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Optimal Maching Parameter Using Taguchi Method On Al-Si (Lm 6)

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Abstract: the recent years the usage of cast Al–Si alloy components in automotive and marine industries has increased significantly. Such alloys are invariably treated for modification and grain refinement prior to casting to achieve improved properties and performance. Grain refinement plays a crucial role in improving characteristics and properties of aluminum silicon eutectic (Al– 12Si) alloy. In the present research work, modified and grain refined Aluminium-Silicon alloys are synthesized from commercially available base alloys using die casting method. An attempt has been made to machine the eutectic Al–12Si (LM 6) alloy using CNC at different conditions. Modified Taguchi robust design analysis is employed to determine optimal combination of Machining parameters. The Analysis of Variance (ANOVA) is also applied to identify the most significant factor. It is found that the Depth of cut is the most significant factor on Material Removal Rate (MRR) and Feed rate is for Roughness of machined surface (Ra). It has been observed that there is good agreement between the predicted and experimental values of optimization. The influence of depth of cut and feed rate on MRR and Ra have been discussed. The addition of modifier and grain refiner had a crucial role in improving the mechanical properties in eutectic LM 6 alloy.

Keywords: Eutectic (Al–12Si) alloys, Material Removal Rate (MRR), Roughness, ANOVA, Multi–Response S/N ratio.

I. INTRODUCTION

Aluminum alloys are used in advanced applications because of their combination of high strength, low density, durability, machinability, availability and relatively lower cost as compared to other competing materials. Silicon is probably one of the least expensive alloying additions commonly made to aluminum, which improves castability, increases strength to weight ratio, enhances corrosion resistance, decreases the co efficient of thermal expansion and imparts wear resistance to aluminum. Al–Si alloys find wide range of applications in marine castings, motor cars and lorry fittings, pistons and engine parts, cylinder blocks and heads, cylinder liners, axles and wheels, rocker arms, automotive transmission casings, water cooled manifolds and jackets, piston for internal combustion engines, pump parts, high speed rotating parts and impellers, etc. [1-7]. Grain refinement greatly influences the microstructure of the alloy. This affects the properties of castings to a great extent; hence the properties of material improve. Eutectic alloys (11-13% silicon) are used for pistons, cylinders, blocks and heads of IC engines in automobile and aeronautical industries. The good machinability indicates good surface finish and integrity, Long tool life, Low power requirements. It is important to develop the aluminum alloy castings possessing a high quality and a high reliability [8, 9]. S.A. Kori et al. studied the effect of grain refiner and or modifier on the wear behaviour of hypoeutectic (Al–0.2, 2, 3, 4, 5 and 7Si) and eutectic (Al–12Si) alloys considering parameters such as alloy composition, normal pressure, sliding speed and sliding distance on the hypoeutectic and eutectic Al–Si alloys and the results reveal an improvement in the mechanical and tribological properties due to the change in microstructure [10] .

Manufacturers are trying to reduce the operation cost and increase the quality of products. The process parameters like cutting speed, feed rate, depth of cut, coolant condition and tool geometry affects the material removal rate in turning. The surface roughness and MRR have significant role in machining of Al- Si (LM6) alloys. The proper selection of process parameters is essential to optimize the metal removal rate.

There is a need to optimize the process parameters in a systematic way to achieve the output characteristics / responses by using experimental methods and statistical models. Taguchi's robust design method is suitable to solve the metal cutting problem like milling with minimum number of trials as compared with a full factorial design and one factor at a time method [11]. The approach adopted by design of experiment through the Taguchi orthogonal array is very popular for solving optimization problems in manufacturing engineering [12-16] and ANOVA has been used successfully in process optimization.

Utility concept is simple and useful concept. It also provides an appropriate solution for multi-response optimization problems. It is found that a little work has been reported [17] on multi-response optimization in machining to determine the best combination of the process parameters. Recently Grey relational analysis is successfully employed in conjunction with Taguchi design of experiments to optimize the multiple response problems [18,19]. Jagannatha, N et.al, [20] have reviewed the approach and adopted by design of experiments through the Taguchi orthogonal array.

It is very popular for solving the optimization problems in manufacturing engineering. ANOVA is successfully utilized for the process optimization. This concept is used to determine the best combination of factors to machine on soda lime glass material using abrasive hot air jet machining.

