IJL, Issue 1, Vol. 23, 2024
https://doi.org/10.31900/ijl.v23i1.426

Research Article

IRAQI JOURNAL OF LASER

Effect of laser cleaning parameters on aluminum 6061 surface properties

Zahraa M.saleh*, Ziad Aeyad Taha

Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq
** Email address of the Corresponding Author: zahraa.mohammed1101a@ilps.uobaghdad.edu.iq*

Article history: Received 4 Oct.2023; Revised 14 Nov. 2023;Accepted 14 Nov. 2023; Published online 15 Jun. 2024

Abstract: This study investigates the crucial factors influencing laser cleaning processes, with a primary focus on aluminum 6061 surfaces. Laser power emerges as the central determinant, as higher power levels intensify the laser-matter interaction, leading to enhanced removal of oxide layers. A Microsecond fiber laser with a wavelength of 1064 nm was used in this study to identify optimal cleaning conditions, comprising parameters such as 3W power, a hatch value of 0.003, a speed of 150 mm/s, and a spot size of 200 µm. Furthermore, the research uncovers intriguing insights into the impact of cleaning speed on oxygen levels, revealing that higher speeds result in increased oxygen levels due to dual heat sources—laser beam and heat transfer from adjacent cleaned lines. The hatch parameter's role is highlighted in controlling the overlapping ratio, where closer line spacing leads to more effective cleaning and reduced surface oxygen content, while wider line spacing impedes cleaning between lines. Additionally, the study explores the potential enhancement of wear rates through laser cleaning, with material roughness playing a critical role, and notes that cleaned samples exhibit fewer defects in their microstructure compared to their uncleaned counterparts. These findings contribute valuable insights to the field of laser cleaning and its applications in surface treatment and material quality improvement.

Keywords: laser cleaning, aluminum 6061, oxide layer, roughness, wear.

1. Introduction

Nowadays, the aluminum alloy is a common material that widely used in industry due to its high strength, light weight , good weldability and corrosion resistance, it has good application in fields of shipbuilding, aerospace, and automobile [1-3]. However, aluminum has grate propensity to oxidize in the natural environment, with an oxide thin layer forming on the surface which is possibly contain impurities [4,5].
As is well-known, cleaning technology is particularly important for traditional industry like pre welding process in order to eradicate the contamination on the surface. Lately, there have been plenty of studies focusing on laser cleaning technology and its efficacy [6-8]. The main purpose of laser cleaning is to remove the oxide substrate on the metal surface. So, the cleaning of the oxide is generally identified by the oxygen content [2]. Latterly, some studies showed that laser cleaning has a significant effect on welding. Apparently, it could reduce welding defects with optimal laser cleaning parameters [9]. The laser cleaning

technique is an interaction between laser light and the substrate; therefore, the binding force between the substrate and the contaminant attached to the substrate surface is disrupted, and the contaminant on the substrate surface is detached from the substrate surface by evaporation, vibration, and impact [10,11]. Noteworthy, the energy density of the laser was the key factor affecting the cleaning process and surface quality In most cases, and the laser cleaning would cause an increase in surface roughness [12,13]. The proper laser cleaning process parameters can remove the rusting and grease from the workpiece surface[14]. Additionally, scanning speed has a significant effect on cleaning by changing heat accumulation on the surface of the rust layer [15,16]. When the roughness slightly increased with the laser power increasing also pulse frequency.

This study aims to remove the oxide layer from the aluminum 6061 surface through laser cleaning by using laser power, scanning speed, and line spacing (hatch) as variants of the cleaning process to examine their effects on the cleaning rate and identify the best parameters for removing oxide layer also explore the relationship between each variant and surface roughness.

2. Experimental procedures

In this study, aluminum alloy 6061 sheets (2 mm in thickness) were used as samples. The sample was cleaned with ethanol and air-dried at room temperature. The chemical composition of 6061 Al alloy is shown in Table 1.

Table 1. 6061 aluminum alloy chemical composition [17].

elements	Si	Fe	Cu	Mn	Mg	Zn	Cr	Al
experimental	0.6	0.36	0.2	0.05	0.95	0.04	0.13	Reminder
standard	0.4-0.8	≤ 0.7	0.15-0.4	≤ 0.15	0.8-1.2	≤ 0.25	0.04-0.35	Reminder

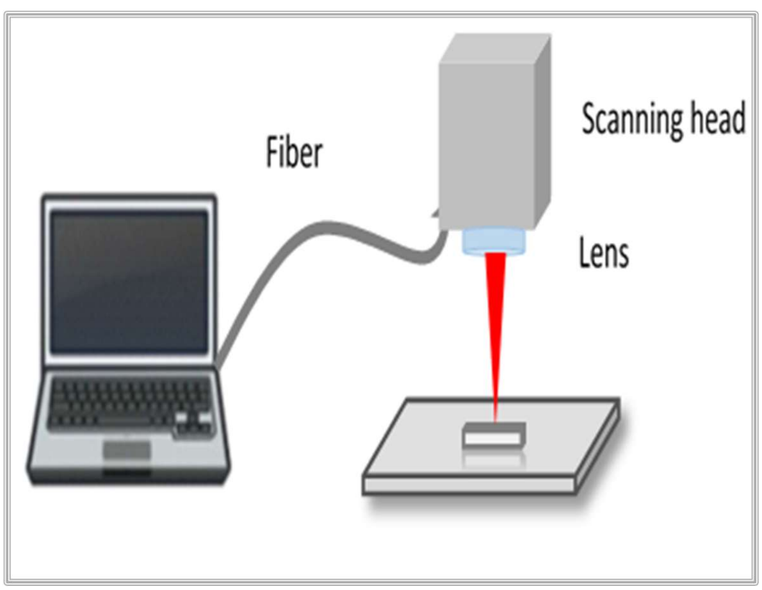

Fig. 1: Schematic of laser cleaning system.

