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Mechanical And Wear Properties Of Hybrid Mmcs: Al7075 Reinforced With Tic And Graphite

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Due to their strong mechanical qualities, metal matrix composites have recently emerged as the notableone, finding wider use in the aerospace and automotive industries. However, most MMCs struggle with rigidity, dependability, and insufficient economical effectiveness. Hybrid metal matrix composites (HMMCs) are created to overcome these constraints while meeting the ever-increasing demand. Aluminum HMMCs have the potential to meet needs due to their lightweight, low cost, high performance, and increased mechanical qualities. The performance of hybrid composites will be improved by selecting the proper combination of reinforcing materials. The basic matrix utilized throughout the present research is Al7075, which is enhanced by graphite (Gr) at 5% weight and Titanium carbide (TiC) at 2, 4, and 6% weight. The stir-casting procedure has been used for building the composites. Optical microscopy images are used to analyze the dispersion of reinforcement particles. The produced composites have been Subjected to tensile, hardness and wear tests. The outcomes demonstrate that mechanical and wear properties get improved with the increase in percentage of reinforcement.

Keywords: *Hybrid metal matrix composite, Al 7075, TiC and graphite, Stir-Casting, mechanical and wear properties.*

1. Introduction

The ability of conventional monolithic materials to achieve combinations of strength, stiffness, and density has limitations. Hence composites which have two distinct materials that are combined to attain improved properties such as low density, high tensile strength, toughness, good wear resistance, and hardness compared to monolithic materials are developed in the recent decades [1-3]. Metal matrix composites (MMCs) obtained by combining metal or alloy as the matrix and most commonly the ceramic particles as reinforcement can meet the technical demands of variety of industries including automobile, aerospace, and electrical sectors due to their more desirable mechanical and corrosion resilient properties [4-10]. Metals having a significant strength-to-weight ratio, resistance to corrosion and wear are required in engineering domains including automotive and aviation. Aluminum, titanium and magnesium are the lightest materials available [11], which greatly aids in making the engineering parts for automobiles and aircraft. When compared to other metals, aluminum and titanium are the most commonly employed as metal matrices. SiC, TiC, B_4C,ZrO_2 [12], TiB_2 [13], Al_2O_3 [14], MoS_2 [15] and Albite [16] are examples of hard ceramic particles that have been reinforced with a light base metal alloy, allowing for the creation of various composites with increased mechanical properties [17-20] while being lightweight.

Nevertheless, several MMCs with single reinforcement are unable to satisfy the technical requirements. As a result, hybrid metal matrix composites (HMMCs) arose, in which more than two materials are reinforced into a base matrix, resulting in a new material with new properties for regulating these issues and achieving a desirable combination of various features. By selecting a better blend of reinforcements, improved mechanical properties can be obtained.

Al7075 an aluminium alloy with Zn as major alloying element is lighter in weight and has good corrosion properties. Al7075 is usedin many transportation applications such as aerospace, aviation, marine and automobile like aircraft fittings, gears, shafts, aerospace construction materials, propeller blades, hulls, deck fittings, automobile engine casing, body panels for racing cars etc. In most of these applications the strength and wear resistance properties are essential for better performance.In the recent years, the researchers have developed composites of Al7075 reinforced with various ceramic reinforcements such as SiC, B_4C, MoS_2 [21-22]. Titanium carbide (TiC) a hard ceramic material and has a high strength-to-weight ratio, incremental of resistance to wear has been selected as the reinforcement [23-25]. Because of its wettability characteristic it can be mixed with matrix materials. Graphite is another reinforcing soft material that acts as a self-lubricating element when sliding in dry conditions, reducing wear rates [26-28]. The limitation is higher addition of Graphite results in the loss of strength properties of composite and hence it is limited to 5%in this work. Therefore, it is proposed to conduct a study on the improvement of strength and wear properties of Al7075 composite with a strengthening reinforcement TiC and a self-lubricating reinforcement Gr (to reduce friction) which is not attempted before. Stir casting technique, the simplest and most cost-effective method is used to cast samples of HAMMC.Microscopic study is conducted to ensure the distribution of reinforcement particles.The current experimental work concentrates on the studying of mechanical and wear behaviour of HAMMC with varying Wt.% of TiC and graphite with the aid of tensile, hardness and wear tests.

