Hybridization of Response Surface Methodology and Genetic Algorithm optimization for CO_2 laser cutting parameter on AA6061 material

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Abstract—Investigation of laser cutting parameters on aluminium alloy (AA6061) is important due to its high reflectivity and thermal conductivity. Generally Aluminium alloy is a widely used material in aeronautical and automation industries for its inherent properties. Although the main problem during laser cutting is occurrence of recasting layer and laser beam incidence that affecting the cutting quality is known as kerf dimensions. In a sense the relationship between the laser cutting parameters such as laser power, cutting speed, gas pressure and focal position with kerf dimensions are having important role in laser cutting operation. So this work considers the response surface methodology (RSM), for making empirical relationship between dependent and independent variables. Simultaneously, this work reveals that laser power, cutting speed, gas pressure and focal position have significant effects on kerf dimension. Thus the development of empirical model and the selection of best parameters are important for manufacturing industries. Hence this work develops the statistical model with RSM and optimizes the cutting parameters with genetic algorithm (GA).

Key words-CO2 Laser cutting, Aluminium alloy, Kerf Dimensions, Response Surface Methodology, Genetic Algorithm

INTRODUCTION

Laser cutting is one of the nontraditional machining processes to achieve high precision and accurate assembly with minimum consumption of work piece material. AA6061 is playing vital role in modern industries. Now a day’s aluminium alloy has significant role in aeronautical industries. However AA6061 is one of the important materials due to its inherent properties such as high strength to low weight ratio, good corrosion resistance, high thermal conductivity and easy machinabilty and formability. Still machining of aluminium alloy with laser cutting is a difficult task due to its high reflectivity and resistance to narrow cutting. Consequently kerf dimensions (top kerf width, bottom kerf width, kerf taper and kerf ratio) play the most significant role in determining the productivity and the quality of a product produced with AA6061. So this work takes AA6061 aluminium alloy as a work piece material for CO2 laser cutting. With regard, to the laser power, cutting speed, gas pressure and focal position are considered as a predominant principal parameter in laser cutting. Lot of researcher and investigations has been done in analyzing the cost and quality of laser cutting. However with regard to the reduction of wastage that is caused in kerf dimension has not been taken up for serious study. Hence this study considers the principal parameters on top kerf width, bottom kerf width, kerf taper and kerf ratio.

Consequently, Laser cutting is one of the extensively used thermal energy based noncontact type cutting process in the order of all type of material [1]. However the kerf dimensions are important during laser cutting, but the kerf dimensions are sensitive with laser power, duty cycle and the work piece material. Although, kerf dimension is usually affected with laser power and gas pressure, Gas pressure and laser power are utilized to evacuate the molten material and melting of material respectively [3]. The cutting quality of the material depends mainly on different gas types and pressures [2, 4]. Further the process of CO2 laser cutting with continuous and pulsed modes was examined with some researcher and their results revealed that pulsed mode generated good surface quality with moderate power. And continuous mode encourages the high cutting speed [5].

For that reason a lot of researchers worked on kerf dimension so as to predict the kerf dimensions, surface quality and operating cost [6 – 8]. Their results show that cutting speed has most significance on kerf width. The lower cutting speed improves the cutting edge quality and surface roughness during laser cutting [10]. In that view many researchers were employed to develop mathematical models for predicting accurate experimental values [11, 12]. On kerf dimension, laser power, cutting speed, gas pressure and pulse frequency were investigated with Taguchi methodology and as a result the minimum was achieved with L27 orthogonal array [9, 20]. As this experimental design utilize higher experimental run for making relationship with higher expensive, many researchers develop the empirical models with other experimental designs such as central composite and Box Behnken designs for reducing the experimental run and cost. Comparatively laser cutting process consumes high cost for carrying out the production. In response the design of experiment concepts was utilized by some of the researchers to reduce the experimental run and cost and avoid the trial and error cost expenditure [13]. So this work tries the Box Behnken design for conducting the experiments.

Modeling techniques were used to relate the experimental work and theoretical work. Using modeling techniques did not propose the optimal results. Optimal result, here, means the selection of best parameter for achieving good response value. In this regard single objective and multi objective optimization are available for best parameter selection. RSM and Taguchi methodology were utilized in Nd: YAG laser cutting process [14 - 19]. And their results show these have best agreement with experimental results. However, nontraditional techniques are playing important role in selection of best parameters rather than traditional techniques. So, many researchers used ANN and Fuzzy logic methods to develop the model for manufacturing processes. But this work tries to combine RSM and GA to optimize the laser cutting processes. Moreover many of the researchers proposed that their future scope GA is one of the best techniques for selecting the best parameter for nontraditional technique [21]. So this work utilizes the GA for best parameter selection. The previous research on kerf dimension had less attention for best parameter selection on aluminium alloys during CO2 laser cutting. But few works were employed in the RSM, Artificial Neural Network and Fuzzy logic for predicting the parameters in CO2 laser cutting. Thus the main aim of this work is to develop a mathematical model using RSM, to optimize laser cutting operation using GA.

A. Proposed Methodology

The selection of machining parameters in manufacturing industries is playing vital role. In sense, the trial and error techniques to select the best parameter increases the production cost and it consumes higher production time. So as to process planning engineer's need mathematical model and optimal set of process parameter to avoid the parameter selection lead time. For that reason, this work is developed for identifying the best parameter for CO2 laser cutting operation on aluminium alloy. Now a day's researchers were utilized the design of experiment concept for reducing the experimental run. On behalf of that design of experiment concept were utilized for conducting the experiments. In regard, RSM is very popular and it was employed for developing the mathematical model. For identifying best set of parameters is also one of the important tasks. On behalf of that the combination of RSM and GA is proposed in this work.

I. EXPERIMENTAL PROCEDURES

The experimental procedure is planned based on Box – Behnken design from the design of experiment concepts for CO2 laser cutting operation. The further following sections A, B and C explains the machine tool, work piece materials and the experimental plan.

A. Machine Tool

The experiments are conducted on AMADA make 4 KW CO2 FO 3015 NT laser cutting machine as shown in Fig.1. And the machine tool specification is tabulated in Table I. Based on the machine tool specification the experimental factor's range and levels are selected. The selected ranges and levels are given as an input to machine through FANUC controlled CNC program.

Fig.1. AMADA Laser cutting machine

TABLE I
Specification of Laser Cutting Machine

Model	**Amada FO-3015NT**
Laser type	carbon di oxide (CO_2)
Mode	Continious Wave(CW)
Power	4000 Watts
Focal length	127.5mm
Assist gas	Nitrogen
Nozzle diameter	1.5mm

B. Work Piece Material

The work piece material considered in this work is AA6061 – T6 aluminium alloy. AA6061 – T6 is the newer material utilized in modern manufacturing industries such as Aeronautical and ship building industries due to its inherent properties. And the specimen size was 1000 X 1000 X 2mm thick sheet; it was clamped on work table with auto location and position about laser beam orientation.

