

# Optimization of Process Parameters in Drilling of Hybrid Aluminium Metal Matrix Composite (AMMC)

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**ABSTRACT:** The main aim of this study is to examine the influence of drilling parameters on Aluminium Hybrid metal matrix composite (Al 6082/5% sic/5% fly ash). In the present work, Al 6082 alloy with 5% sic and 5% fly ash hybrid composite is fabricated by stir casting technique. The drilling experiments were conducted according to Taguchi L18 orthogonal array on Al hybrid metal matrix composite, tool as HSS with 8% cobalt drill bits, each of 10 mm and 12 mm diameter. The influence of different drilling input parameters like diameter of drill bit, speed, feed and cutting fluid on output parameters like MRR, surface roughness, thrust force, torque and diametric error is studied. Optimum machining condition is found out by grey relational analysis. It is found that feed is the significant parameter followed by speed, cutting fluid and diameter of drill bit. With the best parameter combination, confirmation test is conducted.

**KEYWORDS:** Hybrid AMMC, Stir Casting Technique, Drilling, Grey Relational Analysis.

## I. INTRODUCTION

Currently the use of composite materials has increased in various areas of science and technology due to their special physical and mechanical properties. Automotive, air craft and train companies need to replace steel and cast iron in mechanical components with lighter high strength alloys like Al and metal matrix composites. Lighter weight of mechanical components like internal combustion engine causes lesser fuel consumption. If at least two or more reinforcements are added to the matrix, these composites are called hybrid metal matrix composites. These hybrid composites are advanced materials which has the mechanical properties of both reinforcements and the matrix. Despite mechanical properties of hybrid MMC, these materials are difficult to machine as the reinforcements are abrasive and this is the main problem of replacing metals with MMC. Consequently, the development of effective machining methods, leading to a reduction in overall cost of components, is one of the major challenges yet to be solved. During drilling operation, the less dimensional accuracy of hole, more power consumption, reduced tool life because of tool wear and cutting temperature causes undesirable features with regard to product quality. Hence, it is essential to select optimum drilling process parameters which minimize the above characteristics at the production stage. In this work, optimal drilling parameters of the hybrid composite material are studied.

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

## II. LITERATURE REVIEW

Charles et al. have investigated aluminium alloy hybrid Al/sic/Fly ash composite produced by liquid metallurgy technique and mathematical model for MRR and tool wear in EDM were developed [1]. Uday prakash et al. done the experimentations on hybrid AMMC with fly ash and boron carbide by wire edm and found that gap voltage is the influential parameter for MRR and surface roughness [2]. Basavarajappa et al. optimized the cutting parameters of drilling of hybrid AMMC with sic and graphite reinforcements and found that feed is the predominant parameter [3]. Raj mohan performed drilling experiments and predicted thrust force .It is found that feed is the major parameter affecting the thrust force [4]. Jenarathanan and Naresh optimized the process parameters on machining force and MRR of GFRP composites using grey relational analysis [5]. Mahesh Babu et al. [6] have studied the characteristics of the surface quality on machining of hybrid (Al–SiC–B4C) composites. They have asserted that the feed rate is the most influential parameter followed by cutting speed, which influences the surface roughness. Riaz Ahamed et al. [7] have studied the drilling of hybrid Al–5%SiCp– 5%B4Cp metal matrix composites and have used high speed steel as a tool material. They have found that, the lower feed and speed produce better surface with low tool wear. S.Senthil babu, Dr. B K. Vinayagam [8] involved in drilling of composites this work reviewed here investigates the drilling parameters like feed rate, drilling tool, and its geometry, cutting speed and other parameters like influence of coolants,heat treatment etc.Yahya Altunpak [9] has analysed the drilling of a hybrid Al/20 % Sic/10 %Gr and Al/20% Sic/5% Gr composites. While comparing the results of various cutting conditions, the surface roughness has proportionally increased with feed rate. Grey relational analysis [10] is effectively used for analyzing multi performance characteristics incorporating all parameters at a time. Grey relational analysis converts the multiple performance characteristics in to one numerical score called grey relational grade.based on grey relational grade, optimum level of parameters can then be obtained. ANOVA is used to find out the influential output parameter.