2.1 Materials

The aluminium alloy Al7075 is one of 7000 series aluminium alloy with zinc and magnesium as important alloying elements. Although it is an expensive material, it offers superior strength against fatigue and corrosion protection which apt for aircraft,automobile sectors [29] and military weaponry. These materials were procured at Coimbatore Metal Mart. Fig 1 shows the Al7075 material and Table 1 displays the values were taken from Spectroscopy and Table 2 display the Al7075 properties.

Table 1 Composition of Al7075

Elements	**Zn**	**Mg**	**Cu**	**Cr**	**Fe**	**Si**	**Mn**	**Ti**	**Remainder**
Percentage	5.79	2.5	1.69	0.24	0.46	0.4	0.17	0.2	Aluminium

Table 2 Properties of Al7075

Properties	**Hardness**	**Shear Modulus**	**Tensile strength**	**Yield strength**	**Young's modulus**	**Elongation**	**Density**	**Machinability**
Values	60 BHN	26.9GPa	220MPa	95MPa	71.7GPa	17%	2.8 g/cm^3	70%

It is important to choose the reinforcement particles carefully and can be customised with a matrix to satisfy specific requirements or improve mechanical properties.Here, titanium carbide (TiC) is used as a reinforcing element in different weight proportions (2, 4, 6 Wt%), which tends to provide the composite additional hardness. TiC is widely employed in the production of carbide steel, protective coatings, and metalworking equipment, among other things.

Another reinforcement material graphite, which is an allotrope of carbonand a native element mineral.It serves as a self-lubricating component and aids in controlling wear [30]. It is maintained as 5% in all the compositions. The reinforcement materials are shown in Fig 1.

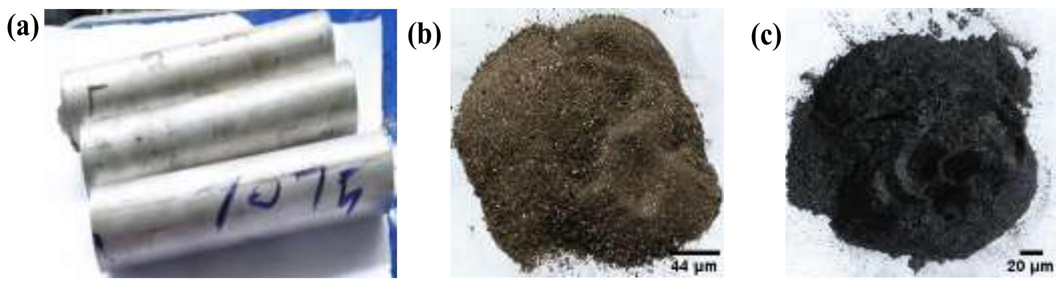

Fig.1 Raw materials (a) Al7075 Material (b) Titanium Carbide (TiC) (c) Graphite

Table 3 Reinforcement Material properties

Properties	**TiC**[31-32]	**Graphite**[30]
Density	4.91 (g/cm^3)	(2.28 g/cm^3)
Melting point	3,067°C	3500 °C

Size	325 mesh(44 microns)	625 mesh (20 microns)

2.2 Fabrication
Based on die dimensions (diameter=30mm and length=250mm) it is calculated that each sample weight is 500g. The composition of matrix and reinforcement materials for various samples in weight percentages and actual weights are shown in Table 4.

