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Research Article

Influence of Future Material Nano-ZrO_2 and Graphene on the Mechanical Properties of Al Composites

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Recent developments in mechanical applications have led to the development of metal matrix composites, which represent the future of composite structures. Al7010 aluminium alloy matrix with nano-ZrO_2 and graphene particle reinforced composite is created in this experiment. By adopting the stir casting procedure in two different casting, 2 percent reinforcement of zirconium dioxide and 1 percent of graphene is included in the composite materials. The composite's metallurgical and mechanical characteristics are studied. The SEM image demonstrates uniform dispersion of the particles in the alloy matrix. The manufactured material's ability to gather particulate matter is clearly found in SEM and EDS. The addition of zirconia particles works together to prevent the alloy matrix from dislocating, which increases the base material's hardness as well as its tensile resistance. Similar results are also found in graphene-casting material. Results from tensile tests reveal that adding nano-zirconium dioxide particle (ZrO_2) and graphene boosts the material's tensile and hardness strength. In terms of the ultimate tensile strength (UTS), the Al7010/2% ZrO_2 composite had a 6% increase and Al7010/1% graphene had a 5.5% increase above the Al7010 alloy. Compared to Al7010 alloy, the microhardness of Al7010/ZrO_2 is 17.64% greater and Al7010/1% graphene is 14% greater.

1. Introduction

High-strength, lightweight, and low-cost metal matrix composites are becoming more common in the industry [1]. Aluminium alloys are often used in aircraft and automobiles due to their outstanding strength-to-weight ratio and corrosion resistance. The metal matrix composite (MMC) made from aluminium alloys may be improved by using the right reinforcements [2]. The commercially available 7010 grade aluminium alloy is one of the most widely used general-purpose materials. The chemical composition of the Al7010 alloy is shown in Table 1.

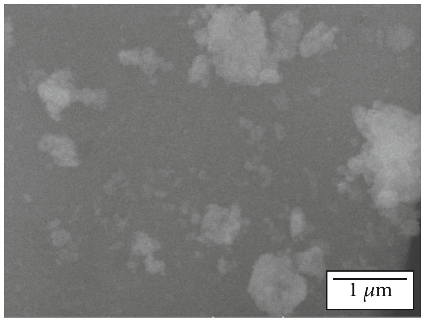
Because of its outstanding mechanical and corrosion resistance, it is widely used in a wide range of industries. This precipitate-hardening aluminium alloy has outstanding weld ability [3]. The most difficult aspect of implementing MMC components has been manufacturing them; nevertheless, mass production techniques using several heat treatments are becoming increasingly realistic. As this technology improves, a greater number of aircraft engines will be able to employ these lighter, more durable components [4]. When compared to an engine made of standard nickel-based superalloys, a jet engine using MMC components has been demonstrated to save between 10% and 15% in fuel. This fuel savings not only saves corporations money but also reduces air travel's severe carbon imprint, making MMCs both economically and ecologically viable. Aircraft now account for roughly 11% of all carbon dioxide emissions in the United States, with estimates that this will quadruple by the midcentury [5]. The immediate advantages of using MMC in aviation engines are evident, but examining the less obvious outcomes is also important. Currently, there are few possibilities for recycling MMCs, but future research may change that. The introduction of MMCs into the aviation sector is a hopeful step toward a more

Table 1: Chemical composition of the Al7010 alloy.

Element	Content (%)
Aluminium, Al	87.8–90.6
Zinc, Zn	5.70–6.70
Magnesium, Mg	2.10–2.60
Copper, Cu	1.50–2.0
Iron, Fe	0.15
Zirconium, Zr	0.10–0.16
Silicon, Si	0.12
Manganese, Mn	0.1
Titanium, Ti	0.06
Chromium, Cr	0.05
Nickel, Ni	0.05
Other, total	0.15

