Application of OFAT approach to examine the effect of laser cutting process parameters onkerf characteristics for metal matrix composite material

Vikas Sharma
Department of Mechanical Engineering, Gulzar Group of Institutions, Khanna

Jaiinder Preet Singh
Department of Mechanical Engineering, Lovely Professional University, Patiala (Punjab), India

Abstract - The current research applies the One Factor at a Time (OFAT) approach to explore the laser cutting process parameters and its affect on the kerf features of laser-machined aluminum metal matrix alloy 5052. The study focuses on examining the impact of nozzle diameter, nitrogen gas pressure, laser power and cutting speed on the kerf taper. An experimental result revealed that laser cutting speed exhibits a high significant effect on kerf taper, while laser power and nitrogen gas pressure demonstrated a moderate influence. The optical micrographs of machined samples were investigated for the microstructural analysis to evaluate the effect on kerf taper with respect to the bottom and topkerf width profiles.

Keywords: kerf width, aluminium alloy (5052), assist gas, laser power

I. INTRODUCTION

A laser beam machining is considered as advanced machining process to remove material from a workpiece without any physical contact with workpiece material. Due to its capability to produce precise and exact machining results on a variety of materials, LBM has attracted substantial attention in a number of sectors. In comparison to conventional cutting methods, the laser machining process has less heat-affected zones, less tool wear, and greater flexibility.

Cristobal et al., (2021) implementedCO2 laser cutting of PMMA sheets and revealed the impact of gas pressure, focal point position, cutting speedand laser power on quality characteristics.The optimal operational parameters were identified which resulted into improved kerf profile deviation. Moreover, an artificial neural network model predicted accurate kerf value deviation values.Rao et al. (2009) conducted a study comparing the kerf width values of aluminum alloy (7050) reinforced with a 20% B4C composite and a 20% Al_2O_3 composite alloy. The results showed that the B4C composite exhibited a smaller kerf width compared to the Al_2O_3 composite. Additionally, the study found that complicated cut profiles had a larger kerf taper as compared to normal cut profiles.Kumar et al. (2013) utilized the Box-Behnken design and wire electric discharge machine to investigate the behavior of pure titanium. Their study focused on optimizing process variables using response surface methodology and desirability.Sharma et al. (2010) examined the normal and complex kerf quality using Nd:YAG laser machined nickel alloy for kerf characteristics. The results showed that the curved cut profiles yielded different outcomes for kerf taper and kerf deviation compared to the straight cut profiles. However, the kerf width remained consistent for both profiles.Mathew et al. (1999) carried out investigations on the laser cutting of a 2 mm thick composite sheet using pulsed Nd:YAG technology. A second-order response model was formulated with the assistance of CCD experimental design, allowing the analysis of the effects of different laser input parameters, including gas pressure and pulse types with different spans, on both heat-affected zone (HAZ) and kerf properties.Yilbas et al. (2014) studied the stresses at different corner points in laser cutting using an alumina tile with a triangular cutting profile. It was examined that high stress concentration lied in between the workpiece profile. Cicala et al. (2008) conducted research on various alloy materials including stainless steel. The research revealed that higher laser pulse frequency and reduced cutting speed has a significant impact on surface roughness. Dubey et al. (2007) applied response surface methodology to identify significant levels of various parameters on laser cutting of aluminium alloy work material. Venkata et al. (2013) conducted deep research on various composite materials based on various SiC and Al2O3 reinforced particles. They found that AMC exhibited superior machinability in terms of cutting force, radial force, and surface roughness compared to the other composites. Riveiro et al. (2010)centered their research on various laser cutting variables with focus on variable wave (continuous-pulse) modes on Al-Cu alloy and compared the results for various waves modules. Caydas et al. (2008) used laser machining with the help of various statistics tools such as GRA and factorial approach to optimize the quality characteristics.Yang et al. (2014) investigated laser welding process on various materials having different physical properties. It was revealed that brass material had greater welded strength over stainless steel.Pandey A. et al. (2012) conducted laser machining of titanium alloy sheet to obtain optimized values of kerf taper and surface roughness. A multi-objective optimisation was applied for the regression models for quality characteristics, whereas the objective functions were generated using genetic algorithm.

