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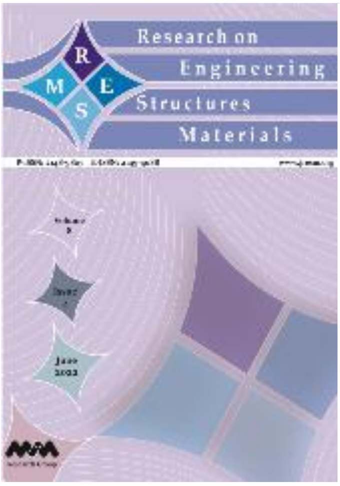

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Research Article

Effect of addition of TiC nanoparticles on the tensile strength of Al7075-graphene hybrid composites

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Abstract

In the current work, the effect of the addition of titanium carbide and graphene nanoparticles on the tensile strength of the aluminum 7075 matrix composites is investigated. The preparation of the mentioned composites is made using a novel ultrasonic stir casting process. The reinforcements used are 0.25wt% graphene nanoparticles and 0.5wt% to 2.5wt% of titanium carbide nanoparticles. Ultrasonic stir casting techniques are used to enhance the wettability of TiC and graphene nanoparticles. To quantify the microstructure of the prepared composites, SEM and EDS are used. An experimental investigation has been carried out to determine the influence of the addition of TiC and graphene nanoparticles on the tensile strength of the mentioned composite. From the SEM analysis, it is observed that the prepared composites have a uniform distribution of the reinforcements and the EDS analysis confirms the existence of reinforcing elements in the Al7075-TiC/Graphene composites. Experimental results show that the addition of TiC and graphene enhances the hardness and tensile strength. This enhancement is lost with the ductility of the Al7075-TiC/Graphene composites. The fractographic samples of the Al7075- TiC/graphene composites shows cracks in the vicinity of the matrix and reinforcements and also show a brittle fracture.

1. Introduction

The limitations of traditional monolithic materials in terms of achieving good strength, toughness, hardness, density, and strength to weight ratio, etc., recent years have seen an exponential increase in the need for low-cost, high performance materials. This has led to the development of new advanced materials. A composite material is one that is made up of two or more separate materials, each of which has its own unique set of physical and chemical properties. Metal matrix composite is a material constituting of metallic matrix combined with reinforcements. The most used matrix material is aluminium, magnesium, copper, zinc, titanium. The most commonly used reinforcements are SiC, alumina, boron, graphite and fly ash [1,2] .

One of the matrix materials which is commonly used in aerospace and aircraft applications is the reinforced aluminum matrix. Aluminum has a high strength [3] when it is chosen as low-density matrix and the main reinforcements used for improving mechanical properties are the ceramics like SiC, Al2O3, TiC, and Boron carbide. Limitations in terms of mechanical properties, working difficulties of B4C particles reinforced composites which is currently ruled in industrial applications can be significantly addressed by using aluminum as a matrix [4].

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The various processing methods of composites are stir casting, powder metallurgy, spray forming, liquid infiltration, ball milling, diffusion bonding, and soon. But the most commonly used process is stir casting & powder metallurgy due to their cost effectiveness as compared to other techniques [5] . In the present work, the ultrasonic liquid stir casting technique has been used owing to its simplicity, cost-effectiveness & complex structures can be easily developed [6–8] . Addition of B4C was done in stages preferably two (or more) to get uniform distribution of the alloy [9,10] . In the said process aluminium was heated to above melting point temperature to soften it, and the melt was stirred continuously for an appropriate time period with simultaneous addition of reinforcement in stages. The prepared specimens were examined for their microstructure using a SEM, an X-ray diffractometer (XRD), tensile tests using a UTM to determine the material behaviour, as well as hardness and wear tests. The Density of the amalgamate is also investigated & compared with the base matrix alloy [11,12] . Many researchers used nanoparticles as reinforcements in the aluminum matrix and found enhanced mechanical properties in comparison with the unreinforced and single-reinforced aluminum alloy composites [13,14].

