WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Optimization of Mechanical Drilling of Metal Matrix Composite using Grey Relational Analysis: A Comparative Study

Rahul Kundiya [a], ***Shubhangi Chougule*** [b]

[a,b] *Assistant Professor, VPM's Maharshi Parshuram College of Engineering, Velneshwar – India*

DOI: https://doi.org/10.55248/gengpi.4.623.44589

A B S T R A C T

This paper discusses the application of a novel approach called Grey Relational Analysis to optimize the process parameters in mechanical drilling of metal matrix composites. In this investigation, Al 6061 was selected as a matrix material, where SiC particles having grit size of 320 as a reinforcement material. MMCs have been used in several applications in aerospace and automotive components. Jaya algorithm of rules is created on the belief that the end result obtained for a given problem need to circulate towards the high-quality result and should avoid the poor end result. This algorithm does now not want any set of rules-precise control parameters. The important process parameters considered are helix angle of drill, spindle speed and feed rate. These parameters independently or in combination influence the surface roughness, thrust force and torque. The experiments were performed using L_9\ mixed Taguchi orthogonal array and the mathematical prediction models are developed for output using regression method. The results indicate that surface roughness increases with higher feed rates and spindle speeds, while decreasing with larger helix angles. Moreover, thrust force increases with increasing feed rates and decreasing helix angles. Torque increases with higher feed rates and decreases with lower spindle speeds. Regression analysis is performed to establish the relationships between the input parameters and the responses, resulting in regression equations for surface roughness, thrust force, and torque. The Grey Relational Grade (GRG) is calculated to rank the performance of each experiment, and the optimum values of the input parameters are determined. The average GRG values for each factor at different levels are analyzed, providing insights into the optimum levels of the input parameters for achieving an improved surface finish. The findings of this study can guide the selection and optimization of drilling parameters for MMCs, leading to enhanced machining efficiency and product quality.

Keywords: Metal matrix composite, Grey relational analysis, Mechanical Drilling, Taguchi Method, Al 6069 & Sic

1. Introduction

As one of the basic material removal processes, drilling is widely applied in aerospace, automotive, and die and machinery manufacturing industries In many instances, drilling is the primary machining operation done inside the entire hole cutting operation. Depending on the specification requirements with respect to surface quality, dimension, and tolerance, other material removal operations such as boring and reaming may need to be performed. Parts with no conformed surface quality may lead to early fatigue failure. Surface roughness is an important measure of the quality of a drilled hole, therefore, being a major factor in manufacturing process. In mechanical drilling, the efficiency and the quality of the finished component is heavily dependent on the process, workpiece, and tool-related parameters used while machining. Drill geometry, feed rate, and spindle speed are the parameters that significantly affect the surface roughness, thrust force and torque. Jaya algorithm of rules is created at the perception that the result obtained for a given problem must circulate in the direction of the best result and should avoid the poor result.

The literature review shows some research-oriented work on the machining of MMCs out of which the important works are presented here. Tosun et al. conducted experiments on drilling of MMCs to understand the effect of process related, tool related parameter and heat treatment effect on the surface roughness. Drilling tests have been accomplished the use of HSS, TiN lined HSS and stable carbide drills. The surface end consequences suggest also that the tool hardness impacts the surface roughness. It can be visible that the hard-carbide tools produce a higher surface end compared to that carried out when the usage of the HSS and the TiN covered HSS drills. Basavarajappa et al. conducted some research on drilling of hybrid metallic matrix composites based on Taguchi strategies. The matrix material used in the present investigation was aluminum alloy Al2219 and Two types of materials were used first with 15% of SiC reinforcement of average particle size of 25(M1), second along with 15% silicon carbide particles, 3% graphite of average particles size 45 µm (M2) was used as the reinforcement materials. The drills used is Solid carbide multifaceted drill of diameter 5mm. It is observed that the surface roughness values are increasing with increase in the feed and decreases with increase in cutting speed.

