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INVESTIGATION OF EFFECT OF LASER CUTTING PARAMETERS ON MICROHARDNESS AND AVERAGE KERF WIDTH OF TI-6AL-4V ALLOY

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Muhammad Alsaadawy [a], Montasser Dewidar [a, b, *],
Ahmed Said [a], Ibrahem Maher [a, c], Taher A. Shehabeldeen [a, *]

[a] *Mechanical Engineering Dept., Faculty of Engineering, Kafrelsheikh University, Kafrelsheikh, Egypt*

[b] *Samannoud Technological University, Samannoud, Gharbia 31111, Egypt*

[c] *Industrial and Manufacturing Engineering Department (IME), School of Innovative Design Engineering (IDE), Egypt-Japan University of Science and Technology (E-JUST), Alexandria 21934, Egypt.*

[*] corresponding author: Orcid: 0000-0003-2930-6989, E-mail: taher_atia@eng.kfs.edu.eg

ABSTRACT. Titanium alloys, particularly Ti-6Al-4V alloy, are important materials due to their exceptional mechanical and chemical characteristics. They are employed in a wide range of high-strength and high-temperature applications, including ships, biomedical, and aerospace applications. Laser machines have recently been utilized to cut a variety of material types. Understanding how laser cutting settings affect cut surface quality is crucial. In this study, a 4 mm-thick sheet of Ti-6Al-4V alloy was cut. The cutting parameters were Laser power, cutting velocity, and assist gas pressure, while microhardness and average kerf width were the measured parameters. the main effective parameter for microhardness values is laser beam power followed by assist gas pressure and cutting velocity, while the main effective parameter for average kerf width is laser beam power followed by cutting velocity and assist gas pressure. The highest microhardness and average kerf width values of 332±10 HV and 909±16 μm, respectively, were observed at a laser power of 3 kW, a cutting speed of 1000 mm/min, and an auxiliary gas pressure of 10 bar. While the lowest microhardness and average kerf width values of 269±10 HV and 431.25±43.5 μm respectively, were observed at a laser power of 2 kW, a cutting speed of 1000 mm/min, and an auxiliary gas pressure of 6 bar.

KEYWORDS: Kerf width; Laser cutting; Microhardness; Ti-6Al-4V Alloy.

1. INTRODUCTION

Titanium alloys [1], have exceptional mechanical and chemical properties, including high tensile strength and toughness, superior corrosion and oxidation resistance, lightweight, severe temperature resistance, and a high strength-to-weight ratio[2]. Titanium alloys are projected to be the most utilized in the approaching years due to their vast commercial availability and economic feasibility. Although various titanium alloys have been developed, they are rarely suitable for large-scale commercial use. Meanwhile, other compositions, such as Ti-8Mn, Ti-7Al-4MO, and Ti-4Al-3Mo-1V, have only seen limited use. Ti-6Al-4V is the most often used alloy and has the greatest demand of any alloy developed in the twentieth century. What sets Ti-6Al-4V apart is that it offers various desirable properties that make it ideal for commercial application in a variety of sectors such as automotive, aerospace, and biomedical. Because of the improved performance and fatigue characteristics, also, the functionality of the parts that rely on the usage of titanium alloys, particularly Ti-6Al-4V. Titanium alloys are used in aircraft hulls, jet engine components, engine compartments, fan blades, and fuel tanks. Ti-alloys provide a good combination of corrosion resistance and antibacterial properties in biomedical applications. These good properties enable a variety of uses in orthodontics, artificial joints, dental implants, and surgical equipment [3]. As a result, it is critical to be able to cut such alloys at a fast rate and with acceptable characteristics to meet the rising demand rate in the field of biomedicine.

These materials, however, are difficult to manufacture using standard cutting methods because of their high mechanical properties[4], [5]. Machinability characteristics indicate several machining issues, such as higher machining force, increased machining temperature, and lower tool life due to tool wear[6], as well as poor surface quality. As a result, it is seen as a difficulty for increasing efficiency [5], [7], However, several research have attempted to assist in the cutting of titanium alloys by preheating the alloy before cutting, which helps to reduce cutting issues and time. [8]. The laser source was then used as a heat source in tests to improve tool cutting quality and life by reducing cutting force[9], [10]. Then, other research compared conventional and laser-assisted machining, adding to the evidence that laser-assisted machining is superior than traditional techniques [11], [12]. As a result, several research concentrated only on unconventional machining techniques such as laser machining (LM) [13].

The laser machining technique is classified as a thermal-machining procedure that employs a laser beam source to cut such materials and is widely used in the manufacturing industry [14]. This is accomplished by directing and focusing a high-power, coherent, monochromatic laser beam with wavelengths spanning from ultraviolet to infrared onto the surface of a workpiece. The workpiece absorbs a large amount of laser beam energy, causing a significant increase in temperature in the targeted area of the machined material. Because of the extreme temperature, the material melts or vaporizes and may undergo chemical changes before being evacuated using a high-pressure support gas, depending on the properties of the substance and the intensity of the beam[14]. Furthermore, laser beam machining has various cutting methods. [13], which are fiber laser, Co2, and ND: YAG Pulsed Laser [15], [16].

