EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES OF AL7075 HYBRID MMCS REINFORCED WITH TiB_2, Mg, GRAPHENE, AND CRAB SHELL ASH

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ABSTRACT
Aluminum 7075 is a high-strength alloy widely used in aerospace, automotive, and defense applications, but further enhancement of its mechanical performance is essential for next generation lightweight components. This study investigates the development of hybrid metal matrix composites (MMCs) by reinforcing AL7075 with Titanium Diboride (TiB_2), Crab Shell Ash (CSA), Graphene, and Magnesium (Mg) using the stir casting method. Four compositions were prepared for evaluation: pure AL7075, AL7075 + 0.5% TiB_2 + 1% Mg + 0.5% CSA + 0.5% Graphene, AL7075 + 1.5% TiB_2 + 1% Mg + 1% CSA + 0.5% Graphene, and AL7075 + 2.5% TiB_2 + 1% Mg + 1.5% CSA + 0.5% Graphene. TiB_2 provides high hardness and excellent load transfer, Graphene improves tensile strength, grain refinement, and wear resistance, while CSA, a bio ceramic containing $CaCO_3$, enhances rigidity and reduces composite density. The composites were mechanically characterized using tensile, hardness, compression, and impact tests, alongside microstructural analysis. Results show that increasing TiB_2 and CSA content improves mechanical performance, with the composition containing 2.5% TiB_2 + 1.5% CSA + 1% Mg + 0.5% Graphene exhibiting the highest tensile strength, hardness, and impact resistance, WEAR TEST. This optimized hybrid MMC is suitable for aerospace, automotive, defense, UAV frames, pistons, brake components, and marine applications where reduced weight and high mechanical performance are critical.

1 INTRODUCTION

1.1 BASICS OF COMPOSITE MATERIALS

Composites are engineered materials that consist of at least two distinct phases, typically a reinforcement phase embedded within a matrix phase, which is in close contact with a well-defined interface. These advanced materials exhibit properties that cannot be achieved by the individual phases alone. Composites are often customized to be cost-efficient, performance-oriented, and application-specific. Generally, the reinforcement phase, which is harder and stronger, enhances the overall mechanical properties, while the matrix phase maintains the desired shape and supports the load. The reinforcement significantly improves the strength, stiffness, wear resistance, and thermal stability of the composite, while simultaneously reducing its density. A composite material is made up of two components that have distinct physical and chemical characteristics. When they are mixed, they form a material that is specialized to do a certain task, and therefore become stronger, lighter, or posses better electrical properties which allows the engineer to pick and choose from materials that are conductive or resistant. They are preferred over traditional materials because they increase the properties of their basic materials and may be used in a variety of applications. Composites can be found in nature too. Long cellulose fibers are bound together by a compound called lignin in a piece of wood, making it a composite.

1.2 CLASSIFICATION OF COMPOSITES

In general, composites are classified according to the type of matrix material and then nature of reinforcement at two distinct levels. The first classification includes ceramic matrix composites (CMCs), organic matrix composites (OMCs) and metal matrix composites (MMCs). The term organic-matrix composite is generally assumed to include polymer Matrix composites (PMCs) and carbon matrix composites. The second classification refers to the reinforcement form; particulate reinforcements, whiskers, continuous fiber, laminated composites and woven composites.

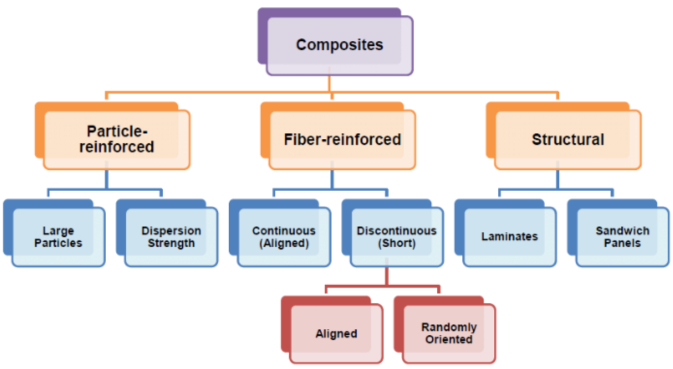


Figure 1 Classification of composites

2 LITERATURE SURVEY

[1] RAJESH KUMAR BHUSHAN et.al [2013], contemplated Fabrication of Al7075 combination interfaced with SiC particulates. The analysis includes preparation of specimens utilizing fluid vortex cast technique for the combinations Al7075 included with SiCp of various work sizes(20-40). The composites of different volume divisions of filler materials (10% and 15%) were examines by EPMA, XRD, SEM, EMPA and DTA investigation. Oxidation of SiC has constrained the synthetic reactions at interfaces. Improvement of wetting operation connecting the base material and Si particles was seen because of very much mixed combinations and filler material. SEM micro pictures demonstrate that the dispersion of filler particles is uniform. The XRD chart sees no rise of Al4C3. EPMA investigation shows that Aluminum as the fundamental compound and the particles contained the alloying component of Zinc, Magnesium, copper. From the above research paper I inferred that Alloying of Al metal with 2.52 wt.% Mg and its detachment at the interfaces has been seen to be amazing in restricting the course of action of the Al4C3at the interfaces during example planning. There are no opposing engineered reactions; in this way, these composites are sensible for car, airplane and protection applications.

[2] MADHURI DESHPANDE et.al [2016], successfully prepared Pitch based carbon fiber added to Al matrix composites from Powder Metallurgy (PM) technique. Weight % of carbon fibre are (5-50)% uncoated (UnCf) and coated milled pitch based carbon fibers (NiCf) and AA7075 as matrix with different volume contents of carbon fibers. Uncoated and Nicoated carbon fibers were reinforced with AA7075 Aluminium alloy powder and subsequently hot pressed and they studied on density and hardness strength. A highest of 11% reduction in density is noticed for 50Vol% Cf Composite compared to as cast Al7075. It indicated that the composites developed with uncoated carbon fiber shows minimum values of hardness as compared with Pure Al7075 hot pressed specimen. Whereas the Ni coated carbon fiber composites show the increase in hardness up to 20Vol%. It is observed from the microstructures that carbon fibers are homogeneously distributed in the Aluminium matrix for all wt % compositions. From the above research paper I concluded that the electroless nickel coating on the fiber surface improves the interfacial bonding which results in increased hardness of the composite. Double action hot pressing experiences improved density and density gradient is not indicated in composite.

