattainable with other surface treatment methods. This is especially true for tribological (Proskurovsky *et al*., 1998; Proskurovsky *et al*., 2000; Gao *et al*., 2005; Zou *et al*., 2010) and corrosion properties (Zou *et al*., 2010; Zou *et al*., 2006; Zhang *et al*., 2006 and Zhang *et al*., 2006). Findings by other investigators showed that use of high energy electron beam treatment on Ti based alloys caused an increase in corrosion and strength properties of treated alloys. More research has been done on effect of surface treatment by high energy electron beam on Ti (Zhang *et al*., 2011), pure Mg (Zhao *et al*., 2008 and Zou *et al*., 2005), and Mg alloys (Gao *et al*., 2005; Gao *et al*., 2005 and Gao *et al*., 2007). The main impetus of this work is to investigate the effect of surface treatment of Al by High energy electron beam and its effect on corrosion behavior of Al in 3.5% NaCl solutions.

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Experimental Procedures

The composition of 413 aluminum alloy used are shown in Table 1. Samples of 413 aluminum alloys were initially cleaned chemically and then were irradiated with10MeV electron energy. Some irradiated and non-irradiated samples were cut in dimensions of $2x2x1cm^3$ for electrochemical tests and some for examination of surface morphology. Surface microstructures of irradiated and non-irradiated samples were examined using Scanning Electron Microscope (SEM). To evaluate the corrosion behavior of irradiated and non-irradiated samples in 3.5% NaCl solution, electrochemical impedance spectroscopy (EIS) cyclic anodic polarization and open circuit potential as a function of time techniques were employed. In EIS Techniques, before running the test the open circuit potentials of samples were allowed to be stabilized with respect to saturated calomel reference electrode and then the experiments were conducted with amplitude of 10 mv and frequencies ranging from 0.1 up to 100 KHz.

Table 1. Elemental composition of 413 aluminum alloy

Elements	Al	Sn	Pb	Ni	Cr	Ti	Zn	Mg	Mn	Cu	Fe	Si
Percent	86.7	0.06	0.008	0.09	0.006	0.009	0.07	0.11	0.04	0.057	0.28	12

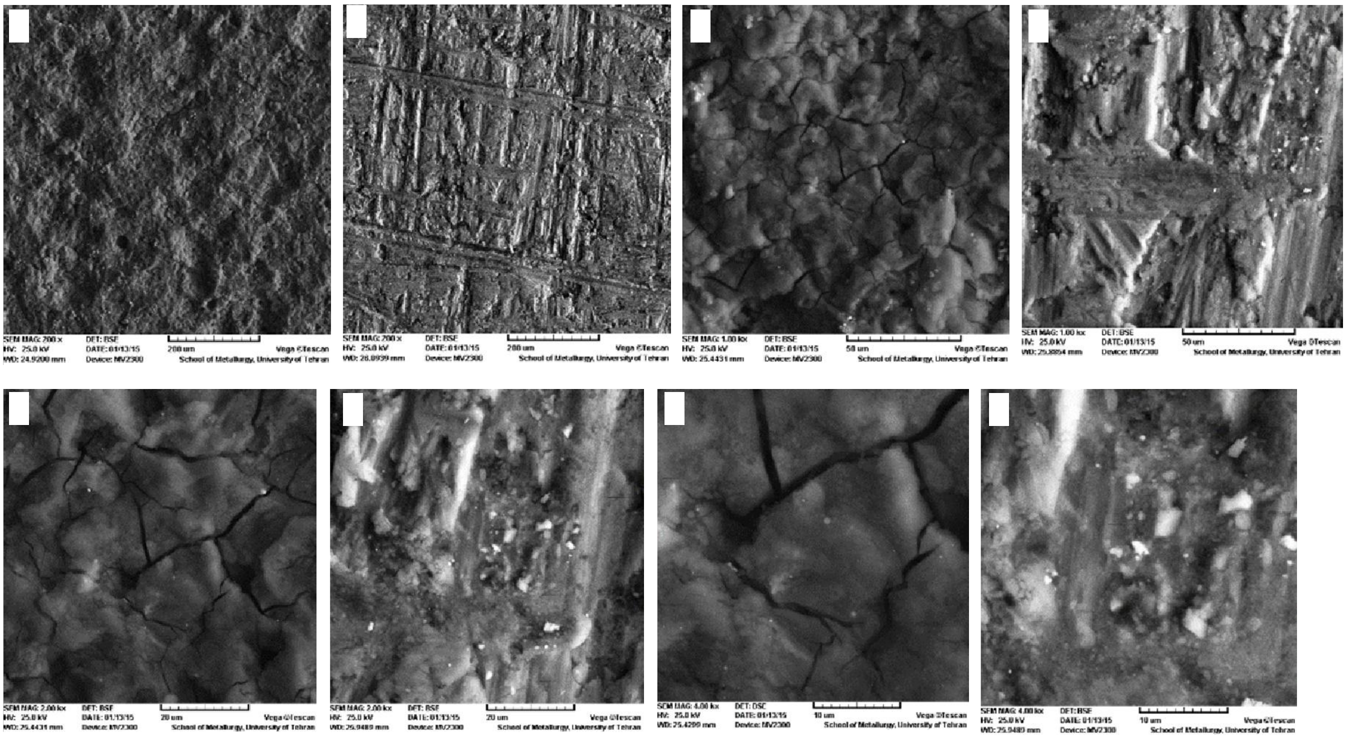

Fig. 1.