The laser cutting process offers parameters that impact the cut surface quality, which must be properly defined in order to get the optimum cut surface quality for the intended applications. To obtain the greatest surface quality, it is vital to recognize the proper cutting process conditions. It is difficult to employ all the components as variable factors since it would necessitate such extensive and complicated work. As a result, the researchers used to make certain variables fixed parameters and others variable parameters; the most commonly utilized variable parameters are laser power, cutting speed, and assist gas pressure[17]–[20]. Most of the past research focused on the effect of these three factors on the surface and kerf quality of titanium alloys. The majority of them have showed that laser power is the most essential element, followed by cutting velocity and assist gas pressure, such as when cutting 2 mm Ti-6Al-4V alloy using nitrogen as an assist gas[21], cutting 3 mm Ti-6Al-4V alloy with azote as an assist gas pressure [20]. However, if one of the cutting speeds or laser power is set as a fixed parameter in the cutting parameters, the other will be the dominant parameter. For example, when cutting 1.4 mm Ti-6Al-4V alloy using nitrogen as an assist gas [22], cutting 1.6 mm Ti-6Al-4V alloy with air as an assist gas [23]. When cutting 3 mm Ti-6Al-4V alloy using oxygen gas as an assist, the laser power was the main parameter when cutting speed was fixed[24].

It has been found that gas pressure has a noticeable effect on the hardness Vickers values as it helps in removing the heat quickly and cause a rapid cooling to the 316 steel alloy[25], also, the microhardness increased in the places of heat affected zone which has a rapid cooling [26]. Also, another study of the effect of laser power on the microhardness has been done during the laser deposition process, which has cleared that if laser beam power increased the microhardness values increase as well[27], another study confirmed that the laser beam power during the laser deposition process has made a big effect on the microhardness values [28]. an exploration through experimentation, to investigate the influence of cutting settings on microhardness in Inconel 718 micro-milling, has discovered that the microhardness of micro-milled Inconel 718 reduces with increasing spindle speed and increases with increasing axial cutting depth[29].

Many investigations have been conducted to explore the influence of laser power, cutting speed, and assist-gas pressure on cut-edge surface quality for thicknesses ranging from 1 mm to 3 mm. However, due to the difficulty of cutting larger thicknesses, there has not been adequate study on the laser machining of Ti-6Al-4V alloys with thicknesses more than 3 mm. As a result, the aim of present study is to create high-quality cuts of thick Ti-6Al-4V alloy sheets utilizing nitrogen as an assist gas to maximize the efficiency of the prementioned applications. Input cutting parameters included the power of laser beam, cutting speed, and assist gas pressure. The Taguchi approach was used to choose efficient cut trials, which resulted in L9 orthogonal arrays. The microhardness and the average kerf width of 4 mm thick sheet of Ti-6Al-4V alloy were studied as output parameters. Minitab software was used to create a 3D graphic of input against output parameters. The most effective cutting settings for microhardness and average kerf width were addressed.

2. Experimental Work and Methodology

2.1 Machine Specifications and Material Properties

To study the microhardness and the average kerf width of a 4 mm thick sheet of Ti-6Al-4V alloy, a CE Mark fiber laser machine (OR_p4020 t3 3000w raycus) was used, the layout of the machine is shown in Fig. 1 and the machine itself is shown in Fig. 2. The assist gas which has been used during the cutting of the prementioned alloy was nitrogen.

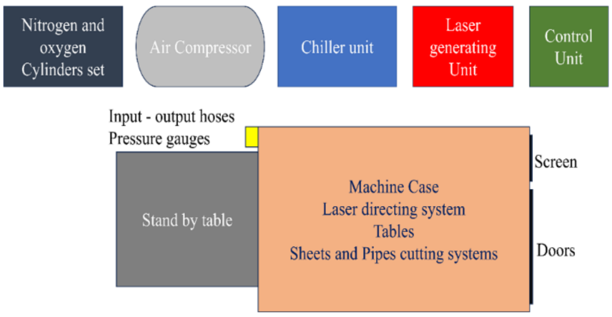

Fig. 1: Machine layout

Fig. 2. laser cutting machine.

Fig. 3: Wire cut machine.

Baoji Lida New Materials Co. Ltd is the supplier of the Ti-6AL-4V alloy sheet. The Ti-6Al-4V alloy sheet chemical and mechanical specifications are shown in Table 1. The 120 x 80 x 4 mm were the dimensions of the supplied sheets and a wire-cutting machine, which is shown in Fig. 3, was used to cut the sheet to a small dimension sample to be ready for laser cutting trials. These small samples were 80 x 10 x 4 mm. A glue has been used to hold the samples to a plate, for more stability during the machining time. The produced samples by laser cutting machine have been cut into tiny specimens to be used for the step of measurement of the values of the microhardness and the average kerf width. The group of the speed of cutting and the laser beam power, and the assist gas pressure were used as variable input parameters beside the other fixed parameters.

Table 1: The Ti-6Al-4V alloy chemical and mechanical specifications.

