Electrochemical properties and surface element analysis of laser-treated weathering steel plate

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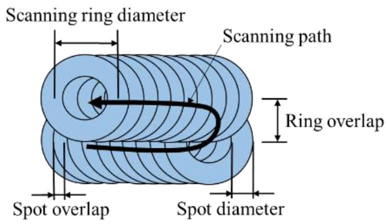
1. Introduction Weathering steel (WS) is a known metal that is generally present anti-corrosion performance when exposed in the atmosphere, because of composing Manganese, Chrome, and Copper elements. It has been widely used for different construction purposes. However, compared with carbon steel, it might show different electrochemical properties and surface properties after surface cleaning processes such as laser treatment. The laser treatment process is based on laser irradiation to obliterate surface contaminations, which presented a better surface condition for coating in comparison to traditional surface preparation. In order to study the anti-corrosion resistance of WS that treated by different processing parameters, the open circuit potential (OCP) and the potentiodynamic polarization curves were applied to clarify the anti-corrosion performances.

2. Specimen and test method The specimen of WS plates with the chemical composition is given in Table 1. About the surface treatment procedure, the continuous wave laser beam was rotated by the prism inside the laser machine, and the laser beam was projected to the steel plate as a scanning circular laser beam, then irradiated the whole steel plate surface with a laser ring under given velocity and direction. The laser-treated surface as shown in Fig.1 (a). To ensure a thoroughly cleaning for the laser-treated steel surface, 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). Three different energy densities were applied to the cleaning procedure, denoted as W-A, W-B, and W-C, as shown in Table 2. For the WS plate surface treated by milling is used as the control group named W-Milling.

Table 1 Chemical composition of tested steel (mass%)

Chemical Composition	C	Si	Mn	P	S	Cu	Ni	Cr	Mo
Mass (%)	0.11	0.25	0.68	0.01	0.02	0.32	0.11	0.49	0.10

(a) Laser surface treatment treated area



(b) Overlap area of laser irradiation

Fig.1 Schematic image of laser surface treatment

Table 2 Energy density of different laser condition

Laser condition	W-A	W-B	W-C
Energy density (J/cm^2)	3077	1739	600

The surface morphology and element composition were analyzed by the scanning electron microscope (SEM) and the energy dispersive spectroscopy (EDX). During the electrochemical measurements, open circuit potential (OCP) and potentiodynamic polarization curves were performed in 3.5 mass% NaCl aq solution as an electrolyte at room temperature using the Princeton Applied Research potentiostat, with an electrochemical cell consisting of three electrodes. A platinum plate as a counter electrode, the WS plate as the working electrode, and an Ag/AgCl electrode in saturated potassium chloride (Sat.KCl) solution as the reference electrode. The potentiodynamic polarization curves was scanned from -250 mV to +250 mV (vs. OCP) with the scanning speed of 0.167 mV/s after one-hour OCP test to ensure the stability of the corrosion rate of each specimen.

3. Test results The surface observation by SEM along with EDX mapping indicates that the surface presented an oxide layer. As shown in Fig.2, with the laser energy density increases, the content of the Oxygen increases on the surface. Comparing with the W-Milling contents of 1.15wt%, after laser-treated, the content of the Oxygen sharply increases to over 10%. Due to higher energy density, a clear laser scanning path was observed on the surface of W-A and W-B specimens, Oxygen was found concentrated on the laser path from SEM-EDX images.

Electrochemical measurement is considered as a fast and efficient method which reflects the transient electrochemical process. Fig.3 shows the OCP distributions of four specimens during 24 hrs., the results show that the OCP of all immersed specimens gradually being steady according to time. Besides, the OCP of WS increases after laser treatment, which shows that it is beneficial for improving the corrosion resistance. After the OCP test, the potentiodynamic polarization curves have been conducted to evaluate the instantaneous corrosion behavior of metal materials. As Fig.4 shows, the corrosion potential (E_{corr}) of the WS shifted to a positive value compared with the milling specimens, which indicated that laser surface treatment has a positive effect on corrosion resistance. The i_{corr} was seen as the most critical parameter to evaluate the corrosion performance, the lower corrosion

