ISSN 0976 – 1411

Available online at www.internationaleJournals.com

International eJournals

International eJournal of Mathematics and Engineering 25 (2010) 246 - 255

INTERNATIONAL eJOURNAL OF MATHEMATICS AND ENGINEERING

www.InternationaleJournals.com

MULTI-RESPONSE OPTIMIZATION OF TURNING PARAMETERS OF AL-6061–TIB2 IN-SITU METAL MATRIX COMPOSITE USING GREY-TAGUCHI METHOD

A.Mahamani[a]*, V.Anandakrishnan[b]

[a]Department of Mechanical Engineering, Sudharsan Engineering College,
Pudukkottai – 622501, India

[b]Department of Production Engineering, National Institute of Technology,
Tiruchirappalli – 620015, India

*Corresponding Author Email ID: mahamanisudhan@gmail.com, Tel: +91-9629035191

Abstract

The recent trend in material science shows considerable interest in replacing cast iron components due to their heavy weight. In-situ metal matrix composites are attracted by many researchers because of better mechanical properties, fine and uniform distribution of reinforcements. The present study is aimed at finding the optimal machining parameters in order to minimize the tool wear, surface roughness and cutting force in the turning of Al-6061-6% TiB_2 in-situ metal matrix composite. The Grey-Taguchi method is applied to optimize this multiple response characteristics problem. The response table and ANOVA show that the depth of cut is a more significant parameter when compared with feed rate and cutting speed. The grey relational grade obtained form confirmation run is closer to the grade evaluated from Grey-Taguchi method. This experimental study reveals that the Grey-Taguchi method can be applied successfully to other machining operation.

Key words: ANOVA; flex assisted synthesis; grey-taguchi method; in-situ composite; multi-response optimization; surface roughness; TiB_2 reinforcement; tool wear;

Introduction

Aluminum matrix composites (AMCs) refer to the class of lightweight high-performance aluminum centric material systems, which is highly sought after in the automotive and aircraft industry. Al 6061 posses good machinability, weldability, workability, wear resistance in addition to good corrosion resistance to sea water, and therefore used in many applications (Demir and Gunduz, 2009).TiB2 is hard, brittle, with extreme melting point and chemical inertness, and therefore used to constitute composite materials in which the presence of the material serves to increase strength and fracture toughness of the matrix (Mahamani, 2010). The typical application of this composite is in marine fittings, components of automobile and aircraft. (Feng and Froyen, 2000). However the machining of ex-situ composite is very difficult due to the presence of reinforcements which are abrasive in nature, lack of distribution, agglomeration and coarseness which leads to more tool wear and poor surface finish, and consequently, poor mechanical property and machinability (Daniel *et al*, 1997). Metal matrix composite fabricated by in-situ route have overcome these problems because of the formation of reinforcement by exothermic reaction [Ma *et al*, 1994]. In-situ composites possess superior mechanical properties when compared with ex-situ composites with the same volume fraction of reinforcements (Kuruvilla *et al*, 1990). Turning is most common method used for metal cutting as well as metal finishing. The growing competition in the industry calls for all effort to be focused towards the economic manufacture of the components. Selecting the optimal cutting parameter for the particular operation is crucial for competitiveness and increasing the demand for a quality product in the market (Jayant and Kumar, 2008; Pal *et al*, 2009). Surface roughness is the most critical quality measure for mechanical components. Frequent tool wear causes poor surface finish, increasing tool cost and manufacturing time. Cutting force is an important measure to assess the friction between the tool and work piece. Taguchi method is usually appreciated for its distribution-free and orthogonal array design and considerable reduction in time. This method is used to determine the important factors affecting operations with simultaneous improvement of quality and cost of manufacturing (Mukherjee and Ray, 2006). Many researchers apply the Taguchi technique to optimize the machining parameters in machining ex-situ aluminum matrix composites. Davim (2003) established a correlation between the cutting velocity, feed and cutting time with tool wear, power and surface roughness in turning of A356/20/Sic$_p$ metal matrix composite. Taguchi technique, orthogonal array and analysis of variance are employed in investigating the cutting characteristics. Manna *et al* (2006) applied the Taguchi method to optimize the flank wear during turning of Al-20%Sic metal matrix composite. Zhang *et al* (2007) presented a study of the Taguchi design application to optimize surface quality in a CNC face milling operation. Confirmation tests verified that the Taguchi design was successful in optimizing milling parameters for surface roughness. Shetty *et al* (2009) reported a Taguchi-based experimental investigation to optimize the cutting force and cutting temperature in turning of Al6061/15/Sic composite. Navensait *et al* (2009) used the Taguchi method to predict the surface roughness, cutting force, flank wear and crater wear as well as to find the optimal process parameter in the machining of aluminum - glass fiber reinforced composite. However the traditional Taguchi method cannot be applied to multi response optimization problem (Jayapaul *et al*, 2005; Datta *et al*, 2008). The combination of the Taguchi method and Grey relational analysis were used to find out the optimum process parameter for multi performance characteristics (Jailani *et al*, 2009). The objective of this paper is to optimize the cutting speed, feed rate and depth of cut to minimize the tool wear, cutting force and surface roughness in the turning of Al-6061-6% TiB_2 in-situ metal matrix composite. Most of the authors applied the Grey-Taguchi method for optimizing the multiple responses. The advantage of Grey relational analysis over the Taguchi method is the optimization of multiple responses can be converted into optimization of single relational grade (Jayapaul *et al*, 2005). Kao and Hocheng (2003) proposed a Grey relational analysis to optimize the electrochemical polishing of stainless steel. Tosun (2006) used the Grey relational analysis in selecting optimum drilling conditions on multi performance characteristics, namely the hole surface roughness and burr height. Haq *et al* (2008) employed the Grey-Taguchi method to multi response optimization of machining parameters of drilling Al-Sic metal matrix composite. Tsao (2009) adopted the Grey-Taguchi method to optimize the milling parameters of aluminum alloy. To the best knowledge of the author of this work, there is no published work on evaluating the optimization and effect of cutting parameters on the multi performance characteristics in tuning of in-situ metal matrix composite. An attempt has been made to find the optimum machining parameters in turning of Al-6061-6% TiB_2 in-situ metal matrix composite by using uncoated tungsten carbide insert.

