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Research Article

Mechanical and wear characteristics of (Al7075/SiC/Gr/Zr) hybrid metal matrix composites using ultrasonic assisted stir casting process

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Abstract

The successful combination of lightweight and high strength continues to propel composite materials into new fields. Due to their surface qualities, composite materials can replace traditional materials such as steel, cast iron, and aluminium alloys. In aeronautical and automotive applications, to replace conventional materials, using the ultrasonic assisted stir casting process, produced the composites based on aluminium alloy (Al7075) were reinforced with a 6% volume fraction of silicon carbide (SiC) particles, 3% volume fraction of zirconium (Zr) particulates, and 2% graphite (Gr) particles make up of the volume portion. The mechanical characteristics of produced composite were evaluated by testing. The density of Al7075/SiC/Gr/Zr was 3.24% greater than pure aluminium and 1.42% lower than Al7075, respectively. Hardness increased by 65.94% when compared to pure aluminium and 22.85% when compared to Al7075. With the aid of universal testing equipment, tensile strength was teste and found to be 59.9% higher than pure aluminium and 44.68% higher than Al7075. Impact strength using the Charpy impact tester decreases by 79% with pure aluminium and 75% with Al7075. When compared to pure aluminum, the composite's yield strength is improved by 64.94 percent. The yield strength of the composite is enhanced by 64.94% when compared to pure aluminium and 16.27% when Al7075 is used. It was discovered that the hybrid metal matrix composite's % elongation was lower than that of pure aluminum and Al7075.The inclusion of SiC reduces the ductility of SiC/Gr/Zr reinforcements. The hybrid metal matrix composite exhibits a reduced elongation of 71.94% when compared to pure aluminium and 25% when compared to Al7075. Scanning electron microscopy (SEM), energy-dispersive x-ray spectroscopy (EDS) with elemental mapping and x-ray diffraction (XRD) were used to analyze the distribution of reinforcement particles and their presence in the composite. In order to produce hybrid composites with better properties, it was determined that the ultrasonic stir squeeze casting process is favored to traditional stir casting.

Keywords

Al7075 alloy, Metal matrix composite, Reinforcements, Wear rate, Stir casting process.

1.Introduction

Al 7075 alloys are important in many technological domains, including the aerospace and automotive industries, on account of their exceptional strength-to-weight ratio and some other tribological and mechanical properties. Under dry and lubricated conditions, Al7075 alloys have poor sliding wear resistance performance. There are several available classes of a few alloys, however, the Al7075 alloy, which is found in a number of elements, exhibits good mechanical qualities that are being developed and researched for use in tribology.

As ceramic particles are added, friction and wear resistance are also improved, which boosts the performance of ceramic-based composites. Aluminum alloy SiC/Gr/Zr filled composites are being investigated in order to improve their wear characteristics. Amith and Lakshmanan [1] utilized ultrasonic assisted stir casting process for the formation of hexagonal boron nitride (h-BN)/Al7075 metal matrix composite. The objective is to enhance the physical properties of the hybrid composite metal than the base matrix. Tensile test was conducted on top of h-BN/Al7075 composite and concluded that 29.46% enhanced in tensile strength and stated only 0.6% is a correct composition. Kumar et al. [2]

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adapted base pouring stir casting for the materialization of Al-4032/GP/SiC hybrid composites.

It examined the grain formation and mechanical features of composite made metal matrix. Scanning electron microscopy test and mechanical tests were conducted over Al4032/GP/SiC metal composite and cluster formation occurs due to stir casting, mechanical properties enhance till 6% composition and then decreases. Moustafa et al. [3] employed the friction stir process for the creation of Al7075/h-BN/Carbide particles composites with a mixed metal matrix. This study intends to look into the hybrid metal matrix composite's mechanical characteristics and microstructure. Researchers were executed over Al7075/h-BN/Carbide particles and figured out that downsized grain size and improved mechanical properties. Saini and Singh [4] used the bottom pouring stir casting for the materialization of Al-4032/SiC hybrid metal matrix composites. Researches were proven over Al-4032/SiC and committed that 6% composition shows better properties and reinforcement coagulation is detected at 8%. Suresh et al. [5] have utilized stir casting for the formation of Al-6061/LM25-SiCP hybrid composites metal. The objective is to evaluate the hybrid metal matrix composites corrosion resistance. Analysis was conducted over Al6061/LM25-SiCP that addition in composition of SiCP improves the corrosion resistance. Divakar [6] made Al2219/ MoS_2/B_4C composites with a mixed metal matrix with the help of stir casting. The goal is to identify the hybrid metal matrix composites wear resistance. Wear test was experimented over Al2219/B_4C/MoS_2 is resulted in improvement of wear resistance.

The main challenges faced by previous literature in the traditional stir casting furnace that previous researchers utilize for single and mixed composite preparations [14, 15] with reinforcement concentrations that have been enhanced by only a particular percentage (Challenges) are (a) effective bonding among reinforcement and matrix impacted by wettability and employment of excellent reinforcements. (b) The rate of reinforcement flow into molten metal and stirrer blade erosion (c) Increased porosity levels (d) uniform dispersion, the creation of clusters, and aggregation because of the differences in density between the reinforcement and matrix. For the manufacturing of aluminum composite, a bottom tapping stir cast furnace with ultrasonic stirring in conjunction attachment will be the best option. Depending on design of furnace and process variables, additions like grain refiners, covering flux, and diluents, it is possible to overcome the difficulties listed above.

Researchers [35–38] used the squeeze casting process to produce nearly net-shaped components, lowering the permeability levels in the composite. The ultrasonic stir squeeze casting method is preferred over the conventional stir casting method in order to generate hybrid composites with better characteristics and get around the difficulties. This approach involves applying tremendous pressure to molten metal to produce the components. In order to reduce the formation of ceramic nanoparticle clusters or agglomerations and to obtain uniform dispersion of nanomaterials throughout the composites as well as improved material characteristics, a few researchers [39–42] investigated the ultrasonic resonance stir casting technique.

The primary objective of this study is to employ the ultrasonic resonance stir casting method and variety of SiC, Gr, and TiC weight percentages were used to manufacture silicon carbide, graphite, and zirconium nanomaterials strengthened with Al7075 composites. With the help of the Al7050 base and pure aluminium, the mechanical and wear qualities were examined. The fabrication of bulk nanocomposites with a uniform distribution of ceramic nanoparticles has been established. Hardness increases but ductility drops; to accomplish hardness and ductility, silicon carbide, graphite, and zirconium were used**.**

The remaining sections of this article are organized as follows regarding the contributions made by various researchers and relevant research efforts; a review of literature was covered in section 2. Section 3 of the present work's materials and technique were addressed. The test findings of the metal matrix composite specimens created with varying proportions, tensile characteristics, hardness, and impact strength are explored in section 4. In section 5 provided a thorough discussion. Section 6 dealt with the work's conclusion and prospective scope. The references were then listed at the end.

