Experimental investigation and fuzzy logic modelling of CO_2 laser cutting parameter for AA6061-T6 sheet

A. Parthiban*

Vels Institute of Science, Technology and Advanced Studies,
Chennai, 600117, India
Email: parthibana@yahoo.co.in
*Corresponding author

S. Sathish

Hindustan Institute of Technology,
Chennai, 603103, India
Email: sathishamg88@gmail.com

R. Ravikumar

Ariyalur Engineering College,
Ariyalur, 621707, India
Email: ravikumarmam@gmail.com

P. Prakash

Vels Institute of Science, Technology and Advanced Studies,
Chennai, 600117, India
Email: prakash1033@gmail.com

Abstract: The laser machining is a thermal energy-based process. The aluminium alloy is a highly reflective material which is difficult to cut by using the laser cutting process. The present paper experimentally investigated about the CO_2 laser cutting of aluminium AA6061-T6 alloy material for the improvement of geometrical accuracy of the curved profile at the same time to minimise the top, bottom kerf width and kerf deviations. The experiments are carried out by using fuzzy logic approach and to predict the effect of CO_2 laser cutting quality based on the cutting parameters on laser power, cutting speed, gas pressure and focal position. The fuzzy logic model is used on fuzzy logic tool box of MATLAB using Mamdani technique. The relationship between experimental value and fuzzy model are compared. Finally, based on the results, the proposed fuzzy logic models are minimised to top, bottom kerf width and kerf deviations of CO_2 laser cutting of AA6061-T6 aluminium alloys.

Keywords: fuzzy logic; CO_2 laser cutting; AA6061-T6; kerf width.

Reference to this paper should be made as follows: Parthiban, A., Sathish, S., Ravikumar, R. and Prakash, P. (2020) 'Experimental investigation and fuzzy logic modelling of CO_2 laser cutting parameter for AA6061-T6 sheet', *Int. J. Rapid Manufacturing*, Vol. 9, No. 1, pp.48–57.

Biographical notes: A. Parthiban completed his PhD in the area of Laser Cutting (Anna University) on June 2015. He joined Vels Institute of Science, Technology and Advanced Studies in July 2016. His teaching experience is nearly 1.2 years in Vels University and overall teaching experience of 10.8 years. He has attended 18 faculty development programs and workshops. He has published in 21 Scopus indexed journals and ten international conference publications. He has been a recognised Supervisor under the Faculty of Mechanical Engineering, Vels Institute of Science, Technology and Advanced Studies from December 2016 and currently guiding six research scholars. He is a life member of ISTE and IE.

S. Sathish completed his PhD in Annamalai University in 2016. He is currently working as an Associate Professor in Mechanical Engineering Department of Hindustan Institute of Science and Technology, Chennai

R. Ravikumar completed his PhD in NIT, Tirchy at 2008. He is currently working as Professor and Principal at Ariyalur Engineering College.

P. Prakash completed his ME in Anna University Tirunelveli Campus in 2014. Currently, he is working as an Assistant Professor in Mechanical Department of Vels Institute of Science, Technology and Advanced Studies, Chennai.

1 Introduction

Nowadays, laser cutting is the advanced machining process used in sheet metal fabrication industries. The aluminium alloy is most difficult to cut because of highly reflective material and complex shapes. Commonly industries have two types of laser machining being used Nd:YAG and CO_2 laser, broadly CO_2 laser is used in most of the industries. In this study, mainly to reduction of wastage to kerf width during the CO_2 laser cutting of aluminium alloys (Srivastava et al., 2018). The Nd:YAG laser is a solid state laser mainly working at a wavelength of 1.06 μm and the CO_2 laser is a gas type laser that has 10.6 μm of wavelength (Shishkovsky et al., 2015). The Nd:YAG lasers has lower beam power, it has worked in continuous and pulsed mode and mainly cutting the lower thickness of sheet metal at high accuracy (Mousa et al., 2014). CO_2 laser is cutting of all types of sheet metals at high speed because it has to deliver the maximum laser power, highest efficiency and good quality of beam (Caydas and Hascalik, 2008). At the same time, the maximum peak laser powers at a high speed of CO_2 laser reflecting a lesser degree by metal surfaces and this high absorptive of the CO_2 laser enables to process so that it is able to cut highly reflective materials with a relatively high cutting speed (Srinivasan et al., 2017). CO_2 laser cutting of aluminium alloys material has the most important research for making of high accuracy of cutting end surfaces (Hiranoa and Fabbroa, 2011). The quality of cut mainly depends on the input parameters, mainly laser power, cutting speed, gas pressure and focal position (Arif et al., 2009). Most of the researchers change only the two and three parameters and to study the effect of cutting surfaces of the metals. That have the more number of experimental run are needed. The mainly used are DOE Taguchi-based approaches in this method and the interaction effects process parameters are not considered (Madic et al., 2012). And not considering about the different cutting profiles like straight and curved types. So that the present work would try to concentrate about the fuzzy logic-based approach used and the cutting of aluminium AA6061-T6 material are also used for the curved profile cutting geometry which is investigated.

