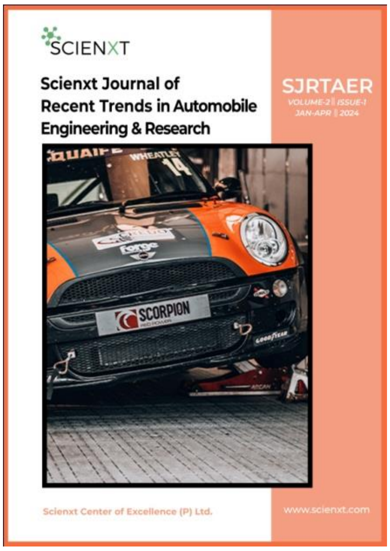

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Evaluation and optimisation of process parameters on quality features of al 7075 metal matrix composite during drilling with hss tool

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Abstract:

Machining metal matrix composite materials presents unique challenges compared to monolithic materials like steel and aluminum due to the abrasive nature of the reinforcement, causing wear on cutting tools and damage to the workpiece. This study focuses on the mechanical characteristics of silicon nitride (Si_3N_4)-reinforced Al 7075 metal matrix composites. Using the stir casting technique, composites were fabricated with Si_3N_4 particles ranging from 2.5% to 7.5% by weight. Mechanical characterization, including hardness tests and Taguchi analysis for process parameter optimization, was conducted. The investigation aimed to provide insights into the aggregation of silicon nitride within the Al 7075 matrix, offering valuable contributions to machining procedures and enhancing the industrial usability of Al-Si_3N_4 composites.

Keywords:

Metal matrix composites, silicon nitride (si3n4), al 7075, stir casting,mechanical characterization, hardness tests, taguchi analysis, process parameter.

1. Introduction:

Since the late 1980s, the pursuit of fuel economy in transportation has driven exploration into materials with enhanced strength-to-weight ratios. Metal matrix composites (MMCs) have emerged as promising candidates, combining lightweight metals with high-strength ceramics. Among these, aluminum alloys stand out for their cost-effectiveness, low density, and resistance to fatigue and corrosion.

However, machining MMCs, especially drilling, poses challenges due to the abrasive reinforcements, causing tool wear and surface imperfections. Understanding drilling parameters and reinforcement materials is crucial for optimizing MMC machinability. AMC drilling, in particular, is a focus due to issues like tool wear and burr formation.

Stir casting enables cost-effective incorporation of reinforcements into aluminum matrices, facilitating fabrication of large components with enhanced properties. Systematic investigation into MMC machining and process optimization is essential for advancing applications in automotive, aerospace, and other industries requiring lightweight, high-performance materials.

2. Objective:

This study investigates the drilling machinability of aluminum 7075/Si_3N_4 metal matrix composites. Objectives include preparing composites with varying Si_3N_4 percentages, analyzing drill bit diameters and drilling conditions, and optimizing parameters for improved surface quality. The focus is on assessing surface roughness and circularity impacted by drilling parameters and reinforcement levels, aiming to provide insights for practical applications and contribute to advancements in MMC machining.

3. Methodology:

This study employs a comprehensive approach to investigate the fabrication and machining behavior of aluminum 7075/Si_3N_4 composites. Drilling operations are rigorously analyzed to evaluate machinability, considering variations in tool material, diameter, geometry, spindle speed, and feed rate. Accurate mold and volume calculations are conducted using stainless steel grade 316 for mold construction to ensure experimental precision. The dimensions of the mold and the volume of aluminum 7075 matrix and Si_3N_4 reinforcement are meticulously measured to maintain consistency.

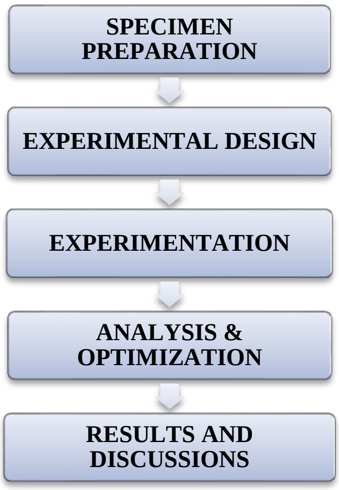

Figure. 1: Methodology

The stir casting process is meticulously executed to prepare the metal matrix and reinforce particles effectively. Aluminum metal matrix is melted under controlled conditions, while reinforcement particles undergo pre-treatment for enhanced adhesion properties.This methodology aims to provide valuable insights into processing parameters and material properties' interactions, advancing composite materials for diverse engineering applications.

