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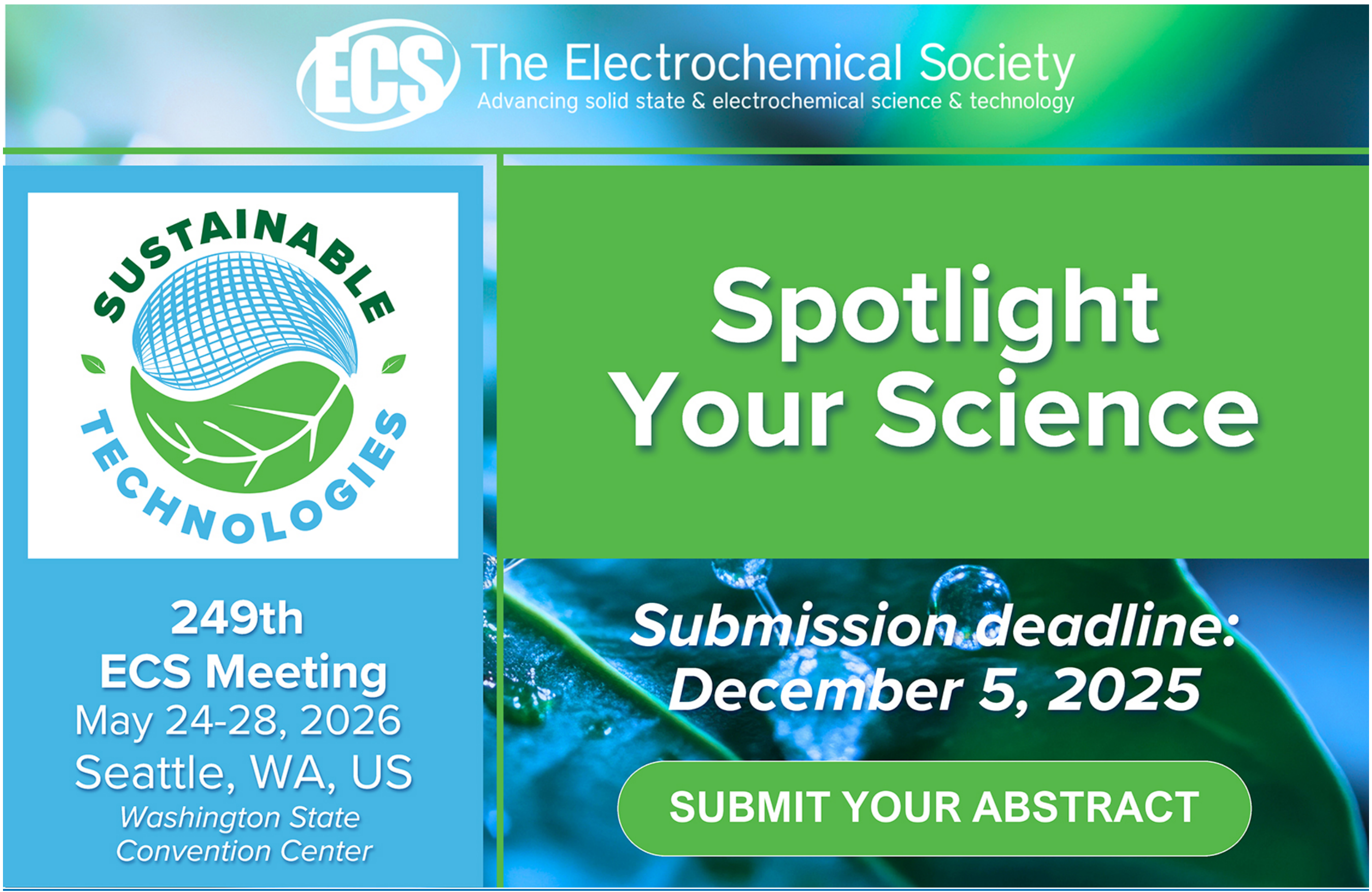

Effect of Laser Cleaning on EH36 Steel Surface Quality in Maritime Industry Applications