2 Materials and methods

In this research work, CO_2 laser cutting of AA6061-T6 sheet metal to cut curved profiles are considered.

2.1 Experimental procedure

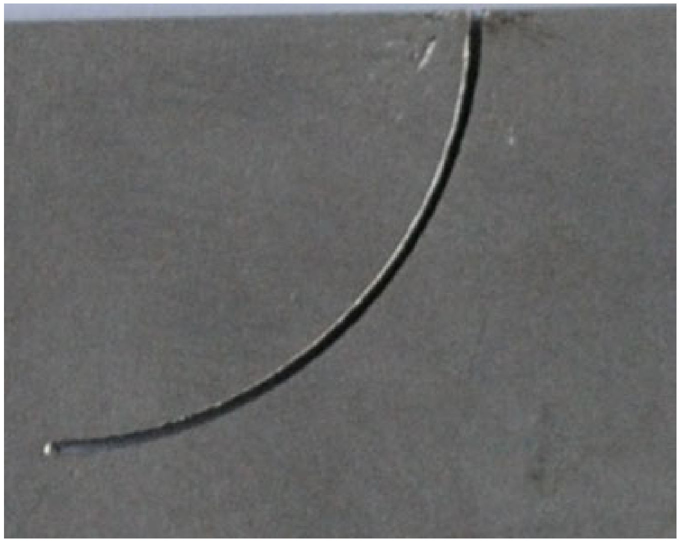
AMADA make CO_2 laser cutting machines is as shown in Figure 1. All the experimental work is done in these machines. And cutting material for aluminium alloys for AA6061-T6 2.5 mm thickness are also considered. To cut geometry for curved profile is shown in Figure 2 (Parthiban et al., 2018). To control parameters are like beam power, cutting speed, gas pressure and focal position. At that time, the controlled parameters are variable levels of beam power of 2,000, 2,150 and 2,300 watts, cutting speed of 2,000, 3,000, 4,000 mm/min, gas pressure are 1, 1.1, 1.2 Mpa and focal position of –1, –1.5 and –2 mm.

2.2 Measurement of responses

After the cutting of sheet metal, measuring the top kerf width and bottom kerf width by using of tool makers microscope with 20× magnification factors at each workpiece of three measurements taken along the cutting length (Dinesh et al., 2016). The kerf deviations are to calculate the maximum kerf width and the minimum kerf width.

Figure 1 CO_2 laser cutting machine (see online version for colours)

