Experimental Study and Optimization of Process Parameters in Drilling of B_4c and Mg Reinforced Hybrid AMMCs Manufactured by Powder Metallurgy

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***Abstract* - In the present study, performance characteristics were calculated and optimized with grey relational analysis in drilling of B_4C and Mg reinforced hybrid aluminium metal matrix composites (AMMCs) manufactured by powder metallurgy. HSS, TiAlN coated and uncoated cementide carbide drills bits were used under dry cutting conditions. The drilling parameters such as feed rate, spindle speed, drill material and material parameters like wt. % of B4C as well as Mg particles were optimized based on multiple performance characteristics including thrust force, torque and surface roughness. Experiments were conducted on a computerised numerically controlled vertical machining centre. Drilling tool dynamometer is used to measure the thrust force and drilling torque. Also, to measure the surface roughness of drilled hole portable surface roughness tester is used which shows the readings in microns. Microstructure of composites and surface morphology of drilled hole is studied by using optical microscopy. Finally, it is concluded that, among the tools used, TiAlN coated carbide drill bit shows the better result than other drill bits used. Composites manufactured in present study shows better strength for all levels of reinforcement. Also, it is found that the drilling feed rate affects on the drilling process significantly.**

Keywords: Powder metallurgy, B_4C and Mg, Drill tool dynamometer, Optimization, hybrid AMMCs, Microstructure.

1. INTRODUCTION

Composites are widely used rather than conventional materials because of their superior properties. Al is most abundant metal in earth's crust. Aluminium acquires about 8% by weight of Earth's solid surface. Al is widely used due to its availability, low cost, high strength to weight ratio, due to enhanced machinability, durability, ductility and malleability. Further, Aluminium based Metal Matrix composites (MMC) have received increasing attention in recent decades as engineering materials due to their enhanced high strength to weight ratio, good mechanical properties, good corrosion resistance, enhanced thermal conductivity, better machinability and recyclability. It is mainly recognized for suitable wear resistance application over conventional Al alloy. It is one of the most prospective matrix metals for the production of composites [1, 2].

Composite materials are consistently increasing importance due to its unique properties and advantages over conventional material. Particulate metal matrix composites are used now days in automobile and aerospace industries. Researchers are working on low cost reinforcement materials for reducing the cost of composite material. The hybrid composites have proved better mechanical and wear resistance properties. The use of hybrid reinforcement in metal matrix is also useful for cost reduction. The machining of composite is always critical task and it affects on performance of material. In present study, Composite materials containing aluminium (Al) as matrix and Mangesium (Mg) as well as Boron Carbide (B_4C) hybrid mixture is used as reinforcement material.

Also, B_4C and Mg are used in today's days for production of MMC because of their inherent mechanical and chemical properties [3, 4]. Today researchers are focusing on B_4C because of their low density (2.51 g/cm3);high stiffness (445 GPa); high melting point (2450 0C);high hardness (3800–4200Hv) and good thermal stability [4,5] and on Mg because of their low cost, easily available, lower co-efficient of friction, elastic and incompressible, high electrical resistance and low temperature coefficient, Melting Point (650^0C), highly tough, having high tensile strength, elastic, and along with being flexible. It has immense compression power and can be machined, die-punched, or hand cut. Also, Mg is a natural occurring mineral and the best part is Mg can resist nearly all mediums like chemicals, acids, gasses, alkalis, and oils. The mechanical properties shown by metal matrix composites (MMCs), such as specific modulus and strength make them attractive for application in the aerospace and automotive sectors [6,15].Aluminium and its alloys have most attention, as a matrix material for MMCs [7,16].

