Influence of Process Parameters on Surface Quality and Kerf Width in Laser Cutting Process of $AlMg_3$ using ANN

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Abstract- *Laser cutting is widely used thermal energy based non-contact type, non- convectional machining process. In the present work Kerf Width and Surface Roughness have been analyzed for the different values of Laser Power, Gas Pressure, Thickness of Material, Nozzle Diameter and Cutting Speed. At the end of experiment it is observed that Cutting Speed and Thickness have significant effect on Surface Roughness and Laser Power has a trivial effect on it. When Thickness and Cutting Speed increase, Kerf Width increases. Surface Roughness decreases with increase in Thickness and Cutting Speed. The experimental results have been used to train ANN using Back-Propagation Algorithm which gives the optimum value of the Performance Parameters like Kerf Width and Surface Roughness (SR) based on the influence of processing parameters such as Laser Power, Gas pressure, Thickness of Material, Nozzle Diameter and Cutting Speed.*

Keywords- Kerf Width, Surface Roughness, Artificial Neural Network (ANN), Back-Propagation (BP)

I. INTRODUCTION

Laser cutting process is a technology that uses a Laser to cut materials and is typically used for industrial manufacturing application but is also starting to be used by small business. Cost of this process is extremely high, but it is used due to its flexibility and high quality product. Industrial Laser cutters are used to cut flat sheet materials as well as structural and piping materials. In 1965 the first production laser cutting machine was used to drill holes in diamond dies. This machine was made by the Western Electric Engineering Research center. In 1970, this technology was put into production to cut titanium for aerospace application. Over the past decade, laser cutting has developed into state-of-the-art technology. It is estimated that more than 40,000 cutting systems are used for the high-power cutting of metals and non-metals worldwide. When including low-power applications, such as plastics cutting and paper cutting, the numbers are even higher.

II. LITERATURE REVIEW

Madi M. J. et. al. [1] analyzed the effect of the laser cutting parameters on the width of HAZ during CO_2 laser nitrogen cutting of AISI 304 stainless steel. Pandey A. K. et. al. [2] reported that the ANFIS based models for predicting the Kerf width (KW) and Material removal rate (MRR) in Laser cutting process were very close to the experimental values of KW and MRR. Baskoro A. S. et. al. [3] reported that the depth of cut during cutting process is influenced by speed, current, voltage number of pass, number of layer and compressed air. Dold Claus et. al. [4] found that laser machining of the PCD-inserts does not cause considerable damage to the tool in regard of resulting work piece quality, wear resistance and process forces. Nizvie V. G. et. al. [5] observed that within the framework of this problem the ultimate laser cutting parameters were estimated and a comparison of cutting efficiency for different polarization types and mode structures was carried out. Eltawahni H. A et. al. [6] seen that the upper kerf width increases as the laser power, nitrogen pressure and nozzle diameter increase, and it decreases as the cutting speed and focal position increase. The laser power, nitrogen pressure and focal position have a positive effect on the lower kerf width while the cutting speed has a negative effect. Eltawahni H. A. et. al. [7] presented that the roughness decreases as the focal point increases from its lowest level till its central level and then it increases as the focal starts to increase above its central level. The roughness decreases as the laser power increases and it increases as the cutting speed increases. Higher cutting speed does not always improve the efficiency of the laser cutting process. Eltawahni H. A. et. al. [8] accounted that focal point position and the laser power are the principal factors affecting the ratio. The roughness of the cut section decreases as the focal point position and the laser power increase, but the laser power effect reduces while cutting thicker MDF sheets. Radovanovic M. et. al. [9] observed that experimental planning according to the Taguchi method so that wider experimental range is covered and empirical data modeling by means of artificial neural networks provides an efficient approach for accurate modeling of laser cutting process. By coupling these models with optimization methods can find optimal cutting parameter settings for satisfying response characteristics in an effective way. Gross