Table 2. Main parameters of laser cleaning.

Parameter	Symbol	Value	Units
Wavelength	λ	1064	nm
Average power	P	10	W
Pulse width	T	10	µs
Pulse spot size	d	200	µm
Pulse repletion rate	p.r.r	20	kHz
scanning speed	V	50-250	mm/s

For laser cleaning, a fiber laser was used in this research. The system was equipped with a galvanometric scanning head, which controls the laser beam's motion in two directions, as shown in Figure 1. A special computer software was used to control the scanning head and to input laser parameters of the cleaning process, which are presented in Table 2.

For laser cleaning, different parameters were employed during the experiment, like speed, power, and hatch (line spacing). A number of trial experiments were carried out before determining the requested experiment range based on the criteria of avoiding the whiting (overheating) and ablation of base material with the oxide layer. A laser cleaning procedure has been carried out on aluminum alloy 6061 to remove a thin oxidation coating by manipulating different parameters with different values; laser power was varied in the range of (1-6)W, scanning speed (50,100,150,200,250)mm/s, and hatch (0.0005, 0.001,0.005,0.01) mm. The laser used in this work was (ytterbium fiber laser). In order to study the effect of laser cleaning aluminum alloy substrate, for surface characterization, scanning electron microscopy (SEM) was used. The chemical compositions and the oxygen contents were characterized using an energy-dispersive spectrometer (EDS). Also surface roughness of each sample was measured. Three positions of each sample were selected to calculate the mean value. In order to clean the entire surface area, the special strategy was based on the overlap in two dimensions depending on the scanning speed and frequency in the X axes and line spacing (Hatch) in the Y axes, as shown in Figure 2.

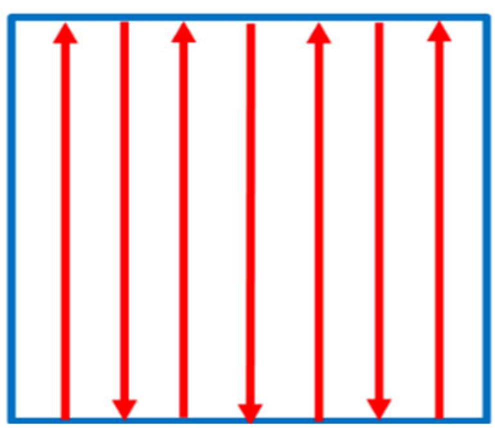

Fig.2: laser scanning strategy.

The overlapping rates of the X and Y axes can be calculated by using Eqs. (1) and (2) respectively[18].

$$Ox = \left(1 - \frac{v/f}{D+v\tau}\right) \times 100 \quad (1)$$

$$OY = \left(1 - \frac{P}{D}\right) \times 100 \qquad (2)$$

Where ν is the beam scanning speed,f is the laser repetition rate, D is the laser spot diameter at the focal plane, τ is the pulse duration, and p is the step size (hatch).

For Wear rate investigation, sliding wear resistance has been conducted by a pin on steel disk method. The conditions through the tests were controlled to be: Normal force (N) = 5 N, speed of sliding (S) = 950 r.p.m, total sliding distance (D) = 65 mm, and time for the test were (5,10,15)min for each sample. Also, the roughness rate was measured by the SRT-6210 roughness device before and after the laser cleaning process.

3. Results and discussion

3.1. effect of laser power

Several power were employed from (1-10)W. Primary results showed that the power below 1 W was insufficient to influence the substance, with no reduction in oxygen content as well as no change in metal surface appearance (brightness), and the power above 6W, the oxygen content increased significantly, and an additional oxide layer formed with dark grey color and at maximum powers, the aluminum 6061 began to vaporize causing engraving of the metal surface. The effective laser cleaning parameter was from power 3 W to 6 W as the result of EDX clarified, as shown in Figure 3. The reduction in oxygen content exceeded 5W when compared to the uncleaned aluminum. The optimal outcome was observed at a 3W power level, a finding that agrees with the EDX mapping analysis in Figure 4; the mapping analysis of the aluminum 6061 surface shows oxygen content in green dots. Increasing the power above 5W led to a subsequent rise in the oxygen content, which was attributed to the formation of an additional oxide layer with a nanometer-scale on the metal surface, as shown in SEM images in figure (5) [19,20].Hence, the material exhibited a dark grey coloration at higher power levels.