C. Experimental Plan

The experimental plan is based on Box -Behnken design and it requires three levels for each factor. So the ranges and levels of each factor considered for this work is tabulated in Table II. The factors are laser power, gas pressure, cutting speed and focal position. Cutting operation carried out on work piece with 20 mm length and single pass were obtained in each experimental run.

D. Measurements of Responses

The top and bottom kerf width is measured by using Tool maker's microscope at 10X magnification. Kerf taper is calculated with the following eqn. (1). Finally the kerf ratio is determined with the ratio of top kerf width and bottom kerf width. The measured performances are tabulated in Table III.

$$K_t = \frac{(top\ \ker f\ width - bottom \ker f\ width)}{2\pi \times work\ piece thickness} \times 180 \qquad \text{……. (1)}$$

TABLE II
Ranges of cutting parameter

Symbol	Parameter	Units	-1	0	+1
A	Laser Power	Watts	2000	2150	2300
B	Cutting Speed	mm/min	2000	3000	4000
C	Gas Pressure	Mpa	1.00	1.1	1.2
D	Focal position	Mm	-1	-1.5	-2

II. SIGNIFICANT ANALYSIS OF CUTTING PARAMETERS

In this section, the cutting parameters influences and the interaction effect of cutting parameters have been discussed. The developed regression models and performance evaluation of developed models with experimental data have been presented. The hybridization of RSM with GA has also been reported.

A. Analysis of Variance

Analysis of variance consists of sum of squares, degrees of freedom, mean square, F – Value and probability of F value. Here, sum of square means the total number of experiments divided by four times the squared factor effect, the number of levels for the factor minus one is known as degrees of freedom. Mean square is the ratio between sum of squares and degrees of freedom. F – Test is conducted between factor variance with residual variance. The ratio will be close to one and it is like that the term has a significant effect on the response. It is the ratio between mean square and residual mean square. The conducted ANOVA analysis for top kerf width, bottom kerf width, and kerf taper and kerf ratio on laser cutting is tabulated from Table IV – VII.The Table IV shows the top kerf width ANOVA table, in that the model F-value 13.06 implies the model is significant. Values of "Prob > F" is less than 0.0500 indicate that the model terms are significant. In this case focal position has most influence that affecting the top kerf width. The Table V shows the bottom kerf width ANOVA table; in that the Model F-value of 13.77 implies that the model is significant. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case focal position has more influence on the bottom kerf width. The Table VI shows the kerf taper ANOVA table; in that model F-value of 3.69 implies that the model is significant. In this case focal position and cutting speed has more influence on the kerf taper. The Table VII shows that the kerf ratio ANOVA table, in that model F-value of 8.25 implies that the model is significant. Values of "Prob > F" less than 0.0500 is indicate that the model terms are significant. In this case focal position and cutting speed has more influence on the kerf ratio.

TABLE III
Experimental Data

Sl. No	Laser power (Watts)	Cutting speed (mm/min)	Gas pressure (Mpa)	Focal position (mm)	Top kerf width (mm)	Bottom Kerf Wi (mm)	Kerf Taper (Deg)	Ratio
1	0	-1	0	-1	0.461	0.283	2.550	1.628
2	0	0	0	0	0.473	0.346	1.820	1.367
3	-1	0	1	0	0.483	0.351	1.891	1.376
4	0	0	1	1	0.502	0.381	1.734	1.317
5	-1	-1	0	0	0.469	0.321	2.121	1.461
6	0	0	0	0	0.472	0.331	2.020	1.425
7	1	0	0	-1	0.469	0.291	2.551	1.611
8	0	-1	1	0	0.475	0.329	2.092	1.443
9	1	0	1	0	0.468	0.319	2.135	1.467
10	1	-1	0	0	0.481	0.352	1.848	1.366
11	0	0	0	0	0.489	0.332	2.250	1.472
12	-1	0	0	-1	0.468	0.295	2.479	1.586
13	0	0	1	-1	0.463	0.289	2.493	1.602
14	1	1	0	0	0.481	0.342	1.992	1.406
15	0	1	-1	0	0.471	0.339	1.891	1.389
16	1	0	0	1	0.512	0.356	2.235	1.438
17	0	1	1	0	0.478	0.341	1.963	1.401
18	0	-1	0	1	0.503	0.379	1.777	1.327
19	-1	0	-1	0	0.472	0.352	1.719	1.340
20	0	0	-1	-1	0.452	0.295	2.250	1.532
21	0	1	0	1	0.519	0.353	2.378	1.470
22	0	0	0	0	0.489	0.351	1.977	1.393
23	0	0	-1	1	0.51	0.378	1.891	1.349
24	-1	0	0	1	0.508	0.372	1.949	1.365
25	0	1	0	-1	0.456	0.289	2.393	1.577
26	1	0	-1	0	0.482	0.342	2.006	1.409
27	0	0	0	0	0.489	0.349	2.006	1.401
28	0	-1	-1	0	0.487	0.343	2.063	1.419
29	-1	1	0	0	0.486	0.341	2.078	1.425

A. Response surface methodology

Response surface methodology is a collection of mathematical and statistical techniques for empirical model building [22]. So this work utilizes the RSM for identifying influences of the process parameters influences and interaction effects of parameters on considered responses. Subsequently regression analysis is used for making empirical relationship between input and output parameters. In this work the laser power, cutting speed, gas pressure and focal position are considered as input parameters and the top kerf width, bottom kerf width, kerf taper and kerf ratio are responses. Based on the effect of process parameters, influences and interaction effects of parameter, the second order polynomial equations are developed for the laser cutting process on aluminium alloy. The following section is about parameter contribution and empirical model development on laser cutting.

