Effects of Laser Surface Treatment with Different Processing Parameters on Electrochemical Properties of Carbon Steel Plate

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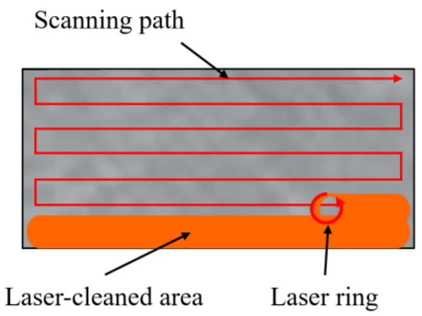
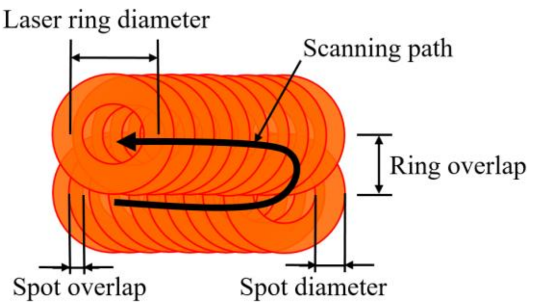
1. Introduction Laser treatment has been considered as a promising technique for the preparation of steel surfaces. Compares to traditional surface preparation techniques such as chemical and mechanical method, laser treatment capacitates with advantages including environmental friendliness and better cleanliness. The treatment process is based on laser irradiation to remove surface contaminations completely, which presented a better surface condition for coating in comparison to traditional surface preparation.

In this study, the electrochemical properties of carbon steel plate after laser surface treatment were tested under various laser conditions, and compared with milling carbon steel plate. Different concentration of electrolyte solution was applied to the electrochemical test. The correlation between change of electrochemical properties 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, as shown in Fig.1 (a). To ensure laser-treated steel plate reached complete surface cleaning, the adjacent laser ring was overlapped in ring width (equals to laser spot diameter), and each parallel laser path was overlapped in ring diameter, these two overlapped areas were labeled as spot overlap and ring overlap respectively, as shown in Fig.1 (b). Carbon steel plate[1)] with dimensions of 150×70×9 mm was irradiated by continuous wave laser to remove rust layer on the steel plate completely. Three different combinations of laser parameters were adopted in the cleaning procedure, and classified into Laser-A, Laser-B and Laser-C, as shown in Table 1. Spot overlap rate and ring overlap rate were fixed at 50% in all laser conditions. Milling was carried on another group of carbon steel plates as a comparison to laser surface treatment.



(a) Laser surface treatment process



(b) Overlap area of laser irradiation

Fig.1 Schematic image of laser surface treatment

Table 1 Parameters of different laser condition

Laser condition	Power (kW)	Rotate speed (rpm)	Ring diameter (mm)
Laser-A	2	4000	10
Laser-B	2	7000	10
Laser-C	3	7000	20

During the electrochemical test, NaCl aq solution with different concentration of 0.1, 3.5, and 26.4 wt% 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 1200 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 20 mV/min, when platinum plate was used as counter electrode.

3. Test results Fig.2 indicates E_{ocp} of carbon steel plate shifted to positive direction after laser surface treatment as a whole. Among the laser-treated specimens immersed in various concentration of NaCl aq solutions, Laser-A and Laser-C specimens possess the most positive and negative potential respectively. In comparison to milling steel plate, largest potential shifting occurred in Laser-A specimen under 0.1 wt% concentration of NaCl aq, and the minimum potential shifting occurred in Laser-C specimen under 26.4 wt% concentration, presented potential shifting of 259 mV and 100 mV respectively. E_{ocp} of laser-treated specimens had dropped dramatically before 3.5 wt% concentration and then decrease slowly with increasing NaCl aq concentration, while E_{ocp} of milling specimens increased after 3.5 wt% concentration. When rotate speed of laser beam increased from 4000 rpm to 7000 rpm, the open circuit potential of laser-treated specimen slightly decreased, in which the velocity of laser ring along scanning path in Laser-B condition is increased for maintaining 50% spot overlap rate, result in shorter laser treatment time and lower heat effect than Laser-A condition. From E_{ocp} of Laser-B and Laser-C specimens presented in Fig.2, open circuit potential of laser-treated specimen decreased dramatically after ring diameter increased from 10 mm to 20 mm, although laser power increased from 2 kW to 3 kW. Indicates smaller ring diameter has greater impact on positive potential shifting of laser-treated specimen compares to slower laser rotate speed. Fig.3 shows the polarization curves of specimens under 3.5 wt% NaCl aq concentration. The corrosion potential (E_{corr}) correspond with E_{ocp} according to test result, and trends of polarization curves between each sample are similar. E_{corr} of carbon steel plate shifted to positive direction after laser treatment, the degree of potential shifting is higher under 10 mm ring diameter. In general, slower scanning velocity result in more significant potential shifting of laser-treated specimens.

