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EXPERIMENTAL INVESTIGATION OF PROCESS PARAMETERS IN DRILLING LM25 COMPOSITES COATED WITH MULTI WALL CARBON NANO TUBES USING SONICATION PROCESS

Aluminium based metal matrix composites are widely used in automobile components such as cardan shaft of Chevrolet corvette, disc brake and engine push rod. In this experiment a Hybrid Metal Matrix Composites (HMMC) are fabricated and drilled. Drilling is the process of making slots in disc brake and thread in the engine parts. The surface quality of the drilled specimen depends on the speed, feed, drill type and the thrust force. Thrust force plays the major role in drilling the specimen. In this experiment HMMCs are fabricated using two processes-called, sonication and casting. Sonication is the process of coating the carbon nanotubes over the silicon carbide particles (SiCp). Semisolid stir casting is used to reinforce the coated SiCp in the LM 25 alloy. A drilling process is performed on HMMC to analyse the extent to which the input parameters influence the thrust force and Ovality. The tools used for drilling are solid carbide tools of three different diameters. Taguchi's experimental design is adopted for the drilling operation. A mathematical model is used to determine the influence of input parameters on the outputs thrust force and ovality. This paper proves the combination of N_3, f_1 and d_1 of the carbide tool results in the lowest value of thrust force and ovality while drilling HMMCs. In this work the HMMC is prepared by coating the abrasive nature, silicon carbide particle and there is a good interfacial bonding between the reinforced particle and matrix and the drilling process becomes smoother. The new being of this article is the treated ceramics, SiCp with carbon nanotubes. This HMMC shows the improved mechanical properties compared to other metal matrix composites surveyed in the literatures.

Keywords: Drilling; Feed Rate; Hybrid metal matrix Composites; Response Surface Methodology; Sonication; Thrust Force.

1. Introduction

Silicon-based metal matrix composites are the most commonly used materials in automobile brake systems [1]. Fabricated hybrid metal matrix composites consist of silicon carbide particles [SiCps] of 400 mesh sizes [2] coated with multi-wall carbon nanotubes [MWCNTs] as reinforcements.

In this paper the grit size of the reinforced particle is 400 mesh because the authors, Meena, et al., reduced the tool wear in their experiments. They preferred the small grit sized reinforcement. The experiment was conducted with 400 mesh sized silicon carbide particle and thus reduced the tool wear from .0025gm per min to .0015gm per min.

10% of silicon carbide particles is used in this experiment. Muthukrishnan and Davim. [3] Conducted an experiment to reduce the wear of the tool. They explored that the tool wear was reduced by using 10 -20% of SiCps.

In this experiment hybrid metal matrix composites, have been used since the authors, Velmurugan, et al [4] compared the surface quality of two specimens namely hybrid composites [Al\SiCp\Gr] and metal composites [Al\SiCp]. The authors proved that the surface quality of hybrid metal composites were better than the metal composites.

The author Wieczorek, proved by an experiment that the mixing of copper and carbon nano powder increased the mechanical properties such as hardness and compressive strength [5].

A. Erotica, proved that the presence of silicon carbide particle extended the cracks and voids during the fatigue loading process and hence the coarse reinforcement should be treated or coated [6].

The authors, Sahar Amiri and Azam Rahimi proved that by adopting a coating process the surface of the substrate was protected from corrosion and they adopted sol gel process for coating [7].

In this paper MWCNTs are coated over SiCps using sonication process. The coated SiCps are mixed with aluminium alloy [LM 25] by the semisolid stir casting process. The reinforced material is treated with MWCNT and hence the surface quality of the fabricated specimen is better than the untreated reinforcements.

Paulo Davim [8,9] conducted a machining operation in a metal matrix composite (A 356/ SiCp/T6). It was proved in

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this experiment the input parameter feed rate (43%) greatly influenced the output surface roughness followed by cutting speed (41%).

Rajmohan et al. [10] proved that the surface roughness increases with the increase in feed rate values and the surface roughness of HMMC (A 356/SiCp/Mica) decreases with the increase in spindle speed values. They also showed that the surface roughness is minimized by a certain combination of spindle speed and feed rate values 3000 RPM and 50 mm per min, respectively. The spindle speed values tested in the experiment were 1000, 2000 and 3000 RPM, and the feed rate values were 50, 100 and 150 mm per min. The drills used were coated carbide tools and Polycrystalline Diamond-coated [PCD] tools.

Muniraj et al. [11] conducted a drilling operation on a hybrid metal matrix composite [Al/SiC/Gr]. The input responses were spindle speed, feed rate and type of drill, and the output responses observed were thrust force and surface roughness. The feed rate values were 0.05, 0.1 and 0.15 mm per rev. The spindle speeds applied were 1000, 2000 and 3000 RPM, and the types of drill bits used were coated carbide drill and multi-faced drill. It was proved that the thrust force had a maximum value of 120 N when the feed rate increased from 0.05 to 0.15 mm per rev. Similarly, the surface roughness also had a maximum value of 3 μm at the maximum feed rate value.

Suresh et al. [12] tested hybrid metal matrix composites with various proportions of reinforced materials [Al/SiC/Gr]. The hybrid metal matrix composites were tested through a machining operation. The input parameters considered for machining hybrid metal matrix composites were cutting speeds of 100, 150 and 200 mm per min, feed rates of 0.075, 0.100 and 0.125 mm per rev and mass fractions of reinforced graphite with percentages of 5, 7.5 and 10. The best combination of input parameters was the 200 RPM spindle speed, 0.075 mm per rev feed rate and 10% graphite reinforcement. It was proved that in certain combinations of input parameters, the surface roughness were reduced to 1.6 μm, and the flank wear was also reduced to 0.18 mg. At the same combination of input parameters, the authors achieved the maximum metal removal rate of 36.4 gm per min and improved the tool life by 43 min.

