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Angular Laser Cleaning of Aluminum Al-4004 with Different Spot Sizes

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Abstract: When it comes to applications in welding, cutting, and surface engineering, the utilization of high-power fiber-delivered beams from solid-state lasers offers several benefits. This paper addresses the issue of cleaning the surface of the samples with different spot sizes (50, 100 and 200) (industrial ytterbium fiber laser) to prepared it to be welded. Angular laser cleaning with incident angles (5, 10, 15, 20, 25, 30) ° with different powers (3, 5, 7, 10) W and hatch distance 0.001 was use for implemented.

Keyword: angular laser cleaning, spot sizes and ytterbium fiber laser.

1. Introduction

Laser cleaning will have a significant impact on the future of cleaning operations. Environmentally hazardous products can now be cleaned without the need of mechanical or chemical procedures [1, 2]. Since there is now a dedicated community that utilizes lasers for this purpose and prominent restoration institutes have recognized the new technology, the success of laser cleaning for cultural heritage has been proven, which has led to an increase in the replacement of chemical treatments with these new techniques. As a result, this has led to an increase in the usage of these new techniques in place of chemical applications [3,4]. Laser cleaning is a technique that employs the use of pulsed laser light to either begin the process of removing pollution from a surface or to assist in this process [4, 5]. The fact that contamination, such as micron and submicron-sized particles, can have a significant influence on optics, semiconductor production, and data storage devices because of the way in which they can get in the way of certain processes has been a driving force behind research in this area. Surface laser cleaning difficulties that involve soiling substances in the form of microscopic particles and films arise in a wide variety of human undertakings, including but not limited to manufacturing, building, art conservation, and medical [7]. Laser cleaning can be accomplished.

1.1. Angular laser cleaning

Unlike typical laser cleaning, this method irradiates the metal surface from multiple angles. The laser beam is aimed towards the target material at an angular angle of incidence appropriate for the target material [15]. as can be observed in Figure 1. The beam is aimed at the surface at a using a variety of processes, including vaporization, spallation, evaporation pressure, photon pressure dries, steam, thermal heating, and laser shock cleaning [8, 9]. It was discovered that the cleaned area irradiated at an angular laser cleaning angles was up to 10 times bigger than the average laser-cleaned area when utilizing a perpendicular angle, which means that it is significant to employ in angular cleaning [10 -14]. In this study, an angular laser cleaning technique is used instead of a perpendicular laser cleaning technique with varying spot sizes to remove the oxide layer from aluminum 4004 alloy, which is then ready for welding. variety of angles that are less than ninety degrees (angle 90°). In comparison to traditional laser cleaning, this method offers a plethora of benefits, one of which is a significant increase in cleaning effectiveness. In addition, cleaning threshold fluences are decreased at angular laser cleaning angles, which, in comparison to perpendicular laser.

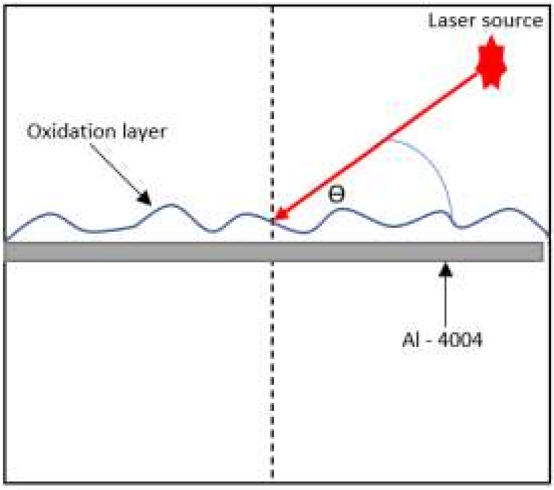

Fig. 1: angular laser cleaning

1.2. Aluminum alloy 4004

Since there is a lot of silicon in the 4000 series of alloys, they are not often used for extrusion applications. They are used in a lot of things, like welding wire and brazing wire, among other things. These alloys are used in sheet metal, forgings, welding, and brazing products, among other things. 4004 aluminum alloy could have a Si content of up to 11% [17]. To weld 4004 aluminum alloy, the oxide layer must be removed first [18 -21]. Because of the surrounding environment, the natural oxidation layer formed on the aluminum alloy 4004's surface. cleaning, results in a diminished danger of surface damage [16]. Figure 2. Illustrated the aluminum alloy 4004.