Element (%)		Mechanical Properties	
Ti	Bal.	Tensile Strength (MPa)	1086
Al	6.4		
V	4.26	Elongation (%)	15
Fe	0.184		
O	0.15	Hardness	320
N	0.012		
C	0.007		
H	0.004		

2.2 CUT TRIALS

Ti6Al4V alloy is recent to the field of laser cutting, so, there is not enough research which discusses the cutting of that alloy using laser cutting techniques, and because of that we have taken the parameters of 3 mm sheet thickness to start the experiments then varying the parameters of the variable set values such as the speed of cutting, the laser beam power, and the assist gas pressure to find the right set of parameters for cutting a 4 mm sheet [20], [30]. When the right set of the parameters was selected, two specimens did not achieve the complete cutting, so, as a result they were excluded from the measurements as it is based on the samples with a full cut. A lot of cutting trials have been done during the pre-final cutting, but they were excluded because of the defects of cutting because of the lack of laser power, and the high or too low speed of cutting. Some of these trials are shown in Table 2 . Some of the defects of these trials are shown in Fig. 4.

Table 2: Different set of parameters which are used for cut trials

Trials	Variable Parameters			Fixed Parameters	
Trial 1	Laser power KW	Cutting speed mm/min	Gas pressure bar		
1	1.5	1400	6	Frequency Hz	1000
2	1.5	2200	8	SOD mm	0.5
3	1.5	3000	10	Focus Position mm	-2
4	2	1400	8	Gas Type	N2
5	2	2200	10	Thickness mm	4
6	2	3000	6	Material	Ti6Al4V
7	2.5	1400	10	Nozzle diameter mm	1
8	2.5	2200	6	Nozzle Type	Single
9	2.5	3000	8	Machine source type	Fiber Laser
Trial 2	Laser power KW	Cutting speed mm/min	Gas pressure bar	Fixed Parameters	
1	2	1000	6	Frequency Hz	5000
2	2	1500	8	SOD mm	0.5
3	2	2000	10	Focus Position mm	-2.5
4	2.5	1000	8	Gas Type	N2
5	2.5	1500	10	Thickness mm	4
6	2.5	2000	6	Material	Ti6Al4V
7	3	1000	10	Nozzle diameter mm	1.5

8	3	1500	6	Nozzle Type	Single
9	3	2000	8	Machine source type	Fiber Laser
Trial 3	Laser power KW	Cutting speed mm/min	Gas pressure bar	Fixed Parameters	
1	2	1000	3	Frequency Hz	1000
2	2	1500	6	SOD mm	0.5
3	2	2000	9	Focus Position mm	-3
4	2.5	1000	6	Gas Type	N2
5	2.5	1500	9	Thickness mm	4
6	2.5	2000	3	Material	Ti6Al4V
7	3	1000	9	Nozzle diameter mm	3
8	3	1500	3	Nozzle Type	Single
9	3	2000	6	Machine source type	Fiber Laser
Trial 4	Laser power KW	Cutting speed mm/min	Gas pressure bar	Fixed Parameters	
1	2.4	1200	6	Frequency Hz	1000
2	2.4	1600	9	SOD mm	0.5
3	2.4	2000	12	Focus Position mm	-3.5
4	2.8	1200	9	Gas Type	N2
5	2.8	1600	12	Thickness mm	4
6	2.8	2000	6	Material	Ti6Al4V
7	3.2	1200	12	Nozzle diameter mm	2.5
8	3.2	1600	6	Nozzle Type	Single
9	3.2	2000	9	Machine source type	Fiber Laser

Fig. 4. Samples with defects produced during the first trials of input parameters.

2.3 DESIGN OF EXPERIMENT

Overall trials number can significantly be reduced by using a well-planned strategy of the experiment without reducing the efficiency of the experimental study of the manufacturing process. Taguchi stated that the best way to make the process resilient is to eliminate the impacts of variation by choosing right set of cutting parameter levels. Taguchi proposed employing orthogonal matrices (OAs), which were correctly constructed experimental matrices, to carry out the testing.

Table 3: The fixed parameters of cutting.

Fixed Parameters							
Material	Thickness (mm)	Frequency (Hz)	Focus Position (mm)	SOD (mm)	Nozzle Type	Nozzle diameter (mm)	Gas Type
Ti6Al4V	4	1000	-3	0.5	Single	2.5	N2

Three control factors were studied in this study, each having three levels. As a result, research may be carried out employing the most fundamental L9 OA[31]–[35]. Table 3 and Table 4 demonstrate the set of fixed and variable parameters based on the Taguchi approach. Three factors were employed in this study to assess their impact on microhardness and average kerf width.

Table 4: The variable parameters and their levels of cutting.

Factors	Levels		
	Level 1	Level 2	Level 3
Cutting Speed: V (mm/min)	1000	1500	2000
Laser beam Power: P(KW)	2	2.5	3
Gas Pressure: P (bar)	6	8	10

2.4 TAGUCHI ARRAYS AND CUT STATE

Taguchi offered nine experiments, which is shown in Table 5, to explore the effect of laser cutting parameters on microhardness and average kerf width. It also displays the condition of cut, which was entirely cut for seven samples but did not occur for samples 3 and 6 due to inadequate power of laser due to the fast-cutting speed.

Table 5: Taguchi array L9 (3x3).

Array	Parameters				
	Cut state	Cutting speed, V(mm/ min)	Laser Power, (KW)	Pu	Assist. gas pressure, P(bar)
1	yes	1000	2		6
2	yes	1500	2		8
3	No	2000	2		10
4	yes	1000	2.5		8
5	yes	1500	2.5		10
6	No	2000	2.5		6
7	yes	1000	3		10

Array	Parameters				
	Cut state	Cutting speed, V(mm/min)	Laser Power, (KW)	Pu	Assist. gas pressure, P(bar)
8	yes	1500	3		6
9	yes	2000	3		8

2.5 MEASUREMENTS

Mitutoyo, Japan, was the device used for measuring the values of microhardness by taking around five values for each line to get the average for each line. Image J program was used to measure the values of upper and lower kerf widths at different places to get the average for each.