Basavarajappa et al. [13] tested both metal matrix composites [Al 2219/15%SiCp]] and hybrid metal matrix composites [Al 2219/15%SiCp/3%Gr] using a drilling operation. Drilling was performed with a multi-faceted drill bit of 5 mm diameter. Spindle speed and feed rate were used as input parameters during drilling operations. It was proved that better machinability was achieved with the graphite-reinforced composites. The input parameters used for the drilling operation were spindle speeds of 1000, 2000 and 3000 RPM and feed rates of 0.10, 0.2 and 0.3 mm per rev. Taguchi experiments and ANOVA were employed to analyze the drilling characteristics. They also proved that the feed rate greatly influenced the thrust force. For metal matrix composites, the thrust force was 800 N at 0.3 mm/rev, and the thrust force was 400 N at a feed rate of 0.1 mm per rev. For the hybrid metal matrix composites, the thrust force was 600 N at the feed rate of 0.3 mm per rev, and the thrust force was 300 N at the feed rate of 0.1 mm per rev. Hence, the author proved that hybrid metal matrix composites result in reduced thrust force compared to metal matrix composites.

Gultosun and Mehtap Muratoglu [14] performed drilling of metal matrix composites [Al /SiCp]. For the drilling operation, the input responses used were spindle speeds of 260 and 1330 RPM, feed rates of 0.08 and 0.16 mm per rev and drill angles of 90°, 118° and 130°. The authors proved that, as the feed rate increased, the temperature increased and the bonding between the matrix and reinforcement was weak. The matrix was softened, and there was a motion of reinforcement in the SiC. The types of drills used are high-speed steel [HSS], TiN-coated HSS and carbide. They also proved that as the point angle increased, a damage zone was formed in the case of the HSS drill.

J.P. Davim [15,16] examined the tool wear using both turning and drilling operations. In those machining operations, the greater feed force resulted in greater flank wear.

Ramulu et al. [17] performed drilling experiments on A6061/Al_2O_3 using three different types of drills namely, high-speed steel, carbide and polycrystalline diamond with a constant diameter of 6.35 mm and a point angle of 118°. The input parameters used for this experiment were cutting speeds of 1320, 2230, 3500 and 5440 RPM; feed rates of 0.0635, 0.127, 0.1905 and 0.2540 mm rev^{-1} and reinforcement percentages of 10% and 20%. It was proved that as the feed rate increased, both the output responses such as torque and the thrust force increased. At the 7^{th} hole with a feed rate of 0.127 mm per rev, the thrust force was 1200 N and the torque was 500 N-cm. At the same hole with a feed rate of 0.0635 mm per rev, the thrust force was 800 N and the torque was 300 N-cm.

Umesh Gowda et al. [18] was conducted the drilling operation on $AlSi_3N_4$ and they proved that the output response, surface finish was improved by increasing the cutting speed and decreasing the feed rate value. The optimized value of cutting speed was 680rpm and the optimized value of feed was 0.095 mm per rev.

Mahamani [19] performed a drilling operation on AA2219/TiB_2/ZrB_2 and tested the surface roughness of the hole. The input parameters taken for drilling were spindle speed [695, 1200, 2000, 3390 RPM], Feed [0.05, 0.1, 0.15,0.2 mm per rev] and point angle [100,110,120,130°]. It was proved in her experiment that the increase in the surface roughness of the hole was obtained at higher values of feed [0.2 mm per rev] and the decrease in surface roughness was obtained at higher values of spindle speed [2000 RPM] and at the lower value of point angle [100°].

Pramanik, et al. [20] performed a machining operation on metal matrix composites and a non-reinforced alloy and proved that the force required for turning the samples was greatly influenced by the feed rate. The input parameters used were spindle speed and feed rate. At the maximum feed rate of 0.4 mm per rev, the cutting force for the non-reinforced alloy was greater compared to 350 N. The cutting force for the metal matrix composites was 330 N at the same feed rate. The author also proved that the surface roughness of the non-reinforced alloy was greater than that of the metal matrix composites. As the feed rate increased from 0 to 0.4 mm per rev, the surface roughness of the metal matrix composites also increased from 0 to 70 µm. The surface roughness of the non-reinforced alloy was 2-80 µm for the same feed rate.

Jayaram and Mahesh Kumar [21] performed a machining operation on AA6063 T6 alloy, the input parameters taken were spindle speed, feed and depth of cut and analyzed the inputs using Grey Relational Analysis [GRA]. In the analysis, it was proved that the feed [57.365%] and depth of cut [25%] were greatly influenced on output response.

Sivapragash et al [22] was done the machining operation on the aluminium titanium boride composite. Input parameters taken for machining the aluminium, titanium boride composites were spindle speeds, feed and depth of cut. The optimized value for maximum metal removal rate was the minimum spindle speed of 1000rpm and maximum feed rate of 1.5mm per min.

Taskesen and Kutukde [23] were carried out a machining operation on boron carbide reinforced aluminium alloy. They proved that reduced tool wear can be achieved by the optimized combination of input parameters. The optimized value of feed rate was 0.3 mm per rev and the optimized value of speed was 1500 revs per min.