M. S. et. al. [10] studied that the gas flow pattern is intrinsically three dimensional with converging and diverging sections. Two-dimensional simplifications are inadequate and lead to wrong conclusions. For non-supersonic nozzles the gas dynamics problem is highly unsteady and therefore steady state simulations are not feasible. Huehnlein K. et. al. [11] demonstrated the potential of a design of experiment (DOE) approach in optimizing laser material processes. Riveiro A. et. al. [12] observed a clear influence of assist gas nature on finishing characteristics and from the point of view of quality and efficiency argon is the best choice for processing Al-Cu alloys. Stock J. et. al. [13] made possible of laser cutting of CFRP. Kheloufi K. et. al [14] identified the different stages during the cutting process and the effect of cutting speed on the formed kerf. Schoeberl M. et. al [15] showed that cutting speeds of up to 12 m/min can be achieved for a material with six layers and a thickness of approximately 3 mm. Stelzer S. et. al [16] reported that under the defined experimental conditions, sudden increase in surface roughness occurs between 4 and 6 mm in case of fiber laser cuts and between 8 and 10 mm for CO_2 laser cutting trials. Dold C. et. al [17] reported that the Laser processing using a laser with a pulse width $\tau P = 10$ ps on fine and coarse grain PCD brazed carbide cutting tools can be done without significant material damage in terms of thermal heat input. Prajapati B. D. et. al [18] observed that the Cutting speed and thickness of plate have high contribution on surface roughness for Mild steel and Hardox-400 materials and Gas pressure had higher effect for cutting of mild steel and less effect for hardox-400. Madia M. N. et. al [20] presented that improper focal length affects the surface roughness and cutting speed and good quality cuts can be produced in brass sheets, at a window of laser cutting speed 7500 mm/min and at a power of 1500 Watts surface is 1.491 µm.

III. EXPERIMENTAL SETUP

3.1 Introduction

Laser cutting process is a technology that uses a Laser to cut materials and is typically used for industrial manufacturing application but is also starting to be used by small business.

3.2 Machine Specification

The experimentation work was carried out on the Laser Cutting Machine (fig.1) has following specifications.

Fig. 1: Laser Cutting Machine

Table 1: Technical Specification of Trumpf Laser

Tru Flow Laser	2000	2700	3200	4000
Wave Length(µm)	10.6	10.6	10.6	10.6
Guaranteed Maximum power output	2000	2700	3200	4000
Continuously adjustable output range	90-2000	120-2700	150-3200	190-4000
Power constancy	2	2	2	2
Beam diameter on the decoupling window (mm)	15	15	15	15
Angle of divergence (half angle) (mrad)	1.0	1.0	1.0	1.0
Power density distribution	TEM00	TEM00	TEM00	TEM00
Pulse frequency	100Hz-100Khz	100Hz-100Khz	100Hz-100Khz	100Hz-100Khz
Pulse width	10µs-CW	10µs-CW	10µs-CW	10µs-CW

3.3 Work piece Material

There are several authors who have researched Laser Cutting Process to be applied on hard materials or materials which are difficult to cut by using machining processes. Among various grades, Wrought Aluminium ($AlMg_3$) has been selected for the experimental work.

Table 2: Mechanical Properties

Sr. No.	Properties	Min. Value	Max. Value
1	Density	2650 Kg/m^3	2650 Kg/m^3
2	Elongation	4 %	17 %
3	Shear Modulus	27000 MPa	27000 MPa
4	Tensile Strength	180 MPa	260 MPa
5	Yield Strength	80 MPa	180 MPa
6	Young's Modulus	70000 Mpa	70000 MPa

Table 3: Thermal Properties

Sr. No.	Properties	Min. Value	Max. Value
1	Melting Temp.	590 °C	645 °C
2	Specific Heat	960 J/Kg.K	960 J/Kg.K
3	Thermal Conductivity	140 W/mK	140 W/mK
4	Thermal Expansion	$24x10^{-6}e$ /K	$24x10^{-6}e$ /K

3.4 Processed Specimen

The specimen of Wrought Aluminium ($AlMg_3$) was used for experimentation is shown below (Fig. 2).

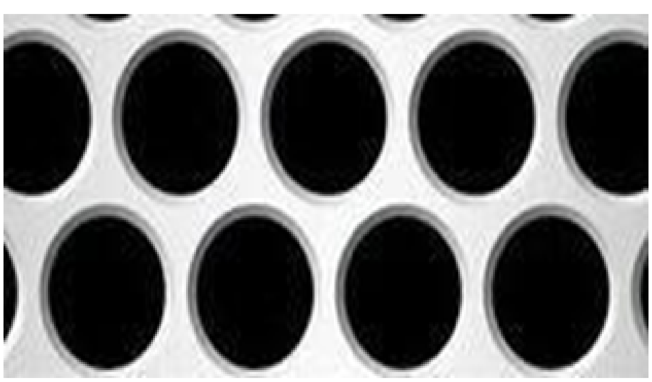

Fig. 2: Specimen of Wrought Aluminium

Surface topography or surface roughness, also known as surface texture is used to express the general quality of a machined surface, which is concerned with the geometric irregularities and the quality of a surface. Surface roughness is measured as the arithmetic average, R_a (µm). The R_a value, also known as Centre Line Average (CLA) or Arithmetic Average (R_a) is obtained by averaging the height of the surface above and below the centre line. The R_a has been measured by Profilometer.