2.5.1 MICROHARDNESS MEASURING INSTRUMENT.

The preparation of samples for the hardness measurements have been done by using the polishing machine shown in Fig. 5. The measurement was done by taking around five values for each line then taking the average of them as shown in Fig. 6 by applying load of 0.5 kg for 15 seconds. The hardness values are measured with Mitutoyo (Japan) device, which shown in Fig. 7

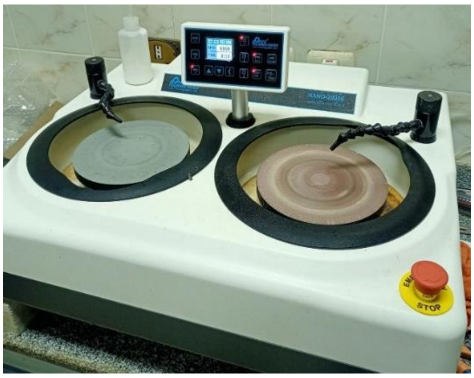

Fig. 5: polishing machine for sample preparation for hardness test.

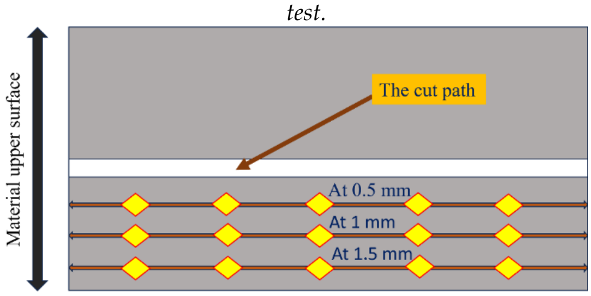

Fig. 6: Places of measuring the hardness values

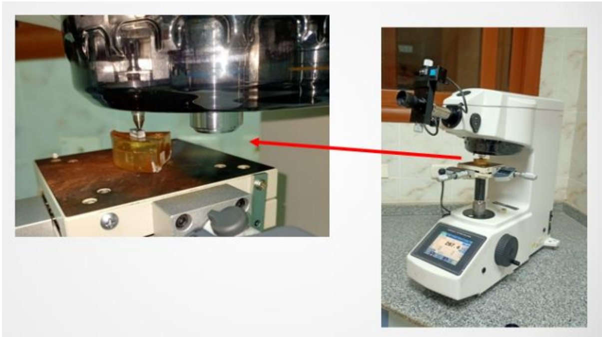

Fig. 7. Hardness test device (Mitutoyo)

2.5.2 KERF WIDTH MEASURING INSTRUMENT

The upper and the lower kerf width values which shown in Fig. 8, were measured using Image J after taking SEM image with the help of JEOL, JSM IT 100. The method of measuring the values has been done by taking around five measures then taking the most appreciate three then taking the average of them. The schematic of upper, lower, average kerf width is illustrated in

Fig. 9.

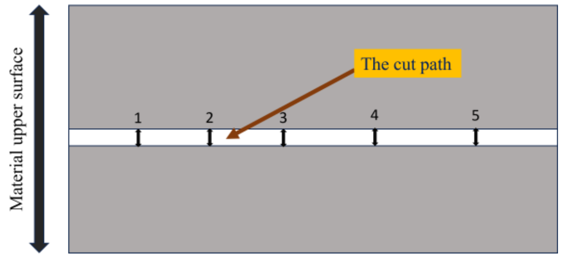

Fig. 8: The upper and lower kerf widths measuring method

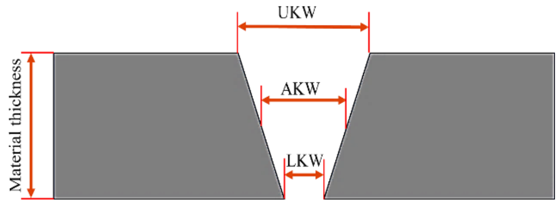

Fig. 9. Schematic of UKW, LKW, and AKW on the cross section of Ti-6Al-4V alloy.

2.5.3 THE MEASUREMENT VALUES

Table 6 shows the values of measured microhardness at three different places. The line of cutting is the reference for these places.

Table 7 shows the different values of the upper, lower, and average kerf width and the method of calculating them.

Table 6. Microhardness measured values.

Array	Microhardness (HV)					
	At 0.5 mm	At 0.5 mm	At 1 mm	At 1 mm	At 1.5 mm	At 1.5 mm
1	272.5 280 255.3 269	269±10	267.4 270.3 243.7 255	259±12	266.5 260.9 253.4 242.9	255.9±10
2	284.5 275.7 267.5 272.2	275.7±7	275.5 259.4 249.8 286.2	267.7±16	247.4 247.4 277.6 257.5	257.5±14
3						
4	342.2 294.5 298.8 327	315.7±22	302.7 295.4 284 308.6	297.7±10.5	271.2 283.3 278 289.6	280.5±7.8
5	284.5 275.8 279.6 286.9	281.7±5	278.2 285.7 275.6 279.4	279.7±4.25	270 279.4 273.9 269.3	273.1±4.6
6						
7	336.4 319 342.4 329.8	332±10	319.5 311.4 330.8 321	320.7±8	288.4 281.2 292.3 325.8	295.5±17.25
8	302.7 318.8 292.7 325.8	310±15	288.4 297.8 308.9 284.9	295±10.75	294.2 297.6 281.5 289.4	290.7±7
9	318.4 304.2 307.4 298.1	307±8.5	299.2 294.1 *288.2* 281	290.6±7.8	279.2 287 292.7 290.6	287.4±6

Table 7. Upper, lower, and average kerf width measured values.