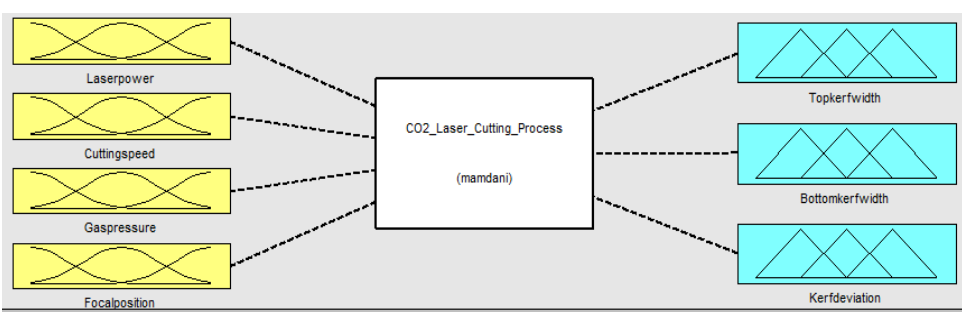
Figure 2 Curved cutting profile



2.3 Fuzzy logic modelling for CO_2 laser cutting

The fuzzy logic model for CO_2 laser cutting of AA6061-T6 sheet metal was developed for this work, to predict the best controlled parameter for top, bottom kerf width and kerf deviation for AA6061-T6 (Parthiban et al., 2017a). Fuzzy model are considered controlled parameters in which beam power, cutting speed, assist gas pressure and focal position are considered. The input and output variables fuzzy logic system is shown in Figure 3. Fuzzy logic systems have input and output variables called linguistic variables.

Figure 3 Fuzzy logic system (see online version for colours)



3 Result and discussion

3.1 Methodology and implementation

The fuzzy models are implemented in this work and MATLAB version R2007b software Mamdani fuzzy logic tool box are used. The input membership functions are low, low medium, medium, high medium and high and the output membership function are very low, low, low medium, medium, high medium, high and very high (Parthiban et al., 2017b).

The input and output membership functions trapezoidal and triangular are shown in Figure 4. The input memberships curved can be used in trapezoidal and it has more number of ranges comparatively triangular edges. So that it achieves high levels of variables. This work has four input variables and three output variables are formed and rule viewer shown in Figure 5. The fuzzy rules are to represent in the form of IF-THEN rules in this work 29 rules training data rule editor are used.

Figure 4 Input and output membership functions (see online version for colours)

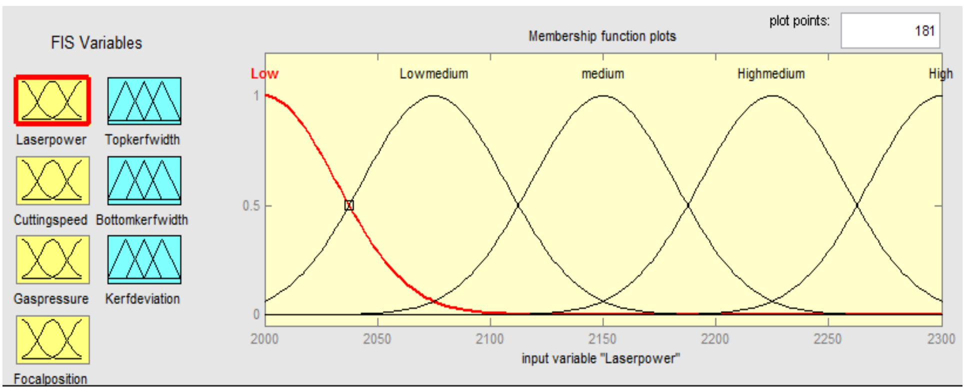


Figure 5 Rule viewer (see online version for colours)

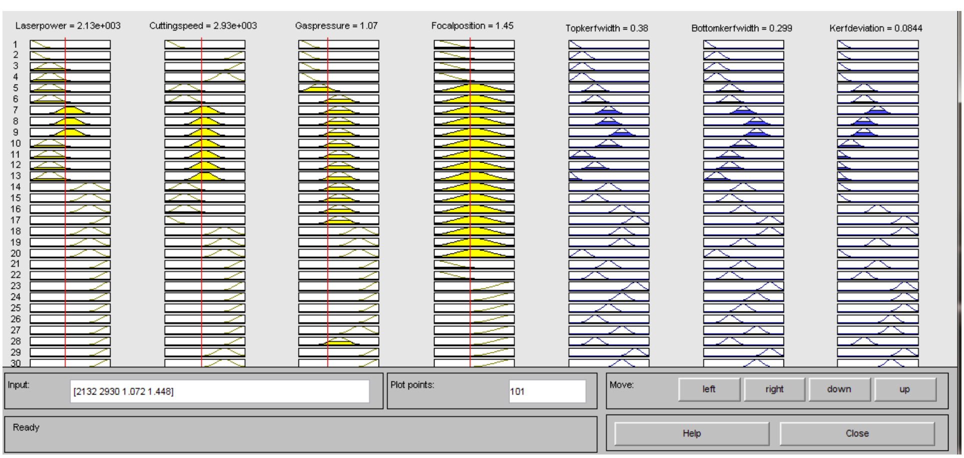


Figure 6 shows the interaction plot for top kerf width, here, assist gas pressure is constant. In this surface plot low beam power at high cutting speed to achieve low top kerf width because of melting of metal is low, however the increase of the beam power and cutting speed the top kerf width is high.