Al7075 alloys are widely used for applications where it requires withstanding high temperatures, high hardness, and strength. The main reinforcing elements in the Al7075 are Si, Mg, Zn, and Fe. The nanoparticles of alumina [15,16] , graphene [17] , TiC [18–20] , SiC [21] , and also in combinations of many reinforcements are introduced in the Al7075 matrix to produce the hybrid composites. Various other composites were prepared using the nano-particle reinforcements are nano-MWCNT [22] , B4C-Al2O3 [23] , B4C-SiC [24], TiC-SiC [25,26], and graphene-Beryl [27] . Researchers also used the nano B4C particles in Al7075 matrix and concluded that addition of reinforcement increase the strength of composites with little increases in weight, in contrast with the monolithic aluminum, and with loss of ductility [28–30].

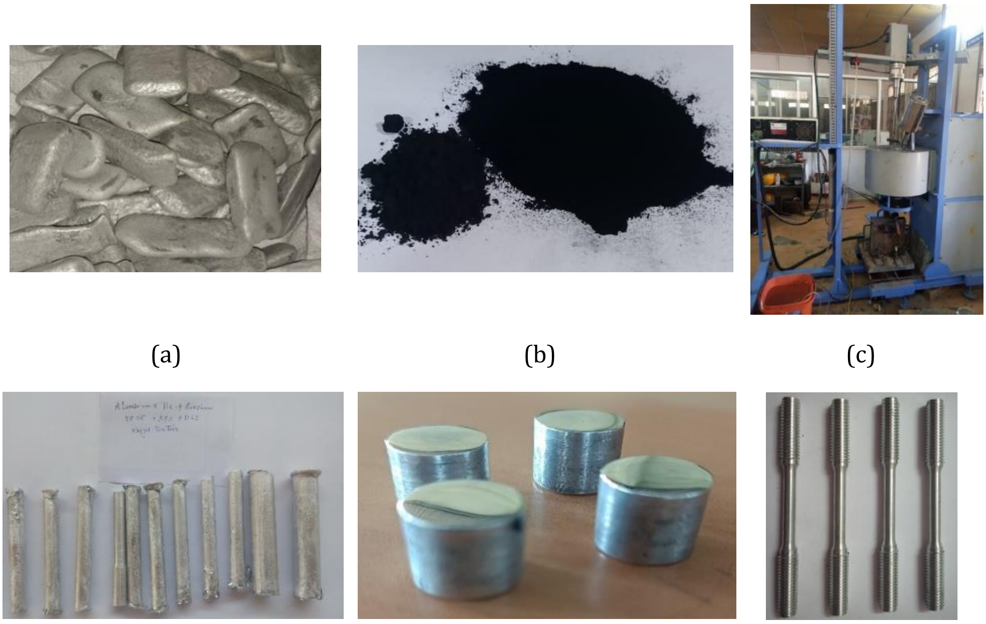
The mechanical behavior of aluminium matrix augmented with different nano-particulate composites has received a lot of attention in the scientific literature. This context opens up opportunities for research into the mechanical properties of hybrid aluminium composites reinforced with TiC and graphene nanoparticles. This study aims to determine how incorporating TiC and graphene nanoparticles into Al7075-TiC/graphene hybrid composites changes their microstructure and tensile behaviour.

2. Materials and Preparations

2.1. Materials

The Al7075 (aluminium alloy) is used as a matrix in this study, and TiC and graphene nano-particles (Fig.1(a-b)) are used as reinforcements to reinforce the structure. The fundamental reason for using these materials is that their densities are practically the same, for example, Al7075 having density of 2.81g/cc and graphene having density of 2.267g/cc. As a result, if the composite is manufactured using the liquid metallurgical method, the dispersion of reinforcements in the matrix will become nearly homogeneous. Aside from that, pure Al7075 has unusually low tensile and yield strengths, with a tensile strength of 80-130MPa and the yield strength measuring 60 MPa, respectively. Ceramics such as TiC and graphene, in particular, are used in high-temperature applications because their melting temperatures are higher than those of other ceramics. Graphene has a melting point of 4250 °C, while SiC has a melting point of 3100 °C. As a result, developing hybrid composites with titanium carbide (TiC) and graphene increases their hardness and tensile strength while reducing their elongation. They are also employed in situations where high temperature resistance is required.