2. Experimental work

Machining tests were carried out in Turn master-35 lathe supplied by Kirloskar, Mysore, India.The uncoated tungsten carbide inserts were clamped in a rigid tool holder. The specification for insert and tool holders are given in Table 1. The length of turning is 110mm. No chip breaker was used in the experiment. The average flank wear was measured using Mitutoya microscope with 30× magnification. A stylus type perthometer was used for measuring surface roughness. The cutting force was measured using a Kistler Dynamometer (model 9257B). Data acquisition was carried out by appropriate software Dynaware Kistler. Machining tests were conducted in dry cutting conditions. The selected machining parameters and their ranges are given in Table 2. Cutting force, tool wear and surface roughness are evaluated as per the L9 Orthogonal array and tabulated in Table 3.

Experimental conditions	
Cutting tool	Uncoated tungsten carbide
Cutting tool specification	SNMG120408 MTTT5100
Tool holder specification	PSBNR-2525M12
Clearance angle (^{o})	7
Cutting edge angle(^{o})	75
Nose radius (mm)	0.8
Reinforcement ratio (wt %)	6
Cutting condition	Dry

Table 1. Experimental conditions

Factor Notation	Factor	1	2	3
A	Cutting speed(m/min)	100	125	150
B	Feed rate(mm/rev)	0.05	0.1	0.2
C	Depth of cut (mm)	0.5	1.0	1.5

Table 2. Factors and levels of experimental work

Trail No.	Levels			Responses		
	A	B	C	Tool wear (mm)	Surface roughness (μm)	Cutting force (N)
1	1	1	1	0.05	2.74	83
2	1	2	2	0.09	2.94	95
3	1	3	3	0.16	3.31	119
4	2	1	2	0.07	2.71	88
5	2	2	3	0.12	2.95	103
6	2	3	1	0.08	2.75	96
7	3	1	3	0.2	2.44	87
8	3	2	1	0.11	2.11	78
9	3	3	2	0.19	2.43	91