Array	Kerf width (μm)				
	UKW	AUKW	LKW	ALKW	AKW
1	366 390 380	378.5±12	411 561 480	484±75	431.25±43.5
2	820 853 790	821±31.5	514 539 618	557±54	689±42.75
3					
4	894 896 901	897±3.5	424 440 495	453±37	675±20.25
5	759 791 776	775.25±16	309 268 446	341±93	558±54.5
6					
7	1368 1395 1371	1378±15	445 454 421	440±17	909±16
8	1196 1178 1203	1192.25±13	573 560 531	554.5±21.5	873.5±17.25
9	1028 1035 1068	1043.5±21	628 621 675	641.25±29	842.5±25

3. Results and Discussion

3.1. Microhardness Investigation

Hardness is the resistance of a material to localized plastic deformation. Hardness ranges from super hard materials such as diamond, boron-carbide to other ceramics and hard metals to soft metals and down to plastics and soft tissues. It has been found that the results have been discovered that the same trend of the effect of laser beam power on the microhardness values is the same as other previous studies found. Microhardness has been discussed in some previous studies and they have found that microhardness is proportional with power and inversely proportional with cutting speed for steel[36].

But for Aluminum, it has been discovered that hardness did not affect cutting speed or power[37]. In our study, it has been found that microhardness depends on the power of laser beam and the cutting velocity. It has been measured in 3 places which are at 0.5 mm, 1 mm, and 1.5 mm.

Fig. 10 Illustrates the values of microhardness at 3 different places (0.5, 1, and 1.5 mm) with different input parameters for cutting processes. Seven samples were cut, however two (samples 3 and 6) were not owing to a shortage of power in sample 3 and a fast-cutting speed in sample 6.

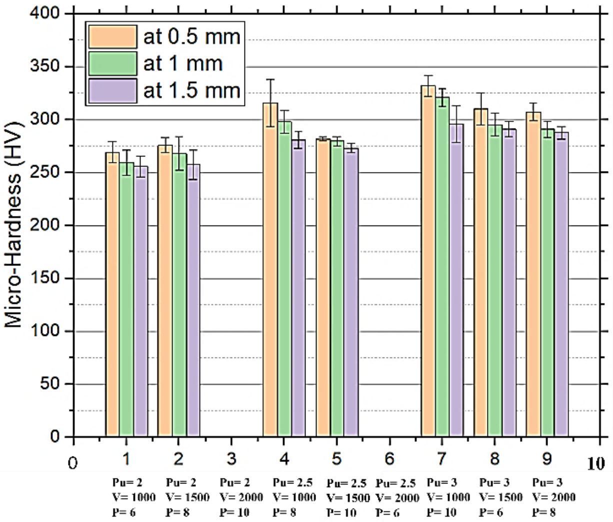

Fig. 10. Microhardness values at three different places for different cutting arrays

Seven of the nine samples were cut based on the laser cutting parameters, and the results are as follows. For sample No. 1, it has been noticed that hardness value is small as the low assist gas pressure led to high value of concentrated heat without removal as the velocity of cutting is low too as it is only 1000 mm/min. Which cause a lack of good cooling to the material, that causes a small values of microhardness at the three places. Also, the three places show a range of decreasing with the distance from the cut line as the heat is decreasing also, so, the values go down. For sample No. 2, microhardness values increase because of an increase in the assist gas pressure to 8 bar. Which causes a good cooling to the path of cut, also increasing the cutting velocity cause a good removal to the molten metal.

For sample No. 3, the input cutting parameter values were not enough to cause a complete cutting of the specimen, because of higher value of cutting velocity against lower value of power of laser beam. Which did not produce enough value of heat needed to fully cut the sample. For sample No. 4, the increase in microhardness value appears again because of the increasing of laser beam power to 2.5 KW and the assist gas pressure to 8 bar. Which causes a good cooling to the path of cut.

For sample No. 5, the microhardness value decreased when compared to sample No. 4 because of increasing of the cutting speed to 1500 mm/ min which led to lower temperature in the place of cutting, but the increasing of the assist gas pressure to 10 bar led to increasing the rate of good cooling and keeping the values higher. For sample No. 6, the input cutting parameter values were not enough to cause a complete cutting of the specimen, because of higher value of cutting velocity against lower value of power of laser beam. Which did not produce enough value of heat needed to fully cut the sample.

For sample No. 7, the increase in microhardness value appears again because of the increasing of laser beam power to 3 KW and the assist gas pressure to 10 bar. Which causes a good cooling to the path of cut. For sample No. 8, the microhardness value decreased when compared to sample No. 7 because of increasing of the cutting speed to 1500 mm/ min which led to lower temperature in the place of cutting, also the decreasing of the assist gas pressure to 6 bar led to decreasing the rate of good cooling.

