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GREY TAGUCHI ANALYSIS ON MILLING OF AL-7075 MMCS AND ITS MICRO-STRUCTURAL STUDY

ASHUTOSH SATPATHY[1], SUDHANSU SEKHAR SINGH[2] & SASMITA KAR[3*]

[1, 2,3] Centre for Advanced Post Graduate Studies, BPUT, Rourkela, India

ABSTRACT

In the current global manufacturing scenario, the material selection and its manufacturing with specific characteristics are very tough. The Hybrid MMCs are frequently used in the aerospace, automobile and electronics field for its outstanding material characteristics as compared to the conventional metals or alloys. Very often due to the reinforcement of high strength material, MMCs are considered to be very difficult to machine. In the current research, MMCs is subject to end milling operation by CNC milling, which is an important operation in the present industrial production system. The Al-7075/Al_2O_3/B_4C is manufactured by stir casting operation in two varying composition of 92% Al-7075, 5% Al_2O_3, 3% B_4C and 97% Al-7075, 2% Al_2O_3, 1% B_4C powder respectively. The material composition after the casting of MMCs is studied by the SEM and EDX. After the composition and micro structural study, the composite having 92% Al-7075, 5% Al_2O_3, 3% B_4C is considered suitable for machining. Taguchi technique grey relational analysis (TTGRA), a multiple standard optimization is carried out for optimizing the milling parameters. This paper emphasizes the productivity goals on surface roughness (SR), material removal rate (MRR), chip thickness (CT) and machining time (MT). Grey relational grades (GRG) are used for determining the optimal process parameters obtained from Taguchi L_9 Orthogonal array (OA) after the grey generation. The influence of different variables with respect to different objective was predicted by Analysis of variance (ANOVA) with effective parametric contributions. Finally it is concluded that, GRG is improved by 3.68% after selecting $A_1B_3C_3$ optimal parameters and spindle speed is the most influencing milling factor.

KEYWORDS: Mmcs (Metal Matrix Composites), Taguchi Method Grey Rational Analysis (TTGRA), CNC Milling, SEM, EDX, GRG (Grey Relational Grade), ANOVA

INTRODUCTION

The most of the used conventional metal parts in the field of transportation, spacecraft, marine, defence, bio engineering and medical applications are nowadays extensively replaced by metal or ceramic reinforced composites for its amazing characteristics. Not only the physical, thermal, mechanical or wear resistance tendencies but also the machining characteristics of metal matrix composites (MMCS) are incredibly directed by relevant selection of reinforcement materials. The MMCs are having excellent performance to-words the current research fields as per its high engineering stability, toughness, inelasticity and light weight, mostly based on aluminium with various ceramic materials such as TiC, Si_3N_4, SiC, TiB_2 and B_4C [1,2]. The good proportion of ceramics with metal combination results excellent microstructure enhancing the interlocking bonds. Excellent dimensional accuracy and geometrical shape can be desired by milling operation.