TABLE IV
For Top Kerf Width Response Surface Quadratic Model

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F
Model	0.0077	14	0.00055	13.06	<0.0001
A	4.08E-06	1	4.08E-06	0.096	0.7607
B	1.88E-05	1	1.88E-05	0.443	0.5165
C	2.08E-06	1	2.08E-06	0.049	0.8276
D	0.00676	1	0.00676	159.9	<0.0001
AB	7.22E-05	1	7.22E-05	1.707	0.2124
AC	0.000156	1	0.00015	3.691	0.0753
AD	2.25E-06	1	2.2E-06	0.053	0.8210
BC	9.03E-05	1	9.03E-05	2.132	0.1663
BD	0.00011	1	0.00011	2.604	0.1288
CD	9.03E-05	1	9.03E-05	2.132	0.1663
A^2	6.85E-07	1	6.85E-07	0.016	0.9006
B^2	2.16E-05	1	2.16E-05	0.51	0.4867
C^2	0.000151	1	0.00015	3.567	0.0798
D^2	0.000174	1	0.00017	4.104	0.0623
Residual	0.000592	14	4.23E-05		
Lack of Fit	0.000265	10	2.65E-05	0.324	0.9323
Pure Error	0.000327	4	8.18E-05		
Cor Total	0.00833	28			
R2	0.9288	Pred R2	0.7552		
Adj R2	0.8577	Adeq Pre	13.108		

TABLE V
For Bottom Kerf Width Response Surface Quadratic Model

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F
Model	0.0207	14	0.00148	13.765	< .0001
A	7.5E-05	1	7.5E-05	0.696	0.4179
B	3.33E-07	1	3.33E-07	0.003	0.9564
C	0.00012	1	0.000126	1.177	0.2962
D	0.0189	1	0.018961	176.13	<0.0001

AB	0.0002	1	0.000225	2.09	0.1703
AC	0.0001	1	0.000121	1.124	0.3070
AD	3.6E-05	1	3.6E-05	0.334	0.5722
BC	6.4E-05	1	6.4E-05	0.594	0.4535
BD	0.00025	1	0.000256	2.378	0.1453
CD	2.02E-05	1	2.02E-05	0.188	0.6711
A^2	1.2E-05	1	1.2E-05	0.111	0.7437
B^2	0.0001	1	0.000109	1.017	0.3303
C^2	2.02E-05	1	2.02E-05	0.188	0.6711
D^2	0.000712	1	0.000712	6.622	0.0221
Residual	0.001501	14	0.000107		
Lack of Fit	0.00114	10	0.000114	1.243	0.4503
Pure Error	0.000367	4	9.17E-05		
Cor Total	0.02225	28			
R^2	0.9322	Pred R^2	0.679		
Adj R^2	0.8645	Adeq Pre	12.809		

1) Role of cutting parameters on kerf dimensions

The effect of input parameter on kerf dimensions is important for studying the performance characteristics of CO_2 laser cutting. Thus this work made discusses the following.

TABLE VI
For Kerf Taper Response Surface Reduced Cubic Model

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F
Model	1.4592	19	0.0768	3.148	0.0410
A	0.0321	1	0.03209	1.315	0.2810
B	0.0025	1	0.00256	0.105	0.7530
C	0.0043	1	0.00433	0.177	0.6831
D	0.4541	1	0.45412	18.61	0.0019
AB	0.0086	1	0.00867	0.355	0.5656
AC	0.00046	1	0.00046	0.018	0.8936
AD	0.01155	1	0.01155	0.473	0.5087
BC	0.00046	1	0.00046	0.018	0.8936
BD	0.14423	1	0.1442	5.912	0.0379
CD	0.04025	1	0.04025	1.653	0.2310
A^2	0.00142	1	0.00142	0.058	0.8146
B^2	0.00694	1	0.0069	0.284	0.6066
C^2	0.05788	1	0.05788	2.373	0.1579
D^2	0.32663	1	0.3266	13.38	0.0052
A^2B	0.00013	1	0.00013	0.005	0.9419

A^2C	0.00719	1	0.00719	0.295	0.6002
A^2D	0.00192	1	0.00192	0.078	0.7851
AB^2	0.06418	1	0.06418	2.631	0.1393
AC^2	0.00369	1	0.00369	0.151	0.7061
Residual	0.21956	9	0.02439		
Lack of Fit	0.12483	5	0.02496	1.054	0.4933
Pure Error	0.09472	4	0.02368		
Cor Total	1.6787	28			
R^2	0.8692	Pred R^2	0.4386		
Adj R^2	0.5931	Adeq Pre	7.444		

Table VII
For Ratio Response Surface Quadratic Model

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	0.1965	14	0.01403	8.251	0.0002
A	0.00172	1	0.00172	1.015	0.3308
B	4.65E-05	1	4.65E-05	0.027	0.8711
C	0.002337	1	0.002336	1.373	0.2608
D	0.13466	1	0.13466	79.153	< 0.0001
AB	0.00143	1	0.00143	0.844	0.3738
AC	0.00012	1	0.00012	0.074	0.7884
AD	0.00056	1	0.00056	0.323	0.5749
BC	3.34E-05	1	3.34E-05	0.019	0.8905
BD	0.00942	1	0.00942	5.541	0.0337
CD	0.00257	1	0.00257	1.513	0.2389
A^2	0.00012	1	0.00012	0.072	0.7921
B^2	0.00098	1	0.00098	0.577	0.4599
C^2	0.00294	1	0.00294	1.731	0.2093
D^2	0.03498	1	0.0349	20.564	0.0005
Residual	0.02381	14	0.0017		
Lack of Fit	0.01742	10	0.0017	1.089	0.5095
Pure Error	0.00639	4	0.00159		
C Total	0.22033	28			
R2	0.8918	Pred R2	0.4991		
Adj R2	0.7837	Adeq Precision	10.415		