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Abstract. This study examines the effect of laser cleaning on EH36 steel plates coated with epoxy paints. These materials are used in maritime applications, such as in shipbuilding. Paint layers were removed by using a laser beam generated by an IPG 100W pulsed nanosecond fiber laser with a wavelength of 1064 nm. The laser cleaning parameters included a pulse width of 25 ns, frequency of 100 kHz, and scanning speed of 450 mm/s. The tests were carried out using a laser power of 25 W, applying four or eight treatment cycles. Surface inspection was performed using a Bruker Alicona Infinite Focus G6 and a Malverna Panalytical Aeris X-ray diffractometer (XRD), along with visual evaluation. Results showed complete removal of paint layers, confirmed by visual inspection and XRD, with no damage to the base metal. Surface roughness values remained within acceptable limits for maritime industry standards. The mechanism of paint removal was identified as ablation, allowing layer-by-layer removal. This suggests that laser-cleaned surfaces can be directly repainted, avoiding time-consuming re-sandblasting. The study highlights the industrial importance of laser cleaning for efficient paint removal and maintenance in maritime applications.

1. Introduction

The removal of paint coatings from metal surfaces is a critical step in maritime maintenance and lifecycle services. EH36 steel is a widely used structural metal material in the marine industry due to its high strength and mechanical properties, which meet the industrial standards. [1,2] Ship hulls, deck structures, and above and below waterline structures require regular maintenance, including the removal of old paint coatings and recoating. In these applications, the quality of the cleaned surfaces are essential for safety, service life and adhesion of coatings. [3] Traditional paint removal methods, such as sandblasting, can cause undesirable changes to the steel surface, including surface deformation, residual contamination or susceptibility to corrosion [4–6]. They also produce significant amounts of waste and are environmentally damaging [7]. For these reasons, laser cleaning has emerged as a potential alternative that enables non-contact and selective paint removal with minimal impact on the base material [8,9]. One of the key mechanisms of laser cleaning is laser ablation, where the energy of the laser beam is absorbed mainly by the paint layer, causing it to heat up rapidly, vaporize and partially ionize into plasma. This could result in the effective removal of the coating in the form of vaporization and dust, without any mechanical contact. [10] Through the selection of laser device and control of process parameters of laser beam, such as power, energy, and pulse duration, it is possible to ensure that the energy of laser beam is selectively absorbed by the surface coating, minimizing heat transfer to the base material [11]. This study examines the effects of process parameters of laser cleaning on the surface quality of EH36 steel in marine applications. Laser cleaning was defined in this study to mean the removal of paint coatings from the EH36 steel surfaces, where the cleaning effect was controlled by adjusting the number of repetition times. Industrial relevance of this study reveals that laser cleaning can effectively remove paint coatings from EH36 steel without altering the structure or quality of the pretreated, sandblasted steel surface underneath, offering a time-efficient and environmentally friendly alternative for maritime maintenance. This study provides valuable scientific insights into the effects of laser cleaning process parameters on the surface quality of EH36 steel, contributing to the understanding of laser-material interactions and the optimization of laser cleaning techniques in marine applications.

2. Experimental setup and procedure

2.1 Materials and samples

The base material used in the study was EH36 steel plates with a thickness of 4 mm. The plates were pretreated by sandblasting in accordance with industry standards. The aim of pretreatment is to ensure a clean and homogeneous starting surface and to increase the adhesion surface area of the coatings [12]. The chemical composition of the EH36 steel used was according the standard of the European Standard EN 10029:2010. In addition to iron, the main alloying elements in the steel are carbon, manganese, and silicon, with the iron content remaining balanced. The main components of the material and their concentrations are presented in table 1. After pretreatment, the plates were painted with products from International Paint Ab AkzoNobel, which are commonly used in marine structural components. The structures, layer thicknesses and adhesion behavior of these coating systems differ from each other, and this is why they were considered separately in this study. Table 2 shows details of reference surface, non-cleaned paint layer surfaces, and laser cleaned surfaces, used in this study.

Table 1. Nominal chemical composition of EH36 steel.

Elements	C	Si	Mn	P	S	Al	Nb	V	Ti	Cu	Cr	Ni	Mo	Ca
EH36	0.055	0.2	1.35	0.009	0.002	0.03	0.025	0.008	0.016	0.012	0.05	0.04	0.005	0.002

2.2 Laser cleaning

The laser system used for the cleaning was an IPG 100 W pulsed nanosecond fiber laser with Gaussian laser beam profile having average wavelength of 1064 nm (minimum value of 1055 nm and maximum value 1075 nm). The cleaning parameters were chosen so that the average laser beam power (25 W) and the number of repetition times (four and eight) ensured effective removal of the paint layer without damaging the base material, as shown in table 3. The laser cleaning was performed in argon shielding gas to prevent oxidation. All cleanings were conducted using fixed laser parameters, with a scanning speed of 450 mm/s, a frequency of 100 kHz and beam overlaps of 25 % in both x and y directions. The cleaning areas were 40 mm x 40 mm in size. The laser beam was focused on the surface so that the process was carried out at the focal point to achieve optimal energy density in the paint layer. The parameter settings were designed to ensure sufficient energy delivery to the paint layer without effects on the base material surface.