Radhakrishnan Ganesh and Kesavan Chandrasekaran [24] proved in their experiment that the thrust force values increased to a maximum of 200 N at higher feed rate and at low speed of 500 rpm. When the speed rose to 1000 RPM the thrust force decreased.

The literatures reviewed above, explain the fabrication of composites and machining of the prepared specimen. It also includes the influence of input parameters with the output response using various analyzing tools. These research results in the greater influenced by feed and drill diameter on the output responses. In this paper HMMCs [LM25 / treated SiCp with MWCNT] are subjected to drilling process and the influence of input parameters are analyzed using mathematical modelling technique.

In this work, it is proved that the input parameters have feed and drill diameter greater influence on output responses thrust force and ovality. The novelty of this work is the reinforced ceramic is treated with MWCNT to a certain faction to improve machining process.

Coating of ceramics leads to a good interfacial bonding between the matrix and reinforcement. Porosity and agglomeration of reinforced particle are overcome by the sonication and semisolid stir casting process. In this paper the improved and mechanical properties are obtained compared with the quoted literatures.

2. Experimental

Alloys are replaced by the metal matrix composites because of its high strength to weight ratio, high stiffness and greater corrosion, wear resistance [25]. The base metal selected for this experiment is LM25, the reinforced material is silicon carbide particle and the coated material is carbon nanotubes.

2.1. Materials

2.1.1. Silicon Carbide Particle [SiCp]

The silicon carbide particle was ordered and received from Sigma-Aldrich, USA. Table 1 indicates the certificate of analysis of the product. It is the hardest ceramics next to the diamond and Boron carbide.

TABLE 1

Analysis of the Product

Product Name	Silicon Carbide – 400 mesh particle size, >= 97.5%
Product Number	357391
Brand	Aldrich
Formula	CSi
Formula Weight	40.1 g/mol
Test	**Results**
Appearance [color]	Grey
Appearance[Form]	Powder
X-ray Diffraction-Particle Size Distribution	400 mesh, Typically >90%

2.1.2. Multi Wall Carbon Nano Tubes [MWCNT]

Multi wall carbon nanotubes are ordered from Chengdu Organic Chemicals Co., Ltd., Chinese academy of sciences, China. Table 2 shows the specification of the product.

TABLE 2

Specification of the product

Product Code	Specification
TNIM3 [ash: 10%]	Industrial MWCNTs, OD: 10-20nm, Purity: >90%, Length: 20-100µm.

2.1.3. Aluminium Alloy [LM25]

Aluminium [LM25] is got from Sargam metals. In this paper LM25 is used as a matrix material and its mechanical properties are given in Table. 3 LM25 is a cast alloy in an aluminium family. It has various applications in automobile and aerospace parts due to its lighter weight.

TABLE 3

Mechanical Properties of Aluminium alloy [LM 25]

Ultimate Tensile Strength [N mm^{-2}]	Elongation [%]	Vickers Hardness Number [VHN]
127	3.27	67.5

2.2. Methods

The hybrid metal matrix composite is prepared by the combination of a sonication process and a semisolid stir casting process. The fabricated composites are machined using Vertical Machining Centre. HMMC contains 10% silicon carbide particles coated with 1%, 1.5% and 2% of carbon nano tubes using sonication process. The coated ceramics are mixed with the molten LM25 aluminium alloy using semisolid stir casting furnace in a muffle furnace. HMMCs are subjected to mechanical testing and their mechanical properties such as hardness, tensile properties and elongations are studied. The combination with higher mechanical properties is chosen and subjected to drilling operation. In drilling the output responses such as thrust forces, ovality are observed. The optimized input combinations are resulted to reduce the output response.

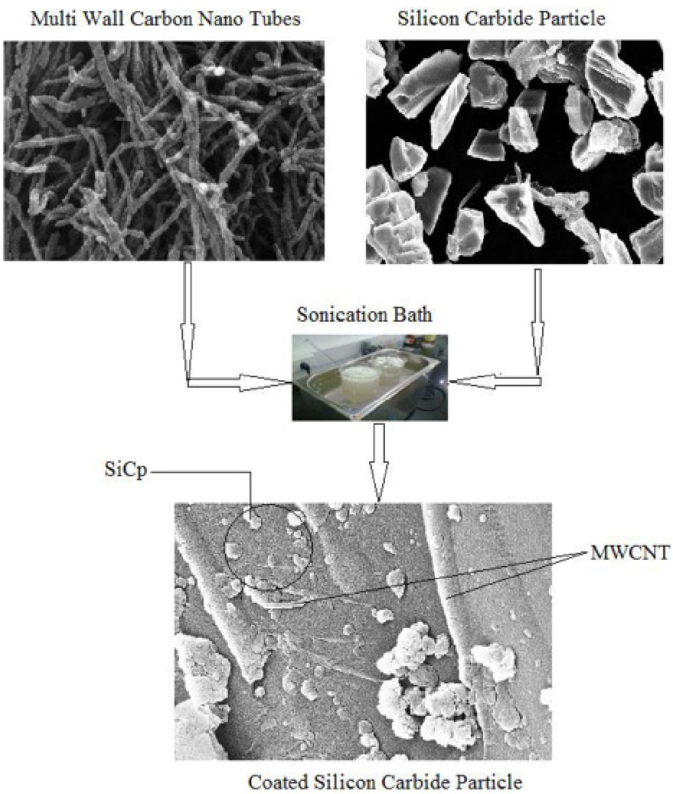


Fig. 1. Experimental set up for sonication Process

2.2.1. Sonication

In the sonication process, the abrasive natured ceramic particles are coated with multi-wall carbon nano tubes to form good bonding between the matrix and the reinforcement [26,27]. In sonication process various fractions of MWCNT is added to 10% of SiCp. The fraction of MWCNT added to 10% of SiCp are 1%, 1.5% and 2%. Both MWCNT and SiCp are filled in a glass beaker and subjected to a vibrating process for about 30 minutes in the presence of poly vinyl alcohol. Then the mixture is dried in a hot air oven. Mixing of MWCNT with aluminium increases the mechanical properties of the base metal [28].