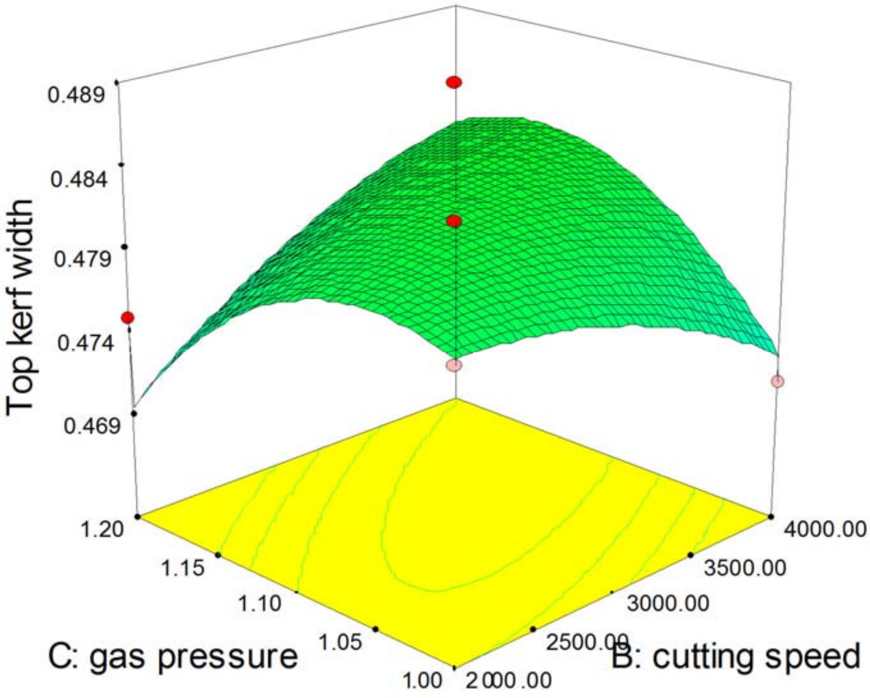

Fig. 2.a. Response surface graph of top kerf width cutting speed vs gas pressure

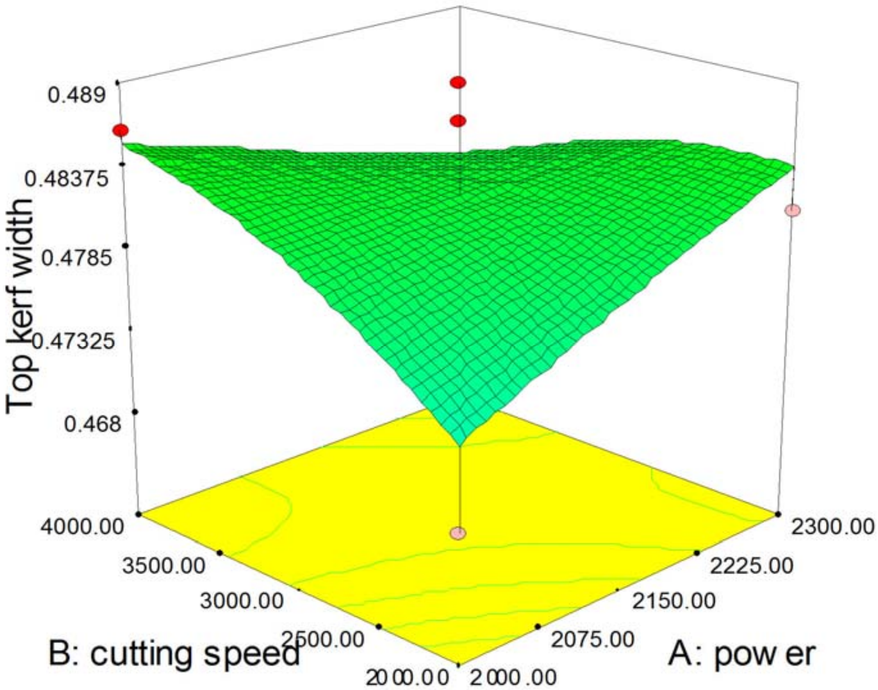

Fig. 2.b. Response surface graph of top kerf width power vs cutting speed

The Fig 2.a. shows the effect of cutting speed and gas pressure while keeping the power and focal position as constant value on top kerf width. This surface plot has been observed top kerf width decreases extensively with increase in cutting speed and decrease in gas pressure. Consequently, the effect of power and cutting speed while on top kerf width is shown in Fig 2.b. keeping the gas pressure and focal position as constant; it tends to decrease the top kerf width with low laser power and cutting speed.

Similarly the Fig 3.a. shows the effect of laser power and cutting speed on bottom kerf width. Bottom kerf width directly affects the uniform kerf width dimensions due to variations in narrow laser cutting.

According to this, the response graph of bottom kerf width shows the nature of variations on bottom kerf width with applied cutting speed and laser power. The Fig. 3.b. predicts the focal position and gas pressure on bottom kerf width. Based on this plot, the results shows that decrement of gas pressure induced the decrease bottom kerf width due to ejaculation velocity of molten material from cutting region. Consequently the increase of cutting speed decreases the bottom kerf width.

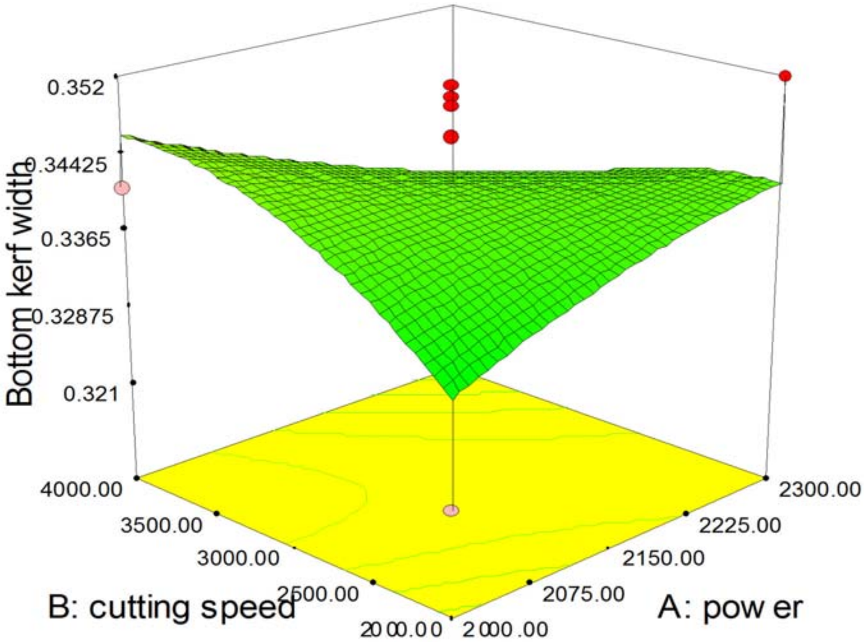

Fig. 3.a. Response surface graph of bottom kerf width power vs cutting speed

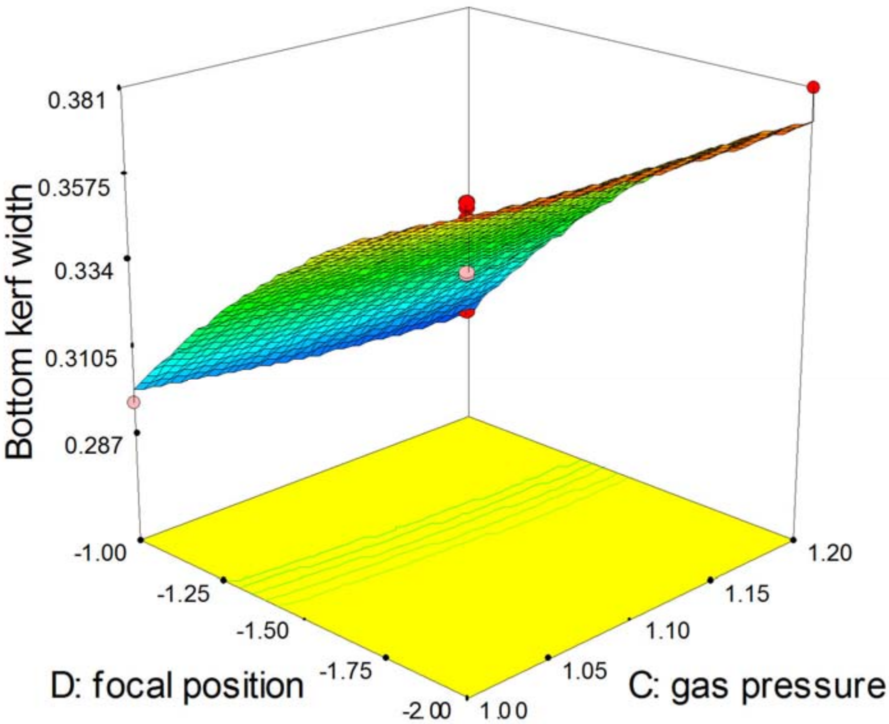

Fig. 3.b. Response surface graph of bottom kerf width gas pressure vs focal position