In this paper, Hybrid AMMC is fabricated by stir casting technique. Experiments are conducted based on L<sub>18</sub> orthogonal array in Radial drilling machine by varying the different parameters like drill dia., speed, feed and cutting fluid. Optimum parameters are obtained by grey relational analysis .The most influential input parameter feed is seen by ANOVA.

## III. EXPERIMENTAL STUDY

The work material used was Al 6082 alloy reinforced with 5%volume fraction of silicon carbide particles of size 54 microns and 5% volume fraction of fly ash of particle size 120 microns by stir casting route. Its chemical composition is given in table 1.. **Fly ash**, an industrial waste can be added as reinforcement in to aluminium to reduce the weight, density and production cost of aluminium .In general, fly ash consists of Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub> as major constituents and oxides of Mg, ca, Na, K etc as minor constituents. **Silicon** carbide has the property of strength to weight ratio, which is three times more than mild steel. In addition, composites containing SiC (reinforcing material) have high wear resistance, less weight and a more effective load carrying capacity

Table 1. Chemical Composition of Al 6082 soft O

Mn	Fe	Mg	Si	Cu	Zn	Ti	Cr	Others	Bal
0.4-1.0	0-0.5	0.6-1.2	0.7-1.3	0-0.1	0-0.2	0-0.1	0-0.25	0-0.05	Al

### A. Fabrication of hybrid AMMC

Stir casting technique of AMMC consists of a furnace with top opening, stirrer setup with a motor, a graphite crucible to hold the molten metal, and K-Type thermo couple to measure the temperature shown in fig 1(a). In this process the aluminium alloy pieces were melted in the stir casting furnace at above the melting point of Al around 850 C. The stirring is carried out with the help of graphite stirrer arrangement for about 10 minutes at a stirring rate of 240 rpm. During stirring process, the preheated reinforcement particles which are pre heated at 100°C in muffle furnace are

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added to molten metal. 1% of magnesium is also added to the molten metal. After stirring process, the mixture is poured into the mould which is made with iron of 500 mm x 60 mm x 20 mm size fig 1(b).

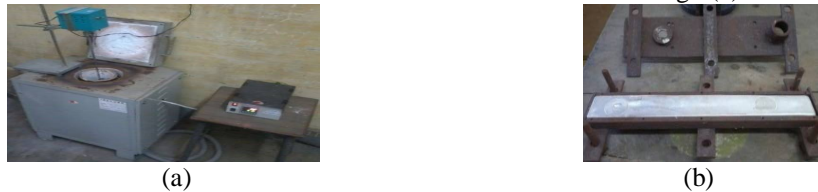


Fig. 1 Fabrication of Aluminium hybrid AMMC: a) stir casting furnace (b) Cast product

### B. Drilling of Hybrid AMMC

The experimental design is taken at three levels of machining parameters speed, feed, and cutting fluid and two levels of diameter of drill bit and are shown in Table 2. Taguchi design of experiments has been selected to optimize the multiple performance characteristics. Accordingly, Taguchi based L18 orthogonal array is selected. The drilling experiments are conducted on hybrid AMMC by radial drilling machine as shown in fig 2(a) and HSS with 8% cobalt drill bits each 10 mm and 12 mm diameter respectively are used and shown in fig 2(b). The specimen after drilling is shown in fig 2(c).

### C. Measurement of Responses

The response characteristics considered to study the parameters on drilling of Al Hybrid MMC Composite are material removal rate, thrust force, torque, diametric error and surface roughness. Experimental results are presented in Table 3.

The **Material Removal Rate (MRR)** in drilling is the volume of material removed by the drill per unit time. For a drill with a diameter D, the cross-sectional area of the drilled hole is  $\pi D^2/4$ .

Conversion of feed rate ( $f_r$ ) in mm/rev to mm/min,  $f = N f_r \dots \dots \dots$  (1). Where, N is rotational speed in rpm. Thus

$$MRR = \frac{\pi D^2}{4} f \quad \text{mm}^3/\text{sec} \quad (2)$$

The Thrust force and torque values are measured using drill tool dynamometer. Surface roughness is measured by using Talysurf surface meter. Diameter of a hole is measured by mitutoyo digital vernier callipers.