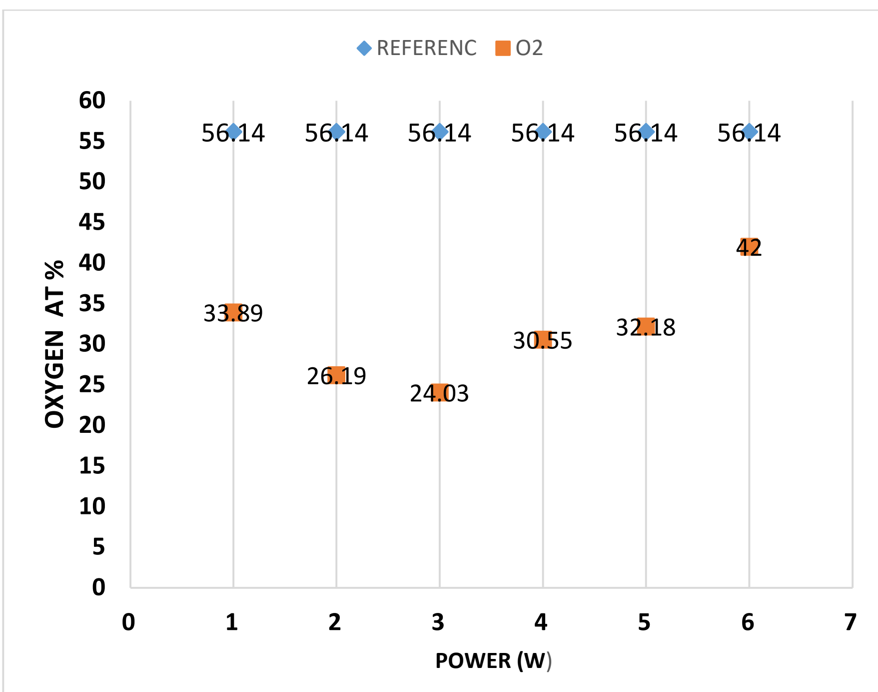

Fig. 3: surface oxygen content of the sample changes with cleaning power.

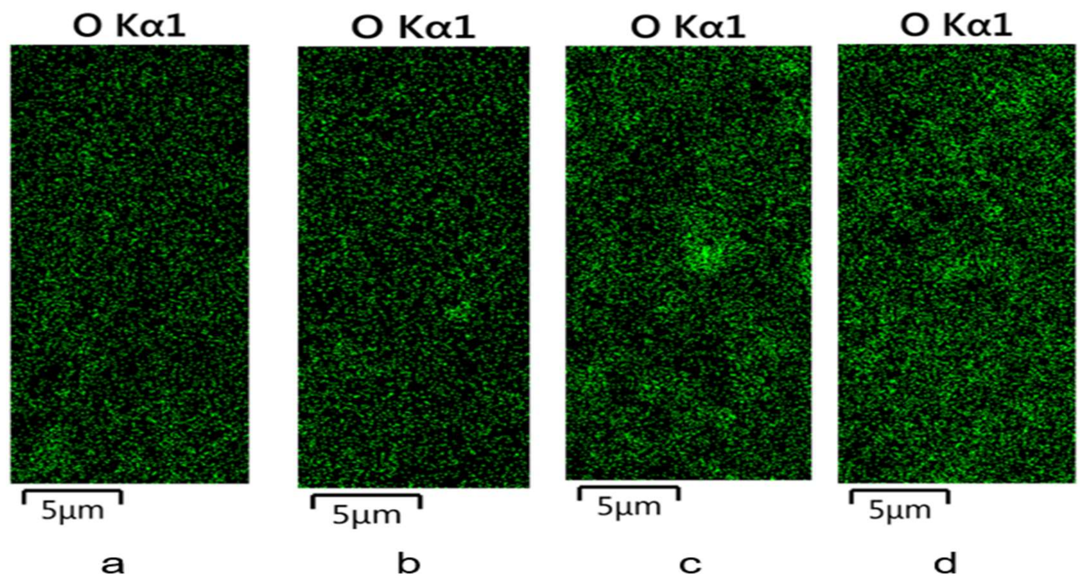

Fig. 4: EDS Mapping of oxygen content on the surface at (a) 2 W, (b)3 W ,(c) 4W, and (d) reference (no cleaning) the green dots are the oxygen particles.