2.Literature review

Joshi and Mohanty [7] used powder metallurgy for the casting of Al/SiC/CF mixture of composites. The objective is to find the resistance of wear, coefficient of friction and mechanical properties. Wear and mechanical investigations were done on Al/ CF/SiC mixture of metal matrix composites is result in improvement of wear, coefficient of friction and mechanical properties on 6% composition. Nirala et al. [8] casted Al/Fly ash/CNT composite metal using casting method of stir process. The idea is to inspect the wear, mechanical and microstructure properties. Testing of the Al/CNT/Fly ash mixture of metal matrix composites reveals so as to fly ash affect wear rate at 15%, hardness increases, wear decreases and grain size reduced. Suresh et al. [9] utilized stir casting to form the Al2218/ Talc /Fly ash composites. Calculating the wear and mechanical properties is the objective. Hybrid metal matrix composite is put to the test and resulted improvement in wear resistance and hardness. Mohammed et al. [10] made use of spark plasma sintering and ball milling to create Al/Al_2O_3/GO metal matrix composites. The objective is to measure the mechanical, microstructure and wear attributes. The Al/ GO /Al_2O_3 mixture of metal matrix composite is studied and the test results exhibiting Al+10%vol Al_2O_3+0.25%GO is better for wear, microstructure and mechanical properties. Kumar et al. [11]utilized two-stage stir casting for the formation of AA7075/CSA composite. This work plan was to examine the wear and mechanical features. This inspection on the test specimen exemplifies the increase in wear, mechanical properties and slight decrease in impact strength, cracks and fractures are occurred. Surya and Gugulothu [12] adapted powder metallurgy to materialize the Al7075/SiC mixture of metal matrix composites. The motive is towards the test out of wear, hardness and surface roughness. Assessing the outcome porosity and cluster formed due to powder metallurgy, SiC at 15% gives better results. Kumar et al. [13] have adapted high vacuum casting for the formation of AA7075/ Graphite/ Marble Dust/ SiC/ mixture of composites. This study goal is to evaluate the wear performance. AA7075/ Graphite/ Marble Dust/ SiC/ composite is examined that is wear and mechanical properties are improved.

Dubey et al. [14] used stir casting for the fabrication of Al7075/B_4C mixture of metal matrix composite. The intention is to test out the machining characteristics of the hybrid metal matrix composite using electrical discharge machining method and surface roughness. The review shows how superior machining and reduced surface roughness have improved. Gnaneswaran et al. [15] had utilized stir casting for the fabrication of LM_6/B_4C aluminum composite made metal. This research goal is to analyze the wear behavior. Reviewing the result indicates addition of fiber downgrades tensile strength; reinforcement addition increases wear resistance, addition of steel fiber with 10%B_4C increases hardness. Aabid et al. [16] AA2219/B_4C, AA2219/Gr, AA2219/MoS_2 were casted by stir casting. The point is to compare the three hybrid metal matrix composites by wear performance. The hybrid metal matrix composites show the findings of increase in wear resistance using 15%B4C and utilizing Gr and MoS_2 reduces friction. Dar et al. [17] used stir casting process to produce AA7075/SiC mixture. This study motive is to inspect the material removal rate in the mixture of composite. A composite made of hybrid metals shows the rise in material removal rate at peak voltage. Vijaya et al. [18] made use of stir casting and reactive high energy milling to create Al7075/Ti and Al7075/NbC composite made of hybrid metal matrix.

The objective is to show the difference in wear and mechanical properties between these composites. The end result explains, adding titanium gives rod like structure, improvement in wear resistance and adding NbC improves micro hardness and mechanical properties. Patil et al. [19] developed AA7076/Graphene Amine/Carbon Fiber composite by motorized stir casting and ball milling and they examined the wear, mechanical and microstructural properties. The tested results showing 1% composition in reinforcements gave better results on mechanical, wear and microstructural properties. Bhowmik et al. [20] used techniques of stir to create composite made metal of Al7075+SiC and Al7075+TiB2.The target is to compare the two composites by mechanical properties and microstructures. Comparing the observed results exhibits Al7075+TiB_2 surpasses Al7075+SiC in mechanical properties and microstructures. Thamizhvalavan et al. [21] formed Al6063/$B_4C/ZrSiO_4$ hybrid composites by using the technique of stir. The idea is to observe the machinability and surface characteristics. Examined the results indicating 15% B_4C is best for machinability and surface characteristics. Raja and Prakash [22] created AA6061/TiB_2/Al_2O^3 hybrid metal matrix composite using powder metallurgy. The intention is to examine the mechanical and micro structural properties. The investigation leads to improved wear resistance and mechanical properties. Reddy et al. [23] utilized stir casting for the making of Al7075/TiC/SiC hybrid metal matrix composites. Investigating the mechanical and metallurgical characteristics is the objective. The observation displays the upgrading in tensile, hardness and superior upgrading the properties of mechanical. Singh et al. [24] developed Al_2O_3/RHA composite using the process of stir. The objective is to analyse the characteristics of mechanical. The inspection conducted on the tests illustrate that mechanical properties are improved. SyedAhamed and Shilpa reviewed the Al7075 containing SiC, Gr, B_4O_3, Al_2O_3 and Carbon Fiber. The examined review illustrates that increase the tensile strength and stress intensive factor [25].

Navuluri et al. [26] utilized the famous technique of stir for the materialization of Al7075/Zr/Gr composite. The intent was to examine the hybrid metal matrix composite by mechanical characteristics. The experimentation is handled on the composite exhibits increase in porosity due to stir casting, 3%Zr and1%Gr composition is best. Stir casting is a technique used by Saritha et al. [27] to create AA7075/Zr hybrid metal matrix composites. The motive is to analyse the behaviour of mechanical properties. The results indicate the 97%AA7075 and 3%Zr gives better result. AA7075/B_4C/Coconut shell fly ash composite was made by casting method of stir casting. To test the mechanical and microstructure properties, conducted tests show that improvement in wear resistance and mechanical properties [28]. Youssef and El-Sayed [29] adapted to stir casting for the creation of Al-10Sb/SiC composite made hybrid metal matrix. This study analyzed the mechanical and microstructure behavior of the metal. The outcome is the development in mechanical properties and clear grain refinement on microstructure properties. Aravindan et al. [30] developed a new combination of metal Al6063/SiC composite. The objective is to test the mechanical and micro structural behaviour. The end result is the improvement of mechanical properties and increase in weight fraction of SiC improves the microstructure distribution of particles.
Raja et al. [31] used the hybrid composite of AA6061/B_4C/TiO_2 and analyzed their mechanical, physical and microstructure Characteristics. Ikumapayi et al. [32] analyzed the effect of thermal processing on the material properties of an aluminum alloy matrix composite soaked in calcium carbonate and silver nanoparticles (Al- AgNp/$CaCO_3$). The hybrid M_oS_2, S_iC, and B_4C-reinforced metal matrix composite made of aluminum alloy 6061. M_oS_2, S_iC, and B_4C reinforcement were studied for their effects on the metal matrix composite's mechanical, physical, morphological and tribological behavior at different weight percentages analyzed by Abebe et al. [33]. Namdev et al. [34] demonstrated the how polymer composite materials are absorbed the water and also analyzed the behavior of swelling thickness. In the beginning, researchers employed powder metallurgy to create hybrid metal matrix composites, which were then tested for hardness, tensile, impact, density, wear, and microstructures. The results varied for different types of composites, but the powder metallurgy process maintained the same porosity and reinforcement coagulation. After that, they started using several stir casting techniques, ball milling, and spark plasma sintering to investigate the microstructure and determine the ideal casting technique. Stir casting was the first method they attempted; it decreased cluster formation and porosity but not completely. Bottom pouring stir casting induced cluster formation, squeezing stir casting and friction stir processing reduced grain size, and two stage stir casting generated cracks and fractures. Ultrasonic assisted stir casting decreases porosity and uniformly distributes reinforcement particles. The porosity development of hybrid metal matrix composites affects their mechanical properties. The formation of clusters reduces mechanical characteristics as well. The focus of the current study is on the production of Al7075/SiC/Gr/Zr composites using the ultrasonic assisted stir casting method, and its effects are examined through mechanical behaviour. Through the use of Scanning electron microscopy (SEM), x-ray spectroscopy (EDS) and x-ray diffraction (XRD) the distribution of reinforcement particles and the presence of different elements are examined.