2.3 Surface characterization

The cleaning results were evaluated using a Malverna Panalytical Aeris X-ray diffractometer. The measurements were performed in the 2θ angle range of 15–120°, 0.02° step-size voltage 40 kV and tube current 7.5 mA (Cu K $K_{\alpha1,\alpha2}$ radiation). The purpose of the measurements was to detect the removal success of coatings by comparing the diffractograms with reference surfaces.

The effect of laser cleaning was evaluated by comparing the XRD diffractograms of the cleaned areas with the diffractogram of the sandblasted EH36 reference surface and untouched coating layers. The effect of laser cleaning was evaluated by comparing the XRD diffractograms of the cleaned areas with the diffractogram of the sandblasted EH36 reference surface and untouched coating layers. The measurements gave a diffractogram of the surfaces where the characteristic peaks could be determined. The broader increase in intensity in the initial part of the diffractograms (2θ < 20°) was interpreted as being due to background noise of the equipment, surface roughness of the surface or amorphous components. The cleaning was determined as successful when the diffractograms of the processed areas fully matched the profile of the reference surface, and no amorphous peaks typical of coatings were observed. Surface roughness measurements were conducted using a Bruker Alicona InfiniteFocus G5 optical microscope. Measurements were carried out by capturing a point cloud image of the surface using a 20x magnification lens, covering an area of 1 mm × 1 mm.

Table 2. Different coating structures for surfaces A-E and reference surface.

Surface	Base treatment	L1	L2	L3	L4	L5
Ref.	*	–	–	–	–	–
Above-water structures						
A	*	1	–	–	–	–
B	*	1	2	–	–	–
Below-water structures						
C	*	1	2	3	–	–
D	*	1	2	3	4	–
E	*	1	2	3	4	5

*=Sandblastig L1=Coating layer 1 L2=Coating layer 2
L3=Coating layer 3 L4=Coating layer 4
L5=Coating layer 5
1=Intershield 300 (epoxy), color bronze
2=Intershield 300 (epoxy), color aluminium
3=Intergard 263 (modified epoxy), color light grey
4=Interspeed 340 (antifouling), color black
5=Interspeed 340 (antifouling), color red

Table 3. Chosen parameters for laser cleaning surfaces A-E.

	Speed (mm/s)	Laser power (W)	Pulse frequency (kHz)	Pulse width (ns)	Repetition times
A	450	25	100	25	4
B	450	25	100	25	4
C	450	25	100	25	8
D	450	25	100	25	8
E	450	25	100	25	8

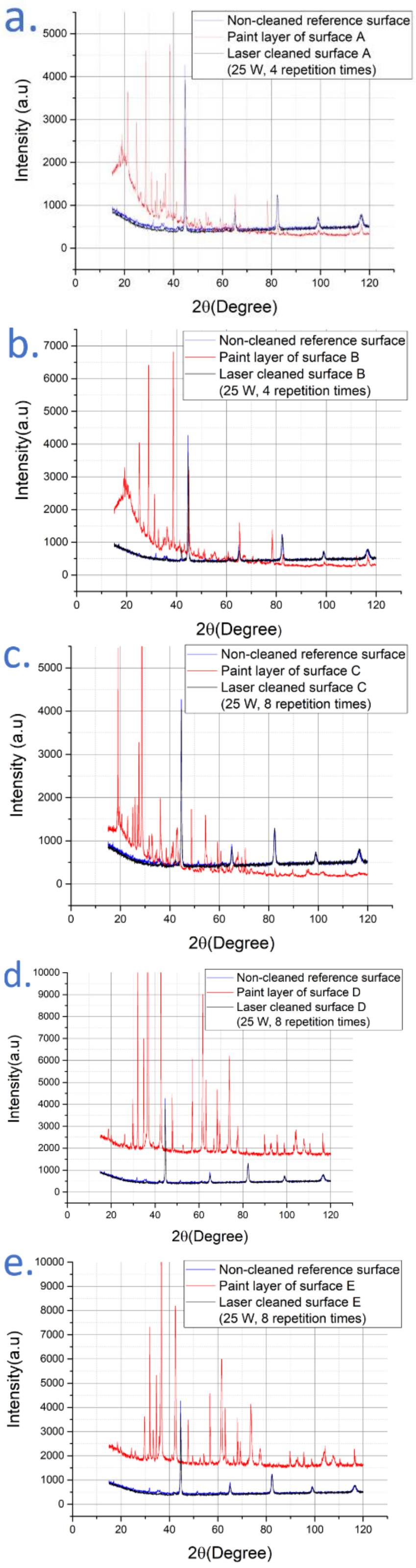
The average areal surface roughness parameter, *Sa*, was calculated using MetMax 3.0 software, which enables the analysis of areal surface characteristics. The obtained *Sa* values for each processed surface were compared with those of the sandblasted reference surface. All measurements were performed in accordance with ISO 4287 and ISO 4288 standards.