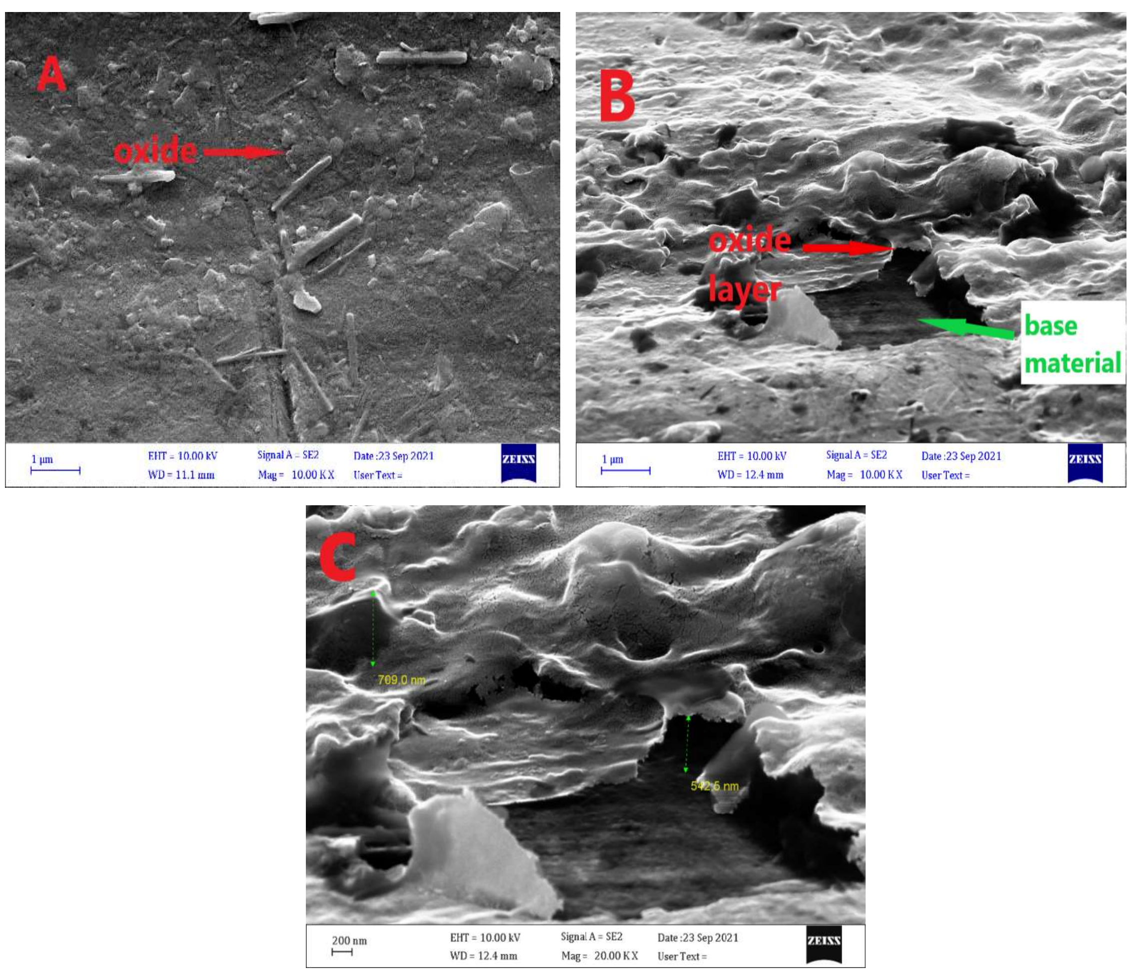

Fig. 5: SEM images for aluminum alloy 6061 A.as reserved B&C. different magnification for cleaned sample with power 5W speed ,150mm/s and hatch 0.004mm.

3.2. effect of laser cleaning speed

At low scanning speed (25mm/s) was not suitable for cleaning due to heat accumulation of aluminum, at (50mm/s) the oxygen content started to reduce, and the optimum result was from (100-150)mm/s the oxygen percentage was reduced by more than 40% from the uncleansed material, and then the oxygen content start to raise again as shown in Figure 6.

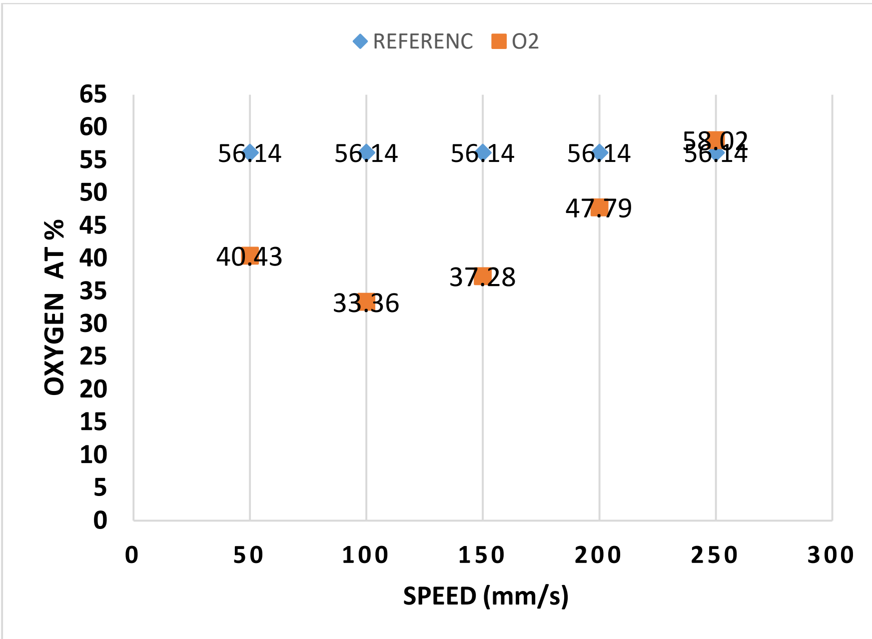

Fig 3 : Oxygen content change at different laser cleaning speeds.

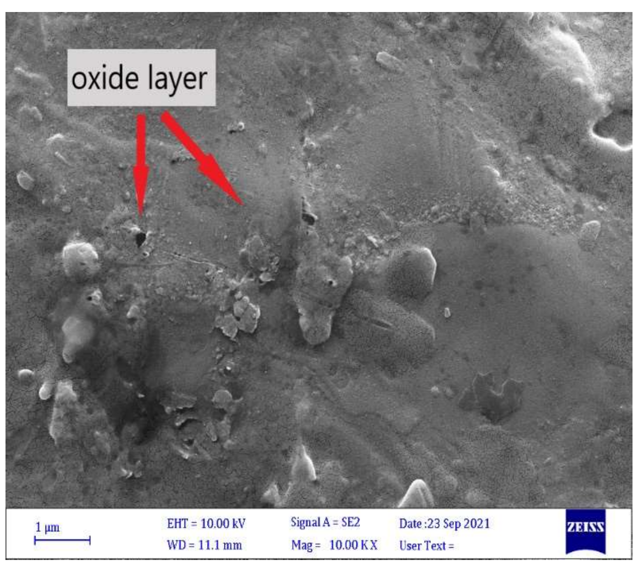

Fig.7: SEM images for aluminum alloy 6061 at high speed 400mm/s, power 3 W, and hatch 0.004 mm.