environmentally friendly future. Hard ceramic particles such as SiC, TiB_2, ZrO_2, Gr, TiC, B_4C, and others are used to reinforce the characteristics of the traditional base metal. These ceramic particles may range in size from micro to nano [6]. The inclusion of microsize reinforcing particles, on the other hand, reduces AMMC ductility and fracture toughness [7]. The use of nanosized particles in aluminium metal matrix composites improves fracture toughness and ductility [8]. Madeva Nagaral et al. examined the mechanical and wear characteristics of ultrasonic cavitation stir cast aluminium-boron carbide nanocomposites [9] . Increases in B_4C nanoparticles boosted hardness and tensile strength, as well as wear resistance, as compared to the base alloy. The addition of nanosized B_4C and BN to an aluminium alloy made by ultrasonic aided stir casting raised the tensile strength by 67%. According to Gurushantha et al., the fracture toughness and hardness of Al 2024/Gr composites declined as the Gr wt. % in the composites increased [10]. Rashad Muhammad et al. documented the mechanical and wear characteristics of metal matrix composites [11]. The zircon particles are evenly distributed throughout the aluminium matrix. The mechanical characteristics of aluminium-zircon composites are excellent, including ultimate tensile strength, compression strength, and impact strength. As the proportion of zircon rises, these characteristics improve. The wear resistance of the aluminium-zircon composite is excellent. The hardness qualities of the aluminium-zircon composite are excellent. To optimise the wear processing parameters, the Taguchi approach may be applied. Abdizadeh et al. stated that the researchers looked at how powder metallurgy may enhance the physical and mechanical characteristics of Al/Zircon composites [12]. In powder metallurgy settings, the microstructures of these composites revealed distinct size distributions of zircon when present in varying quantities in the composite. Green specimens were sintered at two temperatures of 600° and 650°C after being created by the isostatic pressing of prepared powders with varying zircon percentages. These samples were then subjected to a variety of physical and mechanical tests to determine which circumstances yielded the best results. The sample with 5% zircon sintered at 650°C had the best pressure quality. With a high unequivocal surface zone and a high Young's modulus, graphene possesses extraordinary characteristics. Because of its good thermal conductivity, graphene is a good rival for Al matrices when it comes to redesigning thermal conductivity. When compared to other reinforcement particles' interfacial exposure areas, graphene particulates' expansion into the Al alloy matrix affects the composite's tribological as well as mechanical behaviour [13–16]. Stir casting procedures are one of the most extensively utilized manufacturing processes for aluminium-based composites, according to the literature. Reinforcement may be disseminated evenly in the alloy matrix and creates superior strength by maintaining the stirring speed and duration. The inclusion of an unequal amount of reinforcements, such as silicon carbide or graphite, increases hardness while decreasing ductility. It was also noted that research on zirconium dioxide-based composites was restricted and that the potential of such composites had yet to be discovered. The inclusion of ceramic particles such as zirconium dioxide into this grade of aluminium alloy enhances stiffness and corrosion resistance while also lowering weight. The decreased thermal expansion also increases the material's dimensional stability, making it suited for high-precision applications. To improve material behaviour, the potential of zirconium dioxide and particle reinforced metal matrix composites must be investigated. The behaviour of a zirconium dioxide particle reinforced aluminium alloy metal matrix composite was investigated in this study employing stir casting techniques. Friction stir casting, powder metallurgy, mechanical alloying, stir casting, and squeeze casting are some of the procedures used to make metal matrix nanocomposites (MMNCs) [17–21].

Metal matrix composites that are high-strength, light-weight, and inexpensive are becoming increasingly popular in the market. Due to its exceptional strength-to-weight ratio and resistance to corrosion, aluminium alloys are often employed in vehicles and aeroplanes. By employing the appropriate reinforcements, such as ZrO2 and graphene, the metal matrix composite (MMC) manufactured of aluminium alloys may be enhanced. Metal matrix composites that are high-strength, light-weight, and inexpensive are becoming increasingly popular in the market. Due to its exceptional strength-to-weight ratio and resistance to corrosion, aluminium alloys are often employed in vehicles and aeroplanes. By employing the appropriate reinforcements, such as ZrO2 and graphene, the metal matrix composite (MMC) manufactured of aluminium alloys may be enhanced. The approach introduced warmed reinforcing particles into a vortex of molten alloy generated by a revolving impeller; because of the density difference between matrix and reinforcement during the melting and casting processes, the procedure resulted in microstructural inhomogeneities, particle agglomeration, and sedimentation. Casting by mechanical stirring, ceramic reinforcing particles are incorporated into the matrix alloy. This technique combines the advantages of both liquid and solid ceramic production. The uniform dispersion of reinforcement particles is made possible by the matrix phase's high viscosity. There is a stronger influence on the distribution of reinforcement and mechanical characteristics, as well as porosity if the right