Various production methods are used for production of MMC such as Powder Metallurgy (PM), infiltration, stir casting etc. PM has some important advantages such as

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simplicity; cheap processing and its ability to produce near net shape products [8].The machining processes are carried after manufacturing of composites. Drilling is one such process which is carried out in order to calculate responses of material [9]. Tool material, tool geometry, and cutting parameters affects on drilling performance. The tools used for drilling process are HSS tool, uncoated carbide tool, TiAlN coated carbide tool, etc. Ahmet and Kenan worked on drilling performance of Al- B4C composite manufactured by PM method and found that TiAlN coated carbide tool shows the best performance with regards to the surface roughness [4]. Tool geometry and cutting parameters are the most important factors which determine the quality of machining process. Recently machining of composite mainly focused on drilling process [10]. The presence of hard ceramic particles in the composites makes them extremely difficult to machine as they lead to rapid tool wear [11].The grey relational analysis is a method used to optimize the process parameters, since it is a valuable methodology for the design of qualitative and discrete parameters [12]. Grey relational analysis is carried by researchers to identify the influential parameter in drilling process like feed rate and spindle speed. The purpose of grey analysis in literature has been found to reveal the optimal combination of the drilling parameters that obtained the minimum tool wear [13].Also, In case of MMC literature study shows that surface roughness of drilled hole depends on cutting speed and feed rate [14].Literature study also shows that the feed rate is influencing parameter from surface roughness point of view [4].

In present study, drilling process is carried on Mg - B4C hybrid reinforced Al matrix composite manufactured by PM method. Further, the grey relational analysis is used to determine optimum drilling conditions on multi-performance characteristics such as thrust force, torque and surface roughness quality. The drilling parameters are set by Taguchi experimental design method. The thrust force, drilling torque and surface roughness after the drilling experiments with HSS, TiAlN coated and uncoated carbide drills are investigated Fig.1 shows that flow path of the study, which were followed in this study.

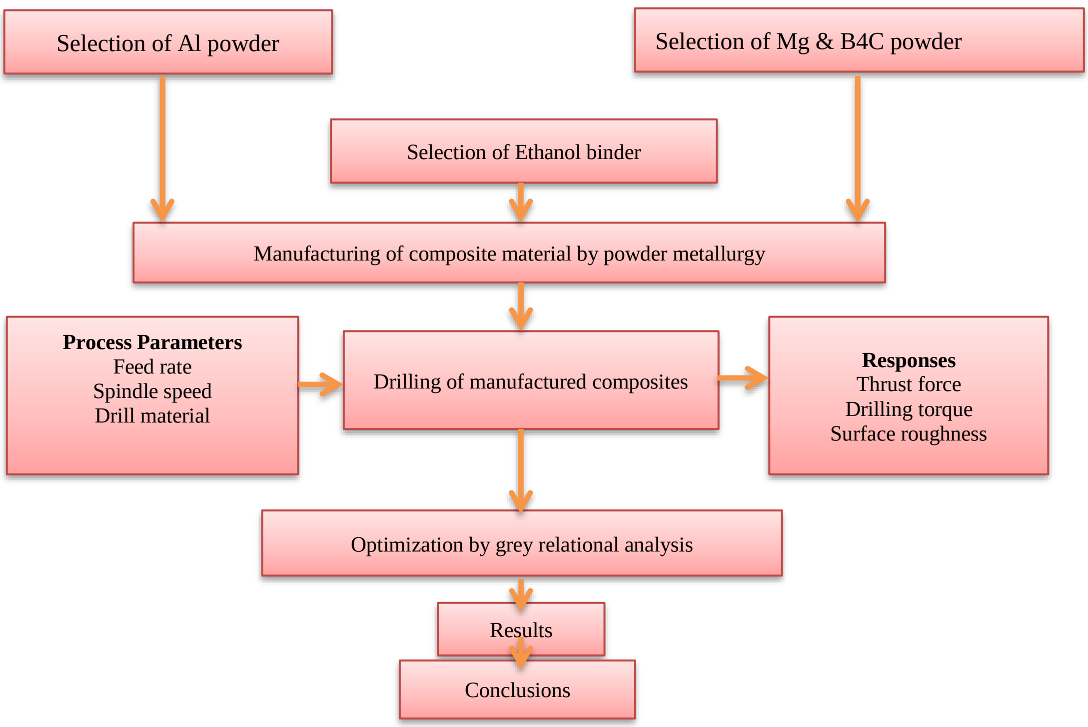

Fig. 1.Flow path of the study.

