Experimental Study of Laser Machining of Al6061 by Fibre Laser

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Abstract

Al6061 find wide applications in aerospace and automotive industries. The challenge lies in cutting this advanced material and obtain the good surface texture. The present study reports the application of non-contact type (thermal energy based) bystronic fibre laser cutting process on Al6061. The process parameter in laser cutting influence the kerf width and surface roughness. These quality characteristics were observed for the various combination of cutting parameter like laser power, feed rate and assist gas pressure. The cutting trial were design according to box behnken method and grey based response surface methodology was disclosed for predicting optimal combination laser cutting parameters substantial improvement in surface finish was observed in the response obtained with the optimal setting of parameters.

Introduction

Al6061 are found to be exhibit good strength to weight ratio and better corrosion resistance. Now days the research attention is focused toward the process optimization of Al6061, though aluminium can be cut by traditional machining processes. It create greater tool wear in conventional cutting[1]. The wide spread application of Al6061 is not possible without solution to the problems associated with cutting. The fibre laser cutting process is used for generating complex cut profiles and also on non-contact mode. It is also faster and cost effective than water jet cutting [2]. The material properties include thermal conductivity, melting point and reflectivity governs the selection of laser system for machining. The fibre laser beam was used for cutting a wide range of materials including metals, ceramics, plastics and aluminium [4]. The various stages involved in the mechanism of metal removal by lasers include melting, vaporizing and degrading. The energy transfer by irradiation without any cutting force eliminates the possibility of mechanically induced damage to the work material [5]. Though limited investigation was found in Al6061 by employing fibre laser it is most sought form an industrial perspective. A vast majority of industrial applications involve cutting of metal sheets using lasers because of better finish and faster operation [8]. Most polymers could be cut with good finish using CO_2 laser, during which the relationship between the cutting speed and surface finish was observed to be non-linear [9]. The high power solid-state fibre lasers were used to cut titanium alloy sheets with good surface quality characteristics [10]. The difficult to machine materials like austenitic stainless steels and Inconel 718 super-alloy sheets could be cut by using a laser beam assisted by nitrogen or oxygen. It was observed that a smooth surface with smaller kerf width was obtained, while using nitrogen as an assist gas [10]. While cutting steel sheets, beam waist position was observed to play a significant role in affecting the kerf width and avoiding the micro-cracks on the cut surface [9]. From the literature, it was found that the cutting parameters play a vital role in deciding the quality characteristics of the cut surface. The process parameters like beam power, cutting speed and gas pressure were investigated in cutting different materials using fibre laser beam and optimization was performed effectively using experimental and graphical method [10]. However these techniques do not describe the non-linear relationship between the design variables and responses. Box behnken method was employed to study the effects of process parameters in laser processing and analysis of variance (ANOVA) was performed to identify the contribution of various input factors [11].

Experimental work

Material:

The work material used in the study was Al6061 sheet of metal of size 200mm*300mm*8mm was cut into seventeen equal parts by using various process parameters. The properties of Al6061 are shown below.

Chemical Composition

The alloy composition of 6061 is:

- Silicon minimum 0.4%, maximum 0.8% by weight
- Iron no minimum, maximum 0.7%
- Copper minimum 0.15%, maximum 0.4%
- Manganese no minimum, maximum 0.15%
- Magnesium minimum 0.8%, maximum 1.2%
- Chromium minimum 0.04%, maximum 0.35%
- Zinc no minimum, maximum 0.25%
- Titanium no minimum, maximum 0.15%
- Other elements no more than 0.05% each, 0.15% total
- Remainder aluminum (95.85–98.56%)

Mechanical Properties

The mechanical properties of 6061 depend greatly on the temper, or heat treatment, of the material. Young's Modulus is 69 GPa regardless of temper.

Machine setup:

The cutting experiments are performed in bystronic fibre laser cutting machine using nitrogen as the assist gas, whose discharge is formed between two RF excited electrodes. The laser beam was focussed to a spot diameter of 0.2 mm by using a lens of focal length 127 mm. The laser machine could operate with a maximum beam power of 6 KW and a PLC based system was employed for varying the speed of cutting and pulsing frequency. The laser beam impact angle was kept at 90 degrees during all the trials and the nozzle workpiece stand-off distance was maintained at 1 mm during various trials.

