Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Parametric Analysis of Process Loop and Scanning Line Distance in Laser Cleaning of Corrosion on Boron Steel

To cite this article: Irfan Bin Azman *et al* 2024 *J. Phys.: Conf. Ser.* **2688** 012018

PARAMETRIC ANALYSIS OF PROCESS LOOP AND SCANNING LINE DISTANCE IN LASER CLEANING OF CORROSION ON BORON STEEL

Irfan Bin Azman[1], Dr. Aiman Bin Mohd Halil[*1], Professor Dr. Mahadzir Bin Ishak @ Muhammad[1] and Dr. Moinuddin Mohammed Quazi[1]

[1]Faculty of Mechanical and Automotive Engineering, Universiti Malaysia Pahang (UMP), 26600 Pekan, Pahang, Malaysia,
aimanmh@ump.edu.my

ABSTRACT

This project is a comprehensive exploration conducted within the Laser Micro Cleaning Lab at the Pekan Campus of University Malaysia Pahang. The objective of the project is to delve into laser material processing, particularly in the context of laser micro cleaning. The undertaking involves a meticulous research approach, drawing insights from authoritative and relevant journal articles sourced primarily from online platforms. The primary goal of this investigation is twofold: firstly, to scrutinize the effects of mark loops on corrosion depth in boron steel, and secondly, to examine how alterations in line distance influence the surface roughness during corrosion laser cleaning. The study will encompass a diverse range of laser cleaning parameters and materials, facilitating a comprehensive assessment of their impact on both laser mark loops and line distances. To delve deeper, a sophisticated 3D microscope analysis will be employed, focusing on evaluating corrosion depth and surface roughness. The anticipated outcomes of this research hold the promise of invaluable insights, offering optimized strategies for enhancing laser cleaning processes and achieving more efficient results.

Keywords. Laser Micro Surface Cleaning; Boron Steel; 3d microscope analysis.

1.INTRODUCTION

Corrosion is a major concern in various industries, particularly in the automotive sector, where the use of high-strength materials like boron steel has become prevalent. Traditional corrosion cleaning methods often fall short in effectively removing corrosion from boron steel without compromising its structural integrity. Laser micro-corrosion cleaning has emerged as a promising technique due to its non-contact nature and precise material removal capabilities. Boron steel has gained significant attention in recent years due to its exceptional mechanical properties such as high strength and good wear resistance, making it an ideal candidate for various application. However, like many other steel alloys, boron steel is susceptible to corrosion, which can compromise its integrity and performance. Corrosion cleaning plays a crucial role in maintaining the material's longevity and functionality by removing corrosive products and restoring its protective surface layer. Understanding the advantages and challenges associated with corrosion cleaning of boron steel is essential for optimizing its performance and expanding its applications in industries where corrosion resistance is vital.

2.MATERIAL AND METHOD

The material selected for this study is Boron steel. A Boron steel, also known as boron-added steel or boron-alloyed steel, is a type of steel that incorporates boron as an alloying element. Boron is added to steel in small quantities (typically less than 1%) to enhance certain properties and improve its performance in specific applications. The outstanding mechanical properties of boron steel, such as its high strength and wear resistance, led to its selection as the study's subject and its significance in a number of industries. But one drawback is that it is susceptible to rust. The high hardenability of boron steel, which allows it to undergo deeper heat treatment than normal steels, is one of its important properties. Due to this characteristic, boron steel is well suited for applications requiring great strength and wear resistance, such as crankshafts, gears, and suspension systems in automobiles. Boron steel also exhibits good formability and weldability, allowing it to be shaped and joined using various manufacturing processes. Its combination of strength, formability, and hardenability makes it a preferred material choice for industries where lightweight, high-strength components are desired, such as the automotive and aerospace sectors.

In terms of corrosion resistance, boron steel exhibits similar properties to other carbon steels. It is susceptible to corrosion when exposed to moisture, oxygen, and corrosive environments. Therefore, appropriate corrosion protection measures, such as coatings or surface treatments, are necessary to mitigate corrosion and extend the service life of boron steel components. The use of boron steel in laser micro corrosion cleaning is particularly intriguing because of its special characteristics and possibilities for specialized cleaning uses. By studying the interaction between laser parameters, such as pulse duration, energy density, and spot size, with boron steel surfaces, researchers can optimize the laser cleaning process for efficient and controlled removal of corrosion without causing damage to the underlying material.