Sozhamannan et al. [3] explored the impact of major input factors like process temperature and holding time in continuous stir casting (CSC) method, where the particles were uniformly distributed as a result of improvement in process temperature where the application duration decreases the liquid metal viscosity of which ultimately influenced the hardness. Auradi and Kori [4] synthesized aluminium build composites by different mass proportion of B_4C powder to study the significant properties such as hardness, compression toughness of materials. Babu and Moorthy [5] used casting process through stirring phenomena in combination of Al7075 silicon carbide MMCs with a conclusion that it was the utmost simple and economic casting method for MMCs. Reddy et al. [6] experimented on the Al/SiC particulate MMCs under end milling operations considering the input variables like speed, feed and depth of cutting. They studied most significant impact of input variables on output responses like surface finish, micro structure, and micro hardness, which mostly depends upon the hardness and composition of the MMCs. Samy et al. [7] deliberated the influence of cutting variables in end milling operation of stir casted AA6351-B_4C composites for the output responses like tool wear, surface roughness, chip thickness, delamination and temperature rise by using carbide cutting tool coated with titanium nitride. The chip behaviour and temperature developed during chip formation analyzed by SEM. Ali and Songmene [8] calculated the cut thickness in milling of malleable material with cutting variables of tool and work piece. The burr formation calculated by the shear angle, friction angle and burr thickness. Reddy and Rao [9] experimented to the influence of geometry of cutting tool and its condition on machining characteristics of end milling operated carbon steel material. The results obtained by response on surface methodology (RSM) and genetic algorithm (GA), where GA gave minimum optimal condition for surface finish and other corresponding optimal conditions. Naidu et al. [10] examined the surface finish on EN-31steel, optimizing the specific milling input process constants like speed, feed, cutting depth and coolant flow using the Taguchi robust design mode. Shao et al. [11] effectively used a cutting power model for verification of experimental data in face milling operation on cast iron and the carbide cutter. Ultimately the power model is successfully used for monitoring the tool wear of single and multi tooth tool with variable cutting condition. Campatelli and Scippa [12] optimized the process parameters feed per tooth and cutting speed for good quality product with least machining time on aluminium 6082-T4 by using a cutting force model. This model depends upon the tangential, radical, axial spindle speed. Soltani et al. [13] critically studied the mechanical behaviour of composites based on their microstructure and processing parameters. They also explained the influence of ceramic reinforcement size, different temperature and stirring speed and time, on stir casting of Al/SiC MMCs. Satpathy and Singh [14] had done the experiment of end milling operation on Al7075 MMCs to improve the selected input parameters in order to minimize machining time using Taguchi's robust design methodology. Sylajakumari et al. [15] upgraded the sliding wear constants by GRA method. The dry sliding wear property of the AA6063 with silicon carbide co-extended composite material, produced by force intrusion method and most predominant factor, sliding distance influenced more as compared to other parameters. Prasanth and Ramesh [16] investigated the surface finish and tool abrasion of end milling operation on Al7075-SiC based co-extended composite. Here the composite material is produced by the pressure intrusion technique. The surface finish and tool abrasion wear, optimized by both GRA and Taguchi method and among the two methods the Grey Taguchi method was best and it gave best optimal result of the two responses as compared to Taguchi method.

The Taguchi method is best suited for single objective optimization characteristics where as grey based Taguchi is based upon multi objectives characteristics in optimization problem. This proposal modifies a collective response development problem to a free response improvement by considering universal GRG [13].

The significance of the research work is to develop the selected input factors of end milling operation on Al7075 based MMCs manufactured by liquid based stir casting method. An experimental design is done by Taguchi L_9 (3^3) orthogonal array considering three input criterion like speed, feed and cutting depth with respect to the process variables i.e. surface finish (SF), material removal rate (MRR), machining time (MT) and chip thickness (CT). In modern CNC system, the component of the CNC machine is programmed in high automation. GRA is mostly used to analyze the responses to predict the optimal parameter and also ANOVA is used to predict most significant influencing parameters.

MATERIALS AND METHODS

Specimen Preparation

In the current research the milling operation is done on the Al-7075 aluminium-based metal matrix composites (AMMCs). The reinforcement phase is depending upon the chemical and physical properties like strength and temperature of matrix phase, which may be heterogeneous and homogeneous in structure. In current research of the MMCs, the matrix phase is Al-7075 alloy; the reinforcement phase is Al_2O_3 and B_4C powder used in varying composition. The composition of the Al-7075 based metal matrix composite material is 92%, 97% Al-7075, 5%, 2% Al_2O_3 powder and 3%, 1% B_4C powder. The experimental process depends upon the melting temperature of the matrix phase and reinforcement phase, the stirring speed, stirrer shape and the process of mixing the reinforcement material and matrix material. Then the reinforcement phase is heated as far as 250°C. Al-7075 alloy small piece is added because it is more suitable for melting purpose. Then Al-7075 alloy is heated up to 800°C, as melting temperature of the Aluminium alloy is generally 650-900°C and takes 45 minutes for melting the aluminium alloys. The Al_2O_3 and B_4C powder takes 2 hours for heating in an oven. After the melting of the Al-7075 alloy in 800°C, the reinforcement material Al_2O_3 and B_4C is added in powder form for two to three minutes. Then stirring is continued for five minutes. During stirring the stir temperature is maintained at 770°C and the stirrer speed is 70 rpm as the stirrer speed is limited within 10-150 rpm.