1.3. Fiber laser

An industrial ytterbium fiber laser with a wavelength of 1064nm was built at the University of Baghdad's Institute of Laser for Postgraduate Studies. The speed of the laser beam scanning was between 2 and 8000 mm/s, and the laser power ranged from 1 to 10 W at a frequency of 20 to 80 kHz. The pulse width was set at 10 s, and the spot size varied from 50 to 200 m. Figure 3 shows how the fiber laser scanned, which looked like a zig-zag.

Fig. 2: Aluminium 4004 alloy.

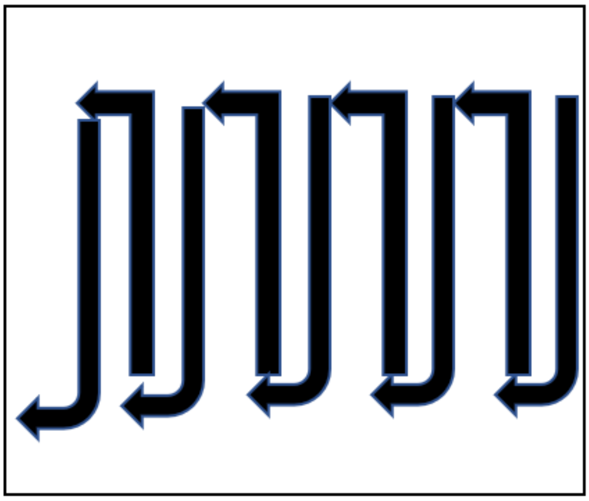

Fig. 3: scanning strategy of fiber laser zig-zag shaped wave..

2. Material and method

2.1 Material

The sample used was aluminum 4004 (Al 90.25% + Si 9.75% ± 0.75%), the material standard according to the international organization for standardization (IOS) equivalents of alloy, manufactured by (BAUHAUS, Sweden). Sample dimensions 2\times2 cm2 and thickness of 2mm. All samples were surface cleaned with diluted ethanol before using laser cleaning.

2.2. Experiment procedure

With pulse repetition rate (PRR) (2, 4 , 6 , 8)Hz, spot size (50, 100, 200)µm and power (3, 5, 7, 10) W and hatch 0.001µm with angular angles cleaning(θ =5, 10, 15, 20, 25, 30) °. So, remaining hatch lay outside the scope of this paper. A laser cleaning procedure has been carried out on aluminum alloy 4004 to remove a thin oxidation coating. The laser used in this work was a microsecond fiber leaser (ytterbium fiber laser) with a pulse duration of 10 µs and a fundamental wavelength of 1064 nm. The laser beam hit the target after passing through a quartz lens with a focal length of 163mm. This study's angular laser cleaning method is illustrated shown in Fig. 4. The beam focus on the surface at angles (θ =5, 10, 15, 20, 25, 30)°. Table 1. illustrates the parameters used at the angular laser cleaning process.

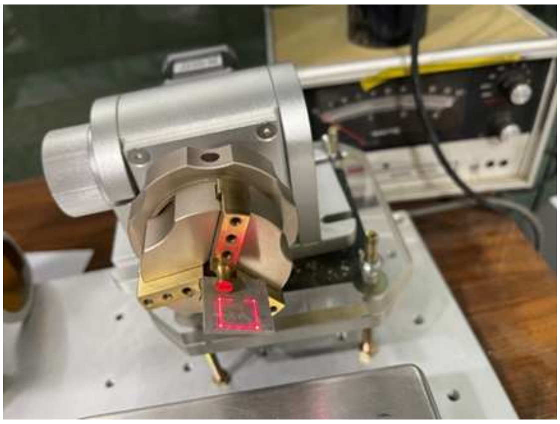

Fig. 4: Angular laser cleaning.