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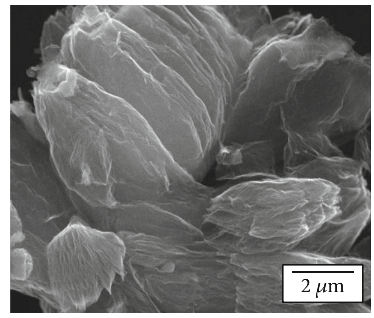


(b)

Figure 1: SEM images of (a) ZrO_2 and (b) graphene.

parameters are used. The combination of zirconium and graphene with Al7070 is not attempted by previous researchers. Based on literature survey, the proposed combination of material will deliver enhancement in the strength and wear resistance because of the hard particle and lubricant property. A stir casting procedure is used in this study to produce Al7070, ZrO_2, and graphene composite, as well as to study the microstructure and mechanical properties of Al7010 alloy reinforced with ZrO_2 ceramic and graphene reinforcements.

2. Materials and Methods

Because of its broad range of applications in the automotive and avionics sectors, Al7010 was chosen as the matrix material. As reinforcements, ZrO_2 particles (2 wt. %) and graphene (1 wt. %) were employed in three distinct casting methods: (1) Al7010 in its pure form, (2) Al7010 with ZrO_2 particles weighing 2%, and (3) for composites, Al7010 with 1% graphene particles.

Fenfee Metallurgical Private Limited in Bengaluru, Karnataka, India, provided the Al7010 composite billets. BT Corp, Hoskote, Bangalore, Karnataka, India, provided the graphene. Minco metal in Bangalore, Karnataka, India, was used to get ZrO_2. Al7010 is used as the matrix material with nanosize (100 nm) ZrO_2 and graphene is used as a reinforcement material. The SEM images of the particles are shown in Figure 1. Initially, the Al7010 was preheated at 450°C in a muffle furnace to remove the surface oxides. The furnace temperature was raised above the liquid temperature of aluminium alloy (750°C) to melt the aluminium alloy completely. Figure 2 shows that the molten metal is stirred in the furnace. The proper stirring produced the best mixing results in a uniform microstructure compared to a conventional stirring. Preheating of the moulds was performed at 250–350°C before pouring the melt. After the removal of slag, the composite melt was transferred to the preheated mould.

The MMC manufacturing process metal matrix composite samples were manufactured utilizing the stir casting procedure in this investigation. The metal matrix was a 7010-grade aluminium alloy, with zirconium dioxide and graphene particles as reinforcement. Samples were made using a reinforcement ratio of 2 wt. %, respectively. Later, two distinct castings of 2 wt. % zirconium dioxide and 1 wt. % graphene particles were introduced to molten aluminium alloy.

Figure 2: Molten metal is stirred in the furnace.

To achieve a homogeneous dispersion of particles, the semiliquid mixture was agitated for around 10 minutes at a 450 rpm constant speed. After that, the semi-liquid mixture was put into a cylindrical casting mould.

3. Results and Discussion

The SEM is used to check for correct reinforcing particle distribution. The SEM of Al 7010 alloy, ZrO_2, and graphene is shown in Figure 2. The consistent homogeneous circulation of ZrO_2 and graphene particles in the Al 7010 alloy may be seen using SEM. It is also clear that there is a strong interfacial interaction between ZrO_2 and graphene and Al7010 alloy, which enhances the alloy's characteristics even more. Al7010's 2 wt. % ZrO_2 and 1 wt. % graphene composites demonstrate Al7010 castability in conjunction with aesthetic fortifications [15].