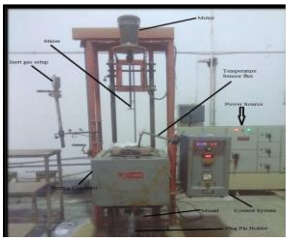

Figure 1: Image of Stir Casting Machine Setup

Figure 2: Image of Rectangular Specimen

Figure 3. Image of Cylindrical Specimen

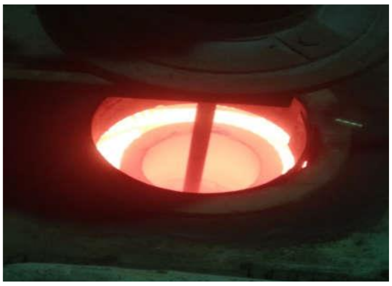

Figure 4: Stirring process

Micro Structural Studies

The principle of SEM study is conducted in two ways i.e., one is “pre-processing” and other one is “during process”. In pre-processing, the work piece is subjected to polishing by SiC foil in 100 rpm in 320µm, 500µm, 800µm, 1000µm, 1200µm respectively. Then the work piece is polished by diamond strip in 100–300 rpm by liquid state of Aluminium oxide. After the completion of the polishing process the work piece is washed by fresh water then subjected to chemical etching process. The etchant is used for the aluminium are sodium hydroxide, hydrofluoric and hydrochloric acid, Nitric acid, Distilled water. Distilled water is used for the dilution of the etchants in chemical reaction. The etching process is done for 3 to 4 sec. In this process the 500x and 1000x magnifying lenses are used. The microscopy study shows the more uniform distribution of B_4C within the white Aluminium powder in case of MMCs that consists of 97% Al-7075.

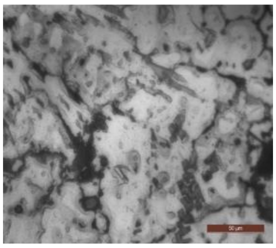

Figure 5: Microscopy Study of Rectangular Work Piece(92% Al-7075) At 500X Lens

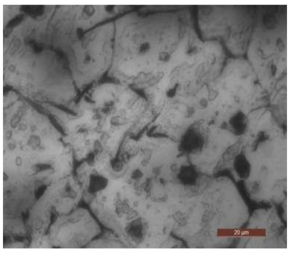

Figure 6: Microscopy Study of Rectangular Work Piece (92% Al-7075) At 1000X Lens

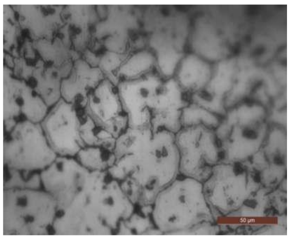

Figure 7: Microscopy Study of Cylindrical Work Piece (97% Al-7075) At 500X Lens

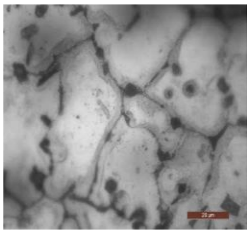

Figure 8: Microscopy Study of Cylindrical Work Piece(97% Al-7075) At 1000X Lens

SEM Study

After the optical micro scope study the work piece is studied by SEM which is executed by 500x and 1000x magnifying lenses for more clear visualization of micro structure obtained after the casting. Eventually it is found that the cylindrical work piece having 97% of Al-7075 results well distribution of particles and better strength.