Beyond a speed of 400 mm/s, the cleaning process exhibited instability. Observations from the experiments revealed that the laser-material interaction initially proceeded normally but then transitioned into an aggressive interaction marked by sparks. This indicated the formation of an additional oxide layer, as shown in Figure 7; these findings contradicted previous research, which suggested that increasing speed would result in decreased energy absorption by the material because of the lower scanning speed of the laser; much more energy is given to the surface. This energy is absorbed and transformed in phonons that increase the material temperature [21]. We proposed that during laser scanning in a line pattern, high speeds introduce two sources of heat to the line: the first comes from the laser beam itself, while the second arises from the heat transferred from the previously cleaned adjacent line, effectively acting as a form of preheating for the material.

3.3. effect of line spacing (hatch)

Different hatch values were used from (0.0005 to 0.01) mm. At the smallest hatch, the oxygen content was high because of the high overlapping ratio, and it began to decrease by increasing the hatch value. At (0.005), the O2 percentage started to rise due to the diminished overlapping, so some places in the specimen will not be cleaned from the oxidation, as it is shown in Figure 8.

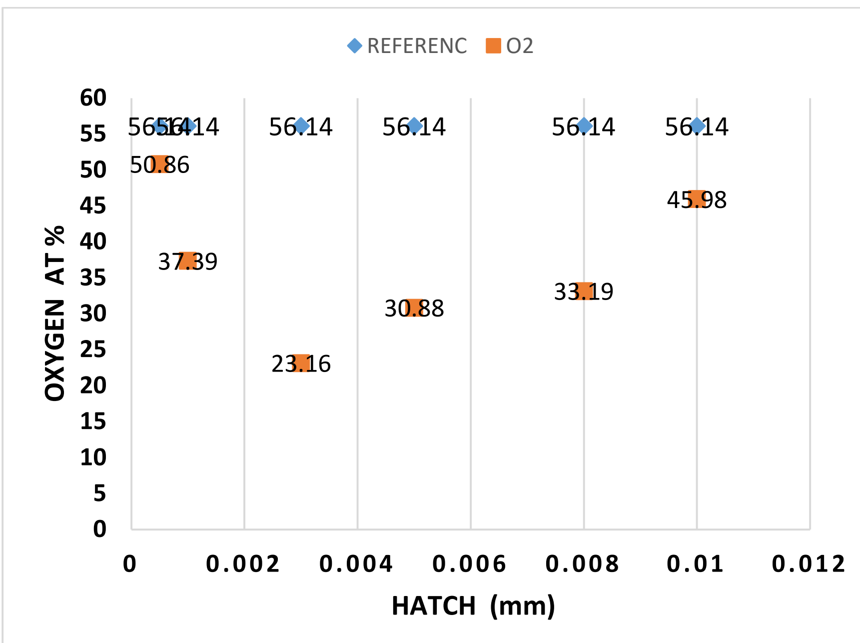

Fig. 4: surface oxygen content changes with Hatch.

4. Roughness test

Surface roughness plays a substantial role in the absorption of incident light by the laser-colored aluminum surface. This was due to the multiple reflections occurring within the hills and valleys of the surface, which lead to enhance the absorption rate hence improvement in the weld quality. Figures 9, 10 and 11 Shows the roughness test results for power, speed and hatch factor respectively .The roughness increases as the power increased less roughness rate was obtained at power 1W and the maximum roughness rate was at 6W power. Regarding the influence of speed, for speeds below 100 mm/s, the roughness of the base material was lower than that of the cleaned material. This behavior remained consistent for high speeds as well. The minimum roughness value was observed at a speed of 150 mm/s. About the hatch factor the roughness value was high when the hatch was small because of high overlapping, and it became to decrease by increasing the hatch till it reached nearly the same value as base material.