[3] MANOJ SINGLA et.al.[2009], successfully conducted Experiments by changing various wt% of SiC (5%-30% at intervals of 5%) They conducted tests on hardness and impact strength. Uniform dispersion of SiC particles in the Al matrix represents raising trend in the specimen preparation through liquid vortex process. The results of study propose that with increament in the particle of SiC, the expansion in hardness, impact strength and standardized strain have been observed. The supreme results for hardness 45.5BHN and maximum impact strength36.6N-m have been obtained for 320 grit size SiC particles at 25% weight fraction. From the above research paper I reasoned that Homogenous mixture of SiC particles in the Al alloy demonstrates an expanding pattern in the examples represented by dosent applying mixing process, with manual directing and with 2-Stage stirring for liquid vortex method separately.

[4] JAMALUDDIN HINDI et.al. [2016], successfully prepared Al 7075 Reinforced with Gray Cast Iron of different wt% 2%,4% and 6% and 2 wt% of Fly Ash are prepared employing stir casting method. It was seen that tensile strength raises with the expansion in wt% of GCI. The maximum tensile strength 275Mpa got at 6% GCI. Hardness increments generously with increment in wt% of GCI in the composite. Wear rate diminishes from 410µm with an expansion in wtt% of GCI. From the above research paper I reasoned that. As the wt% of GCI increments in the grid, the support material increases and the inter molecule space minimizes. There is no sign of hole formation in the matrix. [8] Mohan Kumar S et.al.[2014], finished examinations on an Al 7075-T6 and it's Electroless Nickel covering of 10 – 20 µm in thickness. Plane strain crack mechanics, confirmation was followed in this examination. Uncoated Al 7075-T6 composite exhibits a yield nature of 560 MPa, and again EN covering on mix of 10µm and the 20µm yield nature of amplifies to the 569 MPa and 603 MPa. The uncoated Aluminum essential load is 4.44 KN and K1c esteem is 22.28 mpa√m. Further for 10microns and 20microns secured aluminum compound has an essential load of 6.67 kN and 7.41 kN which separates to KIC estimations of 34.48 MPa√m and 37.67 MPa √m exclusively. From the above research paper I concluded that The EN covering encounters improving delaminating and crack at the most high load, because of the ductile material, plastic deformation occurs. The split development is shaky because of solid attachment between EN covering and Aluminum alloy.

[5] R.KARTIGEYAN et.al.[2012], has effectively developed Al 7075 alloy and Short Basalt Fibre composite through liquid metallurgy technique. The increase in short basalt fibre maximizes the ultimate tensile strength, yield strength and Hardness. The composite containing 6% wt of short basalt fibre signifies higher hardness value of 97.1 Mpa when compare to base matrix hardness 92Mpa. TheAl-7075/short basalt fibre reinforced 6 vol % maximizes the ultimate tensile strength by 65.51%. The distribution of reinforcements in metal matrix is genuinely uniform. From the above research paper I concluded that, under tension loading without affecting the tensile ductility, values of tensile strength increases. Experimental values of short basalt fiber give the best result for the Al-MMC's

[6] PRADEEP P et.al [2017], has fabricated Al 7075 and Titanium DI Boride (Tib2) via the sir casting technique. The quantity fraction of TiB2 prompted are 4%, 6% and 8% . They evaluated the microstructure, wear, hardness properties. At 8% wt of TiB2 notices the maximum hardness of 126 VHN and strengthens the base matrix. Explicit wear rate diminishes as the sliding rate increments up to rotation speed (1.6 m/s) and weight, in light of work solidifying of the material surface. Minimal effect of the wear rate got from the 8 Wt. % of TiB2 fortified composite. The speed and the sliding distance are in most extreme with the insignificant weight. The micro image indicates the Aluminium debris are unvaryingly dispersed within the highest volume fraction of particulate matrix of 8Wt. %. From the above research paper I presumed that wear and abrasive area properties of MMCs having aluminum as base material exceptionally relies upon the particulate utilized for filler, its size and weight division of particles. If the particulates added for reinforced well to the lattice, the wear obstruction increments with expanding volume division of support materials.

[7] ARUNKUMAR D T et.al. [2018], successfully fabricated the Al-7075 composites with mica and kaolinite reinforcements using stir casting technique. They used equal volume fractions of mica and kaolinite are [(2+2)%, (4+4)%, (6+6)%,(8+8)] and conducted a wear test for va
rious time intervals at constant load. The wear loss in composites with 8% volume of mica and kaolinite are observed to decrease at a slower rate. The SEM microstructure of the composite indicates a homogeneous reinforcement distribution into matrices and no evidence of agglomerate. From the above research paper I concluded that the presence of mica and kolonite in the matrix decreased wear loss by increasing wear resistance.

[8] GURURAJ ASKI, DR. R.V.KURAHATTI et.al [2017], developed to study the behavior of LM13 reinforced with ZrSiO4 in 2, 4 and 6 weight%. The tests included tensile test, impact test, microstructure analysis, SEM analysis and hardness test. Increase in volume fraction of ZrSiO4 results in increase in tensile strength. LM13 with 6 wt% ZrSiO4 exhibited highest ultimate strength 128.75N/mm2. Highest hardness of 76 HRB found at composite of 6% wt of ZrSiO4, LM13 with 6 wt% of ZrSiO4 exhibited higher impact strength0.10N-m/mm2compared to other specimens.. From SEM images, it was observed that distribution of ZrSiO4 was homogeneous. This homogeneous mixture was observed in 6wt% ZrSiO4- LM13. From the above research paper From the microstructure analysis, it was inferred that tensile strength values of the composites were inversely proportional to the grain size.