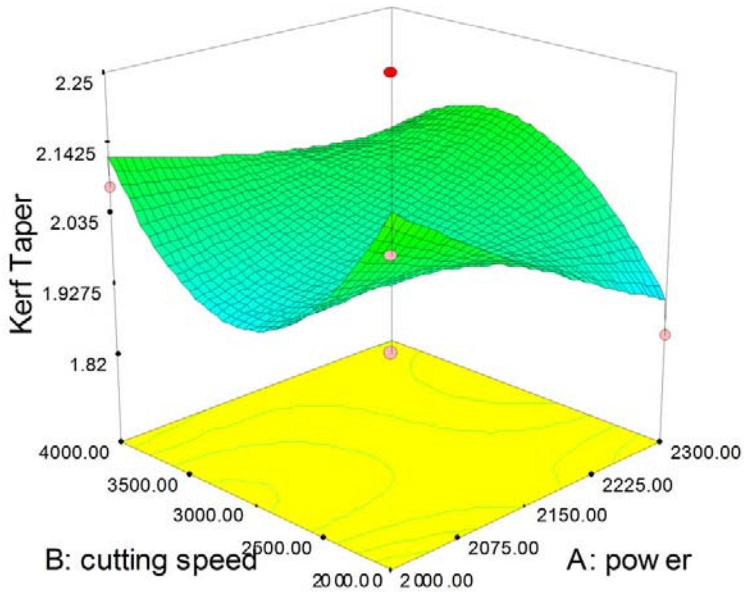

Fig. 4.a. Response surface graph of kerf taper power vs cutting speed

The Fig. 4.a. represents that the laser power and cutting speed on the medium level of laser power is responsible for reduction in the kerf taper according to the considered level of laser power. Based on the plot 4.b. the mid level of gas pressure reduces the kerf taper, mean while there is no significant effect of focal position on kerf taper. These Figures 5.a. and 5.b. shows the effects of cutting speed, laser power, gas pressure and focal position. The effect of input parameters on kerf ratio is similar to the effect on top kerf width as shown in plots of Fig.2.

B. Regression model

All the response surface plots have interaction effects with considered responses. Because for graphs do not contain straight contour plots. This non-containment is the shadow of response surface plots. So the developed models should be second order polynomial equations due to its non linearity. So the developed eq. (2), (3), (4), and (5) are second order statistical models for making relationship between independent and dependent variables. Here P, V, p and z are laser power, cutting speed, gas pressure and focal position respectively.

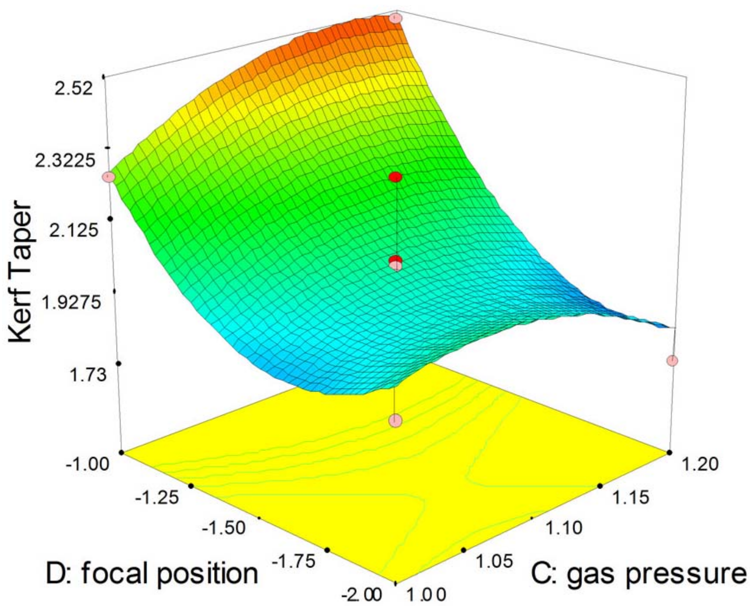

Fig. 4.b. Response surface graph of kerf taper gas pressure vs focal position

A. Performance evaluation of developed models

In the figures are. 6, 7, 8 and 9 the RSM and Experimental models were compared on the basis of their prediction. The models were validated with 29 data sets of Box-Behnken design used for the model development. The Figs 6, 7, 8 and 9 shows that the Top kerf width, bottom kerf width, kerf taper and ratio of both the experimental value and RSM based models are nearer to each other's values. So these developed models were utilized for optimal parameter selection on behalf of considered responses with GA.

