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Effects of Laser Polishing on Surface Roughness and Corrosion Properties on Laser Welds as Post-Treatment

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Abstract. Materials used in maritime industries suffer from severe corrosion due to constant exposure to saltwater and harsh marine environments. Welds in metals are particularly prone to corrosion, leading to mechanical failure and structural degradation of ships and larger vessels. Laser polishing is an effective technique that redistributes molten material into cavities, smoothing the weld surface and enhancing longevity. Aim of this study was to examine the effects of laser polishing on marine grade EH36 steel welds, focusing on corrosion resistance and surface roughness. Laser polishing was performed using an IPG nanosecond pulsed fiber laser with a maximum average power of 100W and a wavelength range of 1055-1075 nm (typically 1064 nm). Samples were polished from the top and root sides of the weld. Corrosion properties were tested using an Ivium electrochemical analyser and a Gamry instruments surface corrosion system, while surface inspection and roughness values were obtained with a Bruker Alicona Infinite Focus G6. The steel surface underwent six treatment cycles with a scanning speed of 450 mm/s and a pulse frequency of 100 kHz. Optimal results were achieved at a laser power of 75 W and a pulse width of 25 ns. Laser polishing decreased areal average roughness *Sa* by about 65 % compared to non-laser polished surfaces. Additionally, the corrosion rate of the top surface of the laser-polished sample showed a substantial reduction of 94 % compared to the non-laser polished weld. The root surface corrosion rate increased 33 % which suggests a significant difference between the root and top surfaces of welds. These findings suggest that laser polishing effectively smooths weld surfaces, leading to improved durability, reduced maintenance requirements, and extended service life of marine structures and ships.

1. Introduction

In recent decades, laser technology has been established as an important technology in multiple industries and has seen remarkable advancements [1]. The growing interest in laser processing technologies, such as laser cutting, laser cleaning or laser polishing, is largely due to their unique advantages, efficiency, accuracy, and versatility which make them suitable for numerous applications [1]. Laser polishing has steadily had a rising interest as a technique for polishing metal surfaces by melting a fine layer of material on the surface. Instead of removing material, the laser polishing involves melting of top surface material to create a smoother texture. [2,3] Laser polishing happens as energy brought to surface of metal material by pulsed or continuous wave (CW) mode of laser beam melts the surface, and then molten metal fills the small surface irregularities. After this the surface cools and solidifies, resulting in a smoother finish to improve the surface quality. [4,5] Materials used in maritime industry have a challenge with corrosion posing risks to materials such as cracking, abrasion and fatigue, which can compromise the safety and reliability of structures [6,7]. Sea water is highly corrosive which means that it accelerates the degradation that happens in metal components [8]. Welds in these areas are especially prone to cracks due to corrosion and it can lead to structural failure. [9] Sassmanhausen et al. [2] laser polished in their study surface of tool steel with a femtosecond pulsed laser beam. They conducted that laser-material interaction enables a controlled surface melting through heat accumulation, which results in surface polishing effect, achieving decrease of 52 % in values of surface roughness. This is reached by precisely changing process parameters such as scanning speed, and focal diameter. [2] Although related research exists, such as in laser polishing of additively manufactured components, studies specifically focusing on this topic are limited. This shows how laser polishing could improve surface quality across metals by precisely controlling process parameters, even beyond additive manufacturing. This article studies the impact of laser polishing on the surface quality and corrosion resistance of EH36 steel used in marine structures. In this study, polishing refers to surface treatment aimed at reducing roughness. Specifically, laser polishing involves melting the top metal layer to achieve a smoother surface. The main aim of this study is to determine whether laser polishing can effectively reduce surface roughness and to assess its influence on corrosion behaviour of the material. This study is significant for the maritime industry, where improving the surface quality and corrosion resistance of EH36 steel can enhance the longevity and performance of marine structures. This study also contributes to academic understanding of laser-material interactions and their effects on surface integrity and electrochemical properties in marine-grade steels.

2. Experimental setup and procedure

The material used in this study was NV E36 (EH36), a high-strength low-alloy (HSLA) steel manufactured by SSAB. It was produced using a hot rolling process, resulting in 4 mm thick plates with grade B classification. The steel has a density of 8.16 g/cm^3 and meets the requirements of the European Standard EN 10029:2010. The nominal chemical composition and corresponding mass percentages are shown in table 1.