2.2.2. Semi Solid Stir Casting

In the semisolid stir casting process, the coated silicon carbide particles are mixed with molten aluminium at the temperature 605°C for 5 minutes and poured into the die to mold the specimen into the shape of the die [29]. Fig. 2 explains the experimental setup for the casting process. The chemical and mechanical properties of the raw materials are given in the Tables 1-3. The resultant products obtained from the sonication process are shown in Fig. 4 and the resultant product of semisolid stir casting is shown in Fig. 5 and they are obtained using scanning electron microscope [SEM] [30].

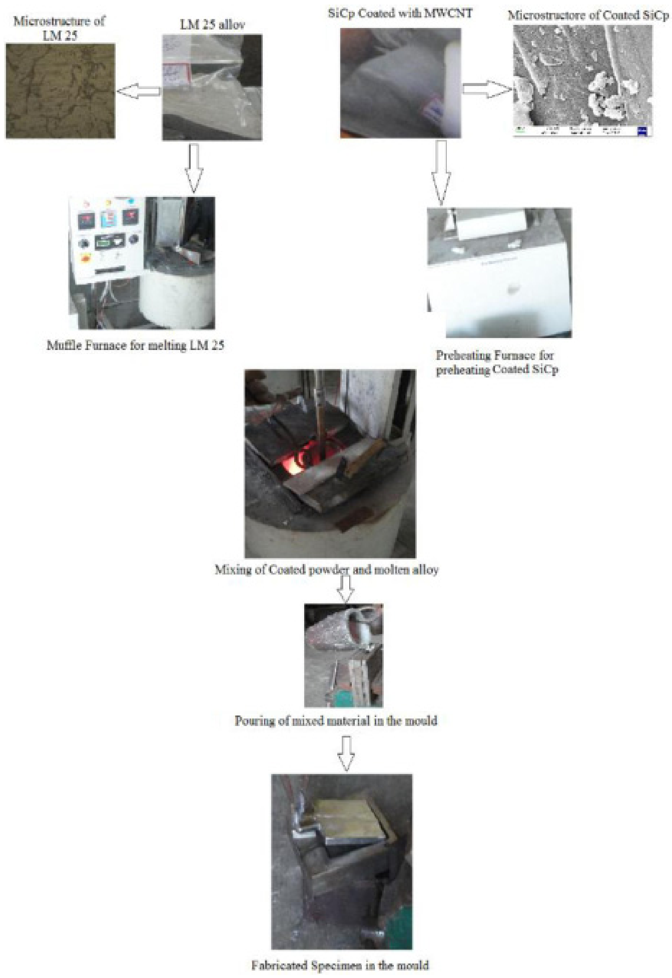


Fig. 2. Experimental set up for sonication CastingProcess

2.2.3. Drilling Process

Machining of metal matrix composites resulted in greatest tool wear due to the presence of ceramics. This tool wear is reduced by certain combinations of machining input parameters [31].

The experiment is performed in a conventional vertical machining center [VMC]. The size of the Table is 1270×230 mm. The thrust force is measured using a three-component Krystler dynamometer based on Taguchi L_{27} array and it is shown in the Table 7. The Krystler charge amplifier receives the thrust force

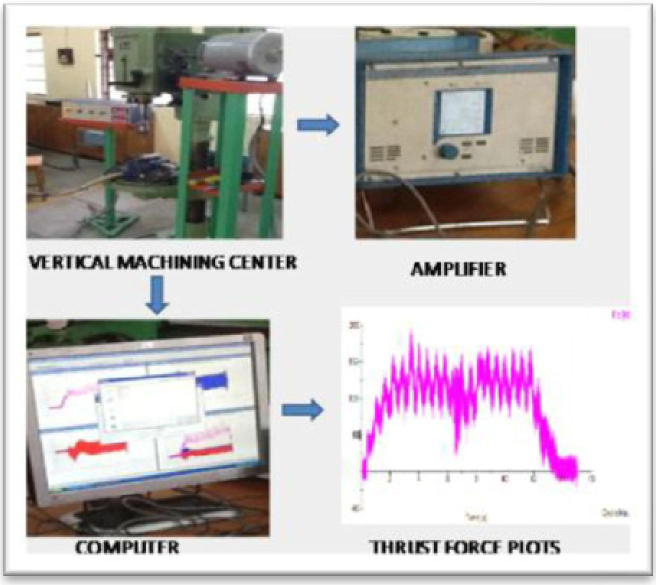


Fig. 3. Experimental Arrangements for the output – Thrust Force with the Vertical Machining Centre