Table 3. Orthogonal table L9 responses

3. Taguchi- Grey relational analysis

Taguchi-Grey relational analysis attracts many researchers for solving multi response optimization problems. Taguchi Orthogonal array (OA) provides a set of well-balanced (minimum experimental runs) experiments and signal-to-noise ratios (S/N), which are logarithmic functions of desired output serve as objective functions for optimization (Sahoo and Pal, 2007; Jadoun *et al*, 2009). This technique helps in data analysis and prediction of optimum results. With selection L_9 orthogonal array using three parameter and three levels for each, the number of experiments required can be drastically reduced nine, which in classical combination of method using full factorial experimentation would require $3^3 = 27$ number of experiments to capture the influencing parameters (Vijian and Arunachalam, 2006). In order to evaluate optimal parameter settings, the Taguchi method uses a statistical measure of performance called signal-to-noise ratio. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The standard S/N ratios generally used are as follows: Nominal is best (NB), lower the better (LB) and higher the better (HB). The optimal setting is the parameter combination, which has the highest S/N ratio. In any machining process, the main objective is to minimize tool wear, surface roughness and cutting force. Hence the lower better type S/N ratio was applied for the machining process.

$$\text{S/N ratio} = -10 \log 1/j \sum_{i=1}^{j} y_i^2$$

where j is the number of repetitions of the experiment and y_i is the average measured of experimental data i

Data processing is the first activity need to be performed in the Grey relational analysis in order to normalize the raw data for analysis. In this study, a linear normalization of the S/N ratio of the experimental results is performed in the range between zero and unity, which is also called the Grey relational generating. Usually, there are three categories of performance characteristics in the analysis of normalized values, i.e. the lower-the-better, the higher-the-better, and the nominal-the-better. In general, the smaller-the-better category is applied to optimize the flank wear, cutting force and surface roughness in the turning of Al6061-6% TiB2 in-situ metal matrix composite. Then, the normalized results can be expressed as

$$x_i(k) = \frac{\max \eta_i(k) - \eta_i(k)}{\max \eta_i(k) - \min \eta_i(k)} \qquad (1)$$

Where $x_i(k)$ is the normalized value of the k^{th} performance characteristic in the i^{th} experiment, $\eta_i(k)$ is the k^{th} experimental result in the i^{th} experiment, and max $\eta_i(k)$ and min $\eta_i(k)$ are the maximum and minimum values of $\eta_i(k)$,respectively. The grey relational coefficient $\text{€}_i(k)$ can be expressed as

$$\text{€}_i(k) = \frac{\Delta \min + \zeta \Delta \max}{\Delta_{0i}(k) + \zeta \Delta \max} \qquad (2)$$

Where Δ_{oi} is the deviation sequence of the reference sequence (x_o) and the comparability sequence (x_i), ζ is the distinguishing coefficient, ie $\Delta_{oi} = \| x_o(k) - x_i(k) \|$. Δ max is largest value in Δ_{oi} and Δ min is smallest value in the Δ_{oi}. Next, the grey relational grade $\xi(x_o,x_i)$ is computed by averaging the Grey relational coefficient corresponding to each performance characteristic. It is defined as

$$\zeta(x_o,x_i) = 1/n \sum_{k=1}^{n} \zeta_i(k) \qquad (3)$$

Where n is the number of performance characteristics. The Grey relational grade shows the correlation between the reference sequence and the comparability sequence. The evaluated G rey relational grade fluctuates from 0 to 1 and equals 1 if these two sequences are identically coincident. A flow chart for the Grey-Taguchi method is shown in Figure 1.

