Grenze International Journal of Engineering and Technology, Jan Issue

Analysis of Multi Objective Response Variables for the Milling Characteristics of AI-Sic Particulate Composites using Taguchi based Grey Relational Analysis

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***Abstract*—In this paper, the Taguchi method and Grey correlation analysis are combined to optimize the response parameters of the end milling characteristics of stir casting LM25AI-SiC particle composite material. In order to obtain high-quality output and obtain the best combination of response parameters, experiments were conducted based on the experimental method designed by Taguchi. Using the input parameters % Vol of SiC, cutter speed, feed rate, depth of cut and machining time, the L27 orthogonal array was developed for machining characteristics such as flank wear, specific energy and surface roughness. Use multi-criteria optimization techniques (Grey Relational Analysis (GRA)) to analyze response data to optimize face milling characteristics. Multiple response performance standards are converted into a single response performance standard, which is the Grey Relational Grade (GRG). The grey relational grade of the response parameters of the main effect plot and the analysis of variance (ANOVA) is analyzed to obtain the optimal parameters.**

***Index Terms*— Grey Relational Analysis, Grey Relational Grade, Taguchi method, ANOVA, Al-SiC composites.**

I. INTRODUCTION

Man-Made composite materials have existed for thousands of years because the homogeneous material formula in composite materials has higher rigidity and strength, traditional engineering materials have been replaced by composite materials. Composite materials are structural materials composed of two or more components. The metal matrix composite material has a metal matrix with higher specific strength and modulus than metal. Senthilkumar.N et.al [9] used L18 Taguchi to study the machining parameters cutting speed, feed rate, depth of cut, geometric parameters, cutting insert shape, relief angle, noise radius, to optimize the output response flank wear, surface roughness and material removal rate based on grey relational analysis. Hossein Hasani et al [3] used the taguchi method to perform grey correlation analysis to optimize the process parameters of open –ended spinning with multiple performance characteristics. Cigdem Sarpkaya et al [2] used taguchi L18 (mixed 3-6 level) to study the efficiency of weaving machine and used grey relational analysis to optimize the sizing process

Grenze ID: 01.GIJET.7.1.506_3

Padmanabh A. Gadge et al [7] used taguchi's experimental design method to determine the reverse osmosis parameters for distillery effluent in ZLD process through grey relational analysis. Prasad Kumar .B et al [8] studied the influence of process parameters on the injection molding of PMC cam bushings based on the taguchi L27 orthogonal array and analyzed the response data, optimized the process parameters to improve the quality of cam bushings using Grey relational analysis. Karthikeyan .R et al. [4] used polynomial models to predict the respective milling characteristics such as flank wear, specific energy and surface roughness. In order to determine the cutting conditions and optimize the processing conditions, they developed a non-linear multi goal programming. Shasha zeng et.al [10] proposed multi-objective optimization problem, such as the combination of taguchi optimization and grey relational analysis to determine the best combination of end milling process parameters. Meenu Gupta et.al [5] proposes the use of Taguchi method and grey relational analysis to optimize the performance characteristics of unidirectional glass fiber reinforced plastic composites. Moshat et al [6] applied the grey-based taguchi method to deal with the multi-criteria optimization of CNC end mills. Bobby et al [1] use the obtained grey relational grade to determine the best drilling parameters, multiple performance characteristics based on grey relational analysis. The data in this article come from Karthikeyan.R et al [4] using Taguchi grey relational analysis to analyze various parameters of the end milling characteristics of A1/SiCp composites, and to optimize the cutting conditions for the better machinability of these materials.

II. Methodology-Grey Relational Analysis (GRA)

Grey relational analysis is formulated based on Grey theory. It was proposed by Professor Julong Deng. He is a professor at Huazhong University of science and technology in Wuhan, china. If the data contains partial information or incomplete information it is called Grey system. If two or more parameters contain incomplete information then it is called a Grey relation. Elements with incomplete information are called Grey element. The Grey number in the grey system represents number with incomplete information. Grey number, Grey element and Grey relation are typical symbols and characteristics of Grey systems.

Grey relational analysis is used to determine the best conditions for various input parameters to obtain the best quality characteristics. It is widely used to evaluate or judge the performance of complex projects. By providing weights for individual responses, it can be used to derive optimum conditions for multi-objective problems.

A. Steps in Grey Relational Analysis

1. **Data Pre-processing**: The experimental data used for grey analysis must be pre processed into quantitative indices to normalize the original data for other analysis.

