parameter, was used. A classification can be done to determine the most significant parameter. When so done, the multiple objective optimization problems are transformed into a single equivalent objective function optimization problem. The higher grey relational grade will be close to the optimal condition. Using the grey relational grade value, the mean of the grey relational grade for each level of different parameters, and the total mean of the grey relational grade is summarized in Table 5.

Table 5: Response table for the mean Grey relational grade

	Grey Grade Analysis for Control Parameter				
Levels	SiC% (A)	SPEED (B) (rpm)	FEED (C) (mm/m)	DEPTH OF CUT(D) (mm)	Cutter Dia (E) (mm)
1	**0.603**	0.5427	**0.5611**	0.4916	0.5251
2	0.5562	0.5168	0.5476	0.5749	0.5012
3	0.5057	**0.6049**	0.5557	**0.5979**	**0.6381**
Delta	0.0969	0.0882	0.0136	0.1063	0.1369
Rank	3	4	5	2	1

(Total mean Grey relational grade = **0.558**)

Then a response graph of the grey relational analysis is obtained by main effect analytic computation, as shown in Figure 8.

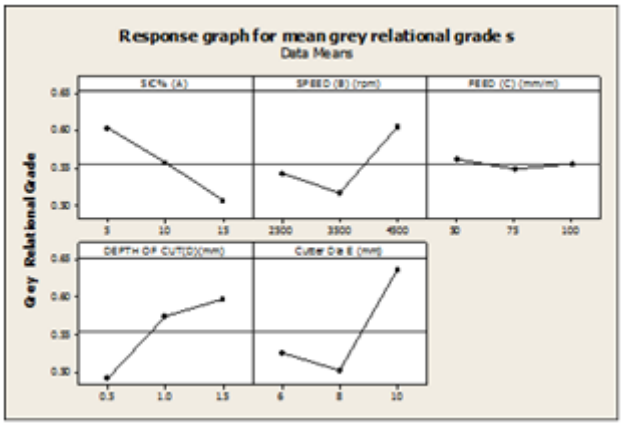

Figure 8: Response graph for mean grey relational grades

From Table 5 and Figure 8, the optimal parameter combination of A_1, B_3, C_1, D_3 and E_3 shows the highest value of the Grey relational grade i.e SiC of 5%, cutting speed of 4500 rpm, feed of 50 mm/min, depth of cut of 1.5 mm and cutter diameter of 10 mm. Therefore compromising surface roughness with high value of material removal rate is obtained for the end milling operation

7. Analysis of Variance

ANOVA is a statistical technique that is used in determining the level of significance of significant parameters. It separates the total variance of the response into contributions rendered by each of parameters. ANOVA was performed for Grey relational grade value to identify the most significant parameters tabulated in Table 6. It is observed that the cutter diameter (27.21%) is most significant parameter.

Table 6: Results of ANOVA

Source	Degree of Freedom (DF)	Adjusted Sum of Squares	Mean Square Value	F_{exp} = MSV/MSV_e	P-Value	% Contribution
SiC%	2	0.042271	0.021136	4.56	0.093	11.95
SPEED	2	0.036959	0.01848	3.99	0.112	10.45
FEED	2	0.000842	0.000421	0.09	0.915	0.24
DEPTH	2	0.056251	0.028126	6.07	0.061	15.90
Cutter Dia	2	0.09628	0.04814	10.39	0.026	27.21
SiC% *Cutter Dia	4	0.017388	0.004347	0.94	0.524	4.91
SPEED *Cutter Dia	4	0.02251	0.005627	1.21	0.428	6.36
FEED *Cutter Dia	4	0.062786	0.015696	3.39	0.132	17.75
Error	4	0.018535	0.004634			5.24
Total	26	0.353823				100

Figure 9 shows the percentile contribution of various input control parameters simultaneously over both surface roughness and material removal rate values.

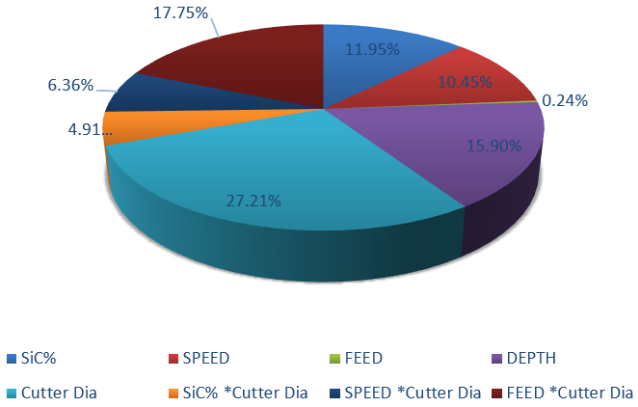

Figure 9: Percentile contribution of parameters

8. Regression Modeling

Regression models can be used to predict the response output behavior by taking different input independent parameters values and grey relational grades associated with each test response results. Equation (6) shows the general form of quadratic regression model.