3.Materials and methods

The ultrasonic assisted stir casting process was used to make the AA7075/silicon carbide/graphite/zirconium metal matrix composite. The casting machine consists of an SS310 crucible, a mechanical stirrer with three blades made of titanium sonotrode (diameter of sonotrode - 30 mm, length - 170m), a digital speed controller with a sonotrode height adjustment switch knob (150 mm travel distance), air-powered actuator, a piezoelectric transducer connected to an overhead motor through pneumatic air cooling, an ultrasonic liquid processing unit by means of a changeable output control stabilizer is a part of the rotational ultrasonication with mechanical stirring system (0.5 kW - 2.5 kW), a gas cylinder for argon that has a flow regulator, a preheating box type furnace, a casting die for SS304 (150mm x 100mm x 15mm) and a rotating ultrasonication mechanical stirring system.

A muffle furnace will be used to melt pure Al7075 rod at 820°C. For 2 hours, reinforcement particles are preheated in an induction furnace at 350°C. Throughout the procedure, one litre per minutes (LPM) of argon gas was employed as a shielding agent. The Al7075 mold received the revolving ultrasonic probe with such a mechanical stirrer pressed 50 mm underneath the melted surface. *Table 1* provides a full description of Al7075's chemical components.

Table 1 Al7075 materials composition

Materials	Composition
Silicon	(0% - 0.4%),
Magnesium	(2.1% - 2.9%),
Titanium	(0% - 0.2%),
Chromium	(0.18% - 0.28%),
Manganese	(0% - 0.3%),
Iron	(0% - 0.5%),
Copper	(1.2% - 2%),
Zinc	(5.1% - 6.1%),
Aluminium	Remaining

In an ultrasonic aided stir casting machine, molten Al7075 is added, together with preheated reinforcement particles in powder form. The rousing speed is put at 650 rpm and the process interval is set to 10 minutes. The complete approach of block diagram is shown in *Figure 1*. The titanium cylindrical rod used to make the ultrasonic probe has a length of 170 mm, diameter of 30 mm and frequency of 20 kHz, and an ultrasonic power of 2.5 kilowatt. The stir casting schematic diagram is shown in *Figure 2*. To produce the optimum shape, the molten material is poured into a die. The machine's ultrasonic waves were used to uniformly scatter the reinforcements in the molten metal, therefore eliminating cluster formation and porosity. The ultrasonic assisted stir casting machine is present in *Figure 3*.