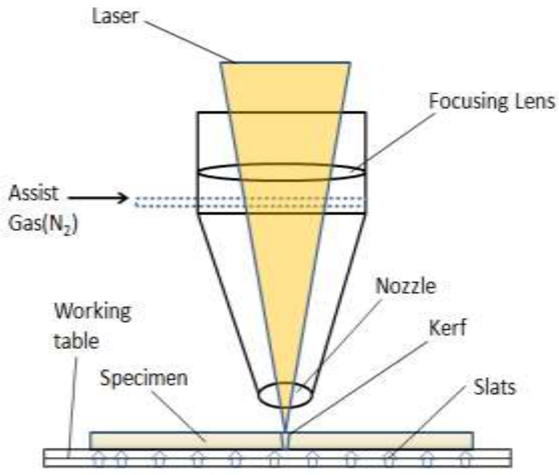


Figure 1: Schematic of laser setup

Table 1: Laser cutting variables and quality characteristics

Run No.	Laser speed	Cutting power	Gas Pressure	OrificeDiameter	Kerf Taper
Units	mm/min	watt	bar	mm	degree
1	1000	1000	6	1.4	0.299
2	1500	2000	8	1.7	0.290
3	1500	1500	10	1.7	0.284
4	1500	1000	8	2	0.348
5	1000	1000	8	1.7	0.455
6	2000	1000	8	1.7	0.324
7	1500	1000	8	1.4	0.257
8	1000	2000	8	1.4	0.379
9	1500	1000	6	2	0.357
10	1500	1000	8	1.7	0.332
11	1500	1500	6	1.7	0.330
12	2000	1000	8	1.7	0.309
13	1000	1000	10	1.7	0.280
14	1500	1000	10	1.4	0.384
15	2000	2000	8	2	0.367
16	1500	1500	10	1.7	0.312

17	1500	1000	8	1.4	0.317
18	2000	1000	8	1.7	0.399
19	1500	1500	8	1.7	0.319
20	1000	2000	8	2	0.398
21	1500	1000	6	1.4	0.478
22	1500	1000	8	2	0.323
23	2000	2000	8	1.4	0.297
24	2000	1500	8	1.4	0.299
25	1000	1000	8	1.7	0.498
26	2000	1000	6	1.7	0.278
27	1000	1500	8	1.4	0.379

II. EXPERIMENTAL PROCEDURE AND MATERIALS

Using a one-factor-at-a-time approach, a series of experimental runs were designed to machine MMCA 5052. The fabrication of different work samples was accomplished using a stir casting setup. The molten aluminium alloy material amalgamated with SiC reinforced particles to fabricate different samples of same dimension. Using OFTA, total 27 experimental runs were conducted (as shown in table 1) to compare the quality characteristics values. The machining of work specimens was conducted using CO_2 laser cutting machine (Trulaser, 3000 W). The schematic of laser cutting setup has been shown in the figure 01. The various laser cutting variables used in the process were laser nitrogen gas pressure, nozzle diameter, cutting speed and laser power.

III. RELATIONSHIP BETWEEN KERF TAPER AND PROCESS VARIABLES

The variation in kerf taper values was investigated by analysing the impact of top and bottom kerf widths. The reduced values of kerf taper may be obtained with the help of various optimized laser cutting variables. The various researchers executed the work to analyse the effect of normal and complex cut profiles on kerf taper. In reference to Equation 2, this research assesses the implications of laser cutting parameters on kerf taper. The below mentioned equation employs the workpiece material thickness, along with the values of top and bottom kerf width, to analyze their impact on kerf taper. The kerf taper values can be calculated using below shown equation:

$$K_t = \{(K_{wt} - K_{wb}) \times 180\} / 2\pi t \qquad \ldots\ldots.(2)$$

where t denotes the thickness of workpeice material, K_{wt} is top surface profile kerf width, K_{wb} is bottom kerf profile width.

