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Effect of Drilling Process Parameters on Surface Roughness of LM6/B_4C/Fly Ash Hybrid Composites

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Abstract

This research seeks to assess the effect of process variables such as feed rate (FR), spindle speed (SS), drill material (DM) and reinforcement (R%) on surface roughness (SR) when drilling LM6/B_4C/Fly ash hybrid composites. The stir casting process was used to fabricate the LM6/B_4C/Flyash hybrid composites utilizing LM6 aluminum alloy as the matrix material and B_4C/Fly ash as strengthening materials. Experiments were carried out using an L_{18} orthogonal array (OA) in a Vertical Machining Centre (VMC). SR was determined with a SR Tester. The results reveal that the developed model can exactly estimate the SR in drilling of LM6/B_4C/Fly ash hybrid composite materials. The current study utilizes signal-to-noise ratio (S/N) analysis to determine the ideal machining parameters for drilling AMC's. The goal with this study is to investigate the effect of feed rate (FR), drill type (D), speed (SS), reinforcing material R % on Surface Roughness (SR) when drilling AMCs. The results of the Response table (RT), Response graphs (RG), and Analysis of Variance (ANOVA) determines the best configuration and the effect of parameter values on SR. Feed rate and Spindle Speed (57.98% and 26.21%) has a particularly significant impact on SR. The investigational findings suggest that utilizing this strategy improves the performance parameters that are needed in the process of drilling.

Keywords: Hybrid composites, surface roughness, drilling, optimization, taguchi technique, ANOVA.

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INTRODUCTION

Aluminium(Al) is a highly valued alloy with an extensive list of possible uses in automobile, building, electricity, transportation in general, and spacecraft. In the aircraft industry, the starter of composites has reduced the use of aluminium in airframe construction. Composites face challenges because to have little impact durability and complex mechanical behaviour caused by external factors [1]. Aluminium alloys continue to be utilized as structural components in aviation nowadays due to the way they are produced, greater corrosion resistance, lightweight nature, and reduced cost as opposed to other materials. Metal matrix composites (MMC) are becoming increasingly useful in a variety of sectors; yet, their extremely abrasive character makes them difficult to machine [2]. Drilling is necessary for about 75% of all items; hence it is an inescapable machining technique. Drilling is the most efficient approach in the aerospace industry, since numerous holes are required for aircraft assembly procedures, particularly in the manufacture of welded and fastened items. Throughout airplane service, these structures are exposed to continuous shock and vibration, which causes fatigue failure [3]. The composite is made up of an LM6 alloy matrix, B_4C particles and fly ash as reinforcements. This heterogeneity structure can cause unequal wear on drill bits because of variations in hardness and abrasiveness across different parts of the composite material [4].

B_4C is exceptionally hard, resulting in quick wear on typical drill bits. Specialized carbide or diamond-coated drill bits are frequently required to ensure cutting efficiency and tool longevity. The combination of B_4C and fly ash particles makes the composite abrasive [5]. When not maintained properly, this abrasiveness can accelerate tool wear and result in roughness in the surface or damage. Drilling generates heat, which can be an issue owing to the thermal characteristics of aluminium alloys. Insufficient cooling can cause thermal deformation, melting of the matrix material, or even chemical interactions among components [6].The process of drilling can cause de-lamination (separation) of the aluminium alloy substrate and reinforcement/filler particulates. The chance of injury increases if the drill bit is not appropriately chosen or if parameters for cutting like speed and feed rate are not maximized. The presence of fly ash particles can impede chip drainage throughout drilling. The varied hardness and thermal expansion coefficients of the composite constituents can make it difficult to ensure dimensional precision and long-term stability of holes that are drilled [7].