4. Material selection:

4.1. Matrix: aluminium 7075 (Al 7075):

The Al-7xxx series, characterized by high zinc content, is recognized as the strongest aluminum series. However, it exhibits drawbacks such as low fatigue resistance and susceptibility to corrosion. Incorporating reinforcing particles like Si_3N_4, SiC, and Al_2O_3 enhances the specific strength and fatigue resistance of aluminum 7075, making it suitable for diverse applications.Renowned for its exceptional strength-to-weight ratio and fatigue resistance, Aluminum 7075 finds extensive use in high-pressure applications, particularly in aerospace for critical components like fuselage frames and wing structures. Its high strength, reduced weight, and fatigue resistance contribute significantly to aircraft performance.

4.2. Reinforcement: silicon nitride (Si_3N_4):

Si_3N_4 serves as a pivotal reinforcement in Al7075 composites, enhancing their mechanical properties, including strength and hardness. Its low density, comparable to aluminum, is crucial for weight optimization in aerospace and automotive engineering. Si_3N_4 also offers enhanced heat resistance, ensuring stability in high-temperature environments, and high wear resistance, improving tribological properties. Additionally, it exhibits exceptional chemical and oxidation resistance at elevated temperatures, making Si_3N_4-reinforced Al7075 composites suitable for high-performance applications across various sectors

Figure. 2: Aluminum 7075

Figure. 3: Silicon Nitride Particles

5. Mould calculation:

The mold for the composite material, made from Stainless Steel grade 316, with dimensions 90 mm x 90 mm x 20 mm, has a volume of 162,000 mm^3. The mass of Al7075 for a 100% volume was calculated as 456 grams. For varying percentages of Si3N4 reinforcement (2.5%, 5%, and 7.5%), volumes were calculated accordingly: 487 grams Al7075 and 12.5 grams Si3N4 for 2.5%, 475 grams Al7075 and 25 grams Si3N4 for 5%, and 462.5 grams Al7075 and 37.5 grams Si3N4 for 7.5%. These precise measurements are critical for achieving desired material properties and performance characteristics in subsequent fabrication processes.

Figure. 4: Rectangular Mould

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6. Stir casting:

Stir casting composites involve melting the aluminum matrix, preparing reinforcement particles, combining them using an automated stirrer, and casting the mixture into a mold. After solidification, the composite undergoes precision machining for desired dimensions and surface characteristics. Parameters like stirrer speed (600rpm), reinforcement preheat temperature(300°C) and stirring time (10mins) are crucial for optimal casting results.

Figure. 5: Bottom Pouring Stir Casting

7. Drilling:

Three twist drill bits with diameters of 6 mm, 8 mm, and 10 mm, along with a radial drilling machine equipped with high-speed steel (HSS), are utilized for drilling aluminum composite reinforced with Si3N4. HSS bits are known for their toughness and heat resistance, making them suitable for high-speed operations and ensuring long-lasting performance. The HSS drill bit features two cutting edges angled at approximately 118 degrees to each other.

The drilling of composite specimens is carried out using an Automatic Radial Drilling Machine, known for its precision and versatility. Equipped with a drilling head positioned along a radial arm, this machine allows for accurate adjustment of drill positions above the workpiece by rotating, elevating, or lowering the arm. To ensure systematic experimentation, three sample holes are drilled in the composite material using this automated radial drill. The input parameters for drilling are determined using the Taguchi design of experiment (DOE) and organized through orthogonal arrays, enabling systematic analysis of drilling properties with Minitab software.