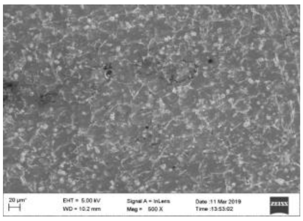

Figure 9: SEM study of rectangular work piece (92% Al-7075) at 500X lens

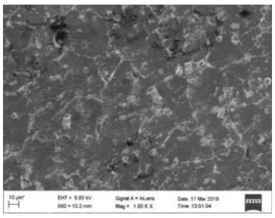

Figure 10: SEM Study of Rectangular Work Piece (92% Al-7075) At 1000X Lens

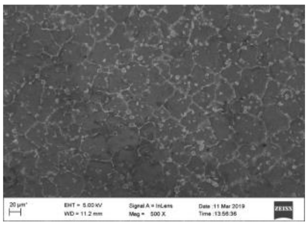

Figure 11: SEM Study of Cylindrical Work Piece (97% Al-7075) At 500X Lens

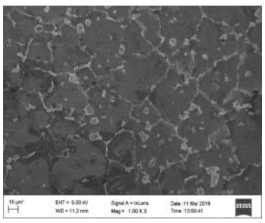

Figure 12: SEM Study of Cylindrical Work Piece (97% Al-7075) At 1000X Lens

EDX Analysis

After the SEM study, the work piece is subjected to EDX study, which consists of 92% of Al-7075 alloys. The study is used to identify the percentage composition of the materials such as matrix and reinforcement in the MMCs to know the strength of the material. Table 1 represents the percentage composition of reinforcement and matrix phase. It also determines the atomic percentage of composition of the constituent materials. But the MMCs consisting of 97% of Al-7075 shows better strength than the MMCs consists of 92% of Al-7075.

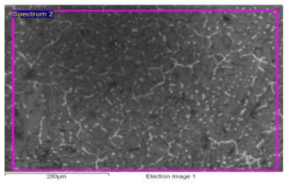

Figure 13: EDX study of MMCs

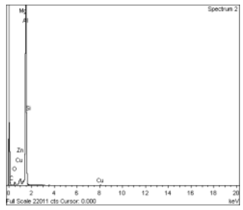

Figure 14: EDX graph of MMCs

Table 1: EDX Table for the MMCs

Element	App Conc.	Intensity Conc.	Mass%	Mass% Sigma	Atomic%
C K	0.32	0.2146	4.84	0.83	10.36
O K	1.43	0.9520	4.84	0.32	7.77
Mg K	0.41	1.2030	1.10	0.11	1.16
Al K	29.15	1.1631	80.95	0.85	77.15
B_4C K	0.09	0.6079	0.50	0.11	0.45
Cu L	0.82	0.8655	3.06	0.34	1.24
Zn L	1.20	0.8218	4.72	0.29	1.85
Totals			100.00		

Milling Machining Operation

In the present work, the cylindrical MMCs having 97% Al-7075 is subjected to milling operation at CTTC, Bhubaneswar. The operation is done on CNC vertical end milling machine. In current research the most influencing input factors considered as spindle speed (SS), feed rate (FR) and depth of cut (DOC). The responses of machining operations are SR, MT, and CT and MRR.

Figure 15: Milling Machine Set-up

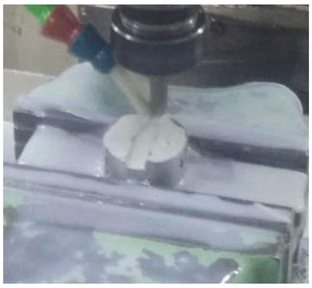

Figure 16: Milling Machining Process

Design of Experiment

In most of the manufacturing industrial research, DOE is highly appreciated for developing a good relationship between different process variables. A key design of orthogonal array is done by Taguchi methodology to analyze the impact of all variables with minimum number of experiments [17]. The number of the levels and the number of the experiment depends upon the DOE, which is based on number of input and output factors.

Table 2: Design of Experiment Table of Input Parameter

Sl No	Factors	Figure	Level-1	Level-2	Level-3	Unit
1	SS	A	800	1200	1500	RPM
2	FR	B	200	350	500	mm/min
3	DOC	C	0.4	0.8	1	mm

OPTIMIZATION METHOD

Taguchi Methodology

The DOE was executed according to L_9 orthogonal array (OA) and according to which total 9 no of experiments are required to be conducted on cutting environment up to three levels.

