EVERGREEN - Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 12, Issue 02, pp. 940-951, June, 2025

Machinability Studies on Aluminium-Silicon Carbide-Graphite Hybrid Composites: A Focus on Drilling with HSS Tool

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(Received October 23, 2024; Revised February 04, 2025; Accepted April 01, 2025)

Abstract: The study aims on the fabrication of AMMCs, which are aluminum 6061 (Al) matrices reinforced in varying weight proportions with silicon carbide and graphite. Additionally, using Taguchi's orthogonal array, drilling operations are carried out on the composites for various combinations of process parameters. The influence of four control factors such as spindle speed (S), feed rate (FR), diameter of drill (D) and % of silicon carbide (SiC) on surface roughness (Ra), circularity and cylindricity was investigated. Based on the experimental results, it is determined that the surface roughness and circularity of the hole at both the entry and exit are significantly influenced by cutting parameters. The lowest Ra was observed at moderate levels of the S and FR, i.e., 580 rpm and 0.575 mm/rev: 8 mm D and 2% SiC. Circularity gets worse as the spindle speed, feed rate and % SiC increase, i.e., at 1160, 1.25 mm/rev. and 8% respectively, with respect to the diameter of the drill bit, 8 mm is yielding larger circularity. However, cylindricity improves with an increase in speed from 300 rpm to 580 rpm and worsens with further increases in speed to 1160 rpm; moderate feed rate, i.e., 0.575 mm/rev, yields better cylindricity; however, lower and higher feed rates yield almost the same cylindricity. Further cylindricity gets worse as the increase in 'D'. Cylindricity improves with increasing % SiC and obtains good value at 8%.

Keywords: cutting parameters; drilling; HSS tool; metal matrix composites, Silicon Carbide

1. Introduction

Many novel materials are being employed to overcome the problems caused by traditional materials' inability to suit the needs of current applications. The machining of newly developed materials, like alloys and composites, is becoming more challenging since these materials are hard to machine and require specific cutting conditions and tools. MMCs are significantly stronger, stiffer, lighter, and have a lower thermal coefficient of expansion than conventional materials [1)]. MMCs have been found to have lifecycle costs that are lower than those of traditional materials. Improving the strength-to-weight ratio characteristics of matrix materials through the synthesis of possible reinforcements with improved repeatable properties and microstructure is relevant to industry. AMCs are widely used materials that can withstand the severe requirements of technological applications that call for characteristics like medium strength, high stiffness, and low weight [2, 3)]. Aluminium metal matrix composites (Al-MMCs) have found widespread uses in today's automotive, aviation, marine, defense, and manufacturing industries due to their high strength-to-weight ratio, thermal stability, toughness, and remarkable corrosion and wear resistance [4)]. While there are several processes that can be utilized to develop and fabricate Al-MMCs, including stir casting, pressure casting, ball milling and powder metallurgy, stir casting appears to be the utmost practical because of the low cost, mass production, homogeneous distribution of reinforcements in the matrix, with little agglomeration effect etc., [4,5)]. Desirable single and multiple reinforcing particles, such as fly ash, silicon carbide (SiC), aluminium oxide (Al_2O_3), graphite (Gr), titanium oxide (TiO_2) and boron carbide (B_4C) can be added to composite materials to improve their properties over base alloy materials. In comparison to the matrix qualities, reinforcements often have a favorable influence on the mechanical characteristics of aluminum alloys [6)].

In most applications, drilling is the most valuable production step, and the drilled holes act as high stress locations that require extra care. For an extended period, researchers and professional engineers have been

Cite: B. Nithyananda et al., "Machinability Studies on Aluminium-Silicon Carbide-Graphite Hybrid Composites: A Focus on Drilling with HSS Tool". Evergreen, 12 (02) 940-951 (2025). https://doi.org/10.5109/7363486.

fascinated by the difficulty of selecting the ideal settings for drilling novel composite materials [2]. Drilling is a fundamental subtractive machining process used to create holes in solid materials with the required geometrical and dimensional accuracy. It was opined that, in a normal workshop, drilling is still the most common process used for creating a hole [4,7]. Aluminium-based metal matrix composites are difficult to produce. As a result, using instruments composed of polycrystalline diamond and sintered carbides is advised [7]. The tool working life, cutting pressures, and the quality of final product are all greatly impacted by the influence of reinforcement. To get good mechanical characteristics, AMC processing is essential [8]. To get the finest technological outcomes, a great deal of study is conducted by the researchers to determine optimal machining parameters. If the production uses the determined ideal drill parameters, the energy and component manufacturing costs can be significantly decreased.

Numerous studies conducted drilling with different input parameters to assess the machinability of the hybrid aluminium based MMC. [9] Abbas Created in-situ hybrid metal matrix composites constructed of AA6061 aluminum alloy reinforced by 10 weight percent boron carbide (B_4C) and 0to 6 weight percent of mica. Used drilling to test the machinability of the hybrid composite while adjusting the rotating speed, feed rate, and percentage of mica reinforcement. The study concluded that, if the production uses the determined ideal drill parameters, the energy and component manufacturing costs can be significantly decreased. [10] Ficici F examined the process' efficacy and hole quality when drilling the hard-to-machine Al/SiC MMC with a cemented carbide tool covered with diamond. The study concluded that drill wear happens on both the bit tip and the minor cutting edge, and that adhesive and abrasive wear processes are common on drill bits. For drilling holes in Al/SiC metal matrix composites, spindle speeds ranging from between 5000 rpm to 7000 rpm performed best.