Figure. 5: Automatic Radial Drilling

Figure. 6: Drilled Specimen with Markings Machine (2.5%, 5%, 7.5%, from left to right)

8. Precision surface measurement with the surfcom flex- 50A:

The Surfcom Flex-50A offers advanced surface roughness and contour measurement capabilities, combining contact and non-contact methods for accurate assessment. Its versatile stylus configurations and tip profiles enable measurement on various surfaces. The intuitive software interface ensures easy setup and operation, while advanced analysis functions allow for in-depth evaluation of surface characteristics. With high-resolution measurement capabilities, it detects even the smallest irregularities, ensuring thorough quality assessment.

Efficiency-enhancing features like motorized movement and automated measurement sequences streamline the inspection process, saving time and increasing productivity. Overall, it provides precise and reliable data for surface inspection applications, enhancing quality control and research insights.

Figure. 7: Surfcom Flex-50A

9. Circularity measurement with profile projector:

Circularity, essential for assessing roundness or deviation from a perfect circle, was measured using a profile projector. This instrument enables precise measurement of component outlines by projecting images onto a screen. Accurate circularity quantification was achieved by comparing captured images with a reference circle. This measurement is vital for evaluating dimensional accuracy and machining process quality, providing valuable insights into component effectiveness.

Figure. 8: Profile Projector measuring Circularity

10. Rockwell hardness test:

The Rockwell hardness testing machine, employing a ball indenter and the B scale for materials up to 100 Rockwell C scale hardness, accurately measures indentation depth with a 100 kgf load. It is utilized in engineering and manufacturing, this equipment provides crucial insights into material mechanical properties for quality control and material selection processes

Table. 2: Rockwell Hardness Test Result

Sample Specification	Recorded Values	Average Values in RHN
2.5% Si3N4	62	61.4
	65	
	59	
	61	
	60	
5% Si3N4	74	73
	75	
	72	
	73	
	71	
7.5% Si3N4	78	82.4
	84	
	81	
	86	
	83	

The hardness is minimum for 2.5% Si3N4 with a value of 61.4 RHN and increases with the increase in percentage of Si3N4 to 5% and increases again for 7.5% Si3N4 with a value of 73 RHN and 82.4 RHN respectively.

11. Taguchi analysis of signal to noise ratios:

Taguchi Analysis optimizes machining processes by identifying critical factors affecting quality and performance. Key parameters like feed rate, spindle speed and drill diameter are assessed to minimize variation and achieve desired outcomes. This method employs signal-to-noise ratios and means to evaluate parameter impacts on machining efficiency and quality, enabling manufacturers to enhance productivity and product quality through process fine-tuning.

11.1. Taguchi Analysis for Optimisation of Roughness:

Taguchi analysis identifies key machining parameters affecting signal-to-noise ratios and means. Optimal roughness is achieved with 7.5% Si3N4, 8mm drill bit diameter, 1160 rev/min spindle speed, and 0.125mm/rev feed rate. Residual plots assess model fit, accounting for material variability.