3. Results and discussion

3.1 XRD analysis

Measured diffractograms for reference surface, non-cleaned paint layer surfaces, and laser cleaned surfaces, are shown in figure 1a-e. Steel diffraction peaks were observed on the reference surface at 2θ angles of approximately 43°, 64°, 83°, 98° and 117°, which represent the main peaks characteristic of the crystal structure of the low alloyed ferritic steel of the base material. In addition, three low-intensity peaks were observed at angles of 31°, 35° and 52°, which may originate from residual phases such as magnetite (Fe_3O_4) or pearlite, both of which are commonly present in ferritic–pearlitic steels.

Figure 1. XRD diffractograms of laser cleaned and non-cleaned paint layer surfaces A-E, and non-cleaned reference surface.



Diffractograms of all laser cleaned surfaces fully matched the reference surface profile, with no amorphous peaks seen with diffractograms of coatings, confirming complete coating removal and exposure of the base material and determine that the laser cleaning process was effective, as shown in figure 1. Amorphous peaks [13] can be detected specially in the 2θ range of 15–35°, where the diffraction peaks of the coating layers were most clearly visible before the laser cleaning process. As can be seen from figure 1a, the non-cleaned painted surface A (one coating layer) exhibited intense amorphous background and characteristic broad peaks at low 2θ angles (15–35°). This indicates that the paint layer fully covered the base material, preventing the detection of substrate diffraction peaks. After laser cleaning with four repetition times at 25 W, the diffractogram of laser cleaned surface A corresponded closely with the non-cleaned reference surface, with clear peaks observed at 2θ angles of approximately 43°, 64°, 83°, 98°, and 117°, which are characteristic for ferritic steel. This confirms that the coating was completely removed. Similarly, figure 1b shows the diffractograms for non-cleaned painted (two coating layers) and laser cleaned surfaces B with four repetition times, and non-cleaned reference surface. The painted surface displayed intensity peaks in the low-angle region, indicating the presence of coating material. After laser cleaning, the pattern closely matched the reference surface, again suggesting successful coating removal. However, a slight increase in the baseline intensity was observed, which may indicate minor residual contamination or surface roughness effects. It can be concluded from figure 1c that for laser cleaned surface C, when laser cleaning was repeated eight times, surface showed complete removal of the coating. It is indicated by the disappearance of coating-related features and the alignment of the diffractogram of non-cleaned painted (three coating layers) surface C with the non-cleaned reference surface. In Figure 1d, the non-cleaned surface D shows coating-related peaks, which disappeared after eight laser cleaning passes. The cleaned surface’s diffractogram matched the base material but showed slight peak broadening and reduced intensity, indicating possible minor microstructural changes from overprocessing or heat effects. Finally, figure 1e illustrates the diffractogram of non-cleaned painted (five coating layers) and laser cleaned surface E with eight repetition times and non-cleaned reference surface. Similar to the results of previous surfaces (figure 1a-1d), complete removal of the coating was achieved, as evidenced by the cleaned surface diffractogram closely matching the reference surface.

3.2 Surface roughness measurements

Figure 2 presents the change in *Sa* surface roughness values of the laser cleaned surfaces compared to the non-cleaned sandblasted reference surface.