The drilling properties of stir-cast Al 7075 composites supplemented with silicon carbide (SiCp) were experimentally studied by C Sarala Rubi [11]. During the drilling process, he employed two distinct drill materials: high speed tool steel (HSS) and Titanium nitride coated HSS. The study concluded that for all drilling activities including surface roughness qualities, TiN-coated HSS drills produced better outcomes compared to untreated HSS drills.

The performance of the boron carbide reinforced LM6 aluminium composite during drilling has been explored by Sagar Shivaji [12]. Evaluated the effects of process factors viz., feed rate, reinforcement percentage, drill type and speed on burr size and thrust force during AMC drilling. study discovered that a 50 mm/min of feed rate, spindle speed of 3000 rpm, drill material treated with titanium nitride, and 3% of reinforcement are best parameters for obtaining the least amount of thrust force. The best parameters to attain the lowest burr height are a spindle speed with 2000 rpm, an HSS drill material, a feed rate with 50 mm/min and 6% of reinforcement.

The Aluminium Silicon Carbide MMC with varying proportion of SiC was studied by Arun Kumar Sharma [13]. Discovered that a rise in the percentage composition of SiC is correlated to an increased hardness. Shallow cut depth and high feed rate are ideal machining parameters for achieving a high level of surface quality. [14] Aamir M stated that aluminum and its alloys are among the most preferred materials because they can meet most of recent requirements and frequently show respectable tribological and mechanical properties when employed as matrix in MMCs. SiC and Al_2O_3 are typically used as reinforcement. The study concluded that AlMMCs require ongoing research and should be anticipated to expand in the future. Multi-spindle drilling with a multi drill head, an industrial hole-making technique that permits simultaneous drilling of holes in composites, has been studied by C. Kannan[15]. Focus had been on applying the Taguchi approach to optimize two drilling processes: multi-hole drilling and one-shot drilling. The study discovered that, while utilizing a poly-drill head and Taguchi optimization, the best drilling parameters happened at minimal feed rates and cutting speeds. The researchers used a fuzzy reasoning approach to anticipate size of holes and surface roughness. The concordance between the experimental values and the fuzzy measured values indicates that the developed models can effectively precisely assess the hole dimensions and surface texture of multiple drilled holes.

Machinability tests on an aluminum matrix nanocomposite subjected to minimum quantity lubrication (MQL) were carried out by Repeto D [16]. Under various working circumstances and settings, they investigated the machining of the hybrid composite i.e., aluminum with boron nitride and aluminum oxide and Al 7075 alloy. The study discovered that minimal feed rate in conjunction with fast cutting rate and a MQL conditions are ideal for obtaining the lowest possible surface irregularity when machining hybrid composites. noticed that there is an improvement in surface irregularity, machining forces, and tool wear out once h-BN was added as reinforcement. Because they are lubricating, the reinforcement particles have contributed to the reduction of friction, which has decreased machining forces and tool wear out.

Al-63%SiC MMCs machinability has been studied by Emin Salur [17]. The material's exceptional microhardness, resulting from its elevated SiC concentration, was evidenced by observations during machining, where tools exhibited significant wear in a short duration, leading to chip formation and segmented arcs.

Machinability properties of MMCs developed with spheroidal graphite iron (GGG-40) and tin bronze

(CuSn10) chips by using high temperature pressing at three distinct pressures, temperatures, and compositions, have been examined by J. Joel [18]. The reinforcement ratio Temperature and pressure were considered as production characteristics; thrust force and surface roughness served as output parameters. The test findings showed that the primary factor influencing the MMCs surface roughness for both material feed rates was the reinforcement ratio. This investigation is more novel because the thrust force and surface irregularity measurements showed a tendency to decline with an increased material feed rate.

A review on the machinability characteristics of aluminium MMCs was conducted by S.K. Lalmuan [19]. The study indicated that the metal matrix composites (MMCs), which include graphene, carbon nanotubes, nanoceramic particles, and their hybrid combinations, are receiving more and more attention. Therefore, it calls for careful consideration on the part of researchers to improve the machining parameters of such innovative composites.

The machinability of hybrid MMCs augmented with various particles, including ZrO_2, CNT, Gr, SiC, B_4C, Al_2O_3 and TiC has been investigated by Doomra VK [20]. To prepare hybrid micro molding compounds (MMCs), SiC was primarily mixed in different quantities with additional reinforcements such B4C, Gr, and Al2O3. The impact of reinforcing type and ratio was demonstrated through the machining analysis and optimization of hybrid MMCs.

Chithirai Pon Selvan[21] used the finite element platform (ABAQUS/Explicit), a finite element analysis has been done in this research investigation to predict the drilling behaviour of aluminum with 10% of SiC MMC. Additionally, an experimental study of the impact of cutting speed and feed speed on the thrust force was carried out. The study discovered that the magnitude of thrust force estimated by the recommended finite element model closely fits the investigative findings. Additionally, it was shown that the suggested finite element model predicts the thrust force produced during drilling of MMC with a high degree of efficiency.