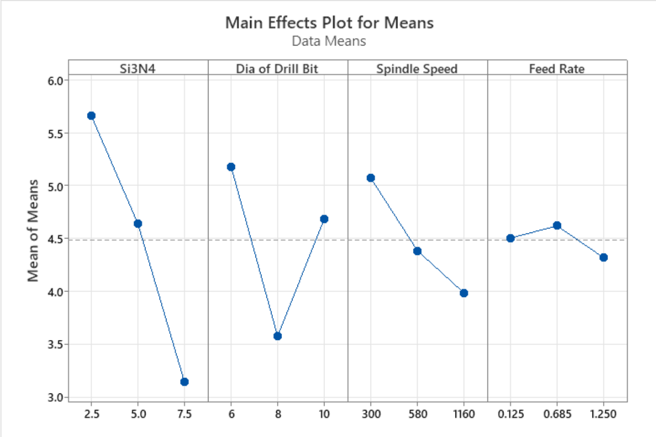

Figure. 9: Means of Means vs Data means

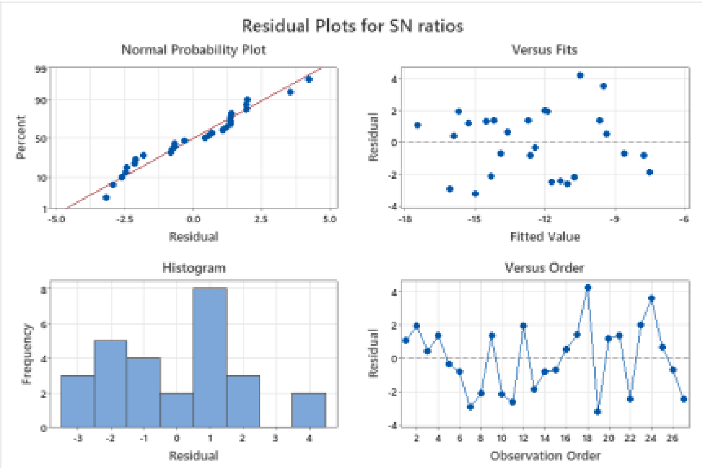

Figure. 10: Residual Plots of SN Ratios

11.2. Taguchi analysis for optimization of circularity:

Taguchi analysis identifies key machining parameters affecting signal-to-noise ratios and means. Optimal circularity is achieved with 7.5% Si3N4, 6mm drill bit diameter, 300 rev/min spindle speed, and 1.25mm/rev feed rate. Residual plots assess model fit, accounting for material variability.

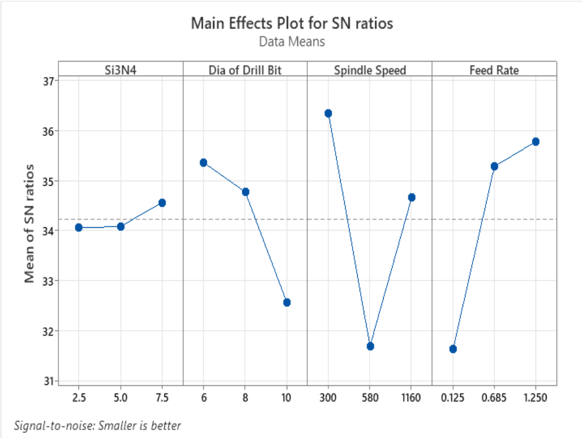

Figure. 11: Means of Means vs Data means

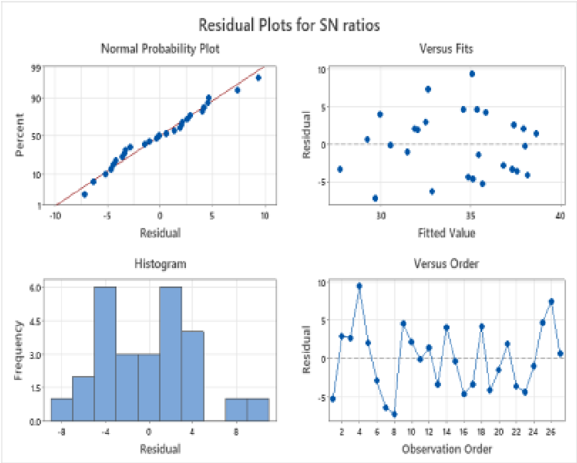

Figure. 12: Residual Plots of SN Ratios

12. Conclusion:

This study investigates the impact of adding silicon nitride (Si3N4) at 2.5%, 5%, and 7.5% mass percentages to AL7075, focusing on drilling optimization. Factors considered include Si3N4%, spindle speed, drill bit diameter, and feed rate. Results show optimal hole quality at 7.5% Si3N4, 6mm and 8mm drill bit diameters, 1160 rpm spindle speed for roughness, and 300 rpm for circularity, with a feed rate of 0.125 mm/rev for roughness and 1.25 mm/rev for circularity. Variability in material and machining can affect data in metal matrix composites.

13. Applications:

Al7075 reinforced with Si3N4 is widely used across industries like aerospace, defense, automotive, tooling, mold making, and sporting equipment. Its superior mechanical properties make it ideal for critical components, enhancing performance, fuel efficiency, and durability. From aircraft parts to vehicle components and sporting gear, Al7075/Si3N4 composites offer strength, durability, and high performance, making them indispensable in various applications.

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