It is the reinforcement's particle size that is most important in determining the material characteristics of the composites. The reinforcement's particle size will have a considerable impact on the microstructure of the composites, among a variety of other aspects. The particle sizes of the reinforcements that were used in this experiment are as follows: TiC has a diameter of 50 nm and graphene has a thickness of 5-10 nm. It is preferred to manufacture the mentioned composite utilizing the liquid metallurgical approach, like the ultrasonic stir casting method (Fig.1(c)) , because it has numerous advantages, like being more cost- effective and simpler to use, as well as ensuring equal dispersion of the reinforcements throughout the matrix.



(a) (b) (c)

(d) (e) (f)

Fig. 1 (a) Al7075 blocks; (b) TiC and Graphene particles; (c) Ultrasonic stir casting setup used in the fabrication of MMC; (d) Casted composites; (e) Hardness and (f) Tensile specimens

2.2. Processing

The graphite crucible was charged with Al7075 and heated to 800°C. The temperature was kept near around 800°C for an hour and to decrease the amount of gas in the aluminium melt, a C_2Cl_6 degassing tablet was employed. Mg particles with a larger grain size were used as a flux to improve the wettability of reinforcements when stirring molten liquid. The nanoparticles were dispersed into the liquid using an adaptation of the double stir casting technique.

The liquid metal pool was introduced to and agitated with, preheated titanium carbide (TiC) and graphene nano-particles at vertex formation speed at 370 to 420 rpm for 30 minutes at 450°C to ensure compatibility with the liquid metal and to avoid organic contaminants and moisture.

In terms of two equal steps, this process will be continued for 20 minutes. A 10-minute stirring period preceded the creation of a semisolid state in between each stage. Adding nanoparticles automatically increased the viscosity of the melt of the aluminum alloy. The flow ability of nanoparticles in a liquid substance was improved to reduce viscosity, and a higher melting temperature of 800^{o}C was maintained inside the crucible to assure the effectiveness of the sonication process. After that, an ultrasonic cavitation process was used for 10 minutes using the probe made of titanium alloy, which is high-temperature resistant. The liquid metal was stirred by a mechanical stirrer for five minutes after the sonication procedure to disperse the blasted clusters and agglomerations. An ultrasonicator with a frequency of 18 to 25 kHz has been used to avoid amalgamation of nanoparticles in casting, and vibrating waves generated by the ultrasonicator will help in uniform distribution of hybrid nanoparticles. The liquid metal was stirred by a mechanical stirrer for five minutes after the sonication procedure to disperse the blasted clusters and agglomerations. The molten liquid was then immediately poured into a graphite mold that had been preheated to 500°C and let to cool naturally at room temperature for 24 hours. The cylindrical work pieces (Fig.1 (d)) were taken out of the mold after they had solidified and machined as per ASTM standards for various tests (Fig.1 (e-f)). Similarly, the processing of aluminum matrix hybrid composites with various wt.% of nano-TiC, including 0.5 to 2.5wt%, and nano-graphene, 0.25wt%, were made. The tensile and micro hardness test specimens were prepared in accordance with ASTM standards.