The survey revealed the importance of the selection of process parameters in the drilling of the material and how they influence the quality of the hole. None of the researchers has suggested the standard levels of control factors to have the best quality hole in composites. The present study strives to address the stated issue, which includes the synthesis of Al-based hybrid high-quality composites using the stir casting process, as it is the cheap and reliable method used by most of the researchers, and investigates the effect of control factors on the surface roughness, circularity, and cylindricity of a hole using a statistical tool based on Taguchi's laws.

It is clear from the literature review above that it is crucial to analyze the drill parameters and how they affect the integrity and features of the hole surface. The goal of this effort is to use the advantages of aluminium as the matrix with SiC and Gr as reinforcements to create materials with better qualities. Because they are easier to fabricate, metal-matrix composites containing aluminium are preferred by most industries. Drilling studies were performed on the fabricated hybrid AMC samples with HSS tools. This work involved the preparation and analysis of composites based on aluminium and reinforced with varying ratios of silicon carbide and graphite. Stir casting was the method used for manufacture, wherein the necessary additives were added to the molten aluminium mixture and stirred continuously. The samples that had hardened were sliced into standard sizes, and a range of tests were done to look at the created composites' machinability and mechanical qualities. To guarantee that the parts function at their best for the duration of their service life, the drilled hole quality is crucial.

The goals were established following a thorough analysis of the relevant literature. Most of the literature places focus on the use of the stir casting technique, which is the most affordable, practical, and efficient way currently accessible, in the manufacturing of composites [21, 22, 23]. The next most important factor, the Design of Experiment (DOE), was developed utilizing the Taguchi Method since it establishes the caliber of the study and outcome [24]. The set objective is justified by the method's effectiveness and the scope for factor optimization it offers, as documented in the literature [25-30]. This investigation seeks to synthesize aluminum 6061-based hybrid MMCs (HMMC) reinforced with silicon carbide (SiC) and graphite (Gr) via the process of stir casting, which is trailed by the study of the impact of drilling operational parameters utilizing the Taguchi method for experimental design. The study also strives to characterize the developed composite material through scanning electron microscopy (SEM) and Rockwell hardness testing. In addition, examination and optimization for the influence of process parameters on drilled hole quality was done.

2. Materials and Methods

2.1. Materials

The first stage is to select appropriate materials to improve the composite's overall properties to develop a hybrid composite. In this work, to prepare composites, Al6061 was chosen as the matrix material while SiC and graphite were selected as reinforcing materials in varying amounts. Silicon carbide compositions range from 2-10% (wt.) in 3% intervals, while graphite compositions remain constant at 2% as further increases in the proportion of graphite decrease the hardness due to the blockage of dislocation in the matrix material by increased graphite particles [37]. Table 1 presents the three samples produced with different compositions of matrix and reinforcement materials.

Table 1: Composition of Hybrid MMC

Specimens	Matrix Material	Reinforcement Material	
	Al6061	SiC	Gr
Specimen 1	96%	2%	2%
Specimen 2	93%	5%	2%
Specimen 3	90%	8%	2%

2.2. Fabrication of Specimens using Stir Casting Technique

The stir casting process is the most prevalent, cost-effective, and straightforward technique for fabricating metal matrix composites (MMCs). The stir casting technique is employed to cast three separate composite specimens with varying volume proportions of Al6061, SiC, and Gr, as shown in Figure1. The preparation of the composites involves the melting of aluminum ingots to their melting temperature, i.e., 750˚C, and holding at that temperature and pouring the measured SiC and Gr at a controlled rate. Stirring the mixture for 4 minutes to get a homogeneous mixture of the composites. Three samples of each composition were fabricated and the best of the three samples was chosen to carry out experimentation. Before subjecting the samples to any drilling operation, the samples were face milled, reducing the thickness by 3-5mm, on the side that would be subjected to the drilling operations.

Fig. 1: Stir casting process

2.3. Measurement of Hardness

The Rockwell hardness testing machine is employed for measuring the hardness of the fabricated composite specimens using a ball indenter as shown in Figure 2. The test is performed using the B scale, which is appropriate for materials with a maximum hardness of 100 on the Rockwell C scale. The test results of hardness testing are shown in Table 2. The hardness is minimum for 2% SiC with a value of 23.4 RHN and improves with the rise in percentage of SiC to 5% but decreases again for 8% SiC but not to the extent observed in 2% SiC. Since the SiC is hard and brittle, reinforcement increases the hardness of the composites with an increase in its proportion in the matrix phase, but the Gr is a soft and lubricating material that tends to restrict the increase in hardness to higher values. 8% of SiC acts as a critical proportion of reinforcement at which hardness of the composite reduces due to the combined effect of reinforcement interaction and clustering tendencies.