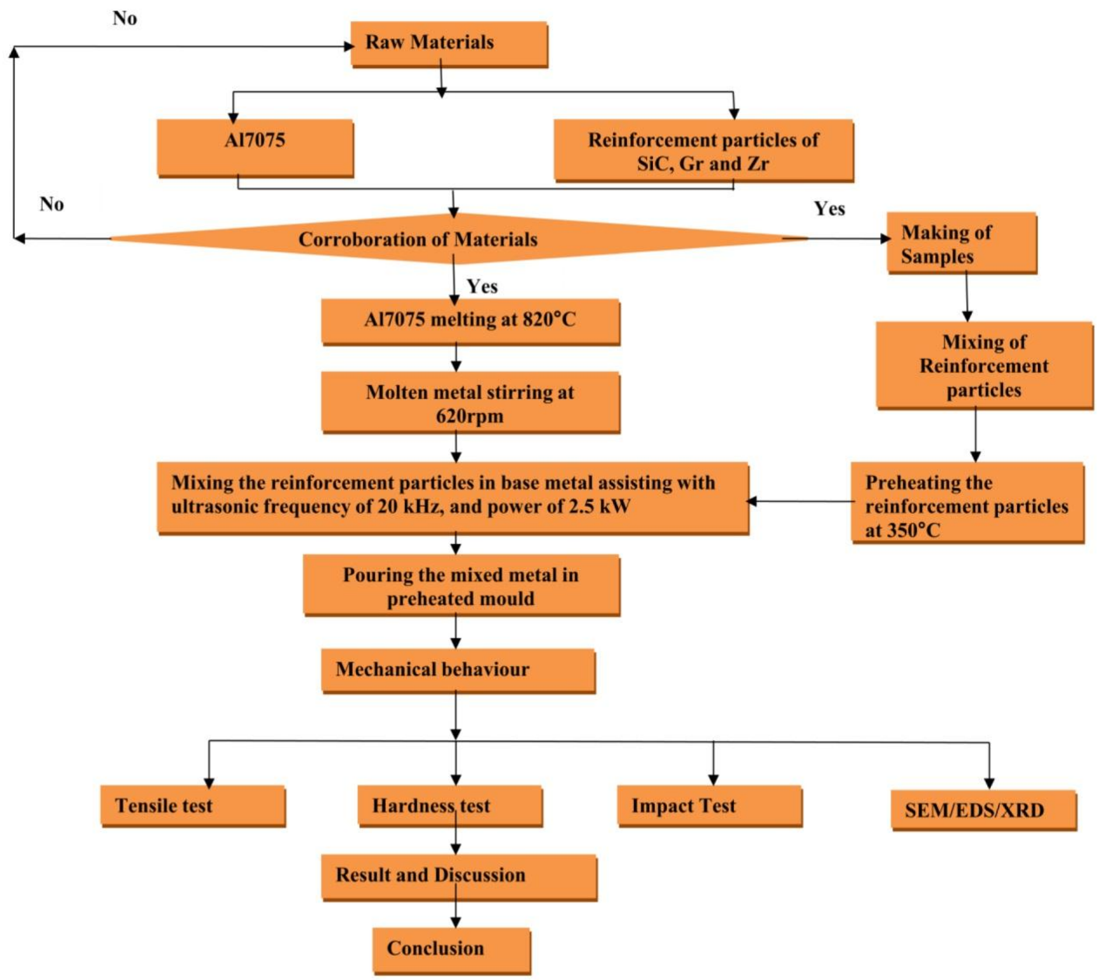

Figure 1 Block diagram of complete approach

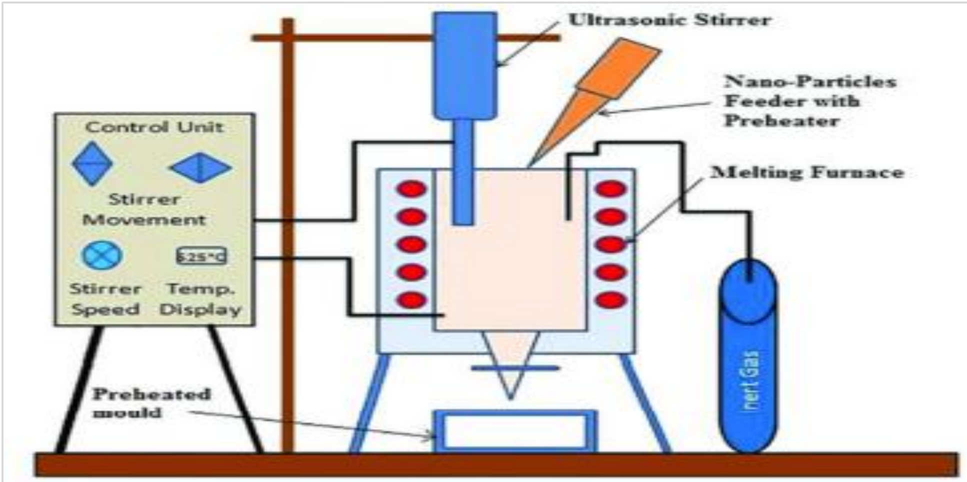

Figure 2 Stir casting method schematic diagrams

Figure 3 Ultrasonic assisted stir casting machine

4.Results

4.1Density and porosity

Measured density and theoretical density of pure aluminium, aluminium 7075 base cast and aluminium hybrid composite were calculated as shown in *Figure 4* to determine the porosity of the above mentioned composite materials given in *Table 2*. The rule of mixtures was utilized to calculate the theoretical density given in Equation 1. Measured density and porosity of the casted sample were calculated by using Equation 2 and Equation 3 respectively.

$$\rho_{theo} = \rho_{matrix} V_{matrix} + \rho_{rein} V_{rein} \quad (1)$$

$$\rho_{measur} = \text{mass of the specimen / volume of the specimen} \quad (2)$$

$$\text{Porosity} = (\rho_{theo} - \rho_{measur}) / \rho_{theo} \quad (3)$$

ρ_{measur} = Density of measured; ρ_{theo} = Density of theoretical; V_{rein} and V_{matrix} = Volume of reinforcement and matrix; ρ_{rein} and ρ_{matrix} = Density of reinforcement and matrix. A very precise electronic weighing device was used to measure the samples' mass directly, and the volume was estimated through multiplying the area of the cross-section by the specimens' length.

Table 2 Density and porosity of aluminium metal matrix composites

Samples	Composition of reinforcement	Theoretical density (gm/cm^3)	Measured density (gm/cm^3)	Porosity in %
1	Pure Al	2.682	2.642	1.42
2	Al7075	2.810	2.756	1.92
3	Al7075/SiC/Gr/Zr	2.771	2.732	1.40

The low levels of porosity observed provided good evidence of the reliability of producing composites using the ultrasonically-assisted agitation casting process. According to the current study, the maximum porosity level is 1.92% for Al7075 and 1.40% for Al7075/SiC/Gr/Zr composites, which is the acceptable porosity level for the fabricated hybrid composites reported in *Table* 2. SiC, Gr, and Zr have densities of 3200, 2720, and 6570 kg/m^3 in that order, which are superior to the aluminium alloy density (2650 kg/m^3). *Figure* 4 shows the results of density of various materials.

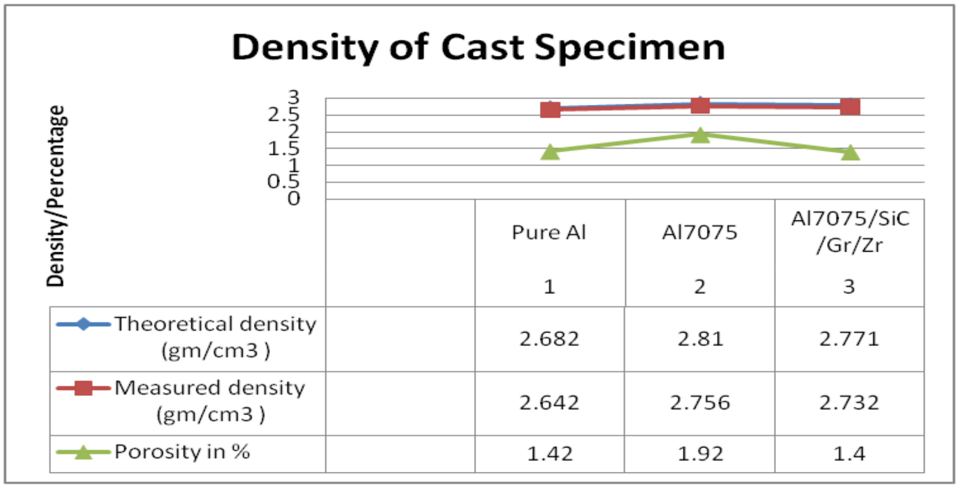

Figure 4 Density of the various materials

4.2Hardness

The property of hardness specifies a material's resistance to limited plastic deformation caused by mechanical penetration or scratching. In general, different materials have varying degrees of hardness. There are three different ways to quantify hardness: rebound hardness, indentation hardness and scratch hardness. *Figure 5* clearly demonstrates the specimen of hardness.

Table 3 present the Rockwell hardness B scale values for base castings made of aluminium alloy 7075, pure aluminium, and composite materials. For each cast sample, two points were measured, and the average value was used to create the graphical plots. Rock well hardness is characterized by physically powerful intermolecular exchanges however the performance of hard materials beneath strain is intricate. *Figure 6* display the hardness values of various materials.

Table 3 Hardness value of composite material

Samples	Composition of reinforcement	Rockwell Hardness B trail-1 value	Rockwell Hardness B trail-2 value	Average Rockwell Hardness B
1	Pure Al	40.25	40.81	40.53
2	Al7075	91.2	92.4	91.8
3	Al7075/SiC/Gr/Zr	118	120	119

Figure 5 Specimen for hardness measurement

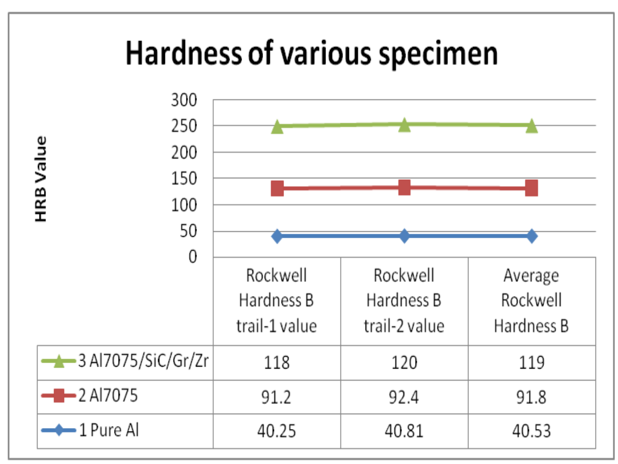

Figure 6 Hardness of the various materials

4.3Tensile strength

As reported in *Table 4*, Tensile strength values for base cast material Al 7075 with 0 wt.% of reinforcements and pure aluminium are 97.47 MPa and70.67 MPa respectively. The tensile strength is further raised to 176.22MPa by adding a certain weight percentage of reinforcing particles such as SiC, Gr, and Zr to the Al7075 base cast.

Tensile strength is a stress that is evaluated in load for each unit area. It is possible to report it simply as a force or load per element width for a few non-uniform materials. The newton per meter square is the standard measurement unit (N/m^2) or pascal (Pa). *Figure 7* shows the tensile test specimen. *Figure 8* illustrates the ultimate tensile strength of different materials.