Table 4 Sample composition

Samples	Al7075		TiC		Gr	
	Wt%	Wt (gm)	Wt%	Wt (gm)	Wt%	Wt (gm)
A	93	462	2	18	5	20
B	91	445	4	35	5	20
C	89	428	6	52	5	20

Stir casting is a widely used technique for creating cast metal matrix composites. It entails adding an insoluble phase to a heated matrix metal and then dispersed uniformly by stirring. After being placed in the furnace, Aluminum alloy was taken in a crucible and melted by raising the temperature gradually to 750°C for an hour. In order to remove moisture from TiC and graphite particles with an average size of 44 µm and 20 µm respectively, they were preheated for 45 minutes at 450°C in a muffle furnace. The particles were then added while the melt temperature was kept at 1200°C. The molten metal is agitated for ten minutes at 850 rpm using a mechanical graphite stirrer. The molten metal was then poured into the die, which was already heated (Diameter=30 mm andLength=250 mm) to fabricate cylindrical specimens as they are simple in geometry, having uniform material properties and allow easier analysis. Rods are made due to their ease of fabrication, consistent material qualities, and suitability for mechanical testing. They are easy to handle, store, and machine for additional processing or uses, and their shape guarantees constant strength and performance. Al-HMMC was manufactured in various weight percentages to adhere to the same process.

2.3 Microstructure
The microstructural study has been conducted for the three compositions. A small portion of the cast sample was taken and was mounted on the base. The sample was properly polished and the microstructure was studied using an inverted optical microscope. The distribution of reinforcing grains in the matrix phase was studied.

The dispersion of the reinforcing phase along the matrix phase is demonstrated by the microstructural study of cast samples. The microstructures of samples are displayed in Fig.2. The micrographs show a strong interfacial adhesion between the reinforcement particles and the Al7075 matrix, as well as a fairly uniform dispersion of reinforcement particles.

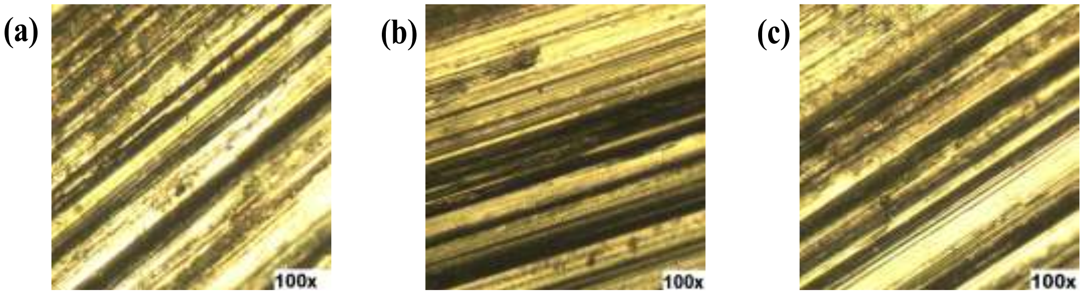

Fig.2 Micrographs of samples (a) Al7075-2%TiC-5%Gr (b)Al7075-4%TiC-5%Gr

(c) Al7075-6%TiC-5%Gr

2.4 Testing

The mechanical and wear properties were assessed through various testing procedures such as tensile test, Vickers hardness test and Pin-on-Disk wear test. In the tensile test, an applied force is measured to stretch the specimen at the breaking point and this test is intended to ascertain the maximal strength or load capability of the material.Three tensile specimens were machined from the manufactured samples in accordance with ASTM-E08standard. The Computer Control Universal Testing Machine (M100) was used to test the machined specimens. When measuring tiny areas in a Composite sample micro-hardness testing is a suitable technique used to ascertain the hardness of a material or barrier to penetration. The Micro Hardness Test was conducted as per ASTM E384 standard. Vickers micro hardness tester has a square pyramid diamond Indenter having an apical angle of 136^{o}. The loads used are between 10gm and 1kgf. The 50gm load was applied on the specimen and an indentation was made using a diamond indenterwhich is then measured and converted into a hardness value.

A pin-on-disc tribometer is used for wear test. The tribometer has a fixed pin against a rotating disc. Although the pin can be any form to mimic a particular contact, spherical tips are frequently utilized to make the contact geometry simpler. The ASTM G95-99 Standards were followed in the preparation of the test specimen. The pins prepared from cast samples were used for wear test.

