Electrochemical, microstructure and XRD study on surface modification effects of laser-treated carbon steel

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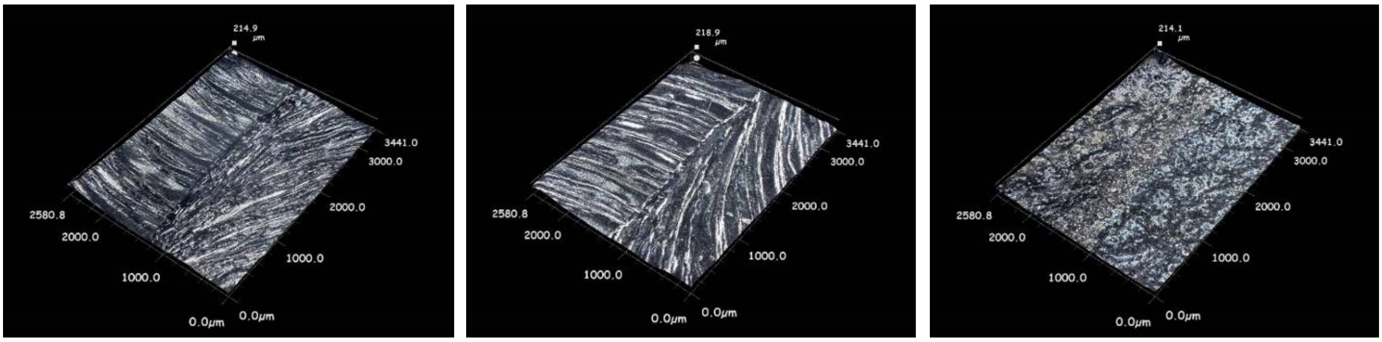
1. Introduction Traditional surface preparation for steel structure including abrasive blasting and chemical method, but both are difficult to reach desirable surface cleanliness. Laser cleaning has found successful applications in automotive, shipbuilding and artwork conservation, yet haven't applied in the construction field. The effects of laser beam including ablation and evaporation, have been expected to remove corrosion products and contaminations on the corroded surface completely.

In this study, Polarization curves of laser-treated carbon steel plate were tested to reveal the effect of laser irradiation on electrochemical properties of carbon steel plate, and surface chemical composition was identified using X-ray diffraction (XRD). The correlation between corrosion resistance and laser treatment was established.

2. Specimen and test method In the surface treatment procedure, continuous wave laser beam was rotated by prism inside the laser machine and projected to the steel plate as a fixed diameter laser ring, then irradiate the whole steel plate surface with laser ring under given velocity and direction. To ensure laser-treated steel plate reached complete surface cleaning, the adjacent laser ring was overlapped in ring width, and each parallel laser path was overlapped in ring diameter. Carbon steel plate with dimensions of 150×70×9 mm was prepared for surface treatment. There was a thin mill scale on the surface of as-received carbon steel plate, thus abrasive blasting was carried on the specimens before laser irradiation to remove the rust layer and provided similar surface conditions. The output energy during laser treatment divided by irradiated area was defined as energy density. Basing on recent researches[1] and for the purpose of applying high power laser to improve treatment efficiency, three different energy density of 3077, 1739 and 600 J/cm^2 were adopted in the laser irradiation procedure and classified into Laser-A, Laser-B and Laser-C, as shown in Fig.1.



(a) Laser-A (3077 J/cm^2) (b) Laser-B (1739 J/cm^2) (c) Laser-C (600 J/cm^2)

Fig.1 Surface of laser-treated carbon steel plate

To identify oxide composition on the laser-treated surface, XRD measurements were carried out with generator settings of 40 kV and 30 mA, and the data was collected over a range of 20° to 90°. The cross-section of laser-treated specimens was prepared, polished and etched with 2% nital, then the microstructure of specimens was observed under an optical microscope. During the electrochemical test, NaCl aq solution with concentration of 3.5 mass% was used as electrolyte. An Ag/AgCl electrode in saturated potassium chloride (Sat.KCl) solution was used as the reference electrode. The Open circuit potential (E_{ocp}) of specimen was measured for 3600 s and reached to stable value. Then the polarization curve was tested from 300 mV lower than E_{ocp} to the required value with scanning speed of 10 mV/min, when platinum plate was used as counter electrode. Corrosion current (i_{corr}) and corrosion potential (E_{corr}) were determined with the Tafel extrapolation method.

3. Test results Table 1 shows the polarization test results. From the calculated protective efficiency (P_{EF}), it is obvious that all laser conditions show beneficial effects. E_{corr} of carbon steel plate increased after laser surface treatment, which indicates lower corrosion tendency. Laser-A specimen possessed the most positive potential among the others. The i_{corr} of laser-treated specimens is lower than abrasive blasting specimens, presents slower corrosion rate.[2] The most significant i_{corr} decreasing appeared under Laser-A condition, results in highest protection efficiency of 47.6%, which confirmed the effects of laser irradiation on electrochemical properties are strongly related to energy density.