[9] SHIVANNAH, V. S. RAMAMURTHY et.al [2012], prepared A356- ZrSio4 (Zirconium Silicate) metal matrix Composites by liquid vortex method. The amount of volume fraction ZrSio4 is varied from 0 to 7.5%. The solid composites were machined and also the specimens were prepared for hardness yet as for wear behavior were ready as per ASTM standards. It is noticed that the hardness of A356- ZrSio4 increment with maximum content of the ZrSio4 Reinforcement. Wear increases as the % of Zirconium silicate increases. Wear rate minimizes as sliding distance increases. The microstructure of the solid composite shows uniform particle distribution with less priority. From the above research paper I concluded that the hardness of the filler matrix found to be higher than the main matrix this is mainly due to the influence of zirconium silicate.

[10] R.S. RAVEENDRA et.al. [2016], Liquid metallurgy course utilizing vortex strategy is utilized to plan Al6061 MMCs material. The microstructural examinations show the unvarying mixture of the reinforcement particles in the matrix. 6% weight dimension of α-Al2O3 shows highest Hardness of 64 BHN nano-ceramic production. A definitive elasticity of the MMCs is established higher 139mpa at 6% wt of Al2O3. The compression strength maximises with increases in α-Al2O3 production. After the investigations it should be noticed that raise in trend of mechanical properties by Al-6061 and Al2O3. From the above research paper I assumed that Al2O3 nanoceramic particles demonstrates an better holding with Al-6061 MMC and furthermore with each other which helps in more load when assessed with Al-6061 base matrix. The hard filler particles restrict bending, stress while growing the properties of the composite.

[11] MISS. LAXMI, MR. SUNIL KUMAR et.al [2017], investigated on the mechanical properties of SiC reinforced with Aluminum 6061 metal matrix composites created by liquid vortex technique. The distinctive weight % is 10%, 15%, 20% of SiC. The test outcomes demonstrate that with the improves in rate from 10% to 15%, hardness of the composites is improved. To further increment of sic particles up to 20%, result as an declination of hardness. Out of every one of these specimens, the hardness is more for 15% SiC with Al example (64BHN). Scanning Electron Microscopy pictures of the considerable number of specimen, exposed to tensile strength is inspected. From the above research paper I concluded that with the increase in the composition of SiC, an increase in hardness has been observed.

[12] Z. HASAN et.al.[2011], composites have been fabricated by applying a Liquid Metallurgy procedure using 2124 Al combination as the base material with 10 and 20 % SiC particulates by weight. The Effect of Load and Disk Surface on the Wear Volume and impact of Load and Disk Surface on Weight Loss has been considered. The weight declination of the materials is displayed for weight 20 N, 30 N and 50 N. The wear volume in every one of the circumstances is the base for the Al-20% SiC composite. With expanding load there is a reliable increment in the wear volume. For a given burden and separation ventured to every part of the, weight reduction is observed to limit in the Al-20% SiC composite. From the above research paper I reasoned that the wear rate is observed to be maximise with load in every one of the materials considered. The expansion in wear rate of the aluminum base alloy is progressively significant because of cutting and wrinkle activity by generous rough particles.

[13] GOPAL KRISHNA U B et al.[2013], By liquid casting technique, aluminum metal matrix was strengthen with boron carbide particulates of 37, 44, 63, 105, 250µ sizes separately. The mechanical and microstructure properties of the manufactured AMCs was examined. In view of the outcomes acquired from tensile strength of the alloy composites of various sizes, 105µ size B4C was picked and changed the wt% of B4C with 6,8,10 and 12wt%. The miniaturized scale vicker's hardness of AMCs was observed to be most extreme for the molecule size of 250µ and discovered greatest for 12 wt% if there should be an occurrence of changing wt% of the fortification of 105µ size. The tensile stress of AMCs was observed to be most extreme for the molecule size of 105µ and discovered greatest for 8 wt% . The Optical micrographic study and XRD investigation uncovered the nearness of B4C particles in the composite with homogeneous scattering. From the above research paper I reasoned that the presence of such hard surface zone of particles offers more protection from plastic twisting which prompts increment in the hardness of composites. The expansion of B4C particles in the lattice prompts more solidarity to framework compound by offering more protection from elastic loads.

[14] SHIVARAJA H B, B S PRAVEEN KUMAR et.al [2012], Al 356 MMC's reinforced with Zirconium Silicate and Silicon Carbide particles has been successfully joined with the stir casting technique. A tensile stress and the yield quality of the composite are more greater within the sight of ZrSiO4 and SiC. The outcome demonstrates the higher hardness with the expansion in the particle volume fractions in wt%. The outcome shows that there is a significant increment in the toughness strength in the presence of silicon carbide and zirconium silicate particles in the MMC'S. The Hybrid composite 2% SiC and 6% ZrSiO4 particles has demonstrated high strength for crack. Microstructure uncovers a sensibly uniform appropriation of SiC and ZrSiO4 particles in the cast composite. From the above research paper I inferred that the presence of hard grain particles in the composite could deter the development of disturbance since these particles are greater than the matrix wherein they are fixed. The distortion and toughness properties of the composite uncover the significance of particle sizes. It is settled that enormous particles are inconvenient to break sturdiness because of their tendency towards crack.

[15] AJAY KUMAR et.al. [2016] the conducted experiments on the Al356 base MMCs having distribution of Graphite, Boron Carbide, and varying fractions of fly ash. The tensile strength of composite materials increased predominantly by 60- 70% (Al356+5%Graphite+5%B4C +15% Fly Ash) compared to the as cast Al-356 alloy,. The hardness of the composite material also raised with increase in wt% of fly ash content in the composite. From the microstructure studies, it is observed that genuinely even dispersion of reinforcements in the composite material. From the above research paper I presumed that uniform appropriation of fly ash particles in the grid without any voids appears to have added to the improved properties of the composite.