Table 3: The Experimental Data of Input Parameters and Responses

SL	SS(A)	FR (B)	DOC (C)	SR(µm)	C T(mm)	MRR	MT (in Sec)
1	800	200	0.4	1.184	0.063	9.45	238
2	800	350	0.8	1.115	0.11	27.43	82
3	800	500	1	1.493	0.156	41.66	54
4	1200	200	0.8	0.618	0.042	18.29	123
5	1200	350	1	0.902	0.073	33.088	68
6	1200	500	0.4	0.995	0.104	21.22	106
7	1500	200	1	0.636	0.033	21.63	104
8	1500	350	0.8	0.574	0.058	29.22	77
9	1500	500	0.4	0.589	0.083	20.83	108

SN Ratio Method

The S/N fraction is considered for different types of properties like higher the better, nominal is the best and lower the better [18]. After selection of factors of milling operation, depending upon the Taguchi design of L_9 OA, S/N fraction is calculated for the MRR considered as Larger is better, but the MT, CT, SR is calculated as smaller is the better.

$$(S/N)_{SB} = -10\log_{10}[y_1^{\,2} + y_2^{\,2} + y_3^{\,2} + --- + y_n^{\,2}]/n$$

$$(S/N)_{LB} = -10\log_{10}\left[\frac{1}{y_1^{\,2}} + \frac{1}{y_2^{\,2}} + \frac{1}{y_3^{\,2}} + --- \frac{1}{y_n^{\,2}}\right]/n$$

Table 4: SN Ratio Table of All Responses

SL NO	SS(A)	FR (B)	DOC (C)	S/N Fraction(MT)	S/N Fraction(MRR)	S/N Fraction(SR)	S/N Fraction(CT)
1	800	200	0.4	-47.5315	19.5086	-1.46703	24.0132
2	800	350	0.8	-38.2763	28.7645	-0.9455	19.1721
3	800	500	1	-36.6479	32.3944	-3.4812	16.1375
4	1200	200	0.8	-41.7981	25.2443	4.18023	27.535
5	1200	350	1	-36.6502	30.3934	0.89587	22.7335
6	1200	500	0.4	-40.5061	26.5349	0.04354	19.6593
7	1500	200	1	-40.3407	26.7011	3.93086	29.6297
8	1500	350	0.8	-37.7298	29.3136	4.82176	24.7314
9	1500	500	0.4	-40.6685	26.3738	4.59769	21.6184

Parameter Evaluation Through ANOVA

Analysis of variance (ANOVA) a mathematical tool is most efficiently known to explore the significant fitness results of experimental design variables on output responses, interaction between factors and different process variables [19]. Table 5 represents the contribution of factors on MT. It is remarked that, among the all input factors feed rate gives maximum contribution on MT as compared to DOC and SS.

Table 5: Results of ANOVA for MT

Factors	DF	Seq SS	Adj SS	Adj MS	F-Value	Improvement
SS	2	1.2207	1.2207	0.6103	4.04	2.82%
FR	2	21.3741	23.1474	11.5737	76.55	49.31%
DOC	2	20.4507	20.4507	10.2254	67.63	47.18%
Error	2	0.3024	0.3024	0.1512		0.70%
Total	8	43.3479				100.00%

Table 6: Results of ANOVA for SR

Factors	DF	Seq SS	Adj SS	Adj MS	F-Value	Improvement
SS	2	0.184163	0.184163	0.092081	26.12	81.82%
FR	2	0.017516	0.010082	0.005041	1.43	7.78%
DOC	2	0.01636	0.01636	0.00818	2.32	7.27%
Error	2	0.007051	0.007051			3.13%
Total	8	0.22509				100.00%

Table 6 represents the maximum influence of spindle speed on SR of the material.

Table 7: Results of ANOVA for MRR

Factors	DF	Seq SS	Adj SS	Adj MS	F-Value	Improvement
SS	2	0.00427	0.00427	0.00214	0.12	0.06%
FR	2	3.6695	3.87859	1.9393	109.43	48.96%
DOC	2	3.78573	3.78573	1.89287	106.81	50.51%
Error	2	0.03544	0.03544	0.01772		0.47%
Total	8	7.49495				100.00%

Table 8: Results of ANOVA for Chip Thickness

Factors	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Improvement
SS	2	0.012366	0.012366	0.006183	415.68	0.002	34.93%
FR	2	0.022665	0.021664	0.010832	728.25	0.001	64.02%
DOC	2	0.000345	0.000345	0.000172	11.59	0.079	0.97%
Error	2	0.00003	0.00003	0.000015			0.08%
Total	8	0.035405					100.00%

Depth cut has maximum influence on MRR and simultaneously feed rate significantly affects on chip thickness of the composite material.