Pawade et al. analysed multi-objective optimization of cutting force and surface roughness in high speed turning of Inconel 718 using GRA. Results showed that depth of cut suggests statistical significance on ordinary turning overall performance. They concluded that an increase inside the value of predicted weighted GRG from zero.1160 to 0.2071 confirms the improvements within the performance of high-speed turning manner using superior values of parameters. Rao developed Jaya algorithm for solving constrained and unconstrained optimization problems. The effects obtained via the proposed Jaya set of rules are compared with the results of famous optimization algorithms inclusive of HM, GA, PSO, ABC, SA and TLBO to taken into consideration constrained benchmark problems. Results have shown the quality overall performance of Jaya algorithm for the confined optimization troubles. Rao et al. Used Jaya algorithm to optimization of surface grinding technique. The Jaya algorithm produced better results than QP, GA, SA, ABC, HS and TLBO techniques in phrases of COF cost with a high convergence rate. Rao et al. has proposed an optimization method as Jaya algorithm for dimensional optimization of a micro-channel heat sink. R. rao et al. also reported to identification of tea category using a Jaya algorithm. In view of the above, the present study is an attempt to apply Jaya algorithm in MMCs.

2. Methodology

Analyze the effect of various input parameters on drilling performance, the experiments are to be carried out carefully. The optimum values were further evaluated by using Grey Relational Analysis. Design drilling experiments on Al 6061 selected as a matrix material, where SiC particles having grit size of 320 as a reinforcement material. Using orthogonal array L9 by varying various parameters such as Helix angle (15 – 45 degrees), Feed (25 – 125 mm/min) and Spindle speed (500 – 2000 RPM). Conduct the analysis of variances (ANOVA) with the help of Minitab 19 software in order to find out the most influential parameters to obtain better solution of thrust force, torque and surface finish. Optimize the regression equation using commonly used optimized techniques Grey Relational Analysis.

2.1 Grey Relational Analysis

Grey relational analysis (GRA) is an effective analysis method to get optimum relation between input parameters and responses of any machining process. It is also used to obtain better results for complex relationships between multi-objective functions. That explains the relationship between input parameters (voltage, speed of the electromagnet and wt. % of abrasives) and response surface finish improvement of MAF process. Based on grey theory, systems can be examined through quantification, modeling, forecasting, and relationship decisions.

- Normalization of date is required to compare it with any other response due to the difference in size or magnitude. The conversion formula is given by [22]. The% of improvement of surface finish is higher the better criterion

$$x*(k) = \frac{xi(k) - min\ xi(k)}{max\ xi(k) - min\ xi(k)}$$

- According to the proposed problem, maximum surface finish improvement is required. Absolute deviation is determined as follows:

$\Delta 0i = \|x(k) - xi(k)\|$

Difference of absolute value $x(k)$ and $xi(k)$

Here $x(k)$ =1, let delta=difference of absolute value

- Calculation of Grey Correlation Coefficient: This relationship essentially represents the difference in the geometry of the curve, so the difference value of the curve can be used as a criterion for evaluating the relevant grey level. The formula for calculating gamma is as follows:

The Grey relational coefficient $\xi i\ (k)$ is

$$\xi_i\ (k) = \frac{\Delta_{min} + \psi \Delta_{max}}{\Delta_{0i}\ (k) + \psi \Delta_{max}}$$

Ψ is the distinguishing coefficient $0 \le \psi \le 1$

$\Delta min^{min\|x}(k) - xj(k)\| min$=the smallest value of $\Delta 0i$

$\Delta max^{max\|x}(k) - xj(k)\| max$ = the largest. Generally, $\psi=0.5$

- The grey relational grade (GRG) γi can be computed as

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi\ (k)$$

- Ranking based on GRG value close to 1

3. Experimental Details

In this section, various aspects starting from selection of cutting tool, workpiece material, and input parameters are explained experimental design.

3.1 Work material and cutting tool

In this investigation, Al 6061 was selected as a matrix material, where SiC particles having grit size of 320 as a reinforcement material. It is also important that the two phases should have small difference in coefficient of thermal expansion when combined to avoid the internal stresses and thermal mismatch strength resulted in the composites. The CTE of reinforcement material is always low as compared to matrix material. Al 6061 have been used in several applications in aerospace and automotive components. The increased specific stiffness and strength can significantly enhance the performance of the aircraft. TiN coated carbide twist drill were used for the machining. Cutting tool specifications are Diameter 5 mm, point angle 130°, Helix angle 15°, 30° and 45°, Clearance angle 10° and flute length 40 mm. The composition of Al 6061 is given in Table 1