For sample No. 9, the microhardness value decreased when compared to sample No. 8 because of increasing of the cutting speed to 2000 mm/ min which led to lower temperature in the place of cutting, but the increasing of the assist gas pressure to 10 bar led to increasing the rate of good cooling and keeping the values higher. To sum up, the microhardness values are proportional with laser beam power and the assist gas pressure and inversely proportional to the cutting velocity and distance from the line of cutting.

3.2. Average Kerf Width Investigation

Kerf width is an important component in affecting the performance of the laser cutting process. which relates to the cutting quality. The effect of input laser cutting parameters on metal kerf width properties was investigated[38]–[40], and it was discovered that the kerf width values is inversely related to the cutting speed and proportionate to the laser beam power. Increasing the power raises the temperature in the cutting region, resulting in more molten metal and, if the speed is similarly low, a greater kerf width will be produced.

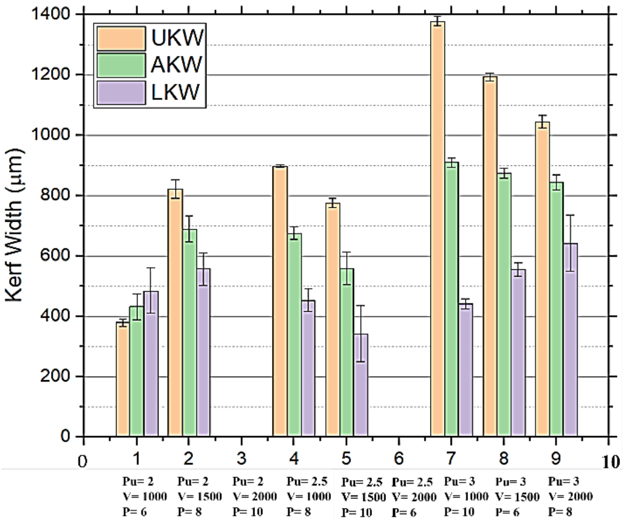

Fig. 11: Upper, lower, and average kerf width values at different cutting arrays

SEM was used to figure out the cut line from both the top and lower sides, as shown in Fig. 12, It has great quality on the top side of the cut, but also demonstrates high quantity of molten metal on the lower side of the cut path, because of a lack of assist gas pressure value. Fig. 11 shows upper, lower, and average kerf width values at different cutting arrays.

Seven of the nine samples were cut based on the laser cutting parameters, and the results are as follows. For sample No. 1, it has been noticed that average kerf width value is small, as shown in Fig. 12 (a, d), as the low assist gas pressure led to high value of concentrated heat without removal as the velocity of cutting is low too as it is only 1000 mm/min.

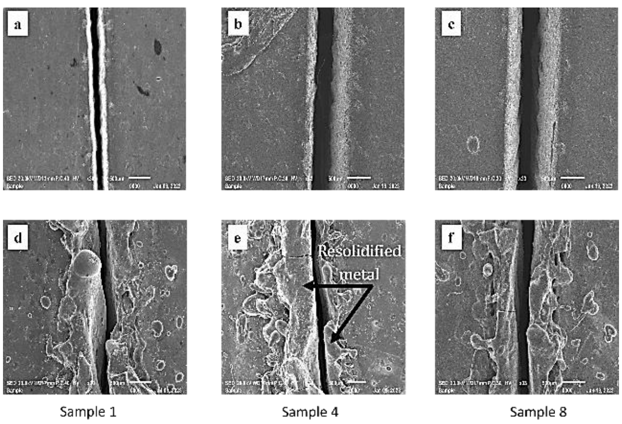

Fig. 12. Upper and Lower kerf width SEM photos of; (a, d) Sample No. 1 (Pu = 2 KW, V= 1000 mm/min, P= 6 bar), (b, e) Sample No. 4 (Pu = 2.5 KW, V= 1000 mm/min, P= 8 bar), and (c, f) Sample No. 8 (Pu = 3 KW, V= 1500 mm/min, P= 6 bar).

For sample No. 2, average kerf width values increase because of an increase in the assist gas pressure to 8 bar. Which causes a good cooling to the path of cut, also increasing the cutting velocity cause a good removal to the molten metal but it was not enough to affect the average kerf width value. For sample No. 3, the input cutting parameter values were not enough to cause a complete cutting of the specimen, because of higher value of cutting velocity against lower value of power of laser beam. Which did not produce enough value of heat needed to fully cut the sample.

For sample No. 4, the increase in average kerf width value appears again, as shown in Fig. 12 (b, e), because of the increasing of laser beam power to 2.5 KW and the decreasing of cutting velocity to 1000 mm/min. Which causes a higher heat concentration to the path of cut which led to a wide line of cutting. For sample No. 5, the average kerf width value decreased when compared to sample No. 4 because of increasing of the cutting speed to 1500 mm/ min which led to lower temperature in the place of cutting, but the increasing of the assist gas pressure to 10 bar led to increasing the rate of removing the molten metal and keeping the values a little higher. For sample No. 6, the input cutting parameter values were not enough to cause a complete cutting of the specimen, because of higher value of cutting velocity against lower value of power of laser beam. Which did not produce enough value of heat needed to fully cut the sample.