Grey Relational Analysis (GRA)

Generation of Grey Relation

The grey relational theory initially developed by "Deng" to minimize the problems arising in statistical method and that ultimately used to know the characteristics of unknown data by using a few set of data [20]. The correlation among the input processing parameters and output response can build using GRA. It is the combined characteristics of all machining performance and results a single value with the help of multiple responses, otherwise it is also known as multi optimization method. The Taguchi method is best suited for single objective optimization characteristics where as grey based Taguchi is based upon multi objectives characteristics in optimization problem. There are generally three different types of grey relation analysis occurs but here two generations are discussed below for the current research work. "Larger the better'' is used for MRR and "Smaller is better" is used for chip thickness, machining time and surface roughness.

Larger is better: $X_i(K) = \dfrac{X_i(K) - \min X_i(K)}{\max X_i(K) - \min X_i(K)}$

Smaller is better: $X_i(K) = \dfrac{\max X_i(K) - X_i(K)}{\max X_i(K) - \min X_i(K)}$

Table 9: Results of Run Trials

Sl No	CT	MT	SR	MRR
1	0.4162	1.0000	0.7574	0.0000
2	0.7750	0.1496	0.6946	0.7183
3	1.0000	0.0000	1.0000	1.0000
4	0.1552	0.4732	0.0772	0.4451
5	0.5111	0.0019	0.4728	0.8447
6	0.7389	0.3544	0.5754	0.5452
7	0.0000	0.3392	0.1072	0.5581
8	0.3630	0.0994	0.0000	0.7609
9	0.5937	0.3694	0.0269	0.5327

Deviation sequence = $\Delta_{0i}(K) = \left| X_0(K) - X_i(K) \right|$

Table 10: Sequence of Deviation of Grey Taguchi Method

Sl No	CT	MT	SR	MRR
1	0.5837	0.0000	0.2425	1.0000
2	0.2249	0.8503	0.3054	0.2817
3	0.0000	1.0000	0.0000	0.0000
4	0.8447	0.5269	0.9227	0.5548
5	0.4888	0.9980	0.5271	0.1552
6	0.2610	0.6455	0.4245	0.4547
7	1.0000	0.6607	0.8927	0.4418
8	0.6369	0.9005	1.0000	0.2390
9	0.4062	0.6305	0.9730	0.4672

Estimation of GRC and GRG

After the calculation of deviation sequence, the GRG is calculated by the grey relational coefficient (GRC) and both are represented in table 11.

Grey Relation Coefficient: $\xi_{(K)} = \dfrac{\Delta_{\min} + \psi\Delta_{\max}}{\Delta_{0i}(K) + \psi\Delta_{\max}}$

Grey Relation Grade: $\gamma_i = \dfrac{1}{n}\sum_{i=1}^{n} \xi_i(K)$

Table 11: GRG and GRC

Sl No	CT	MT	SR	MRR	GRG	Rank of GRG
1	0.4613	1.0000	0.6733	0.3333	0.6169	2
2	0.6897	0.3702	0.6208	0.6396	0.5800	3
3	1.0000	0.3333	1.0000	1.0000	0.8333	1
4	0.3718	0.4868	0.3514	0.4739	0.4209	8
5	0.5056	0.3337	0.4867	0.7630	0.5222	5
6	0.6570	0.4364	0.5408	0.5237	0.5394	4
7	0.3333	0.4307	0.3590	0.5308	0.4134	9
8	0.4397	0.3570	0.3333	0.6765	0.4516	7
9	0.5517	0.4422	0.3394	0.5169	0.4625	6

Analysis between Input Parameter/GRG

Figure-17 represents the graphical representation between input parameter/GRG values. The GRG values are gradually decreased as corresponding to the increase of the Spindle speed value of the milling process.