Table 1: Parameters used in the cleaning process.

Spot size	**50,**	**100,**	**200**
Speed (mm/sec)	**Hatch (µm)**	**Frequency (KHz)**	**Power (Watt)**
150	0.001	20	3
150	0.001	20	5
150	0.001	20	7
150	0.001	20	10

3. Results and discussion

3.1. Microstructure of oxidation layer of aluminium alloy

For spot size 50 µm, figure 5 shows the microstructure of the Al- 4004. Figure 5A illustrate the oxidation layer of Al-4004 while the figures B, C, D, E, F and G illustrated the high damaged on the surface of Al -4004 with the focus spot sizer 50 µm with less removed oxidation layer. While spot size 100 µm, Figure 6 shows the microstructure of the oxidation layer and the cleaning alloy 4004 at powers of 3, 5, 7, and 10 watts, angles of (5, 10, 15, 20, 25, 30)° and hatch sizes of 0.001 micrometers. When looking at the surface that has not been cleaned, the oxygen rich zone can be seen, as seen in Figure 6 A. This region has a high roughness, which indicates that the oxygen layers are co-exiting. Oxides and maybe other chemicals, such as hydrocarbon contamination and moisture, are produced by the oxygen-rich region's outermost layer. This layer also contributes to the formation of oxides. Fig 6 B, C and D show that the surface of AL-4004 was only partially cleaned using a dispersion of Si that was not homogeneous. While in Fig. 6 E, F, and G, the power was concentrated on the oxidation layer with a power of 10W and angles of 20, 25, and 30 degrees, the laser power was partially reflected and lost, and a large amount of laser power was absorbed by thin oxidation layer. This caused the temperature in the oxidation layer to increase rapidly, and when the temperature reached or exceeded the vaporization point of the material, phase change occurred, and thus the oxidation layer disappeared. For spot size 200 µm, the removed oxidation layer less than 100 µm best results shows for angles 15- 25 ° figures 7 C, D and E.

3.2. Energy-dispersive X-ray EDX

In table 2, the chemical composition of AL-4004 was shown. EDS was used for both qualitative and quantitative analysis. After that, the sample was looked at with an XRD to find out what its binary phase composition was.

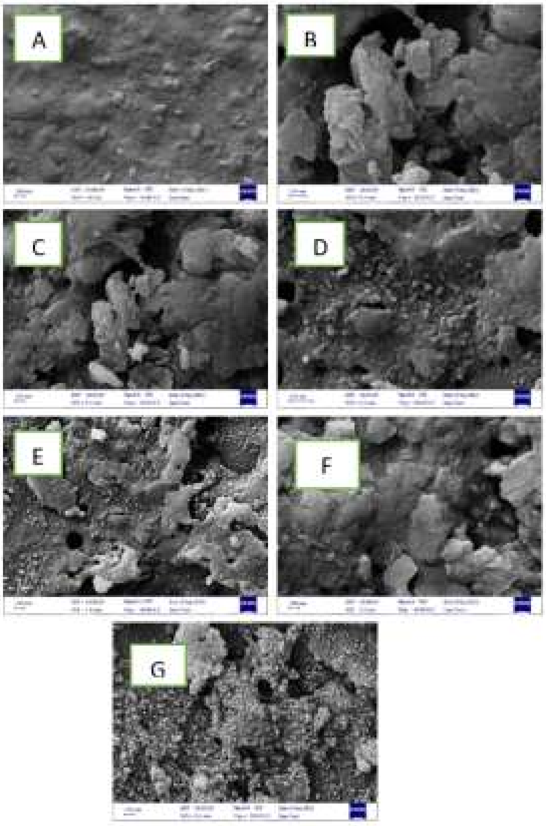

Fig. 5: SEM images A. pure oxidation layer, B. Al -4004 with angle laser cleaning 5°, C. Al -4004 with angle laser cleaning 10°, D. Al -4004 with angle laser cleaning 15°, E. Al -4004 with angle laser cleaning 20°, F. Al -4004 with angle laser cleaning 25° and G. Al -4004 with angle laser cleaning 30°.