2. EXPERIMENTAL

2.1. Material selection

The materials used for fabrication of composites are of four types, i.e. Zinc, pure aluminium, Mg, and B4C. Zinc has ability to improve the bonding between two molecules. Also, Zinc has melting temperature lower than other metals hence it helps to fill the voids between metal and ceramic powders. Aluminium with particle size of 40 micron (μ) and Mg, B_4C with 45 μ, 40μ respectively sizes are used in the present study.

2.2. Composite production

In this work, composites are produced with 10%, 20% and 30% wt. % of Mg and B4C reinforcement in pure Al along with Zn and ethanol by using powder metallurgy route in circular dimensions of ϕ40× 12mm.This method was similar to the fabrication route used by previous researchers [4]. Further, to achieve these powders of aluminium, Mg, B4C and Zinc with above mentioned grain size were weighed with Symmetry EC4000 electronic balance having 0.1 gr accuracy and then uniformly mixed in a mixing bowl. The ball milling method, having 36 zirconium balls, for mixing

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of the powders was used. After filling that mixture in die, it was cold pressed using Universal testing machine until that achieve the 12 mm of thickness, approximately load applied was 275 KN. Later, in order to fill the voids between metal and ceramic powders with zinc, the furnace temperature was kept 540^0C and composite specimens were sintered for a two hours. Finally, the mold was kept inside the furnace until 250^0C furnace temperature and then placed in the open air to complete the cooling. Hardness and Compression tests were performed on the produced composites.

2.3. Drill tool selection

In order to drill the manufactured composites, total three tool materials are selected like HSS, Uncoated cementide carbide tool and TiAlN coated cementide carbide tool. Selected drill tool specifications are shown in table 1.

Table 1.Drill bit type and specifications.

HSS	ϕ8mm, 135^0 tool trip angle, spiral, 30^0 Helical angle
Uncoated Carbide	ϕ8mm, 140^0 tool trip angle, spiral, 30^0 Helical angle
TiAlN Coated Carbide	ϕ8mm, 140^0 tool trip angle, spiral, 30^0 Helical angle

2.4. Drilling of composite on VMC

In this work, for drilling of manufactured composites vertical machining center (VMC), Hytech MT-250 is used. The drilling parameters and levels are presented in Table 2. Coating thickness of TiAlN coated tool and hardness of coating material were 5µm and 2800HV, respectively. Picture of the drilled composite is shown in fig. 2, while picture of the VMC machine is shown in fig. 3.

Table 2. Drilling parameters and levels

Control Factors	Symbols	Units	Levels		
			1	2	3
Wt.% Mica & B_4C	A	%	10	20	30
Feed rate	B	mm/rev	0.1	0.2	0.3
Spindle speed	C	rev/min	1000	1500	2000
Drill material	D	Hv	HSS (800)	Uncoated Carbide (1500)	TiAlN Coated Carbide (2800)

.Fig. 2.Drilled Specimen.

Fig. 3.Drilling setup

2.5. Measurement of responses

While drilling of the manufactured composites on VMC machine with selected drilling parameters and levels, the thrust force and torque are measured by using drill tool dynamometer. Pictured of the drill tool dynamometer is shown in Fig.4.After drilling process has completed, Surface roughness was measured at four different locations by using Mitutoyo SJ-210 measuring instrument. Picture of the Surface roughness tester is shown in fig. 5.In order to obtain optimum surface roughness values of the drilled holes, the hole length should be smaller than 3 times the drill diameter [4].So, the drill bit diameter of 8 mm and hole length of 12 mm were selected. The surface roughness of the drilled composites was measured and average of four surface roughness values was used for reading.

Fig. 4. Drill tool dynamometer.