2.1. Design of Experiment (DOE)

A design of experiment (DOE) on laser micro cleaning entails meticulously controlling and altering numerous input elements, such as laser mark loop and line distance, in order to improve the output, such as depth of corrosion and surface roughness. The DOE technique would require systematic input element variation and organize output measurement to utilize a complete factorial design or a fractional factorial design. The obtained data would next be statistically analyses to identify the pertinent input variables and the ideal values for achieving the desired result. In order to establish the validity and dependability of the results, appropriate control and replication techniques would also be used to determine the accuracy of the experiment.

Specification	**Parameter**
Material	Boron Steel
Thickness	2 mm
Area	20 x 25 mm2
Wavelength	1064 nm
Speed	5500 mm/s
Pulse Frequency	35 Hz
Power	60 Hz
Laser Process Parameters	Mark Loops and Line Distance

Table 1. List of Fixed Parameter

2.2. Setup of Experiment

The process of employing laser technology to remove corrosion from the surface of materials is known as laser surface corrosion cleaning. The corrosion layer is vaporized or abated using the energy from a laser beam without harming the underlying material, making it a non-contact and precise cleaning technique which making the process more accurate, non-contact and ecologically benign method. It offers a quick and easy way to repair the integrity and aesthetics of materials damaged by corrosion. In this experiment, A boron steel was used. Through the use of metal sheet metal cutting, a piece of boron steel measuring 200 mm by 300 mm was reduced to a 20 mm by 25 mm sheet like the picture above. The goal of the reduction was to lessen the issue with laser processing and material analysis. Before performing the laser procedure, the material will then be cleaned with a methanol solution in an ultrasonic cleaner. The ultrasonic cleaner is programmed for a 10-minute cycle. After that, the material is rinsed with clean water, and we utilize an air blower to get rid of any excess dirt and cleaning solution to ensure that the surface is thoroughly cleaned.

A focused laser beam is used in the precise manufacturing process of "laser micro cleaning" to remove corrosion from any material's surface. The setup stage of the procedure involves positioning the material to be cleaned on a stage and aligning it with the laser beam. A lens or mirror system is then utilized to focus the laser beam to a small spot size. The stage is then set up to guide the laser beam at the required spot for the surface cleaning. The surface area is then scanned by the laser to verify appropriate alignment. The cleaning stage starts after the alignment is verified. The substance is targeted by the laser beam when it has been activated. As the beam is focused on the material, the corrosion is gradually removed stage by stage in accordance with the parameter configuration. By altering the laser mark loop and line distance, the depth of corrosion may be managed. The analysis is the last step, where surface roughness and corrosion depth are assessed. This can be done by taking measurements of the cleansed material's surface and the corrosion's original surface. Analyzing the smoothness of the clean region and the starting region will reveal the surface roughness. The height of the original laser surface with the cleaned laser surface can be assessed using the mark loops parameter to determine the depth of corrosion as well.

Process Parameter	**Range**
Laser Mark Loop	5, 10, 20, 30, 60, 100
Line Distance	0.005, 0.01

Table 2. Range of Parameter

Mechanical cleaning is the process of eliminating impurities, trash, or undesired items from a surface by applying pressure or abrasion mechanically. It entails physically scrubbing the surface with brushes, scrapers, or other abrasive tools in order to mechanically loosen and remove the undesirable substances. Numerous mechanical cleaning methods may be employed, depending on the properties of the surface and the contaminants to be removed.