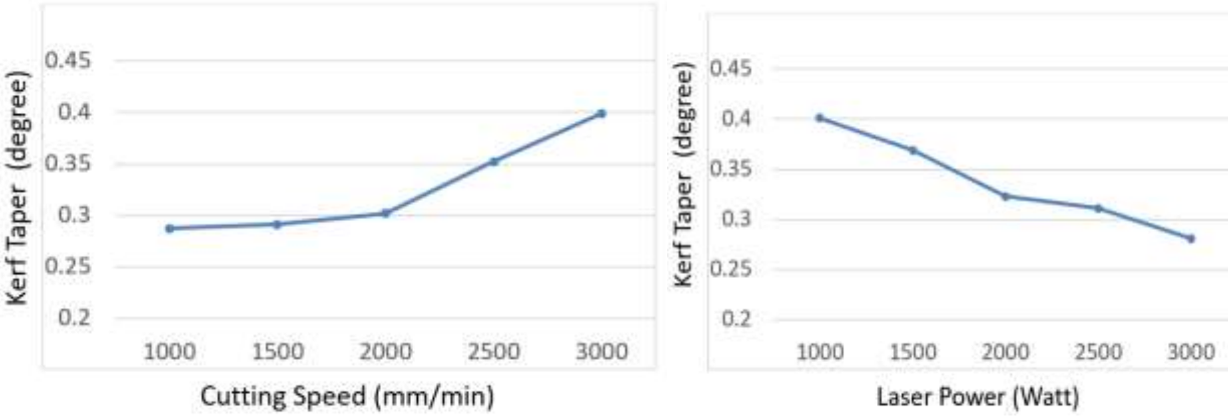


Figure 02: Trends of parameters in terms of Speed and Poweron Kerf Taper

IV. INFLUENCE OF LASER CUTTING SPEED AND LASER POWER SETTINGS

Figure 2 (a) illustrates the effect of laser cutting speed, with the cutting speed range displayed on the x-axis ranging from 1000 to 3000 mm/min. It was identified that incremental values of cutting speed has shown effect on the values of kerf taper values which raised from 0.29 mm to 0.4 mm. A dramatic variation has been examined in case of cutting speed within range of 2000 to 3000 mm/min which resulted into higher kerf taper values from 0.3 to 0.4 mm. The possible reason for the phenomenon is that rapid cutting speed lowers the amount of laser energy accessible to the profile section due to less beam interaction with the cutting surface. As a result, there is a slower rate of temperature rise over the surface and a greater increase in kerf taper due to the diffusion energy transfer in the depth direction.

In the figure 2(b), the detailed analysis of laser cutting power on kerf taper has been shown using graphical representation. In this research, it was revealedthat incremental laser powerinfluence the kerf taper angle. The higher laser power lowered the kerf taper values in significant pattern. Moreover, the higher values of laser cutting power ranging from1000 watt to 3000 watt, a significant decrease in kerf taper has been observed from 0.4 to 0.26 mm. When the laser power raised to higher values of 3000 watt, the heat supplied in the vicinity also increased which resulted into wider kerf width. Due to the high laser power, the laser beam penetrates easily into the material. The significance of wider kerf increases as it reduced the kerf taper values resulted into lower taper formation on the cut surface.