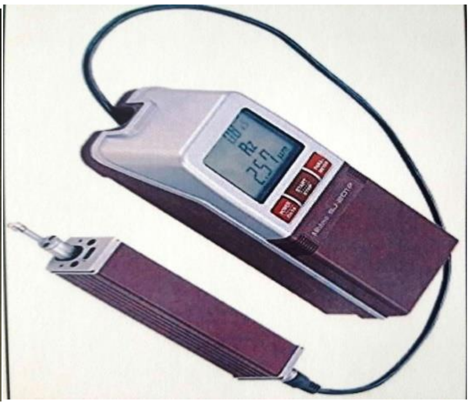

Fig.5. Surface roughness tester.

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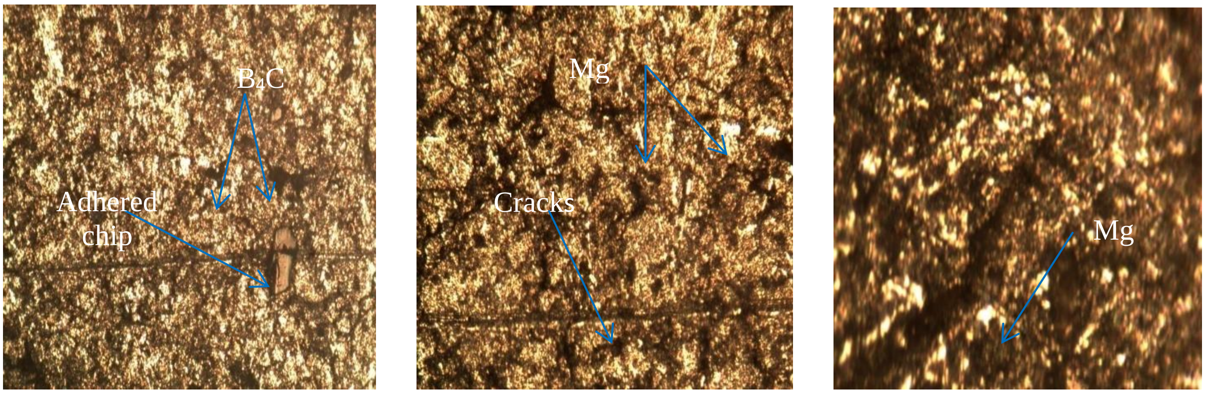
3. RESULTS AND DISCUSSION

3.1. Microstructure



(a)Al- 5% B4C & 5% Mg (b) Al- 10% B4C & 10% Mg (c) Al- 15% B4C & 15% Mg

Fig.6.Microstructure of Al-Mg-B_4C hybrid composites.

Microstructures of Al-Mg-B4C hybrid composites were checked using optical microscope at different levels of reinforcement which are shown in fig.6 (a), (b) and (c). Optical microscopes with camera attachment were used to capture the images of surface structure. A homogeneous distribution of reinforcement practical over the composites can be seen from the figure. In above images particle content of B4C and Mg is also shown with adhered chip and cracks.