Mechanical cleaning techniques can be used on a variety of surfaces, materials, and industries and are frequently efficient for removing tenacious or adherent impurities. Intricate or difficult-to-reach locations, potential surface damage, or labor-intensive methods might be their only drawbacks. In the mechanical material preparation procedure, we will employ the same boron steel with dimensions of 20 mm by 25 mm that we used in the laser cleaning process. For comparison, we'll use the extra material that was created during the laser cleaning process. The material is manually cleaned using a methanol solution for the cleaned portion. We slowly scrape the substance with tissues after applying the methanol solution. We keep doing so until the methanol-scrubbing tissue no longer shows signs of contamination on its surface. If the tissue's surface doesn't become red after being scrubbed, the undesired particles has already been removed from it. Then we rinse with clean water and blow it using air blower to make the cleaning process more efficient.

In mechanical processing, the material is taped with masking tape on the opposite side of the surface area to prevent unintended scratching on the initial surface. The mechanical process then starts utilizing 240, 400, 600, 1200, and 2000 grid sand paper. Starting with 240, 400, 600, and 1200 grid sand paper, we first align four different types of sand paper in the manual grinder machine. Then, moisten the sand paper by turning on the water faucet at the top of the manual grinder machine. Next, we repeatedly scrub the second half of the material into the sand paper, beginning with the lowest grid, until all corrosion has been eliminated. The surface should then be gradually smoothed using sandpaper with progressively larger grid sizes until you reach the final sheet, which has a 2000 grid size. The material is finally prepared to be examined under a 3D microscope for comparison with laser cleaning techniques. For mechanical cleaning, the analysis also started with the measurement of the height between the original surface and the cleaned surface. In addition, it also analyses the surface roughness of the original surface and the cleaned surface like in laser cleaning method.

3.RESULTS AND DISCUSSION

The analysis of micro laser surface cleaning begins with a comprehensive examination of the cleaned surface using a 3D microscope. This advanced microscopy technique allows for precise measurements and evaluation of various surface parameters. The 3D microscope provides valuable insights into the geometry and overall form of the cleaned surface.

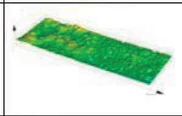
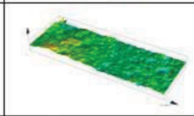
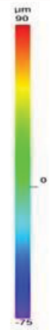
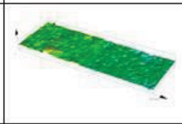
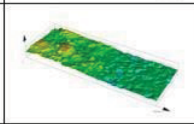
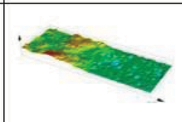
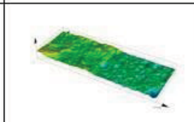
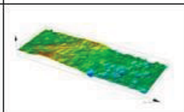
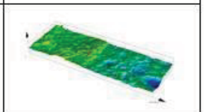
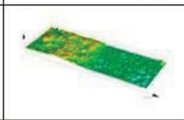
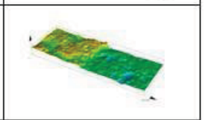
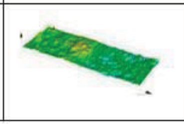
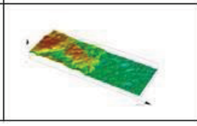
Power (W)	Speed (m/s)	Frequency (Hz)	Mark Loop	Line Distance (µm)		
				0.005	0.001	
60	5500	35	5			
			10			
			20			
			30			
			60			
			100			

Table 3. Range of Parameter with 3d Specimen

According to Table 3, The parameter for power, speed, and frequency in this chapter will be the fix parameters. I set it to a fixed value of 60 watts, 5500 meters per second, and 35 hertz. Mark loop and line distance are the only two parameters we modify here. The number that we choose in this case for the mark loop is 5, 10, 20, 30, 60, and 100 times. The figure we choose for the line distance is between 5 and 10 (µm). The surface area and corrosion depth will both be impacted by these values. As you can see, we used 12 samples in a 3D display to show the depth and surface roughness of the material. The peak value is 90 (µm) and the lowest value is -75 (µm).