Fig.1. Bystronic fibre laser

Experimentation

The quality characteristics of the cut surface depends on dominant process parameters like the laser beam power, cutting velocity, gas pressure [9]. However the focal point was not considered in this investigation as a cutting parameter. The pilot cutting trial were performed to reduce allowable range of process parameter and to sort out acceptable upper and lower bonds of parameters for which cut surface quality remained decent with laser heat affected zone and minimum dross. We select the value of input parameter by Box-Behnkem method in Design Expert software which gives us sixteen parameter with combination of cutting speed, laser power and gas pressure. From this we calculated the surface roughness and kerf width. The schematic layout of the process indicating the principle of laser cutting is shown in Fig.2(a). A uniform distance was ensured between the square profiles cut during each trial in a single pass and a button-hole cut was also made in each specimen for measuring the kerf width. The measured quality characteristics include the surface roughness (SR), kerf width (KW) Fig.2(b). The kerf indicates the loss of material and roughness represents the surface texture. The first six specimens cut during the trials are shown in Fig.2(c).

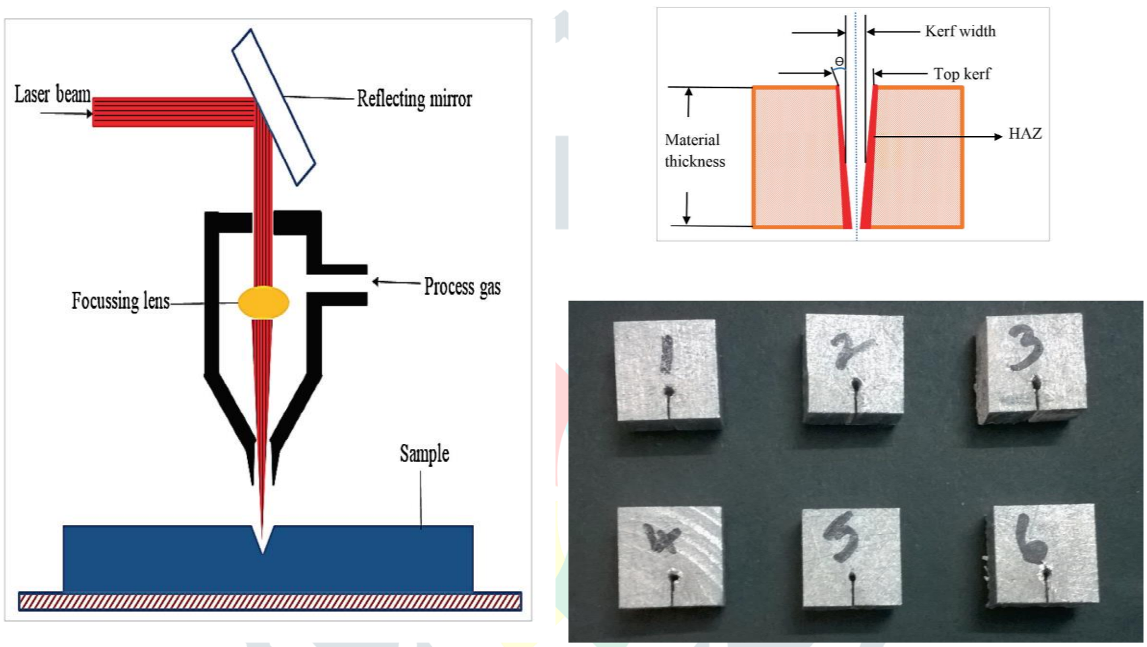


Fig.2. (a) Schematic layout of the process, (b) measurement of kerf width and edge slope angle and (c) first six specimens cut during the trials.

The surface roughness tester was used to measure surface roughness. The roughness measurement was taken at middle of depth (4mm) on all four sides on the direction of cut. The kerf width is measured using profile projector. First kerf width of top surface is measured then kerf width of bottom surface is measured and then average of both is taken.

Results and Discussion

Experimental values of output parameter

		Factor 1	Factor 2	Factor 3	Response 1	Response 2
Std	Run	A:Laser Power	B:Cutting speed	C:Gas Pressure	Surface roughness	Kerf Width
		watt	mm/min	Bar	microns	
9	1	5500	2500	14	2.975	0.325
11	2	5500	2500	18	2.732	0.53
17	3	5500	2750	16	1.835	0.525
5	4	5000	2750	14	1.467	0.445
8	5	6000	2750	18	1.585	0.47
2	6	6000	2500	16	1.712	0.425
13	7	5500	2750	16	2.089	0.525
16	8	5500	2750	16	2.832	0.49
15	9	5500	2750	16	2.018	0.53
7	10	5000	2750	18	2.149	0.48
14	11	5500	2750	16	2.072	0.585
3	12	5000	3000	16	3.287	0.475
6	13	6000	2750	14	2.804	0.395
12	14	5500	3000	18	1.803	0.475
1	15	5000	2500	16	3.086	0.44
4	16	6000	3000	16	3.372	0.46
10	17	5500	3000	14	1.801	0.49

Mathematical model of Grey generation technique.

The generated mathematical model quantify the association and explores the individual and interaction effect of cutting parameter on the response. Hence offering the scope to study the behavior of system [9].