[16] NIRANJAN K.N et.al.[2017] their work was on the investigation of hybrid composites i.e, aluminium alloy 6061 as a base material and reinforced material as sic(6%) and graphite (3%,6%&9%). They calculated mechanical properties of tensile, compressive and hardness tests. They have increased the percentage of reinforcement (graphite), then the hardness will be decreased and tensile, compressive strength will be increases with the influence of sic particles. From the above research paper I concluded that the, parameters of reinforcement material influences greatly the mechanical properties increases increased the percentage of reinforcement (graphite), then the hardness will be decreased and tensile, compressive strength will be increases with the influence of sic particles.

[17] AVINASH PATIL et.al. [2017] contemplated on break sturdiness and weariness development on aluminum compound A384. The Plain strain break durability of Alco pound A384 is resolved. Tests were completed on a widespread testing machine (Axial Fatigue Testing Machine). It is seen that the moderate crack strength esteem around 22.91 MPa is acquired for Al-combination A384. The weakness pre breaking burden is acquired for Al-amalgam A384 material is 1.97 KN which is required to create sharp split close to the break tip. The most extreme load (Pmax) acquired before complete break of the metal is around 2.67 KN. For Al-compound A384 the break load (PQ) is acquired is about 2.068 KN. The temporary crack durability of Al compound A384 was seen around 18.53 MPa. Explanatory calculation like provisional fracture durability and fracture

[18]Z. KONOPKA et.al. [2006], A356 aluminum combination with short carbon fiber with two distinctive volume fraction 7.5% and 12.5% manufactured by stir casting strategy. The toughness strength of Al-Si-carbon composites slowly expanded as a component of the weight fiber division. The greatest estimation of K1c was 8.4 MPa m1/2 for composite with fiber contact 12.5% and length of fiber 7 mm. From the above research paper I presumed that. Crack durability testing did utilizing KIc parameter should be taken on examples with bigger thickness, which ensures plain strain state in tested specimens.

CHAPTER 3 SELECTION OF MATERIAL

3.1 MECHANICAL PROPERTIES OF AL 7075

Aluminum Alloy 7075 (AL7075) is a high-strength aluminum alloy mainly alloyed with zinc, along with small amounts of magnesium, copper, and chromium. It is one of the strongest aluminum alloys available and is widely used in aerospace and high-performance engineering applications. In the T6 condition, AL7075 offers very high tensile and yield strength while maintaining a lightweight density of about 2.81 g/cm³, making it ideal for components that require a high strength-to-weight ratio. It has good fatigue resistance and machinability, but its corrosion resistance and weldability are lower compared to alloys like 6061. Due to its superior mechanical properties, AL7075 is commonly used in aircraft structures, defense equipment, automotive components, and precision molds.

(a) TITANIUM DIBORIDE

Titanium diboride (TiB_2) is an ultra-hard ceramic compound known for its exceptional combination of high melting point (~3,220 °C), extreme hardness, low density, and excellent electrical and thermal conductivity compared to most ceramics. It exhibits outstanding wear resistance, chemical stability, and corrosion resistance, particularly against molten metals, making it valuable in demanding industrial environments. TiB_2 is widely used in applications such as cutting tools, armor materials, cathodes for aluminum smelting, crucibles, and protective coatings, as well as in aerospace and defense components. Its ability to retain strength at high temperatures and conduct electricity distinguishes it from many other advanced ceramics, though its brittleness and difficulty in sintering can pose challenges in manufacturing.

(b) MAGNESIUM

Magnesium (Mg) is a lightweight structural metal valued for its very low density, high specific strength, and excellent machinability, making it one of the lightest metals used in engineering applications. It is widely used in automotive, aerospace, electronics, and biomedical industries to reduce weight and improve fuel efficiency while maintaining adequate mechanical performance. Magnesium also exhibits good damping capacity, thermal conductivity, and recyclability, though it has lower corrosion resistance and absolute strength compared to aluminum and steel, often requiring alloying or surface treatments to enhance its performance.

(c) Crab Shell Ash (CSA)

Crab Shell Ash (CSA) is a bio-derived, calcium-rich material obtained by calcining waste crab shells, making it an environmentally friendly and sustainable reinforcement or filler material. It primarily consists of calcium oxide (CaO) and calcium carbonate ($CaCO_3$), with trace amounts of other minerals, and is commonly used in green composites, cementitious materials, soil stabilization, and waste-derived ceramics. CSA offers low density, good thermal stability, and chemical reactivity, contributing to improved stiffness, hardness, and eco-efficiency of composite materials, though its mechanical properties strongly depend on processing conditions, particle size, and calcination temperature.

(d) GRAPHENE

Graphene is a two-dimensional nanomaterial composed of a single layer of carbon atoms arranged in a hexagonal lattice, renowned for its extraordinary mechanical, thermal, and electrical properties. It exhibits exceptional strength, stiffness, and flexibility while being extremely lightweight, making it highly attractive for applications in advanced composites, nanoelectronics, energy storage, sensors, and thermal management systems. Graphene's large surface area, high aspect ratio, and superior conductivity enable significant property enhancement even at very low loadings, although challenges remain in large-scale production, uniform dispersion, and cost-effective integration into bulk materials.

Property	Value	Unit
Density	2.2	g/cm³
Tensile Strength	~130,000	MPa
Young's Modulus	~1,000	GPa
Poisson's Ratio	0.16–0.19	–
Thermal Expansion	-1 to $+1 \times 10^{-6}$	K^{-1}
Thermal Conductivity	3,000–5,000	W/m·K

Figure 2 mechanical properties of Graphene

3.2 MATRIX MATERIAL

AL 7075 alloy was selected because of its low specific weight and high strength to weight ratio and fatigue and also its excellent machinability, formability and weld ability. This alloy is widely used in automotive industry, aircraft industry and defense industries.