2. **Normalizing:** Converting an original sequence into a decimal sequence between 0 and 1 for comparison. If the expected data sequence is of the form "Higher- the-better" than the original sequence can be normalized as $x_i^*(k)=\dfrac{x_i^0(k)-\min x_i^o(k)}{\max x_i^0(k)-\min x_i^0(k)}$ where $x_i^0(k)$ is the original sequence, $x_i^*(k)$ the sequence after the data preprocessing, $\max x_i^0(k)$ the largest value of $x_i^0(k)$, and $\min x_i^0(k)$ imply the smallest value of $x_i^0(k)$. If the expected data sequence is of the form "Smaller- the-better" than the original sequence can be normalized as $x_i^*(k)=\dfrac{\max x_i^0(k)-x_i^o(k)}{\max x_i^0(k)-\min x_i^0(k)}$

3. **Deviation sequence**: How much our data deviates from the ideal value of one that is full information. The deviation sequence of the reference sequence is given by $\Delta_{0i}(k)=\left\|x_0^*(k)-x_i^*(k)\right\|$

4. **Grey Relational Coefficient**: It is calculated to express the relationship between the ideal and actual normalized experimental results. Thus the grey relational coefficient can be expressed as $\zeta_i(k)=\dfrac{\Delta_{\min}+\zeta\ \Delta_{\max}}{\Delta_{oi}(k)+\zeta\ \Delta_{\max}}$ where $\Delta_{\max}=\max\limits_{\forall j\in i}\ \max\limits_{\forall k}\left\|x_o^*(k)-x_j^*(k)\right\|$, $\Delta_{\min}=\min\limits_{\forall j\in i}\ \min\limits_{\forall k}\left\|x_o^*(k)-x_j^*(k)\right\|$, ζ is distinguishing or identification coefficient, $\zeta\in[0,1]$, $\zeta=0.5$ is used generally

5. **Grey Relational Grade**: Average of all the grey relational coefficients. It is defined as

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

B. Data description

In this paper, data has been extracted from Karthikeyan.R et al [2]. The Experiment is based on Taguchi L27 orthogonal array. The orthogonal array contains five input parameters at three different levels. The input parameters are % Volume of SiC, cutter speed, feed rate, Depth of cut and machining time. Based on Taguchi L27 orthogonal array, experiments were performed and the output was recorded. The three outputs are flank wear, specific energy and surface roughness. After formulating the L27 orthogonal array, perform the Grey relational analysis.

Data preprocessing and normalization are applied in GRA. Normalization converts all values between 0 to 1. For normalizing sequence of flank wear, specific energy and surface roughness the minimum value is zero and the maximum value is one. Then find the deviation from the ideal value one in the deviation sequence. After the deviation sequence, the grey relational coefficient of each quality characteristics is determined according to the formula and the final grey relational grade is the average of all outputs. In order to determine the ideal conditions, Minitab is used to calculate the main effects plot for grey relational grade and in that highest value is the optimal condition. Finally we can draw an interaction plot for grey relational grade. By integrating grey relational with taguchi, its analysis performance can be improved and a perfect interpretation of the data can be obtained.

C. Results and Discussion

MINITAB software has been used for this work. The data has been extracted from Karthikeyan.R et al [2], including input and output, as shown in Table 1.

Step 1: In the grey relational analysis, determine the maximum and minimum values of the machining characteristics (such as flank wear, specific energy and surface roughness) of the L27 value.

TABLE I: DATA USED IN THIS ARTICLE KARTHIKEYAN.R ET AL [2]

	input					Output		
	% vol of sic	**cutter speed**	**feed rate**	**depth of cut**	**machining time**	**flank wear**	**specific energy**	**surface rough**
1	10	315	215	0.5	3	0.14	20.14	6.54
2	10	315	430	1.5	6	0.32	37.23	5.43
3	10	315	600	2.5	9	0.48	45.44	5.38
4	10	630	215	1.5	6	0.38	21.22	3.23
5	10	630	430	2.5	9	0.62	36.42	3.72
6	10	630	600	0.5	3	0.58	10.88	9.89
7	10	1000	215	2.5	9	0.7	37.78	2.37
8	10	1000	430	0.5	3	0.71	21.22	7.3
9	10	1000	600	1.5	6	1.02	24.78	5.22
10	15	315	215	1.5	9	0.25	36.71	3.22
11	15	315	430	2.5	3	0.27	26.86	1.97
12	15	315	600	0.5	6	0.41	48.27	11.13
13	15	630	215	2.5	3	0.33	23.23	1.17
14	15	630	430	0.5	6	0.54	28.82	7.7
15	15	630	600	1.5	9	0.8	42.24	4.87
16	15	1000	215	0.5	6	0.61	20.87	4.89
17	15	1000	430	1.5	9	0.97	35.42	3.6