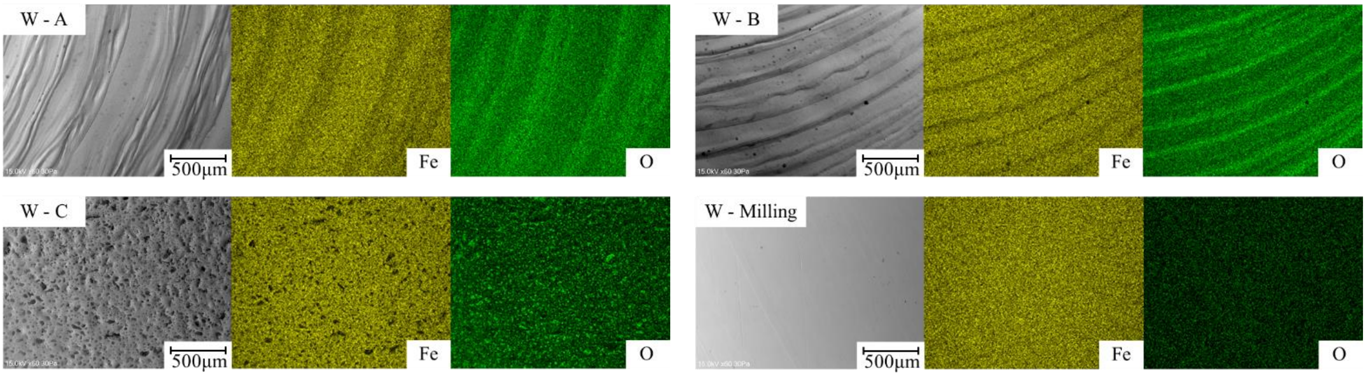


Fig.2 SEM micrograph and EDX mapping results of specimens

Table 3 Content of oxygen in different laser condition

Laser condition	W-A	W-B	W-C	W-Milling
Oxygen(mass%)	19.04%	17.15%	10.48%	1.15%

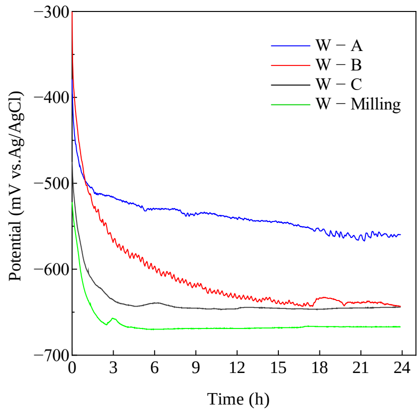


Fig.3 Open circuit potential of the weathering steel in 3.5 mass% NaCl aq for 24 hours

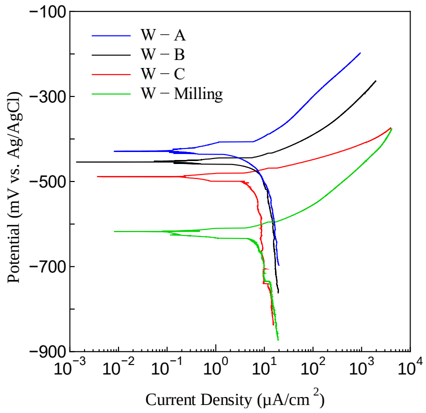


Fig.4 Polarization curves of the weathering steel in 3.5 mass% NaCl aq.

Table 4 Potentiodynamic polarization fitting results and protective efficiency rates of the WS in 3.5 mass% NaCl aq solution.

Specimen	E_{corr} (mV vs. Ag/AgCl)	i_{corr} (μA/cm^2)	$P_{\mathrm{EF}}(\%) = \dfrac{i_{corr,0} - i_{corr,N}}{i_{corr,0}}$
W-A	-448	0.279	60.3
W-B	-513	0.393	44.2
W-C	-589	0.395	43.9
W-Milling	-623	0.703	—

current density indicates the better corrosion resistant performance shows in Table 4. Comparing the degree of potential with other laser conditions, when the energy density is 3077 J/cm^2, the potential reaches the highest corrosion potential E_{corr} of the -448 mV and the lowest corrosion current density of 0.279 μA/cm^2. With the energy density decreases to 600 J/cm^2, the corrosion potential E_{corr} reduced to -589 mV and corresponding corrosion current density increased to 0.395 μA/cm^2. Thus, it is indicated that higher energy density results in more significant potential shifting of laser-treated specimens.

In addition, the potentiodynamic polarization curves fitting results and the protective efficiency (P_{EF}) are listed in Table 4, where the $i_{\mathrm{corr,0}}$ represents corrosion current density of the milling WS plate, and the $i_{\mathrm{corr,N}}$ represents the corrosion current density of the laser-treated WS plates. According to the result, W-A shows the highest value of 60.3%. And protective efficiency of W-B and W-C shows similar values of 44.2% and 43.9%, respectively. Thus, laser conditions treatments show beneficial effects.

4. Summary 1) The laser surface treatment has a positive effect on the corrosion resistance performance of weathering steel. 2) Along with the increasing energy density, the laser-treated WS shows excellent corrosion resistance performance. 3) The oxide layer on the laser surface could provide effective corrosion protection to the steel substrate, especially the W-A specimen exhibited the best corrosion resistance performance.

Reference 1) U. Trdan and J Grum: Evaluation of corrosion resistance of AA6082-T651 aluminum alloy after laser shock peening by means of cyclic polarization and ElS methods, Corrosion Science, Vol.59, pp.324-333,2012. 2) Q. Ma, Z. Tong, and 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.