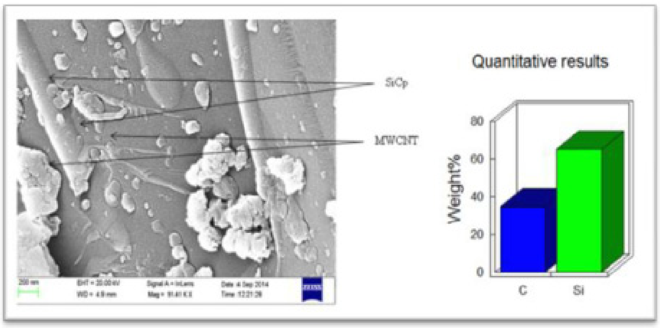


Fig. 4. Scanning Electron Microscopy image of resultant product using sonication process

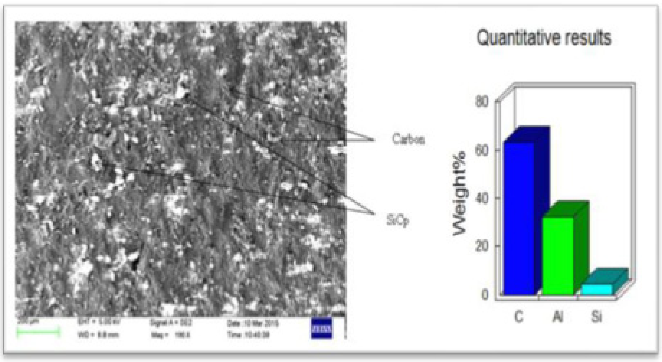


Fig. 5. Scanning Electron Microscopy image of resultant product using stir casting process

signal and then stores it in the computer. The specification of dynamometer is displayed in the Table 5. Fig. 3 explains the experimental arrangements for measuring the thrust force. The input parameters for machining process are listed in the Table 4. The holes of different drill diameter and their corresponding feeds are listed in Table 6.

TABLE 4

Specifications of Dynamometer used for this experiment

Type	Calibrated 9272
Weight	4.2 kg
Accessories: Connecting cable type	1677A5/1679A5
Type of Sensor	Torque sensor
Number of Channels	3 charge amplifier channel
Transducer Sensitivity	$Fx = -7.8PcN^{-1}$, $Fy = -3.5PcN^{-1}$
Natural Frequency	fn[x], fn[y] = 3.1KHz and fn[z] – 6.3KHz
Protection Class	IP67
Operating Temperature	0-70°C

TABLE 5

Input parameters for drilling and their levels

Parameters	Levels		
	1	**2**	**3**
Spindle Speed [RPM]	600	1260	1860
Feed [mm min^{-1}]	25	50	75
Drill diameter [mm]	4	8	12

TABLE 6

Drilled Metal Matrix Composites with different feed ranges and drill diameters

Feed [mm min^{-1}]	**Drill diameter [mm]**		
	4	**8**	**12**
25			
0			
75			

TABLE 7

Taguchi L27 Orthogonal array

Trial No	**Level of Factors**				
	Spindle Speed [RPM]	**Feed [mm min^{-1}]**	**Diameter [mm]**	**Thrust Force [N]**	**Ovality (mm)**
1	**2**	**3**	**4**	**5**	**6**
1	600	25	4	196	0.007
2	600	25	8	202	0.009
3	600	25	12	272	0.01
4	600	50	4	311.9	0.002
5	600	50	8	319.2	0.004
6	600	50	12	420.0	0.006
7	600	75	4	447.1	0.001
8	600	75	8	468.7	0.003
9	600	75	12	500.0	0.003
10	1260	25	4	110.1	0.004

1	2	3	4	5	6
11	1260	25	8	172.3	0.005
12	1260	25	12	250.0	0.006
13	1260	50	4	159.3	0.003
14	1260	50	8	194.1	0.003
15	1260	50	12	280.0	0.004
16	1260	75	4	255.6	0.003
17	1260	75	8	281.4	0.005
18	1260	75	12	350.0	0.007
19	1860	25	4	141.0	0.002
20	1860	25	8	309.6	0.004
21	1860	25	12	320.0	0.006
22	1860	50	4	157.7	0.002
23	1860	50	8	243.9	0.002
24	1860	50	12	330.0	0.002
25	1860	75	4	180.9	0.005
26	1860	75	8	267.1	0.007
27	1860	75	12	350.0	0.008

3. Results and discussion

3.1. Results of sonication Process

The authors, Shiho Kawashima proved that by adopting a sonication process, there was an effective distribution of nano particle which in turn there was a good agreement between the dispersion measurement and mechanical performance coating [32].

As a result of Sonication process, the carbon nanotubes are equally coated over the ceramic, silicon carbide particles and it is clearly indicated in the Fig. 4.

3.2. Results of Stir Casting

Stir casting results in equal distribution of reinforced particles of the base metal without any agglomeration. Hybrid metal matrix composites with silicon carbide particle as reinforcement are used mostly in automobile parts. In this paper, a mathematical modelling is used for modelling the thrust force and Ovality equation. This model formed the empirical relationship between the explanatory variables and one or more response variables. Analysis of the response optimized the input parameters, which resulted in reducing the output. The Fig. 6 describes the variations in mechanical properties such as tensile strength, elongation and the hardness number of the fabricated specimen. The improved mechanical properties are obtained in the specimen with 1.5% of MWCNT. When the percentage of MWCNT extend beyond 1.5% there is a decline in the mechanical properties. Table 7 explains that, the combination of LM25/SiCp /CNT shows the highest mechanical properties compared to other literatures.