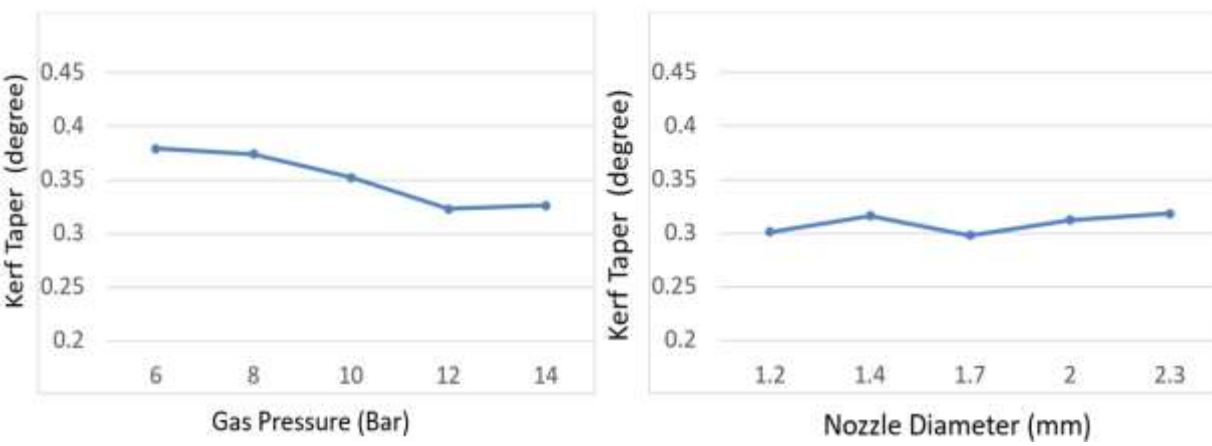


Figure 03: Trends of Gas pressure(a) andOrifice diameter (b) on Kerf Taper

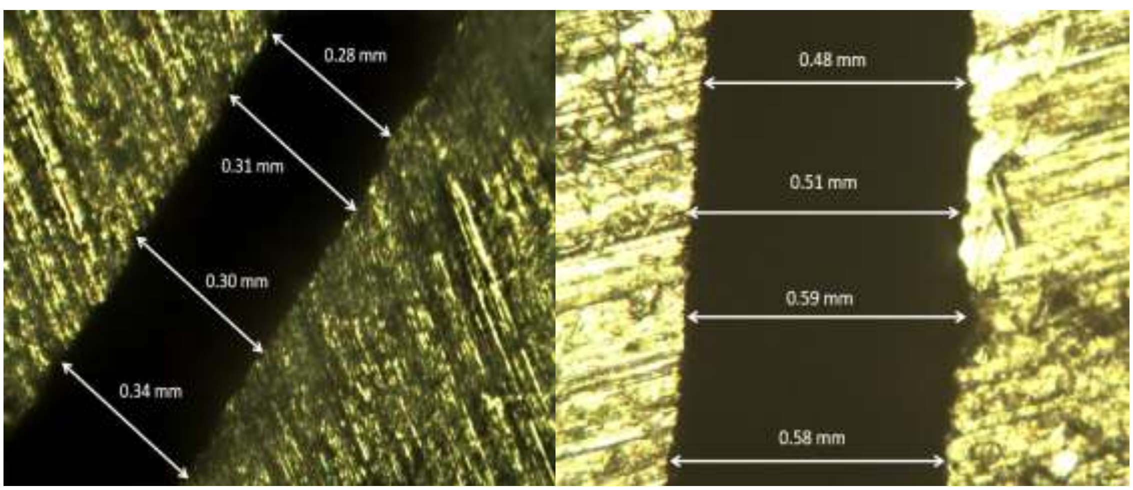
V. ANALYSIS OF GAS PRESSURE AND NOZZLE DIAMETER EFFECTS

The gas pressure is an important parameter to consider as it has large effect on the surface cut quality. Moreover, it becomes more significant to analyse the gas pressure influence with respect to various types of gases such as argon, nitrogen, compressed air etc. on quality characteristics. In the present research, nitrogen gas been used with variation of gas pressure to analyse the influence on kerf taper. Moreover, the research revealed the inverse proportional relation between kerf taper and gas pressure, higher the gas pressure values resulted into lower kerf taper values as depicted in figure 3 (a).

It has been investigated that higher values of gas pressure upto 14 bar, the kerf taper predicted with lower values of 0.32 degree. The lower kerf taper values reported due to removal of molten material with the high gas pressure from the vicinity of kerf profile. This resulted into decrease in the kerf values with respect to top and bottom kerf profile. On the other hand, lower gas pressure not able remove molten material from the lower kerf due to presence of oxide layer.The effect of nozzle diameter has been depicted in the figure 3 (b). It has been examined that with the increase in nozzle diameter there is no significant effect has been seen on the kerf taper. It may be due to the turbulence effect which possibly compensated by the oxide layer formation in the vicinity of kerf profile.

VI. MICROSTRUCTURE ANALYSIS

The machined specimens are examined for microstructural analysis using optical microscope for top surface profile and bottom surface profile kerf width. The variable thermal behaviour of aluminium metal matrix composites material makes it important to analyse the output characteristics with the variation of laser cutting parameters. Due to the variable melting temperatures of the aluminium 5052 and different reinforced particles, the bottom and top kerf width analysed with large variation in values.
Based on the experimental results, the critical factors influencing kerf taper include nitrogen gas pressure, laser power and cutting speed. The microstructure of the machined specimens may change due to the thermal cutting action of laser beam machining. There are many factors which contributes to the stress concentration, which initiate the process of crack formation.