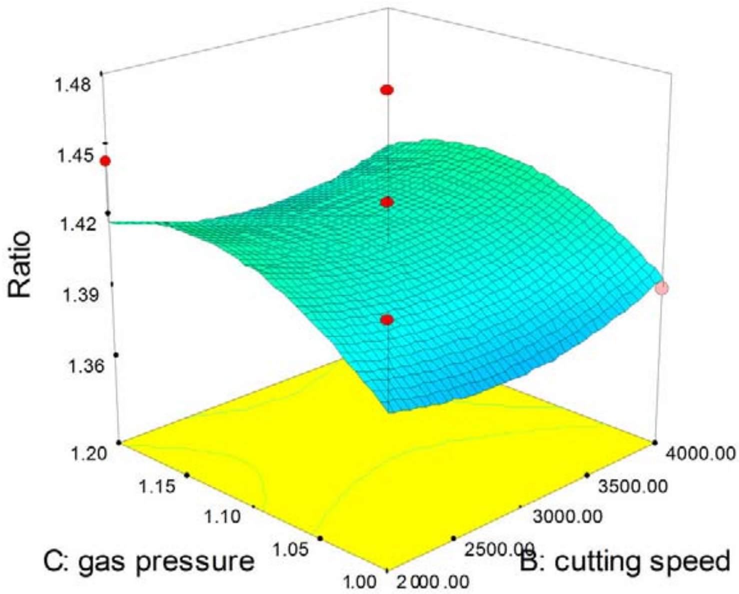

Fig. 5.a. Response surface graph of ratio power vs cutting speed

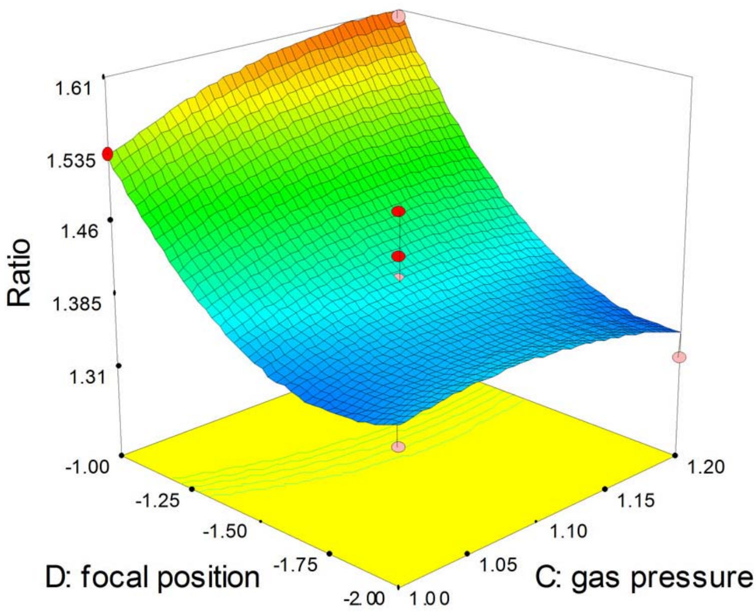

Fig. 5.b. Response surface graph of ratio gas pressure vs focal position

$$Top\ KW = +1.30549 + 5.943e-4\times P + 5.116e-6\times V + 1.953\times p - 0.0369\times z - 2.833e-8\times P\times V$$
$$-4.166e-4\times P\times p - 1e-5\times P\times z + 4.75e-5\times V\times p - 1.05e-5\times V\times z + 0.095\times p\times z - 1.44e-8\times P^2$$
$$-1.825e-9\times V^2 - 0.4825\times p^2 + 0.02\times z^2 \quad 2$$
$$Bottom\ KW = -1.086 + 8.562e-4\times P + 1.119e-4\times V + 0.1796\times p - 0.2898\times z - 5e-8\times P\times V$$
$$-3.66e-4\times P\times p + 4e-5\times P\times z + 4e-5\times V\times p + 1.6e-5\times V\times z - 0.045\times p\times z$$
$$-6.037e-8\times P^2 - 4.108e-9\times V^2 + 0.1766p^2 - 0.0419\times z^2 \quad 3$$
$$Kerf\ Taper = -188.993 + 0.1451\times P - 0.0169\times V + 267.546\times p - 7.398\times z + 7.476e-6\times P\times V$$
$$-0.163\times P\times p + 9.5541e-3\times P\times z + 1.0748e-4\times V\times p - 3.7977e-4\times V\times z + 2.0067\times p\times z$$
$$-2.832e-5\times P^2 + 2.6e-6\times V^2 - 71.0708\times p^2 + 0.897\times z^2 + 2.30892e-5\times P^2\times p$$
$$-2.388e-6\times P^2\times z - 1.194e-9\times P\times V^2 + 0.0286\times P\times p^2 \quad 4$$

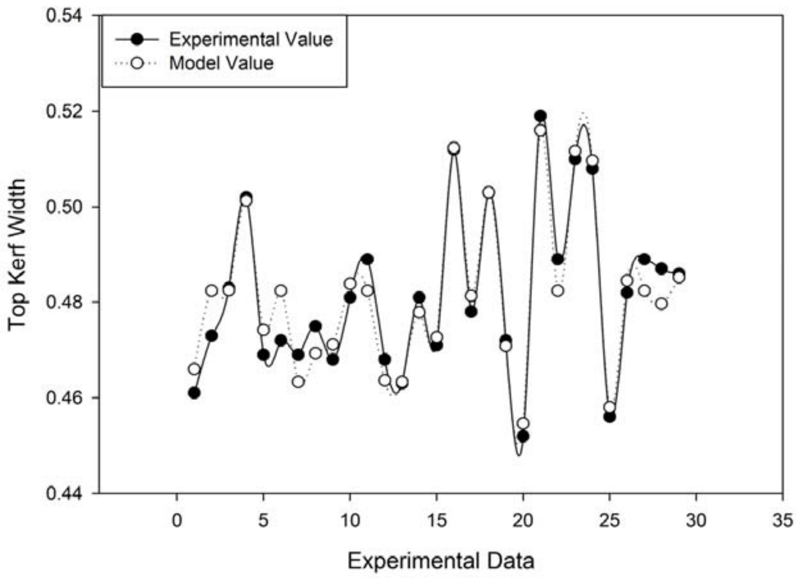

Fig.6. Top kerf width (Experimental data vs RSM based model data)

$$Ratio = +2.203 - 1.7811e-3\times P - 4.573e-4\times V + 4.8673\times p + 1.1657\times z + 1.2632e-7\times P\times V$$
$$+3.7614e-4\times P\times p - 1.5789e-4\times P\times z - 2.8912e-5\times V\times p - 9.709e-5\times V\times z$$
$$+0.5074\times p\times z + 1.933e-7\times P^2 + 1.2308e-8\times V^2 - 2.1311\times p^2 + 0.29377\times z^2 \quad 5$$

III. DETERMINATIONS OF OPTIMAL CUTTING PARAMETERS USING GENETIC ALGORITHM

Genetic algorithm is computerized search and optimization algorithms based on the mechanics of natural genetics and natural selection. A GA allows the uniformly distributed population to maximize or minimize the objective function. The quality of fitness function is evaluated with respect to the objective function. Genetic algorithm mainly consists of three operators reproduction, cross over and mutation. The following section describes the GA operators, GA algorithm and the formulation of combined objective function.

A. Reproduction

Reproduction was the function of expected number of offspring of a chromosome.

