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Optimization of turning parameters for Magnesium Silicon Carbide using TOPSIS method

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Abstract. A composite consists of at least two constituent parts, one being a metal necessarily, and the other material may be a different metal or another material, such as a ceramic or organic compound. As a lightest metal structural material, magnesium matrix composites exhibit many advantages over monolithic magnesium or magnesium alloys, such as high elastic modulus, high strength, and superior creep at elevated temperatures. Magnesium based metal matrix composites had been used in biomedical operations due to biocompatibility and ductility. Magnesium Silicon Carbide (MMC) is casted with Magnesium 90% by mass and Silicon Carbide 10% by mass through Stir Casting process. Turning operation was performed according to the DOE with the utilization of CCD. The input factors considered for the experimentation is of three levels and the output responses are surface roughness, surface hardness and out of roundness. Using Entropy method, weightage for TOPSIS method is calculated. The multi-responses were optimized using Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) and optimal parameters were determined and found to be cutting speed as 500rpm, feed as 0.2mm/rev and depth of cut as 0.2 mm.

1. Introduction

A metal matrix composite (MMC) is a material with two integral parts, one a metal and the other a dissimilar metal or alternative material, such as a ceramic or an organic compound. They cover a widespan variety of materials characterised by three factors namely metal matrix, type and geometry of reinforcements. In vicinity of the matrix, most metallic systems are discovered hence used in MMCs, such as Aluminium, Beryllium, etc. till date, the prime usage is in aluminium MMCs.Aluminium is a very common metal that has low risk in any machining processes. Also, it is very cost effective in nature in comparison with the other kinds of metal. Some properties that aluminium MMC's exhibit are high strength, better-quality stiffness, low density, high oxidization resistance and enhanced damping capabilities. Aluminium MMC's have a wide range of applications in the automotive industry (e.g. valve train, piston and piston pin etc.). Some of the most commonly used Aluminium MMC's are Al/SiC)_p, Al/SiC)_w, and Al/Al₂O₃ etc.

Magnesium based metal matrix composites are being developed only in the recent past and is relatively new type of MMC when compared to its various other types such as zinc or aluminium based MMCs. Silicon carbide particles act as the strengthening segment in light weight metals. These provide increased modulus, roughly 40% more than unreinforced Mg composites. The Magnesium MMC is applied in the Aerospace (canopies, engine compartments etc.) Mechanical (motor racing

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applications) and biomedical (orthopaedic applications) industries. Examples are Mg/SiC)p, Mg/Al2O3 and Mg/Zn etc. CNC machining is a process where computer software allows us to program and run the operations of machine tools. The process is used to regulate a series of intricate machinery. The machining operations are automatic involving little to no manual control. Simulations can be run on the machine before proceeding to the operations to check for any errors that may or may not occur.

Optimization of machining parameters is mainly used to select the most optimum or values of high precision for efficient machining. It is important to reduce the time of machining and the cutting force, in order to increase the yield and tool life so that there will be an improvement in surface finish characteristics. Some methods involved in optimization are ANOVA, Regression, Taguchi analysis, Response Surface Methodology, TOPSIS etcAnalysis of variance is mainly a group of arithmetical representations and its related approximation techniques used to analyse variances between group means in a sample. It provides a statistical test of whether two or more sample size means are equal.Regression analysis is a set of statistical processes for assessing the relationships between a reliant and more than one autonomous variable. It is principally used for two abstractly distinct purposes. The first use is to predict and forecast wherever it has considerable similarity with the field of machine learning. The second use is to surmise spontaneous connections amongst the autonomous and reliant variables.

Taguchi methods are arithmetical approaches, occasionally termed as robust design methods, which are used for the quality improvement of manufactured goods. It contains three primary assistances to measurements namely: definite loss function; the viewpoint of off-line quality control and design of experiments innovations. Response Surface Methodology is the relationships between multiple expressive variables and more than one response variables. RSM is engaged to use a sequence of calculated experimentations in acquiring an optimal response. It is employed in exploiting the production of a special substance by optimization of operational factors.

TOPSIS or Technique for Order of Preference by Similarity to Ideal Solutions is created on the thought that the substitute that is picked ought to have the most limited geometric distance from the positive perfect arrangement and the longest geometrical distance from the negative perfect arrangement. Compensatory collection is utilized to analyse a gathering of substitutes by discovering weightage for every measure, normalizing scores for everyone and ascertaining the geometric separation between each substitute and the perfect other option, which is the best score of model.