Figure 7 Specimen of tensile test

Table 4 Tensile strength value of composite material

Samples	Composition of reinforcement	Tensile strength MPa
1	Pure Al	70.67
2	Al7075	97.47
3	Al7075/SiC/Gr/Zr	176.22

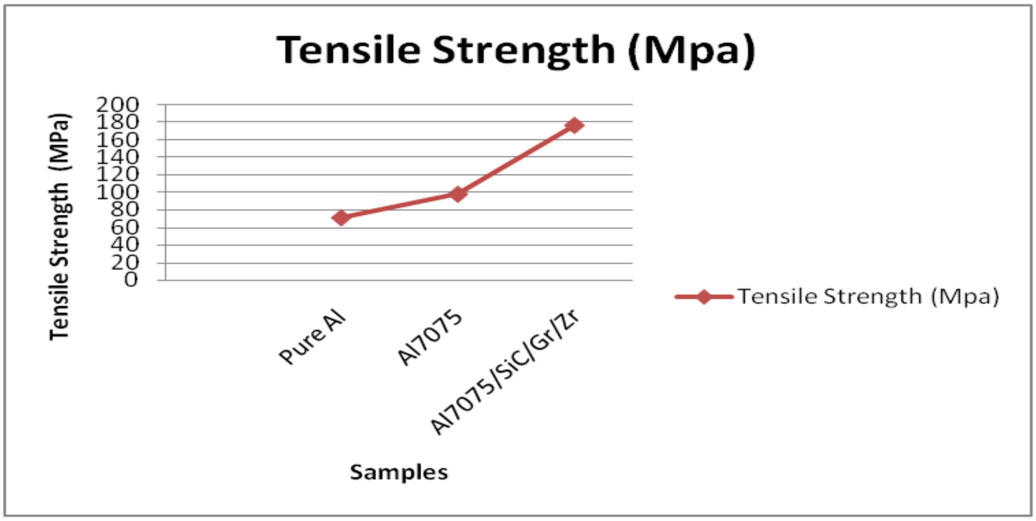

Figure 8 Tensile strength of various materials in MPa

4.4Impact strength

Impact strength, sometimes referred to as impact toughness is the quantity of energy so as to a material is able to resist while a load is rapidly applied to it. It is often referred to as the force per unit area below which a material would shatter. *Figure 9* demonstrates the specimen of impact. *Figure 10* shows the impact power of the materials.

Figure 9 Specimen for impact strength

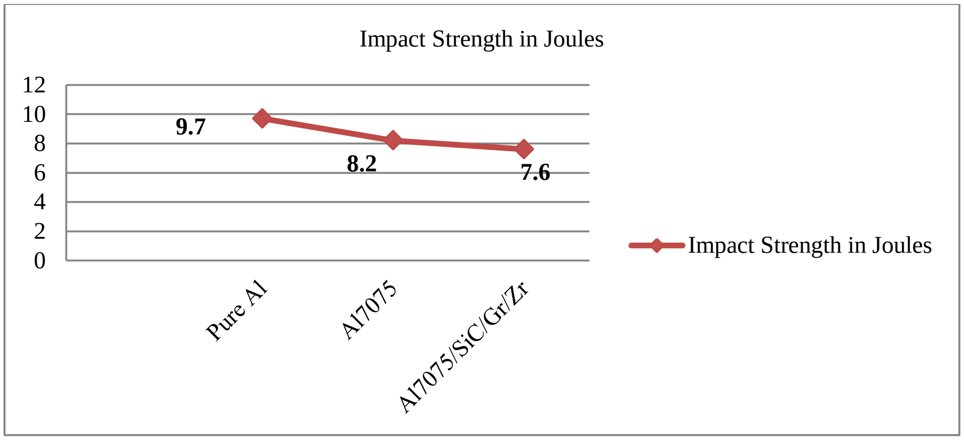

Figure 10 Impact strength of various materials in Joules

4.5Yield strength

The yield stress or strength is a material attribute. That corresponds to the stress at which the material begins to deform plastically. The strength of yield is usually employed to calculate the greatest acceptable force in a component as it indicates the maximum loads that perhaps applied with no enduringly distorting the material. *Figure 11* shows the yield strength of the materials.

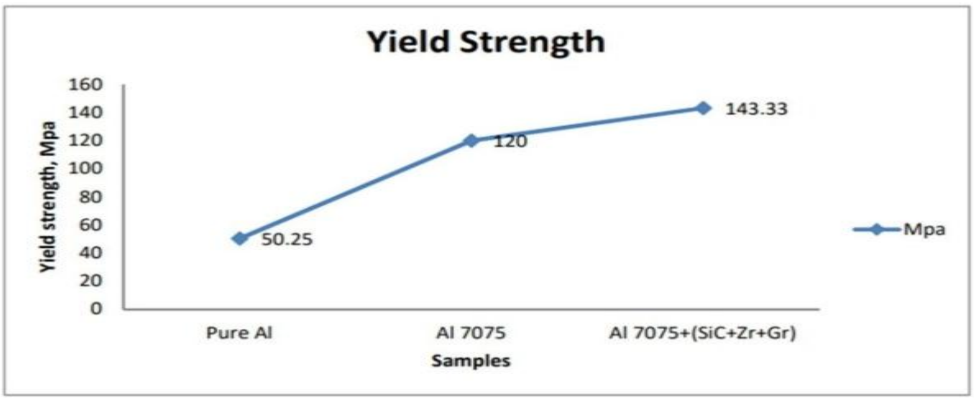

Figure 11 Yield strength of various materials in MPa

4.6Elongation

The number of material will distort elastically and plastically equal to crack is captured in the fraction of elongation. The material ductility is calculated in terms of percent elongation. The ending span of a material is measure up to its initial span to assess its % elongation and ductility. Elongations of various materials are illustrated in *Figure 12.*

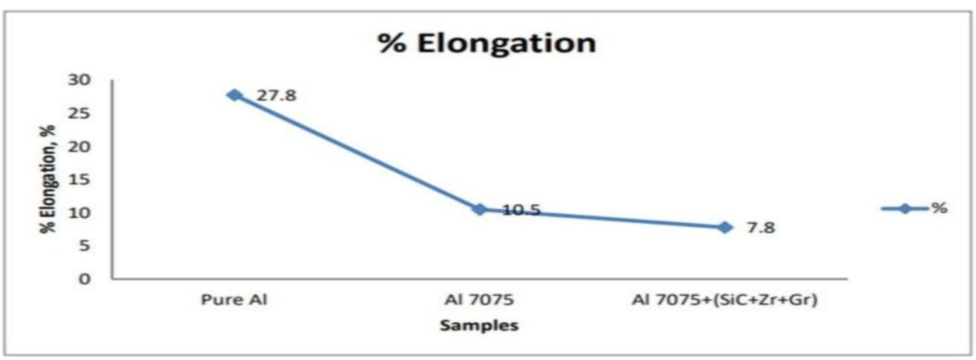

Figure 12 Percentage of elongation

4.7Abrasive wear

While a hard and rough surface of the materials glides above a squashy surface, causing wear abrasive. Material defeat is sourced by hard particles or hard protuberances so as to press up against and moved along a hard face, according to american society for testing and materials (ASTM) international standard. The wear rates are demonstrated in *Figure 13*. *Figure 14* and *15* shows the test specimen.