Figure 3 Aluminum 7075 rods for furnace

3.3 REINFORCEMENT CHOICE (MAGNESIUM, GRAPHENE, CRAB SHELL ASH (CSA) AND TITANIUM DIBORIDE)

Reinforcing Aluminum 7075 (Al 7075), a high-strength, heat-treatable alloy primarily composed of aluminum, zinc, and magnesium, with materials like Titanium Diboride (TiB_2), Crab Shell Ash (CSA), Graphene, and Magnesium (Mg) can significantly enhance its mechanical properties and extend its range of applications. Each reinforcement material has its unique characteristics and advantages, influencing the performance of the composite in different ways.

3.3.1 Graphene Reinforced Al 7075:

Graphene reinforced Al 7075 is a high-performance metal matrix composite (MMC) that combines the exceptional strength and lightweight properties of aluminum 7075 with the superior hardness and wear resistance of Graphene. Al 7075, known for its high strength-to-weight ratio, excellent fatigue resistance, and good corrosion resistance, is widely used in aerospace, automotive, and defense applications. The addition of Graphene as a reinforcement enhances the composite's hardness, stiffness, and wear resistance while maintaining a relatively low density. This reinforcement also improves thermal stability and load-bearing capacity, making it suitable for high-stress environments where strength, durability, and weight reduction are critical. The combination of these properties makes Graphene-reinforced Al 7075 an ideal material for aerospace structural components, military armor, and advanced engineering applications.

3.3.2 Titanium Diboride Reinforced Al 7075:

Titanium Diboride (TiB_2) reinforced Al 7075 is a high-performance metal matrix composite (MMC) that combines the lightweight strength of aluminum with the exceptional hardness and wear resistance of TiB_2. Al 7075, known for its high strength-to-weight ratio and excellent fatigue resistance, is further enhanced by TiB_2, which improves its mechanical properties, including hardness, stiffness, and wear resistance. The addition of TiB_2 particles increases the Young's modulus, tensile strength, and thermal conductivity while reducing thermal expansion, making the composite ideal for aerospace, automotive, and structural applications. This MMC offers superior performance in high-stress environments where enhanced mechanical and thermal properties are required.

3.3.3 Magnesium Reinforced Al 7075:

Magnesium reinforced Al 7075 is a hybrid metal matrix composite that combines the high strength and fatigue resistance of aluminium alloy 7075 with the lightweight characteristics of magnesium. Al 7075 serves as a strong structural matrix, while the addition of magnesium contributes to reduced density and improved specific strength. The presence of magnesium can also enhance machinability and thermal properties while influencing grain refinement and overall mechanical performance. This composite is suitable for aerospace, automotive, and structural applications where high strength-to-weight ratio and improved performance under mechanical and thermal loading are required.

3.3.4 Crab Shell Ash (CSA) Reinforced Al 7075:

Crab Shell Ash (CSA) reinforced Al 7075 is an eco-friendly metal matrix composite (MMC) that combines the high strength and lightweight characteristics of aluminium alloy 7075 with the sustainable, calcium-rich reinforcement derived from waste crab shells. Al 7075 provides excellent strength-to-weight ratio and fatigue resistance, while the incorporation of CSA enhances hardness, stiffness, and wear resistance due to its ceramic nature. The addition of CSA can improve the Young's modulus and surface durability while contributing to reduced material cost and environmental impact. This composite is particularly suitable for lightweight structural, automotive, and engineering applications where moderate mechanical enhancement, sustainability, and cost-effectiveness are desired.

3.5 MATERIAL AND MEASUREMENT:

The fabrication process is carried out as two stages one is composite and hybrid composite. The composite measurements are carried as given table for both composites. The AL7075, TiB_2, Mg, CSA, Graphene alloy which is used forms metal matrix composition and where the AL7075 is mixed with using 1% Mg and 0.5% Graphene in all compositions, TiB2 in the ratio of (0.5%,1.5%,2.5%) and CSA in the ratio of (0.5%,1%1.5%) to form compositions and these alloys are mixed thoroughly in the ball mill for 30 minutes to form the fine mixture (or) mixing in pestle motor thoroughly and the compositions are prepared. In this particular AL7075 – B4C and T AL7075, TiB_2, Mg, CSA, Graphene as reinforcement for composite, increases the mechanical properties of aluminium7075.in the same way for both Mg & TiB2 as reinforcement for hybrid composite. Many researches were done through powder metallurgy by incorporating ceramic particles as reinforcements on pure aluminium7075 whereas, in this work, a novel idea of reinforcing ceramic particles in aluminium7075 alloy is attempted. Powders of aluminium7075 were generated through ball milling for this work. This paper focuses on further enhancement of the properties of aluminium7075 alloy through powder metallurgy process by incorporation AL7075, TiB_2, Mg, CSA, Graphene alloy reinforcement.

S. No	Al 7075 Matrix (%)	TiB_2 (%)	Mg (%)	CSA (%)	Graphene (%)
1	100	0	0	0	0
2	97.5	0.5	1	0.5	0.5
3	96	1.5	1	1	0.5
4	94.5	2.5	1	1.5	0.5

Figure 4 composition of hybrid-composite

4 STIR CASTING PROCESS

4.1 STIR CASTING

Stir casting is a type of casting process in which a mechanical stirrer is introduced to form vortex to mix reinforcement in the matrix material. It is a suitable process for production of metal matrix composites due to its cost effectiveness, applicability to mass production, simplicity, almost shaping and easier control of composite structure. Stir casting setup as shown in consist of a furnace, reinforcement feeder and mechanical stirrer. The furnace is used to heating and melting of the materials.