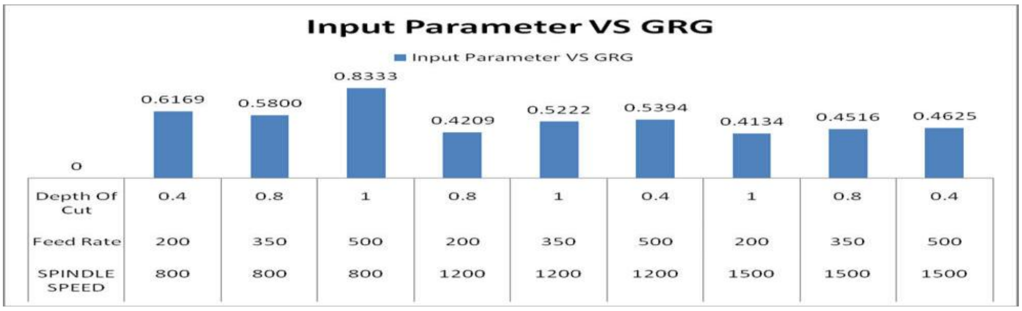

Figure 17: Graph Between Input Parameter and GRG Value

Mean Analysis of GRA

Table 12: Mean Table of GRA

Factors	Figure	Level-1	Level-2	Level-3	Delta	Rank
SS	A	**0.6767**	0.4941	0.4425	0.2342	1
FR	B	0.4837	0.5179	**0.6117**	0.1280	2
DOC	C	0.5396	0.4841	**0.5896**	0.1055	3

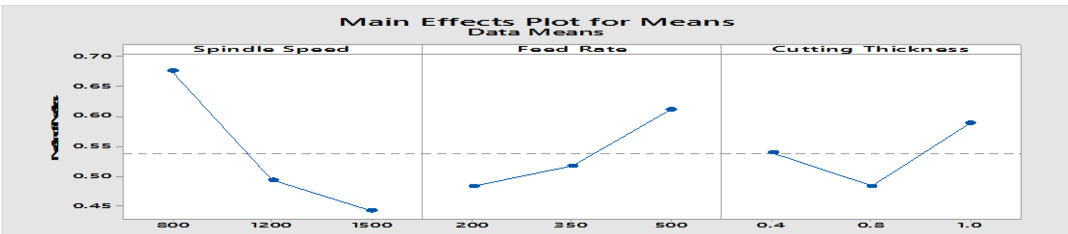

Figure 18: Mean plot of GRG value

The above graph (Fig. 18) and table 12 represents the mean of the Grey Taguchi value of the input parameter and graph between the GRG mean value and the 3-level of the input parameter.

Confirmation Test of Grey Taguchi Method

Table 13: Result Table of GRA

Initial Design Parameter		Optimal Design Parameter	
		Prediction Value	Experimental Value in Orthogonal Array
Setting Level	$A_1B_1C_1$	$A_1B_3C_3$	$A_1B_3C_3$
GRG	0.6169	0.8026	0.8333
Increase in GRG		3.82%	3.68%

GRA is most important to simplify the actual experimental value of input factor and responses.

Predicted GRG= Mean GRG + (Mean GRG – Optimal Grades (1, 2, 3 … N))

S/N Ratio Analysis of Grey Taguchi Method

The S/N fraction of GRG is calculated as “smaller is better” option. The S/N fraction value is progressed in the table. 14.

Table 14: SN Ratio Table of GRA Value

Sl No	SS	FR	DOC	GRA	S/N Fraction of GRA
1	800	200	0.4	0.6169	4.19570
2	800	350	0.8	0.5800	4.73144
3	800	500	1	0.8333	1.583197
4	1200	200	0.8	0.4209	7.51642
5	1200	350	1	0.5222	5.64326
6	1200	500	0.4	0.5394	5.36178
7	1500	200	1	0.4134	7.67259
8	1500	350	0.8	0.4516	6.90492
9	1500	500	0.4	0.4625	6.69777

In the S/N ratio graph (Fig. 19), the spindle speed increases from 3.505 to 7.092 but in case of feed rate, the S/N fraction value is decreased from 6.462 to 4.548. In case of depth of cut, the S/N fraction value is increased from 5.418 to 6.384 then reduced to 4.967. Ultimately it is found that spindle speed is the maximum influencing parameter.