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	0.0516	9	0.0057	6.94	0.0091	significant
A-Laser Power	0.0010	1	0.0010	1.23	0.3048	
B-Cutting speed	0.0041	1	0.0041	4.90	0.0624	
C-Gas Pressure	0.0112	1	0.0112	13.62	0.0078	
AB	0.0000	1	0.0000	0.0000	1.0000	
AC	0.0004	1	0.0004	0.4842	0.5090	
BC	0.0121	1	0.0121	14.65	0.0065	
A^2	0.0082	1	0.0082	9.98	0.0159	
B^2	0.0057	1	0.0057	6.88	0.0342	
C^2	0.0065	1	0.0065	7.85	0.0264	
Residual	0.0058	7	0.0008			
Lack of Fit	0.0011	3	0.0004	0.3176	0.8134	not significant

Pure Error	0.0047	4	0.0012
Cor Total	0.0574	16	

Factor coding is **Coded**.
Sum of squares is **Type III - Partial**

The **Model F-value** of 6.94 implies the model is significant. There is only a 0.91% chance that an F-value this large could occur due to noise.

P-values less than 0.0500 indicate model terms are significant. In this case C, BC, A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.The **Lack of Fit F-value** of 0.32 implies the Lack of Fit is not significant relative to the pure error. There is a 81.34% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Fit Statistics

Std. Dev.	0.0287	**R^2**	0.8992
Mean	0.4744	**Adjusted R^2**	0.7697
C.V. %	6.06	**Predicted R^2**	0.5627
		Adeq Precision	8.6646

The **Predicted R^2** of 0.5627 is not as close to the **Adjusted R^2** of 0.7697 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs.

Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 8.665 indicates an adequate signal. This model can be used to navigate the design space.

Final Equation in Terms of Coded Factors= 0.531 + -0.01125 * A + 0.0225 * B + 0.0375 * C + -7.80116e-17 * AB + 0.01 * AC + -0.055 * BC + -0.04425 * A^2 + -0.03675 * B^2 + -0.03925 * C^2

Final Equation in Terms of Actual Factors= -16.1658 + 0.0017645 * Laser Power + 0.005084 * Cutting speed + 0.58025 * Gas Pressure + -1.20359e-20 * Laser Power * Cutting speed + 1e-05 * Laser Power * Gas Pressure + -0.00011 * Cutting speed * Gas Pressure + -1.77e-07 * Laser Power^2 + -5.88e-07 * Cutting speed^2 + -0.0098125 * Gas Pressure^2

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

Study of response surface

The aluminium alloys were difficult to cut by lasers due to their high reflectivity and thermal conductivity. The problem was further intensified by the self-extinguishing oxidation reaction and a higher power requirement in continuous wave mode of operation [4]. Hence a pulsed laser beam using nitrogen as the process gas was employed to cut with a better laser coupling. The response surface plots were drawn based on the generated polynomial equation associating the dependent variable GRG with the independent variables such as laser power, gas pressure, cutting velocity and pulsing frequency. Three response surface plots were generated and displayed, avoiding the interaction plot with insignificant effect.

Graph of predicted value vs actual kerf width is a straight line passing through the origin which means that actual values taken from experiment are correct [fig.3].

As a laser power increases the kerf width is decreases and at the specific laser power the kerf width is maximum due to high instantaneous energy results in melting.

Higher energy of laser power at lower cutting speed can cause thermal damage to the cutting surface while higher cutting speed causes striations and spoils the finish hence moderate level cutting speed is desired while taking better kerf and finish [fig4].

The use of nitrogen gas as assist gas at high gas pressure leads to easy ejection of molten metal, minimizing the dross. The purging out of dross at high pressure reduces kerf width and surface roughness improved [fig 5].