Diptikanta et al. [1] investigated the influence of process parameters on surface roughness characteristics and optimized the turning process using ANOVA. Four different levels of machining parameters were taken for spindle speed, feed rate and depth of cut. Taguchi L16 DOE was used to conduct trials using signal to noise ratio. Results of ANOVA reveal that for Rz, feed is the most important factor followed by spindle speed and for Rt, spindle speed is the most important characteristic followed by depth of cut.Shankar et al. [2] studied that high-speed machining is an important factor in machining technology, it is hard to machine materials like titanium, and nickelbased alloys. An alternative method suggested was grinding operation for high turning process but in this investigation, the turning operation was executed on Inconel 625. The principle objective of the experimentation was to observe the response parameters like surface roughness and cutting forces while considering feed rate, depth of cut and cutting speed as input parameter. The DOE was carried out as per Taguchi's L9 orthogonal array method throughout the turning process. Further outcomes were examined using ANOVA. Rajesh et al. [3] investigated on obtaining the optimum processing parameters during Electrical Discharge Machining (EDM) of Al-SiC metal matrix composite. The processing parameters were peak current, pulse-on time and flushing pressure for the corresponding outputs such as Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (Ra). Optimization of the numerous responses problem were done using Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) methodology. The Analysis of Variance (ANOVA) technique was used to analyse and find the impact of models and thereby study the consequences of processing parameters. Jaison et al. [4] conducted optimization of numerous elements, which was done

on parameters of the drilling action by methods of Taguchi and TOPSIS. Work piece material was Glass fiber reinforced plastic. Three different levels of input parameters were used for drilling parameters and they are cutting speed, feed rate and drill diameter. The output characteristics measured were surface roughness, material removal rate and delamination factor.Gopal et al. [5] performs end milling operation on Magnesium (Mg) Metal Matrix Composite (MMC) by means of carbide tool and checks effects of machining and material parameters applicable on surface roughness, cutting force and temperature. The effect of four different variables speed, tool diameter, feed rate and depth of cut were the input process parameters. DOE using L27 orthogonal array was used to create trials. Multi-objective optimization was performed by Grey Relational Analysis (GRA) and Techniques for Order Preferences by Similarity to Ideal Solution (TOPSIS).

Jaydev, et al. [6] performs electro-discharge machining with copper electrode and investigates the optimization of process parameters. L9 orthogonal array was used to conduct the trials. Input current, flushing pressure, pulse-on time and pulse-off time were the input process parameters while material removal rate, surface roughness, rate of tool wear, and percentage of radial overcut, crack width, and surface crack density were the output parameters. TOPSIS was performed to get the ideal solution. Analysis by ANOVA yields input current to be the most significant factor than other parameters.Jimmy et al. [7] studied the process characteristics of Al–Si–TiB2 composite. Cutting speed, feed rate & depth of cut were the process parameters whereas feed force, cutting forces & surface roughness were the output parameters. The process was analysed using ANOVA.Manikandan et al. [8] studied the selection of material, machining conditions and optimization techniques for finding the feasible solutions. Cutting speed, feed rate, depth of cut & nose radius were the process parameters. Average surface roughness was taken as the output parameter. The process was further optimized using ANOVA & Taguchi Methods.

Prasanth et al. [9] studied the friction characteristics of AA6063/SiC co-continuous composite using Taguchi grey Relational analysis method. The process parameters were applied load, sliding load and sliding distance. Coefficient of friction and wear rate were the output parameters. Ananthakumar et al. [10] studied the PAC characteristics of Monel 400 super alloy which was further optimized using TOPSIS. Cutting speed, arc current, gas pressure & stand-off distance were the input parameters. The output parameters were material removal rate, kerf taper & heat affected zone. Seyed et al. [11] studied the turning characteristics of Ti under various flow rates. The process parameters were cutting speed, constant length of cut & flow rate. The output parameters that has been considered were the cutting forces & surface roughness. ANOVA method was used for process optimization..Avijit et al. [12] investigated electric discharge machining done on the work-piece material AlSiC MMC (20% SiC reinforcement) by copper tool electrode. Input current, pulse on time, duty cycle & gap voltage were the input parameters. The output parameters were material removal rate, tool wear rate, and diametrical overcut and surface roughness. Principal component analysis (PCA) and TOPSIS were the methodologies applied for process optimization.

From the above literature studies, very limited machining processes have been carried out on Magnesium Metal Matrix composites and due to its limitation of high flammability. Hence turning operation has been conducted at an ideal rate by means of optimization of machining parameters using TOPSIS methodology.

