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INVESTIGATION OF MECHANICAL PROPERTIES OF AA6061 COMPOSITE REINFORCED WITH TiO2 PARTICLES USING STIR CASTING PROCESS

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Abstract: This project investigates the mechanical properties of AA6061 (Aluminum Alloy 6061) reinforced with Titanium Dioxide (TiO2) particles through the Stir Casting process. Specimens were fabricated according to ASTM standards using conventional machining techniques. The percentage of TiO2 reinforcement varied between 5%, 10%, and 15% in the composite material. Mechanical tests were conducted to assess the impact of reinforcement percentage on the composite's properties. Additionally, the microstructure of the specimens was analyzed using Scanning Electron Microscopy (SEM). Results reveal significant alterations in mechanical properties corresponding to variations in reinforcement percentage, highlighting the potential of TiO2 reinforcement in enhancing composite performance.

Keywords: Al MMC, Stir casting, Al6061, TiO2 micro particles, Composite materials

I. INTRODUCTION

The burgeoning demand for cutting-edge engineering materials possessing attributes like heightened strength, reduced mass and heightened resilience to abrasion is notably pronounced across aerospace, civil, and automotive sectors. In response, Aluminum Matrix Composites (AMCs) have emerged as a pivotalinnovation. These composites involve the reinforcement of aluminum primarily with robust phases such as SiC, TiC, TiB2, and Al2O3, alongside softer phases like graphite (Gr) and MoS2. By infusingnano particles, AMCs exhibit physical and mechanical traits distinct from traditional metals. These micro particles elevate the base material across a spectrum ofcharacteristics including tensile and compressive strength, hardness, wear resistance, damping capabilities, porosity, corrosion resistance, and overall mechanical properties. The optimization of nano particle reinforcement in metal matrices hinges upon various factors including primary and secondary processing methods, matrix composition, particle size, volume fraction, morphology of reinforcement, and heat treatment protocols. Among the diverse range explored, Titanium dioxide nano particle reinforcement stands out as particularly efficacious in fortifying the strength properties of Aluminum, especially when integrated via ingot metallurgy procedures.

Metal matrix composites exhibit significant potential across various domains, particularly in automotive engineering where they are employed in braking systems, piston components, frames, and more. Their versatility extends to military and civil aviation,enhancing axle tubes, reinforcements, and various critical components. Within aerospace, these composites find utility in frames, aerials, and joining elements. Notably, aluminum-based metal matrix composites are renowned for their exceptional specific strength, hardness, and favorable tribological characteristics. Silicon carbide-reinforced aluminum composites are increasingly favored as alternatives for crucial automobile components such as cylinder heads,liners, pistons, and brake disks. The primary aim of producing particulate-reinforced metal matrixcomposites is to achieve materials with exceptional wear resistance, reduced weight, and superior strength-to-weight ratio. This endeavor ultimately aims to diminish costs associated with technological applications and fuel usage.