GRA = a + b*A + c*B + d*C + e*D + f*E + g*A^2 + h*B^2 + i*C^2 + j*D^2 + k*E^2 + l*A*E + m*B*E + n*C*E + o*D*E (6)

In the above formula a, b, c, d, e, f, g, h, i, j, k, l, m, n & o are the regression coefficients to be estimated. In this study, based on the GRA data given in Table 4, the regression model is developed and regression coefficients obtained using DataFit software. The independent variables in model (7) are weight percentage of SiC (A), cutting speed (B), feed rate (C) depth of cut (D) and cutter diameter (E).

GRA = 2.888836577 - 0.034112223*A -0.000228111*B - 0.013719556*C + 0.150311112*D -0.392618750*E - 0.000083778*A^2 + 0.000000057*B^2 + 0.000017369*C^2 - 0.120311111*D^2 +0.020109722*E^2 + 0.003262500*A*E - 0.000017504*B*E + 0.001375667*C*E + 0.024575000*D*E
(7)

9. Model validation and ANOVA Results

Analysis of variance (ANOVA) is a mathematical way to determine precision and adequacy of regression modeling. It shows how well the proposed model fits the experimental data and, therefore, represents the actual process under study [18]. It is also a powerful tool in analyzing the variable effects on the process output responses. A summary of ANOVA results for regression model have been presented in Table 7. Based on the statistical analysis results, the coefficient of determination (R^2) for this model is equal to 91.59%. This indicates that the model has good compatibility to the actual data. The p-value of the model is also close to zero which shows the model is good at 95% confidence level. These demonstrate the appropriate compliance of the model with the actual test results.

Table 7: Result of ANOVA

Source	DF	Sum of Squares	Mean Square	F Ratio	p
Regression	14	0.3241005	0.02315	9.3467286	0.00021
Error	12	0.0297217	0.0024768		
Total	26	0.3538221			

10. Confirmation Test for Proposed Methodology

The grey relational grade value is 0.6736 at combination $A_1B_3C_1D_3E_3$ was calculated from regression equation (7). This GRA value validate that the proposed grey-taguchi approach is good for trade off among conflicting multi objectives of CNC end milling process for composite material LM 6/Al SiC_p.

11. Conclusion

This research work successfully demonstrated a methodology for making trade off among conflicting multiple objectives of CNC end milling process for composite material LM 6/Al SiC_p and validate that methodology with using the regression models. The conclusions can be drawn from the present work were as follows:

(a) The highest Grey relational grade of 0.849 was observed for the semi-finishing milling process in experiment no. 9, shown in Table 4. So, we can say that experiment no. 9 among performed 27 experiments has best combination $A_1B_3C_3D_3E_3$ for controllable parameters.
(b) Proposed grey-taguchi methodology given best combination $A_1B_3C_1D_3E_3$ which is not in the range of performed 27 experiments.
(c) Regression model validate proposed methodology by obtaining good GRA value.
(d) The most significant parameter in the minimizing surface roughness (R_a) and maximizing material removal rate (MRR), is cutter diameter.

As a result, this methodology can be effectively applied for optimizing multiple objective problem. This methodology also is found efficient for determining the optimal combination of parameter levels.