2. Methodology

2.1. Fabrication.

The composite Mg-SiC is fabricated by Bottom Pouring Stir Casting method. The composite is of the composition 90% by weight of Mg and 10% weight by SiC. Stir casting (Figure 1) is a processing method used to produce or manufacture MMC's such as magnesium matrix based composites and magnesium compound matrix based composites as it is a feasible process and is suitable for bulk production.

Stir casting (Table 1) primarily involves melting of magnesium blocks as this is a liquid-state method. Stir casting system set-up comprises of components such as furnace, reinforcement feeder, mechanical

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stirrer, electrical motors and crucible. The incinerator is utilized for warming and liquefying of the materials. The base poring heater is progressively agreeable and fitting for the mix as after mixing of blended slurry immediate poring is essential to avoid settling of the solid particles to the bottom of the crucible. Simultaneously, reinforcements (here SiC powder) are pre-heated in another incinerator to a temperature that helps eliminate humidity and other impurities. After liquefaction of the matrix material at set temperature the mechanical stirrer is pivoted to shape whirlpool for given time length after which the reinforcements particulates are added by the feeder provided in the arrangement at a steady feed rate to the middle of the whirlpool formed. Stirring procedure is continued for some time after completely serving reinforcement particles. The dimensions of prepared composites are 50 mm diameter and 300 mm length.



Figure 1. Bottom Pouring Type Stir Casting Machine.

Table 1. Stir Casting Process Parameters			
Stirring Speed	300 rpm		
Stirring Time	10 – 15 min		
Melting point Temperature	750^{0} C		
Furnace Temperature	800^{0} C		

(As per machine standard)

2.2. Design of Experiments.

Design of experiments is a statistical approach of planning, conducting and analysing tests or trials of a process. It helps to ascertain and discover the relationship between factors affecting that process and the output of that process. The experiments set up trials based on pre-conditions and checks the effect of varying parameters on the output.

2.3. Central Composite Design.

CCD is used to create a designed experiment for 2-10 factors and identify factors that could optimize response. The DOE is expressed as a Central composite design of 3 continuous factors. The input parameters for the DOE is taken as Speed (rpm), feed (mm/min), Depth of Cut (mm) based on literature ^[14] for optimal parameters of Mg- SiC.

2.4. Turning.

Turning operation is performed on both the sets of components. It is performed at the interval of 15mm for each set of values. After the completion of the turning process each of the separate specimens are measured for output parameters such as surface hardness, surface roughness and out of roundness.

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2.5. Output Parameters.

2.5.1. Surface Roughness. Surface roughness or just irregularity, is a subsidiary of surface quality and finish. It is measured by the divergences in the direction of the normal vector to a real surface from its idyllic form. If these are large beyond a certain level, the surface can be considered rough; if minimum, the surface is considered smooth. Surface roughness is measured using SURFCOM 1400 G Zeiss (Figure 2) which has a stylus range of 5mm. The stylus used is 2µm diamond tip.



'Figure 2. Surface Roughness Tester.

2.5.2. Surface Hardness. The hardness of the surface of a component affects their tribological performance. It is the measure of resistance to indentation on application of force. The hardness of a component is estimated by creating an indentation with a small indenter made of a harder material by applying force to it. The hardness can then be deduced from the breadth, depth or spread of the indentation. In the above test we used Vickers hardness (Figure 3) to the measure the hardness values. Load of 10 kgf is applied for a dwell time of 10 seconds. A diamond tip indenter is used for the same.



Figure 3. Vickers Hardness Machine.

2.5.3. Out of Roundness (Circularity). Out-of-roundness is "the radial deviation of the actual profile from ideal roundness," and the out-of-roundness value (OOR) is "the difference between radiuses of the largest roundness and the smallest roundness of a measured profile". These radii must be computed from a common point. The Moving bridge type coordinate measuring machine (Contura G2) (Figure 4) is used to measure the circularity. The stylus used is made of ruby of 3 mm and stem length is of 33 mm. Tolerance band is 0.05.



Figure 4. Coordinating Measuring Machine.