3.2 Drilling forces and surface roughness

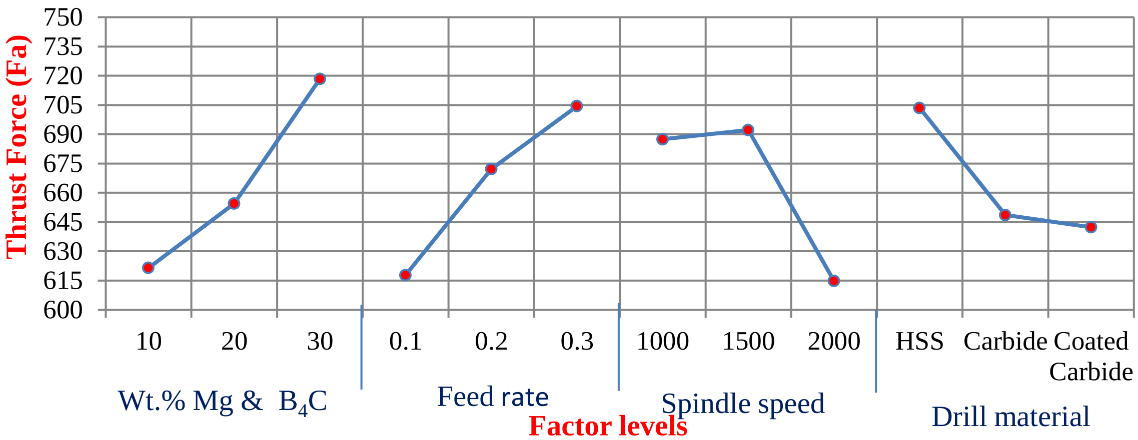


Fig.7. Effect of process parameters on the thrust force (Fa)

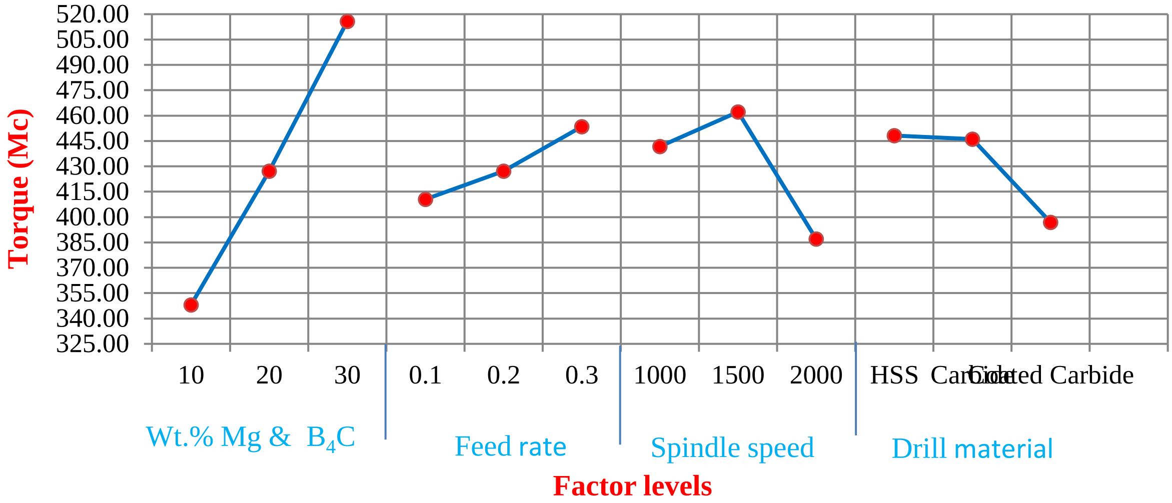


Fig.8. Effect of process parameters on the Drilling torque (Mc)