The EDS allows experts to see what those specific components and quantities are. EDS is one of the most amazing and beneficial sorts of elemental research. The EDS investigation of Al7010 alloy combinations, as well as Al7010-ZrO_2 and graphene, is shown graphically. The EDS spectrograph of Al7010 aluminium amalgam is shown in Figure 3. EDS examinations of Al7010 2 wt % ZrO_2 and 1 wt% graphene composites in the range are shown in Figures 4(a)–4(c) demonstrating the presence of Z and C inside the aluminium alloy Al7010.

3.1. SEM Micrograph. Scanning electron microscope was utilized to inspect the internal structure of the composite and spreading of the reinforcement particles in the produced MMC. The illustrations were refined by means of numerous results of emery sheets reaching from 220 to 1200 grid size

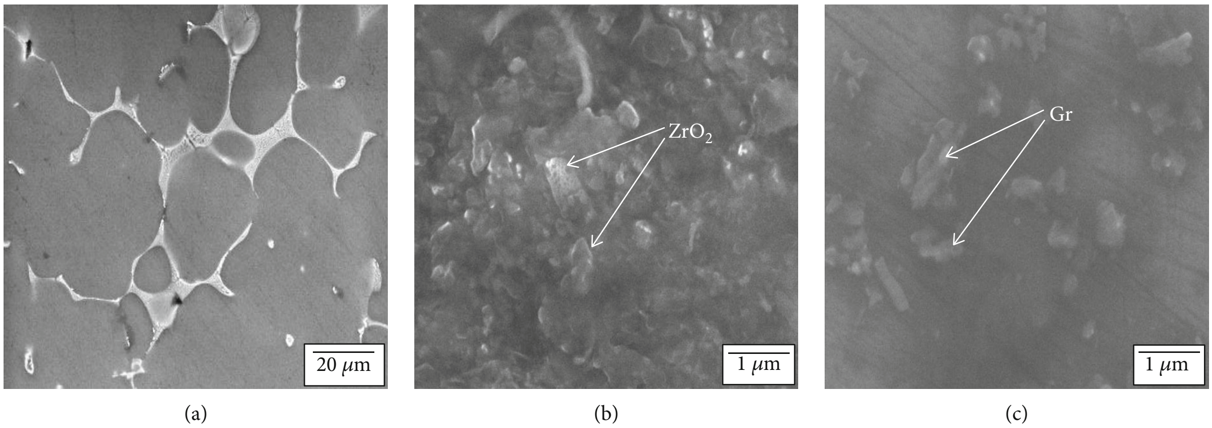


Figure 3: SEM images of (a) Al7010, (b) Al7010 + 2% ZrO_2, and (c) Al7010 + 1% Gr.

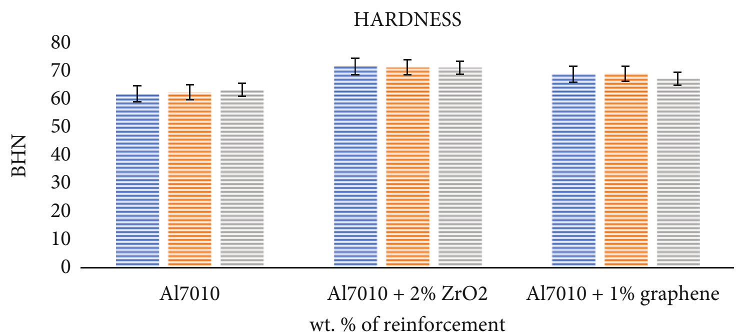


Figure 4: Hardness of Al7010, Al7010 + 2% ZrO_2, and Al7010 + 1% Gr.

and then elegant through an alumina answer to realize a mirror excellence. Keller's agent is used to etch the practiced samples according to conventional methods [16].