Creating a smooth and clean hole surface can be difficult, especially when dealing with abrasive particles like B_4C and inconsistencies from fly ash. Surface roughness can be reduced with proper tool selection and cutting parameters. To survive the abrasive properties of B_4C and fly ash, use of carbide or diamond-coated drill bits specifically intended for composite materials. Optimize cutting speeds and feed rates to strike a balance between effective material removal and heat management [8].Never apply too much tool pressure to decrease wear and the possibility of de-lamination. Use an efficient coolant or cutting oil to reduce heat and increase chip outflow. This serves to reduce tool wear and improve surface smoothness. Consider peck drilling (drilling in short bursts with periodic retraction) to control chip production and reduce accumulation of heat. Securely clamp the composite work piece to reduce vibration and motion, resulting in precise drilling and avoiding possible harm [9]. For tackling several particular problems using suitable tools, slicing methods such as and processing approaches, producers may effectively drill the LM6/B_4C/fly ash composite materials while preserving quality and productivity. Real-time observation of drilling parameters (such as thrust force, torque, and vibration) enables modifications to improve drilling performance and ensure dimensional correctness [10].

Adaptive control systems are used to provide continuous cutting processes. Surface integrity studies look at how drill affects composite materials qualities including surface roughness and damage. Investigators can design innovative drilling procedures adapted to specific composite materials, optimize cutting parameters, increase tool life, and further enhance machining efficiency whilst retaining component integrity by combining the results of these thorough reviews. They are great tools for learning about the problems and obstacles of drilling composites in a variety of sectors [11]. Resistance between the drill and the chip generates heat, resulting in an insufficient surface finish and the formation of concentrated stress regions [12]. Drilling is an inevitable aspect of machining because it is needed for about 75% of the parts. As numerous holes are required for the assembly operations of ships, particularly in producing riveted and bolted components, drilling with a twist drill is the most efficient approach in the maritime sector. The structures above are constantly exposed to impacts and vibrations while in naval service, which causes endurance failure. The Taguchi technique is a methodology for determining the optimal control factor settings for rendering a product or process insensitive to noise [13]. The Taguchi-based optimization technique has resulted in a unique and powerful optimization discipline that differs from standard practices. Taguchi methodology is quite straightforward and takes less time than traditional methods [14].

The Taguchi approach employs a particular highly fractionated factorial design and other forms of fractional design derived from OA to inspect the full trial region that is important for an investigator using just a handful of trials. It lowers trial time and costs while also allowing for process optimization. An OA's columns designate the experimental parameters to be optimized, while its rows indicate each

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trial (level combinations). Traditionally, data from experiments is utilized to calculate the average reaction [15].As a consequence, the aviation sector's stringent hole quality requirements make drilling in aeronautical constructions extremely problematic. The present paper evaluates the SR when drilling LM6/B_4C/Fly ash hybrid composite materials using Carbide, and TiN-coated carbide drills. Taguchi's OA was employed in the studies [16]. The hypothesis's robustness is tested through ANOVA. The results demonstrate that the framework developed is capable of calculating the TF, SR, and BH in LM6/B_4C/Fly ash composites drilling within the parameters tested. The present investigation analyses the consequence of process variables on hole excellence in drilling.

MATERIALS AND METHODS

Aluminium Alloy LM6

The matrix substance that was used in this study was selected specifically for its quality, price, and functionality. LM6 alloy is problematic to process because of its substantial silicon concentration and pulling propensity. During regular and marine conditions, the aluminum alloy (LM6) gives the best protection [17]. LM6 alloy primarily consists of aluminum (Al), with additions of silicon (Si) and magnesium (Mg). Typical composition ranges are approximately 7% Si and 0.5% Mg. LM6 has good mechanical properties, including decent tensile strength and hardness.

Boron Carbide (B_4C)

B_4C is a ceramic material that is composed of boron and carbon atoms. Here are some key features and applications of boron carbide, Boron carbide is enormously hard, with a Vickers hardness of 30 GPa. This makes it suitable for applications requiring wear resistance and protection against abrasion. In addition to its hardness, boron carbide is lightweight and has a high compressive strength, making it useful in applications where strength and toughness are necessary. Boron carbide is utilized extensively in ballistic armor applications, such as body armor plates and vehicle armor, due to its high hardness and lightweight nature. It is used to protect against high-velocity projectiles and is valued for its ability to absorb and dissipate kinetic energy [18].