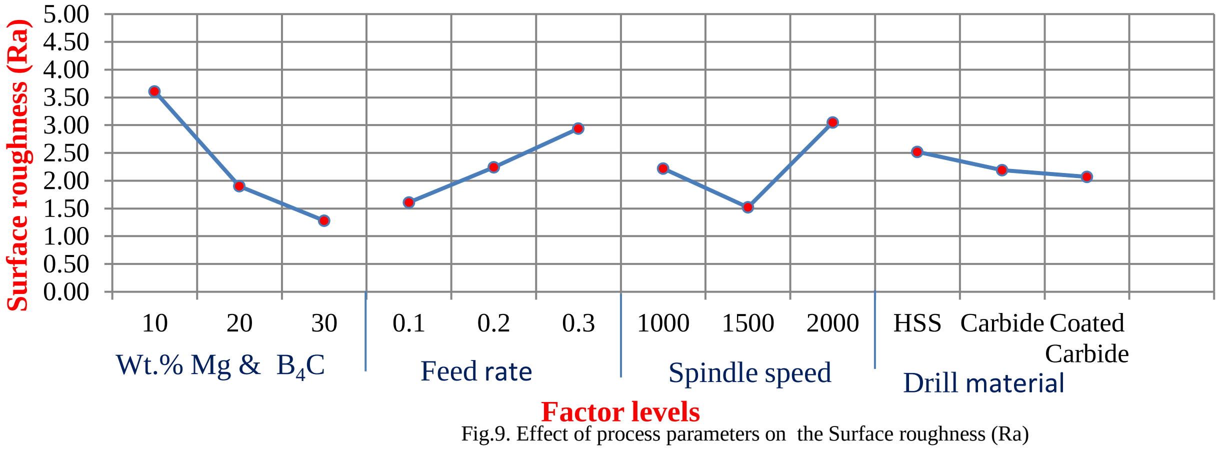


Fig.9. Effect of process parameters on the Surface roughness (Ra)

Experiments conducted on VMC, shows that the influence of the process parameters such as Wt.% of Mg and B_4C, spindle speed, feed rate and drill material on the thrust force and drilling torque is shown in Fig. 7 and Fig. 8 respectively. According to Fig.7 and Fig. 8 as Wt.% of Mg and B_4C increases thrust force and drilling torque both are increases. Also, as feed rate increases thrust force and torque increases. While using TiAlN coated carbide drill bit there is drastically decrease in thrust force and drilling torque. But, in case of surface roughness this results are different. As Wt. % of Mg and B_4C increases surface roughness decreases, while surface roughness increases in increasing feed rate.

3.3 Optimization by grey relational analysis

The optimization of Process parameters considering multiple performance characteristics of the drilling process forAl-Mg-B4C hybrid composites using the GRA is presented. Performance characteristics including thrust force, torque and surface roughness are chosen to evaluate the effects of process parameters while machining on VMC. Experiments based on the appropriate L9 Orthogonal array (OA) are conducted first. The normalized experimental results of the performance characteristics are then introduced to calculate the coefficient and grades according to GRA. The experimentally obtained values of thrust force, torque and surface roughness are also presented in Table 3. In this section, the use of the OA with the GRA for determining the optimal machining parameters is reported step by step.

Table 3.Experimental layout using an L9 OA and Experimental results

Exp.No.	Factors				Experimental Results		
	A	B	C	D	Fa(N)	Mc(N cm)	Ra(µm)
1	1	1	1	1	635.84	357.3	3.172
2	1	2	2	2	640.04	392.4	2.769
3	1	3	3	3	588.6	294.3	4.887
4	2	1	2	3	612.46	405.7	0.312
5	2	2	3	1	650.52	398.4	2.926
6	2	3	1	2	700.56	477.5	2.463
7	3	1	3	2	605.27	468.5	1.346
8	3	2	1	3	725.94	490.5	1.024
9	3	3	2	1	824.04	588.6	1.478

In GRA, data pre-processing is required since the range and unit in one data sequence may differ from the others. For this purpose, the experimental results are normalized in the range between zero and one, and these are presented in table 4. To obtain optimal drilling performance, the "smaller-the-better" quality characteristic has been used for minimizing the thrust force, torque and surface roughness. The Eq. (1) has been used to normalize the values between zero and one.

$$X_i^*(K) = \frac{max\, X_i\,(K) - X_i(K)}{max\, X_i\,(K) - min\, X_i\,(K)} \quad (1)$$

$$X_i^*(K) = \frac{824.04 - 635.84}{824.04 - 588.6}, \quad X_i^*(K) = \frac{188.2}{235.44}, \quad X_i^*(K) = 0.799$$

Similarly the remaining calculations are also made and all the sequences after data pre-processing using Eq. (1) are presented in Table 4.