3. Experimentation

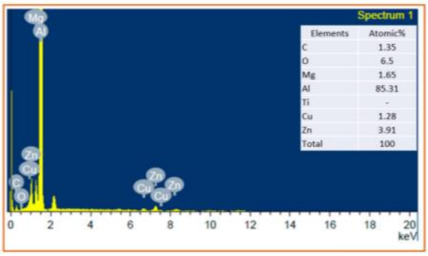
Universal testing equipment was used for tensile tests as per ASTM E8, and the Micro Vickers hardness machine for hardness tests as per ASTM E384. SEM was used to examine the dissemination of ceramic particle reinforcement in the composites. The various elements present in the various parts of the sample were identified using an energy-dispersive spectroscopy (EDS) record. The test specimen is indented using a diamond indenter as part of Vickers' indentation hardness testing process. The diamond indenters in use have a square base, a pyramidal shape, and a point at a 136^0 degree angle in the middle. The indenter applies the load of 0.5kgf on the specimen material for 10sec. After the applied force has been removed, the specimen's indentation has been measured using a microscope for both surface diagonals, and the average value has been considered. The area of diagonal slant surfaces' is calculated. The ratio obtained by dividing the kgf load by the square mm indentation area is known as the Vickers hardness. The circular rod of mentioned hybrid composites is tested to evaluate the ultimate tensile strength as per ASTM E8 standard. To brighten and reduction of the effects of surface area faults on the specimen, fine grit grinding mesh paper was utilized. The tensile test was carried out using a computerized universal testing machine (UTM) loaded with a 50 kN load. The values of the load and displacement were recorded.

4. Results and Discussions

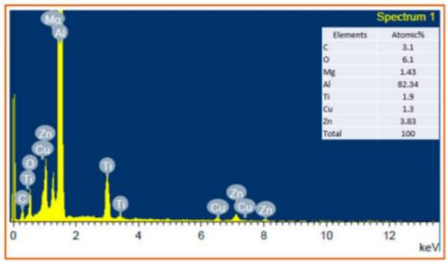
4.1 Microstructure

The existence of the three principal alloying elements (Zn, Mg, and Cu) confirmed by the energy dispersive spectroscopy (EDS) study of the matrix Al7075 (Fig. 2a).

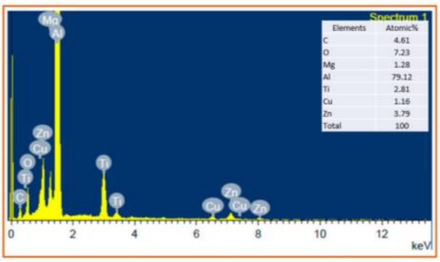
Due to their low content, alloying elements of less than 0.1wt% cannot be seen in the graph. Additionally, a small oxygen peak can be seen in the Al7075 EDS spectra. To confirm that the created hybrid composites contained an Al7075 matrix, 0.5 to 2.5wt% TiC reinforcements, and 0.25wt% of graphene, the EDS analysis of the hybrid composites was conducted (Fig 2(b-f)). It should be highlighted that the spectrum of the Al, Ti, and C peaks confirms the presence of Al7075, TiC, and graphene in the casted hybrid composite samples. The peaks of the alloying elements Cu, Zn, and Mg could be seen in the hybrid composite sample. Oxygen peaks, on the other hand, were furthermore noticed and are related to the creation of oxides during the ultrasonic stir casting process. Table inside the Fig 2 shows the various alloying elements of the mentioned hybrid composites. Thus, it confirms the presence of Zn, Mg, and Cu which are the reinforcing elements in Al7075. The presence of Ti and C indicates the reinforcing elements such as TiC and graphene in the prepared hybrid composites.