Table 2. Process parameters and their levels

Factor	Level-1	Level-2	Level-3
Dia. of drill bit (mm)	10	12	-
Speed (rpm)	250	355	500
Feed (mm/rev)	0.15	0.2	0.3
Cutting fluid	Kerosene	Diesel	Veg oil



(a)

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Fig. 2 Experimental set up: (a) Radial drilling machine (b) cobalt drill bits (c) Specimen after drilling.

## IV. GREY RELATIONAL ANALYSIS

In this section, the grey relational analysis is used for determining the optimal machining parameters. Data pre-processing (Data Normalization) is normally required since the range and unit in one data sequence may differ from the others. It is also necessary when the sequence scatter range is too large, or when the directions of the target in the sequences are different. Depending on the characteristics of a data sequence, there are various methodologies of data pre-processing available for the grey relational analysis.

If the target value of original sequence is infinite, then it has a characteristic of the “larger the better”. The original sequence can be normalized as follows

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (3)$$

If the purpose is “the-smaller-the-better”, then the original sequence is normalized as follows

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (4)$$

Table 3. Experimental results and normalisation of the each individual quality characteristic

Exp. No.	Experimental results					Normalised values of Responses				
	MRR (mm <sup>3</sup> /sec)	Thrust Force (Kgf)	Torque (Kg-m)	Diametric Error (mm)	Surface roughness (µm)	MRR (mm <sup>3</sup> /min)	Thrust Force (Kgf)	Torque (Kg-m)	Diametric error (mm)	Surface roughness (Ra in µm)
1	47.14	74	0.7	0.2	0.76	0.0000	0.8958	1.0	0.4444	0.5761
2	62.98	64	0.8	0.19	0.84	0.0687	1.0000	0.8	0.4815	0.4579
3	91.99	81	0.8	0.32	0.96	0.1946	0.8229	0.8	0.0000	0.2806
4	65.855	75	0.9	0.28	0.623	0.0812	0.8854	0.6	0.1481	0.7784
5	89.076	67	0.8	0.21	0.776	0.1820	0.9688	0.8	0.4074	0.5524
6	133.069	84	0.9	0.23	0.84	0.3729	0.7917	0.6	0.3333	0.4579
7	94.86	78	0.8	0.17	0.53	0.2071	0.8542	0.8	0.5556	0.9158
8	125.716	85	0.9	0.2	0.59	0.3410	0.7813	0.6	0.4444	0.8272
9	188.189	95	1.0	0.21	0.473	0.6121	0.6771	0.4	0.4074	1.0000
10	69.86	91	0.7	0.07	0.85	0.0986	0.7188	1.0	0.9259	0.4431
11	93.151	103	1.0	0.07	0.96	0.1997	0.5938	0.4	0.9259	0.2806
12	138.79	144	1.2	0.25	1.12	0.3977	0.1667	0.0	0.2593	0.0443
13	99.539	97	0.8	0.05	0.76	0.2274	0.6563	0.8	1.0000	0.5761
14	132.496	122	1.0	0.06	0.903	0.3704	0.3958	0.4	0.9630	0.3648
15	197.084	152	1.1	0.11	1.02	0.6507	0.0833	0.2	0.7778	0.1920
16	140.196	83	0.8	0.05	0.64	0.4038	0.8021	0.8	1.0000	0.7533
17	184.121	125	1.0	0.14	0.85	0.5944	0.3646	0.4	0.6667	0.4431
18	277.58	160	1.0	0.11	1.15	1.0000	0.0000	0.4	0.7778	0.0000

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Based on the the data pre-processing, a grey relational coefficient can be calculated using the pre-processed sequences. The grey relational coefficient is defined as follows.

$$\chi_i(k) = \frac{\Delta_{\min} + \xi \Delta_{\max}}{\Delta_{0i}(k) + \xi \Delta_{\max}} \quad (5)$$

Where,

$\Delta_{0i}(k) = |x_0(k) - x_i(k)|$  = difference of absolute value  $x_0(k)$  and  $x_i(k)$ ;

$\xi$  = the distinguishing coefficient  $0 \leq \xi \leq 1$ ;

$\Delta_{\min} = \min_k \in I \forall k \in I |x_0(k) - x_i(k)|$  = The smallest value of  $\Delta_{0i}$ ; and

$\Delta_{\max} = \max_k \in I \forall k \in I |x_0(k) - x_i(k)|$  = the largest value of  $\Delta_{0i}$ .