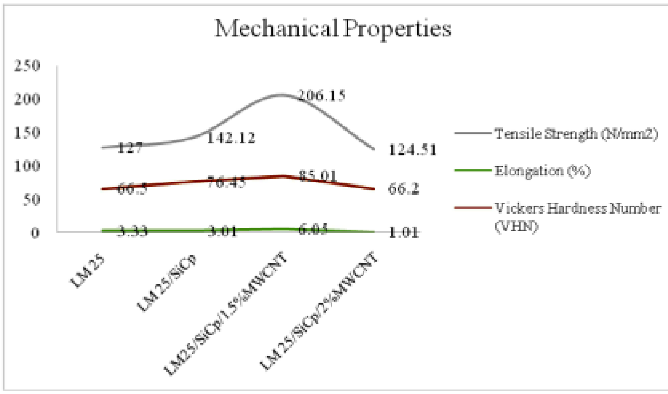


Fig. 6. Mechanical Properties of the fabricated hybrid metal matrix composites and alloys

3.3. Response Surface Methodology (RSM)

RSM is a mathematical and statistical model whose second-order model can be fitted by factorial design. The optimization model can be improved significantly by the second-order model compared to the first-order model. The second-order model is defined as follows:

$$y = a_0 \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n} a_{ij} x_i^2 + \sum_{i=1}^{n} a_{ij} x_i x_j \;\; [i < j] \qquad (1)$$

x_i and x_j are the design variables, the a's are the tuning parameters and y is the thrust force. The second-order model can be constructed efficiently by central composite design [CCD]. Model summary statistics are shown in Table 8, which was developed by design expert software.

TABLE 8

Comparison of Mechanical Properties with the literatures

Author	**Material**	**Ultimate Tensile Strength [N mm^{-2}]**	**Elongation [%]**	**Vickers Hardness Number [VHN]**
Rajmohan	A 356/10SiCp/ 3% mica	150	3.27	—
Madea Nagarval	A6061/Al_2O_3/ Graphite	160	—	98
R.M. Rashad	A 356/1.5MWCNT	200	5.2	—
LM25/SiCp/CNT		203.15	6.03	84.26

3.4. Measurement of Thrust force

The drilling operation is performed on the prepared specimen using three different tools. The input responses are spindle speeds of 600, 1260 and 1860 RPM, feed rates of 25, 50 and 75 mm per min and drilling diameters of 4 mm, 8 mm and 12 mm. The drilling parameters are shown in the Table 4. Table 5 indicates the specifications of the dynamometer used in this experiment Table 6 indicates the drilled metal matrix composites with different diameters and feed ranges. The Fig. 7 explains the details of output response thrust force.

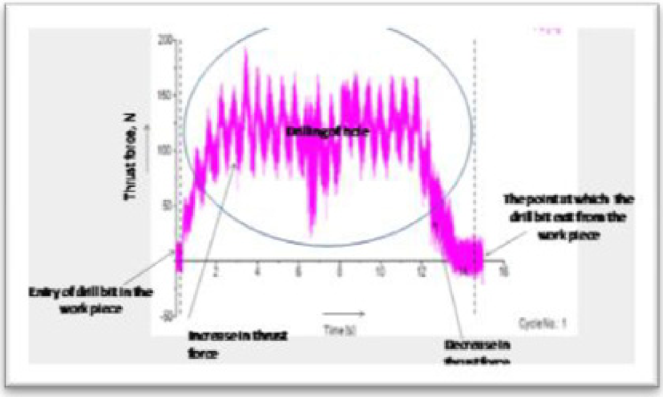


Fig. 7. Details of Thrust force while drilling the hole

3.5. Measurement of Ovality

Ovality is the deviation from the perfect circularity. It is termed as non-circularity. Ovality is measured after the machining process called drilling. It is the measure of major and minor axis. Profile projector was calibrated as per method number DOLG in NLQM/001/07 with metric traceability. The input responses considered while measuring ovality are speed, feed and drill diameter and the measurements are made using L27 array. TABLE. 8 shows the model summary statistics for output responses.

Fig. 8 represents the normal probability plot of the residuals. The points along the line are normally plotted; hence, the design is termed as effective. In a process, the normality assumption can be calculated by a normal probability plot.

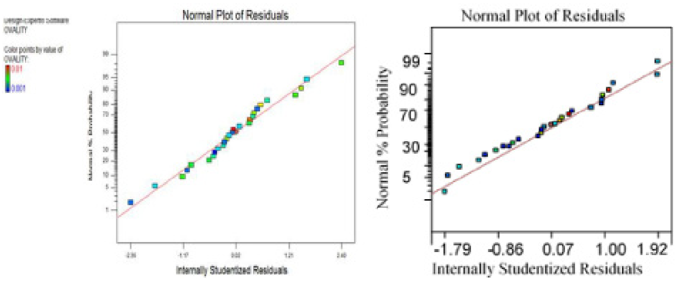


Fig. 8. Normal probability plot for internally studentized residuals (thrust force and Ovality)

In this case, N, f, d, f*d, and d^2 are significant model terms that influence the thrust force in drilling hybrid metal matrix composites and it was obtained from the Table 9. Table 10 is the response Table for means which explains that feed rate values are greatly depending on the thrust force followed by drill diameter and it is displayed in terms of rank 1 and 2. Table 11 displays the optimized values of input responses and it is obtained by a mathematical model.