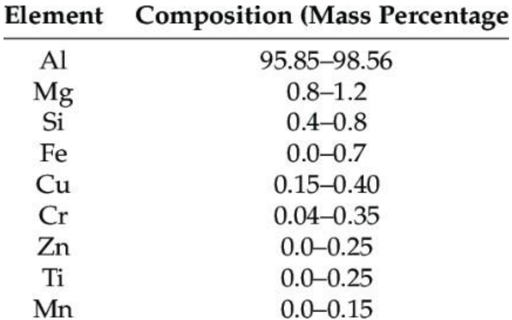
II. LITERATURE REVIEW

[1] Surabhi Lata et al. delved into the mechanical characteristics of AA5051 alloy fortified with varying percentages (5%, 10%, and 15%) of TiO2 via the casting process. Employing sand casting and electric resistance furnace at 1200°C, they observed an augmentation in tensile strength, impact strength, and average hardness with increasing concentration of titanium dioxide particles, albeit a decline in compressive strength. The optimum enhancement in mechanical properties of AA5051 was achieved with 15wt% TiO2 reinforcement. [2] Mithilesh Kumar et al.conducted a study on metal matrix composites fabricated via stir casting, employing TiO2 as reinforcement with varying volume fractions (4%, 8%,12%, and 16%). They noted an incremental improvement in mechanical properties, including tensile strength, compressive strength, and torsionalstrength, with increasing volume fraction of thereinforcement material. [3] M. Haripriya et al. developed an aluminium metal matrix composite usingstir casting, with pure aluminium (660.4°C) as the base matrix and titanium (1660°C) as reinforcement (3wt% and 6wt%). Upon evaluation and comparison with pure aluminium, they found the reinforced composite exhibited superior mechanical properties. Notably, the 6wt% reinforced aluminium displayed heightenedtensile strength, compressive strength, yield strength, albeit with reduced elongation from 21.14% (0% Ti specimen) to 9.72% (6% Ti specimen). [4] Ramesh B T and colleagues developed a stirring casting apparatus utilizing refractory bricks, a crucible furnace, a blower, a stirrer, and charcoal for ignition and heating. The stirrer's speed ranges from 250 to 800rpm, with an optimal speed of 400 rpm. The furnace heats up to 900°C, accommodating approximately 450 grams at a time, ensuring proper heat entrapment with refractory bricks. It reaches temperatures sufficient to melt aluminum and similar metals. The stirrer aids in uniformly dispersing reinforcement particles throughout the molten metal. [5] Arunkumar Sharma and co-researchers explored the diverse applications ofaluminum metal matrix composites (Al MMCs), noting their significance in automotive, rail and marinetransportation, aerospace, construction, electronics,sports, recreation, and defense industries. [6] T P Bharathesh et al. investigated an AA6061 matrix composite reinforced with 8wt% TiO2, processed through liquid metallurgy followed by hot forging. Microstructure studies revealed fine and uniform distribution of TiO2 particles after hot forging. Although the hardness and tensile strength increased compared to the unreinforced alloy, the ductility of both casted and forged composites decreased with higher TiO2 percentages. [7] Badran and colleagues explored the impact of varying stir casting parameters, particularly stirring speed and duration. They determined that the optimal conditions were achieved at 1000rpm for 10 minutes. In their study, incorporating 2wt% and 5wt% of TiO2 into AA6061 resulted in the highest recorded tensile strength and hardness, respectively. [8] Hugar et al. delved into the mechanical properties of a hybrid metal matrix composite, consisting of TiO2, red mud, and AA6061. They varied the weight fractions of TiO2 (2%, 4%, and 6%) while maintaining a constant 2% of red mudin AA6061. This led to significant enhancements in yield strength, ultimate tensile strength, compressive strength, and hardness compared to pure AA6061. [9] Veeresh Kumar and his team investigated the interplaybetween physical, mechanical, and tribological characteristics in AA6061 metal matrix composites reinforced with TiO2. By incorporating TiO2 in varying concentrations (up to 3 wt%) using powder metallurgy, they observed superior physical, mechanical, and wear resistance properties in the AA6061–3wt% TiO2 composite.