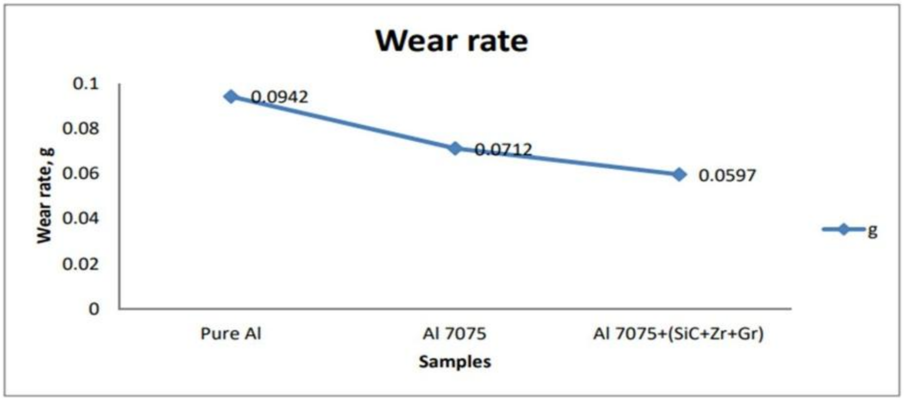

Figure 13 Wear rates of various materials

Figure 14 Specimen for before wear

Figure 15 Specimen for after wear

5.Discussions

5.1Scanning electron microscopy analysis of Al7075/SiC/Gr/Zr

In order to determine the composition of the matrix, the placement of the reinforcement materials, and the dispersion of the reinforcing particles inside the matrix, it is crucial to examine the microstructures of composite materials. This will enable us to link the notable advancement in the mechanical and tribological characteristics of the microstructures of various compositions. SEM, XRD and EDS were used to study the microstructures of newly produced composite materials for the current work. According to ASTM standards, the manufactured composite sample is cut into cylindrical shape of 10 mm in diameter and 10 mm in length. A micro structural analysis of an Al7075-SiC-Gr-Zr composite sample was performed to assess its characteristics. To achieve a smooth surface finish, samples are polished with fresh emery sheets of various grades. The specimen was treated with Keller's reagent to erode the surface and reveal the microstructure. Tensile strength of the composite is significantly influenced by interfacial and strong interfacial bonds among the reinforcing particles and the metal matrix made of the aluminum alloy Al7075. Aluminium composite interface information can be seen in SEM pictures and it also demonstrates that the surfaces are continuous and devoid of voids or contaminants. The SEM examination of metal matrix composites found in the literature is covered in the section that follows. In tribological studies and surface morphology were analyzed using SEM images. The particles are equally dispersed throughout the molten Al in *Figure 16 (a)* and *(b)*, which shows SEM pictures of the produced matrix Al 7075. The average atomic number of the different states found in the metals has a significant impact on the SEM image. *Figures 16(a)* and *16(b)* indicate a fair distribution of the reinforcements in the Al 7075 composite, in accordance with Bhushan et al. findings [43].

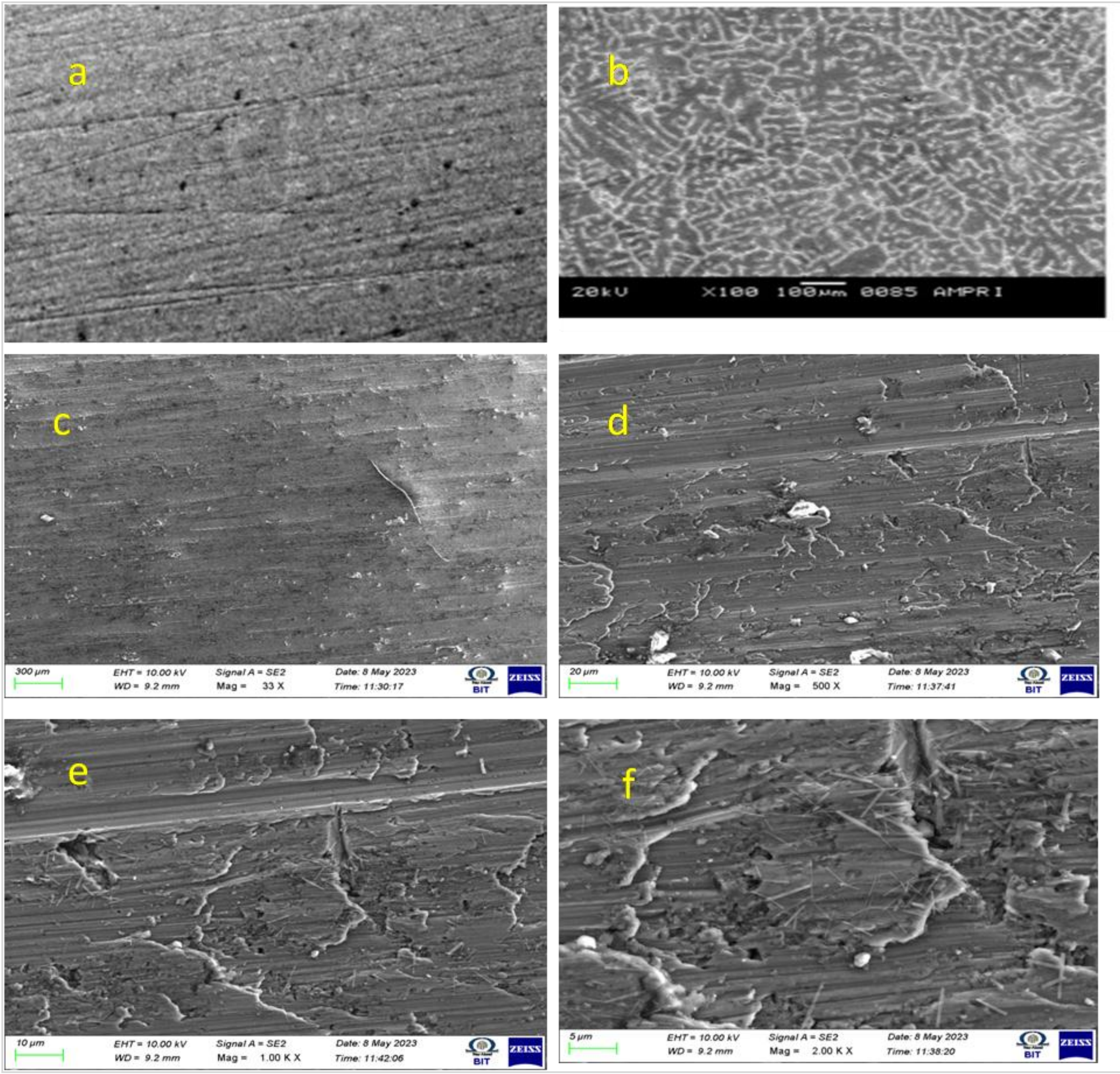

Figure 16 SEM micrograph of Al7075/SiC/Gr/Zr Composite; (a) Pure Al (b) Al7075 0 wt.% [43] (c)Al7075/11 wt.% SiC/Gr/Zr 33X (d) Al7075/11 wt.% SiC/Gr/Zr 500X (e) Al7075/11 wt.% SiC/Gr/Zr 1.0KX (f) Al7075/11 wt.% SiC/Gr/Zr 2.0KX