Fig. 2: Rockwell Hardness Testing Machine

Table 2: Test Results of Hardness Testing

Specimens	Average Hardness
Al6061 + 2%Vol .of SiC + 2%Vol .of Gr	23.4 RHN
Al6061 + 5%Vol .of SiC + 2%Vol .of Gr	41.8 RHN
Al6061 + 8%Vol .of SiC + 2%Vol .of Gr	37.6 RHN

2.4. Designing Experiments by Taguchi

The Taguchi array was devised on Minitab 21 software. This array enables the effective testing of several factors using a small number of experiments [31-34]. The study employs four control factors, each at three levels; the specifics of these control factors and their levels are detailed in Table 3. High speed steel (HSS) will be utilized for drilling the aluminium composite in the radial drilling machine, and three twist drill bits of 6mm, 8mm, and 10mm diameter will be employed. Table 4 presents the experimental design obtained from Taguchi method in Minitab software.

Table 3: Factors considered and levels of each factor

Factors	Level-1	Level-2	Level-3
Spindle Speed	300	580	1160
Feed Rate	0.125	0.575	1.25
Drillbit diameter	6	8	10
% of SiC	2	5	8

Table 4: Taguchi Design

Hole No.	Speed of Spindle	Feed rate	Diameter of drillbit	SiC %
1.	300	0.125	6	2
2.	300	0.125	8	5
3.	300	0.125	10	8
4.	300	0.575	6	2
5.	300	0.575	8	5
6.	300	0.575	10	8
7.	300	1.25	6	2
8.	300	1.25	8	5
9.	300	1.25	10	8
10.	580	0.575	6	8
11.	580	0.575	8	2
12.	580	0.575	10	5
13.	580	1.25	6	8
14.	580	1.25	8	2
15.	580	1.25	10	5
16.	580	0.125	6	8
17.	580	0.125	8	2
18.	580	0.125	10	5
19.	1160	1.25	6	5
20.	1160	1.25	8	8
21.	1160	1.25	10	2
22.	1160	0.125	6	5
23.	1160	0.125	8	8
24.	1160	0.125	10	2
25.	1160	0.575	6	5
26.	1160	0.575	8	8
27.	1160	0.575	10	2

2.5. Drilling of Hybrid Composite Specimens

The three samples of hybrid composites were drilled by using automated radial arm drilling machine. The specification of the machine used is displayed in Table 5. The range of spindle speed is 40- 1800 rev/min and the range of feed rate lies in between 0.125-1.25 mm/rev. Figure 3 shows the radial drilling machine used in this study. High speed steel (HSS) will be used for drilling of hybrid aluminum composite in radial drilling machine and 3 twist drill bits of 6mm, 8mm and 10mm diameter respectively are used as shown in Figure 4 and specifications are mentioned in Table 6.

Table 5: Radial Drilling Machine

Make	SAHYOG
Type	8 Spindle speed
Model	SMTR I
Stroke length of Ram	18”
Vertical Travel	900 mm
Horizontal Travel	600 mm
Bed Size	830*600 mm
Spindle Power Rating	2 HP
Spindle Speed range	65-1980 rpm
Weight approximated	1105 kg

Table 6: Specifications of HSS drill bit

Make	International tool manufacturing
Type	M2
Point angle	118˚

Fig. 3: Radial Drilling Machine

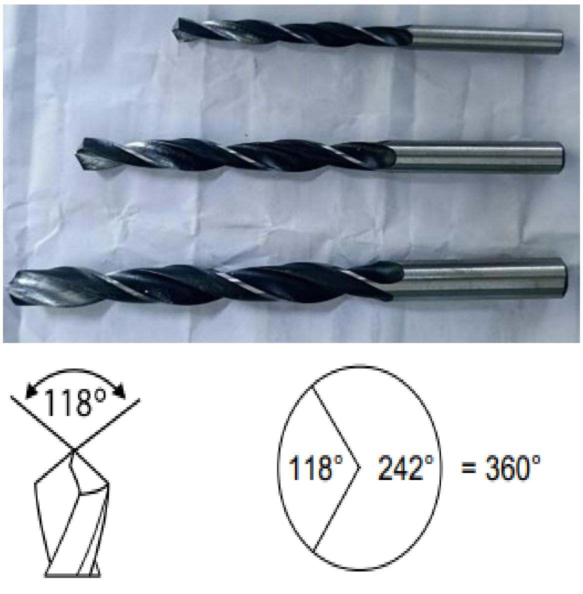

Fig. 4: HSS Drill bit

2.6. Measurement of Circularity and Surface Roughness

In this study, the quality of hole is evaluated by considering surface irregularity and circularity. The surface roughness of hole is assessed utilizing the Surfcom Flex - 50, a high-precision surface roughness tester whose accuracy is 3 μm/50 mm, is depicted in Figure 5. The circularity measurement is assessed using a Tool Maker's microscope, a specialized device used to properly measure the diameter of small holes, as shown in Figure 6.

Fig. 5: Surfcom Flex

Fig. 6: Tool Maker's Microscope

3. Results and Discussions

The drilling of holes was conducted according to the Taguchi array, and the output responses, namely surface roughness, entry circularity, and exit circularity, were measured. The results acquired are presented in Table 7.

