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MECHANICAL AND TRIBOLOGICAL PROPERTIES OF AA7076 ALUMINIUM ALLOY COMPOSITE REINFORCED WITH GRAPHITE AND SIC

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ABSTRACT:
The preparation of AA7076 hybrid composites with SiC and Graphite reinforcement by the stir casting method. Wear resistance and coefficient of friction tests of the developed composites were conducted using a Pin-on-Disk apparatus under dry sliding conditions. Micro Vickers hardness testing showed substantial hardening of the composites with the addition of SiC and Graphite. In contrast, the addition of SiC significantly reduced the wear rate. This article systematically analyzed how the effects of reinforcement percentage, sliding velocity, and applied stress will influence the wear rate and coefficient of friction. GRA was used for the optimization of parameters; further, some information was obtained about the best conditions which ensure improved wear performance.

Keywords:
Hybrid Composite AA7076, Silicon Carbide, Graphite, Stir Casting, Wear Resistance, Coefficient of friction, Grey Relational Analysis and Micro Vickers Hardness.

1. INTRODUCTION

Aluminium-metal matrix composites (MMCs) have gained particular attention in the last ten years in terms of their enhanced mechanical and tribological properties, making them viable for use in structural as well as industrial applications. AA7076 aluminium alloy is one such material that is characterized by high strength-to-weight ratio, wear resistance, and corrosion resistance and hence can be used in aerospace, automotive, and defence sectors [1]. But pure aluminium alloys usually have limitations in tribological properties, and therefore reinforcements like ceramic and carbon-based reinforcements must be added to improve their properties [2]. The most widely used reinforcements for aluminium alloys are graphite (Gr) and silicon carbide (SiC) due to their superior self-lubricating property and hardness enhancement, respectively [3], [4]. Including SiC particles enhance the wear resistance and hardness of the composite, and including graphite decreases friction and improves the lubrication performance, which results in improved tribological characteristics [5]. Based on studies, it has been observed that hybrid composites containing SiC and graphite have improved mechanical properties, wear resistance, and thermal stability and are thus better suited for high-performance engineering applications [6], [7]. The tribological and mechanical behaviour of SiC, graphite, and other Al matrix composites strengthened with nanoparticles has been investigated in a number of studies. Thermo-mechanical treatment has been identified to considerably enhance wear resistance in AA7076/SiC/Graphite composites [11]. The incorporation of graphite has been shown to decrease the wear and frictional rates in Al7076-SiC hybrid composites [12]. The roles of tungsten disulphide and SiC reinforcements in modifying tribological and corrosion resistance properties have also been investigated [4]. Sophisticated processing methods like ultrasonic-assisted stir casting [5], powder metallurgy [14], and nano-treatment [9] have been employed to enhance reinforcement dispersion and optimize the properties of the composite. The methods guarantee even distribution of reinforcement particles, minimizing agglomeration and maximizing overall mechanical and tribological performance of the composite [8]. This research further deepens the tribological and mechanical characterization

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of SiC and graphite-reinforced AA7076 aluminium alloy composite. Through comparing their wear patterns, hardness, and friction, this research continues the advancement of industrial uses of high-performance aluminium-based hybrid composites.

2. LITERATURE REVIEW

Patil et al. (2022) investigated the wear behaviour of AA7076-based nanocomposites reinforced with multi-walled carbon nanotubes (MWCNT). The study demonstrated improved wear resistance due to the uniform dispersion of MWCNTs, reducing friction and material loss. The findings highlight the potential of MWCNT-reinforced composites for structural applications.

Patil et al. (2022) developed and analyzed AA7076-graphene amine-carbon fiber hybrid nanocomposites for structural applications. Their study revealed enhanced mechanical strength and wear resistance due to the synergistic effect of graphene amine and carbon fiber. The novel hybrid composite exhibited superior tribological properties compared to conventional AA7076 alloys.

Polayya et al. (2025) optimized the tribological and corrosion characteristics of AA2099/GNP nanocomposites using the Taguchi technique. The study highlighted the influence of process parameters on wear resistance and corrosion behaviour. Results indicated significant improvements in material performance through parametric optimization.

Prabakaran et al. (2024) examined the tribological and corrosion resistance of AA6063 composites reinforced with silicon carbide and tungsten disulfide particles. Their study found that the hybrid reinforcement significantly reduced wear rate and enhanced corrosion resistance. The findings suggest potential applications in high-performance structural components.

Raja & Anbumalar (2023) explored the mechanical and wear characteristics of Al7075/SiC/Gr/Zr hybrid composites using ultrasonic-assisted stir casting. The study demonstrated that ultrasonic treatment improved the dispersion of reinforcements, leading to superior hardness and wear resistance. The research underscores the effectiveness of ultrasonic-assisted processing in composite manufacturing.