Figure 16 (c) and *(d)* displays nano composites captured by SEM. It demonstrates the presence of SiC, Gr, and Zr nano particles in Al7075 alloy as well as their uniform distribution and percentage variation. Consequently, improve in mechanical characteristics was noted as a result of the uniform distribution of reinforcement particles. The homogeneous distribution of SiC, Gr, and Zr nanoparticles is confirmed by *Figure 16(c)*. The varying amount of a composite of ultrasonic assisted stir casting methods determines the uniform distribution of silicon, graphene and oxide particles in the matrix. SEM pictures of the composite created using the ultrasonic assisted stir casting techniques are shown in *Figure* 16. The confirmation test-based composite materials' SEM morphology as well as their EDS was displayed in *Figure 16 and 17*. The reinforcements are dispersed equally throughout the entire sample, according to the elemental mapping image for carbon (Graphene and Silicon carbide). During the creation of the composite, the Sic, Gr, and Zr reinforcement particles are distributed over the dendritic grains of the aluminum 7075 matrix using the ultrasonic stir casting technique. The microstructure of the matrix and the distribution and agglomeration of SiC, Gr, and Zr reinforcement particulates in the grains and boundaries are examined using a SEM analysis on composite specimens using a field emission scanning electron microscope, Carl Zeiss- Sigma 300 Model. To identify the various reinforcing elements contained in the reinforced composite material, EDS analysis was carried out. It is made sure that the tougher, stiffer SiC, Gr, and Zr reinforced nanoparticles are evenly distributed throughout the aluminum 7075 matrix alloy. The reinforcing mechanism of grain boundaries can also be significantly improved as a result of the strong bonding between the most powerful reinforcement particles and matrix alloy. The matrix alloy's clustering of reinforcement is lessened by the uniform distribution. As a result, the durability of the reinforced particles in the alloy's aluminum matrix is distributed evenly throughout the composite specimens. It can improve a metal matrix composite's mechanical properties.

5.2Energy-dispersive X-ray spectroscopy analysis

The existence of the aluminum matrix, carbide (SiC and graphite), and oxide (Zr) reinforcing particles was established by XRD peaks. Major aluminum peaks can be seen in the XRD pattern of the base cast of the aluminum alloy 7075. Along with the large aluminum peaks, the hybrid composite's XRD pattern showed two other small peaks (carbide and oxide), confirming the presence of the matrix's reinforcing particle distribution. Due to the inclusion of more SiC and graphite, there is also a little shift in the peak angles of aluminum.

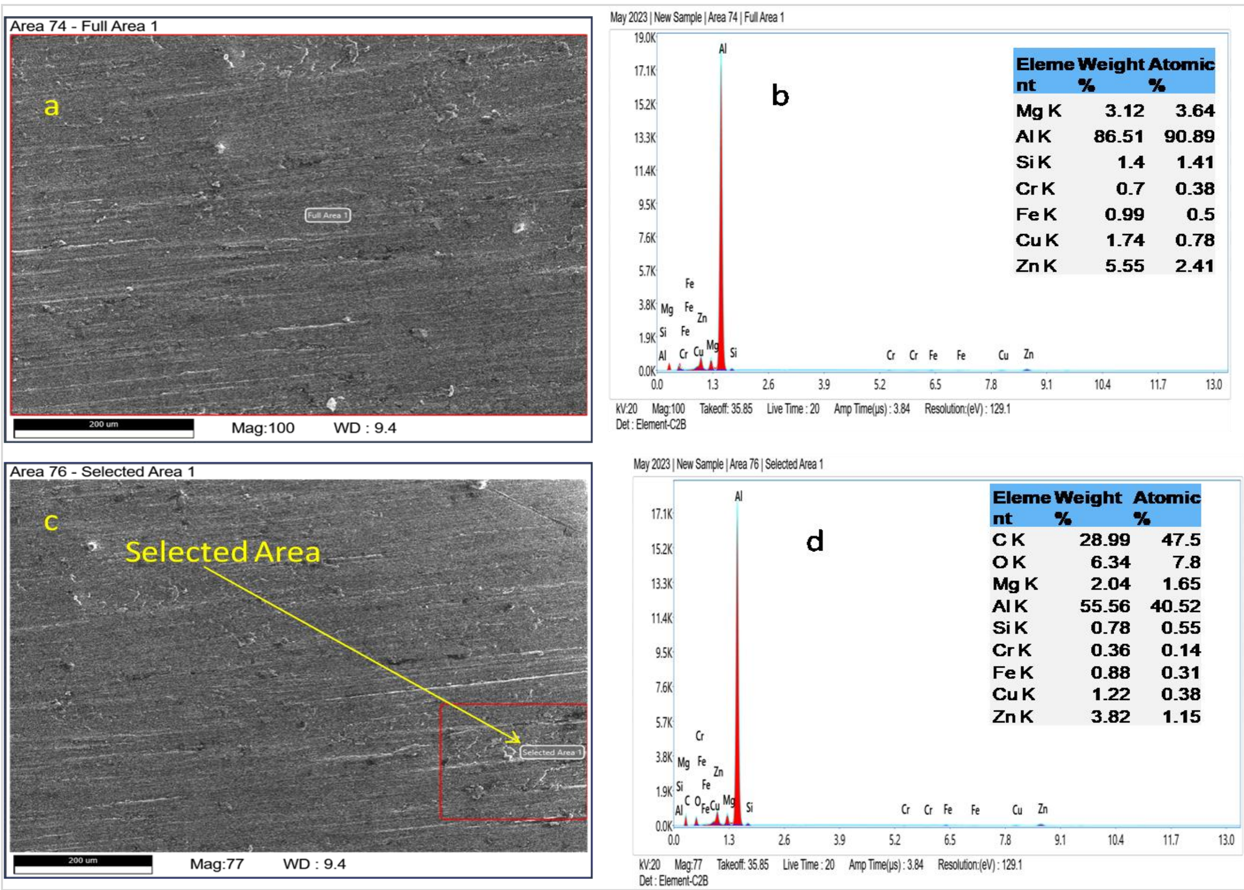

Figure 17 EDX analysis of Al7075/SiC/Gr/Zr Composite; (a) EDX analysis of full area (b) EDX spectrum of full area; (c) EDX Analysis of selected area (d) EDX spectrum of selected area

The homogeneous distribution of SiC, Gr, and Zr nanoparticles is confirmed by *Figure 17*. Each particle distribution photograph's EDS were used to examine the associated elemental analysis. An important component of Al7075 as well as SiC, Gr, and Zr nanoparticle reinforcement with elemental peak intensities are revealed by EDS spectroscopy. Additionally, it has been found that when the weight percentage of reinforced nanoparticles increases, the permeability of nanocomposites decreases, which has a significant impact on the improvement of the characteristics of composites. Ultrasonic aided stir casting is primarily responsible for the decrease of permeability and homogenous dispersion of nanoparticles. Due to the ultrasonic action, the bulk of nanoparticles are disseminated throughout the composite material. *Figure 17 (a)* and *(c)* displays the EDS analysis for full and selected area of the Al7075-silicon carbide, grapheme and zirconium made using the ultrasonic stir casting procedure. *Figure 17 (b)* and *(d)* displays the mapping analysis of the EDS images. A strong Al peak may be seen in the composite under EDS analysis. The carbide (SiC and Gr) and another moderately intense oxide (Zr) peak are the next two intensities to be noticed. The EDS in *Figure 17* shows that C, O, Mg, Al, Fe, and Zn are present. Using X-ray mapping, it was determined how the elements (C, O, Mg, Al, Si, Cr, Fe, Cu, and Zn) were distributed in the Al7075-SiC-Gr-Zr composite. The high-magnification SEM micrograph in *Figure 17(b)* and *17 (d)* makes it abundantly evident that the connection among the matrix and reinforcement is both good and clean. Through EDS examination of the Al7075-graphene composite made using the ultrasonic assisted stir casting process, it was established that the iron component was visible along with reinforcement.