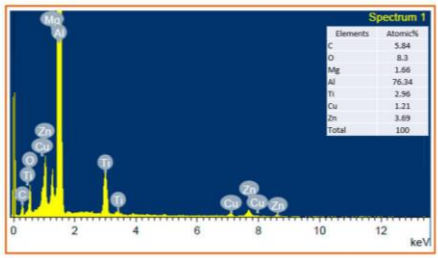
(a) Al7075+0wt%TiC+0.25wt% Graphene



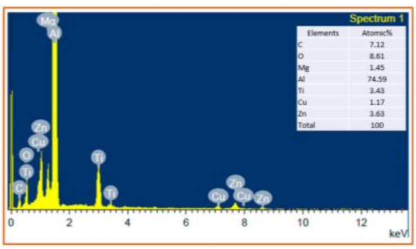
(b) Al7075+0.5wt%TiC+0.25wt% Graphene



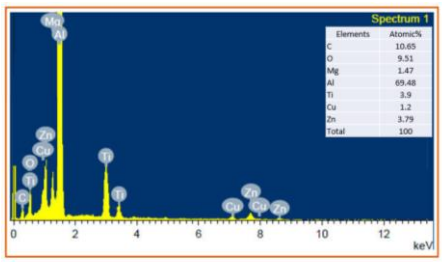
(c) Al7075+1.0wt%TiC+0.25wt% Graphene



(d) Al7075+1.5wt%TiC+0.25wt% Graphene



(e) Al7075+2.0wt%TiC+0.25wt% Graphene



(f) Al7075+2.5wt%TiC+0.25wt% Graphene

Fig. 2 EDS Spectrum of Al7075-graphene and Al7075-graphene-TiCp composites

The elemental mapping analysis reveals that TiC and graphite (carbon) are distributed equally throughout the matrix Al7075. The EDS mapping of the mentioned hybrid composites and their reinforcements may be seen in Fig. 3. The composite was effectively cast with a random and uniform distribution of TiC and graphene in the Al7075 matrix. The presence of an ‘O’ indicates the development of different oxides during casting and machining.