Table 1 Polarization test results of specimens under 3.5 mass% NaCl aq

Specimen	E_{corr} (mV$_{Ag/AgCl}$)	i_{corr} (µA/cm^2)	P_{EF} (%)
Unirradiated	-659	7.02	/
Laser-A	-398	2.90	47.6
Laser-B	-432	3.87	30.1
Laser-C	-516	5.01	9.60

Keywords: Laser treatment, Electrochemical analysis, XRD pattern, Heat affected zone, Corrosion resistance
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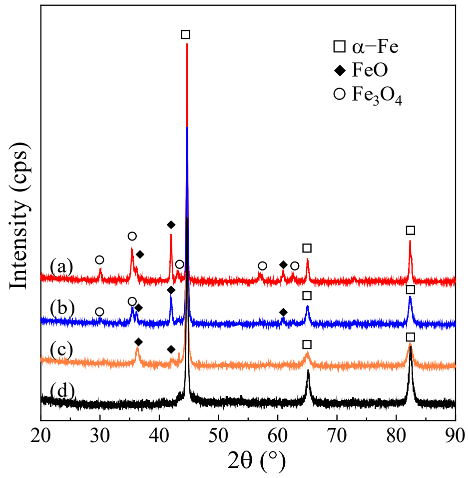
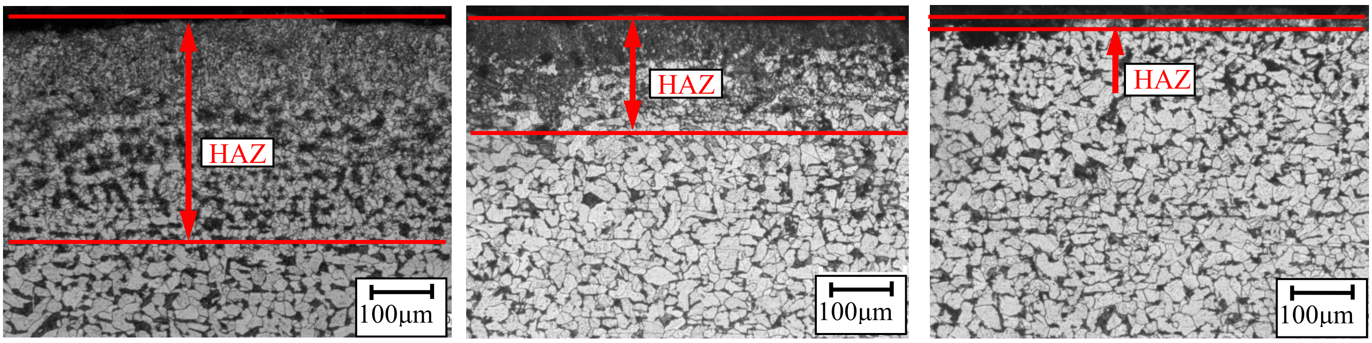


Fig.2 XRD diffraction patterns of specimens: (a) Laser-A, (b) Laser-B, (c) Laser-C, (d) Unirradiated

Laser energy density also affects the composition of surface oxide, as shown in Fig.2. From the peaks observed, oxide was identified in all laser-treated specimens. The patterns of magnetite and wustite were presented in Laser-A and Laser-B specimens, yet only wustite can be observed in Laser-C specimen. XRD results revealed a passive layer was formed on the laser-treated steel surface, hence increased corrosion resistance of steel plate. Besides the chemical composition on the surface, oxide thickness also affected by laser energy density. Semi-quantitative results of XRD indicated Laser-A and Laser-B have more proportion of metallic oxide on the surface about 54.0 and 39.4 mass% respectively, while Laser-C only showed 1.32 mass%.

From the results mentioned above, laser irradiation improved corrosion resistance of carbon steel plate. Increasing laser energy density results in higher heat effects, hence modified the electrochemical properties of steel surface with more complex iron oxide layer formed on it.



(a) Laser-A (3077 J/cm^2) (b) Laser-B (1739 J/cm^2) (c) Laser-C (600 J/cm^2)

Fig.3 Microstructure of laser-treated carbon steel

Fig.3 shows the heat affected zone (HAZ) and microstructure on the cross-section of laser-treated specimens. In the case of higher energy density, Laser-A specimen presented approximately 400 μm HAZ, which is twice the HAZ of Laser-B specimen. While a HAZ thickness of less than 20 μm was observed in Laser-C specimen. Microstructure in HAZ shows tempered sorbite features, consisting of fine ferrite and pearlite on the near-surface area. The transformation of metallographic phase also affects corrosion resistance of HAZ layer, many have suggested that as grain size decreases corrosion rate decreases.[3] Thus the corrosion resistance of Laser-A specimen is better than the others as a result of oxide layer formed on the surface, and microstructure modification of thick HAZ.

4. Summary 1) Corrosion resistance of carbon steel plate increased after laser surface treatment. 2) Oxide layer formed on the laser-treated surface providing corrosion protection. 3) The transformation of microstructure in HAZ modified the electrochemical properties of carbon steel plate.

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