S.	Input Parameters			Output Parameters		
No.	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)	Surface Roughness (µm)	Out of Roundness (mm)	Surface Hardness (HV)
1	300	0.1	0.3	0.3755	0.0552	62.3
2	300	0.3	0.3	0.7585	0.0326	69.6
3	700	0.3	0.3	0.6314	0.0187	70.5
4	700	0.1	0.3	1.0479	0.0192	98.5
5	500	0.2	0.3	0.677	0.0103	98.3
6	300	0.2	0.2	0.8318	0.082	73.8
7	500	0.3	0.2	0.5733	0.086	63
8	500	0.2	0.2	0.3772	0.0173	61.4
9	700	0.2	0.2	0.5465	0.0196	51.8
10	500	0.1	0.2	0.6641	0.0436	66.6
11	300	0.3	0.1	0.9066	0.0253	46.26
12	700	0.3	0.1	0.5018	0.0115	50.1
13	300	0.1	0.1	0.2403	0.079	53.8
14	500	0.2	0.1	0.249	0.041	49.8
15	700	0.1	0.1	0.2967	0.0158	52.8

Table	2.	Exper	imental	Cond	litions
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3. TOPSIS optimization methodology

Technique for Order Preference by Similarity to an Ideal Solution or TOPSIS is an Optimization tool where multiple process parameters could be optimized and the best results are obtained among various experiments.

In this method three alternatives are hypothesised:

1. Ideal Alternative: One which shows the best attribute value (Ex. Max. Hardness, Min. Surface roughness, Min. out of roundness)

2. Negative Ideal Alternative: One which shows the worst attributes value (Ex. Min Hardness, Max. Surface roughness, Max. out of roundness)

The entropy based TOPSIS method is an objective method, in which the process of determining the weights and decision result does not cause inclusion of any subjective predilection but completely depends upon the objective data of alternatives. The Steps of this technique are as follows:

3.1 Entropy Method.

Step 1: The Decision matrix is normalized using the formula

$$p_i = \frac{x_i}{\sum_{i=1}^m x_i} \qquad x_i - Output Parameter \tag{1}$$

			(1.)
S.	Min (SR)	Min (OOR)	Max
N0.	0.040070	0.164075	(Hardness)
1	0.043272	0.164875	0.064322293
2	0.087409	0.097372	0.071859255
3	0.072762	0.055854	0.072788469
4	0.120759	0.057348	0.101697365
5	0.078017	0.030765	0.101490873
6	0.095856	0.024492	0.076195589
7	0.066067	0.025687	0.065045015
8	0.043468	0.051673	0.063393078
9	0.062978	0.058542	0.053481457
10	0.07653	0.130227	0.068761873
11	0.104476	0.075568	0.047761626
12	0.057827	0.034349	0.051726274
13	0.027692	0.023596	0.055546378
14	0.028695	0.122461	0.051416536
15	0.034191	0.047192	0.054513918

Table 3. Normalized matrix (p_i).

Step 2: Compute Entropy index (E _i)	
$E_i = \left(\frac{1}{\ln(m)}\right) \sum_{i=1}^m p_i \ln p_i - 1$	(2)
Step 3: Compute d_i value	
$d_i = 1 - E_i$	(3)
Step 4: Compute w_i , which gives the entropy weight for index <i>i</i>	

$$w_i = \frac{d_i}{\sum_{i=1}^n d_i} \tag{4}$$

S No. Surface Roughness Out of Roundness Vickers's Har	dness
5. 10. Sufface Roughiless Out of Roundiless Vicker's Sifiar	
E 2.612381 2.513499 2.666520427	
D -1.61238 -1.5135 -1.66652042	
W 0.336445 0.315812 0.347742285	

3.2 TOPSIS Method.

Step 1: Calculation of the normalised decision matrix (r_{ij}) using formula

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{k} x_{ij}^2}} \tag{5}$$

Step 2: Weighted normalised decision matrix (V_{ij}) is computed. Matrix is formed by as:

 $V_{ij} = w_j \times r_{ij}$ The calculated weighted normalized matrix should be depicted in this format: $V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_n r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_1 r_{k1} & w_2 r_{k2} & \dots & w_n r_{kn} \end{bmatrix}$ (7)

S.	Min (SR)	Min (OOR)	Max
No. 1	0.111179	0	(Hardness) 0.084215
2	0.047851	0.051551	0.094083
3	0.068867	0.083258	0.0953
4	0	0.082117	0.133149
5	0.061327	0.102418	0.132879
6	0.035731	0.107208	0.099761
7	0.078474	0.106296	0.085162
8	0.110898	0.086451	0.082999
9	0.082905	0.081205	0.070022
10	0.06346	0.02646	0.090028
11	0.023364	0.068203	0.062533
12	0.090296	0.099681	0.067724
13	0.133534	0.107893	0.072725
14	0.132096	0.032391	0.067318
15	0.124209	0.089872	0.071373

 Table 5. Weighted Normalized Matrix.