Table 1. Nominal composition of NV E36 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

Before laser polishing, metal plates were laser welded using 4 kW power and a speed of 4 m/min. Laser polishing was applied to both the top and root) sides of the weld to achieve smooth surfaces on both sides; here, the root side refers to the weld root. The study involved four samples, detailed in Table 2. An IPG YLPN nanosecond pulsed fiber laser with an integrated scanner head was used for polishing. It features a scanning area of 100 mm × 100 mm, operates typically at a wavelength of 1064 nm (range 1055–1075 nm), with a maximum power of 100 W, a focal length of 283 mm, and a focal spot diameter of 60 μm. Table 2 lists the laser polishing parameters, selected to melt the surface sufficiently for smoothening. Argon gas was used as local shielding during polishing to prevent oxidation. Both top and root side surfaces were polished with identical settings: 450 mm/s scanning speed, 100 kHz pulse frequency, 25% beam overlap in x and y directions, over an area of 40 mm × 7 mm, repeated six times. The parameters and repetition times were chosen based on that they ensure the smoothest steel surface. The laser beam was focused on the surface to ensure processing at the focal point. Preliminary visual analysis of non-polished and laser-polished weld surfaces was done using a commercial microscope with 5x magnification. Good surface quality was identified by light reflectivity in polished areas, while poor quality surfaces lacked reflectivity. The Bruker Alicona Infinite Focus G6, an optical measurement system, was used to capture 3D surface topologies. It works on both organic and inorganic materials by emitting light only. Surface roughness measurement values such as linear *R*- and areal *S* values can be obtained by MetMax 3.0 software to analyse the images taken with Alicona. The *Ra*

Table 2. Samples and the chosen parameters for laser polishing.

Sample	Treatment	Side of weld	Speed (mm/s)	Average laser power (W)	Pulse frequency (kHz)	Pulse width (ns)	Repetition times
A	–	top	–	–	–	–	–
B	–	root	–	–	–	–	–
C	laser polished	top	450	75	100	25	6
D	laser polished	root	450	75	100	25	6

measurements were done based on ISO 4287 and ISO 4288 from the topography images that were obtained from the metal surface. The area imaged was the non-polished top and root surfaces of weld and laser processed area in laser polished top and root surfaces of welds. The *Ra* measurements were done on three separate areas to get an average *Ra* value. The same images were used to obtain the *Sa* values based on areal topography. Corrosion testing was conducted using a Gamry surface corrosion system and Ivium electrochemical analyser. To simulate marine conditions, an artificial saline solution was prepared according to ASTM D1141-98, with pH adjusted to 8.20 using 0.1 M NaOH. The test setup included a decanter placed over the weld area and filled with the saline solution. A masking sticker with a 1 cm radius opening (0.785 cm^2 area) was used to confine the test area. Electrodes connected to the analyser generated current through the solution, and corrosion rates were calculated using IviumSoft software.

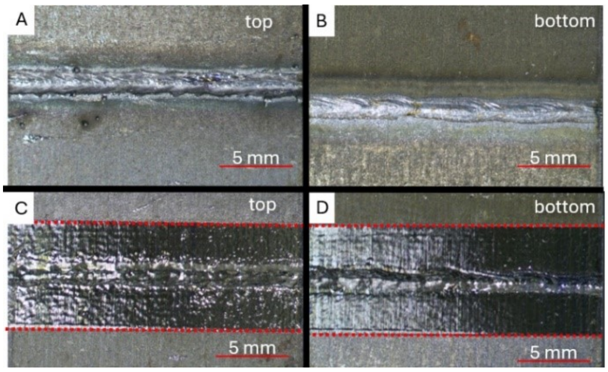

Figure 1. Micrographs from a) non-polished top side surface of weld, b) non-polished root side surface of weld, c) laser polished top side surface of weld and d) root side surface of weld. Red dotted line shows the laser polished area in the laser polished top (c) and root (d) surface of welds.