In this paper, the multi characteristics optimization model based on Taguchi method and Utility concept has been employed to determine the optimal combination of the machining parameters to attain the minimum surface roughness (Ra) and maximum MRR. The confirmation test is also conducted to verify the results. The effect of machining parameters like speed, feed rate, depth of cut etc., are on MRR and Ra is discussed.

II. MATERIALS & METHODS

2.1. Experimentation

Machinability of a particular material has evaluated by assessing any one of the following five parameters: (a) tool life or wear, (b) surface finish of test piece, (c) cutting force requirement, (d) power requirement, and (e) cutting temperature. In the present investigation of machinability, the cutting speed, feed rate and the depth of cut are important parameters. The material used in the experiment are eutectic Al-Si alloy. The composition of base material used is shown in the Table 1 below. The turning operation is performed on work piece to study the machinabilty (Fig. 1).

Table 1 Composition of LM 6 Al-Si alloy used in the experiments

Elements present in the alloy (wt. %)						
Si	Fe	Cu	Mg	Mn	Others	Al
10-13	0.3	0.1	0.1	0.5	0.55	Balance

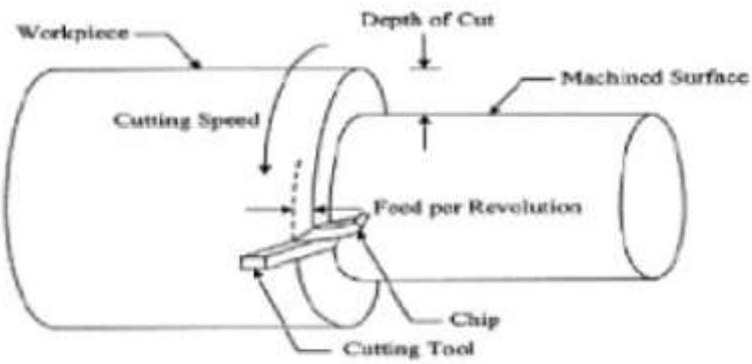

Figure 1 Turning operation of Al-Si alloy

The effect of the length and diameter of work piece was considered and suitable size of work piece is selected for machining operations. The material removal rate (MRR) plays an important characteristic in turning operation and according and high MRR is always desirable for increasing the productivity.

In this work, the three cutting parameters: cutting speed, feed rate and depth of cut are considered for three levels. The other parameters were kept constant. The details of CNC machine used for turning operation is given in Table 2. The geometry of the cutting tool selected for the turning operation is shown in Fig.2 and its specifications are given in Table .3.

Table 2 Specifications of CNC machine

Specification	Data
Capacity	
Maximum Turning Length	262 mm
Maximum Turning Diameter	200 mm
Chuck Size	169 mm
Spindle	
Spindle Nose	Flat Ø140
Spindle Speed Range	45-4500 Rpm
Maximum Torque On Spindle	64 Nm
Feed System	
Cross Travel (X –Axis)	105 mm
Longitudinal Travel (Z-Axis)	320 mm
Rapid Travel X,Z Axis	20,000, 20,000 mm/min
General	
Machine Size (L*B*H)	2450*1640*1620 mm
Coolant Tank Capacity	80 Litre
Accuracy	
Position Of Slides	0.015/0.25 mm
X-Axis/Z-Axis Repeatability	+ or – 0.003 mm

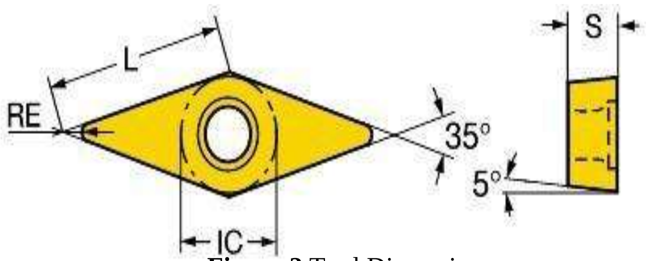

Figure 2 Tool Dimensions

Table 3 Specifications of Tool

Product Category	Cutting Tool Inserts
Applications	Milling, Turning
Geometry	
Shape	Diameter; Chip breaker
Tip Angle	35□
I.C	9.5 mm
Thickness	4.7 mm
Radius	0.4 mm
Construction	
Material	Carbide
Coating	None

2.2. Materials

In the present work, eutectic (Al–12Si) alloy (grain refinement and modification) was used as the work material. The suitable size of specimen was used for turning processes. The specimens were weighed before machining. After the machining, the samples were cleaned a nd final weight was measured using a digital electronic balance (BSA224S-CW SARTORIOUS, Germany) with resolution of 0.1 mg. Four measurements for each sample were taken and the average value was considered. The weight loss per unit time for each specimen is calculated and material removal rate is calculated in mm3/min. Similarly the roughness of machined part was measured using a surface roughness tester (Tally Surf Tester, Mitutuyo, Japan). The average Roughness value Ra of the machined part was recorded at four different locations and the mean value was consi dered as a roughness of the machined surface.