The grey relational grade for each experimental run can be obtained by accumulating the grey relational coefficient of each quality characteristic. The average grey grade for the *i*th experimental run for all 'n' responses is given by;

$$\gamma_i = \frac{1}{n} \sum_{k=1}^n \chi_i(k) \quad (6)$$

Where, n is the number of process responses and  $\chi_i(k)$  is the grey relational coefficient of *k*th response in *i*th experiment.

## V. RESULTS AND DISCUSSION

A. The experimental results for the surface roughness, material removal rate, thrust force; torque and diametric error are listed in Table 3. Basically, the surface roughness, thrust force, torque and diametric error are belongs to the “smaller-the-better” methodology that in Eq. (4) which is employed for data pre-processing, whereas larger value of the MRR are desirable and hence it belongs to “larger-the-better” methodology, that is Eq. (3) which is employed for data pre-processing. After normalizing the experimental values the grey relational coefficients are calculated using the Eq. (5) and also shown in Table 4. Grey relational grade is calculated using the Eq. (6) and tabulated in Table 4 and the optimal level for each factor is identified based on their individual grey relational grade values. The optimal level of any influential factor has highest grey relational grade value among their considered levels.

In Table 5, the combination of A1,B3, C1, and D3 shows the largest value of the grey relational grade for the factors A, B, C, and D respectively. The optimum parameters in drilling of hybrid AMMC are observed that the drill diameter 10mm, speed 500rpm, feed 0.15 mm/rev and cutting fluid as vegetable oil.

Table 4. Grey relational coefficients of responses and Grey relational grade

Exp. No.	Grey relational coefficients					Grey relational grade
	Surface roughness (Ra in $\mu\text{m}$ )	MRR (mm <sup>3</sup> /min)	Thrust Force (Kgf)	Torque (Kg-m)	Diametric error (mm)	
1	0.5412	0.3333	0.8276	1.0000	0.4737	0.6352
2	0.4798	0.3493	1.0000	0.7143	0.4909	0.6069
3	0.4101	0.3830	0.7385	0.7143	0.3333	0.5158
4	0.6929	0.3524	0.8136	0.5556	0.3699	0.5569
5	0.5277	0.3794	0.9412	0.7143	0.4576	0.6040
6	0.4798	0.4436	0.7059	0.5556	0.4286	0.5227
7	0.8559	0.3867	0.7742	0.7143	0.5294	0.6521
8	0.7431	0.4314	0.6957	0.5556	0.4737	0.5799
9	1.0000	0.5631	0.6076	0.4545	0.4576	0.6166
10	0.4731	0.3568	0.6400	1.0000	0.8710	0.6682
11	0.4101	0.3845	0.5517	0.4545	0.8710	0.5344

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12	0.3435	0.4536	0.3750	0.3333	0.4030	0.3817
13	0.5412	0.3929	0.5926	0.7143	1.0000	0.6482
14	0.4405	0.4426	0.4528	0.4545	0.9310	0.5443
15	0.3823	0.5887	0.3529	0.3846	0.6923	0.4802
16	0.6696	0.4561	0.7164	0.7143	1.0000	0.7113
17	0.4731	0.5521	0.4404	0.4545	0.6000	0.504
18	0.3333	1.0000	0.3333	0.4545	0.6923	0.5627

Table 5. Response table (mean) for overall grey relational grade

Factors	Level-1	Level-2	Level-3
A	<b>0.5878</b>	0.5594	-
B	0.5570	0.5594	<b>0.6044</b>
C	<b>0.6453</b>	0.5622	0.5133
D	0.5545	0.5759	<b>0.5904</b>
Mean grey relational grade = 0.5736			