Table1: Compositions of Al 6061

Component	Wt %	Component	Wt%	Component	Wt%
Al	95.8-98.6	Mg	.8-1.2	Zn	Max 0.25
Cr	0.04-0.35	Mn	Max 0.15	Other each	Max 0.05
Cu	0.15-0.4	Si	0.4 -0.8	Other total	Max 0.15
Fe	Max 0.7	Ti	Max 0.15		

3.2 Design of Experiment

The machining process consists of several input variables out of which few variables show significant effect on response variable. After extensive literature survey, the important input variables considered in the present work are helix angle, feed and depth spindle speed. Initially, trial experiments were conducted under consideration to decide the variables range and their levels. Finally, three levels of the input parameters as shown in Table II. The experimental design was according to an L_9 array based on Taguchi method, orthogonal array would be reduce the number of experiments.

Table 2: Parameters and levels

Parameters	Level 1	Level 2	Level 3
Helix angle C_1	15	30	45
Feed mm/min C_2	25	75	125
Spindle Speed RPM C_3	500	1000	2000

3.3 Experimental Procedure

Drilling experiments were conducted on CNC drilling machine. The maximum spindle speed of 20000 rpm and a power of 12 kW. Cutting force components were measured using piezo-electric dynamometer (Kistler, Model 9257). Torque were measured using digital torque tester. After machining, surface roughness was measured using Taylor Hobson surface roughness tester.

4. Result and Discussion

It is observed from fig. 3 when feed is increases, also increases surface roughness at different speed, When spindle speed at 1000 RPM at that point increases surface roughness, and helix angle increases , also decreases surface roughness.

Regression evaluation of the received result is completed to set up the relationship among the variables. The estimated coefficients for surface roughness are obtained by using response surface modelling. Various models are attempted like only linear, linear with interaction effects, linear and square terms, full quadratic, etc. All tests to find out the coefficient of determination (R2) for each model are carried out. R2 is used for the prediction of future outcomes on the premise of related statistics between the variables. From various models, the full quadratic model given by below Eq.in un coded form is finalised which gives better R2 value (88.90 %).

F(x) = Surface Roughness = 7.70 - 0.0052 C_1 + 0.0102 C_2 - 0.000698 C_3

F(x) = Thrust Force = 47.4 - 0.465 C_1 + 0.130 C_2 - 0.0088 C_3

F(x) = Torque = 7.77 - 0.0186 C_1 + 0.0086 C_2 - 0.00027 C_3

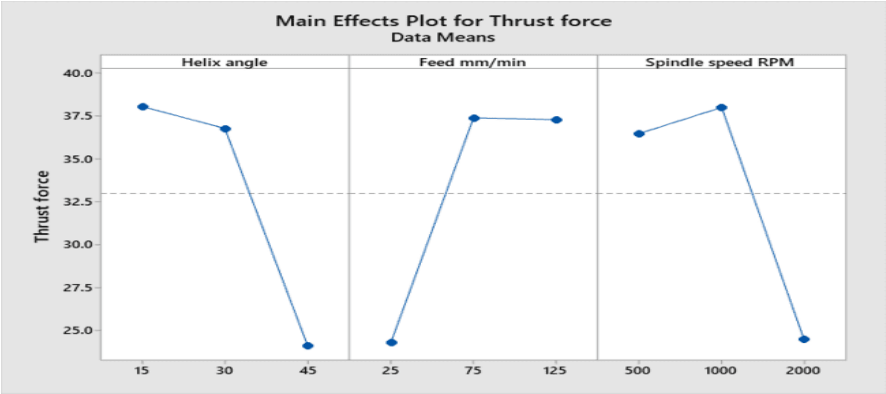

Figure 3: Main effects plot for surface roughness

4.1 Effect of input parameter on thrust force

It is observed from fig. 4 when feed is increases, also increases thrust force at different speed and When helix angle decreases, also increases thrust forces.