Table 4 Process parameters and their levels

Symbol	Parameter	Level 1	Level 2	Level 3
A	Speed (rpm)	500	1000	1500
B	Feed raate (mm/rev)	0.1	0.2	0.3
C	Depth of cut (mm)	0.4	0.6	0.8

2.3. Parameters and Design

In this process, a large number of parameters are involved and all thhese parameters affect the machining results. In this work, only three parameters like speed, feed rate and depth of cut were considered. The other experimental parameters were kept constant throughout the machining process. The machining parameters and their levels are shown in Table 4. In order to obtain high efficiency in the planning and analysis of experimental data, the Taguchi parameter design was applied. The standard S/N ratios used in the present work are Larger-the-Better for MRR and Smaller-the-better for Ra. The orthogonal array is used to determine least number of experiments. In this work, the orthogonal array L9 was selected. The optimal setting is the parameter combinattion is obtained by considering the highest value of the S/N ratio, [15,21].

The multi-response methodology based on Taguchi's robust desig n technique and Utility concept was use d for optimizing the multi-responses like MRR and Ra. Taguchi's standard S/N ratios were selected to obtain the optimum parameters combination [22] . They were, Larger the better type S/N ratio for M RR and Smaller the better type S/N ratio f or Ra as calculated by equations (1) and (2) reespectively.

(1)

(2)

2.4. Utility Concept

Utility can be defined as the usefulness of a product or a process in reference to the levels of expectations to the consumers [23]. The overall usefulness of a process / product can be represen ted by a unified index termed as utility which is the summation of the individuual utilities of various quality characteristics. It is difficult to obtain the best combinati on of process parameters, when there are multi-responses to be optimized. The adoption of weights in the utility concept helps in this difficult situations by differentiatin g the relative importance of various responsees.

If xi represents the meeasure of effectiveness of ith process responsse characteristic and n represents number of responses, then the overall utility function can be written as (Bunn, 1982).

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(3)

where U (x1, x2, x3 ... xn) is the overall utility of n process response characteristics and Ui(xi) is utility of ith response characteristic. Assignment of weights is based on the requirements and priorities among the various responses. Therefore the general formm or weighted form of equation (3) can be ex pressed as

(4)

where

where $W_i$is the weight assigned to the *i*th response characteristic.

The utility concept employs the weighing factors to each of S/N ratio of the responses to obtain a mullti response S/N ratio for each trial of the orrthogonal array. The multi-response S/N ra tio is calculated by the equation.

(5)

where w1 and w2 are the weighing factors associated with the S/ N ratio of MRR and Ra respectively. The se weighing factors were decided based on the priorities among the various responses to be simultaneously optimized. In thee present work, weighing factors of 0.5 fo r MRR and 0.5 for Ra are assumed. This gives priorities to all responses for simultaneous minimization and maximization. The ov erall mean of η associated with k number of trials is computed as;

(6)

III. RESULTS AND DISCUSSION

3.1. Analysis of Single Response

Experiments were on eute ctic (Al–12Si) alloy bar of size Φ20 mm x100 mm to study the performance of turning using orthogonal array L9. The values of Single-response S/N ratios MRR (η1) and Ra (η2) are calculated using equatio ns (1) and (2) respectively. The combin ed multi-response S/N ratio is calculated using equation (5) and values are shown in Table 5.