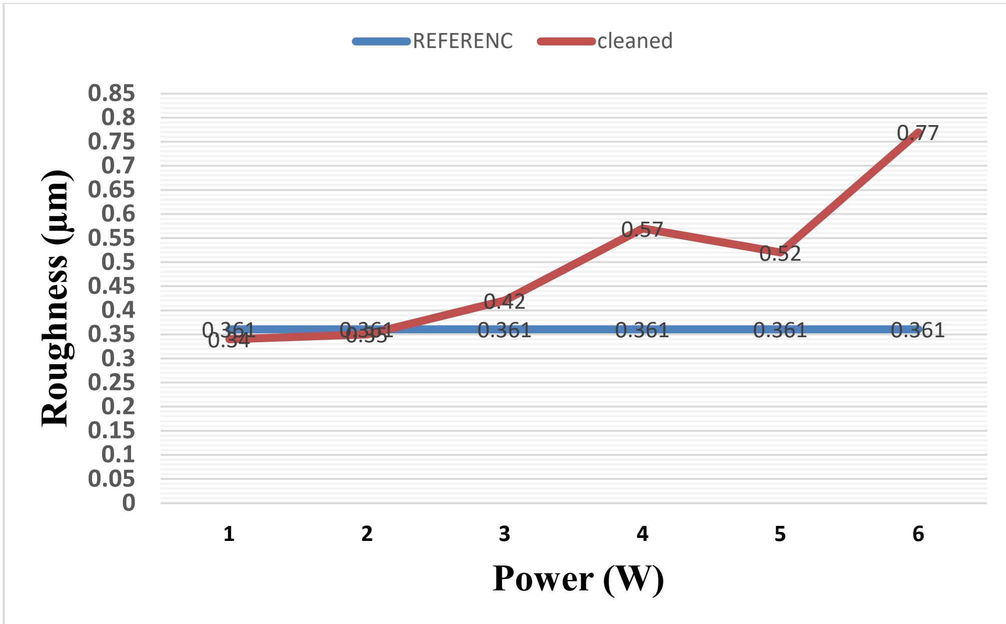

Fig. 9: The roughness for different power of cleaning.

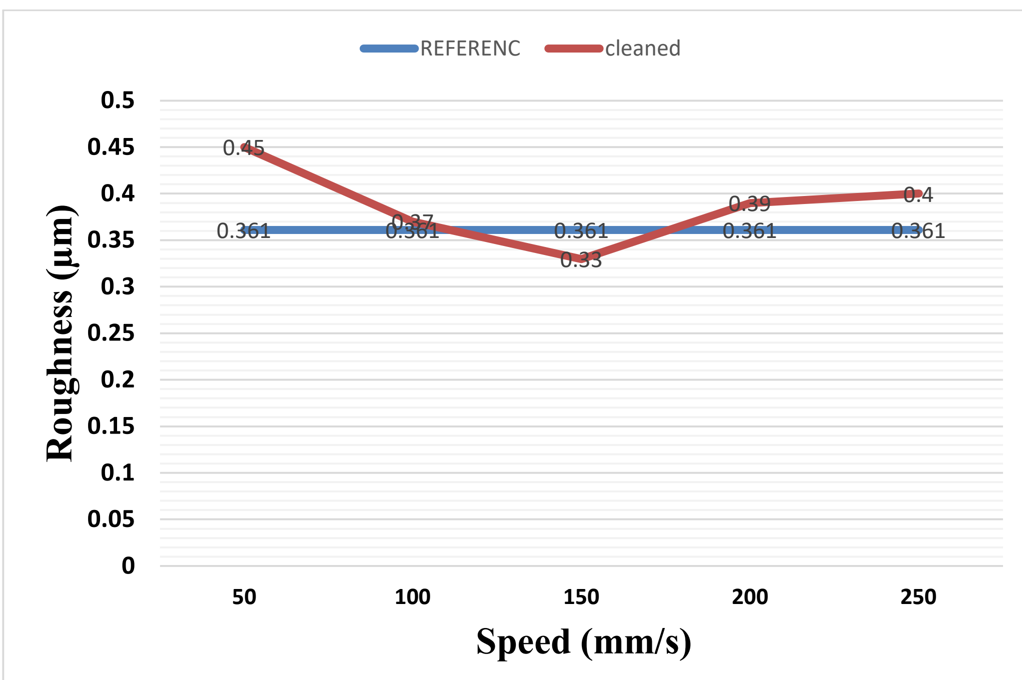

Fig. 10: The roughness for different speeds of cleaning.

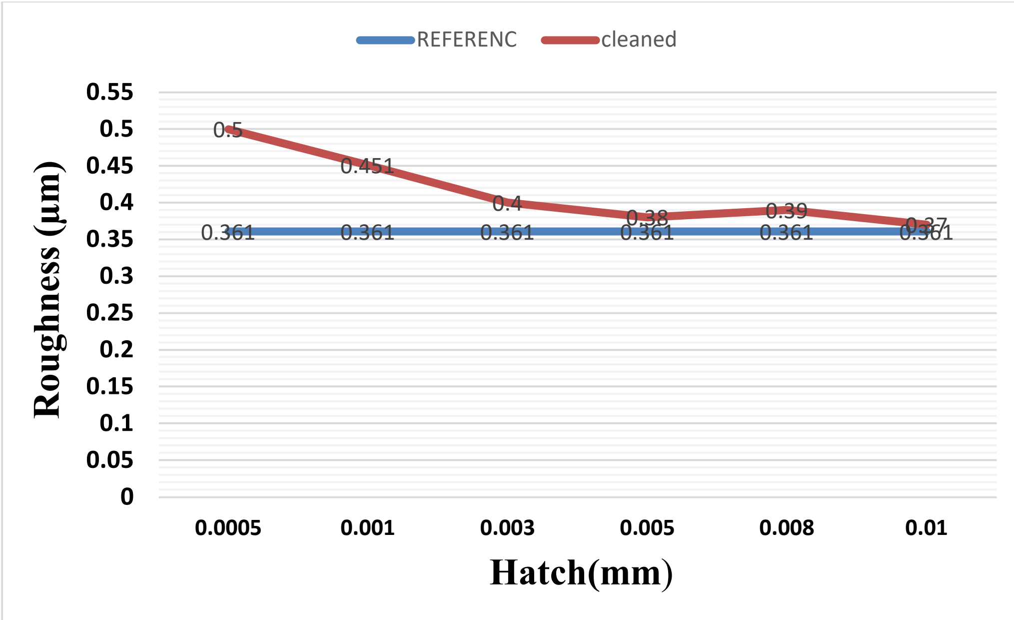

Fig. 11: The roughness for different line spacing (hatch).

