STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 1, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Drilling Parameters Optimization in LM6/B_4C/Fly Ash Hybrid Composites by Taguchi Technique

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Abstract

Aluminium matrix composites (AMCs) are challenging to machine due to its abrasive characteristics. Because of the broad adoption of MMCs, it is vital to create sufficient equipment to facilitate efficient manufacturing. 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 Thrust Force (TF) when drilling AMCs. AMCs were made using an affordable stir casting process, utilizing LM6 aluminum alloy as the matrix material and B_4C/Fly ash as strengthening materials. CNC Vertical Machining Centre (VMC) equipped with a cutting tool dynamometer was used for drilling and measuring TF. L_{18} orthogonal array was utilized in the tests. 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 TF. The investigational findings suggest that utilizing this strategy improves the performance parameters that are needed in the process of drilling.

Keywords: Optimization, Taguchi technique, hybrid composites, ANOVA, drilling, thrust force

INTRODUCTION

Aluminium matrix composites (AMC) are growing more essential in today's sectors. AMCs have emerged as a material, attracting significant interest because of their superior technical features. Aluminium matrix composites are manufactured using fluid partially solid, and powdered metallurgical technologies [1]. Stir casting is a liquid-state process to make composites whereby glazed ceramic particle is completely blended into a melted matrix metal using mechanical stirrer [2]. B_4C is currently attracting interest from academics on account of its relatively low density (2.51 g/cm^3) and excellent thermal stability. Aluminium matrix composites enhanced with boron carbide are now used in the nuclear sector. Drilling is done during the last preparation stages preceding assembly, when the drilled holes serve as concentrations of stress points. As a result, greater emphasis is being devoted to the possibility of service problems due to creep and fatigue. The thrust force created when drilling composites ought to be reduced to a minimal [3]. Drilling is required for structural connections as well as other purposes. There's an enormous distinction in drilling ordinary metals

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Received Date: August 02, 2024
Accepted Date: October 18, 2024
Published Date: December 10, 2024

Citation: S. Jebarose Juliyana, J. Udaya Prakash, C. Sarala Rubi, K. Sunil Kumar, S. Ananth, Priscilla Whitin. Drilling Parameters Optimization in LM6/B_4C/Fly ash Hybrid Composites by Taguchi Technique. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S890–S897p.

and alloys versus MMC. The DOE is a strong analysis method for modelling and evaluating the impact of many control factors on performance results. Taguchi DOE strategy processes optimization and identify the ideal combination of parameters. It also offers an influential and dynamic way for generating items that perform repeatedly and effectively underneath a wide range of scenarios [4]. The Taguchi technique generates an ordinary orthogonal array to account for the effect of several factors on the goal value and determines the experimentation strategy. Experiments are devised and carried out to investigate the factors that influence the response. S/N ratios are intended to quantify the effect of noise factors on performance metrics. ANOVA determines which design variables or combinations have a meaningful influence on the outcome. It is a method of computations that quantify the corresponding role of the controlling component to the measured response and show it in percentages [5].

Boron carbide (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 cut effectiveness and tool longevity. The combination of B_4C and fly ash particles makes the composite abrasive. If not maintained properly, this abrasiveness can accelerate tool wear and result in SR or damage [6]. Drilling generates heat, which can be an issue owing to the thermal characteristics of aluminium alloys. High temperatures can cause thermal deformation, melting of the matrix material, or even chemical interactions among elements [7]. The drilling operation may result in separation of the composites aluminium matrix and reinforcement particles. The danger increases if the drill bit is not appropriately chosen or if cutting restrictions like SS and FR are not maximized. The presence of fly ash particles can impede chip evacuation while drilling. Proper peck drilling techniques (drilling in short increments) and the use of a successful coolant/lubricant are critical for controlling chip development and out flow [8]. The varied hardness and thermal expansion coefficients of the composite constituents can make it difficult to ensure dimensional accuracy and stability of drilled holes. Creating a smooth and clean hole surface can be difficult, especially when dealing with abrasive particles like B_4C and inconsistencies from fly ash. SR can be reduced with proper tool selection and cutting parameters. To survive the abrasive nature of B_4C and fly ash, use carbide or diamond-coated drill bits specifically intended for composite materials [9]. Optimize cutting speeds and feed rates to strike a balance between effective material ablation and control of heat. Do not apply too much tool pressure to decrease wear and the possibility of delamination. Use an efficient coolant or cutting oil to reduce heat and increase chip evacuation. This serves to reduce tool wear and improve surface smoothness. Consider peck drilling in brief waves with periodic retraction) to control chip production and reduce heat buildup [10]. Securely clamp the composite workpiece to reduce vibration and movement, resulting in precise drilling and avoiding potential damage. By tackling these specific issues using suitable tools, cut strategies, and processing approaches, manufacturers may effectively drill the LM6/B4C/fly ash hybrid composites while preserving quality and productivity. Actual tracking of drilling parameters (such as thrust force, torque, and vibration) enables modifications to improve drilling performance and ensure dimensional correctness [11]. Surface integrity studies look at how drilling affects composite qualities including surface roughness and damage [12]. Researchers can design innovative drilling procedures adapted to specific composite materials, optimize cutting parameters, increase tool life, and boost machining efficiency whilst retaining component integrity by combining the findings of these comprehensive literature reviews [13]. These investigations are great tools for learning about the difficulties and challenges of drilling composites in a variety of sectors. During drilling, the chisel edge cuts the material and chips become lodged in the flutes, generating a significant TF that makes efficient thermal dissipation hard [14]. Resistance between the drill and the chip generates heat, results in a poor surface finish and the formation of stress concentration areas. As a consequence, the aerospace industry's stringent hole quality requirements make drilling in aeronautical constructions extremely problematic.