Table 5 Orthogonal array and Experimental Results with S/N Raatios

Sl. No.	**Factors**			**MRR (mm^3/min)**	**R_a (µm)**	**S/N ratio MRR η_1 (dB)**	**S/N ratio R_a η_2 (dB)**	**S/N ratio Multi-response η (dB)**
	A	**B**	**C**					
1	500	0.1	0.4	426.751	3.10	52.6035	-9.8272	21.3881
2	500	0.2	0.6	496.863	3.01	53.9247	-9.5713	22.1767
3	500	0.3	0.8	576.220	2.46	55.2118	-7.8187	23.6965
1	1000	0.1	0.6	563.408	3.83	55.0165	-11.6640	21.6762
2	1000	0.2	0.8	706.845	3.69	56.9865	-11.3405	22.8230
3	1000	0.3	0.4	537.911	2.93	54.6142	-9.3374	22.6384
1	1500	0.1	0.8	749.117	3.95	57.4910	-11.9319	22.7795
2	1500	0.2	0.4	551.508	3.30	54.8310	-10.3703	22.2303
3	1500	0.3	0.6	605.150	3.01	55.6373	-9.5713	23.0330

The individual mean values of S/N ratios of responses of MRR (η1) and surface roughness Ra (η2) are shown in Table 6 and Table 8 respectively. It can be found from the main effect plots (Figures 3) that the largest value of S/N ratio for MRR is obtained at combination A3B2C3. From fig. 4, it is found that the largest value of S/N ratio for Ra at the combination of A1B3C1. In other words, the optimum condition for MRR is at level 3 (1500 rpm) of Speed, level 2 (0.2 mm/rev) of Feed rate and level 3 (0.8 mm) of depth of cut. Similarly, optimal combination for Ra is at level 1 (500 rpm) of Speed, level 3 (0.3 mm/rev) of Feed rate and level 1 (0.4 mm) of depth of cut.

The statistical software with an analytical tool of ANOVA is used to determine which parameter significantly affects the performance characteristics. The results of ANOVA for the Single-response S/N ratios of MRR (η1) and surface roughness Ra (η2) are shown in Table 7 and Table 9 respectively. It can be seen that depth of cut has the highest contribution of about 57.75% for MRR and feed rate has the highest contribution of about 56.49% for Ra, the other parameters have less contributions. It is clear that the depth of cut and feed rate are the significant factors that have more impact than other factors on MRR and Ra.

Table 6 Means of S/N ratio values of MRR

Symbol	Parameter	Level 1	Level 2	Level 3
A	Speed (rpm)	53.913	55.539	55.986*
B	Feed rate (mm/rev)	55.036	55.247*	55.154
C	Depth of cut(mm)	54.016	54.859	56.714*

Table 7 Results of ANOVA for MRR

Source	DF	Adj SS	Adj MS	F	P-value	Contribution (%)
A	2	7.1409	3.57044	39.81	0.025	40.83
B	2	0.0667	0.03335	0.37	0.72	0.38
C	2	10.0999	5.04994	56.30	0.017	57.75
Error	2	0.1794	0.08969			1.02
Total	8	17.4869				

Main Effects Plot for S/N for MRR

Data Means

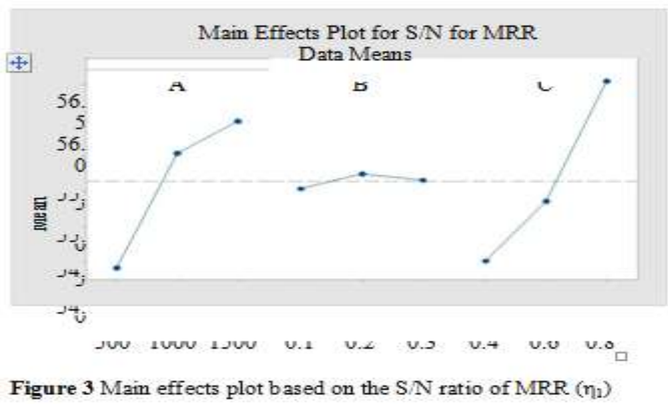

Figure 3 Main effects plot based on the S/N ratio of MRR (η_1)
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Table 8 Means of S/N ratio values of R_a

Symbol	Parameter	Level 1	Level 2	Level 3
A	Speed (rpm)	-9.072*	-10.780	-10.624
B	Feed rate (mm/rev)	-11.140	-10.427	-8.908*
C	Depth of cut(mm)	-9.844*	-10.268	-10.363

Table 9 Results of ANOVA for Ra

Source	DF	Adj SS	Adj MS	F	P-value	Contribution (%)

A	2	5.3515	2.67573	27.20	0.035	38.78
B	2	7.7957	3.89787	39.62	0.025	56.49
C	2	0.4578	0.22888	2.33	0.301	3.32
Error	2	0.1967	0.09837			1.42
Total	8	13.8017				