Laser Surface Cleaning						
Line Distance (µm)	0.005			0.01		
Mark Loop	Depth (µm)	Surface Roughness (µm)	Initial Surface Roughness (µm)	Depth (µm)	Surface Roughness (µm)	Initial Surface Roughness (µm)
5	23.708	4.693	7.579	22.023	4.892	8.225
10	27.166	4.538	7.556	25.151	4.785	7.494
20	28.618	4.278	8.3	28.081	4.543	7.92
30	36.277	4.181	7.842	32.096	4.424	7.938
60	41.811	3.737	8.205	38.036	4.182	7.818
100	48.429	3.482	8.322	41.698	3.857	8.27
Average	-	-	7.967	-	-	7.944

Table 4. Range of Result for Laser Cleaning Method

Referring to Table 4, the results shown above are for all laser surface cleaning processes that use the two parameters mark loop and line distance for all 12 sample. Data on depth of corrosion and surface roughness can be used to highlight how these two parameters affect each other. As a reference value for this data, we also assess the initial surface roughness data.

Mechanical Cleaning Using Sand Paper			
Data	Depth (μm)	Surface Roughness (μm)	Initial Surface Roughness (μm)
1	28.713	4.373	8.371
2	31.091	4.491	8.565
3	32.29	4.536	8.465
Average	30.698	4.467	8.467

Table 5. List of Result for Mechanical Cleaning Method

Table 5 show the results from our analysis of the mechanical data are shown above. In the data above, we calculated the average values for depth of corrosion, surface roughness after cleaning, and initial surface roughness as a reference value using measurements from 3 distinct samples. With the use of this information, we can compare how the mechanical and laser cleaning methods affect the depth of corrosion and surface roughness

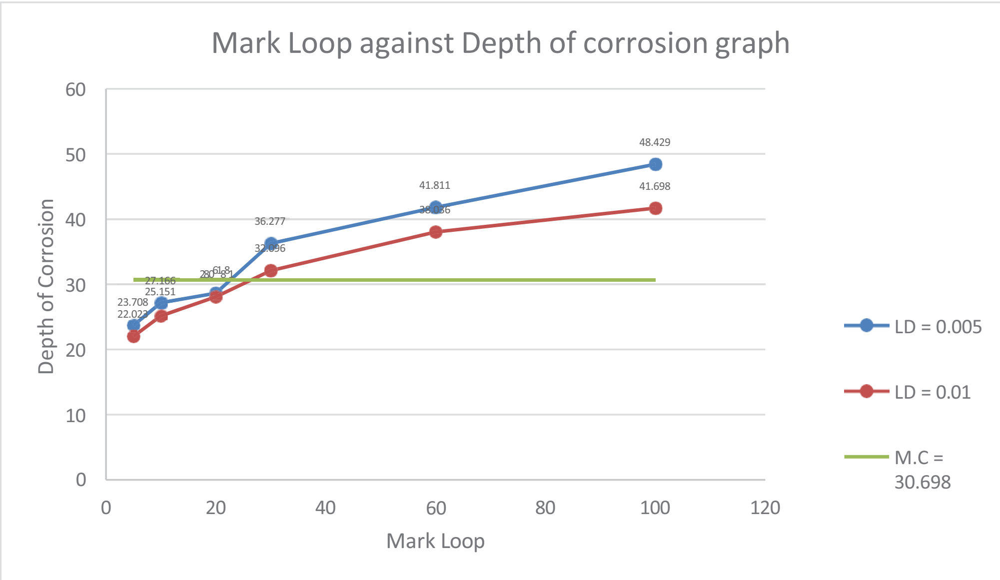


Figure 1. Mark Loop against Depth of Corrosion Graph

According to Figure 1, we can conclude that the depth of corrosion is exponentially increase as the laser mark loop increase. In the graph the LD stand for line distance meanwhile MC stand for mechanical value that we got from table above. The laser mark loop is one of the parameters that affects the depth of corrosion in micro laser surface cleaning. As the laser mark loop increase, more laser passes or repetitions are made over the same region of the surface. The exponential growth in corrosion depth with increasing laser mark loop size may be caused by the cumulative effect of several laser passes. When the laser beam passes over the rusted material, a certain depth of the corrosion layer is ablated or eliminated. As the laser mark loop increase, more lasers pass over the corroded area. As a result, there is a greater deposition of overall energy and a greater removal of material. Repeated exposure to laser radiation causes a more aggressive removal of the corroded material, which exponentially deepens the corrosion.