5. Wear test

The wear resistance test was carried out for power (10% and 60 %) speed(50 and 150 mm/s) and hatch (0.0005 and 0.01mm). Also, the base material (without cleaning) was tested, and the samples were subjected to the same load for a similar period of time; Figure 12 illustrates the wear test results. The wear mainly increased with time increasing. The best result was at a power of 10 %, which is attributed to the low roughness value, which has a direct relation with the wear rate. Similarly, at 150mm/s speed, the wear rate was less than the base material due to the low roughness. The maximum wear rate was at 0.0005 mm hatch; this may be related to a new oxide layer of aluminum alloy that formed due to high accumulated heat; this oxide layer has low adhesion to the base material, which led to an increased depth of wear scar [22].

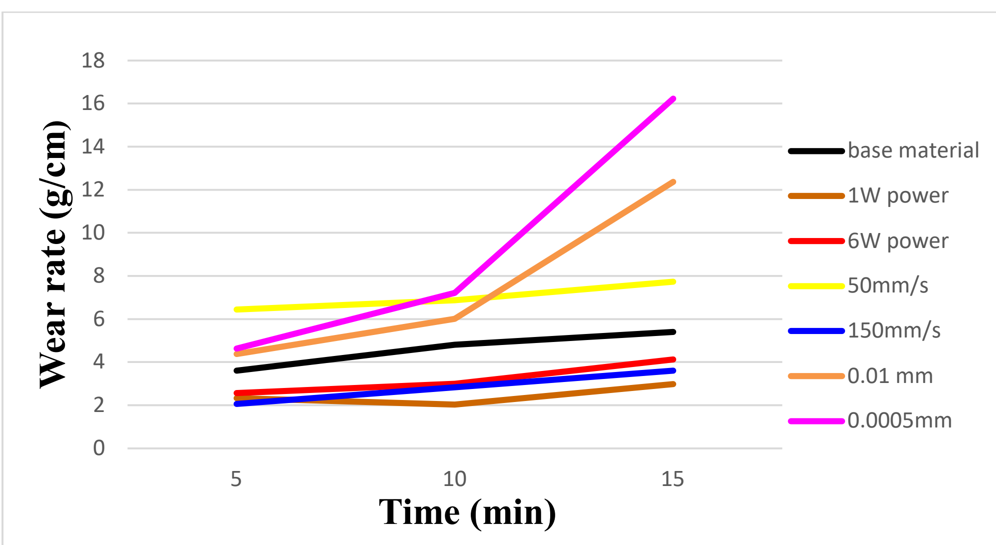

Fig. 12: Wear rate for aluminum 6061 cleaned with different parameters.

6. Conclusion

1. The key factor in the cleaning process is laser power, where higher power intensifies the laser-matter interaction, resulting in increased oxidation removal from the surfaces of aluminum 6061.
2. These effective cleaning results were achieved using parameters such as 3W power, a hatch of 0.003, a speed of 150 mm/s, and a spot size of 200 µm.
3. When cleaning at high speeds, oxygen (O_2) levels increase. The explanation is that during laser scanning in a line style, the high speed causes the line to receive heat from both the laser beam and the adjacent line that was cleaned previously, acting as preheating for the substances.
4. The hatch parameter plays a significant role in the cleaning process by controlling the overlapping ratio directly; closer line spacing leads to a higher overlapping ratio, resulting in more effective cleaning
5. Laser cleaning has the potential to enhance wear rate, with the extent of enhancement being directly related to material roughness. The microstructure of cleaned samples exhibits fewer defects compared to those left uncleaned.