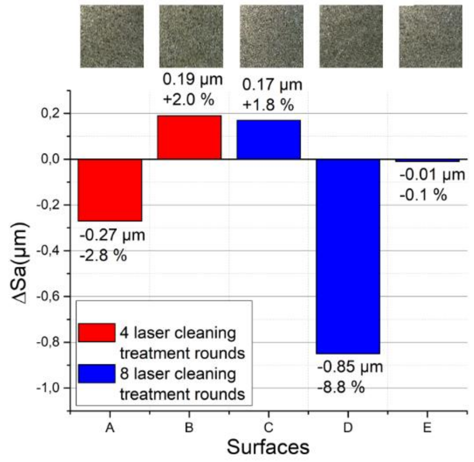


Figure 2. Change in Sa value (µm) for laser cleaned surfaces A–E compared to the reference surface.

Figure 2 shows the values that represent the calculated difference in *Sa* value relative to the reference. The effect of laser cleaning on the surface *Sa* value was small in the surfaces cleaned at 25 W laser power, for laser cleaned surfaces A, B, C and E. Figure 2 shows that laser cleaned surface D, with eight repetition times, had lowest value of *Sa* of -0.85 µm in comparison to the non-cleaned reference surface. This was assumed to be due to surface smoothing caused by the laser beam affecting the base material surface, which may result from too high values of laser power of 25 W or if eight repetition times was too much. As seen in figure 2, laser cleaned surface A, with one paint layer, had a decrease in *Sa* value of 0.27 µm compared to the non-cleaned sandblasted reference surface, corresponding to a 2.8 % reduction. This change indicates that the laser beam did not affect the base material surface. As seen in figure 2, laser cleaned surface B, with two paint layers, had an increase in surface roughness of 0.19 µm, corresponding to 2.0 % higher roughness compared to the non-cleaned reference surface. This increase may be caused by localized residues or incomplete coating removal, rather than changes in the substrate itself. As seen in figure 2, laser cleaned surface C, with three paint layers, had a *Sa* value increase of 0.17 µm (1.75%) compared to the non-cleaned reference surface, also suggesting minor surface roughening due to residues or incomplete cleaning. As figure 2 shows, value of Sa in laser cleaned surface D, with five paint layers, was 0.85 µm, corresponding to an 8.8 % reduction compared to the reference. This indicates that surface has been smoothened, possibly caused by partial melting of the base material due to the eight repetition times in laser cleaning. As shown in Figure 2, surface E (with five coating layers and eight laser cleaning passes) had a *Sa* reduction of only 0.01 µm, under 0.1%, indicating minimal effect on surface roughness. Across all samples, roughness changes ranged from −0.85 µm to +0.19 µm compared to the non-cleaned reference, suggesting the base material surface was not significantly altered. The minor change in surface E may result from thick coatings absorbing most of the laser energy. These results confirm that laser cleaning effectively removes coatings while preserving the original surface roughness, even under intensive processing conditions. The correlation between values of surface roughness and XRD measurements confirms that when the coating was successfully removed, the surface roughness remained unaffected, supporting that laser cleaning is based on evaporation of paint, and original roughness of surface remains constant.

4. Conclusions

This study evaluated the suitability of laser cleaning for the removal of various coating layer structures from EH36 steel and the effect of laser beam on the surface of base material based on XRD peak and surface roughness value analysis. Based on XRD measurements, it could be concluded that laser cleaning was effective in all coating systems studied when the process parameters were chosen correctly. In the cleaned surfaces, the diffractograms fully corresponded to the profile of the sandblasted reference surface, and no amorphous peaks typical of coatings were observed, especially in the 2θ range of 15–35°, which indicated complete removal of the coatings without residues. Results of surface roughness measurements supported the XRD observations, showing that the effect of laser cleaning on the value of surface roughness was minor (-2.8 % – 2 %) all surfaces expect for laser cleaned surface D, which had four coating layers and eight laser cleaning repetition times. For this surface, the decrease in *Sa* value of 8.8 % was observed, indicating surface smoothing and possible melting of the base material surface. A significant observation was that in most cases the value of surface roughness remained close to the original sandblasted surface roughness value after laser cleaning, and laser cleaning did not cause melting-related changes to the surface. This study focused on uniform coatings, but real-world surfaces may be irregular or damaged, affecting cleaning efficiency. Adaptive parameter control and real-time monitoring can help maintain consistent results under such conditions. Offshore or in situ use also demands safety measures, including laser shielding, fume extraction, confined-space handling and explosion risk mitigation. In future, it would be important to further examine changes in the crystal structure and microstructure of laser-cleaned surfaces, for example, by electron microscopy and/or EBSD methods.

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