3. Results and discussion

Figure 1. shows the macrographs of the non-polished and laser polished top and root side surfaces of welds. As shown in figure 1a, there are tiny amount of impurities next to the top side of the non-polished weld that were produced by the welding process (red arrows in figure 1a) due to spattering during the welding process. However, since the laser polishing is the focus of the study, this point of view is not further discussed. Figure 1b (the root side of the non-polished weld) shows a smoother weld compared to figure 1a which could be due to the difference in cooling in the root of the weld. Shown in figure 1c, when laser polishing power has value of 75 W and polishing speed value of 450 mm/s in laser polished top side of weld, the laser polished area (in between red dotted lines in figure 1c) can be clearly seen as reflective area than the surrounding the non-polished area. Similarly, figure 1d indicates that the laser polished root surface of weld shows reflectiveness in the laser polished area in between the red dotted lines. The original shape of laser weld is still visible in both figures 1c and 1d. Figure 2 illustrates surface profiles of non-polished and laser polished top side of weld. The zero point in the height (y-axis) has been set to a specific point by the program MetMax from which the data was obtained.

When the non-polished and laser-polished top side surfaces of welds profiles are compared (see figure 2), it can be noticed that laser polished surface is much smoother with the length values of 0 mm – 3 mm as profile of non-polished surface of top side of weld has variations between the length values 0 mm and 3 mm due to the laser polishing process. It can be concluded that the laser beam in the laser polishing process has melted the weld and base material surfaces. As the plates have been misaligned during the welding process, the missing material between

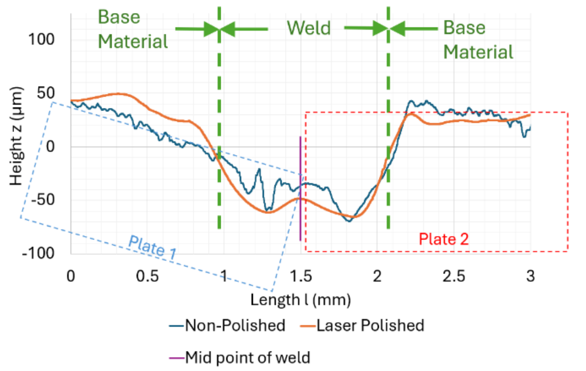

Figure 2. Surface profiles of the non-polished and laser polished welds from the top side.

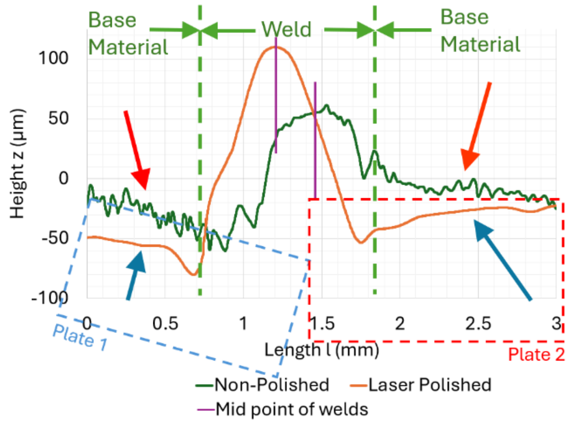

Figure 3. Surface profile of laser polished and non-polished weld surface from the root side.

them would explain why the weld has an incompletely filled groove (see figure 2, plate 1 and plate 2).

Both profiles of non-polished and laser polished surfaces decrease between 0.0 mm — 1.3 mm from 40 µm to the height of -60 µm, in which the base material is between 0 mm — 1 mm. The weld in both the non-polished and laser-polished top side surfaces of welds profiles have the welds between 1 mm — 2 mm. The base material is also between the length of 2 mm — 3 mm (see figure 2). The laser weld can be seen in these values as a local maximum, since the both of the non-polished and laser-polished top side surfaces of welds profiles decrease to the height of -60 µm — -70 µm on both sides of the midpoint of the weld. Figure 2 shows that the laser polished surface profile compared to non-polished surface profile does not have any local minimums or maximums, as laser beam has melted surface and thus smoothened surface. It is to be assumed that due to this fact the cracking ability of this weld is decreased since the areas where stresses are most concentrated are removed. This issue needs further studies or validations of these assumptions. Figure 3 illustrates surface profiles of non-polished and laser polished top side of weld. The zero point in the height (y-axis) has been set to a specific point by the program MetMax from which the data was obtained. As shown in figure 3, the non-polished weld and laser polished root side surfaces of welds are compared. The non-polished and laser polished root surfaces of weld profiles are at a length of 0.75 mm – 1.7 mm (between the green dotted lines in figure 3). The profiles on left and right of the welds (between 0 mm — 0.75 mm and 1.7 mm — 3 mm) are the base material. The non-polished and laser polished root side surfaces of weld both have a high peak at the midpoint of the welds (purple lines). For the non-polished root surface of weld profile, the peak is highest at a height of 60 µm at around 1.5 mm in length. The laser polished surface of weld profile has a peak at the weld at the height of 110 µm at around 1.2 mm in length. These peaks are caused by the welding, as the root side has a higher welding bead compared to the top side surface. As shown in figure 3, the weld is much smoother in the laser polished root surface of weld profile, compared to the non-polished root surface of weld profile as the laser polishing process has melted the local minimums and maximums to a smooth surface, similar to figure 2. As the figure 3 shows, the non-polished root surface of weld profile decreases between 1.5 mm – 1.7 mm after the peak of 60 µm to 0 µm.