18	15	1000	600	2.5	3	0.96	27.51	1.89
19	25	315	215	2.5	6	0.25	34.66	1.21
20	25	315	430	0.5	9	0.37	82.64	7.04
21	25	315	600	1.5	3	0.38	41.91	2.36
22	25	630	215	0.5	9	0.46	42.52	4.19
23	25	630	430	1.5	3	0.51	23.98	1.64
24	25	630	600	2.5	6	0.79	36.68	1.83
25	25	1000	215	1.5	3	0.58	17.56	1.04
26	25	1000	430	2.5	6	0.95	31.38	1.35
27	25	1000	600	0.5	9	1.05	38.19	6.77

Step 2: The Machining characteristics (such as flank wear, specific energy and surface roughness) should be minimized. Then the sequence can be normalized using the formula, “lower-the-better”.
Step 3: Normalization is done by subtracting the maximum value of each response data from individual values of each response data, and then dividing by subtracting maximum, minimum value of each response data.
Step 4: The deviation sequence is used to understand how far these values differ from the ideal value one. It is calculated by subtracting the normalizing sequence by one.
Step 5: The determination of the Grey relational coefficient is to calculate the ideal and actual normalized experimental results. $\Delta_{\min}$ represent the minimum value of the deviation sequence. $\Delta_{\max}$ represent the maximum value of the deviation sequence, $\Delta_{oi}(k)$ represent the individual value of the deviation sequence and ζ represents 0.5 .
Step 6: The Grey relational grade (GRG) is the average of the grey relational coefficient for machining characteristics such as flank wear, specific energy and experimental surface roughness. The calculated values of normalized sequence, deviation sequence, grey relational coefficient and grey relational grade are shown in Table II.

TABLE II: CALCULATED VALUES OF NORMALIZING SEQUENCE, DEVIATION SEQUENCE, GREY RELATIONAL COEFFICIENT AND GREY RELATIONAL GRADE

normalizing sequence			Deviation sequence			grey relational coefficient			grey relational grade
flank wear	specific energy	surface roughness	flank wear	specific energy	surface roughness	flank wear	specific energy	surface roughness	GRG
1.0000	0.8710	0.4549	0.0000	0.1290	0.5451	1.0000	0.7949	0.4784	0.7578
0.8022	0.6328	0.5649	0.1978	0.3672	0.4351	0.7165	0.5766	0.5347	0.6093
0.6264	0.5184	0.5699	0.3736	0.4816	0.4301	0.5723	0.5094	0.5376	0.5398
0.7363	0.8559	0.7830	0.2637	0.1441	0.2170	0.6547	0.7763	0.6973	0.7094
0.4725	0.6441	0.7344	0.5275	0.3559	0.2656	0.4866	0.5842	0.6531	0.5746
0.5165	1.0000	0.1229	0.4835	0.0000	0.8771	0.5084	1.0000	0.3631	0.6238
0.3846	0.6251	0.8682	0.6154	0.3749	0.1318	0.4483	0.5715	0.7914	0.6037
0.3736	0.8559	0.3796	0.6264	0.1441	0.6204	0.4439	0.7763	0.4463	0.5555
0.0330	0.8063	0.5857	0.9670	0.1937	0.4143	0.3408	0.7208	0.5469	0.5362
0.8791	0.6401	0.7839	0.1209	0.3599	0.2161	0.8053	0.5814	0.6983	0.695
0.8571	0.7773	0.9078	0.1429	0.2227	0.0922	0.7778	0.6919	0.8444	0.7713
0.7033	0.4790	0.0000	0.2967	0.5210	1.0000	0.6276	0.4897	0.3333	0.4835
0.7912	0.8279	0.9871	0.2088	0.1721	0.0129	0.7054	0.7439	0.9749	0.8081
0.5604	0.7500	0.3399	0.4396	0.2500	0.6601	0.5322	0.6667	0.4310	0.5433
0.2747	0.5630	0.6204	0.7253	0.4370	0.3796	0.4081	0.5336	0.5685	0.5034
0.4835	0.8608	0.6184	0.5165	0.1392	0.3816	0.4919	0.7822	0.5672	0.6138
0.0879	0.6580	0.7463	0.9121	0.3420	0.2537	0.3541	0.5938	0.6634	0.5371
0.0989	0.7683	0.9158	0.9011	0.2317	0.0842	0.3569	0.6833	0.8558	0.632
0.8791	0.6686	0.9832	0.1209	0.3314	0.0168	0.8053	0.6014	0.9674	0.7914
0.7473	0.0000	0.4054	0.2527	1.0000	0.5946	0.6642	0.3333	0.4568	0.4848