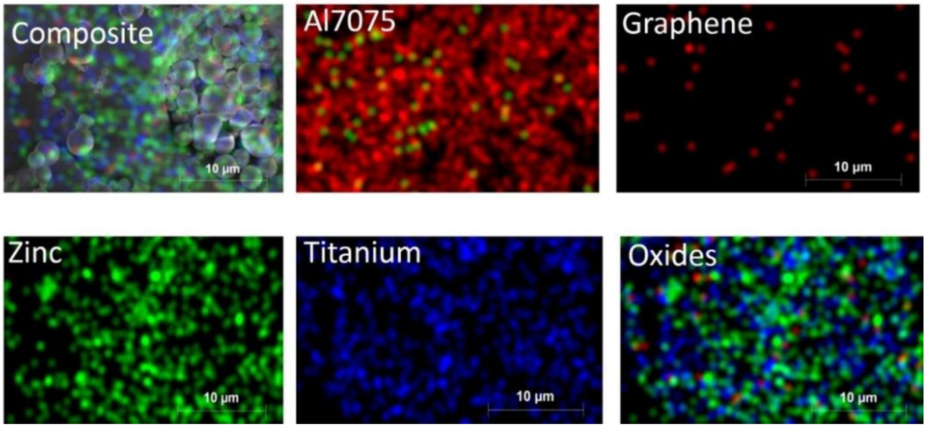


Fig. 3 EDS Images showing the mapping of composites and reinforcements

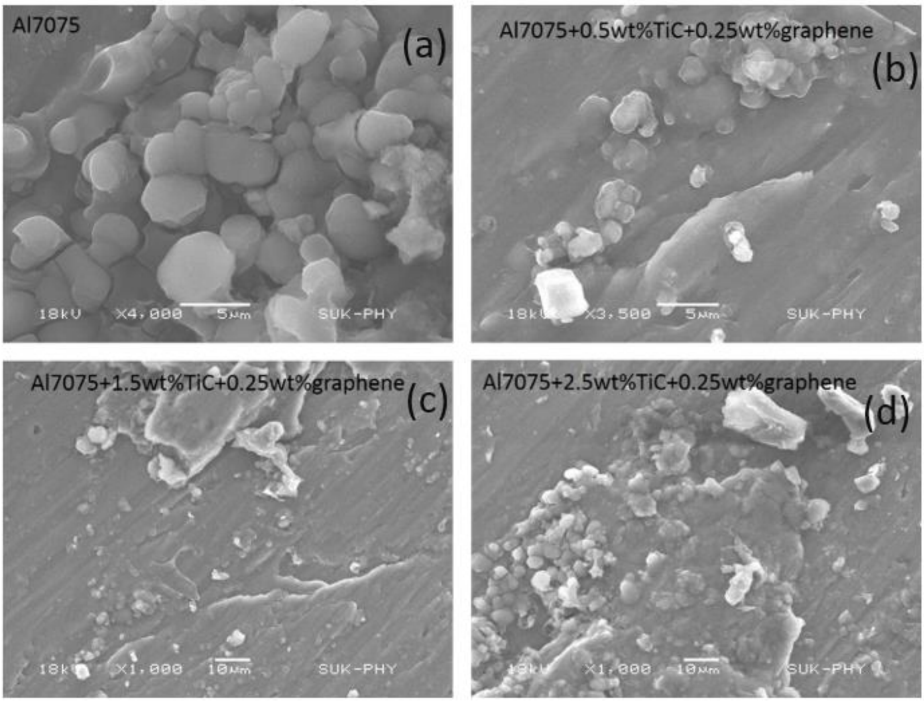


Fig. 4 SEM micrographs: (a) Al7075 alloy, (b-d) Al7075-TiC/graphene hybrid composites

4.2 Micro-Hardness

Al7075 alloy micro hardness values and different TiC concentrations in Al7075-TiC/graphene hybrid composites were measured. Fig. 5 presents a summary of the findings. The micro hardness of the composites increases as the content of nanoparticles of TiC rises. Al7075 alloy sample has a micro hardness of 88 HV. For identical experimental settings, the micro hardness of Al7075-TiC/graphene hybrid composites is increased from 88 to 127.3 HV, 44.5 percent increase over the unreinforced Al7075. This result is due to the addition of nanoparticles of TiC and graphene which can prevent grain growth in an aluminum matrix by the pinning of grain boundaries, resulting in an aluminum alloy with finer grains. Higher micro hardness levels may be the result of finer grain formations.

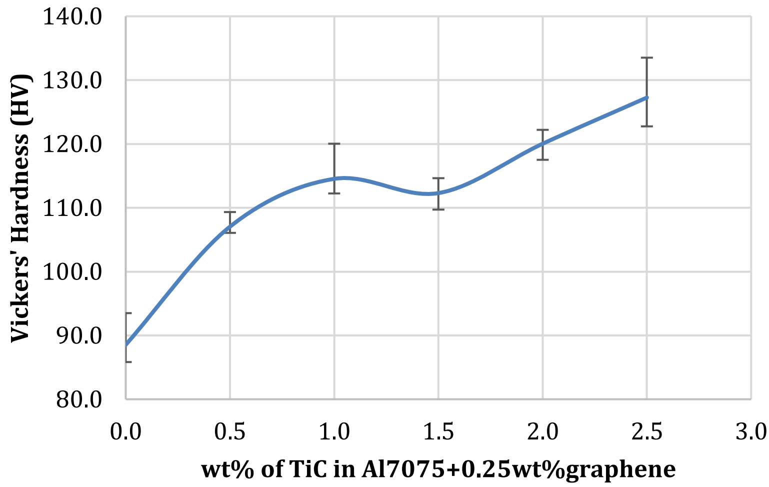


Fig. 5 Micro hardness of Al7075 alloy and the composites

4.3 Tensile Strength

The tensile strength figures for the TiC and graphene reinforced Al7075 hybrid metal matrix composites are shown in Fig 6. Al7075 hybrid composites outperform the base alloy in terms of tensile strength. The presence of hard reinforcing particles underlies the composites' strengthening effect. The aluminium alloy composite's uniform ceramic particle distribution (TiC and graphene) serves as a barrier to the matrix alloy's dislocation motion, reducing fracture. By transferring stress from the aluminum matrix's (ductile) to the reinforced particles' (brittle) surfaces, the addition of ceramic particles primarily increases the composite material's impacting fracture and tensile strength. This is due to the Orowan mechanism, which allows a dislocation to avoid significant impediments when one is constrained around a particle. This results in an increase in tensile strength. When compared to the base alloy, Al7075+2.0wt% TiC+0.25wt% graphene shows the maximum strength of 192.5 MPa, which is rose by roughly 122 MPa (or 58 percent). Fracture will result from the buildup of stress at the nucleation point.

The fracture surfaces of Al7075 hybrid MMC are shown in Fig 7. A small degree of material displacement and matrix cracks near the TiC and graphene particles are shown in the fractography of aluminum alloy composites with a higher reinforcing content. In the current study, Al7075-TiC/graphene hybrid composite fractured tensile specimens were subjected to scanning electron fractography. Investigation of the materials' failure mechanisms was done using a fractography study.