References

[1] Abhishek Dubey, Devendra Pathak, Nilesh Chandra, Ajendra Nath Mishra and Rahul Davis, "A Parametric Design Study of End Milling Operation using Grey Based Taguchi Method", International Journal of Emerging Technology and Advanced Engineering, IV (4), pp. 1140 – 1146, 2004.
[2] Venkata Rao. R., Advanced Modelling and Optimization of Manufacturing Processes, Springer, 2011.
[3] Jignesh G. Parmaran and Prof. Alpesh Makwana, "Prediction of surface roughness for end milling process using Artificial Neural Network", International Journal of Modern Engineering Research, II (3), pp. 1006-1013, 2012.
[4] Mohammed T. Hayajneh, Montasser S. Tahat and Joachim Bluhm, "A Study of the Effects of Machining Parameters on the Surface Roughness in the End-Milling Process", Jordan Journal of Mechanical and Industrial Engineering, I (1), pp. 1 – 5, 2007.
[5] Bharat Chandra Routara, Saumya Darsan Mohanty, Saurav Datta, Asish Bandyopadhyay and Siba Sankar Mahapatra, "Optimization in CNC end milling of UNS C34000 medium leaded brass with multiple surface roughnesses characteristics", Indian Academy of Sciences, XXXV (5) , pp. 619–629, 2010.
[6] Sanjit Moshat, Saurav Datta, Asish Bandyopadhyay and Pradip Kumar Pal, "Optimization of CNC end milling process parameters using PCA-based Taguchi method", International Journal of Engineering, Science and Technology, II (1), 2010, pp. 92-102, 2010.
[7] B.Shivapragash, K.Chandrasekaran, C.Parthasarathy, and M.Samuel, "Multiple Response Optimizations in Drilling Using Taguchi and Grey Relational Analysis", International Journal of Modern Engineering Research, III (2), pp. 765-768, 2013.
[8] A.Mahamani and V.Anandakrishnan, "Multi-response optimization of turning parameters of AL-6061–TIB2 in-situ metal matrix composite using grey-taguchi method", International eJournal of Mathematics and Engineering 25, pp. 246 – 255, 2010.
[9] B. Mohan, A. Rajadurai and K.G. Satyanarayana, "Electric discharge machining of Al/SiC metal matrix composites using rotary tube electrode", Journal of Mater Process Technology 153 -154, pp. 978-985, 2004.
[10] K.Kadirgama, M.M.Noor, N.M.Zuki.N.M, M.M. Rahma, M.R.M. Rejab, R. Daud, K. A. Abou-El-Hossein, "Optimization of S urface Roughness in End Milling on Mould Aluminium Alloys (AA6061-T6) Using Response Surface Method and Radian Basis Function Network", Jordan Journal of Mechanical and Industrial Engineering, II (4), pp. 209- 214, 2008.
[11] Raghuraman S, Thiruppathi K , Panneerselvam T and Santosh S, "Optimization of EDM Parameters Using Taguchi Method and Grey Relational Analysis for Mild Steel is 2026", International Journal of Innovative Research in Science, Engineering and Technology, II (7), pp. 3095 – 3103, 2013.

[12] Mohd H.I. Ibrahim, Norhamidi Muhamad, Abu B. Sulong , Khairur R. Jamaludin , Nor H.M. Nor and Sufizar Ahmad, "Optimization of Micro Metal Injection Molding with Multiple Performance Characteristics using Grey Relational Grade", Chiang Mai J. Sci., 38(2), pp. 231-241, 2011.
[13] B. C. Routara & A. Bandyopadhyay & P. Sahoo, "Roughness modeling and optimization in CNC end milling using response surface method: effect of workpiece material variation", Int J Adv Manuf Technol 40, pp. 1166 – 1180, 2009.
[14] Phillips. J .Ross, "Taguchi Techniques for Quality Engineering", Mc Graw Hill Publication, 2nd ed., pp. 281-285, 1996.
[15] Sanjeev Kumar Pal and Rahul Davis, "A Design of Experiment Approach to Compare the Machining Performance of CNC End Milling", IPASJ International Journal of Mechanical Engineering, II (7), pp. 34-44, 2014.
[16] S. Y. Chavan, V. S. Jadhav, "Determination of Optimum Cutting Parameters for Multiperformance Characteristics in CNC End Milling of Al-Si7Mg Aluminum Alloy", International Journal of Engineering and Technical Research, I (6), pp. 15-21, 2013.
[17] S.Balasubramanian, "Grey Relational Analysis to determine optimum process parameters for Wire Electro Discharge Machining", International Journal of Engineering Science and Technology, III (1), pp. 95 – 101, 2011.
[18] A. Al-Refaie, L. Al-Durgham, and N. Bata, "Optimal Parameter Design by Regression Technique and Grey Relational Analysis", The World Congress on Engineering (WCE) , III, 2010.

Author Profile

Neeraj Kumar received the B.E. degrees in Mechanical Engineering from M.B.M. Engineering College, Jodhpur in 2004. Then, he received M.Tech degree in Manufacturing System Engineering from MNIT, Jaipur in 2008. He is now pursuing P.hd in Faculty of Engineering from Pacific Academy of Higher Education and Research University, Udaipur, Rajasthan, India

Prof. K.K. Chhabra is currently working as Director at Pacific College of Engineering, Udaipur, Rajasthan, India