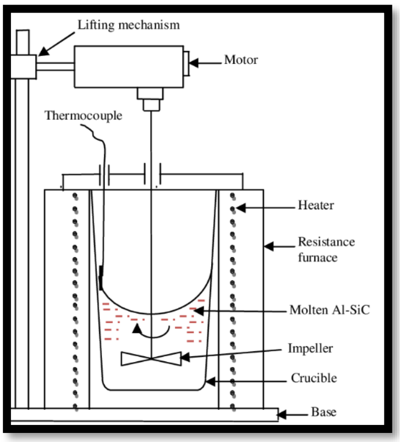


Figure 5 Schematic of stir casting setup

The bottom poring furnace is more suitable for the stir casting as after stirring of the mixed slurry instant poring is required to avoid the settling of the solid particles in the bottom the crucible. The mechanical stirrer is used to form the vortex which leads the mixing of the reinforcement material which is introduced in the melt. Stirrer consists of the stirring rod and the impeller blade. The impeller blade may be of, various geometry and various number of blades. Flat blade with three numbers is the preferred as it leads to axial flow pattern in the crucible with less power consumption. This stirrer is connected to the variable speed motors; the rotation speed of the stirrer is controlled by the regulator attached with the motor. Further, the feeder is attached with the furnace and used to feed the reinforcement powder in the melt. A permanent mold, sand mold or a lost-wax mold can be used for pouring the mixed slurry.EXPERIMENTAL PROCEDURE AND EQUIPMENT:

- Aluminum powders of 50μm size are mixed with TiB_2, Mg, CSA, Graphene mixed in above given table powders are prepared.
- The mixture was carried out in pestle mortar to ensure uniform distribution of TiB_2, Mg, CSA, Graphene with Aluminum.
- Stir casting is a liquid state method for the fabrication of composite materials, in which a dispersed phase is mixed with a molten matrix metal by means of mechanical stirring.In this process, the matrix material is kept in the bottom pouring furnace for melting. Simultaneously, reinforcements are preheated in a different furnace at certain temperature to remove moisture, impurities etc. After melting the matrix material at certain temperature, the mechanical stirring is started to form vortex for certain time period then reinforcement's particles are poured by the feeder provided in the setup at constant feed rate at the center of the vortex, the stirring process is continued for certain time period after complete feeding of reinforcement's particles. The molten mixture is then poured in preheated mold and kept for natural cooling and solidification. Further, post casting process such as heat treatment, machining, testing, inspection etc. has been done. There is various impeller blade geometry are available. Melting of the matrix material is very first step that has been done during this process.

4.3 MELTING OF MATRIX MATERIAL

Out of various furnaces, bottom pouring furnace is suitable for fabrication of metal matrix composites in stir casting route, this type of furnace consists of automatic bottom pouring technique which provides instant pouring of the melt mix (matrix and reinforcement). Automatic bottom pouring is mainly used in investment casting industry. In this technique, a hole is created in the base of melting crucible to provide bottom pouring and was shielded by a cylinder-shaped shell of metals. In stir casting process, the matrix material is melted and maintained a certain temperature for 2–3 h in this furnace. Simultaneously, reinforcements are preheated in a different furnace. After melting of the matrix material, the stirring process has been started to form the vortex.

CHAPTER 5 TESTINGS

5.1 SCANNING ELECTION MICROSCOPE

A typical SEM instrument, showing the electron column, sample chamber, ED's detector, electronics console, and visual display monitors. The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens.

Figure 6 SEM equipment

5.1.1 FUNDAMENTAL PRINCIPLES OF SCANNING ELECTRON MICROSCOPY (SEM)

Accelerated electrons in an SEM carry significant amounts of kinetic energy, and this energy is dissipated as a variety of signals produced by sample interactions when the incident electrons are decelerated in the solid sample. These signals include secondary electrons (that produce SEM images), backscattered electrons (BSE), diffracted backscattered electrons (EBSD that are used to determine crystal structures and orientations of minerals), photons (characteristic X-rays that are used for elemental analysis and continuum X-rays), visible light (cathode luminescence --CL), and heat. Secondary electrons and backscattered electrons are commonly used for imaging samples: secondary electrons are most valuable for showing morphology and topography on samples and backscattered electrons are most valuable for illustrating contrasts in composition in multiphase samples (i.e. for rapid phase discrimination).

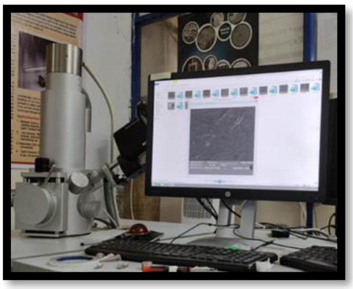


Figure 7 Schematic drawing of election and x-ray option on system

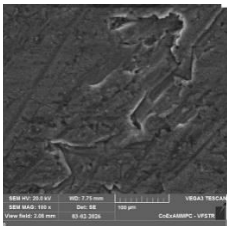


Figure 8 SEM Analysis on the AL7075 + 1. 5% TiB_2+1%Mg + 1 CSA + 0.5% Graphene.

5.2 HARDNESS TEST

Hardness is a measure of how much a material resists changes in shape. Ability of material to resist wear, tear, scratching, abrasion cutting is called hardness. Harder materials are more difficult to cut and shape than softer ones. They are also usually more brittle which means they do not bend much but can shatter. The Vickers hardness test was developed in 1921 by Robert L. Smith and George E. Sand land at Vickers Ltd as an alternative to the Brinell method to measure the hardness of materials. The Vickers test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The basic principle, as with all common measures of hardness, is to observe a material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). The hardness number can be converted into units of Pascal's, but should not be confused with pressure, which uses the same units. The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not pressure.

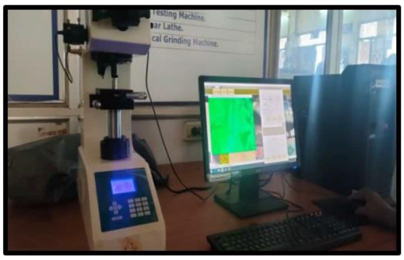


Figure 9 Vickers hardness tester

5.3 TENSILE TEST RESULTS:

The provided table summarizes the mechanical properties of four distinct aluminum-based composite samples, specifically focusing on the relationship between their chemical composition, maximum load capacity, and Ultimate Tensile Strength (UTS).