In Al7075-1.0wt%TiC/0.25wt%graphene, shallow dimples, ductile initiated brittle fractures were seen in SEM fractography. The transgranular fracture surface is provided by the presence of hard, very brittle TiC and graphene particles. Perpendicular to the applied tensile load, the TiC and graphene particles exhibit plastic deformation. Additionally, it has been noted that when TiC content increases, the production of dimples decreases, and ductility decreases as a result. The greater TiC content causes brittle fracture, and when tensile stress was applied, TiC particles were drawn out and dragged off. Therefore, a notable transfer of external stress from Al7075 to hard particles of TiC and graphene occurred, increasing the strength as depicted in Fig.7.

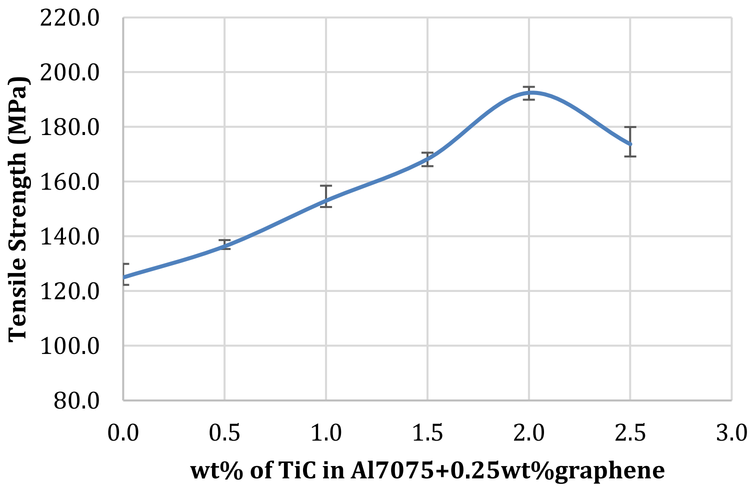


Fig. 6 Tensile strength of TiC and graphene reinforced Al7075 composites

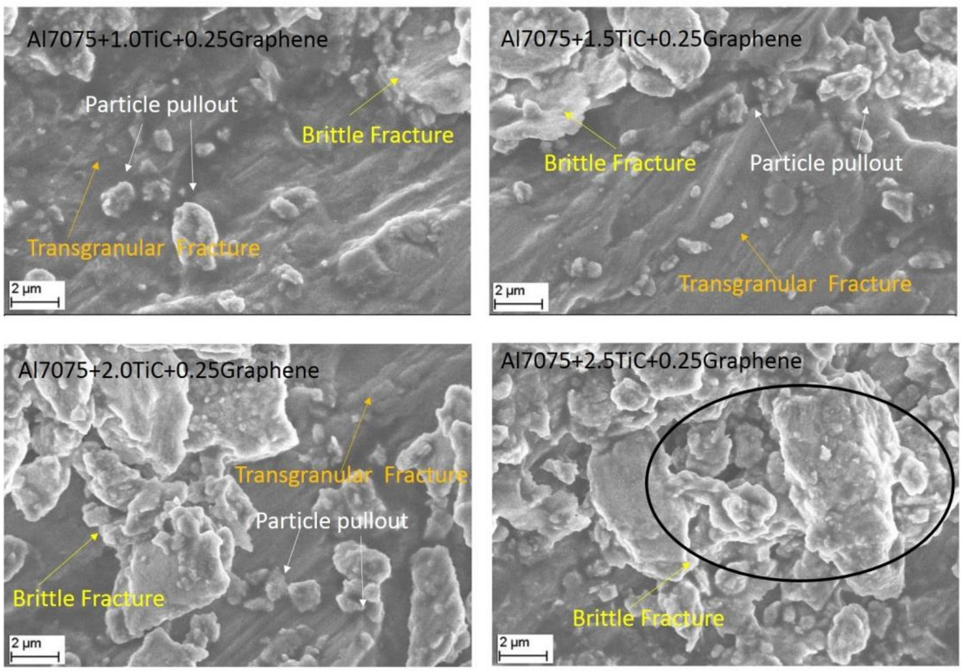


Fig. 7 SEM micrographs of the tensile fracture surface

4.4 Yield Strength and Elongation

The tensile yield strength and elongation for the TiC and graphene reinforced Al7075 hybrid metal matrix composites are listed in the Table 1.