TABLE 9

Model Summary Statistics for output responses

Output Response	S	R-sq	R-sq [adj]	R-sq [pred]
Thrust Force	22.5425	96.82%	95.13%	91.58%
Ovality	15.005	89.29%	83.62%	70.78%

TABLE 10(A)

Analysis of Variance (Thrust Force)

Source	Sum of Square	df	Mean Square	F-Value	P-Value
Model	262722	9	29191.4	57.44	0.000
N	38893	1	38892.6	76.54	0.000
f	72797	1	72796.5	143.25	0.000
d	67892	1	67892.0	133.60	0.000
N*N	30873	1	30872.6	60.75	0.000
f*f	1081	1	1080.9	2.13	0.163
d*d	245	1	244.9	0.48	0.497
N*f	43097	1	43097.4	84.81	0.000
N*d	6652	1	6652.4	13.09	0.002
f*d	514	1	513.5	1.01	0.329
Residual	8639	17	508.2		
Cor Total	271361	26			

TABLE 10(B)

Analysis of Variance (Ovality)

Source	Sum of Square	df	Mean Square	F-Value	P-Value
Model	1.292E-004	9	1.435E-005	15.74	< 0.0001
N	2.722E-006	1	2.722E-006	2.99	0.1021
f	7.533E-006	1	7.533E-006	8.26	0.0105
d	2.950E-005	1	2.950E-005	32.36	< 0.0001
N*N	1.316E-007	1	1.316E-007	0.14	0.7087
f*f	2.817E-005	1	2.817E-005	30.90	< 0.0001
d*d	1.667E-007	1	1.667E-007	0.18	0.6743
N*f	6.149E-005	1	6.149E-005	67.45	< 0.0001
N*d	3.437E-007	1	3.437E-007	0.38	0.5473
f*d	0.000	1	0.000	0.000	1.0000
Residual	1.550E-005	17	9.116E-007		
Cor Total	1.447E-004	26			

TABLE 11(A)

Response table for means (Thrust Force)

Level	Speed (N) – RPM	Feed (f) – mm/rev	Diameter (d) – mm
1	348.5	219.2	217.7
2	228.1	268.5	273.1
2	255.6	344.5	341.3
Delta	120.5	125.3	123.6
Rank	3	1	2

TABLE 11(B)

Response Table of Means (Ovality)

Level	Speed (N) – RPM	Feed (f) – mm/rev	Diameter (d) – mm
1	47.92	45.42	51.10
2	47.43	50.80	47.43
3	48.82	47.95	45.64
Delta	1.39	5.38	5.47
Rank	3	2	1

TABLE 12

Optimized values for Output Response

Spindle Speed (RPM)	Feed rate (mm/min)	Drill diameter (mm)	Thrust Force (N)	Ovality (mm)	Durability
1747.1	34.37	4.00	145.01	0.0016919	0.904

3.6. Effect of Factors and Interactions

Drilling is one of the machining operations used in the automobile industry. Drilling is an unavoidable operation on automobile parts while generating slots and threads in engine parts.

Drilling may lead to various defects in engine parts and efficiency. The defects due to drilling can be overcome by a proper combination of input parameters and tool materials used for drilling. A thrust force equation and the ovality equations are modelled using response surface methodology and is given below.

$$Fz = 242.8 - 0.4041\,N + 5.60\,f + 0.8\,d + \\ + 0.000181\,N*N + 0.0215\,f*f + \\ + 0.399\,d*d - 0.003804\,N*f + \\ + 0.00934\,N*d - 0.0654\,f*d \qquad (2)$$

$$\text{Ovality} = + 0.019363 - 8.18412E - 006\,N + \\ - 5.49265E - 004\,f + 5.69361E - 004d + \\ + 1.43672E - 007N*f - 6.71366E - 008N*d + \\ + 0.000000f*d + 3.74111E\text{-}010N^2 + \\ + 3.46667E - 006f^2 - 1.04167E - 005d^2 \qquad (3)$$

Where N = spindle speed in RPM, f = feed in mm min^{-1}, d = drill diameter in mm. The drilling parameters are analysed by the graphs.

The Fig. 9 shows the 3D surface plot of thrust force with the combination of feed rate and spindle speed. Fig. 6a indicates that the thrust force is reduced at the combination of lower feed rate and higher spindle speed. The thrust force decreased as the spindle speed increased. When the spindle speed increased, the temperature of the drilling zone increased, which made the work piece soft; therefore, the thrust force decreased with the increasing spindle speed. The effect of the thrust force with the interaction of drill diameter and spindle speed. The reason for the increased thrust force was that with the larger values of feed rate, the contact area between the tool and the work piece is large, and hence, the load required for machining was greater. Fig. 6b proves that the ovality values greatly influenced by feed rate and drill diameter.