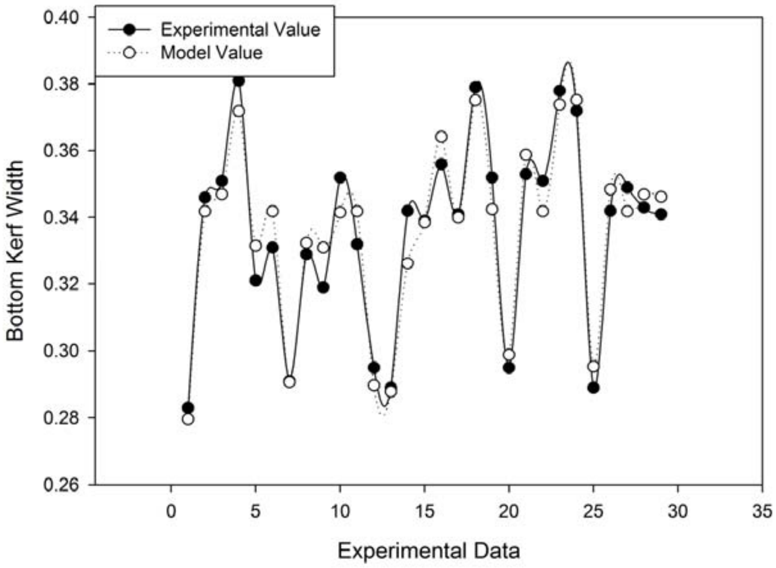

Fig.7. Bottom kerf width (Experimental data vs RSM based model data)

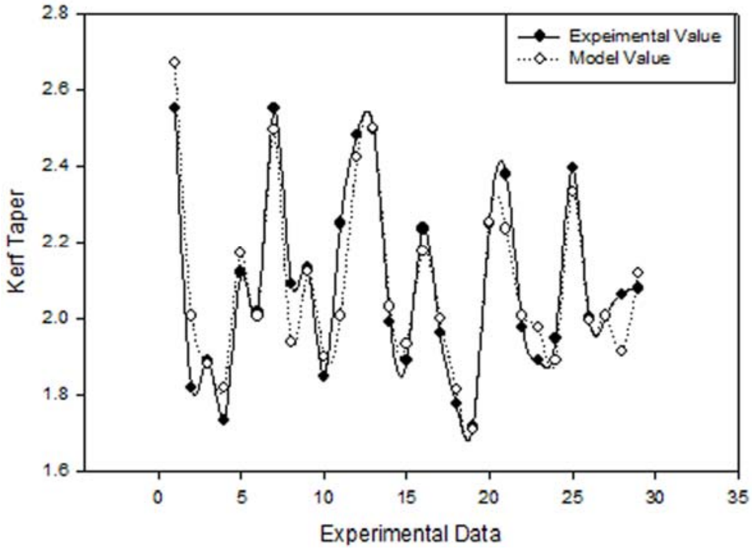

Fig.8. Kerf taper (Experimental data vs RSM based model data)

B. Cross over

Cross over is a genetic operator that combines two chromosomes to produce new chromosomes. Cross over operator randomly selects one crossover point and then copy everything before this point from the first parent and then everything after the cross over point copy from the second parent.

C. Mutation

After cross over is performed, mutation takes place mutation is a genetic operator used to maintain genetic diversity from one generation of a population of chromosome to the next. Mutation occurs during evolution according to a user definable mutation probability to set 0.1.

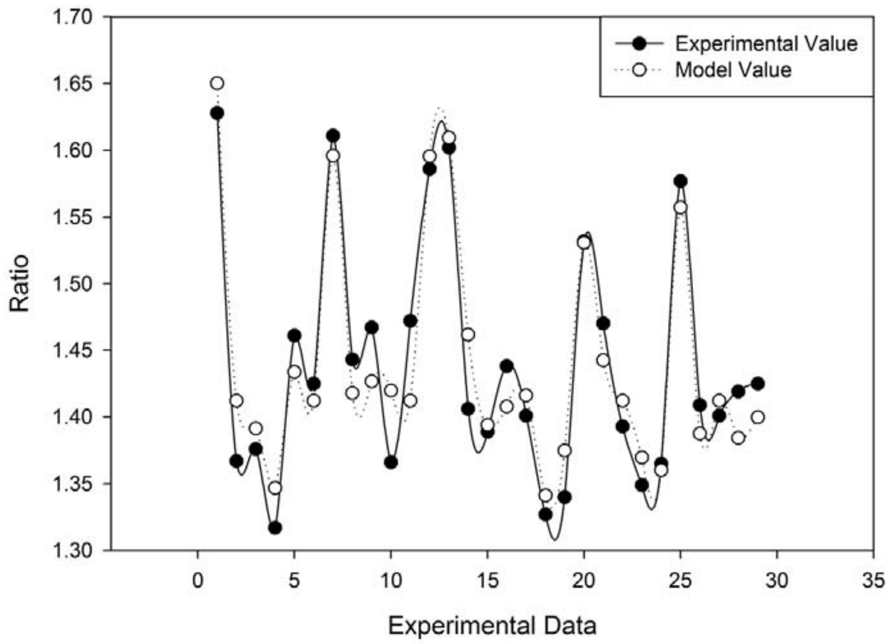

Fig. 9. Kerf width Ratio (Experimental data vs RSM based model data)

D. GA algorithm

Step 1 to minimize the objective function f(x) =f(x) and to select the cross over and mutation operator. Population size is 100, cross over probability pc=0.8 and mutation probability pm= 0.1 random population of string size l=16 generation is 500.

Step 2 Evaluate each string in the population.

Step 3 If t>t max or other termination criteria is satisfied, terminate.

Step 4 to perform reproduction on the population.

Step 5 to perform crossover on random pairs of strings.

Step 6 to perform mutation on every string.

Step 7 Evaluate strings in the new population. Set t=t+1 and go to step 3.

E. Combined objective function

The equation 6 represents the combined objective function for kerf dimensions and all responses consume equal weight age of 0.25. And the fig.10 shows the GA output result. The GA program is developed by using Microsoft C^{++} software. The result found is that the 137th iteration gives best value from total considered iteration. The combined objective value obtained is 3.824.

$$\min(cof) = 0.25 \times \frac{tkw}{\min(tkw)} + 0.25 \times \frac{bkw}{\min(bkw)} + 0.25 \times \frac{kt}{\min(kt)} + 0.25 \times \frac{ratio}{\min(ratio)} \quad \ldots\ldots (6)$$

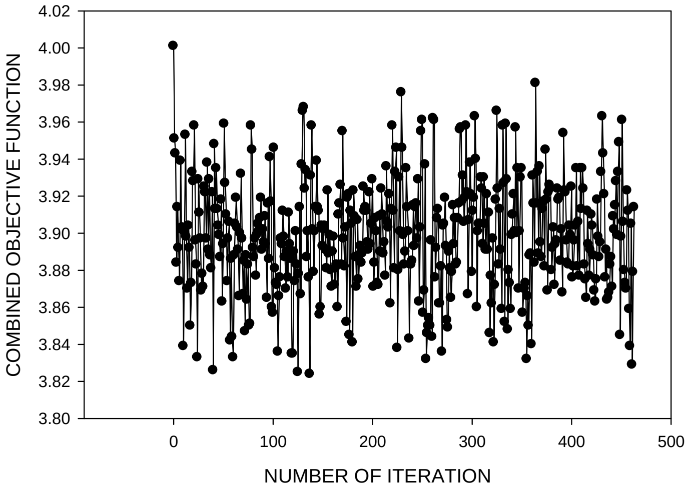

Fig.10. Genetic algorithm (Number of iteration vs combined function)

TABLE VIII
Optimum Parameter Found and the Minimum Kerf Dimension

Sl. No	Cutting parameters	GA predicted values	COF	Responses	GA Predicted value
1	Laser power (watts)	2134.64	3.824	Top kerf width (mm)	0.4898
2	Cutting speed (mm/min)	2038.67		Bottom kerf width (mm)	0.3710
3	Gas pressure (Mpa)	1.19		Kerf taper (deg)	1.2740
4	Focal position (mm)	-1.98		Ratio	1.3180

V. CONCLUSIONS

The hybridization of RSM with GA has been used to optimize the laser cutting operation on aluminium alloy. Based on experimental and theoretical investigations the following conclusions were made.