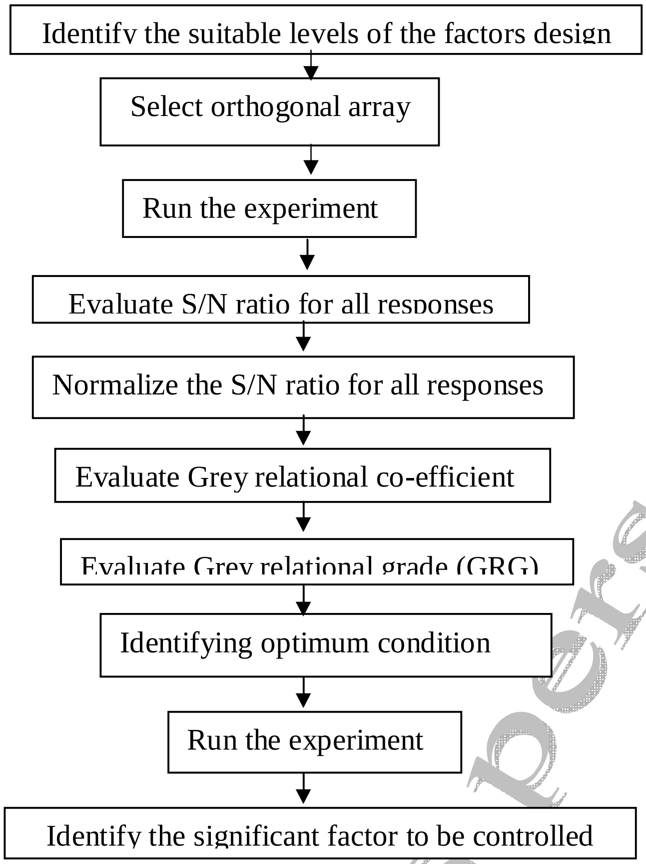

Figure 4. Grey-Taguchi design procedure

4. Analysis and discussion of experimental results

S/N ratio value for each responses are evaluated as per the L_9 orthogonal array lay out lay out. Lower tool wear, surface roughness and cutting force are indication of better performance. Therefore the lower better was applied to minimize the responses. Table 4 shows the S/N ratio and normalized S/N ratio for tool wear surface roughness and cutting force. The responses were considered as lower-than-better type data processing and the normalized S/N ratio values evaluated by using Equation 1. The deviation sequences Δ_{oi} values for all responses are calculated and reported in Table 5. The table indicates that Δ max is zero and Δ min is one. The distinguishing co-efficient is ζ is taken as 0.5 (Tsao, 2009). By substituting the above said value in Equation 2, the Grey relation co-efficient was estimated. The Grey relational grade for each experiment was calculated from Equation 3 and tabulated in Table 6. An experiment run with higher relational grade will be better for multi response characteristics. Figure 2 show that Experiment 3 has the highest Grey relational grade, and hence it was selected as an optimal parameter. Table 7 and Figure 3 show the response table and graph for each level of the parameters. The optimum process parameter for the turning process obtained from table 7(A1 B3 C3). The last column in Table 7 shows the difference between maximum and minimum value of Grey relational grade. This value helps us find the most effective parameter affecting multi response characteristics. The max-min value of Grey relational grade for turning of in-situ Al-6061-6% TiB_2 is as follows: 0.1066 for cutting speed, 0.1791 for feed rate and 0.2766 for depth of cut. Table 7 indicates that depth of cut has the strongest effect on multi response characteristics when compared to feed arte and cutting speed. Figures 7-8 show the photographic and microscopic view of the cutting edge of the insert after machining. Worn out cutting edge, micro cracks and buildup edge formation are observed from the figures 8. The excessive wear and build up edge formations are possible for wrong selection of levels of the factors. Therefore this experimental investigation guides to select the optimum machining parameter to minimize the tool wear, surface roughness and cutting force.

Trail No.	S/N Ratios			Normalized values of S/N Ratios		
	Tool wear (mm)	Surface roughness(μm)	Cutting force(N)	Tool wear (mm)	Surface roughness(μm)	Cutting force(N)
1	26.02	-8.76	-38.38	0	0.580563	0.147139
2	20.92	-9.37	-39.55	0.423588	0.736573	0.46594
3	15.92	-10.40	-41.51	0.83887	1	1
4	23.10	-8.66	-38.89	0.242525	0.554987	0.286104
5	18.42	-9.40	-40.26	0.631229	0.744246	0.659401
6	21.94	-8.79	-39.65	0.33887	0.588235	0.493188
7	13.98	-7.75	-38.79	1	0.322251	0.258856
8	19.17	-6.49	-37.84	0.568937	0	0
9	14.42	-7.71	-39.18	0.963455	0.31202	0.365123

Table 4. S/N ratio and Normalized S/N ratio for tool wear, surface roughness and cutting force

Deviation sequences	$\Delta_{0i}(1)$	$\Delta_{0i}(2)$	$\Delta_{0i}(3)$
1	1	0.419437	0.852861
2	0.576412	0.263427	0.53406
3	0.16113	0	0
4	0.757475	0.445013	0.713896
5	0.368771	0.255754	0.340599
6	0.66113	0.411765	0.506812
7	0	0.677749	0.741144
8	0.431063	1	1
9	0.036545	0.68798	0.634877