Main Effects Plot for S/N for Ra
Data Means

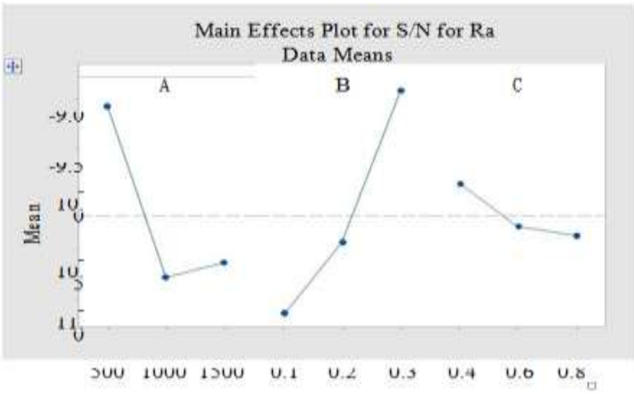

Figure 4 Main effects plot based on S/N Ratio of R_a (η_2)

Figure 4 Main effects plot based on S/N Ratio of R_a (η_2)

3.2. Optimal Parameter Combination of multi- response

The optimal combination of process parameters for multi–response system for MRR and Ra is obtained by the mean values of the multi-response S/N ratio of the overall utility value as shown in Table 10. The larger value of the multi-response S/N ratio means the comparable sequence exhibiting a stronger correlation with the reference sequence. Based on this study, the combination A3B3C3 shows the largest value of the multi-response S/N ratio for the factors A, B, and C respectively. Therefore, A3B3C3 is the optimal parameter combination of the machinability of eutectic (Al– 12Si) alloy.

Table 10 Means of multi-response S/N Ratio

Symbol	**Parameter**	**Level 1**	**Level 2**	**Level 3**
A	Speed (rpm)	22.427	22.397	22.680*
B	Feed rate (mm/rev)	21.947	22.409	23.122*
C	Depth of cut(mm)	22.085	22.292	23.101*

Manjunatha, T.M Chandrashekaraiah, Girish Kumar and N. Jagannatha The results of ANOVA for the Multi-response S/N ratios are presented in Table 11. On examining the percentage contributions of different factors, it can be seen that the Feed rate has the highest contribution of about 52.43 and the otther parameters have lower contributions. It is clear that the feed rate is one of the sig nificant factors that have more impact than any other factors.

Table 11 Results of ANOVA for multi-response S/N Ratio

Source	**DF**	**Adj SS**	**Adj MS**	**F**	**P-value**	**Cont ribution (%)**
A	2	0.160060	0.080 30	5.74	0.148	4.01
B	2	2.101127	1.050 64	75.13	0.013	52.43
C	2	1.719931	0.859 66	61.47	0.016	42.89
Error	2	0.027797	0.013 99			0.69
Total	8	4.009916				

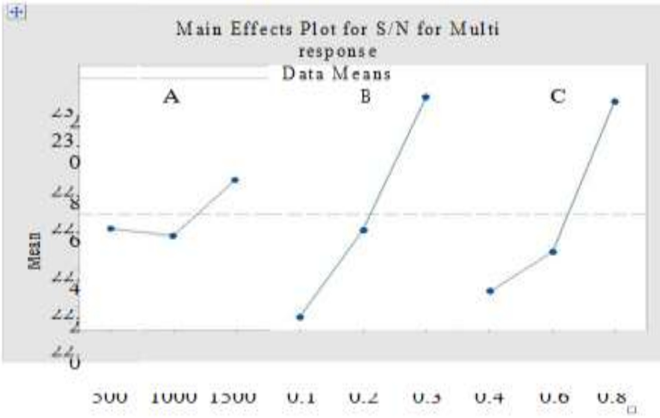

Figure 5 Mai n effects plot based on the multi- response S/N ratio

Figure 5 Mai n effects plot based on the multi- response S/N ratio

The main effect plots (Figure 5) indicates that the optimum condition for Multi-response is at level 3 (1500 rpm) of Speed, level 3 (0.3 mm/rev) of Feed rate and level 3 (0.8 mm) of depth of cut.

3. 3. Confirmation Test

The final phase is to verify the experimental results (MRR and Ra) by conducting the confirmation test. The A3B3C3 is an optimal parameter combination of the machining process of single as well as multiple responses. Therefore, the combin ation A3 B3 C3 is treated as the confirm ation test. The predicted optimal value of response can be calculated using the equation:

(7)

where m is the total m ean of the response S/N ratio at the optimal level and mi is the S/N ratio at optimal p arameter. The predicted optimal values for single-response and multi-responses are listed in Table 12.