The density of pure aluminium, Al7075, as well as Al7075/SiC/Zr/Gr is 2.68g/cc, 2.81g/cc and 2.77g/cc respectively. Density ofAl7075/SiC/Gr/Zr was marginally higher than pure Aluminium by 0.09 g/cc and lower than Al7075 by 0.04 g/cc respectively. Al7075/SiC/Gr/Zr density was 3.24 percent higher than pure aluminium and 1.42 percent lower than pure aluminium. pure aluminum, Al7075, and Al7075/SiC/Zr/Gr hardness values are mentioned in *Figure 6* which is 40.53HV, 91.8HV, and 119HV respectively. Hardness increased by 78.47 HV in comparison with pure Aluminium and 27.2 HV compared to Al7075. Hardness increased by 65.94% over pure aluminium and 22.85% over Al7075. The tensile strengths of pure aluminum Al7075 and Al7075/SiC/Zr/Gr are 70.67Mpa, 97.47Mpa, and 176.22Mpa, respectively. The presence of SiC/Gr/Zr reinforcements improves the tensile strength of a composite made hybrid metal matrix. When compared to pure aluminium, the tensile strength increased by 105.55 Mpa, and Al7075 increased by 78.75 Mpa. A universal testing apparatus was utilized to assess tensile strength and it increased by 59.9% when compared to pure aluminium and 44.68% when compared to Al7075. Pure aluminium, Al7075 and Al7075/SiC/Zr/Gr, respectively, have Impact strengths of 9.7J, 8.2J, and 2J. With pure aluminium, the presented reinforcement particles have lower impact strength of 7.7 J and 6.2 J with Al7075. Impact strength evaluated with a charpy impact tester tends to decrease by 79% with pure aluminium and 75% with Al7075. *Figure 10* illustrate results the specimen of impact.

Table 5 Comparison values of materials

Material/property	Pure aluminium	Al7075	Al7075/SiC/Gr/Zr
Density (g/cc)	2.68	2.81	2.77
Hardness (HV)	40.53	91.8	119
Tensile strength (Mpa)	70.67	97.47	176.22
Impact strength (J)	9.70	8.2	7.6
Yield strength (Mpa)	50.25	120	143.33
Elongation (%)	27.8	10.5	7.8
Abrasion wear (g)	0.0942	0.0712	0.0597

The yield strengths of pure aluminium, Al7075 and Al7075/SiC/Zr/Gr are 50.25Mpa, 120Mpa, and 143.33Mpa, respectively. Hybrid metal matrix composite yield strength is compared to pure aluminium and Al7075. The yield strength of the composite is 93.08 Mpa when compared to pure aluminium and 23.33 Mpa when Al7075 is used. The composite's yield strength is increased by 64.94% when compared to pure aluminium and 16.27% when combined with Al7075. *Figure 12* makes it clear that pure aluminium, Al7075 and Al7075/SiC/Zr/Gr, respectively have elongation of 27.8%, 10.5%, and 7.8%. In SiC/Gr/Zr reinforcements the adding of SiC lowers the composite material ductility. The hybrid metal matrix composite has a lower elongation of 71.94 percent when compared to pure aluminium and 25 percent when compared to Al7075.

Abrasive wear are 0.0942g, 0.0712g, and 0.0597g for pure aluminium, Al7075 and Al7075/SiC/Zr/Gr, respectively. It is evident from *Figure 13* so as to the wear rate lowers since the quantity of reinforcing particles rises. Hybrid matrix composite shows less abrasive wear than pure aluminium and Al7075. The wear rate of composite made hybrid metal matrix is reduced by 36.62% when compared to pure aluminium and 16.15% in Al7075. Comparison values of various materials are given in the *Table 5.*

5.3Limitations of study

The main limitation of this study is that it does not use the squeeze casting method. The near-net-shaped product can be obtained because the molten metal solidifies under the high pressure of the squeezing process. Casting defects such as shrinkage and porosity are not present in the finished casting products. The ultrasonic aided stir casting technique was employed in this investigation. Researchers may also make use of these coupled processes, which have a substantial impact on the mechanical 673luminiu of composite materials.

A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion and future work

The main findings of this research on density, hardness, tensile strength, % elongation, abrasive wear 673luminiu, impact strength, and yield strength of hybrid metal matrix composites are summarized in this section. Al7075/SiC/Gr/Zr had a density that was 3.24% higher than pure aluminium and 1.42% lower than Al7075. The hardness increased by 65.94% when compared to pure aluminium and 22.85% when compared to Al7075. A universal testing apparatus has been used to assess tensile strength and it increased by 59.9% when compared to pure aluminium and 44.68% when compared to Al7075. Impact strength is reduced by 79% with pure aluminium and 75% with Al7075 when tested with a charpy impact tester. When compared to pure aluminium, the composite's yield strength is increased by 64.94%, and with Al7075, it is increased by 16.27%. The hybrid metal matrix composite had a lower percentage elongation than pure aluminium and Al7075. SiC reduces the ductility of SiC/Gr/Zr reinforcements. The elongation of the hybrid metal matrix composite is 71.94% less than that of pure aluminium and 25% less than that of Al7075. The hybrid metal matrix composite shows less abrasive wear than pure aluminium and Al7075. The wear pace of the composite metal matrix is 36.62% lesser than that of pure aluminium and 16.15% lower than that of Al7075. SEM micrographs demonstrated the homogeneous dispersion of SiC, Gr, and Zr reinforced particles in the base aluminum matrix. In future, researchers can try to improve the Impact strength and Elongation with other properties by varying the composition percentage and change in reinforcements.

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None.

Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contributions statement

S.Raja:Conceptualization, dataset creation, implementation, writing-original draft, reviewing and editing. Dataset augmentation, conceptualization, draft manuscript preparation and identification of challenges.
V.Anbumalar: Analysis and interpretation of results, reviewing and editing, Design and data analysis, manuscript preparation.

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Appendix I

S. No.	Abbreviation	Description
1	Al / AA	Aluminium
2	ASTM	American Society for Testing and Materials
3	B_4C	Boron Carbide
4	C	Carbide
5	Cr	Chromium
6	Cu	Copper
7	EDS	Energy-Dispersive X-ray Spectroscopy
8	Fe	Iron
9	Gr	Graphite
10	h-BN	Hexagonal Boron Nitrate
11	LPM	Litre Per Minutes
12	Mg	Magnesium
13	O	Oxide
14	SEM	Scanning Electron Microscopy
15	Si	Silicon
16	SiC	Silicon Carbide
17	TiC	Titanium Carbide
18	XRD	X-ray Diffraction
19	Zn	Zinc
20	Zr	Zirconium