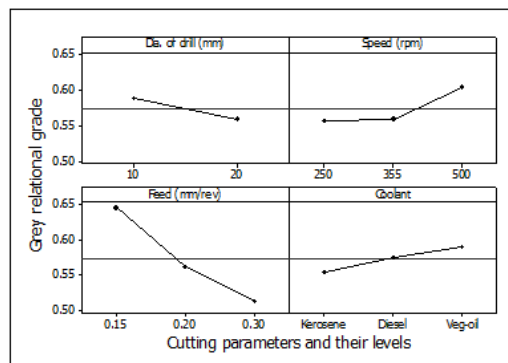


Fig 3. Effect of drilling parameters on multi- performance characteristics

The optimal parameters setting for better MRR and lesser surface roughness, thrust force, torque and diametric error are (A<sub>1</sub>B<sub>3</sub>C<sub>1</sub>D<sub>3</sub>) as presented in Table 5 and fig 3. Optimal level of the process parameters is the level with the highest grey relational grade. Therefore, from the table 5 and Fig 3, it is observed that the optimum combination of influential parameters is identified as

Table 6. Optimal parameters

Parameter	Value
Diameter of drill bit (mm)	10
Speed (rpm)	500
Feed (mm/rev)	0.15
Cutting fluid	Vegetable oil

## B . Confirmation test

The confirmation test is the final step in verifying the results in Grey Relational Analysis. Confirmation experiment is conducted at optimal levels (A<sub>1</sub>B<sub>3</sub>C<sub>1</sub>D<sub>3</sub>) and actual grey relational grade is determined from the corresponding measured responses.

### i. Prediction of Grey Relational Grade for optimal level settings

The predicted grey relational grade ( $\xi$ ) using the optimal level of the process parameters can be expressed as

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$$\xi^* = \xi_{m1} + \sum_{k=1}^q (\bar{\xi}_k - \xi_{m1}) \tag{7}$$

Where ‘K’ denotes Response,  $\xi_{m1}$  is mean of grey relational grade,  $\bar{\xi}_k$  is mean of grey relational grade at optimal level parameters (Table 5), and ‘q’ is the number of parameters that significantly affect the multiple responses. After calculation, Predicted grey Grey relational grade is found to be **0.7071**

**ii. Determination of Actual grey relational grade for optimal level settings**

**Confirmation test:** confirmation test is conducted to see the improvement of performance characteristics in drilling. The optimum parameters are selected for the confirmation test as presented in Table 6.

Confirmation test is conducted at obtained optimal values i.e at diameter of drill at 10mm, speed at 500rpm, feed at 0.15 mm/rev and cutting fluid as vegetable oil.

The outputs obtained are given in table 7,

Table 7. Outputs obtained for optimum inputs

Parameter	MRR	Surface roughness	Thrust force	Torque	Diametric error	Actual Grey Relational Grade
value	96 mm <sup>3</sup> /sec	0.42	53 kgf	0.4 kg-m	0.08 mm	<b>0.8413</b>

Table 8. Comparison of Predicted and Actual grey relational grades

	Optimal machining parameters	
	Predicted	Actual
<b>Levels</b>	A <sub>1</sub> B <sub>3</sub> C <sub>1</sub> D <sub>3</sub>	A <sub>1</sub> B <sub>3</sub> C <sub>1</sub> D <sub>3</sub>
<b>Grey Grade</b>	0.7071	0.8413

Table 8 shows the comparison of the predicted and actual grade for the optimal parameter levels. There is good agreement between the predicted and actual values.

**C. Analysis of Variance (ANOVA)**

Analysis of variance (ANOVA) is a method of apportioning variability of an output to various inputs. The purpose of the statistical ANOVA is to investigate which design parameter significantly affects the performance characteristic First, the total sum of the squared deviations  $SS_T$  from the total mean of the grey relational grade can be calculated as:

$$SS_T = \sum_{j=1}^m (r_j - \gamma_T)^2 \tag{7}$$

Where, m is the number of experiments in the orthogonal array and  $r_j$  is the grey relational grade for the j<sup>th</sup> experiment.

$S$  is the total sum of the squared deviation. The analysis is carried out for the level of significance of 5% (the level of confidence is 95%). Table 6 shows the result of ANOVA for the response characteristics of hybrid AMMC. From the Table 6, it is observed that the feed (Percentage contribution, P = 50 %) is the more significant machining parameter followed by speed (P = 8%), coolant (P=3.7%) and diameter of drill (P=3.4%) affecting the multiple performance characteristics for hybrid AMMC.