Drilling parameter optimization in industrial applications has important ramifications for many different industries, particularly in mining, construction, oil and gas, and even the production of medical devices. Numerous advantages result from optimizing drilling parameters like feed, speed, drill, and reinforcement percentage. Drilling parameter improvement drives efficiency, safety, cost-effectiveness, and environmental responsibility, with broad consequences for industrial use. The capacity to precisely control and modify drilling settings is essential for optimizing process variables as industries continues to develop and adopt automation [15].

This article evaluates the TF when drilling LM6/B_4C/Fly ash hybrid composites using two different drills (Carbide, and TiN-coated carbide) [16]. Taguchi's OA was employed in the studies. The model's validity is tested using ANOVA. The results show that the model developed is capable of estimating the TF in LM6/B_4C/Fly ash hybrid composites drilling within the parameters tested. The present research examines the impact of process variables in drilling.

MATERIALS AND METHODS

Aluminium Alloy LM6

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. Due to its corrosion resistance, LM6 is often used in marine environments for components such as marine fittings, boat fittings, and ship structures. LM6 is used in various general engineering applications where lightweight components with good mechanical properties are required. LM6 alloys are generally used in automotive applications, such as engine components, transmission cases, and other structural parts where a combination of strength, lightweight, and corrosion resistance is required [17].

Boron Carbide (B_4C)

B_4C is a ceramic material that is composed of boron and carbon atoms. Boron carbide is extremely hard, with a Vickers hardness of around 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 armour applications, such as body armour plates and vehicle armour, 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 particles that is formed as an outcome of pulverized coal combustion in Thermal 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 as a supplementary cementitious material in concrete production to improve workability, reduce 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 AMCs were fabricated by stir casting. Figure 1 shows a stir cast system. LM6 ingots in graphite crucible are melted by an electric furnace. The degree of heat was gradually elevated to 850^o Celsius. The melted material had been degassed by dry hexachloroethane (C_2Cl_6, 1% wt) degasser at 800°C [20]. The liquefied metal was swirled to form a whirlpool and preheated (150^o C) B_4C particles and fly ash were added. The slurry was churned at 600 rpm for ten minutes. The hot metal was treated with 1% weight potassium hexaflurotitanate (K_2TiF_6). The deliberate inclusion of K_2TiF_6 to the cast of Al/B_4C/Fly ash hybrid composites is to generate an inflammatory zone on the interface between the materials including Titanium Carbide (TiC) and Titanium Boride (TiB_2) to expand dampness and liaise bonding. The inclusion of titanium (Ti) in the form of K_2TiF_6 eliminates the oxide coating from the aluminum surface [21]. Boron carbide and fly ash has been included at wt% of 0, 1.5, and 3%.

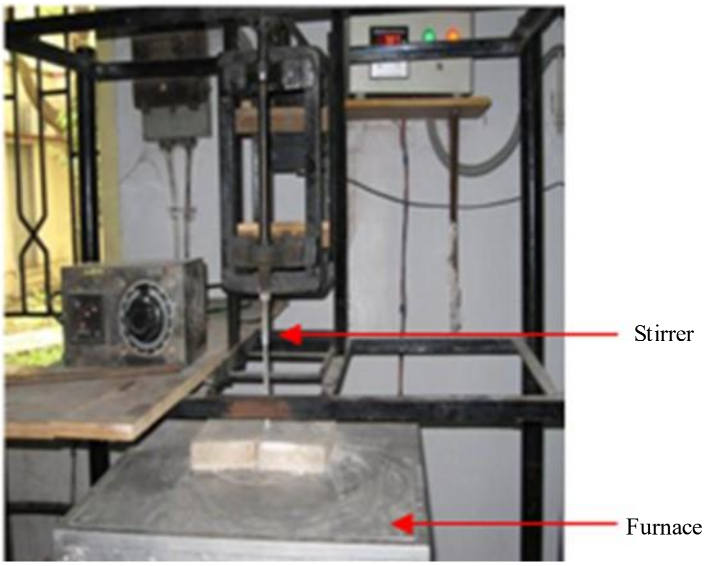

Figure 1. Stir casting set up.