Figure 6 Interaction surface plot for top kerf width (see online version for colours)

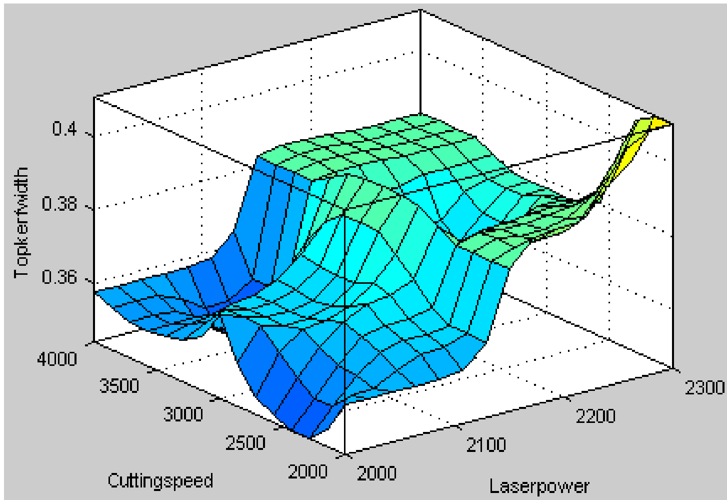


Figure 7 can be observed when the bottom kerf width is low at low beam power and high cutting speed. And low cutting speed at minimum beam power to have more bottom kerf width at all level of assist gas pressure is constant.

Figure 7 Interaction surface plot for bottom kerf width (see online version for colours)

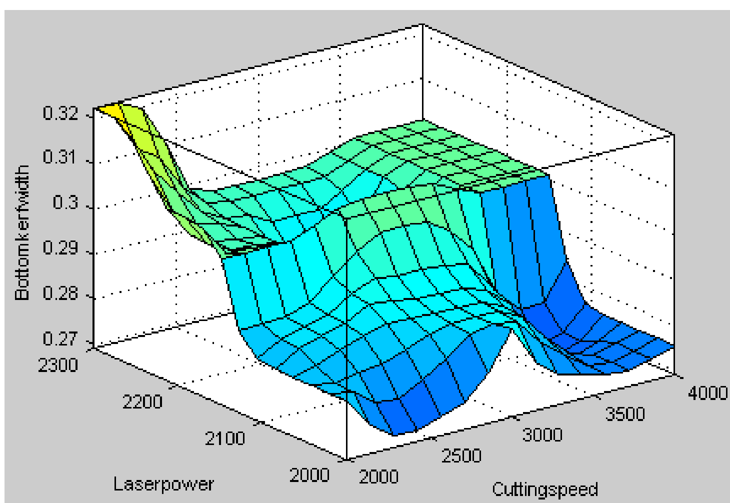


Figure 8 shows the increment to assist gas pressure and the kerf deviation is minimised, at the same time beam power is constant at all levels of conditions. Because of the increase of the beam power, the kerf deviation also increases.

Table 1 shows the comparison of experimental and fuzzy logic model values and all level of conditions are experimental and fuzzy models values are within the deviations (Suresh Kumar et al., 2016).