Table 4.The sequences of each performance characteristic after data processing

Exp.No.	Normalization		
	Fa	Mc	Ra
Reference Sequence	1.000	1.000	1.000
1	0.799	0.786	0.375
2	0.782	0.667	0.463
3	1.000	1.000	0.000
4	0.899	0.621	1.000
5	0.737	0.646	0.429
6	0.524	0.378	0.530
7	0.929	0.408	0.774
8	0.417	0.333	0.844
9	0.000	0.000	0.745

Now, $\Delta_{0i}(K)$ is the deviation sequence of the reference sequence $X_0^*(K)$and the comparability sequence$X_i^*(K)$, i.e.

$$\Delta_{0i}(K) = |X_0^*(K) - X_i^*(K)| \quad (2)$$

The deviation sequence$\Delta_{0i}(K)$can be calculated using Eq. 2 as follows;

$\Delta_{0i}(1) = |X_0^*(1) - X_i^*(1)| = |1 - 0.799| = 0.201$, $\Delta_{0i}(2) = |X_0^*(2) - X_i^*(2)| = |1 - 0.786| = 0.214$

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$$\Delta_{0i}(3) = |X_0^*(3) - X_i^*(3)| = |1 - 0.375| = 0.625$$

So, for experiment no.1, $\Delta_{0i} = (0.201, 0.214, 0.625)$

Similar calculation is performed for i =1 to 9 and the results of all for i=1 to 9 are presented in Table 5. $\Delta_{\max}(K)$and $\Delta_{\min}(K)$ are obtained and are as follow:

$$\Delta_{max} = \Delta_{01}(1) = \Delta_{01}(2) = \Delta_{09}(3) = 1.00 \ \& \ \Delta_{min} = \Delta_{03}(1) = \Delta_{03}(2) = \Delta_{04}(3) = 0.00$$

Table 5.The deviation sequences

Exp.No.	Deviation sequences		
	$\Delta_{0i}(1)$	$\Delta_{0i}(2)$	$\Delta_{0i}(3)$
1	0.201	0.214	0.625
2	0.218	0.333	0.537
3	0.000	0.000	1.000
4	0.101	0.379	0.000
5	0.263	0.354	0.571
6	0.476	0.622	0.470
7	0.071	0.592	0.226
8	0.583	0.667	0.156
9	1.000	1.000	0.255

After data pre-processing is carried out, a grey relational coefficient can be calculated with the pre-processed sequence. It expresses the relationship between the ideal and actual normalized experimental results.ζ is distinguishing or identification coefficient. If all the parameters are given equal preference, ζ is taken as 0.5. The grey relational coefficients are calculated by Eq. (3) as follows:

$$\xi_i(K) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0i}(K) + \zeta\Delta_{max}} \quad (3)$$

$$\xi_i(K) = \frac{0 + (0.5 \times 1)}{0.201 + (0.5 \times 1)}\ , \quad \xi_i(K) = \frac{0.5}{0.701}\ , \quad \xi_i(K) = 0.714$$

Grey relational grades are calculated by Eq. (4) as follows, and all values are prescribed in Table 6.

$$\gamma_i = \frac{1}{3}\left(\xi_i(1) + \xi_i(2) + \xi_i(3)\right) \quad (4)$$

$$\gamma_i = \frac{1}{3}(0.714 + 0.700 + 0.444) \quad , \quad \gamma_i = 0.619$$

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Table 6.The calculated grey relational grade and its rank in the optimization process

Exp.No.	Grey relational coefficient			Grey relational grade	Rank
	Fa $\xi_i(1)$	Mc $\xi_i(2)$	Ra $\xi_i 3$	$\gamma_i = \frac{1}{3}(\xi_i(1) + \xi_i(2) + \xi_i(3))$	
1	0.714	0.700	0.444	0.619	4
2	0.696	0.600	0.482	0.593	5
3	1.000	1.000	0.333	0.778	2
4	0.831	0.569	1.000	0.800	1
5	0.655	0.586	0.467	0.569	6
6	0.513	0.445	0.515	0.491	8
7	0.876	0.458	0.689	0.674	3
8	0.462	0.429	0.763	0.551	7
9	0.333	0.333	0.662	0.443	9

The overall evaluation of the multiple performance characteristics is based on the grey relational grade, that is:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(K) \tag{5}$$

The higher grey relational grade represents that the corresponding experimental result is closer to the ideally normalized value. Experiment 4 has the best multiple performance characteristics among nine experiments because it has the highest grey relational grade. Since the experimental design is orthogonal, it is then possible to separate out the effect of each machining parameter on the grey relational grade at different levels. The mean of the grey relational grade for each level of the machining parameters is summarized and shown in Table 6. In addition, the total mean of the grey relational grade for the nine experiments is also calculated and presented in Table 6.