Fig. 3: Profilometer for Roughness Measurement

IV. DESIGN OF EXPERIMENTS

To determine influential parameters for Laser Cutting Machine, 27 experiments have been carried out based on L27 Orthogonal Array (Level-3, Factor-5) in order to have representative data. Laser Power, Gas Pressure, Cutting Speed, Thickness, Nozzle Diameter are influential parameters to the common performance measures like kerf Width and Surface roughness. Table 4 presents the five different process parameters chosen and their levels.

Table 4: Laser Cutting Process Parameters and Levels for $AlMg_3$

Sr. No.	Laser Power Watt	Nitrogen Gas Pressure Bar	Cutting Speed mm/min	Thickness mm	Nozzle Diameter mm	Kerf Width mm	Surface Roughness µm
1	2700	14	3000	1	1.4	0.201	4.690
2	2700	14	3100	1	1.4	0.212	4.255
3	2700	14	3200	1	1.4	0.223	3.437
4	2700	15	3000	2	1.7	0.335	2.940
5	2700	15	3100	2	1.7	0.343	2.532
6	2700	15	3200	2	1.7	0.349	2.102
7	2700	16	3000	3	2.3	0.401	1.727
8	2700	16	3100	3	2.3	0.415	1.429
9	2700	16	3200	3	2.3	0.427	1.170
10	3200	14	3000	2	2.3	0.352	2.750
11	3200	14	3100	2	2.3	0.359	2.392
12	3200	14	3200	2	2.3	0.379	2.112
13	3200	15	3000	3	1.4	0.375	1.909
14	3200	15	3100	3	1.4	0.387	1.631
15	3200	15	3200	3	1.4	0.398	1.282
16	3200	16	3000	1	1.7	0.280	3.559
17	3200	16	3100	1	1.7	0.295	3.222
18	3200	16	3200	1	1.7	0.305	2.878
19	4000	14	3000	3	1.7	0.352	1.934
20	4000	14	3100	3	1.7	0.358	1.623
21	4000	14	3200	3	1.7	0.369	1.308
22	4000	15	3000	1	2.3	0.235	3.444
23	4000	15	3100	1	2.3	0.247	3.218
24	4000	15	3200	1	2.3	0.260	2.838
25	4000	16	3000	2	1.4	0.305	2.303
26	4000	16	3100	2	1.4	0.318	1.842
27	4000	16	3200	2	1.4	0.329	1.333

Table 5: Result Table for $AlMg_3$

Sr. No.	Process Parameters	Level		
		L1	L2	L3
1	Laser Power (Watt)	2700	3200	4000
2	Gas Pressure (Bar)	14	15	16
3	Cutting Speed (mm/min)	3000	3100	3200
4	Thickness (mm)	1	2	3
5	Nozzle Diameter	1.4	1.7	2.3

V. ANN PERFORMANCE

Many efforts have been made to model the performance parameters of EDM process using ANN. To obtain a superior ANN model, generally ANN architectures, learning/training algorithms and numbers of hidden neuron are varied, but the difference has been made in a random manner. The most familiar process parameters that are varied to obtain an efficient ANN model are ANN architectures, learning / training algorithms and numbers of hidden neuron. These parameters have been chosen here as process parameters to a random. The performance parameters for evaluating the ANN model are taken as mean.

The error function that has been used here for supervised training is the mean squared error function (E_{avg}). Mathematically it can be expressed as:

Where *dnk* is the desired output for exemplar n at neuron k of output layer and *ank* is the network output for exemplar n at neuron k of output layer. K is the numbers of neuron in the output layer and N is the numbers of exemplar in the data. Mean squared error (MSE) is two times of the average mean squared error function (E_{avg}). The factor 1/2 is multiplied here with the mean squared error function to make the differentiation of this function easier. Lower value of MSE is preferable for a superior ANN model [6].

Table 6: Important specifications of parameters used in ANN modeling

Sr. No.	Parameter	Data / Data Range	Technique used
1	Numbers of input neuron	5	-
2	Numbers of hidden neuron	4	-
3	Numbers of output neuron	2	-
4	Total numbers of exemplar	27	-
5	Proportion of training, validation and testing data	70:15:15	-
6	Data normalization	-1 to 1	Mapminmax data normalization technique
7	Weight initialization	-	Random weight initialization technique
8	Transfer function	-	Tansig and Purelin (for both hidden and output layer)
9	Error function	-	Mean squared error function
10	Type of Learning rule	-	Supervised learning rule
11	Stopping criteria	-	Early stopping

Correlation Coefficient can be used to determine how well the network output fits the desired output. The correlation coefficient between a network output (a) and a desired output (d) can be mathematically defined as above.