Table 7: Taguchi Experimental Array with Responses

Hole No	Responses		
	Ra (μm)	Circularity-Entry	Circularity-Exit
1.	4.816	0.021	0.3985
2.	8.18	0.0415	0.07
3.	7.319	0.0265	0.0375
4.	7.114	0.013	0.1215
5.	12.862	0.052	0.5125
6.	8.197	0.015	0.0145
7.	5.456	0.016	0.1655
8.	7.231	0.054	0.4915
9.	9.569	0.0165	0.0495
10.	7.621	0.043	0.03
11.	3.895	0.006	0.1235
12.	9.91	0.019	0.5925
13.	6.871	0.031	0.1285
14.	10.06	0.048	0.2985
15.	8.216	0.03	0.387
16.	11.335	0.006	0.1415
17.	4.929	0.038	0.113
18.	13.875	0.0325	0.365
19.	7.057	0.0505	0.2175
20.	5.55	0.09	0.0355
21.	6.324	0.0485	0.2825
22.	5.363	0.0265	0.3105
23.	6.614	0.1265	0.081
24.	13.336	0.0165	0.0775
25.	8.505	0.014	0.3845
26.	7.581	0.076	0.048
27.	5.786	0.007	0.066

3.1. Signal to Noise Ratio Analysis

It was discovered that with smaller values of Ra, spindle speed at level 3, feed rate at level 3, drill bit diameter at level 1, and SiC% at level 1 exhibited higher S/N ratio values. Therefore, the optimal set of parameters to obtain minimum value of Ra is 1160 rpm of spindle speed, 1.250 mm/rev of material feed rate, 6 mm drill bit and 2% reinforcement of SiC, which can be observed in Figure 7. The interaction plot for Ra, for smaller is better condition is depicted in Figure 8. The interaction plot can show how the combined effect of the process factors influences the output response [35]. The response table of signal to noise ratios for the average Ra for the condition smaller is better as illustrated in Table 8.

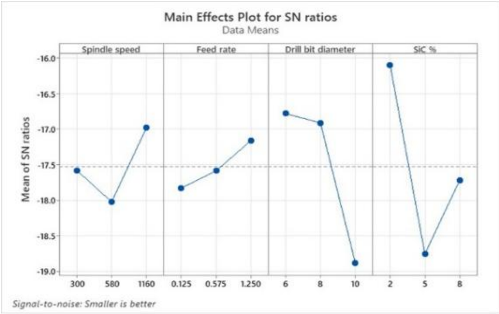

Fig. 7: Main effects plot for Ra

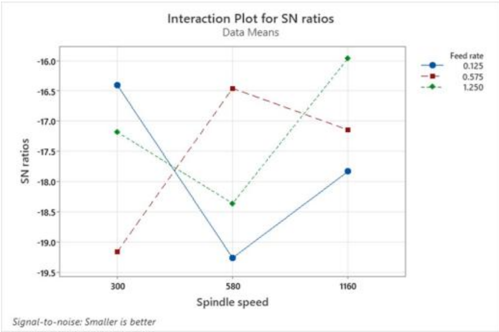

Fig. 8: Interaction plot for Ra

Table 8: Response Table for Ra

Level	Speed of Spindle	Feed rate	Diameter of drill bit	SiC %
1.	-17.58	-17.83	-16.78	-16.10
2.	-18.03	-17.59	-16.91	-18.76
3.	-16.98	-17.17	-18.89	-17.73
Delta	1.05	0.66	2.11	2.66
Rank	3	4	2	1

It was discovered that for smaller value of circularity at entry, spindle speed at level 2, feed rate at level 2, drill bit diameter at level 1 and level 1 of SiC% were found to have more S/N ratio value. Therefore, the optimal set of parameters to attain least value of circularity at entry is spindle speed of 580 rpm, feed rate of 0.575 mm/rev, drill bit diameter of 6 mm and SiC% of 2% as indicated in Figure 9. The interaction plot for circularity at entry, for smaller is better condition as illustrated in Figure 10. Table 9 indicates the response table for circularity at entry.

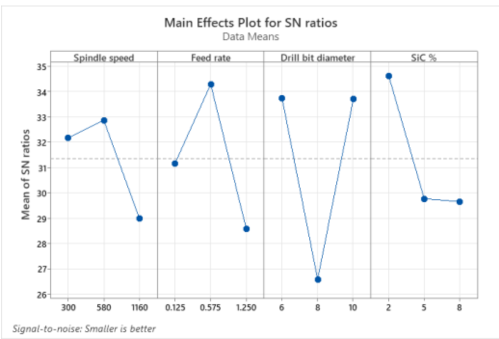

Figure 9: Plot of Main Effects: Circularity Entry

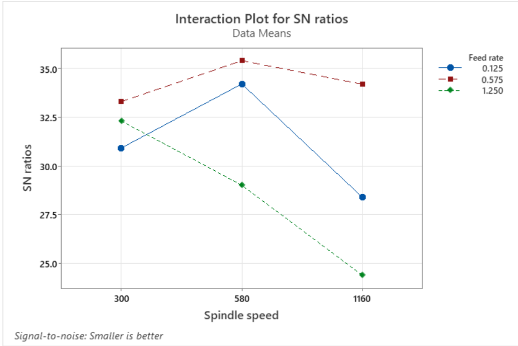

Fig. 10: Interaction Plot for Circularity Entry

Table 9: Response Table - Circularity Entry

Level	Speed of Spindle	Feed rate	Diameter of drill bit	SiC %
1.	32.17	31.16	33.74	34.60
2.	32.87	34.29	26.57	29.76
3.	28.98	28.56	33.70	29.65
Delta	3.88	5.73	7.17	4.95
Rank	4	2	1	3