Fly Ash

Fly ash is an extremely fine powder composed primarily of spherical, glassy particles that is formed as an outcome of pulverized coal combustion in electric power plants. It serves as one of the oldest and most prevalent coal combustion products (CCPs) and is often extracted from flue gases via electrostatic precipitators or other particle filtration equipment. Fly ash is frequently used to improve workability, lessen heat of hydration, and increase over time strength and durability. Fly ash is an adaptable substance that provides economic, environmental, and technological benefits in a wide range of construction and engineering applications. Its use grows as academics look for innovative approaches to optimize its efficiency whilst resolving issues such as variability and performance consistency [19].

Fabrication of Hybrid Composites

The hybrid aluminium composites were made-up using the stir casting method. The Aluminium Alloy (LM6) ingots were set and melted in a graphite crucible by an electric furnace. The outside temperature rose gradually to 850º C. The melted material was purified at 800°C with a solid dry hexachloro ethane (C_2Cl_6, 1% wt) degasser. Preheated (250º C) B_4C and fly ash particles were added. The fluid was churned at 600 rpm for 10 minutes. The hot metal was treated with 1% potassium hexafluro titanate (K_2TiF_6)to eliminate the oxide coating from the aluminum surface [20]. B_4C and Fly ash has been included at weight percentages of 0, 1.5, and 3% respectively. The molten metal was swirled before being poured into molds (650°C) and cooled to room temperature. The stir casting set up is shown in Figure 1.

Drilling of Hybrid Composites

Drilling was carried out in the hybrid composite utilizing a VMC. Information regarding studies is collected and recorded utilizing computer-based data collection equipment. The Kistler dynamometer is used to determine the TF. SR evaluation is critical for various fundamental concerns, including friction, surface deformation, heat transmission and current transmission, rigidity of joints, and temporal accuracy [21]. The photograph of VMC and drills used in this research work is shown in figures 2 and 3 respectively. Surface roughness of the machined component was measured using surface roughness tester (Surfcorder SE 3500) and shown in Figure 4.

Figure 1. Stir casting set up.

Figure 2. Vertical machining centre.

Figure 3. Photograph of drills.

Figure 4. Surface Roughness Tester.

Design of Experiments

The Taguchi approach is a technique utilized in production engineering to assess and analyze experimental data. It is employed to assess significant consequences and combinations. It can be a useful tool to figure out the best cutting parameters, with a rapid, successful, and methodical approach. This strategy significantly reduces the number of experiments required to model the responses as opposed to the traditional method for experimentation. DoE approaches are used to transform the conventional design into a sturdy one. The goal of the study is to identify the parameters that effect drilling operations to achieve the lowermost SR. The research study used an L_{18} OA to investigate the influence of drilling process factors. In this study, four variables with three levels each were utilized. Table 1 displays the process parameters [22].

RESULTS AND DISCUSSION

Microstructure Analysis of fabricated Composites

Metallographic analyses offer a powerful quality control as well as an important investigative tool. The samples were cut from each composites and fine polishing was done to get mirror like surface finish. The main objective of microstructure analysis is to confirm the homogeneous distribution of reinforcement particles in the matrix. The composite specimens were analyzed using optical microscope. The optical photo micrographs show the homogeneous distribution of reinforcement particles in the matrix. Micrographs are shown in Figures 5 a - c.

Table 1. Process Variables and their Levels.