Squared Error (MSE), training Correlation Coefficient (R), testing R and validating R which are the default performances assessing parameters assumed by the Neural Network Toolbox of MATLAB 7.1. Weight and bias matrix connected with the inputs are adjusted / updated using the learning rule. The back propagation training algorithm viz. Levenberg-Marquardt (LM) has been implemented for training the neural architectures. Here single hidden layer has been chosen for back-propagation neural network to define the input-output mapping. The numbers of neuron in the input layer and the output layer are fixed on numbers of input and output.

where n = exemplar or run number, *an* and *dn* are the network output and desired output respectively at a particular exemplar, and are the data mean of network output and desired output respectively. Higher value of R is desirable for an effective ANN model.

The process parameters and response parameters of the EDM process are used here for modeling ANN. The total numbers of exemplar in the data set for SS 440 C Steel is 27. The whole data set has been divided into 3 sets viz. training, validation and testing data set. The training data set is used to fit the model or to establish the input-output mapping. The validation data set is used to stop the training by early stopping criteria. The testing data set is used to evaluate the performance and generalization error of fully trained neural network model. Generalization means how well the trained model response to the data set that does not belong to the training set [7]. The training, validation and testing data have been set at 70%, 15% and 15% respectively. The important specifications of parameters used for ANN modeling are shown in Table 6.

Here the data of neural network model is scaled in the range of -1 to 1. The mapminmax data normalization technique has been used for this purpose using the following equation:
X = 2× -1

Where, X is the normalized value of the real variable, Rmin = -1 and Rmax = 1 are the minimum and maximum scaled range respectively, R is the real value of variable, and R_{min} and R_{max} are the minimum and maximum values of the real variable, respectively. The dataset of the normalized values of variables for the neural network model has been shown in table7.

Table 7: Dataset for $AlMg_3$ (The values of variables are normalized)

Sr. No.	A. Laser Power Watt	B. Nitrogen Gas Pressure Bar	C. Cutting Speed mm/min	D. Thickness mm	E. Nozzle Diameter mm	Kerf Width mm	Surface Roughness µm
1	-1	-1	-1	-1	-1	-1	1
2	-1	-1	0	-1	-1	-0.903	0.753
3	-1	-1	1	-1	-1	-0.805	0.288
4	-1	0	-1	0	-0.333	0.186	0.00568
5	-1	0	0	0	-0.333	0.257	-0.226
6	-1	0	1	0	-0.333	0.31	-0.47
7	-1	1	-1	1	1	0.77	-0.684
8	-1	1	0	1	1	0.894	-0.853
9	-1	1	1	1	1	1	-1
10	-0.23	-1	-1	0	1	0.336	-0.102
11	-0.23	-1	0	0	1	0.398	-0.306
12	-0.23	-1	1	0	1	0.58	-0.465
13	-0.23	0	-1	1	-1	0.54	-0.58
14	-0.23	0	0	1	-1	0.646	-0.738
15	-0.23	0	1	1	-1	0.743	-0.936
16	-0.23	1	-1	-1	-0.333	-0.3	0.357
17	-0.23	1	0	-1	-0.333	-0.168	0.166
18	-0.23	1	1	-1	-0.333	-0.08	-0.029
19	1	-1	-1	1	-0.333	0.336	-0.566
20	1	-1	0	1	-0.333	0.389	-0.743
21	1	-1	1	1	-0.333	0.487	-0.922
22	1	0	-1	-1	1	-0.7	0.292
23	1	0	0	-1	1	-0.593	0.164
24	1	0	1	-1	1	-0.593	-0.0522
25	1	1	-1	0	-1	-0.08	-0.356
26	1	1	0	0	-1	0.035	-0.618
27	1	1	1	0	-1	0.133	-0.907

VI. RESULT AND DISCUSSION

6.1 Results from Modeling Kerf Width and SR of Laser Cutting Process of AlMg3

The best process parameter setting for ANN modeling was selected with the help of Taguchi method. The chosen optimal process parameters are Levenberg-Marquardt training algorithm and 4 numbers of hidden neurons. ANN modeling of Kerf width and SR with the optimal process parameters setting has been shown here. MATLAB representation of ANN topology that has been utilized for modeling is shown in Fig. 4. Variation of MSE of data set w.r.t. the epoch has been shown in Fig. 5. Validation data set is used to stop the training process in late stopping criteria for providing better generalization. So the training was stopped at this point and the weights and biases were used to model kerf width and SR.