Table 5. The deviation table

Trail No.	Grey relational co-efficient			Grey grade	Rank
	Tool wear (mm)	Surface roughness(μm)	Cutting force(N)		
1	0.333333	0.543811	0.369587	0.415577	8
2	0.464506	0.654941	0.483531	0.534326	5
3	0.756281	1	1	0.91876	1
4	0.397622	0.529093	0.411897	0.446204	7
5	0.575526	0.661591	0.594814	0.610644	2
6	0.430615	0.548387	0.496617	0.491873	6
7	1	0.424539	0.402854	0.609131	3
8	0.537021	0.333333	0.333333	0.401229	9
9	0.931888	0.420883	0.440576	0.597782	4

Table 6. Grey relational co-efficient, Grey relational grades and its rank

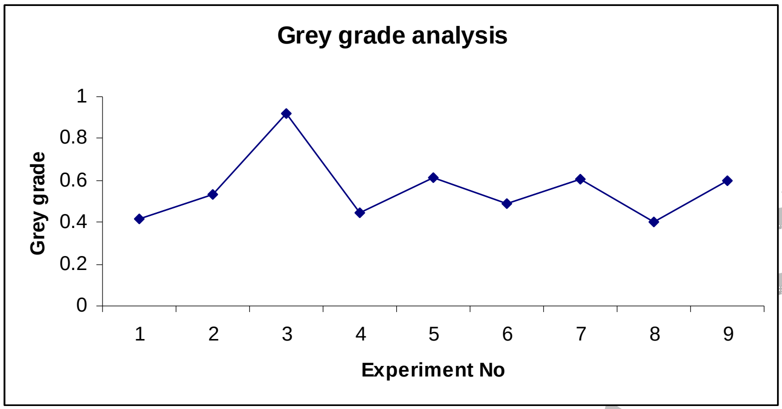

Figure 2. Grey relational grades for minimum tool wear, surface roughness and cutting force

Factor notation	Control factor	Average grey relational grade by factor level			Max-min
		Level 1	Level 2	Level 3	
A	Cutting speed(m/min)	0.6228	05162	0.5360	0.1066
B	Feed rate(mm/rev)	0.4902	0.5153	0.6694	0.1791
C	Depth of cut (mm)	0.4361	0.5260	0.7128	0.2766

Table 7. Response table of the average grey relational grade

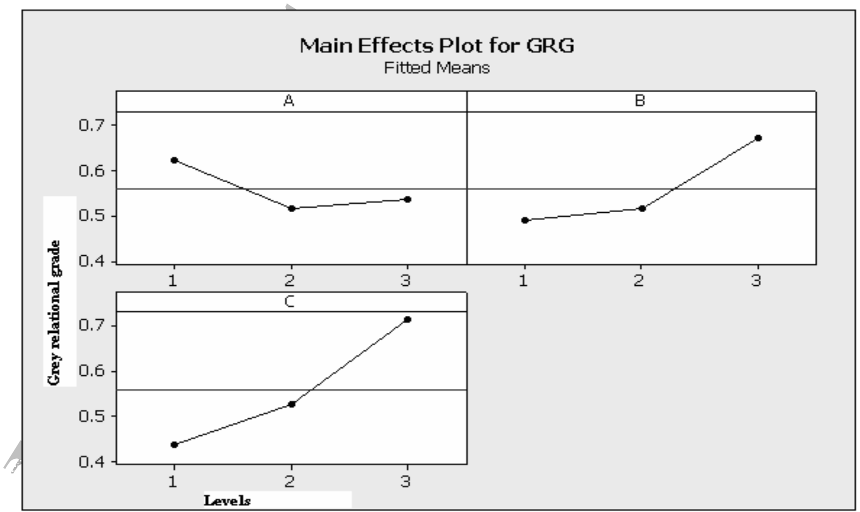

Figure 3. Response graph of the average Grey relational grade

5. Analysis of variance

ANOVA is a statistical technique that is very useful in determining the level of significance of influencing factors. It separates the total variability of the response into contributions rendered by each of parameters. Using the Grey relational grade value, ANOVA was performed to identify the significant factors tabulated in Table 8. It is observed that the depth of cut (59.93%) is most significant factor followed by feed rate (28.31%) and cutting speed (9.68%). From tables 7 and 8 it can be noted that in order of importance, the factors are in same sequence, which reveals the accuracy of the Grey-Taguchi method.