III.EXPERIMENTAL PROCEDURE

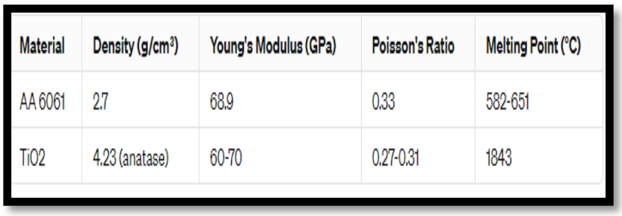
A. Materials and Method

The current investigation focuses on the utilization of AA6061 as the matrix material, while Titanium oxide (TiO2) is chosen as the reinforcing agent in varying compositions. Specifically, TiO2 compositions of 5%, 10%, and 15% by weight of Aluminum are considered. AA6061, an Aluminum alloy, serves as the foundational matrix, undergoing a melting process at 585°C, slightly exceeding the liquid temperature by 30°C. The fabrication process employs stir casting, wherein a manual stirrer coated with aluminates is utilized to create a stirring motion within the molten matrix alloy. TiO2 particles are introduced into the melted Aluminum, preceded by preheating the Aluminum alloy to facilitate improved wetting properties and the removal of absorbed hydroxide and other gases. Thorough stirring ensues, followed by reheating the composite slurry to achieve a fully liquid state. Mechanical mixing is then conducted at an average stirring speed before the composite slurry is poured into permanent metallic molds for casting. Subsequently, the cast composites, containing the added TiO2 particles, undergo testing to assess their properties in accordance with ASTM Standards. Tensile and compression tests are performed at room temperature utilizing a Universal Testing Machine, while hardness evaluation is conducted via a Vickers hardness tester. Impact testing is carried out using a Charpy impact test machine, and the microstructure of the composite is examined using an optical microscope.



Element	Composition (Mass Percentage
Al	95.85–98.56
Mg	0.8–1.2
Si	0.4–0.8
Fe	0.0–0.7
Cu	0.15–0.40
Cr	0.04–0.35
Zn	0.0–0.25
Ti	0.0–0.25
Mn	0.0–0.15

Table 2. Composition of AA6061



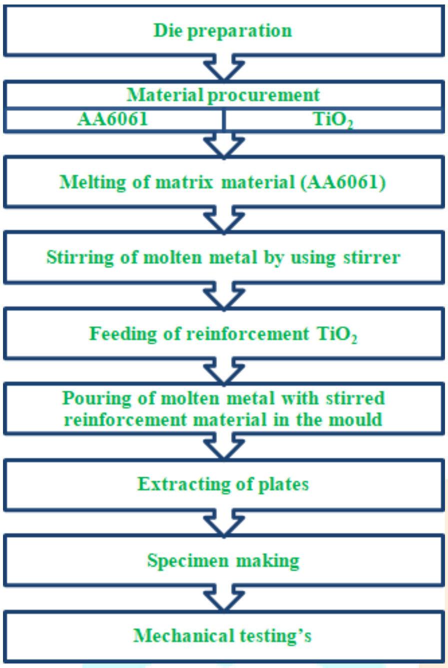
Material	Density (g/cm³)	Young's Modulus (GPa)	Poisson's Ratio	Melting Point (°C)
AA 6061	2.7	68.9	0.33	582-651
TiO2	4.23 (anatase)	60-70	0.27-0.31	1843

Table 1. Material Properties

B. Experimental Setup

Initially, the process commences with the melting of aluminum within an open-hearth furnace, raising the temperature to an impressive 600 degrees Celsius, exceeding the melting point of aluminum.

Fig. 1. Project Methodology



This metal, initially in pellet form, undergoes transformation within a die designed for casting rectangular plates measuring 150 by 100 by 6 millimeters. Prior to casting, crucibles undergo preheating to expel any residual moisture content. Once molten, titanium dioxide reinforcement particles are introduced into the aluminum, followed by a meticulous stirring process using a mechanical stirrerto ensure homogeneous distribution. Subsequently, theamalgam is poured into a permanent metallic mould, yielding rectangular plates with a thickness of 6 millimeters upon solidification. Post-solidification, the plates are extracted from the mould, and the procedure iterates for other weight percentage compositions. These plates are then sectioned into distinct specimens adhering to ASTM standards to facilitate subsequent testing protocols.

Fig. 2. Die for Plate

Fig. 5. Melting of matrix material

Fig. 3. AA6061 Pallets

Fig. 6. Extraction of plates

Fig. 4. Titanium Dioxide TiO2

Fig. 7. Tensile test specimen

Fig. 8. Impact test specimens

Fig. 9. Bend test specimens

An array of examinations has been executed on synthesized metal matrix composite specimens to scrutinize the strength attributes of aluminum/TiO2 metal matrix composite. Mechanical traits encompassing tensile strength, compressive strength, flexural strength, impact strength, and hardness have been evaluated on the crafted metal matrix composite. Tensile strength and compressive strength evaluations were performed at ambient temperature utilizing a universal testing machine. Hardness examination was conducted using a Vickers hardness testing machine, while the impact test was executed employing the Charpy impact tester.