Cyclic anodic polarization (CAP) experiments were carried out from -.8 volt vs open circuit potential up to 1.5 volt with respect to SCE with scan rate of 0.1 mv/sec and then reversed until the reverse scan intersects with the forward curve. In this experiment a standard cell with three electrodes one as a counter and another as a working and the third one as a reference electrode were used. From the obtained curves, corrosion rates and resistance polarization and capacitance were calculated and the pitting parameters were obtained.

RESULTS AND DISCUSSION

Figure 1 is SEM images for irradiated and non-irritated samplesin different magnifications. A comparison for irritatedand non-irritated samples from SEM images reveals that the high density electron of short durations induce dynamic field in the surface layers giving rise to superfast shock and possible moving dislocation. This is evident from the crack on surface of the irradiated samples. This may be followed by a rapid solidification and cooling of materials surface. In addition, a dynamic stress field may be formed that caused an intense deformation in material sub-layers. As a result, non-equilibrium microstructure may be achieved. This kind of result was also found by the work of (Dong *et al*., 2003 and Zou *et al*., 2004). When an electron beam with a certain energy density irradiates a target surface several phenomena take place at the surface layer of target. The electron beam may penetrate only a very shallow depth, for example about several micrometers when the electron energy is about several tens of keV. Therefore, the energy absorption is only limited within this thin surface layer through interactions of electrons and atoms, and the scattering process mainly converts the electron beam energy into heat. In the energy deposition layer, about 75% to 85% of the electron energy is transferred into shock and the rest in different ways. The energy deposition in the top surface layer creates an extremely high temperature gradient. After the shut off of the electron beam, depending on different threshold shock of a given material, a layered structure may form on the heated material. It is well known that three different zones are usually observed in the surface depth of HEEB treated sample (Zou *et al*., 2004 and Qin *et al*., 2004). A schematic illustration of these zones created by HEEB treatment is shown in Fig. 2. Generally at top surface is a zone that has been shocked. It is often a few μm in thickness but can be avoided for high conductivity alloys when energy provided by electron beam is not sufficient high. Below the top surface is shock affected zone (SAZ) that extends generally over a few tens of μm (Qin *et al*., 2004). Figure 3 is a nyquist plot of electrochemical impedance spectroscopy (EIS) for the irradiated and non-irradiated samples in 3.5% NaCl solution.

The results on this figure shows that the irradiated sample has much larger impedance than the non-irradiated sample which is an indicative of more corrosion resistance for the irradiated sample than that of non-irradiated sample. Figure 4 is a typical equivalent circuit for the irradiated sample that from this fit, the kinetic parameters for this sample was calculated and shown in Table 2.

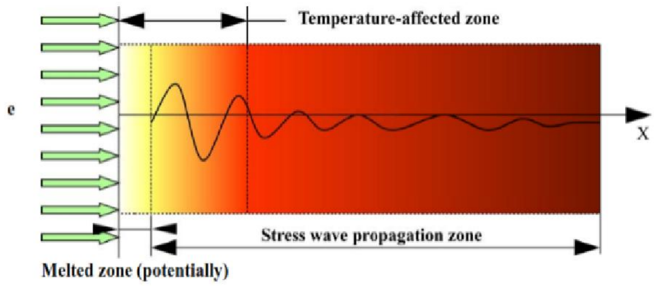

Fig.2. Schematic diagram of different affected zones bombarded by HEEB treatment

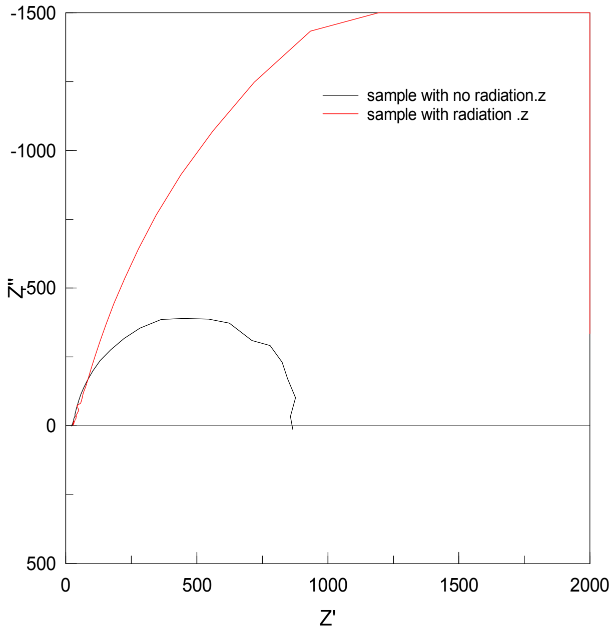

Fig.3. A comparison between the nyquist plots for irradiated and non-irradiated 413 aluminum alloysamples in 3.5 % NaCl solution