Factor notation	Control factor	DOF	Seq SS	Adj SS	Adj MS	F-Test	Percentage of contribution
A	Cutting speed(m/min)	2	0.0193	0.0193	0.0096	4.63	9.688755
B	Feed rate(mm/rev)	2	0.0564	0.0564	0.0282	13.54	28.31325
C	Depth of cut (mm)	2	0.1194	0.1194	0.0597	28.66	59.93976
E	Error	2	0.0041	0.0041	0.0020		2.058233
Total		8	0.1992				100

Table 8. Results of ANOVA

6. Confirmative test

After the optimal level of test parameters has been identified, a confirmative test was conducted to verify the improvement of multiple performance characteristics at the optimal levels of selected turning parameters. The optimum parameters for the above turning operation were set, and two trials were conducted in the confirmative test. The estimated Grey relational grade (ζ) using the optimal level of the turning parameters can be expressed as

$$\zeta = \zeta_m + \sum_{i=1}^{q} \zeta_i - \zeta_m \qquad (4)$$

where ξm is the total mean of the Grey relational grade, ζ_i is the mean of the Grey relational grade at the optimal level, and q is the number of turning parameters that significantly affect the multiple performance characteristics. The predicted value obtained from the relation 4 is 0.89. The grade value obtained from the confirmation experiment is 0.92 with tool wear 0.12 mm, surface roughness 3.2 μm and cutting force is 109 N. There was a 3.2% improvement in the Grey relational grade over the predicted mean value in a confirmation experiment.

7. Conclusion

In this paper, the optimal machining parameters were determined for multi response characteristics namely tool wear, surface roughness and cutting force in the turning of Al-6061 -6% TiB_2 in-situ metal matrix composite by using the Grey-Taguchi method. The max-min value of Grey relational grade obtained from the response table shows that the depth of cut has strongest effect among the other turning parameters. The analysis of variance also confirmed that depth of cut has significant influence on multi response characteristics with 59.93% contribution followed by a feed rate of 28.31% and cutting speed of 9.68%. The optimum levels of turning parameters are cutting speed 100m/min, feed rate 0.2 mm/rev and depth of cut 1.5 mm. It is observed form the confirmation experiment that there is a good agreement between the estimated value and experimental value of the Grey relational grade. This experimental study reveals that the Grey-Taguchi method can be applied successfully to the other operations with multi response characteristics.

Acknowledgements

The authors acknowledge the Management, Sudharsan Engineering College for providing the resources to carry out this research

Reference

1. Daniel, B.S.S., Murthy V.S.R. and Murty, G.S. (1997) ‘Metal-ceramic composites via in-situ methods’, *Journal of Materials Processing Technology*, Vol.68 No.2, pp.132-155.

2. Datta, S., Bandyopadhyay, A. and Pal, P.K. (2008) ‘Grey-based taguchi method for optimization of bead geometry in submerged arc bead-on-plate welding’, *International Journal of Advanced Manufacturing Technology,*Vol. 39, pp.1136-143.

3. Davim, P.J. (2003) ‘Study of drilling metal-matrix composite based on the taguchi techniques’, *Journal of Materials Processing Technology*, Vol.132, pp. 250-254.

4. Demir, H. and Gunduz, S. (2009) The effects of aging on machinability of 6061 aluminum alloy, *Materials and Design*, Vol.30, pp.1480-1483.

5. Feng, C.F. and Froyen, L. (2000) ‘Microstructure of in-situ Al-TiB2 MMC prepared by casting route’, *Journal of Material Science*, Vol.30, pp. 837-850.

6. Haq, A,N., Marimuthu, P. and Jeyapaul, R. (2008) Multi response optimization of machining parameters of drilling Al/SiC metal matrix composite using grey relational analysis in the Taguchi method. *International Journal of Advanced Manufacturing Technology*, Vol.37, No.3. pp.250-255.

7. Jadoun, R.S., Kumar, P. and Mishra B.K. (2009) ‘Taguchi’s optimization of process parameters for production accuracy in ultrasonic drilling of engineering ceramics’, *Production Engineering Research and Development,*Vol.3, pp.243-253.