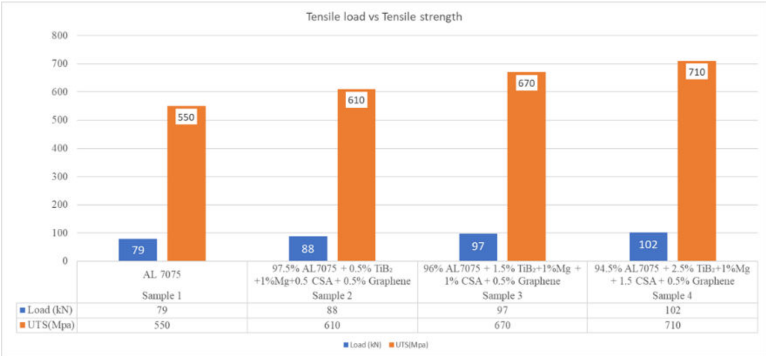
Samples	Compositions	Load (kN)	UTS(Mpa)
Sample 1	AL 7075	79	550
Sample 2	97.5% AL7075 + 0.5% TiB_2 +1%Mg+0.5 CSA + 0.5% Graphene	88	610
Sample 3	96% AL7075 + 1.5% TiB_2+1%Mg + 1% CSA + 0.5% Graphene	97	670
Sample 4	94.5% AL7075 + 2.5% TiB_2+1%Mg + 1.5 CSA + 0.5% Graphene	102	710

Figure 10 TENSILE TEST RESULTS FOR Pure AL7075 Composition

The experimental data compares a base alloy, AL 7075, against three reinforced variations. As the concentration of reinforcements—specifically Titanium Boride (TiB_2), Coconut Shell Ash (CSA), Magnesium (Mg), and Graphene—increases, there is a clear and consistent improvement in the material's strength.

5.3.1 TENSILE TEST GRAPH

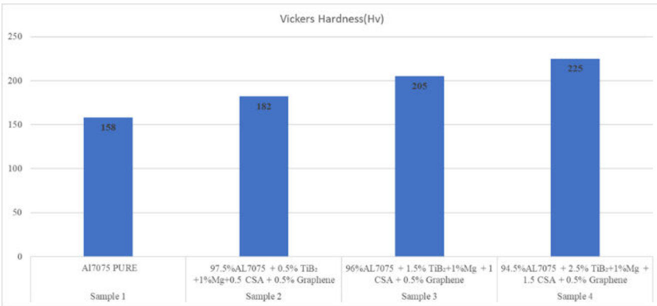
The graph demonstrates a clear, linear progression in material strength as reinforcing elements—specifically Titanium Boride (TiB_2), Magnesium (Mg), Coconut Shell Ash (CSA), and Graphene—are added to the AL 7075 base alloy. Sample 1 serves as the baseline with a tensile load of 79 kN and a UTS of 550 MPa. As the concentration of TiB_2 and CSA increases across Samples 2 through 4, both the tensile load and UTS values rise consistently. This trend culminates in Sample 4, which exhibits the highest performance with a load of 102 kN and a UTS of 710 MPa. The data indicates that increasing the weight percentage of these reinforcements significantly enhances the material's ability to withstand structural stress, with Sample 4 showing roughly a 29% improvement in tensile strength compared to the base AL 7075 alloy.



GRAPH 1 TRNSILE RESULT

5.4.1 HARDNESS TEST GRAPH

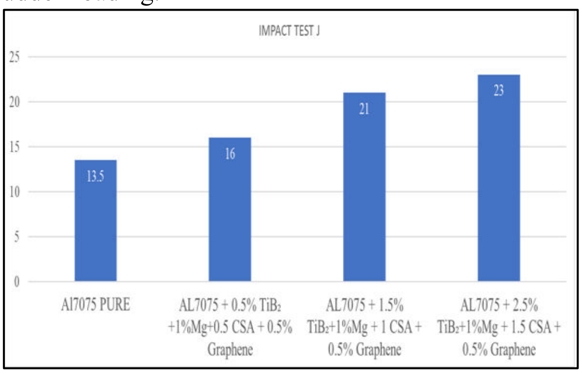
The graph demonstrates a direct linear relationship between the volume of reinforcing agents and the overall strength of the composite. Starting from the control (Sample 1) with a UTS of 550 MPa, each successive sample shows an incremental improvement as the weight percentages of Titanium Boride (TiB_2) and Coconut Shell Ash (CSA) are increased. The peak performance is observed in Sample 4, which achieves a maximum tensile load of 102 kN and a UTS of 710 MPa. This significant enhancement—a 29% increase in UTS over the base alloy—is likely due to the synergistic effect of the hard ceramic TiB_2 particles and the silica-rich CSA, which act as barriers to dislocation movement within the aluminum matrix.



GRAPH 2 HARDNESS RESULT

5.5.1 IMPACT TEST GRAPH

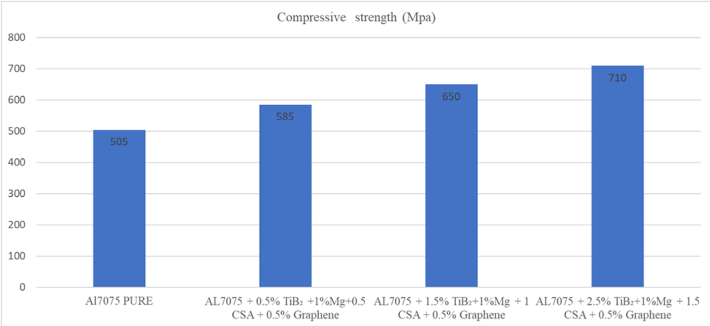
The graph demonstrates a significant and consistent improvement in the impact toughness of the material as the weight percentage of reinforcements increases. The base alloy, AL 7075 PURE, exhibits the lowest energy absorption at 13.5 J. As the concentration of Titanium Boride (TiB_2) and Coconut Shell Ash (CSA) is incrementally raised while maintaining constant levels of Magnesium and Graphene, the impact strength rises steadily. This trend peaks with the final sample, which achieves an impact energy of 23 J. This represents an approximate 70% increase in toughness compared to the pure alloy, suggesting that the combination of these reinforcements effectively enhances the composite's ability to absorb energy and resist fracture during sudden loading.