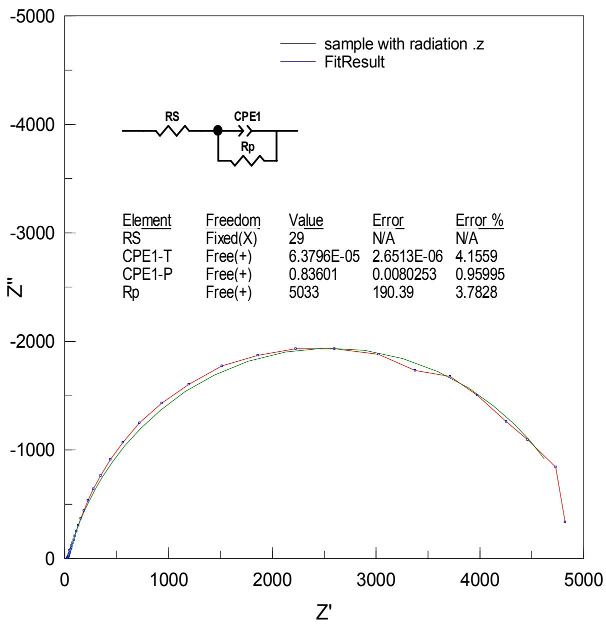

Fig.4. Equivalent circuit for irradiated 413 aluminum alloysample

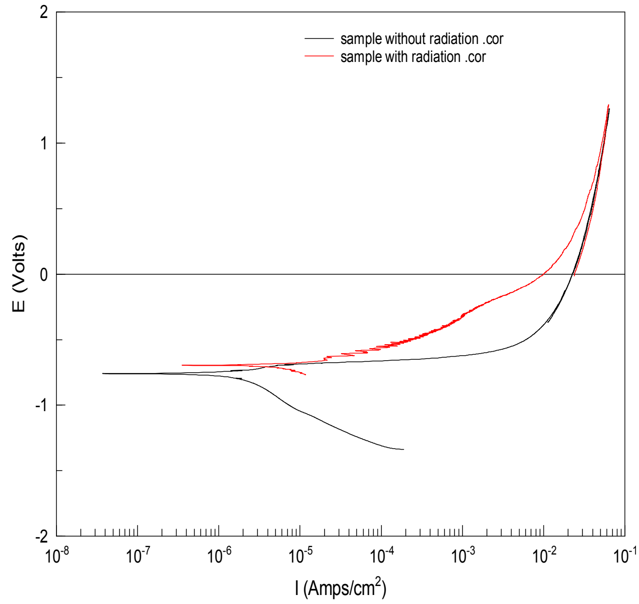

Fig.4. A comparison of cyclic anodic polarization curves for the irradiated and non-irridiated 413 Al alloysamples in 3.5% NaCl solution

Table 2. Kinetic parameters for the irradiated and non-irradiated 413 aluminum alloysamples calculated from equivalent circuit

Sample	R_p, ohm	C, Farad
Irradiated	5033	$6.38x10^{-5}$
Non-irradiated	904	$8.2x10^{-5}$

The R_p value for the irradiated sample is much larger than the non-irradiated sample which means that the irradiated sample are more resistant to corrosion than that of non-irradiated sample. It seems the microstructure formed by irradiation on sample surface has a significant effect on its corrosion behavior. Anodic cyclic polarization curves also show that the irradiated sample has lower current density than that of the sample without irradiation which is an indicative of more corrosion resistance for the irradiated sample. This result is in good agreement with the results obtained from EIS. The surface layer of the sample as a result of irradiation changes from original microstructure to different microstructures which are more corrosion resistance than that of the sample with no irradiation.

Conclusion

Based on the results obtained from this study the following conclusion can be drawn:

- Irradiation of 413 Al alloy caused the energy deposition in the top surface layer to create an extremely high shock gradient. After the shut off of the electron beam, the energy absorbing layer was shocked down rapidly as a result of the heat conduction through the region adjacent to the heated layer which caused the microstructure of the sample to change.
- The change in microstructure due to irradiation caused the sample to be more resistive to corrosion.

- The R_p values obtained for the irradiated sample was much higher that non-irridiated sample which was a good sign for corrosion resistance for the irradiated sample.

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