Process variables	Symbol	Levels		
		1	***2***	***3***
Drill	D	Carbide	Coated Carbide	-
Spindle Speed (rpm)	S	1000	2000	3000
Feed Rate (mm/min)	F	50	100	150
Reinforcement (%)	R	0	3	6

Figure 5(a) shows the microstructure of LM6 alloys, the Al-Si eutectic particles in spike and script like appearance and are more due to higher percentage of Silicon. The acicular arm of the Al-Si is longer.Figure 5(b) shows the distribution of 3% hybrid (1.5% boron carbide and 1.5% fly ash) in the aluminium matrix composites. The Eutectic constituents of Al-Si of the LM6 alloy are long acicular, script like shape and unchanged. Figure 5c shows the photomicrographs of hybrid metal matrix composite LM6 alloys with 6% addition of hybrid (3% boron carbide and 3% fly ash) composites. The distribution of composites is even and Al-Si is finer.

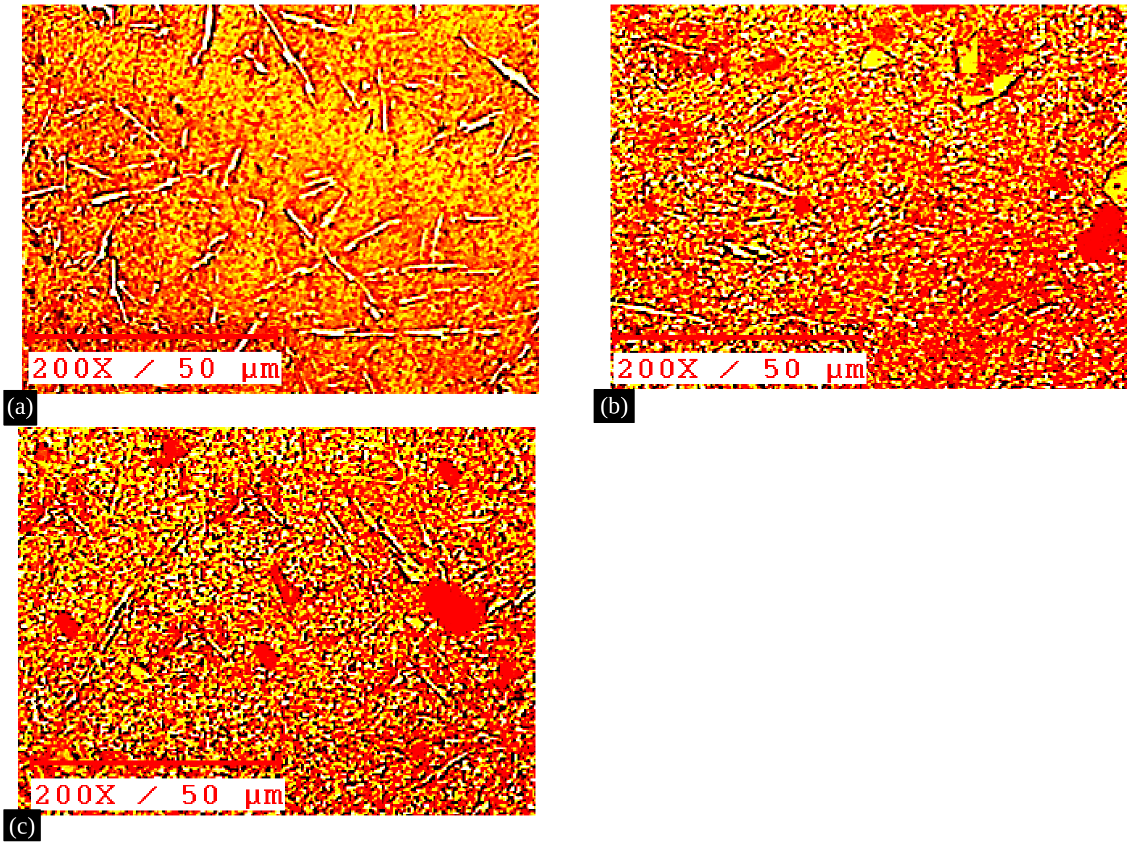

Figure 5. Micrographs of B_4C/Fly Ash reinforced hybrid Composites.(Aluminium Alloy) (LM6) (LM6+3% Hybrid) (LM6+6% Hybrid)

Experimental Results of SR

The L_{18} array was picked because it comprises 18 rows, one for each test. The variables and their relationships are given to columns. The initial column assigned to drill material, the second column to Spindle speed, the third column to FR, the fourth column to R% shown in Table 2.