GRAPH 3 IMPACT TEST

5.6.1 COMPRESION TEST GRAPH

The graph demonstrates a clear and consistent increase in compressive strength as reinforcing elements are added to the AL7075 aluminum matrix. The baseline material, Al7075 PURE, exhibits a compressive strength of 505 MPa. As the weight percentages of Titanium Boride (TiB_2) and Coconut Shell Ash (CSA) are incrementally increased, the strength follows a linear upward trajectory. The most reinforced variant, containing 2.5% TiB_2 and 1.5% CSA, achieves the highest compressive strength at 710 MPa. This indicates that the addition of these specific ceramic and organic reinforcements significantly enhances the material's ability to resist crushing loads, resulting in an overall improvement of approximately 40.6% over the pure aluminum alloy.



GRAPH 4 COMPRESSIVE TEST

5.7 SLIDING WEAR TEST RESULTS (ASTM G99 – PIN-ON-DISC):

The pin-on-disc test is a commonly used tribological testing method to evaluate the wear and friction characteristics of materials under sliding contact. In this test, a stationary pin made of the test material is pressed against a rotating disc under a controlled normal load. As the disc rotates at a specified speed, sliding occurs at the contact interface, resulting in friction and material removal from the pin surface. The test is conducted for a predetermined sliding distance or time, and the wear is typically quantified by measuring the weight loss or wear depth of the pin. The pin-on-disc method provides reliable and repeatable results and is widely used to compare the wear resistance and frictional behavior of different materials, coatings, and surface treatments under controlled laboratory conditions.

Test Parameters (as per your figure)

- **Loads**: 10 N, 20 N, 30 N
- **Sliding speeds**: 1.5 m/s, 3.0 m/s, 4.5 m/s
- **Sliding distances**: 1000 m, 2000 m, 3000 m
- **Specimen**: Ø8 × 25 mm
- **Method**: Weight loss method
- *(ASTM G99, Pin-on-Disc)* **5.7.3 LOAD = 30 N, Sliding Speed = 4.5 m/s**

The table presents the wear test results of samples S1 to S4 conducted under a higher operating condition of 30 N normal load and 4.5 m/s sliding speed at sliding distances of 1000 m, 2000 m, and 3000 m. The wear behaviour is evaluated based on the reduction in specimen weight before and after testing. For all samples, the weight loss increases consistently with increasing sliding distance, indicating progressive material removal due to enhanced frictional interaction at higher load and speed. Among the tested specimens, S1 exhibits the highest wear loss, reaching 41.8 mg at 3000 m, signifying poor wear resistance under severe conditions. S2 and S3 show moderate wear, with S3 performing better than S2 at all distances. S4 demonstrates the lowest weight loss across all sliding distances (7.9 mg to 18.0 mg), confirming its superior wear resistance even under elevated load and speed. The results clearly indicate that increasing load and sliding speed significantly intensify wear, while material composition and surface properties play a crucial role in improving wear resistance.

Sample	Distance (m)	Initial Weight (g)	Final Weight (g)	Weight Loss (mg)
S1	1000	9.8420	9.8234	18.6
S1	2000	9.8420	9.8111	30.9
S1	3000	9.8420	9.8002	41.8
S2	1000	9.8655	9.8514	14.1
S2	2000	9.8655	9.8421	23.4
S2	3000	9.8655	9.8337	31.8
S3	1000	9.8890	9.8785	10.5
S3	2000	9.8890	9.8714	17.6

S3	3000	9.8890	9.8649	24.1
S4	1000	9.9140	9.9061	7.9
S4	2000	9.9140	9.9008	13.2
S4	3000	9.9140	9.8960	18.0

CHAPTER 6
CONCLUSION

The experimental results across tensile, compressive, and impact testing reveal a consistent linear relationship between reinforcement concentration and material strength. The base AL 7075 PURE (Sample 1) consistently represents the lowest performance tier, with a Tensile Load of 79 kN, a UTS of 550 MPa, an Impact Energy of 13.5 J, and a Compressive Strength of 505 MPa.—reaching up to 2.5% and 1.5% respectively in Sample 4—the material properties improve significantly. The Ultimate Tensile Strength (UTS) rises from 550 MPa to 710 MPa (a 29% increase), while the Compressive Strength experiences a more dramatic surge, growing from 505 MPa to 710 MPa, reflecting a 40.6% improvement.

The most substantial gains are observed in impact toughness, where energy absorption jumps from 13.5 J in the pure alloy to 23 J in the final hybrid composite, marking an approximate 70% increase. This indicates that while TiB_2 and CSA effectively increase the hardness and resistance to static loads, they also synergistically enhance the material's ability to absorb sudden kinetic energy and resist fracture. The addition of 1% Magnesium and 0.5% Graphene across all reinforced samples likely aids in grain refinement and wear resistance, contributing to a more stable and high-performance material matrix.

Finally concluded that, the development of this hybrid metal matrix composite through the stir casting method successfully addresses the need for high-strength, lightweight materials for next-generation engineering. The study confirms that Sample 4—containing 2.5% TiB_2, 1.5% CSA, 1% Mg, and 0.5% Graphene—is the optimized composition, exhibiting the superior mechanical profile across all tested parameters. The integration of hard ceramic TiB_2 particles and silica-rich bio-ceramic CSA creates effective barriers to dislocation movement, significantly bolstering the AL 7075 matrix against structural stress.

This optimized hybrid composite offers a compelling balance of reduced weight and enhanced structural integrity, making it an ideal candidate for critical applications in the aerospace, automotive, and defense sectors. Specifically, its improved toughness and compressive strength make it highly suitable for UAV frames, pistons, brake components, and marine hardware where failure resistance and weight efficiency are paramount.

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