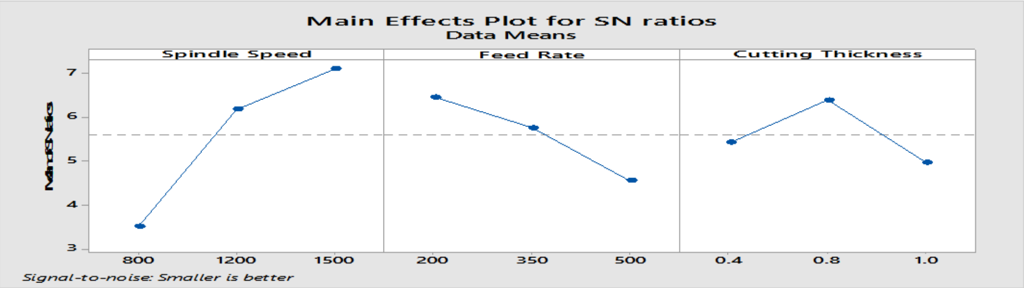

Figure 19: SN Ratio Plot of GRG Analysis

ANOVA Analysis of GRA

Table 15: ANOVAs Analysis of GRA

Factors	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Improvement
SS	2	0.039295	0.039295	0.019648	12.26	0.075	68.22%
FR	2	0.010905	0.008604	0.004302	2.68	0.271	18.93%
DOC	2	0.004193	0.004193	0.002096	1.31	0.433	7.28%
Error	2	0.003206	0.003206	0.001603			5.57%
Total	8	0.057599					100.00%

This table 15 represented that the ANOVA analysis of the input factor of grey relation grade. It defines the percentage of the contribution chart of the ANOVA analysis where spindle speed has maximum influence on machining process.

ANOVA Contribution Chart

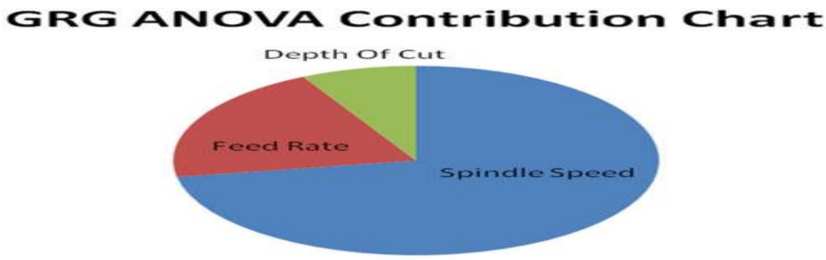

Figure 20: Pie Chart of the ANOVA Contribution Chart of GRG Value

Figure-20 indicates the exact ratio of contribution of the all input factors. The percentage of contribution is 74%, 19%, 7% analogous to speed of spindle, feed rate, depth of cut. This pie chart predicts the contribution percentage of spindle speed is greater as compared to feed rate and cutting depth.

CONCLUSIONS

The foremost target at the present experimental form is to optimize the multi response characteristics of the CNC milling process on Al 7075 MMCs, equipped by casting method followed by stirring action. The Grey Taguchi method is successfully implemented for optimizing the process parameters and simultaneously etching factor and manufacturing process parameters influences a lot for micro-structural image analysis. From the EDX study, the weight percentage of Al alloy, Al_2O_3 and B_4C are 80.95%, 8.23% and 1.5% respectively. The 'p' value obtained from the GRG calculations for all input factor is less than 0.5 that shows the significance of the result. The calculated GRG value is in the orthogonal array is corresponding to the ($A_1B_3C_3$). The theoretical GRG value is 0.8026. The experimental GRG value is 0.8333. The improvement value of the GRG is 0.0307 on initial design parameters $A_1B_1C_1$. From the GRG ANOVA, it is concluded that spindle speed contributed more as compared to other process parameters for machining through milling.

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