References

[1] Hirsch, J. Recent development in aluminium for automotive applications. Trans. Nonferrous Met. Soc. China. 2014, 24, 1995–2002
[2] Zhu, Guodong, et al. "Investigation on the surface properties of 5A12 aluminum alloy after Nd: YAG laser cleaning." Coatings 9.9 (2019): 578.
[3] Khudhair AM, Hussein FI. High-Speed Shock Peening by Fiber Laser for Al Alloy 6061-T6 Thin Sheets. J Mater Eng Perform. 2022;31(10):8585-8595.
[4] Tawfeeq, I.S. and Taha, Z.A., 2022. Study the absorbance and band-gap of AL-4004 alloy via angular laser cleaning. Optik, 269, p.169842.
[5] AlShaer, A.W.; Li, L.; Mistry, A. The effects of short pulse laser surface cleaning on porosity formation and reduction in laser welding of aluminium alloy for automotive component manufacture. Opt. Laser Technol. 2014, 64, 162–171
[6] T. Shi, C. Wang, G. Mi, F. Yan, A study of microstructure and mechanical properties of aluminum alloy using laser cleaning, J. Manuf. Processes 42 (2019) 60-66
[7] M.K.A.A. Razab, A.M. Noor, M.S. Jaafar, N.H. Abdullah, F.M. Suhaimi, M. Mohamed, et al., A review of incorporating Nd: YAG laser cleaning principal in automotive industry, J. Radiat. Res. Appl. Sci. 11 (2018) 393-402
[8] Tawfeeq, I.S. and Taha, Z.A., 2022. The effect of laser parameters on the angular cleaning of aluminum 4004 alloy. Optik, 271, p.170078.
[9] Li R, Yue J, Shao X, Wang C, Yan F, Hu X (2015) A study of thick plate ultra-narrow-gap multi-pass multi-layer laser welding
[10] Bäuerle, D. Laser Processing and Chemistry; Springer Science & Business Media, Springer: Berlin, Germany, 2013.
[11] Shaker, E. and Taha, Z.A., 2023. Angular Laser Cleaning of Aluminum Al-4004 with Different Spot Sizes. Iraqi Journal of Laser, 22(1), pp.9-17.
[12] Zhang, Guangxing, et al. "Effect of laser cleaning process parameters on the surface roughness of 5754-grade aluminum alloy." The International Journal of Advanced Manufacturing Technology 105.5 (2019): 2481-2490
[13] Messaoudi H, Mehrafsun S, Tromenschläger W (2017) Picosecond laser cleaning of hot stamped 22MnB5 steel. J Mater Sci Surface Eng 5(1):504–508
[14] Zhu, L., Sun, B., Li, Z., Pan, X., Chen, Y. and Cao, Y., 2020. The weld quality improvement via laser cleaning pre-treatment for laser butt welding of the HSLA steel plates. *Welding in the World*, *64*, pp.1715-1723.
[15] Wang Z, Zeng X, Huang W (2003) Parameters and surface performance of laser removal of rust layer on A3 steel. Surf Coat Technol 166(1):10–16
[16] Ali, S.N., Taha, Z.A. and Mansour, T.S., 2014. Laser cleaning using Q-switched Nd: YAG laser of low carbon steel alloys. Advances in Condensed Matter Physics, 2014
[17] 6. Davis JR. Aluminum and aluminum alloys. ASM international; 2001
[18] J. Sabbaghzadeh et al., "Effect of process parameters on the melting ratio in overlap pulsed laser welding," Metall. Mater. Trans. B 39(2), 340–347 (2008).

[19] Andreeva, Y.M., Luong, V.C., Lutoshina, D.S., Medvedev, O.S., Mikhailovskii, V.Y., Moskvin, M.K., Odintsova, G.V., Romanov, V.V., Shchedrina, N.N. and Veiko, V.P., 2019. Laser coloration of metals in visual art and design. Optical Materials Express, 9(3), pp.1310-1319
[20] Khafaji, N.Y., Demir, A.G., Taha, Z.A. and Previtali, B., 2019. Influence of Processing Gas Composition on Laser Colouring of Commercially Pure Titanium. Lasers in Engineering (Old City Publishing), 42.
[21] Maltais, J., Brochu, V., Frayssinous, C., Vallée, R., Godmaire, X. and Fraser, A., 2016. Surface analysis study of laser marking of aluminum. Proceedings of ICSOBA
[22] Ren, Y., Wang, L., Li, J., Cheng, W. and Ma, X., 2022. The surface properties of an aviation aluminum alloy after laser cleaning. Coatings, 12(2), p.273.

تأثير عوامل التنظيف بالليزر على خصائص سطح الألومنيوم 6061

زهراء محمد صالح ، زياد اياد طه

معهد الليزر للدراسات العليا، جامعة بغداد، بغداد، العراق

*البريد الالكتروني للباحث: Zahraa.mohammed1101a@ilps.uobaghdad.edu.iq

الخلاصة: تتناول هذه الدراسة التحقيق في العوامل الحاسمة التي تؤثر على عمليات تنظيف الليزر، مع التركيز الأساسي على سطوح الألومنيوم 6061. يظهر القدرة الليزرية كعامل محوري، حيث تزيد مستويات القدرة العالية من تفاعل الليزر مع المادة، مما يؤدي إلى إزالة محسنة للطبقات الأكسيدية. تحدد الدراسة شروط التنظيف الأمثل، متضمنةً معلمات مثل 3,واط من القدرة، قيمة تقاطع بمقدار 0.003، سرعة 150 ملم/ث، وحجم بقعة الليزر بمقدار 200 ميكرومتر. علاوة على ذلك، تكشف البحث رؤى مثيرة حول تأثير سرعة التنظيف على مستويات الأكسجين، مُظهرًا أن السرعات العالية تؤدي إلى زيادة مستويات الأكسجين نتيجة وجود مصدري حرارة مزدوجين - الشعاع الليزري ونقل الحرارة من خطوط التنظيف المجاورة. يتم التأكيد على دور معلمة التقاطع في التحكم في نسبة التداخل، حيث يؤدي التقاطع الأقرب بين الخطوط إلى تنظيف أكثر فعالية وانخفاض محتوى الأكسجين على السطح، بينما يعيق التقاطع الأوسع تنظيف الفجوات بين الخطوط. بالإضافة إلى ذلك، تستكشف الدراسة إمكانية تحسين معدلات التآكل من خلال تنظيف الليزر، حيث يلعب تخطيط المواد دورًا حاسمًا، وتشير إلى أن العينات المنظفة تظهر عيوبًا أقل في هيكلها المجهري مقارنةً بأقرانها غير المنظفة. تقدم هذه النتائج رؤى قيمة في مجال تنظيف الليزر وتطبيقاته في معالجة الأسطح وتحسين جودة المواد.