3. Results and Discussion

3.1 Tensile Test

The composite samples were subjected to the tensile test. The Yield strength, tensile strength and percentage of elongation results are shown in Fig 3. From the results, it is evident that reinforcing is essential for strength of the composites. It is found that increase in the percentage inclusion of reinforcements increase the yield strength and ultimate tensile stength of composite specimens.When comparing A (Al7075-2TiC-5Gr), the yield strength for B (Al7075-4TiC-5Gr) and C (Al7075-6TiC-5Gr) has increased6% and 15.4%respectively. Similarly the percentage increase in ultimate tensile strength is 3.8% and 11% respectively.The TiCreinforcement particles prevent dislocation movement, which increases yield strength and resists plastic deformation. As a load-bearing reinforcement, it increases the overall strength of the composites by better dispersing the stress.

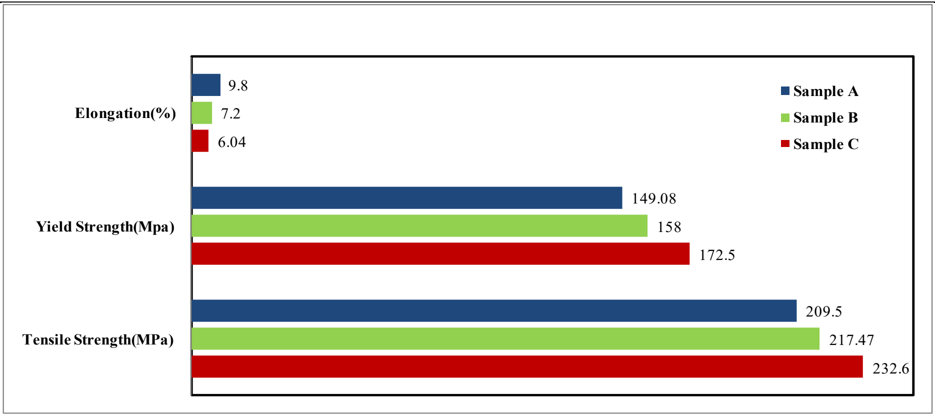

Fig.3 Tensile Strength For Composite Material Samples

The percentage of elongation decreases as the percentage ofTiC particles increases.The addition of TiC from 2% to 4% causes a 3.1% decrease in percentage of elongation and when the percentage of TiC is further increased to 6% causing a 4.76% reduction in percentage of elongation. As TiC is stronger and more brittle, it can tolerate the stress without experiencing appreciable deformation.Hence, an increase in the TiC percentage causes a decrease in elongation.

3.2 Micro-Hardness

The micro hardness in HVN of sample A, B and C are 102, 152.46 and 176 respectively. It is evident that the hardness of the composite is influenced by the percentage of reinforcement. The hardness values of B (Al7075-4TiC-5Gr) and C(Al7075-6TiC-5Gr) are 49.4% and 72.5% higher than A (Al7075-2TiC-5Gr). From this, the higher volume fraction of TiC increases the resistance to plastic deformation resulting in significant increase in the hardness of the composite. The graphite adds lubrication but has little effect on hardness on its own.

3.3 Wear Analysis

The weight loss method was applied to determine the wear rates. Initially the weight of the pin was measured. The pin was fitted in the equipment. The load was applied and the disc was rotated at a specific speed. After a time interval, the specimen was removed from the apparatus. It was cleaned and weighed.The wear was determined by the difference in weight of the specimenmeasured before and after the test. A wear graph was plotted as shown in the Fig.4

Table 5 Weight loss for 3 kg load

Samples	Load (kg)	Speed (rpm)	Time (min)	Initial weight (gm)	Final weight(gm)	Change in weight(gm)
A	3	500	5	6.65	6.55	0.1
B	3	500	5	6.10	6.05	0.05
C	3	500	5	5.70	5.65	0.005

When compared to Al7075-2%TiC-5%Gr and Al7075-4%TiC-5%Gr samples Al7075-6%TiC-5%Gr exhibits decreased wear and wear rate. The wear resistance is improved by the addition of TiC. The presence of TiC particles makes the composite harder and more wear resistant. TiC guards against surface damage and abrasion. Graphite provides lubrication to reduce friction which further reduces wear. These reinforcements work together to enhance the wear characteristics, increasing its resistance to abrasive wear and frictional wear.