A. Tensile Strength

The tensile test was conducted using a computerized Tensometer for both the as-cast base material and the reinforced material. The test specimen, reflecting the macro-image of a fractured sample from the FS processed region of the composite, was subjected to a welding speed of 50 mm/min and a constant rotational speed of 1000 rpm, employing a square profiled tool.

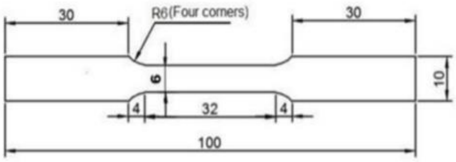
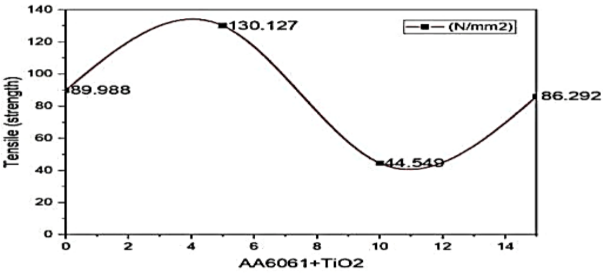


Fig. 10. Tensile test specimen as per ASTM

Macroscopic examination revealed ductile failure, which was further analyzed using SEM to observe the effects of tensile force on the composite's microstructure. The fracture exhibited three primary mechanisms: cracking of reinforced particles, decohesion at the particle-matrix interface, and growthand propagation of voids within the matrix. To assess tensile strength, four samples were selected, each reinforced with varying compositions of TiO2.



Graph 1. Tensile Strength

Specimen	Tensile strength (N/mm^2)	Percentage Elongation (%)	Load at Break (KN)
AA6061 + 0% TiO_2	89.988	10.08	3.218
AA6061 + 5% TiO_2	130.127	16.24	4.003
AA6061 + 10% TiO_2	44.549	9.84	1.576
AA6061 + 15% TiO_2	86.292	11.28	3.065

Table 3. Tensile Strength

B. COMPRESSIVE STRENGTH

A compression examination elucidates the traits of substances when subjected to crushing forces. During the procedure, a specimen undergoes compression, andits deformation under different loads is meticulously observed. The compression assessment necessitates theexamination of five specimens crafted via stir casting, comprising an aluminum metal matrix infused with TIO2 composite at varied compositions: 5%, 10%, and15%.

Specimen	Compression Strength(N/mm^2)	Load at Peak (KN)
AA6061 + 0% TiO_2	26.561	1.021
AA6061 + 5% TiO_2	21.168	0.778
AA6061 + 10% TiO_2	11.321	0.419
AA6061 + 15% TiO_2	16.184	0.606

Graph 2. Compression Strength

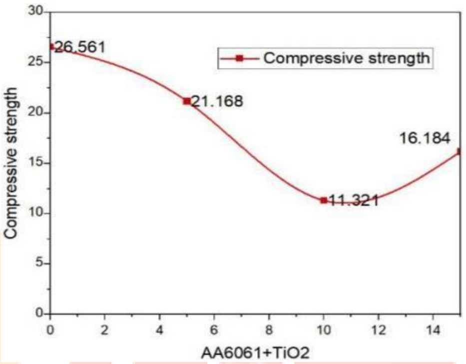


Table 4. Compressive Strength

C. Impact Strength

The impact assessment technique assesses the resilience, impact resistance, and notch sensitivity of various engineering materials. A specially prepared specimen with a notch is subjected to the force of a heavy pendulum or hammer, dropped from a specific height and velocity. The primary parameter measuredis the energy absorbed during the specimen's fracture in a single strike, as seen in tests like the Charpy and Izod impact tests.