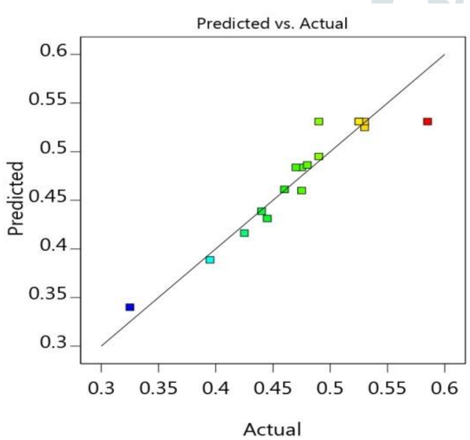


Fig.3.Graph of predicted vs actual kerf width

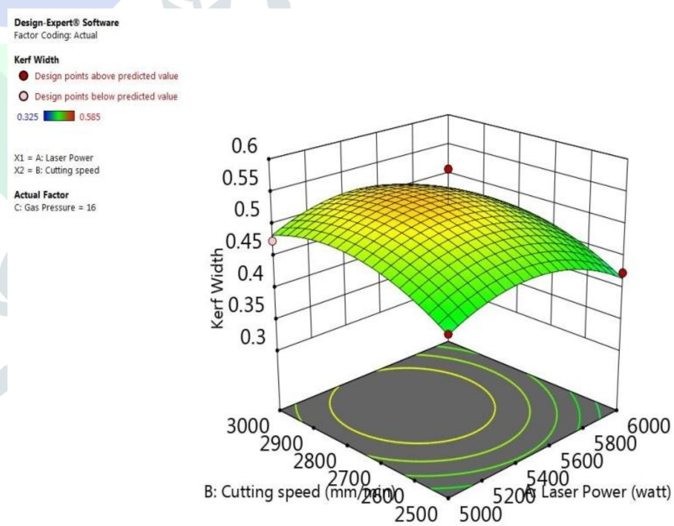
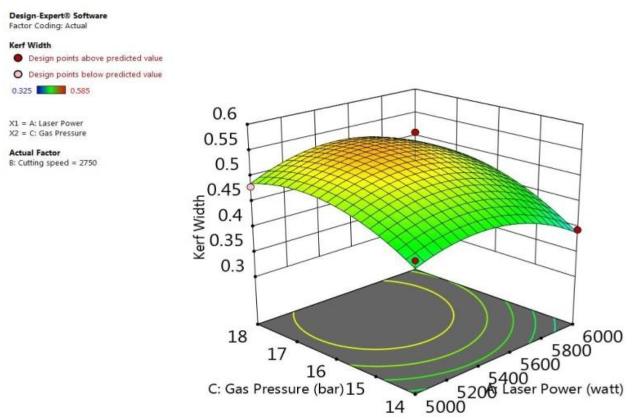


Fig.4. Graph of laser power vs cutting speed vs kerf width

Fig.5. Graph of laser power vs gas pressure vs kerf width



Conclusion

In the present experimental work, Al6061 was selected as specimen for conducting experiments. Aluminium was selected due to its wide range of applications. Using Design expert software experimental runs were finalized. Minimum and maximum laser power that was selected was 5000 and 6000 watt respectively. Performance parameters that were measured were surface roughness and kerf width. It was observed that as there is increase in laser power, kerf width and roughness of samples increases. With increase in cutting speed surface roughness of the material also increases but gas pressure showed very less effect on roughness and kerf width.

The optimal level of cutting parameter for minimum surface roughness was identified as: laser power =5000watt, cutting speed =2750mm/min, pressure =14bar.

Similarly for minimum kerf width optimal level of cutting parameter are as: laser power =5500watt, cutting speed =3000mm/min, gas pressure =14bar.

References

[1] Cong Chen, Ming Gao, Xiaoyan Zeng, "Fiber Laser Cutting Of Aluminium alloy.",(Machine tool & manufacture),(6),(2016),(0890-6955)

[2] Priyanka Joshi, Amit Sharma, "Heat Affected Zone In Fiber Laser Cutting Of Al6061.",(Precision Engineering),(18),(2018),(6359-30148)

[3] G. Costa Rodrigues, M. Cuypers, J. R. Duflou. "Laser Cutting With Direct Diode Laser", (physics procedia),(56),(2014),(901-908)

[4] Abhishek Sharma, Shiwendu Sagar, Rajuprasad Mahto, "surface Modification of Al6061."(surface And coating technology),(337),(2018),(12-23)

[5] R. Adalarasan, M. Santhanakumar "Optimization of Laser Cutting Parameters For Al6061",(Mesurment),(73),(2015),(596-606)

[6] N.Hosseini, F. Karimzadeh, M. H. Abbasi "Properties Of Coarse-Grained Al6061 Alloy And Al6061 composite"(TribologyInternational),(54),(2012),(58-67)

[7] G. Costa Rodrigues, J. R. Duflou.“Performance Comparision With Conventional Fiber and CO_2 Technologies” (physics Procedia),(56),(2014),(901-908)

[8] R. A. Walsh, Machining and Metalworking Handbook, third ed., McGraw-Hill, New York, 2006.

[9] M. Kurt, Y. Kaynak, E. Bagci, H. Demirer, M. Kurt, Dimensional analyses and surface quality of the laser cutting process for engineering plastics, Int. J. Adv. Manuf. Technol. 41 (3-4) (2009) 259–267.

[10] L.D. Scintilla, G. Palumbo, D. Sorgente, L. Tricarico, Fiber laser cutting of Ti6Al4V sheets for subsequent welding operations: effect of cutting parameters on butt joints mechanical properties and strain behaviour, Mater. Des. 47 (2013) 300–308.

[11] K. Abdel Ghany, M. Newishy, Cutting of 1.2 mm thick austenitic stainless steel sheet using pulsed and CW Nd:YAG laser, J. Mater. Process. Technol. 168 (3) (2005) 438–447.