Table 1 Comparison of experimental and fuzzy logic model values

Si. no.	*Beam power*	*Cutting speed*	*Gas pressure*	*Focal position*	*Top kerf width*		*Bottom kerf width*		*Kerf deviation*	
					Experimental value	*Fuzzy model value*	*Experimental value*	*Fuzzy model value*	*Experimental value*	*Fuzzy model value*
1	2,150	2,000	1.1	–1	0.3839	0.3993	0.2889	0.2922	0.0645	0.065
2	2,150	3,000	1.1	–1.5	0.3921	0.4015	0.3141	0.3063	0.0769	0.0858
3	2,000	3,000	1.2	–1.5	0.3833	0.3932	0.2882	0.2982	0.0821	0.0853
4	2,150	3,000	1.2	–2	0.4181	0.4123	0.3141	0.3117	0.103	0.1071
5	2,000	2,000	1.1	–1.5	0.348	0.3417	0.265	0.2575	0.0717	0.0814
6	2,150	3,000	1.1	–1.5	0.3924	0.4015	0.3143	0.3063	0.0769	0.0858
7	2,300	3,000	1.1	–1	0.401	0.3918	0.3015	0.3128	0.0645	0.0701
8	2,150	2,000	1.2	–1.5	0.3832	0.3845	0.301	0.2971	0.0717	0.0814
9	2,300	3,000	1.2	–1.5	0.3651	0.38	0.2652	0.261	0.0821	0.0857
10	2,300	2,000	1.1	–1.5	0.418	0.412	0.3019	0.3121	0.0926	0.0836
11	2,150	3,000	1.1	–1.5	0.392	0.4015	0.3148	0.3063	0.0769	0.0858
12	2,000	3,000	1.1	–1	0.403	0.405	0.3019	0.2986	0.0645	0.0719
13	2,150	3,000	1.2	–1	0.4021	0.4047	0.3014	0.3097	0.0645	0.072
14	2,300	4,000	1.1	–1.5	0.418	0.417	0.3148	0.3132	0.0821	0.0827
15	2,150	4,000	1	–1.5	0.409	0.4027	0.3019	0.3065	0.0821	0.0856
16	2,300	3,000	1.1	–2	0.4321	0.4218	0.3378	0.3438	0.113	0.1144
17	2,150	4,000	1.2	–1.5	0.4031	0.3977	0.3012	0.2974	0.0821	0.0796
18	2,150	2,000	1.1	–2	0.3361	0.3451	0.3378	0.3473	0.113	0.1082
19	2,000	3,000	1	–1.5	0.4189	0.4262	0.3144	0.3275	0.0821	0.0886
20	2,150	3,000	1	–1	0.4021	0.3997	0.3019	0.3097	0.0645	0.0681
21	2,150	4,000	1.1	–2	0.4181	0.4301	0.3144	0.3191	0.103	0.1083
22	2,150	3,000	1.1	–1.5	0.3929	0.4015	0.3149	0.3063	0.0769	0.0858
23	2,150	3,000	1	–2	0.3838	0.3937	0.2889	0.2908	0.121	0.1175
24	2,000	3,000	1.1	–2	0.4091	0.4183	0.3144	0.3086	0.103	0.1121
25	2,150	4,000	1.1	–1	0.3487	0.3743	0.2659	0.2683	0.0645	0.067
26	2,300	3,000	1	–1.5	0.4013	0.4297	0.3141	0.3093	0.0717	0.0888
27	2,150	3,000	1.1	–1.5	0.3921	0.4015	0.314	0.3063	0.0769	0.0858
28	2,150	2,000	1	–1.5	0.3652	0.3559	0.2653	0.2582	0.0717	0.0817
29	2,000	4,000	1.1	–1.5	0.4009	0.3967	0.3141	0.3184	0.0717	0.0844

Figure 8 Interaction surface plot for kerf deviation (see online version for colours)