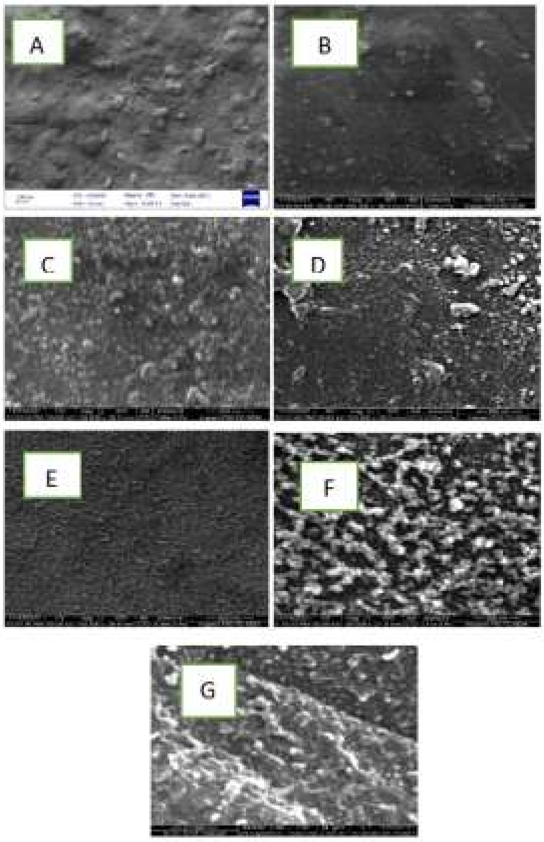

Fig. 6: SEM images of spot size 100 µm with power 10W A. pure oxidation layer, B. Al -4004 with angle laser cleaning 5°, C. Al -4004 with angle laser cleaning 10°, D. Al -4004 with angle laser cleaning 15°, E. Al -4004 with angle laser cleaning 20°, F. Al -4004 with angle laser cleaning 25° and G. Al -4004 with angle laser cleaning 30°

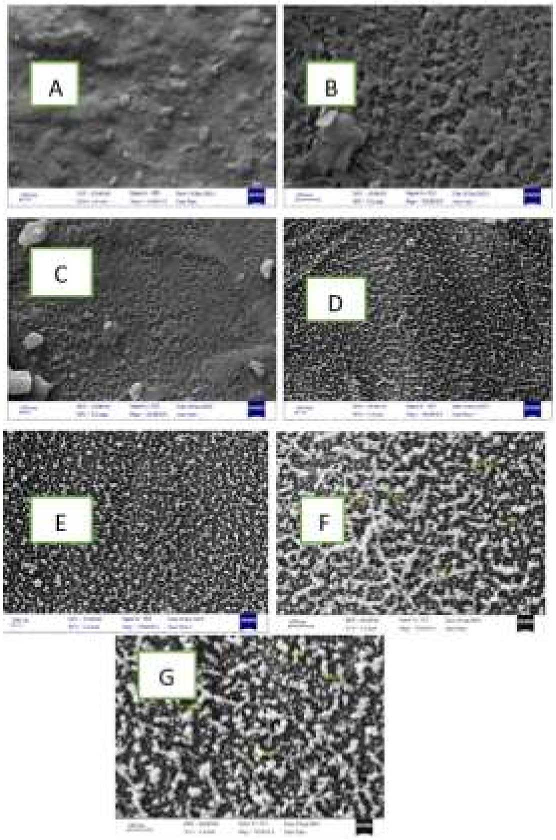

Fig. 7: SEM images of spot size 200 µm with power 10W A. pure oxidation layer, B. Al -4004 with angle laser cleaning 5°, C. Al -4004 with angle laser cleaning 10°, D. Al -4004 with angle laser cleaning 15°, E. Al -4004 with angle laser cleaning 20°, F. Al -4004 with angle laser cleaning 25° and G. Al -4004 with angle laser cleaning 30°.

Table 2: chemical composition of oxidation layer AL-4004.