Drilling of Hybrid Composites

Drilling is a crucial procedure. Although LM6 is quite simple to drill due to its reduced hardness and strong thermal conductivity, heat management and tool wear are crucial factors to take into account. Because of its great hardness, brittleness, and low thermal conductivity, B_4C is challenging to drill, necessitating the use of specialized drill, slower feeds, and speeds. Fly ash is scratchy but soft; its porous nature and tiny particle size making drilling difficult because of the possibility of blockage and the quick tool wear. Fly ash presents problems with chip removal and tool longevity because of its abrasive nature and small particles, B_4C requires specialist tooling and slow speeds because of its hardness and brittleness [22].

Drilling experiments was carried out in a way that guarantees consistency and dependability by meticulously managing factors, standardizing methods, and utilizing calibrated equipment, carrying out repeated trials, and applying statistical analysis. In addition to reducing biases and errors, this methodology guarantees that the outcomes are repeatable and relevant to actual industrial applications [23].

The studies have been carried out on a Vertical Machining Centre (VMC 100) using predetermined cutting parameters. The data from the tests are collected and documented using a computer-controlled data gathering. Kistler dynamometer is used to record the thrust force [24].

Design of Experiments

The investigational plan is intended to recognize the parameters that influence the drilling process with a view to achieve the lowest possible TF. The tests were planned by an L_{18} orthogonal array, with the goal of determining the influence of reinforcement, DM, SS, and FR. Table 1 shows the process parameters and their respective levels [25].

Table1. Levels of Process Variables.

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

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Taguchi technique is a potent statistical tool for optimization of processes, including drilling. Its use in drilling parameter optimization is founded on a number of fundamental ideas that are meant to increase process effectiveness, lower expenses, and improved product quality. Taguchi contributes to the development of a process that produces reliable outcomes by making it less susceptible to unpredictable circumstances. To reduce the number of experiments needed while still determining the best variable combinations, it makes the most of orthogonal arrays. By balancing drilling settings, it minimizes downtime, waste of material, and wear on the tools. Additionally, it strikes equilibrium between a number of goals, including cutting speed, surface finish, and tool life. Additionally, it offers unbiased, fact-based knowledge on how variables affect the drilling process. Consequently, the Taguchi technique provides a methodical, effective, and statistically sound way to optimize drilling parameters for increased process dependability, reduced costs, and better performance [26].

RESULTS AND DISCUSSION

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% [27]. Table 2 displays the experimental results.

Analysis of TF

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 Thrust Force. The ideal machine variables are determined at the level where each variable has the highest S/N. According to Figure 2, the TF drops when the feed rate is lowered, the spindle speed is raised, and coated drill material is used. Minitab data analysis software had been employed to construct everything of the plans, graphics, and findings for this study [28].

Table2. Experimental Results.

No	D	S(rpm)	F(mm/min)	R (%)	TF(N)	S/N of TF
1	Carbide	1000	50	0	285	-49.10
2	Carbide	1000	100	3	330	-50.37
3	Carbide	1000	150	6	351	-50.91
4	Carbide	2000	50	0	200	-46.02
5	Carbide	2000	100	3	332	-50.42
6	Carbide	2000	150	6	401	-52.06
7	Carbide	3000	50	3	211	-46.49
8	Carbide	3000	100	6	267	-48.53
9	Carbide	3000	150	0	330	-50.37
10	Coated	1000	50	6	122	-41.73
11	Coated	1000	100	0	247	-47.85
12	Coated	1000	150	3	405	-52.15
13	Coated	2000	50	3	131	-42.35
14	Coated	2000	100	6	288	-49.19
15	Coated	2000	150	0	342	-50.68
16	Coated	3000	50	6	100	-40.00
17	Coated	3000	100	0	238	-47.53
18	Coated	3000	150	3	270	-48.63

Optimal Levels for TF

The minimal thrust force is shown in Figure 2 at level 2 of DM (A_2), level 1 of FR (C_1), level 3 of SS (B_3) 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 TF amongst the factors examined. Ranks have been assigned according to delta values; Upper most delta value is assigned rank1, rank 2 to the second uppermost, and so on. The rankings show the corresponding reputation 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 TF are FR, SS and drill.

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 88.66 % is present for TF. While the p-value for FR and DM is less than 0.05, showing substantial impact of these variables on Thrust force.