Table 6. Response table for the grey relational grade

Symbol	Machining Parameters	Grey relational grade			Main effect (max-min)	Rank
		Level 1	Level 2	Level 3		
A	Wt.% Mg & B_4C	0.663*	0.620	0.556	0.107	4
B	Feed rate	0.698*	0.571	0.571	0.127	2
C	Spindle speed	0.554	0.612	0.674*	0.120	3
D	Drill material	0.544	0.586	0.710*	0.166	1
Total mean value of the grey relational grade γ_m = 0.6132						
* Levels for optimum grey relational grade						

Fig.10.shows the grey relational grade obtained for different parameters. The mean of grey relational grade for each parameter is shown by horizontal line. Basically, the larger the grey relation grade is, the closer will be the product quality to the ideal value. Thus, larger grey relational grade is desired for optimum performance. Therefore, the optimal parameters setting for lesser thrust force, torque and surface roughness are (A1B1C3D3) as presented in Table 6. Optimal level of the process parameters is the level with the highest grey relational grade.

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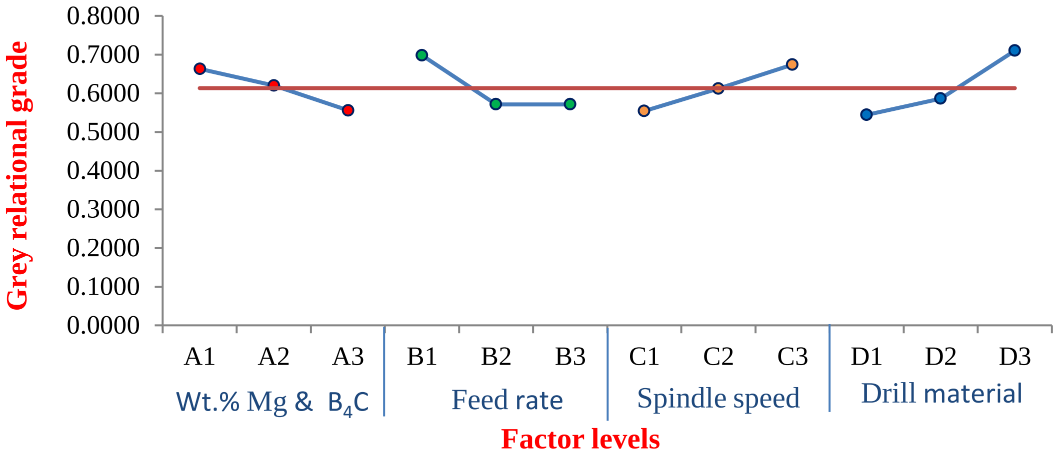

Fig. 10. Effect of EDM parameters on the multi-performance characteristics

4. CONCLUSION

In this work, drilling experiments were performed to study the effects of drilling process parameters such as reinforcement percentage, feed rate, spindle speed and drill material on thrust force, drilling torque and surface roughness. According to the experimental result carried out following conclusions are given below.

1) From the experimental results, as the reinforcement percentage and feed rate increases thrust force and drilling torque increases.

2) Surface roughness drilled hole decreases as reinforcement percentage increases, while as feed rate increases, surface roughness also increases, while the results of surface roughness are excellent by using TiAlN coated carbide drill bit.

3) From the grey relational analysis, the best levels of Wt.% of Mg and B_4C was 10% reinforcement, feed rate was 0.1, spindle speed was 2000 and drill bit was TiAlN coated carbide tool because they gives the higher grey relational grade.

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