Chemical element	Wt.%
Aluminum	48.9
Silicon	6.5
Oxygen	44.6

Following EDS examinations, the atomic composition of oxygen is reduced from 44.8 percent to 42.57 for spot size 50 µm figure 8 best result showed at angle 25 ° with power 10W which was 42.9, while the EDS examinations for spot size 100, the atomic composition of oxygen is reduced from 46.4 percent to 12.88 percent using spot size 100 µm respectively in Fig 9. The result indicated best-removed oxide at hatch 0.001µm with power 10W and for angle 20°. EDS of spot size 200 µm illustrated at figure 10, the oxygen percentage increased from 45.33 to 45.78 best results showed at angle 20 ° with power 10 W and it was 44.58.

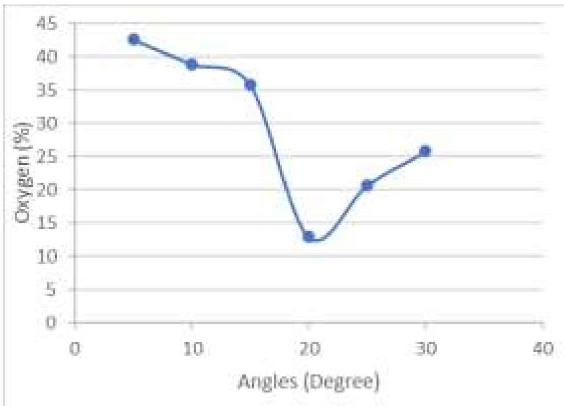

Fig. 8: EDX analysis of AL 4004 at angles (5,10,15,20,25,30) °with hatch 0.001and power 10W and spot size 50 µm.

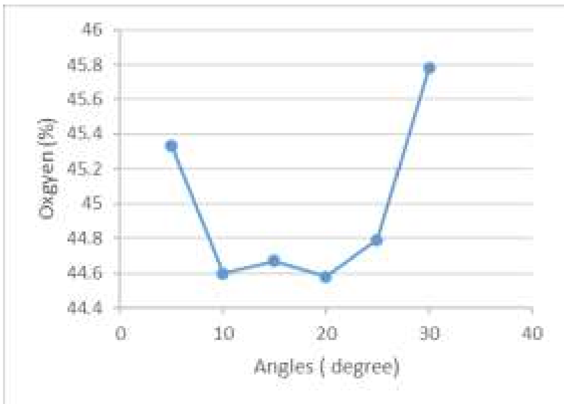

Fig. 9: EDX analysis of AL 4004 at angles (5,10,15,20,25,30)°with hatch 0.001and power 10W and spot size 100 µm.

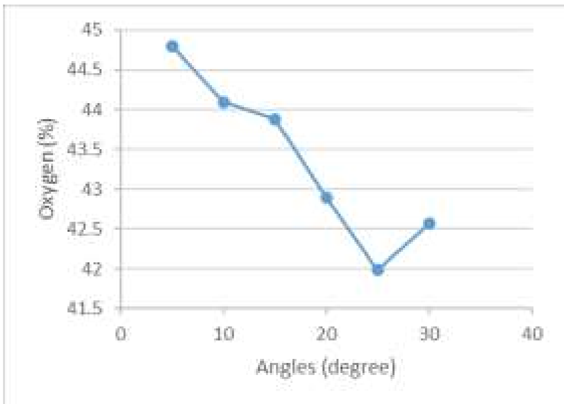

Fig. 10: EDX analysis of AL 4004 at angles (5,10,15,20,25,30) °with hatch 0.001and power 10W and spot size 200 µm.

3.3. Roughness and hardness test

The vertical variation that has been measured over a distance is what is meant when we talk about surface roughness. It is possible to define it in a number of different ways, including by the average roughness (Ra), the root mean square roughness (Rq), the height of the roughness profile's highest peak (Rp), and the depth of the roughness profile's deepest valley (Rv), amongst other possible ways. In between these two properties is Rq, which is more closely connected to the optical quality of a surface. Because of this, it is believed that the Rq value is associated to laser cleaning more closely than the other features. In addition, Rv may influence the effectiveness of the laser cleaning. In cases where Rv is high, the oxide layer may function more efficiently. As a result, laser cleaning could be challenging:

$$R_a = \frac{1}{a}\int_{x=0}^{a} |f(x)|\, dx \qquad (1)$$

Where, f(x) is the surface height measured from the mean line and 'a' is the total distance that surface roughness is considered. The laser cleaning procedure is affected not only by the adherence of the graffiti, but also by the laser's absorption at the specific laser strength. Increased adhesion will make laser cleaning harder. At the same time, as absorption rises with constant laser power, laser cleaning will be simple. Figures 11, 12 and 13 Shows the roughness test results for spot size 50 -200 µm respectively, and these results revealed that roughness decreased with increasing the laser power and the best impact was at 20° angle for spot size 100 µm while less roughness recorded for spot size 50 µm at angle 10° and power 10W while spot size 200 less roughness illustrated at angle 30°. while for the hardness, as shown in Figures 14, 15, 16 for spot size 50 -200 respectively, these values were selected according to the best distribution of Si. the behaviour of the curves shows that, by increasing the power the hardness value increases, the reason behind such behaviour for aluminum alloy can be explained as follows: first) when laser power density increases, the temperature at the surface metal increases too, due to the absorption of the laser energy, this increase of the temperature allows the structure of the alloy to be harder. Furthermore, second) the rise in the hardness value with the rise of the power might be due to the melting of the alloy's surface layer, causing decreases of silicon particles size below the critical size to fracture, strengthening the Al-Si alloy [23, 24].

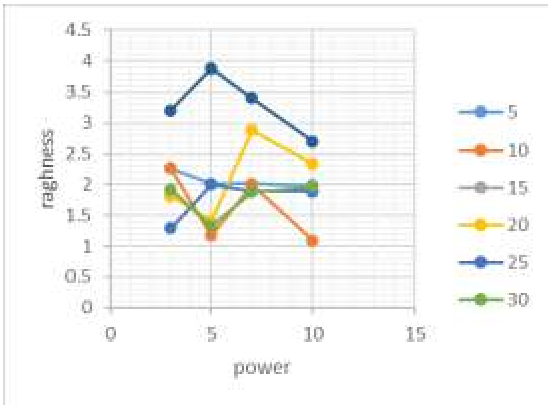

Fig .11: The roughness of different angular angles with different power with spot size 50.

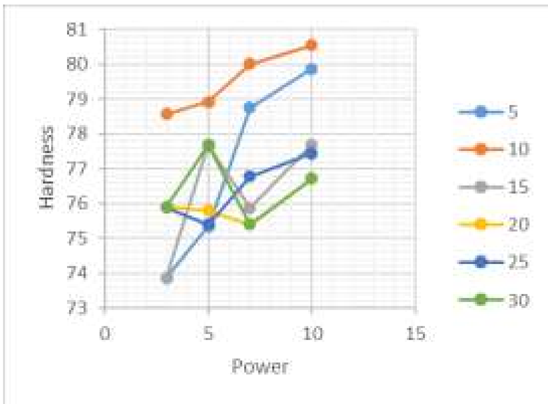

Fig. 12: The roughness of different angular angles with different power with spot size 100.

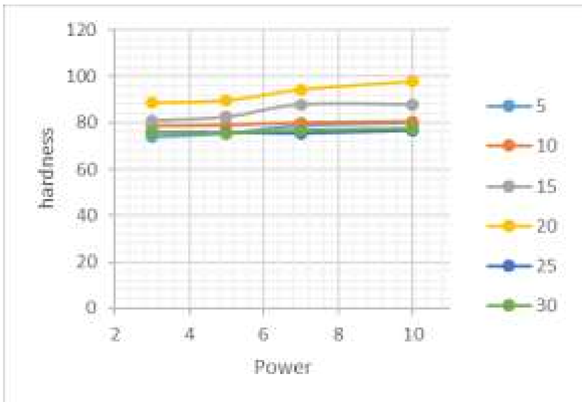

Fig. 13: The roughness of different angular angles with different power and spot size 200.