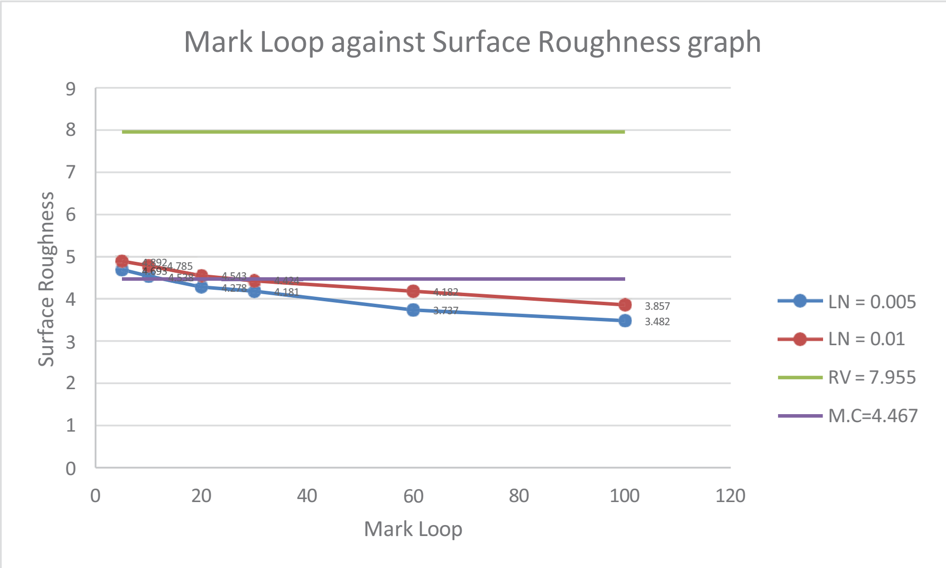


Figure 2. Mark Loop against Surface Roughness Graph

From the graph we can see that the surface roughness is exponentially decrease as the laser mark loop increase. The meaning of RV is reference value which will be the initial value for surface roughness. When the mark loop is increased, it means that the laser beam has made multiple passes or repetitions over the same area during the cleaning process. This can lead to more extensive material removal and a reduction in surface roughness, particularly if the initial surface had significant roughness or corrosion. A smoother overall surface profile can be achieved by removing high spots or protrusions from the surface with multiple laser passes. As a result, as the mark loop increase, the surface area for roughness may decrease, indicating a decrease in the amplitude or height of surface abnormalities.