Step 3: Compute the Positive Model (Ideal Matrix) and Negative Model Solutions (Worst matrix) using formula

$A^* = \{v_1^*, v_2^*, \dots, v_n^*\} = \{$	$\max v_{ij} \mid j \in J), (\min v_{ij} \mid j \in J'\}$	(8)
$A^- = \{v_1^-, v_2^-, \dots, v_n^-\} = \{$	$\{(\min v_{ij} j \in J), (\max v_{ij} j \in J')\}$) (9)

Table 6. Ideal matrix.				
S. No.	Min	Min	Max	
	(SR)	(OOR)	(Hardness)	
1	0.022532	0.065193	0.049321	
2	0.086361	0.032379	0.039375	
3	0.065179	0.012196	0.038149	
4	0.134591	0.012922	0	
5	0.072779	0	0.000272	

(6)

6	0.098577	0.104105	0.033653
7	0.055496	0.109913	0.048368
8	0.022815	0.010164	0.050548
9	0.05103	0.013503	0.063627
10	0.070629	0.04835	0.043463
11	0.111043	0.021779	0.071175
12	0.04358	0.001742	0.065944
13	0	0.099749	0.060902
14	0.00145	0.044575	0.066352
15	0.009399	0.007986	0.062265

Table 7. Worst matrix.

S. No.	Min (SR)	Min	Max
		(OOR)	(Hardness)
1	0.112059	0.04472	0.021854
2	0.04823	0.077534	0.0318
3	0.069412	0.097716	0.033026
4	0	0.09699	0.071175
5	0.061813	0.109913	0.070903
6	0.036014	0.005808	0.037522
7	0.079095	0	0.022808
8	0.111776	0.099749	0.020628
9	0.083561	0.09641	0.007548
10	0.063962	0.061563	0.027713
11	0.023548	0.088134	0
12	0.091011	0.10817	0.005232
13	0.134591	0.010164	0.010273
14	0.133141	0.065338	0.004823
15	0.125192	0.101927	0.008911

Step 4: Separation measures are calculated for every substitute from the best solution by using formula

$$S_i^* = \sqrt{\sum_{j=1}^n (V_j^*)^2}$$
(10)

Step 5: Relative closeness is calculated to the best solution for each by means of formula

$$C_i^* = \frac{s_i^-}{s_i^- + s_i^*}$$

(11)

Table 8. Relative closeness.				
S. No.	Si*	Si ⁻	CI*	
1	0.120562	0.113873	0.485735	
2	0.109736	0.077089	0.412625	
3	0.078875	0.112908	0.588727	

4	0.135999	0.824201	0.858364
5	0.072415	0.138561	0.656762
6	0.103347	0.11898	0.535157
7	0.073055	0.134049	0.647254
8	0.059053	0.142095	0.706421
9	0.08521	0.116291	0.577125
10	0.115763	0.074049	0.390118
11	0.136746	0.072094	0.345211
12	0.078851	0.134598	0.630586
13	0.060424	0.171977	0.740001
14	0.100182	0.136093	0.575996
15	0.065023	0.153568	0.702536

Step 6: Alternatives are ranked in their reducing order in respect to their relative closeness to the ideal solution

Thus, the optimum machining parameters for Turning process of Magnesium MMC was found to occur at 500 rpm speed, 0.2 mm/min feed, 0.2mm depth of cut and output parameters were 0.3772 μ m Surface roughness, 0.0173 Out of Roundness and 61.4 Vickers Hardness. The optimization was carried out using TOPSIS methodology. Conformity test was conducted, and the corresponding output results was found to be 0.3631 μ m Surface roughness, 0.018 Out of Roundness and 63.70 Vickers Hardness with an error percent of 3.75%.

4. Conclusion

Thus, the research regarding the process of turning on Mg / SiC Metal Matrix composite was done and then further optimized using the process of TOPSIS. The most optimum value was found to be for each output parameters at 0.3772 for surface roughness, 0.0173 for out of roundness and 61.4 for Vickers Hardness. The subsequent process parameters were found to be 500 rpm speed, 0.2 mm/rev feed and 0.2 mm depth of cut. Using these three values, the turning process was once again performed on the composite to arrive at the most optimum condition for the Magnesium Silicon Carbide Metal Matric Composite.

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