0.7363	0.5676	0.8692	0.2637	0.4324	0.1308	0.6547	0.5362	0.7926	0.6612
0.6484	0.5591	0.6878	0.3516	0.4409	0.3122	0.5871	0.5314	0.6156	0.578
0.5934	0.8174	0.9405	0.4066	0.1826	0.0595	0.5515	0.7325	0.8937	0.7259
0.2857	0.6405	0.9217	0.7143	0.3595	0.0783	0.4118	0.5817	0.8646	0.6194
0.5165	0.9069	1.0000	0.4835	0.0931	0.0000	0.5084	0.8430	1.0000	0.7838
0.1099	0.7143	0.9693	0.8901	0.2857	0.0307	0.3597	0.6364	0.9421	0.6461
0.0000	0.6194	0.4321	1.0000	0.3806	0.5679	0.3333	0.5678	0.4682	0.4565

Step 7: To determine the ideal conditions from this grey relational grade. We require MINITAB software to draw the main effect plots based on the response data and it is shown in Fig 1.

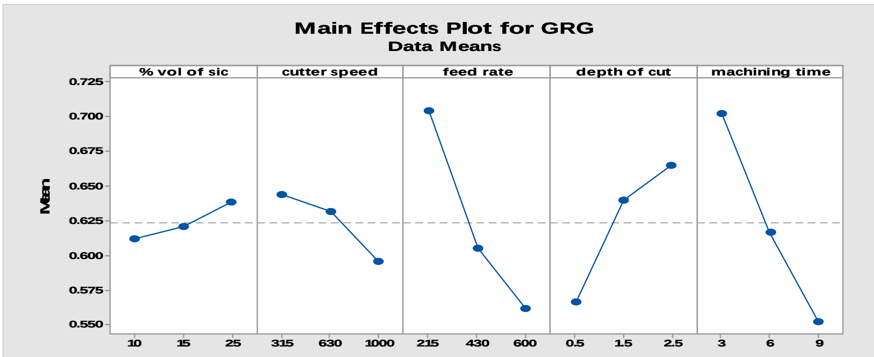

Fig 1. Main Effects plot for GRG

Step 8: Analysis is done in MINITAB by importing the input values as % Volume of SiC , cutter speed, feed rate, Depth of cut, machining time and response data as grey relational grade values. From the Main Effects plot for Grey relational grade we can find the optimal condition of % Volume of SiC is 25, cutter speed is 315, feed rate is 215, Depth of cut 2.5, machining time is 3 are optimum. Main effect plots are formulated based on the response table. Response table is formulated by considering the level values and the corresponding grey relational grade value. Response value of % Volume of SiC in level 1 is 0.612225, level 2 is 0.620829, level 3 is 0.638553, cutter speed in level 1 is 0.643776, level 2 is 0.631770, level 3 is 0.596060, feed rate in level 1 is 0.704552, level 2 is 0.605318, level 3 is 0.561737, Depth of cut in level 1 is 0.566324, level 2 is 0.640139, level 3 is 0.665145 and machining time in level 1is 0.702153, level 2 is 0.616915, level 3 is 0.552539.

Step 9: Interaction plot is obtained for all the input values and grey relational grade, shown in Figure 2.