Table 3. Response Table.

Level	Drill	Speed	Feed	Reinforcement %
1	-49.36	-48.68	-44.28	-48.59
2	-46.68	-48.45	-48.98	-48.4
3	-	-46.92	-50.8	-47.07
Delta	2.68	1.76	6.52	1.52
Rank	2	3	1	4

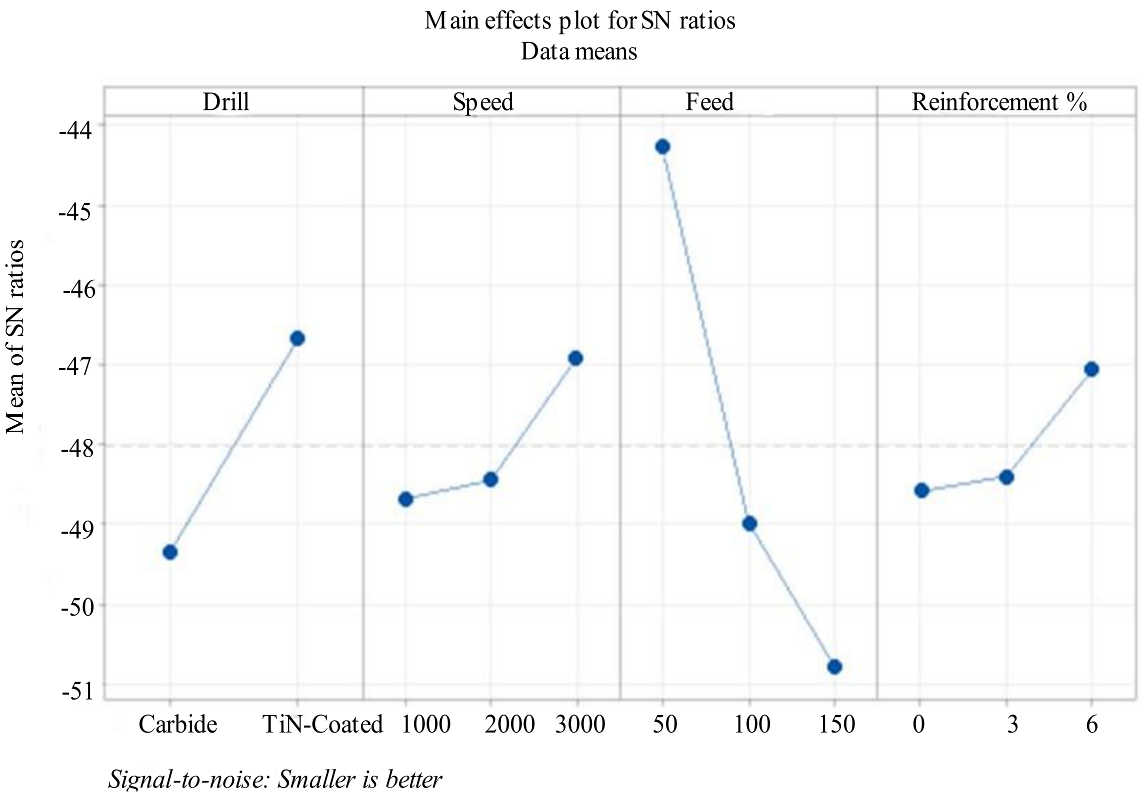

Figure 2. Response graphs.

Table 4. ANOVA Table.

Sources	Dof	SS	MS	F	P	Contribution %
DM	1	32.44	32.44	13.53	0.00	15.34
SS	2	10.98	5.49	2.29	0.15	5.18
FR	2	135.87	67.93	28.33	0.00	64.24
R %	2	8.26	4.13	1.72	0.23	3.90
Error	10	23.98	2.40			11.34
Total	17	211.52				100.00

Confirmation experiments

Determining the most practical combination of parameters impacting Thrust Force, the 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. Interestingly the optimum process parameters are, R% 6, FR of 50 m/s, SSof 3000 rpm, and TiN-coated drill for obtaining minimum TF. The confirmation experiment at optimum level gives a thrust force of 100 N and the predicted TF is 95 N. So it can be seen that the performance characteristics has been improved through S/N analysis.

CONCLUSIONS

The ensuing conclusions were drawn as a result of studying the outcome of drilling process factors on LM6/B_4C/ Fly ash hybrid composites.

- The stir casting method was used to fabricate LM6/B_4C/Fly ash hybrid composites effectively.
- Feed rate and drill material (64.24% and 15.34%) has a particularly significant impact on TF.
- The error between the experimented and predicted values is less than 5%.

Acknowledgments

This article is published with the Research and Development fund - Seed money provided by Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai – 600062, Tamil Nadu, India.

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