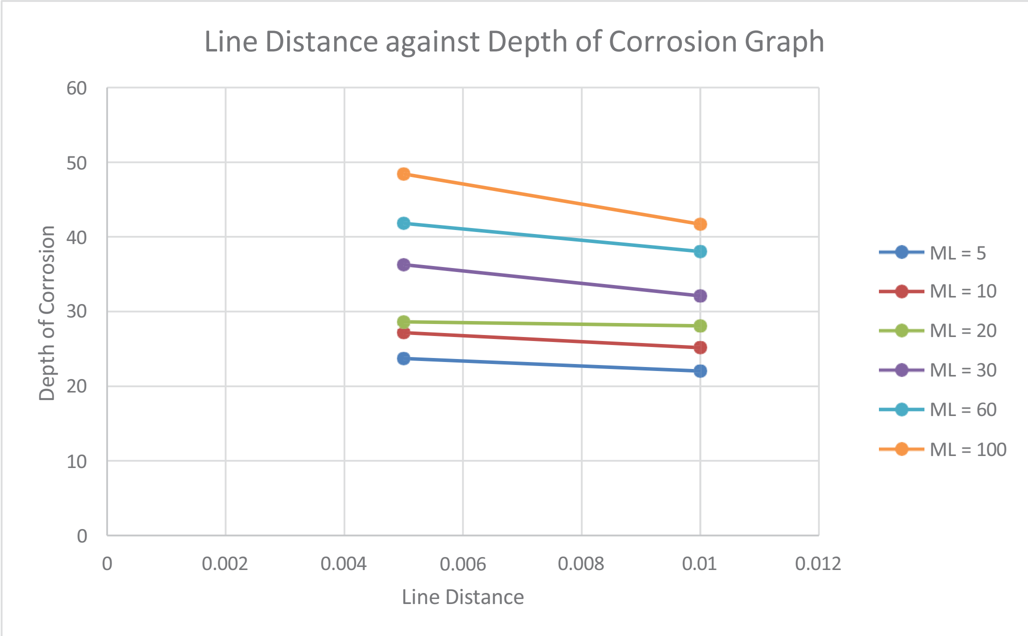


Figure 3. Line Distance against Depth of Corrosion Graph

According to Figure 3, we can conclude that the depth of corrosion is gradually decrease as the line distance increase. When the line distance is increased, it means that the laser beams are spaced further apart during the scanning process. This allows for a larger area to be covered by each laser pass, reducing the overlap between consecutive laser scans. During laser cleaning, a longer line distance may result in more effective heat dispersion and thermal diffusion. As a result, thermal damage to the underlying material and the heat-affected zone are reduced. A deeper depth of corrosion is the result of less severe heating since there is less of a chance of material ablation or removal from above the corroded layer. Nevertheless, it's crucial to keep in mind that there is an ideal line distance that must be chosen depending on the particular cleaning requirements, material qualities, and features of the corroded surface. If the line distance is too large, the corrosion or impurities may not be completely removed, whereas if the line distance is too tiny, too much material may be removed and the substrate may be damaged.

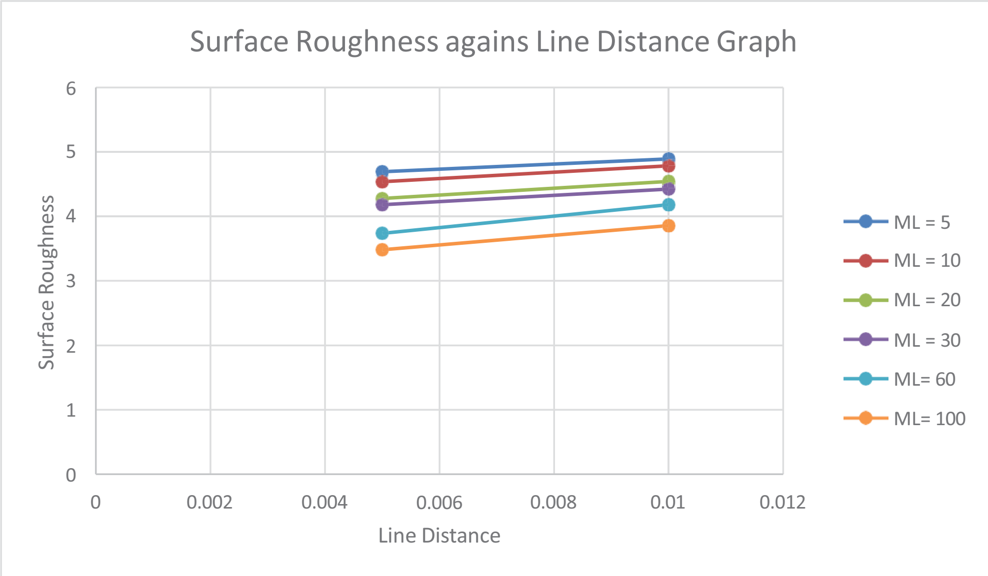


Figure 4. Surface Roughness against Line Distance Graph

From the graph we can see that the surface roughness increases as the line distance increase. When the line distance in laser cleaning is increased, it means that the laser beams are spaced further apart during the scanning process, resulting in larger gaps between the laser tracks. In certain cases, this increased line distance can lead to an increase in surface roughness. One reason for this is the potential for insufficient coverage, where gaps between laser tracks may lead to incomplete cleaning and the presence of residual contaminants or corrosion. These remaining imperfections can contribute to an increase in surface roughness.