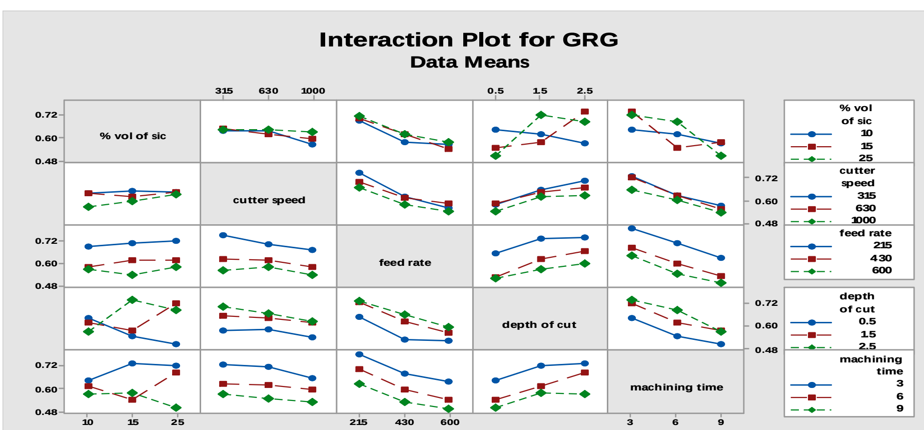

Fig 2. Interaction plot for GRG

Step 10: From ANOVA table, the variance that exists between two parameters can be studied and percentage contribution of each and every parameter can be determined. ANOVA is based on 95% of confidence interval. To obtain the R square value and to check whether my modal is a fitted one or not can be obtained by ANOVA and is shown in Table III. Model summary is shown in Table IV.

TABLE III: ANALYSIS OF VARIANCE

Source	DF	Adj SS	Adj MS	F-Value	P-Value
% vol of Sic	2	0.003244	0.001622	2.05	0.161
Cutter speed	2	0.011089	0.005544	7.01	0.006
Feed rate	2	0.096429	0.048214	61.00	0.000
Depth of cut	2	0.047519	0.023759	30.06	0.000
Machining time	2	0.101382	0.050691	64.13	0.000
Error	16	0.012647	0.000790		
Total	26	0.272309			

TABLE IV: MODEL SUMMARY

S	R-sq	R-sq (adj)	R-sq (pred)
0.0281150	95.36%	92.45%	86.77%

Step 11: ANOVA table is formulated based on input values and response data as grey relational grade. With R-square value of 95.36% the regression coefficient value, the ideal value of regression coefficient is one and we have ended up with 95.36%. So it is a good model. Then the

Regression Equation is

GRG = 0.62387 - 0.01164 % vol of sic_10 - 0.00304 % vol of sic_15 + 0.01468 % vol of sic_25
+ 0.01991 cutter speed_315 + 0.00790 cutter speed_630 - 0.02781 cutter speed_1000
+ 0.08068 feed rate_215 - 0.01855 feed rate_430 - 0.06213 feed rate_600
- 0.05755 depth of cut_0.5 + 0.01627 depth of cut_1.5 + 0.04128 depth of cut_2.5
+ 0.07828 machining time_3 - 0.00695 machining time_6 - 0.07133 machining time_9

Step 12: Finally Residual plot for Grey relational grade is obtained and it is shown in Figure 3.

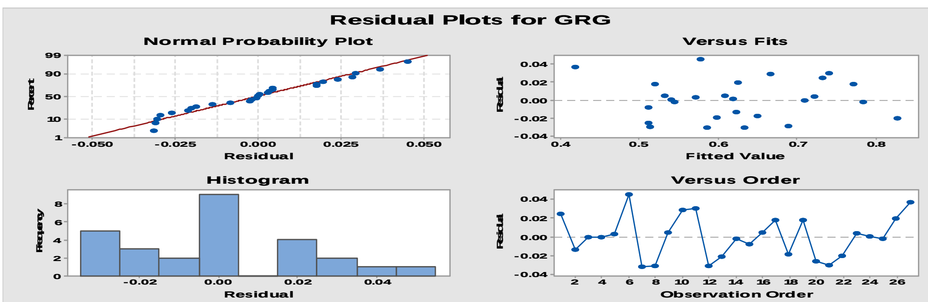

Fig 3: Residual plots for GRG

III. CONCLUSION

The Grey relational analysis method is used to determine the best process parameters by enhancing mechanical properties. The purpose of this research paper is to establish the relationship between % Vol of SiC, cutter speed, feed rate, depth of cut and machining time. The influence of these parameters on the flank wear, specific energy and surface roughness was also studied in detail. The current work evaluates the use of ANOVA and GRA to optimize process parameters. Due to the highest degree of Grey relational grade, the best parameter combination that can better combine flank wear, specific energy and surface roughness is % Vol of SiC = 15 , cutter speed = 630rpm , feed rate = 215mm/min, depth of cut = 2.5 mm and machining time = 3 min. In order to find a suitable manufacturing process to meet industry needs, it is important to develop accurate evaluation methods.

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