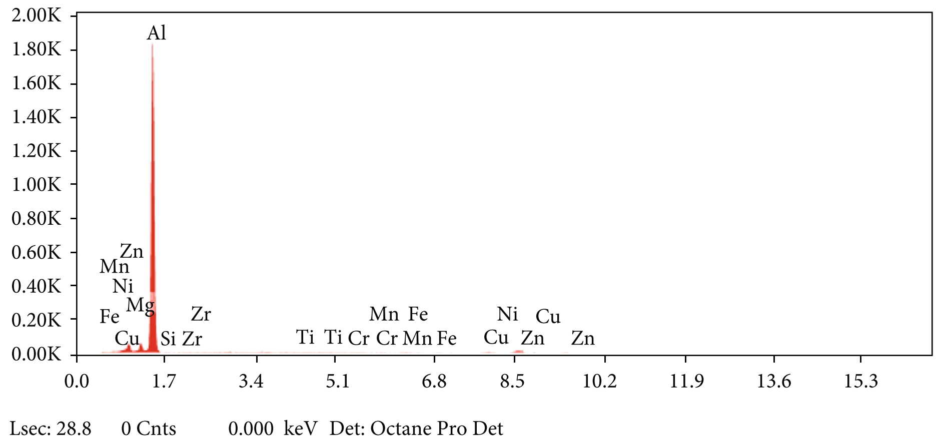
Figure 3 shows a scanning electron micrograph of all of the samples. In the 7010 alloy with reinforcement, it demonstrates homogeneous dispersion of ZrO_2 and graphene particles, respectively. The amount of particle aggregation has significantly decreased. It ensures that appropriate stirring was used during MMC manufacturing as cast material has consistent strength due to the random orientation of particles.

3.2. EDS. Figure 5 shows the EDS patterns of base Al7010, Al7010 + 2%ZrO_2, and Al7010 + 1% graphene nanocomposites (a–c). The presence of matrix, ZrO_2, and graphene phases is seen in the result. The intensity diffraction peaks of aluminium in aluminium nanocomposites are high owing to the large quantity of matrix material, but the intensity diffraction peaks of ZrO_2 and graphene nanoparticles are low due to their presence being less than the matrix material. Furthermore, the intensity peaks of aluminium are steadily diminishing as the number of particles reinforced increases. The nanoparticles were found to be evenly dispersed throughout the Al matrix.

3.3. Hardness. The hardness of manufactured MMC with reinforcing weight percentage was measured. Because MMC is made up of a soft matrix alloy and a hard ceramic reinforcement, the position of the hardness measurement is critical. On pure matrix alloy or reinforcement agglomeration zones, measurement should be avoided. The hardness test was carried out according to the ASTM E10 standards using a 10 mm steel ball indenter of 500 Kgf load for a dwell time of 10 seconds. Hardness measurements were made at different locations throughout the material, and the mean results are displayed in Figure 5 with an error bar. It has been observed that as reinforcement increases, hardness improves. MMC's hardness is increased by the inclusion of ZrO2 and graphene particles.

The Brinell hardness number of the sample with 2% ZrO_2 and 1% Gr inclusion is high, as shown in Figure 4, and the values have been shown to rise owing to the addition of particles in the composites. Changes in BHN values from one level to the next are compared and depicted in Figure 4 to analyse the influence of ZrO_2 and graphene inclusion in weight percentage. In contrast, there has been a significant improvement in the microhardness value. The average hardness value for ZrO_2 and graphene is 74.66 BHN and 72.36 BHN. As a result of the inclusion of ZrO_2 particles, the resistance behaviour of the Al7010/ZrO_2 composites to indentation has been dramatically improved.

3.4. Ultimate Tensile Strength and Yield Strength. The mechanical strength of produced MMC samples, including yield and ultimate tensile strength, was determined using the ASTM-E8 tensile test. Figure 4 depicts the major role