After the drop in the non-polished root weld surface, the profile decreases between 1.7 mm and 3 mm, reaching –30 µm, with visible local roughness peaks (red arrows, figure 3), likely due to the transition from weld to base material. In contrast, the laser-polished root surface shows a peak of 110 µm, then drops between 1.2 mm and 1.7 mm to –50 µm, before rising to –20 µm

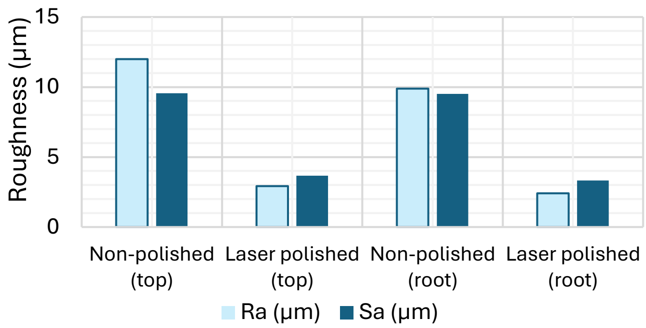

Figure 4. The *Ra* and *Sa* roughness values from top and root surfaces of the non-polished and laser polished welds.

between 1.7 mm and 3 mm. Unlike the non-polished profile, which has clear roughness peaks and valleys, the laser-polished surface is smoother, with no visible fluctuations (blue arrows). Figures 2 and 3 confirm this smoothing effect. The profiles of the non-polished and laser-polished top surfaces of the welds were not measured at identical locations, as the polishing was performed on a separate sample. Therefore, Figures 2 and 3 illustrate general changes in surface roughness rather than direct, location-specific comparisons. The values for *Ra* and *Sa* for the non-polished and laser polished top and root welds are shown in figure 4.

Figure 4 shows that the non-polished top and root weld surfaces have Ra values of 10 µm and 12 µm, respectively, with differences possibly due to the linear roughness measurement missing local peaks and valleys. In contrast, the laser-polished top and root surfaces have Ra values of 2 µm and 3 µm, representing a 76% reduction in surface roughness for both. This indicates that laser polishing significantly smoothened the surfaces. The Sa values for the non-polished top and root surfaces are both 9.5 µm, while the laser-polished surfaces show decreases of 62% for the top and 65% for the root. These results confirm that laser polishing effectively reduces surface roughness and smoothens both the top and root weld surfaces. Comparing corrosion rates of the weld surfaces (Figure 5) reveals notable differences. The corrosion rate is in the unit of millimetres per year (mm/y). The non-polished top weld surface has a corrosion rate of 0.5 mm/y, while the laser-polished top surface shows a much lower rate of 0.03 mm/y, indicating a 94% improvement. This reduction likely results from the decreased surface roughness of the polished weld. However, the root weld surfaces show no improvement: the non-polished root surface corrodes at 0.12 mm/y, but the laser-polished root surface corrodes faster at 0.18 mm/y, a 33% increase. This higher corrosion rate after polishing may be due to oxidation during the laser process or the presence of incomplete melting or microcracks on the polished surface, which can accelerate corrosion. [10,11] The welding process may cause oxide formation on the weld bead side due to metal vapour, which, when removed, improves corrosion resistance. The root side lacks vapour, retaining the original surface with inherently better corrosion resistance. [12] This issue needs further studies as research done by Nguyen et al. [13] suggests that there is a correlation between corrosion rate and surface roughness. With higher surface roughness the corrosion rate increases accordingly.