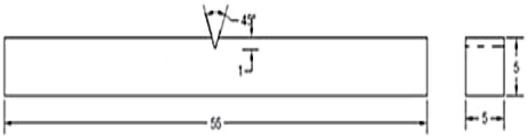
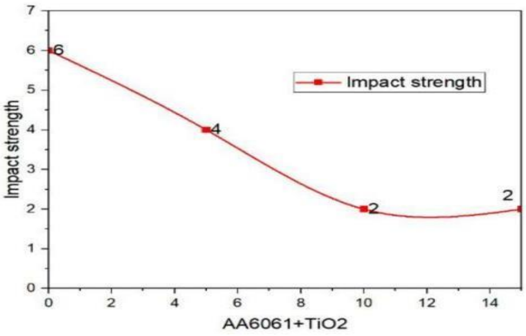


Fig. 11.Impact Strength specimen as per ASTM

Specimen	Impact Strength (J)
AA6061 + 0% TiO_2	6
AA6061 + 5% TiO_2	4
AA6061 + 10% TiO_2	2
AA6061 + 15% TiO_2	2

Table 5. Impact Strength



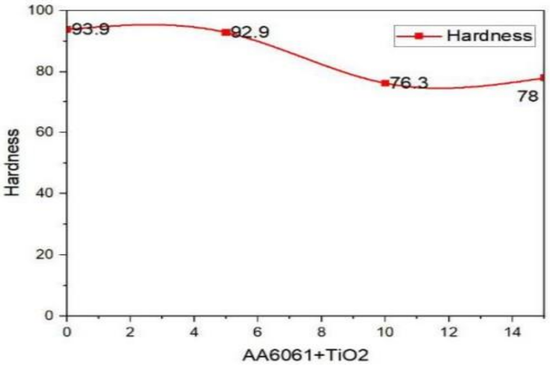
Graph 3. Impact Strength

D. Hardness Test

One common method to assess hardness involves applying pressure from a precisely sized and weighted object (an indenter) onto the material surface. Hardness is then gauged either by measuring the depth of indenter penetration or by evaluating the size of the impression it leaves behind.

S.No.	AA6061 + 0% TiO_2	AA6061 + 5% TiO_2	AA6061 + 10% TiO_2	AA6061 + 15% TiO_2
	Hardness Value [Hv 0.1]	Hardness Value [Hv 0.1]	Hardness Value [Hv 0.1]	Hardness Value [Hv 0.1]
1	94.5	92.8	76	77.6
2	93.2	93.2	76.3	77.9
3	94.1	92.8	76.6	78.5
Avg	93.9	92.9	76.3	78

Table 6. Hardness



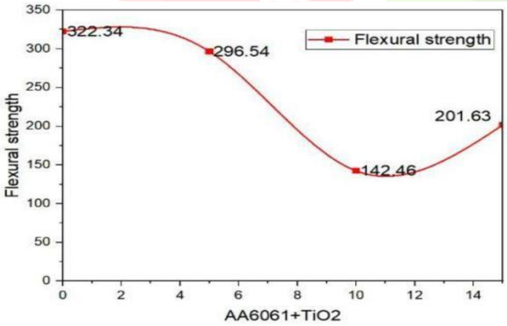
Graph 4. Hardness

E. FLEXURAL STRENGTH

Flexural resilience, alternatively termed as the modulus of fracture or bending resilience, represents a distinctive material characteristic denoting the stress threshold before yielding in a flexure examination. Theprevalent method for assessment involves thetransverse bending trial, wherein a sample with a circular or rectangular profile undergoes bending until fracture or yielding, employing the three-point flexuraltesting approach.

Specimen	Flexural Strength (N/mm^2)
AA6061 + 0% TiO_2	322.34
AA6061 + 5% TiO_2	269.54
AA6061 + 10% TiO_2	142.46
AA6061 + 15% TiO_2	201.63

Table 5. Flexural Strength



Graph 5. Flexural Strength

F. SEM MICROGRAPH

The arrangement of particles within a substance can uniquely impact its characteristics such as its ability to resist corrosion, its strength, durability, flexibility, and overall hardness. These traits play a crucial role in dictating the material's performance within specific contexts.