For sample No. 7, the increase in average kerf width value appears again because of the increasing of laser beam power to 3 KW and the assist gas pressure to 10 bar. Which causes a good removing of the molten metal from the path of cut. Also, the decreasing of cutting velocity to 1000 mm/min. Which causes a higher heat concentration to the path of cut which led to a wide line of cutting. For sample No. 8, the average kerf width value did not show a big decrease when compared to sample No. 7, as shown in Fig. 12 (c, f), because of increasing of the cutting speed to 1500 mm/ min which led to lower temperature in the place of cutting, also the decreasing of the assist gas pressure to 6 bar led to decreasing the rate of removing the cut metal which cause a big difference in the values of upper and lower kerf width which led to a small value of the average kerf width.

For sample No. 9, the average kerf width value did not show a big decrease when compared to sample No. 8 because of increasing of the cutting speed to

2000 mm/ min which led to lower temperature in the place of cutting, but the increasing of the assist gas pressure to 10 bar led to increasing the rate of good removing the cut metal and keeping the values close, because of the big difference between upper and lower kerf width values . To sum up, the average kerf width values are proportional to laser beam power and the assist gas pressure and inversely proportional to the cutting velocity.

3.3 3D PLOT OF MICROHARDNESS AND AVERAGE KERF WIDTH VERSUS INPUT CUTTING PARAMETERS.

To determine the optimal laser cutting process input parameters versus cutting surface output performance. Minitab was used to create a 3D graphic of the input against output parameters, which demonstrates the impact of input factors on output parameters as shown in Fig. 13, Fig. 14, and Fig. 15.

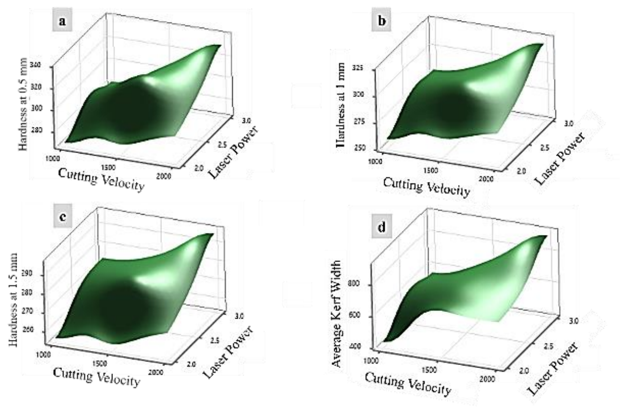

Fig. 13: 3d plot of input parameters (Laser beam power vs Cutting velocity) for (a) Microhardness at 0.5mm, (b) Microhardness at 0.5mm, (c) Microhardness at 0.5mm, and (d) Average kerf width.

It was noticed that the microhardness values are proportional with laser beam power and the assist gas pressure and inversely proportional to the cutting velocity and distance from the line of cutting. the average kerf width values are proportional to laser beam power and the assist gas pressure and inversely proportional to the cutting velocity.

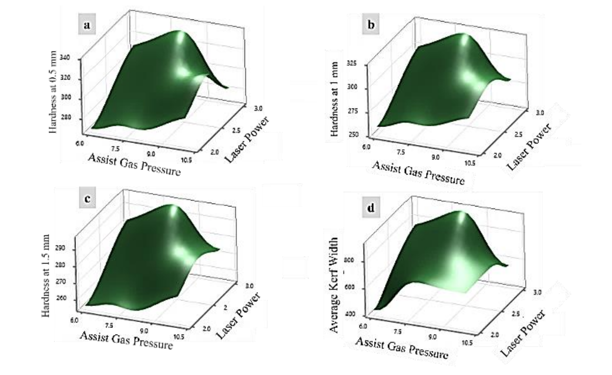

Fig. 14: 3d plot of input parameters (Laser beam power vs Assist gas pressure) for (a) Microhardness at 0.5mm, (b) Microhardness at 0.5mm, (c) Microhardness at 0.5mm, and (d) Average kerf width.

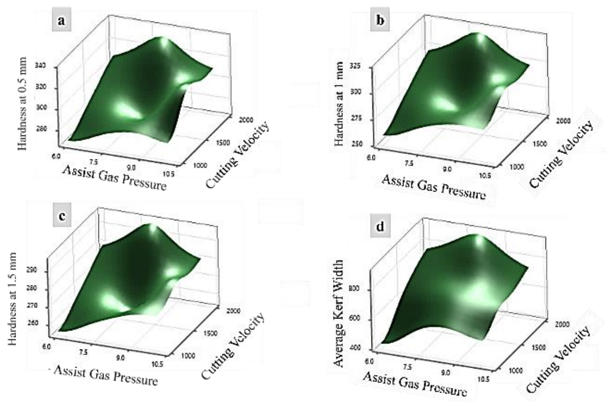

Fig. 15: 3d plot of input parameters (Cutting velocity vs Assist gas pressure) for (a) Microhardness at 0.5mm, (b) Microhardness at 0.5mm, (c) Microhardness at 0.5mm, and (d) Average kerf width.

3.4 THE MAIN EFFECT OF INPUT PARAMETERS ON MICROHARDNESS AND AVERAGE KERF WIDTH VALUES

To check the most effective input parameter among laser beam power, the velocity of cutting, and the pressure of the assist gas on the output parameter values, which are microhardness and average kerf width.

The main effect plots of input parameters on performance parameters have been done using Minitab software, which are shown in Fig. 16 to Fig. 19, that provide a clear response to the question of which parameters have a greater impact on performance parameters than others.