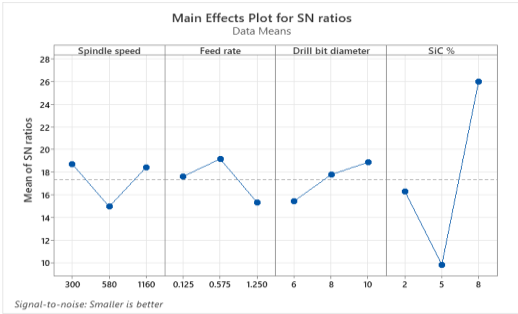

Fig. 11: Plot of Main effects: Circularity Exit

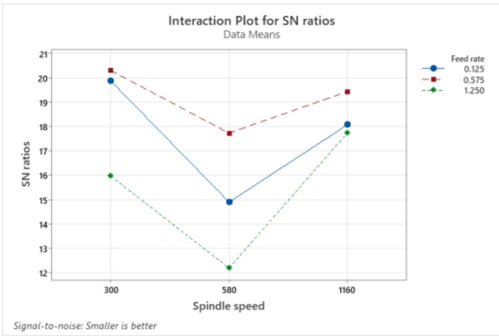

Fig. 12: Interaction Plot for Circularity Exit

It was discovered that for smaller value of circularity at exit, spindle speed at level 1, feed rate at level 2, drill bit diameter at level 3 and level 3 of SiC% were found to have more S/N ratio value. Therefore, the optimal set of parameters to obtain minimum value of circularity at exit is 300 rpm of spindle speed, 0.575 mm/rev of feed rate, 8 mm of drill bit diameter and SiC% of 8% as observed in Figure 11. The interaction plot for circularity at exit, for smaller is better condition is shown in Figure 12. Table 10 indicates the response table for circularity at exit.

Table 10: Response Table for Circularity Exit

Level	Speed of Spindle	Feed rate	Diameter of drill bit	SiC %
1.	18.711	17.610	15.433	16.259
2.	14.935	19.149	17.765	9.815
3.	18.413	15.300	18.861	25.985
Delta	3.776	3.850	3.428	16.170
Rank	3	2	4	1

3.2. Effect of Cutting Parameters on Surface Roughness, Circularity at Entry and Circularity at Exit

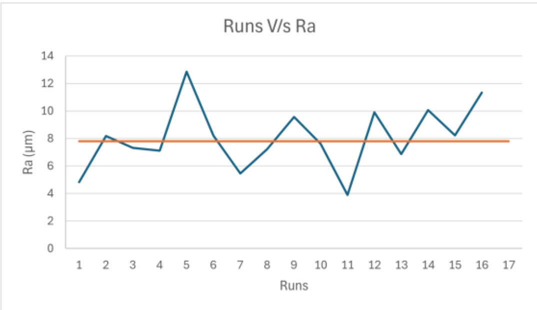

Fig. 13: Graph of Runs vs Ra

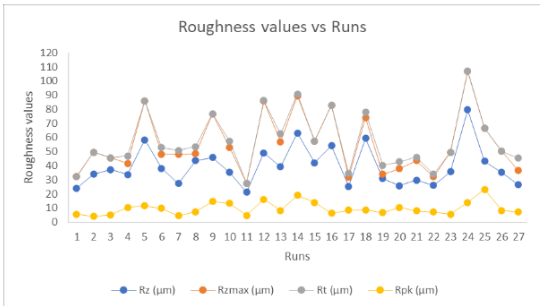

Fig. 14: Graph of Roughness Values vs Runs

The roughness of the dill surface was measured for the sampling length of 20mm. Figure 13 shows the graph of Runs vs Roughness. Figure 14 depicts the graph of roughness values Rz, Rzmax, Rt and Rpk vs Runs. All the parameters have the same effects as discussed for Ra. The roughness profiles of the holes with the best and worst circularity as obtained from Surfcom Flex is depicted in Figure 15 and Figure 16, respectively. Figure 17 displays the graph of circularity entry vs runs and Figure 18 displays the graph of circularity exit vs runs.

Effect of silicon carbide on surface roughness: It is apparent from Figure 16 that the Ra is substantially altered by the % reinforcement of SiC. As the proportion of SiC increases from 2% to 5% Ra value decreases due to minimum hardness but the roughness sharply deteriorates from 5% to 8% due to the high hardness but again improves at 8%.

Effect of drill bit diameter on surface roughness: The Ra of the drilled surface is influenced by the diameter of the drill bit. Surface roughness diminishes as the diameter of the drill bit rises due to a larger area of contact with the workpiece.

Effect of spindle speed on surface roughness: Spindle speed is the third most significant element affecting the surface roughness (Ra). The surface roughness improves with increased spindle speed.