Table2. Experimental Results.

No	D	S(rpm)	F(mm/min)	R (%)	SR (µm)	S/N of SR
1	Carbide	1000	50	0	2	-6.02
2	Carbide	1000	100	3	3	-9.54
3	Carbide	1000	150	6	4	-12.04
4	Carbide	2000	50	0	2.22	-6.93
5	Carbide	2000	100	3	2.67	-8.53
6	Carbide	2000	150	6	3	-9.54
7	Carbide	3000	50	3	1.78	-5.01
8	Carbide	3000	100	6	2.06	-6.28
9	Carbide	3000	150	0	3.66	-11.27
10	Coated	1000	50	6	2.97	-9.46
11	Coated	1000	100	0	3	-9.54
12	Coated	1000	150	3	3.75	-11.48
13	Coated	2000	50	3	2.1	-6.44
14	Coated	2000	100	6	2.58	-8.23
15	Coated	2000	150	0	3.81	-11.62
16	Coated	3000	50	6	1.46	-3.29
17	Coated	3000	100	0	2	-6.02
18	Coated	3000	150	3	2.56	-8.16

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Analysis of SR

In this study of S/N analysis, Taguchi discovered three elements of performance features: lower is better, nominal is the best, and higher is better. The S/N ratio can be leveraged to quantify quality features. Since a lower amount is considered more advantageous for surplus product quality, the "smaller is better" class is selected for the S/N calculation of surface roughness. The ideal machined variables are determined at the level wherever each variable has the highest S/N. According to Figure 6, the SR drops when the FR is lowered, the SS is raised, coated DM and 6 R % is used. Minitab statistical software had been employed to construct all of the strategy, graphics, and analysis for this study. Figure 6 demonstrates that whenever the material's reinforcing percentage, drill type, spindle speed, and feed rise, so does the SR. The response Table 3 shows based on the mean of each response characteristic at every stage of the factor. The table includes rankings determined by delta statistics, which evaluate the magnitudes of impacts. The delta statistic is the most significant minus the smallest average for each factor [23].

Selection of Optimal Levels

The minimal surface roughness is shown in Figure 6 at level 2 of DM (A_2), level 3 of SS (B_3), level 1 of FR (C_1), and level 3 of R%. Because of this, it is found that the $A_2B_3C_1D_3$ variants (A_1 = TiN coated drill, B_3 = 3000 rpm, C_3 = 50 mm/min and R% 6) have the lowest SR amongst the factors examined.

Ranks have been assigned according to delta values; rank 1 corresponds to the highest delta value, rank 2 to the second highest, and so on. The rankings show the corresponding importance of each element in the response that was given. The placement order in response to Table 3 is calculated using the delta statistics. The difference between the two delta values is calculated for every variable by deducting the smaller value from the larger one. The most significant value is represented by rank one, the next highest by rank two, and so on. The three factors that most significantly affect SR are FR and SS [24].

Table 3. Response Table.

Level	Drill	Speed	Feed	Reinforcement %
1	-8.351	-9.68	-6.19	-8.566
2	-8.25	-8.549	-8.024	-8.195
3		-6.671	-10.686	-8.139
Delta	0.101	3.009	4.496	0.427
Rank	4	2	1	3