Correlation coefficient between desired target and actual output of training, validation and testing is shown in Fig. 6. Fig. 7 and Fig. 8 show the variation of Kerf width (desired output) and Kerf width (ANN output) of training and testing data set w.r.t. exemplar respectively. The variation of SR (target) and SR (ANN output) of training and testing data set w.r.t exemplar is shown in Fig. 9 and 10 respectively.

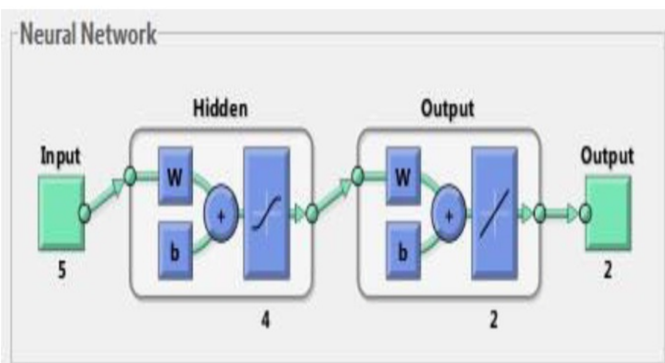

Fig. 4: ANN Network Topology of Selected Model

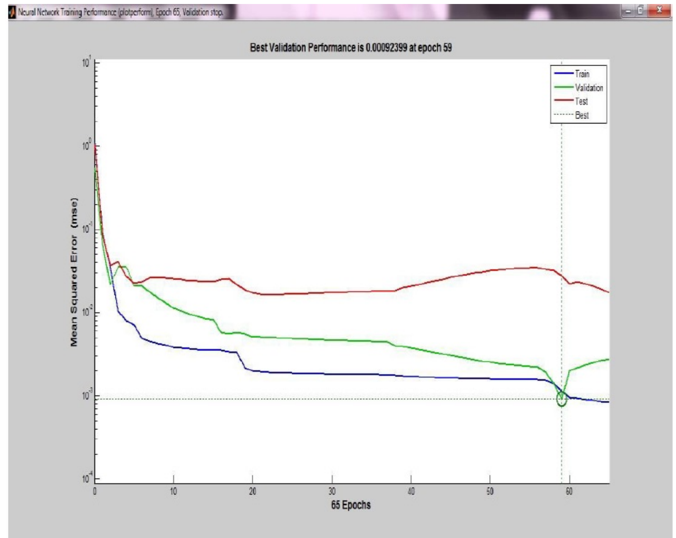

Fig. 5: Variation of MSE w.r.t. epoch

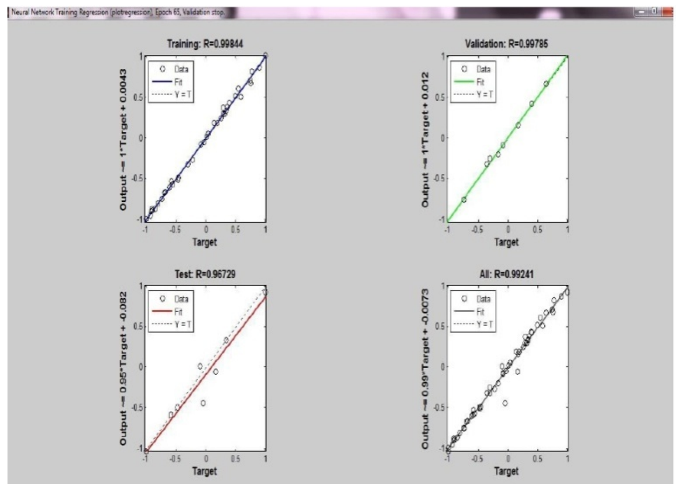

Fig. 6: Correlation Coefficients

VII. CONCLUSION

Laser Cutting Process has been found to be a good machining technique to obtain desired dimensional accuracy and intricacy from $AlMg_3$. It is observed that the cutting speed and thickness have significant effect on Surface Roughness and Laser Power has immaterial effect on it. Kerf Width increases with increase in Thickness, Cutting Speed and Gas Pressure. Surface Roughness decreases with increase in Thickness and Cutting Speed. As the training data set is used to fit the model and testing data set is used to evaluate the model. The plot of testing data set was considered for evaluation of best ANN model. From the plot of MSE and R, Levenberg-Marquardt training algorithm and 4 numbers of hidden neuron are seen to be efficient for optimal values of responses of $AlMg_3$ and hence 5-4-2 network architecture was selected for proficient ANN modeling. This work can be extended using other techniques like GA. ANN modeling can be reproduced with different numbers of neurons / layers.

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