Fig. 12. SEM microstructure of 0% TiO2 at x2000

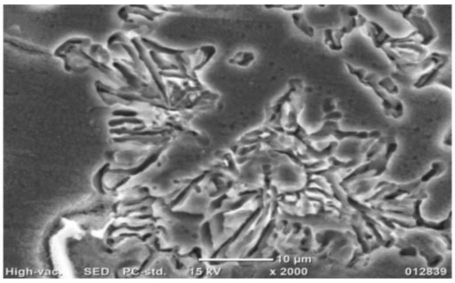
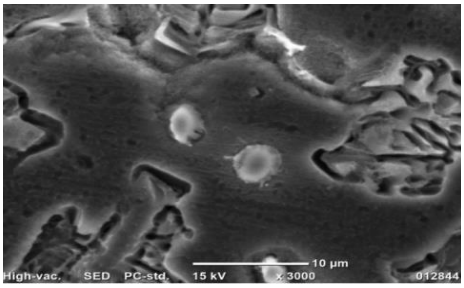


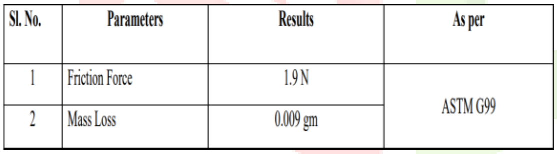
Fig. 13. SEM micrograph of 15% TiO2 at x3000



G.WEAR TEST

Tests are conducted according to the ASTM G99-95 standard, operating under both dry and lubricated conditions. Initially, the pin is cleaned with acetone and meticulously weighed using a digital electronic balance.

Fig. 14. Pin-On-Disc wear testing machine



Sl. No.	Parameters	Results	As per
1	Friction Force	1.9 N	ASTM G99
2	Mass Loss	0.009 gm	

Table 6. Parameters of frictional force and loads

Throughout the experiment, the pin remains in contact with a rotating steel disc (hardness: 65HRC), exerting pressure to act as a counterweight and stabilize the pin.The diameter of the track varies within the range of 70 mm to 110 mm for each experimental batch

Sl. NO.	Parameters	Load(kg)	Specific Wear Rate(m^3/Nm)
1	Wear	1	7.23
2		1.5	10.34
3		2	13.73

Table 7. Results of wear at loads 1,1.5,2 kg's

Parameters such as load, sliding speed, and slidingdistance are adjusted accordingly within predefinedranges. The difference between the initial and final weights serves as a measure of slide wear loss. Tests are conducted for each condition, and the average weight loss value is documented.

Graph 6. Wear rate (m^3/Nm) vs load (in kg)

IV.CONCLUSION

In this study concerning Metal Matrix Composite comprising Al6061 alloy reinforced with TiO2, severalnoteworthy findings emerge:

- A peak in tensile strength is observed at 5% TiO2reinforcement, with a subsequent decline up to 10%, followed by enhancement at 15%.
- Compression strength diminishes up to 10% reinforcement, and then experiences an upswing at 15% TiO2.
- Impact strength exhibits a consistent decline withincreasing TiO2 content.
- Hardness decreases up to 10 wt% TiO2, and then rises again at 15 wt%.
- Stir casting parameters, such as stirring speed andduration, significantly influence mechanicalproperties.
- Stir casting emerges as the most facile method for manufacturing aluminum metal matrixcomposites.
- SEM images reveal uniform distribution of TiO2 particles at 15 wt%, leading to enhanced mechanical properties.
- And for wear analysis of composites samples are made in form of pin to test at pin on disc machineby different wear parameters such as load, slidingdistance and sliding speed. Also the effects of these parameters on the wear behavior are taken into consideration.

Overall, the study indicates that a 5% TiO2 reinforcement is optimal for AA6061 metal matrix composite via stir casting. Additionally, enhancing stir casting parameters is essential for augmenting composite material mechanical properties.

V.FUTURE SCOPE

The investigation suggests that MMC (Al + 5% TiO2) holds promise as a viable alternative to medium carbonsteel for constructing connecting rods in internal combustion engines. Further research will delve into the performance of connecting rods crafted from Al + 5% TiO2 due to its promising outcomes across variousmetrics.

Additionally, it's recommended to introduce an additional reinforcement such as red mud, ceramics, ash powder, etc., to continually improve the mechanical properties of AA6061. The incorporation of multiple reinforcements transforms the material intoa hybrid composite, which exhibits superior mechanical characteristics compared to mono- reinforced composites.

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