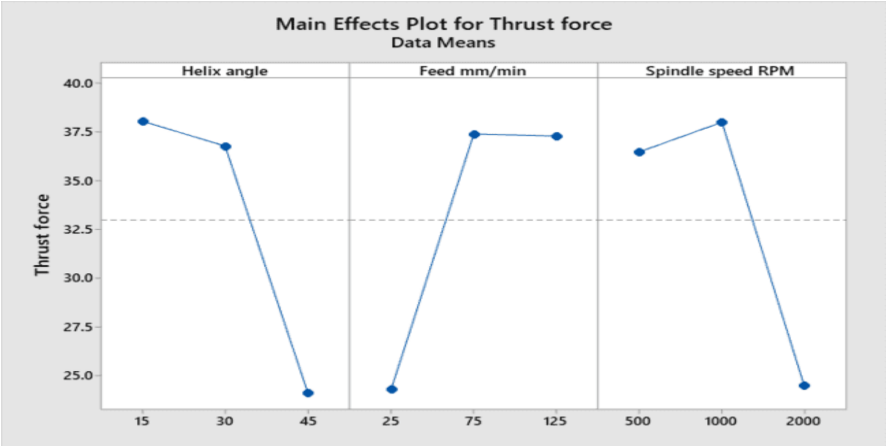

Figure 4: Main effects plot for thrust force

4.2 Effect of input parameter on torque

It is observed from fig. 5 when feed is increases, also increases torque at different speed. When spindle speed at 500 RPM at that point increases torque.

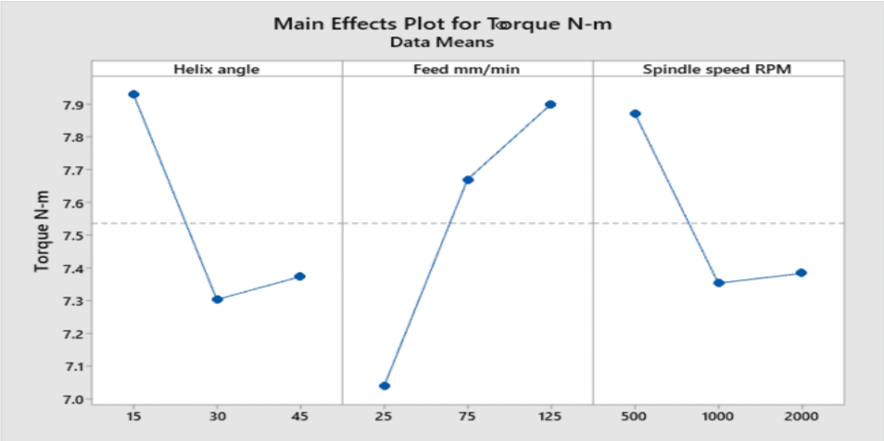

Figure 5: Main effects plot for torque

4.3 Parameter optimization using Grey Relational Analysis:

In this present work, Maximization of %ΔRa is GRA required and the steps are followed based on. Based on GRG ranking, 3rd experiment was considered the optimal best treatment compared to other treatments listed in Table 3..

Table 3: GRA to table 2 the result shown in the table along with ranking

S. No	C1	C2	C3	%ΔRa	GRG Rank
1	15	25	500	12.00	9
2	15	75	1000	28.25	7
3	15	125	2000	54.00	1
4	30	25	500	21.50	8
5	30	75	1000	42.75	2
6	30	125	2000	33.45	4
7	45	25	500	31.00	6
8	45	75	1000	32.50	5
9	45	125	2000	36.50	3

The optimum average GRG value at each factor for different level are noted in Table 10. The average GRG value at each level represents the impact of each factor on surface finish improvement. By comparing each factor with another factor, it can estimate which level of each factor is optimum.

Table 4: Average gray relational grade at each level of the factor

Factor	Average GRG at different levels for each factor		
	1	2	3
C1	0.545231	0.446982	0.512369
C2	0.356529	0.520235	0.623564
C3	0.416294	0.412554	0.657146