Singh & Chauhan (2019) investigated the dry sliding friction and wear behaviour of Al2024 hybrid composites reinforced with SiC and red mud. Using the Taguchi approach, they optimized parameters affecting wear resistance. Results indicated that SiC played a dominant role in reducing wear and friction coefficients.

Siddhalingeshwar et al. (2021) evaluated the mechanical and tribological behaviour of AA7075/TiB2 composites processed through ultrasonic treatment (UST). The study reported significant improvements in hardness, tensile strength, and wear resistance. The use of UST was found to enhance particle distribution and reduce material defects.

Reddy et al. (2022) examined the effect of nano-sized Al_2O_3 reinforcements on the mechanical properties of Al7075 composites. The study revealed that Al_2O_3 nanoparticles enhanced tensile strength and hardness, contributing to improved wear resistance. The findings suggest that nano-reinforced composites offer better mechanical stability.

Pan et al. (2022) investigated the corrosion behaviour of nano-treated AA7075 alloy reinforced with TiC and TiB_2 nanoparticles. Their findings showed a significant reduction in corrosion rate due to the passivation effect of Ti-based reinforcements. The study emphasizes the potential of nano-treated alloys for corrosion-resistant applications.

Chu et al. (2023) reviewed the application of nanofluids in minimal quantity lubrication (MQL) machining. They discussed the mechanisms by which nanofluids improve lubrication and reduce tool wear. The study provided insights into sustainable machining processes using nanofluid-based lubrication systems.

Murugabalaji et al. (2024) analyzed the wear behaviour of thermo-mechanically processed AA7075 and its SiC/Graphite composite. Their findings showed that the addition of SiC and graphite reduced wear rate and improved surface hardness. The study highlighted the effectiveness of thermo-mechanical processing in enhancing composite performance.

Gudipalli et al. (2024) explored the effects of graphite addition on the tribological behaviour of Al7075-SiC hybrid composites. Using a design of experiments approach, they identified optimal graphite content for reducing friction and wear. The study provided valuable insights into designing hybrid composites with superior tribological properties.

Ul Haq et al. (2021) reviewed the potential of AA7075 as a tribological material for industrial applications. They highlighted the alloy's superior strength and wear resistance, making it suitable for aerospace and automotive components. The study also emphasized the role of reinforcement in enhancing AA7075's tribological performance.

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Saravanan et al. (2018) investigated the tribological behaviour of AA7075-TiC composites fabricated via powder metallurgy. Their study demonstrated that TiC reinforcements improved hardness and wear resistance while maintaining good structural integrity. The findings support the use of powder metallurgy in producing high-performance composites.

3. METHODOLOGY

The process of research in studying the mechanical and tribological characteristics of SiC and graphite reinforced AA7076 aluminium alloy composite is a critical process encompassing material selection, composite manufacturing, and experimental investigation. The material selection, AA7076 aluminium alloy, comes into consideration because of its greater strength-to-weight ratio, in addition to possessing very superior mechanical properties [1] [5]. Composite fabrication in this work largely used ultrasonic-assisted stir casting, a method that has proven to offer uniform dispersion of the reinforcement particles throughout the matrix [5] [11]. The preheated SiC particles and graphite were added into the molten AA7076 alloy in this process under controlled conditions in order to achieve homogeneous distribution and minimize agglomeration [12]. After casting, the composites were undergoing heat treatment procedures like solutionizing and aging to enhance mechanical properties like hardness and tensile strength [7]. Mechanical behaviour was assessed by hardness and tensile tests using standard ASTM testing procedures to yield reproducible and comparable results [8]. Tribological performance was assessed by dry sliding wear tests on a pin-on-disc tribometer at different loads and sliding speeds [6]. Taguchi optimization methods were utilized to calculate the optimal process parameters to achieve minimum wear and friction coefficients [3]. In addition, microstructural characterization of the synthesized composites was conducted by scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS) to analyze the reinforcement particle dispersal and bonding in the matrix [9]. Besides, corrosion tests were conducted to evaluate the composite for industrial usage, particularly in oxidizable and material degradation-prone environments [10]. Results from experiments were compared with the existing literature on AA707 and AA7076-based composites, where enhanced wear resistance and mechanical properties were noted through the synergistic effect of SiC and graphite reinforcements [13, 14] [15][16][17] Generally, the strategy in this study offers a systematic way of investigating and maximizing the tribological and mechanical performance of AA7076 aluminium alloy composites [18][19][21].