Another factor is the reduced overlap between adjacent laser tracks. Overlapping laser tracks help ensure thorough and uniform cleaning. With a larger line distance, the amount of overlap is reduced, resulting in uneven cleaning and potential variations in surface roughness. Inadequate energy distribution may also be a result for the longer line distance. Lower energy density on the surface results from the laser beam's energy dissipating over a wider area. The level of surface smoothness that is sought or the efficient removal of impurities may not be possible with this reduced energy density. As a result, the roughness of the surface may be more obvious.

Energy concentration on the surface can be improved by changing the laser's power and pulse duration, utilizing a smaller beam size, making numerous passes, experimenting with different scanning patterns, and incorporating real-time monitoring systems. The effectiveness of cleaning and smoothing is maintained despite increased line lengths because to the cooperative action of these solutions, which also optimize the laser cleaning procedure.

4.CONCLUSION

In conclusion, this study has produced significant findings about the interaction of laser cleaning factors, specifically mark loop length and line distance, and their significant impacts on the corrosion cleaning process for boron steel. Through a meticulous analysis of these factors, it has not only illuminated the optimal conditions for corrosion removal but also emphasized the clear advantages of laser cleaning over traditional mechanical methods. Specifically, in terms of corrosion depth, the research highlights that controlled adjustments in laser parameters, such as mark loop length, directly influence the depth of corrosion removal. Laser cleaning's precision and controllability emerge as key factors, enabling the removal of corrosion without excessive material loss.

Moreover, with regard to surface roughness, the study underscores the fine-tuning capability of laser parameters in influencing the resulting roughness. Unlike mechanical methods, where surface irregularities can arise due to abrasive actions, laser cleaning allows for a more tailored approach. The outcomes reveal that by carefully adjusting parameters like line distance, the surface roughness can be maintained within desired limits, offering a smoother finish compared to mechanical alternatives. The study therefore not only deepens our understanding of the impact of laser parameters on boron steel but also firmly establishes the superiority of laser cleaning in terms of precision, controllability, and achieving desired surface characteristics, all of which are critical for maintaining the material's integrity and performance.

4.1 DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

4.2 CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Irfan Bin Azman: Conceptualization, Methodology, Writing-Original draft preparation, Data curation, Investigation. Dr. Moinuddin Mohammed Quazi: Writing-Reviewing and Editing. Dr. Aiman Bin Mohd Halil: Visualization, Supervision, Validation, Professor Dr. Mahadzir bin Ishak @ Mohammad: Writing- Reviewing and Editing.

5.ACKNOWLEDGEMENTS

The authors would like to thank Universiti Malaysia Pahang for funding this research under the Internal Grant PDU213002-2. The author would like to thank the technical team at Universiti Malaysia Pahang for their work in providing laboratory facilities for materials preparation and laser texturing equipment at the Faculty of Mechanical and Automotive Engineering Technology, including the 3D confocal microscope at the Faculty of Manufacturing Engineering.