5. Conclusion

In conclusion, the present study focused on the analysis of drilling performance in MMCs (Metal Matrix Composites) using Grey Relational Analysis (GRA). The experiments were carefully conducted to analyze the effect of various input parameters on drilling performance. The results obtained from the experiments were then optimized using GRA to determine the most influential parameters for achieving better solutions in terms of thrust force, torque, and surface roughness. Based on the analysis of variance (ANOVA) conducted using Minitab 19 software, it was found that the helix angle, feed rate, and spindle speed significantly influenced the drilling performance. The regression equations were established to establish the relationship between the input parameters and the response variables. The full quadratic model yielded the best coefficient of determination (R2) value of 88.90% for surface roughness. The main effects plots showed that an increase in feed rate and a decrease in helix angle led to an increase in thrust force and torque. On the other hand, an increase in spindle speed resulted in an increase in torque. These findings provide valuable insights into the machining process of MMCs and can aid in optimizing the drilling parameters to achieve desired surface quality and dimensional accuracy. Furthermore, the application of Grey Relational Analysis (GRA) allowed for the optimization of the drilling parameters. The GRA results identified the optimal treatment, which involved a helix angle of 15 degrees, a feed rate of 125 mm/min, and a spindle speed of 2000 RPM, for maximizing the improvement in surface roughness. Overall GRA proved to be an effective approach for analyzing and optimizing the drilling performance in MMCs. The findings of this study can contribute to the development of efficient and cost-effective drilling processes for industries such as aerospace, automotive, and machinery manufacturing.

References

Gul tosun, Mehmet kurt, The porosity, micro structure and hardness of Al-Mg composites reinforced with micro particle SiC/Al203 produced using powder metallurgy, Composites Part B: Engineering, Volume 174, 2019, 106965, ISSN 1359-8368

Basavarajappa, Satyappa & G.,Chandramohan.(2005). Dry sliding wear behaviour of hybrid metal matrix composites, Material science. 11.

P. N. Singh, K. Raghukandan, and B. C. Pai, “Optimization by Grey relational analysis of EDM parameters on machining Al-10%SiC P composites,” J. Mater. Process. Technol., vol. 155–156, no. 1–3, pp. 1658–1661, 2004.

R. Venkata Rao, D. P. Rai, and J. Balic, “A new optimization algorithm for parameter optimization of nano-finishing processes,” Sci. Iran., vol. 24, no. 2, pp. 868–875, 2017.

Abdul Wadood, et al, "Application of the JAYA Algorithm in Solving the Problem of the Optimal Coordination of Overcurrent Relays in Single and Multi-Loop Distribution Systems", Complexity, vol. 2019, Article ID 5876318, 13 pages, 2019.

Pawade et al.,”Application of Jaya Algorithm in Optimization of High Speed Turning of AISI S7 Tool Steel”, October 2016 Conference: 6th International & 27th All India Manufacturing Technology, Design and Research Conference (AIMTDR-2016)

Y. C. Lin and H. S. Lee, "Optimization of machining parameters using magnetic-force-assisted EDM based on gray relational analysis," Int. J. Adv. Manuf. Technol., vol. 42, no. 11–12, pp. 1052–1064, 2009.

J. Prasanna, L. Karunamoorthy, M. Venkat Raman, S. Prashanth, and D. Raj Chordia, "Optimization of process parameters of small hole dry drilling in Ti - 6Al-4V using Taguchi and grey relational analysis," Meas. J. Int. Meas. Confed., vol. 48, no. 1, pp. 346–354, 2014.

M. Durairaj, D. Sudharsun, and N. Swamynathan, "Analysis of process parameters in wire EDM with stainless steel using single objective Taguchi method and multi objective grey relational grade," Procedia Eng., vol. 64, pp. 868–877, 2013.

R. V. Rao, D. P. Rai, and J. Balic, "Surface grinding process optimization using Jaya algorithm," Adv. Intell. Syst. Comput., vol. 411, pp. 487–495, 2016.

R. V. Rao and D. P. Rai, "Optimization of submerged arc welding process parameters using quasi-oppositional based Jaya algorithm," J. Mech. Sci. Technol., vol. 31, no. 5, pp. 2513–2522, 2017.

K. Vasantharaj, M. Jerold, B. Deepanraj, M. Velan, and V. Sivasubramanian, "Assessment of a sulfidogenic system utilizing microalgal biomass of Chlorella pyrenoidosa as an electron donor: Taguchi based grey relational analysis," Int. J. Hydrogen Energy, vol. 42, no. 42, pp. 26545–26554, 2017.

M. Sushil, K. Vinod, and K. Harmesh, "Multi-objective optimization of process parameters involved in micro-finishing of Al/SiC MMCs by abrasive flow machining process," Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl., vol. 232, no. 4, pp. 319–332, 2018.

R. V. Rao, D. P. Rai, and J. Balic, "A multi-objective algorithm for optimization of modern machining processes," Eng. Appl. Artif. Intell., vol. 61, no. August 2015, pp. 103–125, 2017.