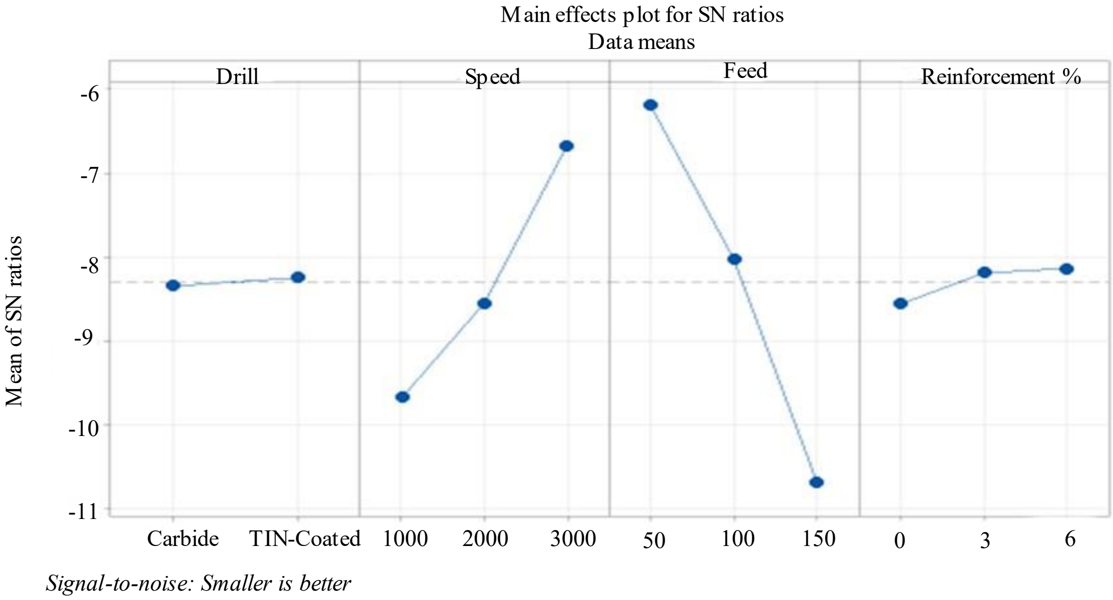

Figure 6. Response Graphs.

Table 4. ANOVA Table.

Source of variation	DoF	SS	MS	F	P	Contribution %
Drill Material (D)	1	0.046	0.0463	0.03	0.868	0.05
Spindle Speed (S)	2	27.721	13.8607	8.65	0.007	26.21
Feed Rate (F)	2	61.321	30.6607	19.13	0	57.98
Reinforcement %	2	0.647	0.3235	0.2	0.82	0.61
Error	10	16.024	1.6024			15.15
Total	17	105.76				100.00

In the current analysis, ANOVA is used to examine the respective roles of the process factors regarding their percentage contributions to the response to optimize the process variables. A level of confidence of 95% was used to establish the evaluation method's efficacy. Table 4 displays the findings of the ANOVA for TF. An ideal R^2 of 85.85% is present for SR. While the p-value for FR and SS is less than 0.05, showing substantial impact of these variables on SR [25].

Confirmation Experiments

Determining the most practical combination of parameters impacting Surface Roughness while drilling of the hybrid composite materials, confirmation experiments were successfully carried out. According to Taguchi, the verification of an investigation is an essential step in confirming the experimental results. The tests were conducted three times to obtain the average value after which received data were compared to the predicted value. The findings from the confirmation experiments shows the optimum process parameters are R% 6, FR of 50 m/s, SS of 3000 rpm, and TiN-coated DM for obtaining minimum SR. The confirmation experiment at optimum level gives a SR of 1.46µm and the predicted value is 1.5 µm. So it can be seen that the performance characteristics has been improved through Taguchi analysis.

CONCLUSIONS

The following conclusions were drawn as a result of studying the consequence of drilling process factors on aluminum alloy LM6/B_4C/ Fly ash hybrid composite materials.

- The stir casting method was utilized to fabricate LM6/B_4C/ Fly ash hybrid composites effectively.
- The surface roughness values of LM6/B_4C/fly ash composites are slightly more than the base alloy because of the inclusion of harder ceramic particles.
- Feed rate and Spindle Speed (57.98% and 26.21%) has a particularly significant impact on SR.
- The error between the experimented and predicted values is less than 5% for the response SR.

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