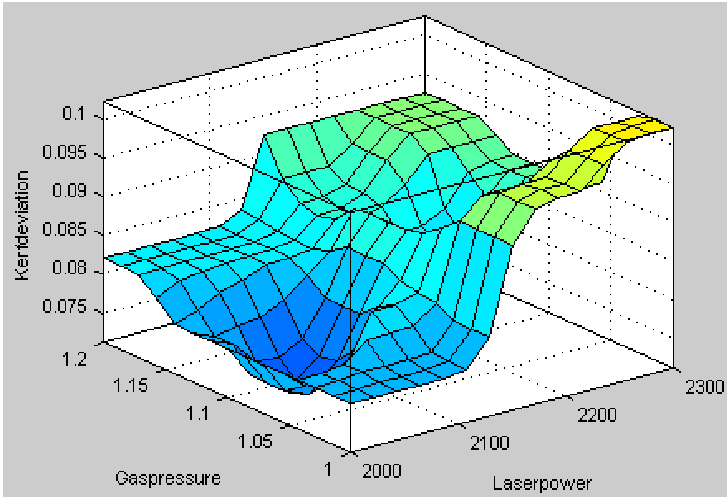


Figure 9 shows the validation plots for the top and bottom kerf width. The plots are plotted at all conditions of fuzzy logic rules, so that from the plots at experimental values are nearer to the fuzzy model, and is satisfied at all level of conditions. Figure 10 also indicates the comparison and validation plots for kerf deviation which is satisfied at all experimental values of fuzzy logic models.

Figure 9 Comparison and validation of result for top and bottom kerf width

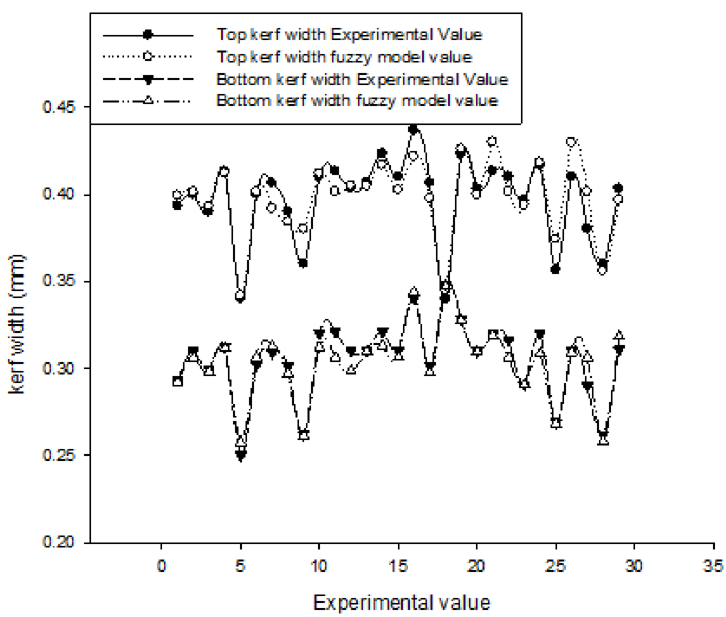
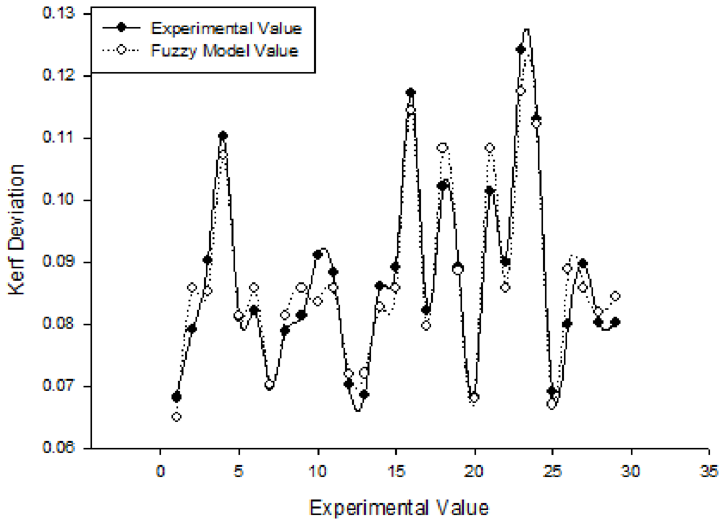


Figure 10 Comparison and validation of result for kerf deviation



4 Conclusions

In this work, the fuzzy logic model – Mamdani type is used. The developed fuzzy model predicts the top, bottom kerf width and kerf deviation and to set the laser beam power, cutting speed, assist gas pressure and focal position of CO_2 laser cutting of AA6061-T6. From this analysis the following conclusions are made.