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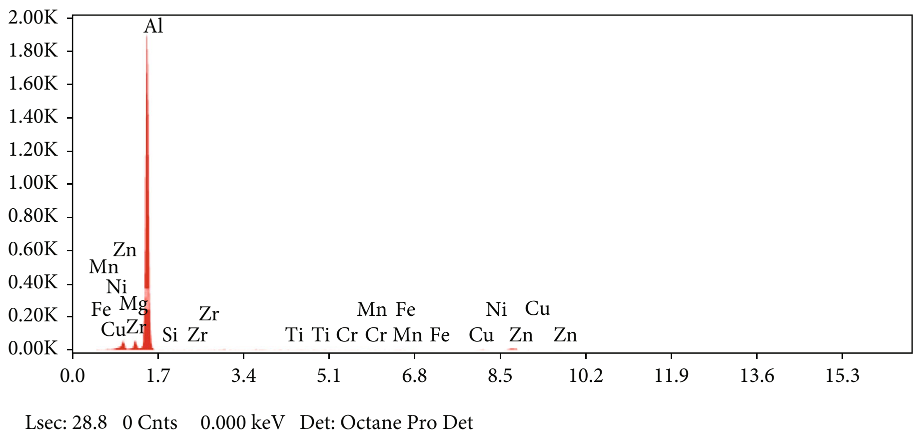

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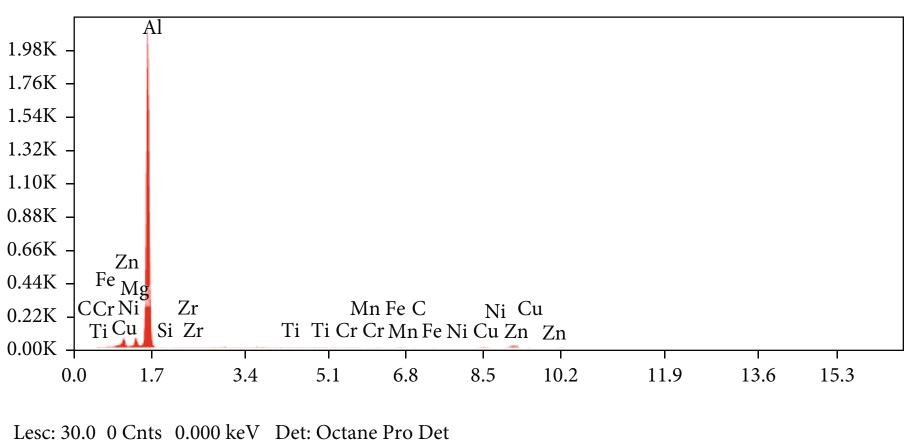

(c)

FIGURE 5: EDS images of (a) Al7010, (b) Al7010 + 2%, ZrO_2, and (c) Al7010 + 1% Gr.

of reinforcement in the MMC, the experimental results of the basic metal, and the alloy with 2% reinforcement, respectively. It has been shown that as the reinforcement of MMC increases, so does the variance in load-bearing capability. The maximum breaking load of MMC is increased by lowering the reinforcing weight %. With more reinforcement, MMC's maximum displacement and breaking load-displacement decrease. Because of the reinforcement, it loses strength quickly during plastic deformation. The effect of graphene and ZrO_2 nanoparticles on the ultimate and yield strength of Al7010 alloy is shown in Figures 6 and 7, respectively.

The inclusion of nanographene and ZrO_2 particles to the Al7010 alloy increased its tensile strength. Al7010 alloy has ultimate and yield strengths of 215.1 and 178.5 MPa, respectively. The presence of nanographene and ZrO_2 dual particles leads to the basic Al7010 alloy's increased strength [17]. The specimens with 2 percent ZrO_2 inclusions showed

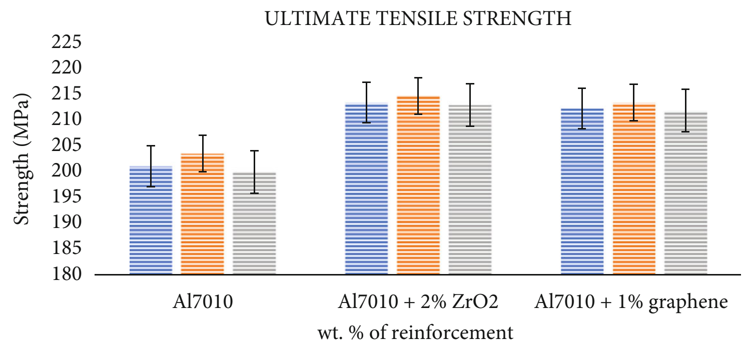

Figure 6: Ultimate tensile strength of Al7010, Al7010 + 2% ZrO_2, and Al7010 + 1% Gr.