(a) (b)

Figure4: Bottom and top kerf width for metal matrix composite aluminium alloy

The variation in top and bottom kerf width resulted into variable values of kerf taper. The results derived from optical micrographs predicted low values of bottom kerf width as compare to top kerf width. Moreover, the clustering of reinforced particles may also result into variable heat absorbing mechanism in the profile of kerf zone. In the figure the bottom kerf width values were observed in the range of 0.28 to 0.34 mm where in figure b the top kerf width was observed with higher values of the range 0.48 to 0.58 mm. It has been investigated that various reinforced particles show different behaviour with respect to laser heat absorbing behaviour. Due to low clustering of particles, a high variation was investigated which resulted into higher viscosity levels and surface tension of liquid material.

The stress concentration also resulted into high variation in kerf taper values which may be causeddue to the presence of reinforced particles.

VII. CONCLUSION

In this current study, an analysis of different laser cutting parameters was conducted to assess kerf taper values, taking into account both bottom and top kerf measurements. With the help of one factor at time, it has been examined the laser cutting speed, laser power and gas pressure shown significant effect on kerf taper. The effect of nozzle diameter not effected significantlythe kerf taper values. The variable laser heat absorbing mechanism has been confirmed using variable top and bottom kerf width values for respective kerf taper values. The agglomeration effect of reinforced particles has been considered for the output characteristics. From the optical micrographs the kerf values were investigated to examine the effect on the kerf taper values.

VIII. REFERENCES

[1]. Cristobal, L. and Ivan,L. (2021). Kerf profile analysis and neural network-based modeling of increasing thickness PMMA sheets cut by CO2 laser, Optics & Laser Technology, 144: 107386
[2]. Rao, R. and Yadava, V. (2009) Multi-objective optimization of Nd:YAG laser cutting of thin super alloy sheet using grey relation a analysis with entropy measurement. Optics and Laser Technology.41:922–30.
[3]. Kumar, A, Kumar V., and Kumar J. (2013) Multi-response optimization of process parameters based on response surface methodology for pure titanium using WEDM process. International J. of Adv. Manufacturing Tech. 68:2645–2668
[4]. Sharma, A., Yadava, V., and Rao, R. (2010) Optimization of kerf quality characteristics during Nd:YAG laser cutting of nickel based super alloy sheet for straight and curved cut profiles. Optics and Lasers in Engineering. 48:915–925
[5]. Mathew, J., and Goswami L. (1999) Parametric studies on pulsed Nd:YAG laser cutting of carbon fibre reinforced plastic composites, Journal of Materials Processing Technology. 89: 198–203
[6]. Yilbas, S., Akhtar, S.,andKaratas, C., (2014) Laser Cutting of Triangular Geometry into Alumina Tiles: Morphological Changes and Thermal Stress Analysis, Machining Science and Technology. 18: 424-447
[7]. Cicala, E., Soveja, A., and Sallamandb, P. (2008) The application of the random balance method in laser machining of metals. Journal of Materials Processing Technology. 196: 393–401
[8]. Dubey, A., and Yadava, V.,(2007) Simultaneous optimization of multiple quality characteristics in laser beam cutting using Taguchi method. International Journal of Precision Engg and Mfg.; 8:10–5.
[9]. Venkata, B., Ganguly, R., Srinivasarao G., andSahoo K., (2013) Machinability of Aluminum Metal Matrix Composite Reinforced with In-Situ Ceramic Composite Developed from Mines Waste Colliery Shale. Materials and Manufacturing Processes. 10: 1082-1089
[10]. Riveiro, A., Quintero, F., andLusquinos, F., (2010) Parametric investigation of CO2 laser cutting of 2024-T3 alloy. Journal of Materials Processing Technology. 210:1138–1152
[11]. Caydas, U., andHascalik, A. (2008) Use of grey relational analysis to determine optimum laser cutting parameters with multi-performance characteristics. Optics and Laser Tech. 40: 987–94
[12]. Yang, Li., andShengsun, Hu., (2014) Dissimilar Welding of H62 Brass-316L Stainless Steel Using Continuous-Wave Nd:YAG Laser. Materials and Manufacturing Processes. 29:916-921
[13]. Pandey, A., andDubey A., (2012) Simultaneous optimization of multiple quality characteristics in laser cutting of titanium alloy sheet, Optics & Laser Technology. 44: 1858–1865