Table 1 Mechanical properties of the Al7075-TiC/graphene composite

Sl. No	Composite	Yield Strength (MPa)	Percentage Elongation
1	Pure Al7075	94.5	14.47
2	AL7075+0.5%TiC+0.25 % Graphene	98.3	14.15
3	AL7075+1.0%TiC+0.25 % Graphene	105.0	13.76
4	AL7075+1.5%TiC+0.25 % Graphene	118.5	13.12
5	AL7075+2.0%TiC+0.25 % Graphene	133.0	12.87
6	AL7075+2.5%TiC+0.25 % Graphene	122.2	12.01

From the Table 1 it can be observed that the increment in the reinforcement such as TiC increases the yield strength of the mentioned hybrid composite material whereas addition of TiC and graphene decreases elongation. The addition of hard particles in the aluminum matrix increases the strength whereas decreases the ductility. The decrement in the ductility observed is 17% whereas the increment in the yield strength is 29%.

Table 2 shows the comparison of the properties of Al7075-TiC/graphene composite with Al7075 matrix composites.

Table 2 Comparison of mechanical properties of different composites

Sl. No	Properties	Al7075-TiC/ graphene [PW]	Al7075+TiC+Si [25]	Al7075-TiC [18]
1	Tensile Strength, MPa	192.5	155	184
2	Yield Strength, MPa	133.0	120	-
3	Percentage elongation, %	12.01	13	10
4	Density, g/cc	2.75	2.82	2.73
5	Hardness, HV	127.3	150	102

From the table it can be observed that Al7075-2.0wt%TiC/ 0.25wt%graphene composite is better than the Al7075-TiC composites and Al7075+TiC+Si hybrid composites.

5. Conclusion

- In this experimental work, the influence of the addition of the TiC and graphene nanoparticles on the tensile strength and hardness of Al7075-TiC/graphene hybrid composite has been studied. The Al7075-TiC/graphene nano-particulate hybrid composite is prepared using an ultrasonic two-step stir casting method as shown in fig.1 (a-f).
- It is confirmed by the EDX analysis, as shown in Figs. 2 and 3, that Al7075 contains reinforcing elements including Zn, Mg, and Cu. The presence of Ti and C suggests that the cast hybrid composites have reinforcements made of TiC and graphene. The random and uniform distribution of reinforcements in the aluminum matrix is confirmed by EDS elemental mapping analysis. When an "O" is present, it means that distinct oxides have formed during casting and machining. The Al7075 matrix contains reinforcement nanoparticles that are uniformly distributed without clumping, according to SEM examination.
- The micro-hardness of the Al7075-TiC/graphene hybrid composites increases with an increase in wt.% of TiC as shown in fig.5. This increment is due to the

pinning of matrix grain boundaries by the reinforcements which results in the finer grains of aluminum. The maximum micro-hardness that is obtained is 127.3HV for 2.5wt% of TiC, which is 44% higher than the unreinforced Al7075.

- The presence of uniformly distributed reinforcing particles in the Al7075 matrix as shown in fig.4, which acts as a block-off for the matrix alloy's dislocation motion, leads to increase in the strength of the composites. Also, the addition of the ceramic reinforcements takes the load of the matrix material, thus increases the tensile strength. Al7075+2.0wt% TiC+0.25wt% graphene composites as shown in fig.6 exhibits the higher tensile strength of 192.5MPa which is 54% higher than the unreinforced Al7075.
- Above results from fig.5, fig.6, and fig.7 shows that addition of TiC and graphene nanoparticles in Al7075- TiC/graphene hybrid composite, the tensile strength and hardness of the composite increases. However, this growth is gained with the loss of ductility, which is evident from the SEM images showing the brittle fracture.

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