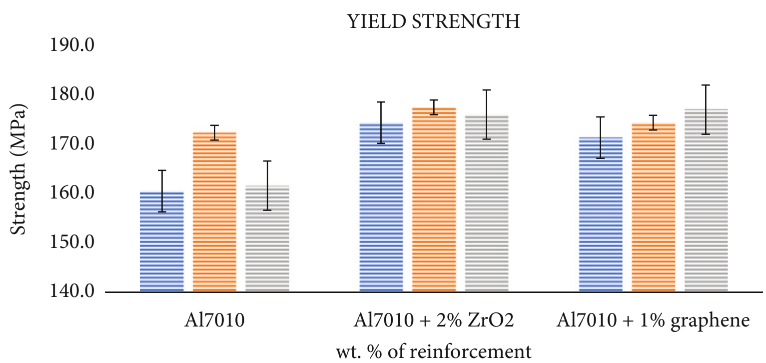

Figure 7: Yield strength of Al7010, Al7010 + 2% ZrO_2, and Al7010 + 1% Gr.

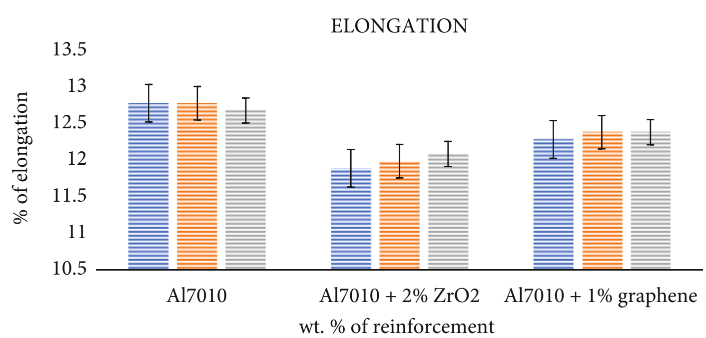

Figure 8: Percentage of elongation of Al7010, Al7010 + 2% ZrO_2, and Al7010 + 1% Gr.

a larger improvement in tensile strength. The average tensile strength for ZrO_2 and graphene is 214.06 MPa and 212.86 MPa. When comparing the ZrO_2 and graphene inclusion specimens, it was shown that graphene has a lower rise in tensile strength due to its solid lubrication, followed by a fall in strength, and the strength at reduced.

3.5. Percentage of Elongation. Figure 8 depicts the influence of nanographene and ZrO_2 particles on the ductility of the Al7010 alloy [22]. The Al7010 alloy's ductility was reduced due to the combined influence of nanographene and ZrO_2 particles. In most cases, graphene particles increase the elongation of the Al matrix; however, in this study, graphene and ZrO_2 composites had lower ductility than the base. The inclusion of hard nano-ZrO_2 particles causes the ductility to be reduced. These ZrO_2 particles outnumber the base Al7010 particles, resulting in a reduction in elongation [17]. These particles function as a limit on the Al7010 alloy matrix's deformation.

4. Conclusion

The following conclusions may be derived based on synthesis and material characterization:

(i) ZrO_2 and graphene particle reinforced aluminium alloy MMC were made in various ratios. The reinforcement is spread evenly within the alloy matrix, according to SEM micrographs. Particle agglomeration in the matrix alloy is minimized by swirling for a long time

(ii) According to hardness testing, the introduction of ceramic particles increases the hardness by 62.8 BHN to 72.6 BHN in reinforcing content. This is because the ceramic particles limited the matrix alloy's dislocation, resulting in improved hardness

(iii) The addition of zirconium dioxide particle reinforcement raises tensile strength from 200.2 MPa to 215.1 MPa, improving the strength

(iv) The prepared material can be used in brake pad application in motorcycles because of its improved strength and hardness

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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