- The relationship between the top, bottom kerf width and kerf deviations and the CO_2 laser cutting parameters as well as interactions are considered.
- Assist gas pressure are constant. An increase of the cutting speed top, bottom kerf width and kerf deviation is decreased.
- The cutting speed is at lower level of 2,500 mm/min, laser beam power of 2,000 watts, assist gas pressure of 1.1 Mpa at all level of focal position is the lower value of top, bottom kerf width and kerf deviation values.
- The cutting speed is the highest influence on the top, bottom kerf width and kerf deviation followed by other parameters.
- The validation of result fuzzy logic model is satisfied at all experimental values are nearer. From the result the fuzzy logic model, it can be used successfully to predict the top, bottom kerf width and kerf deviation in CO_2 laser cutting of AA6061-T6 material.

References

Arif, A.F.M., Yilbas, B.S. and AbdulAleem, B.J. (2009) 'Laser cutting of thick sheet metals: residual stress analysis', *Optics & Laser Technology*, Vol. 41, No. 1, pp.224–232.

Caydas, U. and Hascalik, A. (2008) 'Use of the grey relational analysis to determine optimum laser cutting parameters to determine optimum laser cutting parameters with multi-performance characteristics', *Optics& Laser Technology*, Vol. 40, No. 1, pp.987–994.

Dinesh, S., Godwin, A.A., Rajaguru, K. and Vijayan, V. (2016) 'Experimental investigation and optimization of machining parameters in CNC turning operation of duplex stainless steel', *Asian Journal of Research in Social Sciences and Humanities*, Vol. 6, No. 10, pp.179–195.

Hiranoa, K. and Fabbroa, R. (2011) 'Experimental observation of hydrodynamics of melt layer and striation generation during laser cutting of steel', *Physics Procedia*, Vol. 12, No. 1, pp.555–564.

Madic, M., Radovanovic, M. and Nedic, B. (2012) 'Correlation between surface roughness characteristics in CO_2 laser cutting of mild steel', *Tribology in Industry*, Vol. 34, No. 4, pp.232–238.

Mousa, A.A., Pham, D.T. and Shwe, S.P. (2014) 'Pre-processing studies for selective laser sintering of glass beads-filled polyamide 12 composites', *International Journal of Rapid Manufacturing*, Vol. 4, No. 1, pp.28–48.

Parthiban, A., Prasath, J.P., Vivek, P. and Pugazhenthi, R. (2018) 'Experimental investigation of plasma arc cutting for stainless steel sheet', *International Journal of Mechanical and Production Engineering Research and Development*, Vol. 8, No. 1, pp.907–914.

Parthiban, A., Sathish, S. and Chandrasekaran, M. (2017a) 'Optimization of abrasive water jet cutting parameter for AISI 316L stainless steel sheet', *Journal of Applied Fluid Mechanics*, Special Issue, Vol. 10, pp.15–22, pp.15–22.

Parthiban, A., Sathish, S. and Chandrasekaran, M. (2017b) 'Fuzzy logic based modeling of co2 laser cutting for stainless steel sheet', *ARPN Journal of Engineering and Applied Science*, Vol. 12, No. 6, pp.1780–1784.

Shishkovsky, I., Kakovkina, N. and Missemer, F. (2015) 'Laser in situ synthesis of gradient aluminides in metal matrix composite during DMD process', *International Journal of Rapid Manufacturing*, Vol. 5, Nos. 3/4, pp.349–366.

Srinivasan, R., Vijayan, V. and Sridhar, K. (2017) 'Computational fluid dynamic analysis of missile with grid fins', *Journal of Applied Fluid Mechanics*, Special Issue, Vol. 10, No. 1, pp.33–39.

Srivastava, M., Rathee, S., Maheshwari, S. and Kundra, T.K. (2018) 'Multi-objective optimisation of fused deposition modelling process parameters using RSM and fuzzy logic for build time and support material', *International Journal of Rapid Manufacturing (IJRAPIDM)*, Vol. 7, No. 1, pp.25–42.

Suresh Kumar, B., Vijayan, V. and Baskar, N. (2016) 'Comparison of coated and uncoated carbide drill bits for drilling titanium grade 2 material', *Mechanika*, Vol. 22, No. 6, pp.571–576.