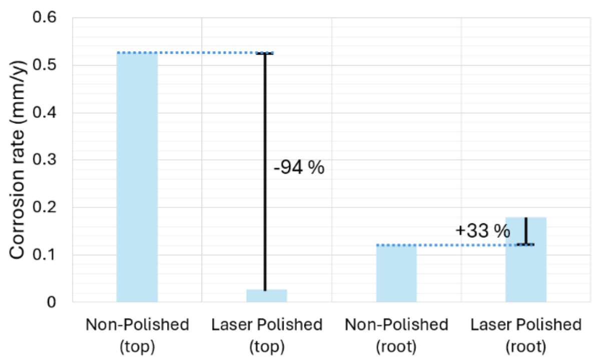

Figure 5. The corrosion rates of the non-polished and laser polished top and root surfaces of welds.

4. Conclusions

Laser polishing is increasingly recognized as a precise and efficient technique for enhancing metal surfaces by melting a thin surface layer, allowing molten material to fill surface irregularities and solidify smoothly. Welded areas, which are particularly susceptible to corrosion due to microstructural changes, can benefit from this process. This study aimed to evaluate the feasibility of laser polishing the top and root surfaces of laser-welded NV E36 steel, focusing on surface roughness and corrosion behaviour. The polishing process used a laser power of 75 W, speed of 450 mm/s, and pulse frequency of 100 kHz. Visually, the polished weld surfaces reflected more light, indicating smoother finishes. Surface roughness measurements (Ra and Sa) confirmed this, with Ra values showing a 76% decrease after polishing. Corrosion test results were mixed: the laser-polished top surface had significantly improved resistance (0.03 mm/y vs. 0.5 mm/y for non-polished), while the polished root surface showed a slightly higher corrosion rate than its non-polished counterpart. Further research is needed, but the improved corrosion resistance of the polished top surface is promising.

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References

[1] Willner A E, Byer R L, Chang-Hasnain C J, Forrest S R, Kressel H, Kogelnik H, Tearney G J, Townes C H and Zervas M N 2012 Optics and Photonics: Key Enabling Technologies *Proc. IEEE* **100** 1604–43

[2] Sassmannshausen A, Brenner A and Finger J 2021 Ultrashort pulse laser polishing by continuous surface melting *J. Mater. Process. Technol.* **293** 117058

[3] Davim J P 2012 Lasers in Surface Engineering *Laser in Manufacturing* (John Wiley & Sons, Incorporated) p 314

[4] Marimuthu S, Triantaphyllou A, Antar M, Wimpenny D, Morton H and Beard M 2015 Laser polishing of selective laser melted components *Int. J. Mach. Tools Manuf.* **95** 97–104

[5] Gisario A, Barletta M and Veniali F 2022 Laser polishing: a review of a constantly growing technology in the surface finishing of components made by additive manufacturing *Int. J. Adv. Manuf. Technol.* **120** 1433–72

[6] Shreir L L, Jarman R A and Burstein 1994 *Corrosion* vol 1–2 (Butterworth Heinemann)

[7] Kurth J C, Krauss P D and Foster S W 2019 Corrosion Management of Maritime Infrastructure *Transp. Res. Rec. J. Transp. Res. Board* **2673** 2–14

[8] Féron D 2021 *Marine Corrosion of Stainless Steels* ed D Féron (CRC Press)

[9] Lu C, Yao Q, Li N, Sun L, Dai W, Zhang C and Ma H 2024 Corrosion fatigue cracking behaviors of Q690qE high-strength bridge steel as a weld joint in simulated marine environment *Fatigue Fract. Eng. Mater. Struct.* **47** 4341–55

[10] Guzmán-Nogales R, Estupiñán-López F, Gaona-Tiburcio C, Lopez-Botello O E, Ramírez-Rodríguez J G and Zambrano-Robledo P C 2021 Corrosion Resistance Measurement of 316L Stainless Steel Manufactured by Selective Laser Melting *Materials* **14** 4509

[11] Li P, Wang Y, Li L, Gong Y, Zhou J and Lu J 2023 Ablation oxidation and surface quality during laser polishing of TA15 aviation titanium alloy *J. Mater. Res. Technol.* **23** 6101–14

[12] Zhao X-Y, Cheng C-Q, Cao T-S, Zhao J, Sun X-G and Zhang D-J 2024 The effect of oxide scale on the corrosion resistance of SUS301L stainless steel welding joints *Mater. Charact.* **217** 114431

[13] Nguyen T L, Blanquet A, Staiger M P, Dias G J and Woodfield T B F 2012 On the role of surface roughness in the corrosion of pure magnesium *in vitro J. Biomed. Mater. Res. B Appl. Biomater.* **100B** 1310–8