Table 12 Results of Confirmation Test

	erformance haracteristic	**ptimal etting**	**redicted optimal / N ratio**	**xperimental ptimal S/N ratio**
ingle response	IRR	$_3B_2C_3$	7.655	7.618
ptimization	a	1B3C1	.506	.640
Iulti response ptimization	IRR and R_a	$_3B_3C_3$	3.917	3.879

In order to validate, the experiment (four trials) is conducted according to the optimal parameters levels (A3B3C3) and the individual corresponding values of responses are taken. Table 9 shows the predicted multi-response S/N ratio and multi-response S/N ratio obtained from the experiment. It is found that there is a good agreement between the estimated value (23.917) and the experimental value (23.879). The condition A3B3C3 of the parameter combination of the machining of Al-Si alloy is treated as optimal. The optimal combination A3B3C3 (1500 rpm 0.3 mm/ rev and 0.8 mm) is also confirmed by ANOVA. It can be found that the feed rate and depth of cut are more influencing parameters on MRR and Ra of turninig.

3.4. Influence of Parameters on MRR and R_a

The effect of Dept of cut on MRR and Ra was studied for turning tool on CNC. The results are plotted and presented in Figure 6 and Figure 7. It can be noticed from Figure 6 that the Dept of cut has more significant effect on MRR at 0.8 mm and above. From Figure 7, it can be seen that the roughness of machined surface decreases as the feed rate is increased. It is further observed that the value of surface roughness is very less (0.3 mm / rev) for the speed of 500 rpm. It is found that the MRR is maximum at 0.8 mm depth of cut and at 1500 rpm.

The removal of material in the form of continuous chip creates a new smooth surface of work piece at high speed and more feed rate and thus the roughness of the machined surface in reduced. It can be observed that at high feed rate, uniform chip formation of metal takes place due to more plastic deformation. Hence, metal rate increases and thus the depth of cut influence in increasing MRR and reducing roughness of machined surface.

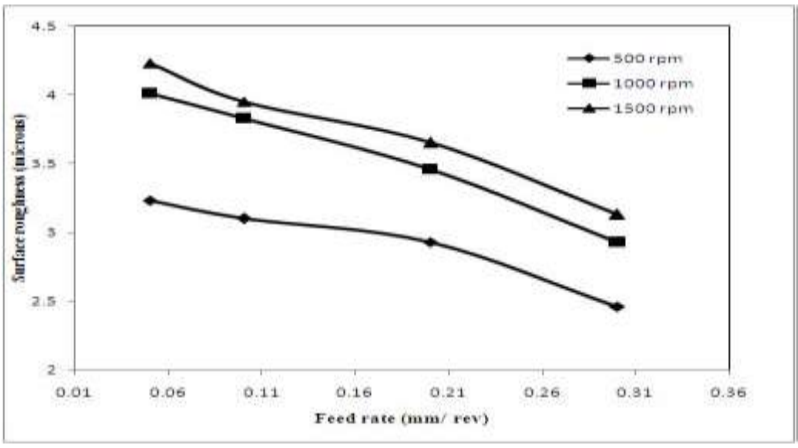

Figure 7 Effect of Feed rate on Roughness

IV. CONCLUSION

The optimization of machining parameters using Taguchi orthogonal array with multi-response analysis is discussed in this paper. From the experimental investigation and analysis, the following conclusions can be drawn.

- It has been found that the combination A3B3C3 show the largest value of the Multi-response S/N ratio for the factors A (speed), B (feed rate), and C (depth of cut), respectively. Therefore, A3B3C3 is the optimal parameter combination (Speed of 1500 rpm, the Feed rate of 0.3mm/ rev and the Depth of Cut of 0.8 mm) for the machining of Al-Si alloy.
- Through ANOVA, the percentage of contribution to the Depth of cut is more as compared to other parameters on MRR. Hence, the depth of cut is the most significant factor for the machining and maximization of MRR. Feed rate is the most significant factor for the minimization of the roughness of machined surface.
- A good agreement between the estimated value (23.917) and the experimental value (23.879) is observed. Therefore, the condition A3B3C3 of the parameter combination of the machining of Al-Si (LM 6) can be treated as optimal.
- From the experimental results, it has been found that the depth of cut has the greatest impact on MRR and Ra and followed by feed rate.

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