6.REFERENCES

1. Baruah, M., Prasad, S. B., Tudu, N., Murmu, B. K., & Singh, S. (2020). Experimental investigation of Inconel welded joints formed by pulsed micro plasma welding. Materials Today: Proceedings, 33, 5751–5756. https://doi.org/10.1016/j.matpr.2020.06.604
2. Cai, X., Li, H., Wan, L., Xu, G., Yu, H., Sun, D., Nie, H., & Deng, Z. (2023). Microstructural characterization and mechanical properties of Ti3Al-Nb/Ni-based superalloy laser-welded joints with different type of V/Cu composite interlayers. Optics and Laser Technology, 157(September 2022), 108736. https://doi.org/10.1016/j.optlastec.2022.108736
3. Desai, R. S., & Bag, S. (2014). Influence of displacement constraints in thermomechanical analysis of laser micro surface cleaning process. Journal of Manufacturing Processes, 16(2), 264–275. https://doi.org/10.1016/j.jmapro.2013.10.002
4. Dontu, O., Ganatsios, S., Besnea, D., & Beca, P. (2008). <title>Micro cleaning of stainless steel by pulsed Nd: YAG laser</title>. May, 70070O-70070O – 6. https://doi.org/10.1117/12.802020
5. Haddad, E., Chung, W. S., Katz, O., Helm, J., Olowinsky, A., & Gillner, A. (2022). Laser micro cleaning with fiber lasers for battery and fuel cell based electromobility. Journal of Advanced Joining Processes, 5(November 2021), 100085. https://doi.org/10.1016/j.jajp.2021.100085
6. Haddad, E., Helm, J., Olowinsky, A., & Gillner, A. (2020). Nanosecond pulsed fiber laser as a tool for laser micro cleaning. Procedia CIRP, 94, 571–576. https://doi.org/10.1016/j.procir.2020.09.077
7. Hummel, M., Schöler, C., Häusler, A., Gillner, A., & Poprawe, R. (2020). New approaches on laser micro cleaning of copper by using a laser beam source with a wavelength of 450 nm. Journal of Advanced Joining Processes, 1(November 2019), 100012. https://doi.org/10.1016/j.jajp.2020.100012
8. Kumar, B., Kebede, D., & Bag, S. (2018). Microstructure evolution in thin sheet laser cleaning of titanium alloy. International Journal of Mechatronics and Manufacturing Systems, 11(2–3), 203–229. https://doi.org/10.1504/IJMMS.2018.092875
9. Lin, H. L., & Chou, C. P. (2008). Modeling and optimization of Nd:YAG laser micro cleaning process using Taguchi Method and a neural network. International Journal of Advanced Manufacturing Technology, 37(5–6), 513–522. https://doi.org/10.1007/s00170-007-0982-3
10. Mehlmann, B., Olowinsky, A., Thuilot, M., & Gillner, A. (2014). Spatially modulated laser beam micro welding of CuSn6 and nickel-plated DC04 steel for battery applications. Journal of Laser Micro Nanoengineering, 9(3), 276–281. https://doi.org/10.2961/jlmn.2014.03.0019
11. Nawi, I. N., Saktioto, Fadhali, M., Hussain, M. S., Ali, J., & Yupapin, P. P. (2011). Nd:YAG laser cleaning of stainless steel 304 for photonics device packaging. Procedia Engineering, 8, 374–379. https://doi.org/10.1016/j.proeng.2011.03.069
12. Walsh, C. A. (2002). LASER CLEANING - Literature Review. July.
13. Yan, S., Li, Z., Song, L., Zhang, Y., & Wei, S. (2023). Research and development status of laser micro-cleaning of aluminum-copper dissimilar metals: A review. Optics and Lasers in Engineering, 161(September 2022), 107312. https://doi.org/10.1016/j.optlaseng.2022.107312
14. Yan, S., & Shi, Y. (2019). Influence of laser power on microstructure and mechanical property of laser surface cleaning Al/Cu dissimilar lap joints. Journal of Manufacturing Processes, 45(7089), 312–321. https://doi.org/10.1016/j.jmapro.2019.07.009
15. Zhong, Y., Xie, J., Chen, Y., Yin, L., He, P., & Lu, W. (2022). Microstructure and mechanical properties of micro laser cleaning NiTiNb/Ti6Al4V dissimilar alloys lap joints with nickel interlayer. Materials Letters, 306(August 2021), 130896. https://doi.org/10.1016/j.matlet.2021.130896
16. K. I. Yaakob, M. Ishak, S. R. A. Idris, M. H. Aiman & M. M. Quazi. (2017). Characterization of heat-treated gas metal arc-welded boron steel sheets.

http://umpir.ump.edu.my/id/eprint/19226/1/fkm-2018-mishak-Characterization%20of%20heat-treated%20gas%20metal%20arc-welded1.pdf

17. M. N. M Salleh, M. Ishak, M. H. Aiman, Q. Zaifuddin & M. M. Quazi. (2014). The effect of laser surface hardening on the surface hardness of mild steel. https://www.researchgate.net/publication/341979428_The_effect_of_laser_surface_hardening_on_the_surface_hardness_of_mild_steel
18. Y. Arshad, R. Linggamm, M. M. Quazi, M. H. Aiman, M. Ishak, A. Q. Zaifuddin & Abdullah Qaban. (2021). Laser Surface Modification of Duplex Stainless Steel 2205 to Modify the Surface Roughness. https://journal.ump.edu.my/ijame/article/view/5975