Effect of feed rate on surface roughness: The feed rate is the second most significant element affecting Ra. Surface roughness is directly correlated with the feed rate; an increased feed rate results in improved surface roughness.

Effect of drill bit diameter on circularity at entry: There is no clear relationship between circularity and drill bit diameter but minimum circularity can be obtained consistently for a 6 mm diameter drill bit.

Effect of feed rate on circularity at entry: Minimum circularity can be obtained for lower feed rates and at a feed rate of 0.575, circularity can be consistently minimum.

Effect of Silicon Carbide on circularity at entry: At 2% SiC, minimum circularity can be consistently obtained due to low hardness.

Effect of spindle speed on circularity at entry: The circularity deteriorates as the spindle speed increases.

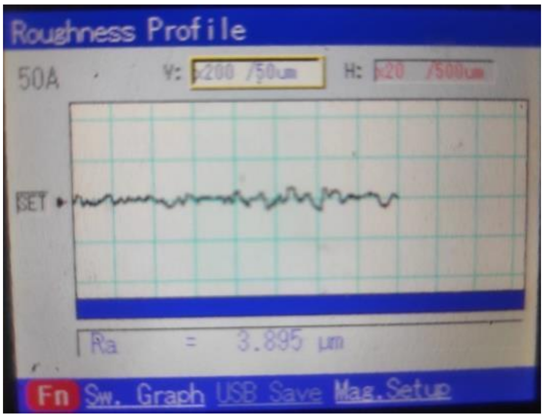

Fig. 15: Roughness Profile of Hole with Best Roughness Value

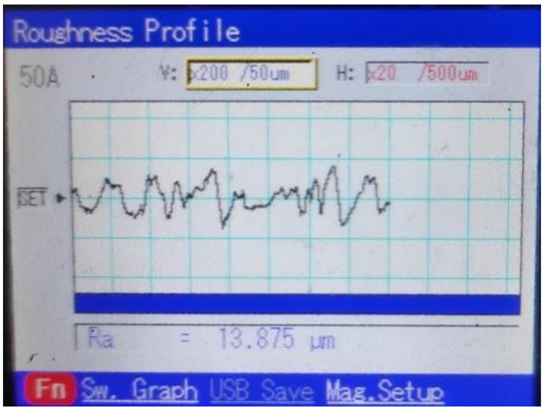

Fig. 16: Roughness Profile of Hole with Worst Roughness Value

Cite: B. Nithyananda et al., "Machinability Studies on Aluminium-Silicon Carbide-Graphite Hybrid Composites: A Focus on Drilling with HSS Tool". Evergreen, 12 (02) 940-951 (2025). https://doi.org/10.5109/7363486.

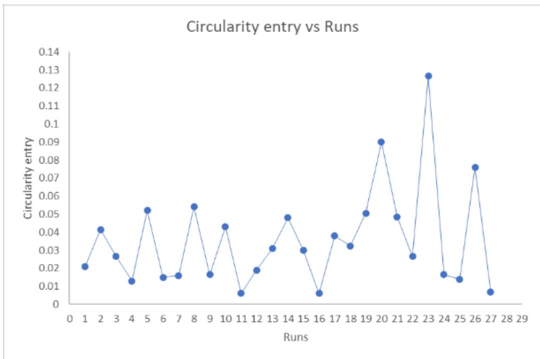

Fig. 17: Graph of Circularity Entry vs Runs

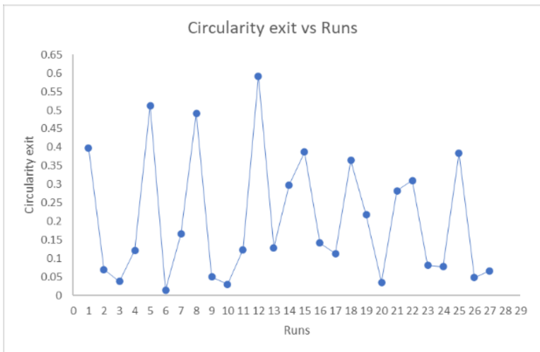

Fig. 18: Graph of Circularity Exit vs Runs

Figure 18 interprets that the circularity at exit fluctuates significantly across runs, particularly in the early and mid-ranges. large variations, especially around runs 6, 10, 12, and 14, indicate unstable circularity outcomes at the exit. After run 15, the overall trend appears to stabilize with lower fluctuations, although some variability remains. Some runs (e.g., 7, 8, 21, 28) show very low circularity at exit, suggesting deformation or loss of shape retention. The presence of SiC tends to resist deformation, potentially leading to irregular shapes at exit due to uneven wear or material removal.

Effect of Silicon Carbide on circularity at exit: At 5% SiC, the circularity deteriorates to a large extent due to high hardness and minimum circularity can be obtained consistently for 8 % SiC.

Effect of feed rate on circularity at exit: The circularity deteriorates with the rise in feed rates.

Effect of spindle speed on circularity at exit: There is no clear relation among speed of spindle and circularity, as circularity is minimum for both 300 rpm and 1160 rpm.