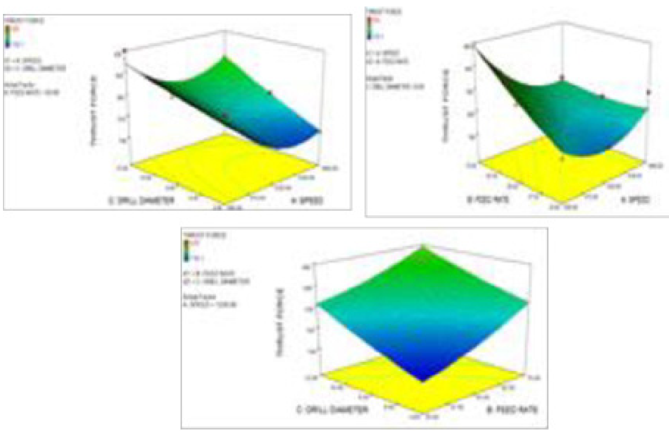


Fig. 9a. Effect of Thrust force with the interaction of Input Parameters

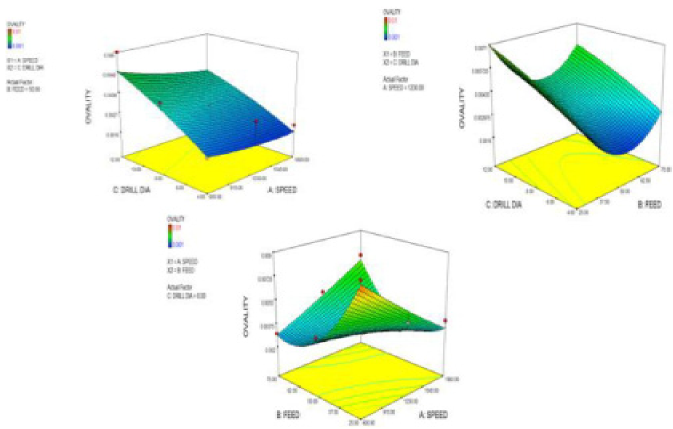


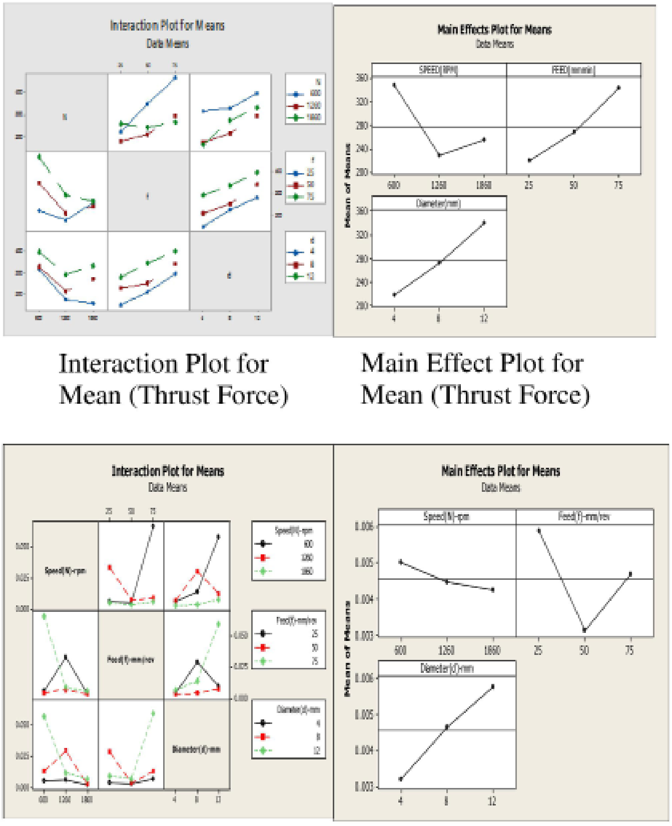
Fig. 9b. Effect of Ovality with the interaction of Input Parameters

Fig. 10 proves that the lowest feed rate and the smallest drill diameter, the thrust force is reduced to the minimum value. By using the tool with the largest diameter, the thrust force was

maximized. Because the contact area of the larger-diameter tool with the workpiece was greater compared to the smaller diameter drill bit, the load required for the larger diameter drill bit was greater.

3.7. Output response Ovality

Ovality is the measure of deviation from the circularity of a drilled hole. In this experiment the hybrid metal matrix composite is drilled. The circularity of the hole changed due to the damping stress causes during the drilling process. If the damping stress continues the deviations in the circularity happens and the assembling of automobile parts causes difficulty. In order to avoid this difficulty, the optimized combination of input parameters is preferred using Taguchi technique.



Interaction Plot for Mean (Thrust Force)

Main Effect Plot for Mean (Thrust Force)

Interaction Plot for Mean(Ovality)

Main Effect Plot for Mean (Ovality)

Fig. 10. Interaction Plot and Main Effect Plot for Thrust force and Ovality

4. Conclusions

In this paper LM 25/10SiCp/MWCNT is fabricated in different combinations by two different process called sonication and stir casting. The proportion with high mechanical properties is subject to drilling and the optimized combination of input parameters is studied to reduce the output responses such as thrust force and ovality.

Response surface methodology is used to generate a model for the output responses thrust force and ovality while drilling hybrid metal matrix composites. The input parameters are analyzed with respect to the thrust force and the ovality using response surface methodology. Based on the experimental results, the following conclusions are made:

- Sonication process resulted in the equal distribution of Multi wall carbon nano tubes on the silicon carbide particle.
- Stir casting morphology shows the proper distribution reinforcement on the aluminium alloy without any agglomeration and porosity. The improved mechanical properties are obtained by the combination of LM 25 with coated ceramics. The ultimate strength obtained is 203.15 Nmm^{-2}, the elongation of 6% and Vickers hardness value of 84.26 VHN
- The thrust force is reduced to 110.1 N at the combination of the lowest feed rate of 25 mm min^{-1}, the lowest drill diameter of 4 mm and the highest spindle speed of 1260 RPM. The optimized combination of input parameters is f_1, d_2 and N_3.
- The output responses ovality is obtained using an optical projector and analysed. Both the responses are highly affected by feed rate and drill diameter. As the feed increases the ovality increased and it decreased as the spindle speed increased. The optimized values of input parameters to obtain minimum ovality values are N_3, f_2 and d_1.
- The input responses of feed rate and drill diameter had a greater influence on the thrust force than the spindle speed.

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