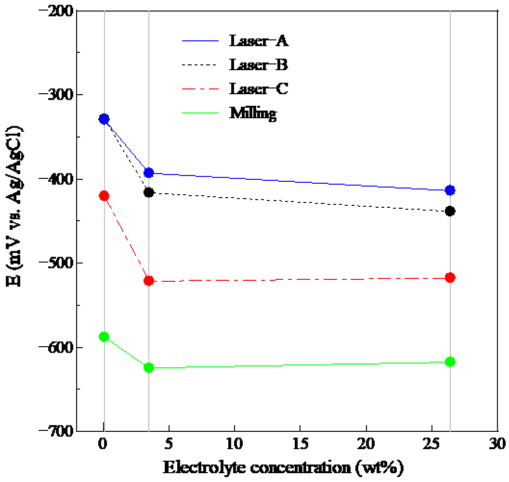


Fig.2 Open circuit potential of samples immersed in different concentration of NaCl aq for 20 min

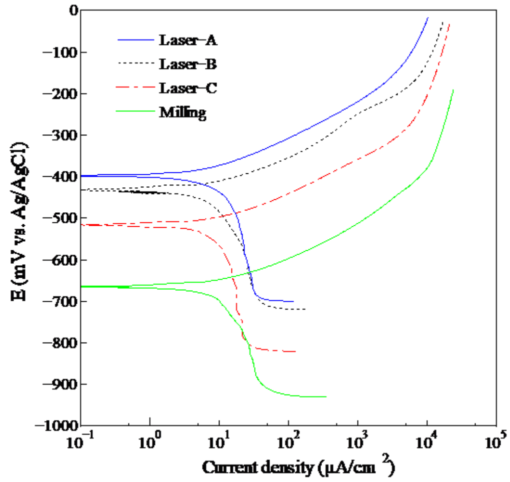
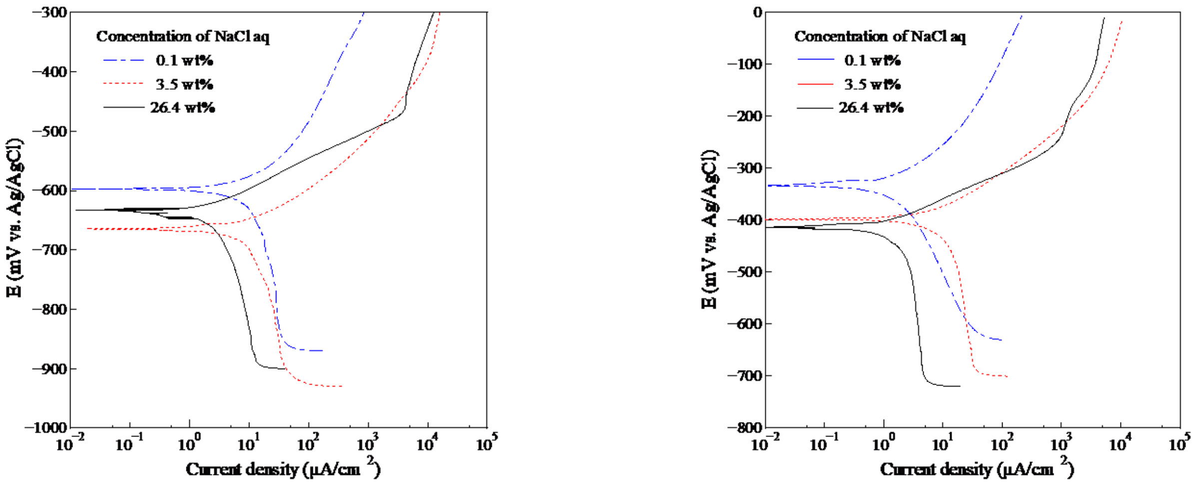


Fig.3 Polarization curve of samples under 3.5 wt% NaCl aq



(a) Polarization curve of Milling specimen

(b) Polarization curve of Laser-A specimen

Fig.4 Polarization curve of samples under 0.1, 3.5 and 26.4 wt% NaCl aq

Fig.4 shows the polarization curves of Laser-A and milling specimen in 0.1, 3.5 and 26.4 wt% NaCl aq solutions. The E_{corr} of milling specimen decreased before 3.5 wt% concentration and increased at saturated concentration, whereas E_{corr} of laser-treated specimen decreased continually with increasing NaCl aq concentration. The corrosion current density (i_{corr}) of milling specimen remain relatively stable before 3.5 wt% NaCl aq concentration and declined at 26.4 wt% concentration. On the other hand, i_{corr} of laser-treated specimen increased at 3.5 wt% concentration then decreased at 26.4 wt% concentration, but remain smaller than milling specimen in every NaCl aq concentration. Generally, i_{corr} was seen as the most important parameter to evaluate the corrosion performance[2], lower corrosion current density indicates better corrosion resistant performance.

4. Summary 1) Corrosion resistance of carbon steel plate increased after laser surface treatment. 2) Slower laser scanning speed result in more significant change of electrochemical properties of laser-treated specimen.

Reference 1) Japanese Standards Association, Japanese Industrial Standard (JIS) G3106: Rolled Steels for Welded Structure, 2008. 2) Q. Ma, Z. Tong, W. Wang, G. Dong: Fabricating robust and repairable superhydrophobic surface on carbon steel by nanosecond laser texturing for corrosion protection, Applied Surface Science, Vol.455, pp.748-757, 2018.