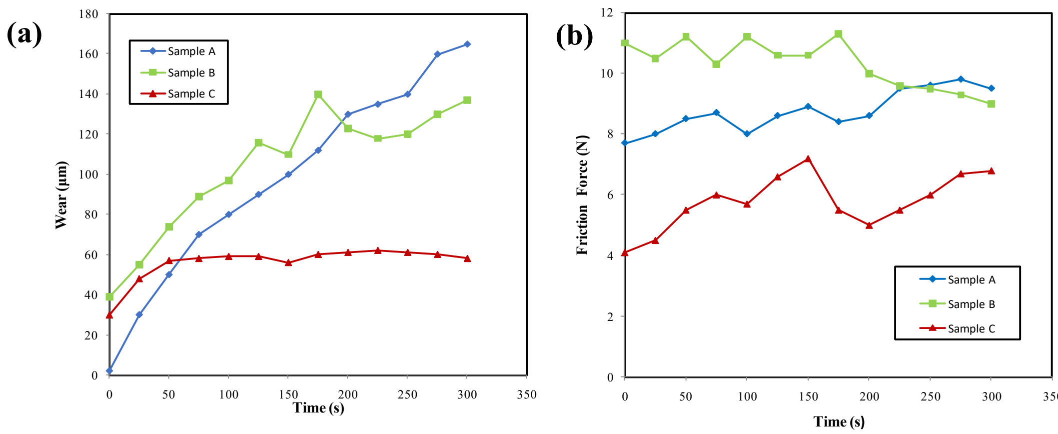

Fig.4 (a) Wear graph for Different Samples (b) Frictional Force for Different Samples

4. Conclusion

Using the stir casting technique, hybrid composite samples of Al7075 alloy reinforced with graphite and TiC particles were effectively created. Based on an analysis of mechanical and microstructural properties, the following conclusions were drawn:

- **Microstructure:** The TiC and graphite particles were found to be uniformly distributed throughout the Al7075 matrix, which contributed to the overall material characteristics and ensured effective reinforcing.
- **Mechanical Strength:** In comparison to other compositions, the hybrid composite containing 6% TiC and 5% graphite demonstrated the best yield strength and ultimate tensile strength, suggesting a notable improvement in structural integrity.
- **Hardness:** The reinforcing components, especially TiC and graphite, markedly increased the composite's hardness, as seen by the maximum hardness of 176 VHN.
- **Wear Resistance:** The hybrid composite with 6% TiC and 5% graphite showed better wear resistance than other composite compositions, according to the wear characteristics, indicating that it is suitable for high-stress situations.
- **Enhancement of Mechanical qualities:** As the proportions of TiC and graphite in the composites increased, the material's overall performance was improved by the composites' better mechanical qualities (yield strength, tensile strength, hardness, and wear resistance).
- **Applications and Prospects:** Al7075 + 6% TiC + 5% graphite is the ideal material composition for applications that call for strong wear resistance, strength, and hardness.The graphite particles served as a solid lubricant, lowering the wear rate and friction coefficient and enhancing the composite's resistance to high-stress conditions.

With less material degradation and less friction, the wear tests verified that this composite performed better than other samples. The synergistic action of graphite and TiC enhanced the material's strength, hardness, and long-term wear performance, making it perfect for use in heavy machinery, automobiles, and aircraft where it is essential to improve performance, reduce maintenance costs, and provide longer service life under challenging conditions.

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