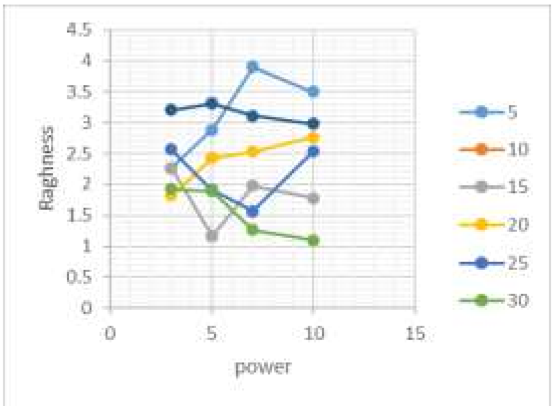

Fig. 14: The hardness of different angular angles with different power and spot size 50.

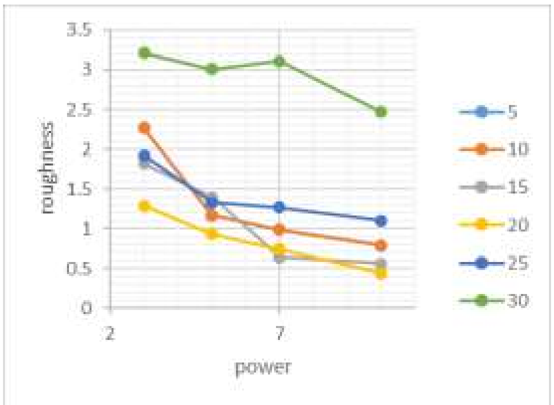

Fig. 15: The hardness of different angular angles with different power and spot size 100.

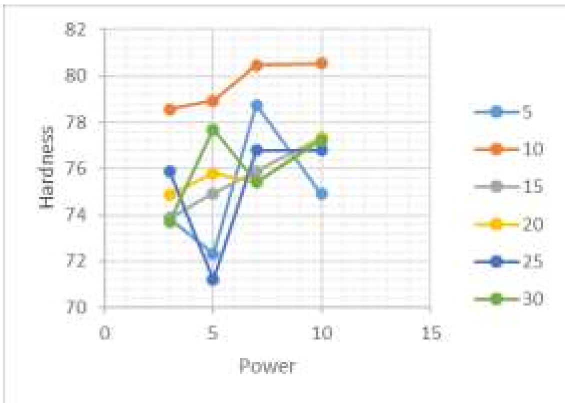

Fig. 16: The hardness of different angular angles with different power and spot size 200.

4. Conclusion

With the help of an angular laser, the oxidation layer was removed from AL-4004 surfaces. Using power 10 W and hatch 0.001, cleaning at an angle of 20° is more effective than cleaning at other angular angles (5, 10, 20, 25, 30) with power 10W especially for spot size 100 µm. The oxidation layer was successfully eliminated and AL2O3 was reduced by cleaning with hatch 0.001. The roughness decreased as the cleaning angle and power were increased. Hardness was found to rise with increasing amounts of silicon particles on the alloy surface, as well as with the strength and cleaning process used. In order to better understand how the technique works, the adhesion forces and the cleaning forces created by the laser have been taken into account, while at 50 and 200 µm different behaviour of roughness And hardness at angle 10° and 30° .

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التنظيف الزاوي الليزري لسبيكة المنيوم نوع 4004 بنقاط ليزر مختلفة

ايمان شاكر توفيق* **زياد اياد طه**

معهد الليزر للدراسات العليا/جامعة بغداد

الخلاصة

عندما يتعلق الامر بالتطبيقات والقطع وهندسة الاسطح، فأن استخدام حزم الألياف عالية الطاقة من ليزر الحالة الصلبة يوفر العديد من الفوائد. يتضمن هذا البحث تنظيف الاسطح بنقاط ذات احجام مختلفة (50، 100، 200) مايكرومتر (ليزر الألياف الإيتربيوم الصناعي) لتجهيزها للحام. تم استخدام التنظيف بالليزر بالزوايا التالية (5، 10، 15، 20، 25، 30)° وبقدرات مختلفة (3، 5، 7، 10) وات ومساحة التنظيف 0.001