8. Jailani, H.S., Rajadurai, A., Mohan, B., Senthil Kumar, A. and Sornakumar, T. (2009) ‘Multi-response optimization of sintering parameters of Al–Si alloy/fly ash composite using Taguchi method and grey relational analysis’, *International Journal of Advanced Manufacturing Technology*, Vol.45, pp. 362-369.

9. Jayant, A. and Kumar, V.(2008) ‘Prediction of surface roughness in CNC turning operation using taguchi design of experiments’, *Journal of Institution of Engineers (India)*, Vol. 88, pp. 19-25.

10. Jeyapaul, R., Shahabudeen, P. and Krishnaiah, K. (2005) ‘Quality management research by considering multi response problems in the taguchi method-a review’, *International Journal of Advanced Manufacturing Technology*, Vol.26, pp.1331-1337.

11. Kao, P.S. and Hocheng, H. (2003) ‘Optimization of electrochemical polishing of stainless steel by grey relational analysis’, *Journal of Materials Processing Technology*, Vol. 140, pp. 255–259.

12. Kirby, E.D., Zhang, Z., Joseph, C. and Jacob, C.C. (2006) ‘Optimizing surface finish in a turning operation using the Taguchi parameter design method’, *International Journal of Advanced Manufacturing Technology*,Vol.30, pp. 1021-1029.

13. Kuruvilla A.K. *et al*, (1990) *Sripta Metall.*, Vol.24, pp.873.

14. Ma, Z.Y. *et al*, (1994), *Scripta Metall.*, Vol. 31, pp.635.

15. Mahamani, A., Muthu Krishnan, T., Dinal, M., Pandiyarajan, A., Hariharan, S. (2010) ‘Fabrication and characterization of in-situ AA6061-TiB_2 metal matrix composite by flex assisted synthesis’, *Proceedings of national conference on “Advances and challenges in mechanical engineering-ACME-2010*, pp. 123-130.

16. Manna, A. and Bhattacharyya, B. (2006) ‘Taguchi method based optimization of cutting tool flank wear during turning of PR-Al/20vol.% SiC-MMC’, *International Journal of Machining and Machinability of Materials*’, Vol.1, No. 4, pp. 488-499.

17. Mukherjee, I. and Ray, P.K.(2006) ‘A review of optimization techniques in metal cutting process’, *Computers and Industrial Engineering*, Vol.50, pp. 15-34.

18. Naveen Sait, A., Aravindan, S. and Haq, A.N. (2009) 'Influence of machining parameters on surface roughness of GFRP pipes', *Advances in Production Engineering and Management*, Vol.4, pp.47-58.
19. Pal, S., Malviya, S.K., Pal, S.K. and Samantaray, A.K.(2009) 'Optimization of quality characteristics parameters in a pulsed metal inert gas welding process using grey-based Taguchi method', *International Journal of Advanced Manufacturing Technology*, Vol . 44, pp.1250-1260.
20. Sahoo, P. and Pal. S.K. (2007) 'Tribological performance optimization of electroless Ni–P coatings using the Taguchi method and Grey relational analysis, *Tribol Lett*, Vol. 28, pp.191-201.
21. Shetty, R., Pai, R. and Rao, S.S. (2009) 'Experimental studies on turning of discontinuously reinforced aluminum composites under dry, oil, water emulsion and steam lubricated conditions using taguchi's technique', *G.U. Journal of Science*, Vol.22, No.1, pp.21-32.
22. Tosun, N. (2006) 'Determination of optimum parameters for multi-performance characteristics in drilling by using grey relational analysis', *International Journal of Advanced Manufacturing Technology*,Vol. 28, pp. 450-455.
23.Tsao, C.C. (2009) 'Grey–Taguchi method to optimize the milling parameters of aluminum alloy', *International Journal of Advanced Manufacturing Technology,* Vol. 40, pp.41-48.
24. Vijian, P. and Arunachalam, V.P. (2006) 'Optimization of squeeze cast parameters of LM6 aluminum alloy for surface roughness using Taguchi method', *Journal of Materials Processing Technology*, Vol.180, pp.161-166.
25. Zhang, J.Z., Chenb, J.C. and Kirby, D.E. (2007) 'Surface roughness optimization in an end-milling operation using the Taguchi design method', *Journal of Materials Processing Technology*,Vol.184, pp.233-239.