According to those plots, To attain the lowest microhardness values, it is advised to employ high cutting speed values at medium laser beam power and assist gas pressure, as shown in Fig. 16, Fig. 17, and Fig. 18. Also, to attain the lowest average kerf width values, it is advised to employ high cutting speed values at medium laser beam power and assist gas pressure as shown in Fig. 19.

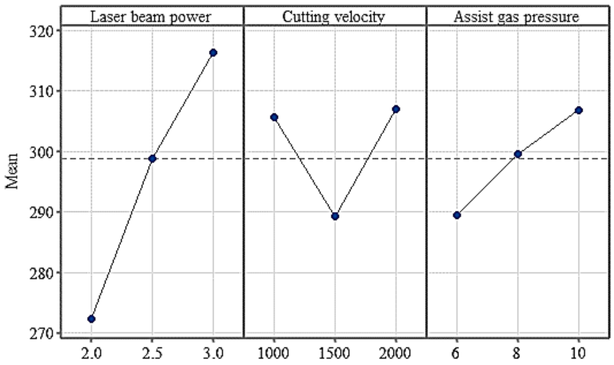

Fig. 16. Main effect plot of cutting parameters on microhardness at 0.5 mm.

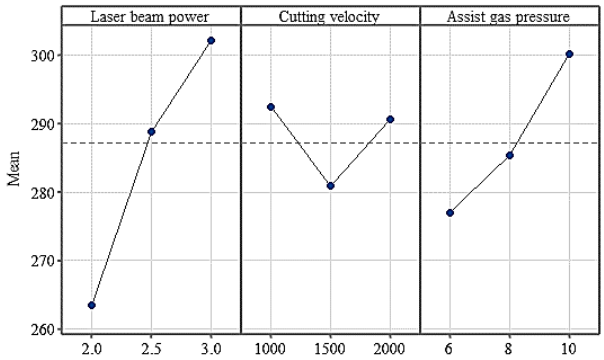

Fig. 17. Main effect plot of cutting parameters on microhardness at 1 mm.

So, the main effective parameter for microhardness values is laser beam power followed by assist gas pressure and cutting velocity. The main effective parameter for average kerf width is laser beam power followed by cutting velocity and assist gas pressure.

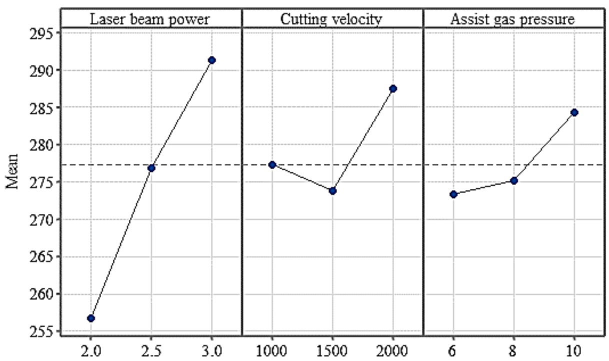

Fig. 18. Main effect plot of cutting parameters on microhardness at 1.5 mm.

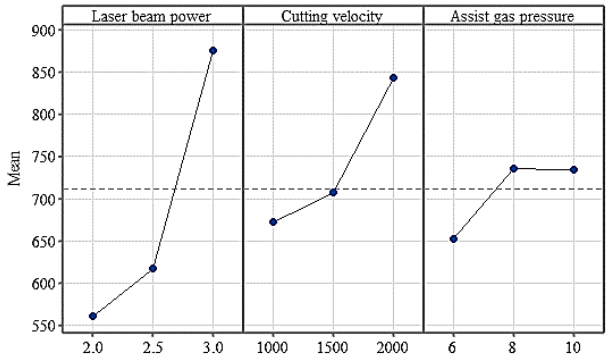

Fig. 19. Main effect plot of cutting parameters on average kerf width values.

4. Conclusions

A fiber laser machine was utilized to cut 4 mm-thick Ti-6Al-4V alloy sheets, and the most successful cutting settings were chosen and studied. Microhardness and average kerf width were investigated as output parameters to see the effect of laser beam power, cutting speed, and assist gas pressure on their values. The key findings of this study can be introduced in the coming points:

1. The main effective parameter for microhardness values is laser beam power followed by assist gas pressure and cutting velocity. While the main effective parameter for average kerf width is laser beam power followed by cutting velocity and assist gas pressure.
2. Assist gas pressure is an important factor in the laser machining process because it helps in refining the cut surface by removing the molten metal, resulting in a good surface quality.
3. The highest microhardness and average kerf width values of 332±10 HV and 909±16 μm, respectively, were observed at a laser power of 3 kW, a cutting speed of 1000 mm/min, and an auxiliary gas pressure of 10 bar.
4. The lowest microhardness and average kerf width values of 269±10 HV and 431.25±43.5 μm respectively, were observed at a laser power of 2 kW, a cutting speed of 1000 mm/min, and an auxiliary gas pressure of 6 bar.

5. Future work

In the future, it is recommended to investigate the effect of laser cutting parameters on both the straight and the curved paths and make a comparison between straight and curved cut paths.

DECLARATION OF COMPETING INTEREST

The authors affirm that they have no known financial or interpersonal conflicts that would have seemed to have an impact on the research presented in this study.

DATA AVAILABILITY

Data will be made available on request.

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