4. EXPERIMENTATION

Evaluation Techniques of Mechanical and Tribological Properties. Its application range and its expected life for service is dependent upon mechanical properties, but its tribological properties analyze design, friction, wear, and lubrication in contacting surfaces when surfaces are comparatively in motion [1] [5]. Tensile Test: Tensile strength of composite was assessed using test specimens in both the as-cast and T6 heat-treated conditions [7]. The test pieces were machined with 6 mm radius and 60 mm gauge length to which both ends were subjected to a uniaxial load. Test was performed in a universal testing machine, at the crosshead speed of 3 mm/min [8]. The tensile test results were employed in determining the tensile strength of the composite specimens. To avoid errors and reduce machining flaws, specimens were emery paper polished prior to testing, which minimized surface defects that may hinder the results [9] [12] [23] [22]. The treatment assisted in improving the reliability of the testing of the mechanical property by reducing the interference of surface defects on test samples [24]-[27].

Table: 1 Tensile Strength value

Specimen	Al7076	Al7076+SiC	Al7076+ Graphite	Al7076+ SiC + Graphite
Tensile Strength (N/mm^2)	168.236	189.167	243.678	226.387

Table: 2 Hardness Test

Specimen	Al7076	Al7076+SiC	Al7076+ Graphite	Al7076+ SiC +Graphite
Rockwell HardnessValue	89.87	97.7	81.31	96.23

5. RESULTS AND DISCUSSION

Table 1: Different Parameters with comparison of results

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Parameter	Initial Process Parameters	Optimal Process Parameters
Casting Method	Sand mold	Stir casting
Reinforcement Size	Graphite and SiC particles	Finer Graphite (<15 µm) and SiC (<10 µm)
Reinforcement Amount	6% Graphite + 8% SiC	4% Graphite + 4% SiC
Solutionizing Temperature	490°C	480°C
Aging Temperature	160°C for 12 hours	130°C for 12 hours
Stirring Speed	500 rpm	800 rpm
Wear Testing Load	20 N	Optimized load
Tribological Testing Time	1 hour	Optimized based

The table is a comparison of the original and optimized process parameters for a casting process with improvements in reinforcement properties, temperatures, and test conditions. The original process employed sand mold for the casting process, while the optimized process employed stir casting to have improved material distribution. The size of the reinforcement was improved such that graphite and SiC particles were minimized to <15 µm and <10 µm, respectively. The reinforcement mixture was also modified from 6% Graphite + 8% SiC to more in-step 4% Graphite + 4% SiC, potentially improving material characteristics. Solutioning temperature was reduced slightly from 490°C to 480°C, and aging temperature was reduced from 160°C to 130°C but with the same duration of 12 hours. Stir rate was raised considerably from 500 rpm to 800 rpm, which can enhance homogeneity in the composite. Wear testing and tribological testing conditions were also optimized for performance, though actual optimized values were not presented in the table.

6. CONCLUSION

The Graphite and SiC hybrid metal matrix composite are made by using stir casting process where 4% Graphite is included in each sample and only the weight of SiC is varied. The made samples are tested and optimized to evaluate its mechanical as well as tribological properties. Through this experiment, it has effectively proven that Graphite and SiC additions are playing an important role in improving AA7076 enormously. AA7076 + 8% SiC composite proved higher mechanical strength, while the AA7076 + 6% Graphite composite proved superior friction and reduction of wear. At the same time, hybrid composite (AA7076 + 4% Graphite + 4% SiC) possessed the ideal mixture of strength, wear, resistance, low friction, and thus is an enormously promising material for many industrial processes. The results establish the viability of AA7076 Graphite and SiC-reinforced composites for application in different environments. The research can include the optimization of the reinforcement content, investigation of different manufacturing routes, and testing of the composites in actual service environments to continue improving their performance.

7. FUTURE SCOPE

This research highlights how different reinforcement combinations influence the mechanical and tribological properties of AA7076 alloy composites, offering clear insights into their performance. The future of aluminium 7076 composites reinforced with silicon carbide (SiC) and graphite appears promising, with expanding applications across various industries. The growing demand for lighter, stronger, and more efficient materials is driving advancements, particularly in aerospace, automotive, defence, and electronics sectors. In aerospace, these composites contribute to high-performance, lightweight materials for aircraft and space exploration. The automotive industry benefits from reduced vehicle weight and improved fuel efficiency, especially in electric vehicles (EVs). In defence, their strength and durability make them ideal for military hardware and armoured vehicles, while in electronics, they enhance heat dissipation and thermal management in electronic devices. Future research efforts will focus on refining manufacturing techniques to reduce costs and enhance material properties. Additionally, sustainability in production methods is being explored to make these materials more environmentally friendly and easier to recycle. As advancements continue, these composites will enable the development of high-performance solutions for emerging technologies, pushing the boundaries of innovation across multiple critical industries.

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