Effect of drill bit diameter on circularity at exit: There is no clear relationship between circularity and diameter of drill bit.

3.3. Microstructure Study using SEM Analysis

The surface morphologies were examined by employing Scanning Electron Microscope (SEM) [36]. The magnification is 50,000×, meaning fine microstructural details are being analyzed. Figure 19 to Figure 23 summarizes the variation of surface roughness and circularity across different holes. Figure 20 and Figure 23 shows a rough, uneven surface with striations and deformations, suggesting it could be fractured or processed material. The presence of elongated streaks might indicate material flow, mechanical wear, or polishing effects. The areas encircled in red seem to highlight agglomerates or foreign particles embedded in the material matrix. The images were obtained for optimized holes, where the optimization was done on Minitab software, and holes worst hole parameters. Images that best show the composite characteristics are included herein. We observe regions with incomplete and irregular mixing of reinforcement particles in holes with worst recorded parameters. Aggregation of the particles was observed at higher proportion of reinforcement. We also observe cases of clustering of reinforcement particles in the worst holes, the clustering is more pronounced in Hole No.12.

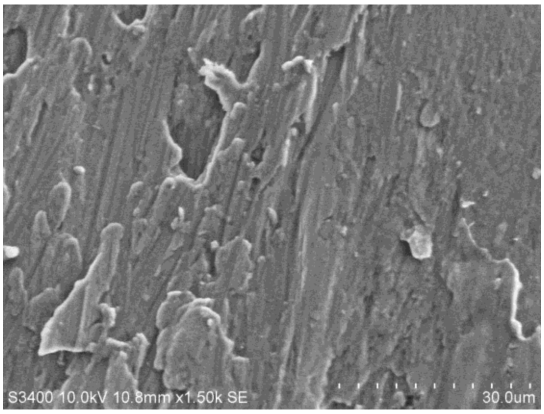

Fig. 19: Min roughness and circularity at entry (hole 11)

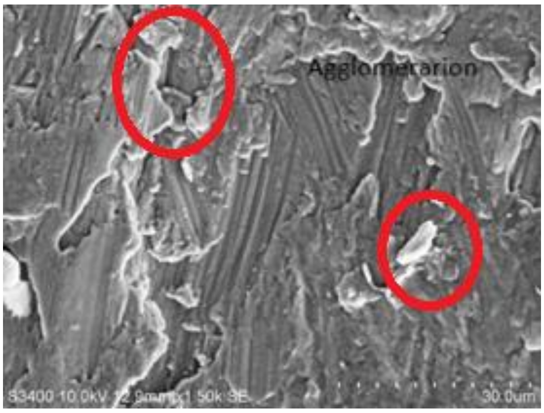

Fig. 20: Max roughness (hole 18)

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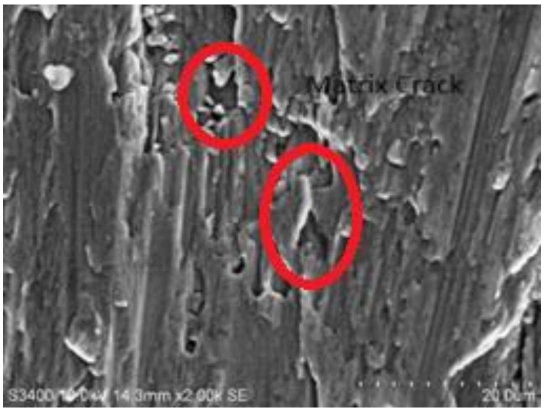

Fig. 21: Max circularity at entry (hole 23)

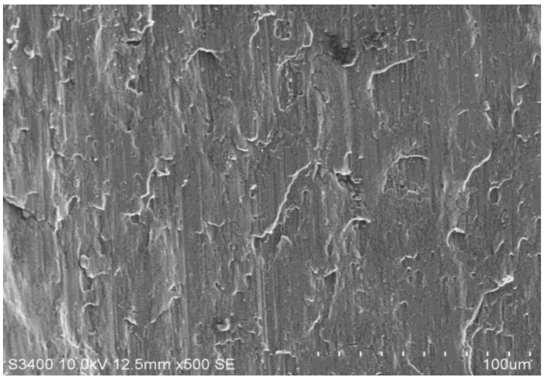

Fig. 22: Min circularity at exit and optimized circularity at exit (hole 6)

Fig. 23: Max circularity at exit (hole 12)

4. Conclusions

From the results and discussions, it is evident that the process parameters such as spindle speed and feed rate along with the dia. of drill bit and % reinforcement of SiC on Ra and circularity at entry and exit. By exercising the Taguchi technique, the optimized combination of process parameters is obtained, and which yields in better Ra and circularity. The following conclusions are drawn based on the results and discussions.

SiC %: The samples with 2% and 8% SiC had better values of roughness, circularity entry and circularity exit.

Drill Bit Diameter: Optimised holes parameters were frequently recorded for the Drill Bit of diameter 6mm.

Spindle Speed: The quality of the hole improved with the rise in spindle speed with some of the best holes occurring at 1160rpm.

Feed Rate: Feed Rate had minimal effect on hole quality with the feed rate of 1.250 mm/rev being the optimised value.

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