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Table 9. Results of the ANOVA

Factors	DOF	Sum of squares	Mean square	F value	% Contribution
Dia. of drill bit (mm)	1	0.0036	0.0036	0.98	3.4
Speed (rpm)	2	0.0086	0.0043	1.16	8.0
Feed (mm/rev)	2	0.0534	0.0267	7.24	50
Cutting fluid	2	0.0039	0.002	0.53	3.7
Error	10	0.0369	0.0037		35
Total	17	0.1065			100

## VI. CONCLUSION

In this work, optimization of process parameters in drilling of hybrid AMMC has been attempted. It is observed that the most influential parameter as feed. The conclusions based on this study are summarized below:

- First, Hybrid AMMC with 5% sic and 5% fly ash is successfully fabricated by stir casting technique.
- Experiments are conducted based on  $L_{18}$  orthogonal array in Radial drilling machine by varying the different parameters like drill dia., speed, feed and cutting fluid.
- Optimum parameters are obtained from grey relational analysis which converts the multiple performance characteristics with simplified optimization procedure. And the optimal parameters are observed as drill bit dia. of 10mm, feed at 0.15mm/rev, speed at 500 rpm and cutting fluid as vegetable oil.
- With this best parameter combination, confirmation test is conducted .Actual grey relational grade is obtained from confirmation test. From table 8, it is seen that there is good agreement between the predicted and actual grey relational grade.
- The ANOVA of grey relational grade for multiple performance characteristics revealed that the feed is the most significant parameter affecting AMMC composite followed by speed, cutting fluid and diameter of drill.

## REFERENCES

- [1] Charles.S and Arunachalam.V.P, "Property analysis and mathematical modeling of machining properties of alluminium alloy hybrid (Al-Alloy/Sic/Fly ash) composites produced by Liquid Metallurgy and Powder metallurgy Techniques", Indian journal of engineering and material science, vol.11, pp. 473-480, 2004.
- [2] Uday prakash.J, Moorthy.T.V, Milton Peter.J, "International conference on Design and Manufacturing", Procedia Engineering, vol.64, pp. 1344-1353, 2013.
- [3] Basavarajappa.S, Chandramohan.G, paulon.J, Prabu.M, Mukund.K, Aswin. M, Prasanna kumar.M , "Drilling of Hybrid composites" ,International Journal of Advanced Manufacturing Technology, vol.35, pp. 1244-1250, 2008.
- [4] Rajmohan .T, Palani kumar.K, "Mathematical model to predict thrust force in drilling Hybrid metal matrix composites", IEEE 978-4244-9082-0/10, 2010.
- [5] Jenarthan.M.P, N.Naresh, "Optimization of process parameters on machining force and mrr in milling by grey relational analysis", i-manager's Journal of Material Science, vol.1, pp. 29-36, 2013.
- [6] Mahesh Babu, M.S. Aldrin Sugin, N. Muthukrishnan," Investigation on the characteristics of surface quality on machining hybrid metal matrix composite (Al-SiC-B4C), Proc. Eng. 38 (2012) 2617-2624.
- [7] A. Riaz Ahamed, Paravasu Asokan, Sivanandam Aravindan, M.K. Prakash," Drilling of hybrid Al-5%SiCp-5%B4Cp metal matrix Composites", Int. J. Adv. Manuf. Technol. 49, pp: 871-877, 2010.
- [8] S. Senthil babu, Dr. B. K.Vinayagam "Parameters involved in drilling of Al based Metal Matrix Composites" International Journal of Engineering and Innovative Technology (IJEIT) Volume 1, Issue 4, April 2012.
- [9] yahya Altunpak , Mustafa Ay, Serdar Aslan, 'Drilling of a hybrid Al/Sic/Gr metal matrix composites', Int J Adv Manuf Technol DOI 10.1007/500170-011-3644-4, 2011.
- [10] NihatTosun Determination of optimum parameters for multi-performance characteristics in drilling by using grey relational analysis. Int J AdvManufTechnol 28:pp: 450-455, 2008