1. The RSM technique was used to study the effects of process parameters on laser cutting. The findings of RSM technique shows that the top kerf width, bottom kerf width, kerf taper and ratio are mainly affected by gas pressure, laser power, focal position and cutting speed. Gas pressure and cutting speed exert a simultaneous effect on kerf dimensions.

2. Consequently laser power and focal position exert less effect on kerf dimensions compared to gas pressure and cutting speed. For achieving minimum kerf dimensions moderate cutting speed and gas pressure is required.

3. The optimal values for achieving minimum kerf dimensions are achieved through the hybridization of RSM and GA. The predicted best value of laser power is 2134.64 watts, cutting speed is 2038.67 mm/min, gas pressure is 1.19 Mpa and focal position is -1.98 mm.

4. Future scope: The present work can be extended to optimize the other laser parameters such as standoff distance and nozzle diameter etc. on kerf dimensions. And also similar work can be utilized for Nd: YAG laser cutting process parameter optimization

REFERENCES

[1] Choudhury, S. Shirley, Laser cutting of polymeric materials: An experimental investigation Optics & Laser Technology 42 (2010) 503–508
[2] Amit Sharma, Vinod Yadava, Modeling and optimization of cut quality during pulsed Nd:YAG laser cutting of thin Al-alloy sheet for straight profile Optics & Laser Technology 44 (2012) 159–168
[3] Avanish Kumar Dubey, Vinod Yadava, Multi-objective optimization of Nd:YAG laser cutting of nickel-based super alloy sheet using orthogonal array with principal component analysis Optics and Lasers in Engineering 46 (2008) 124–132
[4] Arun Kumar Pandey, Avanish Kumar Dubey, Taguchi based fuzzy logic optimization of multiple quality characteristics in laser cutting of Duralumin sheet Optics and Lasers in Engineering 50 (2012) 328–335

[5] Avanish Kumar Dubey, Vinod Yadava, Multi-objective optimization of laser beam cutting process Optics & Laser Technology 40 (2008) 562–570.

[6] H.A. Eltawhni, M.Hagino, K.Y.Benyounis, T.Inove, A.G.Olabi, Effect of CO_2 laser cutting parameters on edge quality and operating cost of AISI 316L, Optics & laser Technology 44 (2012) 1068-1082.

[7] H. A. Eltawahni, A.G.olabi, K.Y. Benyounis, Investigating the CO_2 laser cutting parameters of MDF wood composite materials, Optics& laser Technology 43 (2011) 648-659.

[8] H.A. Eltawahni, A.G. Olabi, K.Y. Benyounis, Effect of process parameters and optimization of CO_2 laser cutting of ultra high-performance polyethylene, Materials and Design 31 (2010) 4029-4038.

[9] F. Caiazzo, F. Curcio ,G. Daurelio , F. Memola Capece Minutolo, Laser cutting of different polymeric plastics (PE, PP and PC) by a CO2 laser beam Journal of Materials Processing Technology 159 (2005) 279–285.

[10] Arun Kumar Pandey and Avanish Kumar Dubey, Intelligent Modeling of Laser Cutting of Thin Sheet International Journal of Modeling and Optimization, Vol. 1, No. 2, June 2011.

[11] A. Riveiro, F. Quintero, F. Lusquiños, R. Comesaña J. del Val, J. Pou, The Role of the Assist Gas Nature in Laser Cutting of Aluminium Alloys Physics Procedia 12 (2011) 548–554.

[12] K.Huehnlein, K. Tschirpke, R. Hellmann, Optimization of laser cutting processes using design of experiments Physics Procedia 5 (2010) 243–252.

[13] Bekir Sami Yilbas & S. Khan & K. Raza & Omer Keles & Mustafa Ubeyli & Teyfik Demir & M. Serdar Karakas, Laser cutting of 7050 Al alloy reinforced with Al2O3 and B4C composites Int J Adv Manuf Technol (2010) 50:185–193.

[14] Stournaras, P. Stavropoulos, K. Salonitis, G. Chryssolouris, An investigation of quality in CO2 laser cutting of aluminium CIRP Journal of Manufacturing Science and Technology 2 (2009) 61–69.

[15] H. Golnabi, M.Bahar, Investigation of optimum condition in oxygen gas-assisted laser cutting Optics & Laser Technology 41 (2009) 454–460.

[16] Riveiro, F. Quintero, F. Lusqui˜nos, R. Comesa˜na, J. Pou Parametric, Investigation of CO2 laser cutting of 2024-T3 alloy Journal of Materials Processing Technology 210 (2010) 1138–1152.

[17] Avanish Kumar Dubey & Vinod Yadava, Robust parameter design and multi-objective optimization of laser beam cutting for aluminium alloy sheet Int J Adv Manuf Technol (2008) 38:268–277.

[18] J.M.Patel, D.M.Patel, Parametric investigation in co2 laser cutting Quality of hardox-400 materials / International Journal of Engineering Science and Technology (IJEST) Vol. 3 No. 7 July 2011

[19] Ulas Caydas, Ahmet Hascalık, Use of the grey relational analysis to determine optimum laser cutting parameters with multi-performance characteristics Optics & Laser Technology 40 (2008) 987–994

[20] Y. Nukman, M. A. Hassan, M. Z. Harizam, Optimization of Prediction Error in CO2 Laser Cutting process by Taguchi Artificial Neural Network Hybrid with Genetic algorithm, Appl. Math. Inf. Sci. 7, No. 1, (2013) 363-370.

[21] Saravanan, P.Asokan, M. Sachindanandam. A multi-objective genetic algorithm(GA) approach for optimization of surface grinding operations, International Journal of Machine Tools & Manufacture 42 (2002) 1327-1334.

[22] B. Suresh kumar, N. Baskar, integration of fuzzy logic with response surface methodology for thrust force and surface roughness modeling of drilling on titanium alloy.Int J Adv manuf Tecnology 65 (2013) 1501-1504.