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A STUDY ON MORPHOLOGICAL AND MECHANICAL CHARACTERIZATION OF Al-4032/SiC/GP HYBRID COMPOSITES

*Deepak Kumar, Pardeep Saini, Pradeep K Singh**

Department of Mechanical Engineering, Sant Longowal Institute of Engineering and Technology, Longowal, 148106, India

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Abstract

The pattern of metal matrix composites can be enhanced by integrating the concept of hybrid metal matrix composite to produce newer engineering materials with improved properties. The morphological and mechanical characteristics of Al-4032/SiC/GP hybrid composites have been investigated. The aluminium alloy (Al-4032) based hybrid composites have been fabricated through the bottom pouring stir casting set up, by reinforcing the silicon carbide (SiC) and granite powder ceramic particles as the reinforcement material at various fraction levels i.e. 0, 3, 6, 9 weight% in equal proportion. The reinforcement particle size is up to 54µm. The microstructural characterization of the hybrid composite samples has been carried out using an optical microscope, SEM, and XRD. The study reveals that the reinforcement hybrid particles (SiC + GP) are almost uniformly distributed throughout the matrix phase. The mechanical properties (tensile strength, impact strength, and microhardness) of the hybrid composite samples have been obtained and found to be better than the unreinforced alloy.

Keywords: Al-4032; Silicon carbide; granite powder; hybrid composite; morphological characterization; mechanical properties

Introduction

Material scientists have been working for the development of advanced materials for fulfilling the demand of the engineering sector to enhance efficiency and reduce costs of the manufacturing sector, for decades. The aluminum-based metal matrix composites (AMCs) are highly demanding materials in the aerospace industry, automobile industry, and other engineering applications. There has been an increasing interest in AMCs for low density and good mechanical, wear, and anti-corrosion properties with low

*Corresponding author: Pradeep K Singh, *pksinghcommunications@gmail.com*

fabrication costs. The AMCs seem to be quite significant for both, industrial application and research [1].

The AMCs are used extensively in various fields due to their low density, high strength-to-weight ratio, good damping properties, and better chemical properties. The hybrid metal matrix composite, having two or more reinforcement materials simultaneously in equal or different proportions, is the new concept in this field for research. It is the fourth-generation composite of significant potential in the materials world [2]. If a waste or cheaper reinforcement is used, it may yield a relatively cheaper composite, while maintaining reasonably good mechanical properties.

Recent research investigations have revealed that agro/industrial waste materials such as fly ash, graphite, rice husk ash, etc., can be successfully used as a complementary reinforcement in AMCs [3–5]. The properties of the hybrid reinforcements (primary and secondary) can be combined to achieve optimization of material properties. Moreover, the use of the stir casting technique for the fabrication of AMCs reduces the cost of the composites, as it is economical, simple to perform, and a highly productive method [6, 7].

Aluminum matrix composites with multiple reinforcements (hybrid AMCs) are finding increased applications because of improved mechanical and tribological properties and hence are better substitutes for single reinforced composites. The very first research on the AMCs appears to have been taken up by S. Ray in 1968 as Masters' dissertation at IIT Kanpur [8]. But, the concept of hybrid composites appeared in the early 1990s [9]. A review of relevant research reported in the literature has been presented below.

Dolata and Wieczorek [10] fabricated the aluminium hybrid composites containing two carbide phases: chromium (Cr_3C_2) and titanium carbides (TiC) with 5-10% (by weight) through centrifugal casting and tested the wear behavior. An increase in the reinforcing phase fraction allowed the elimination of the phenomena connected with adhesion wear. The 10% fraction of a carbide reinforcing phase ensures a uniform wear mechanism and has a beneficial influence on the operation of the tribological couple. When using a 5% fraction of the NiC/Cr_3C_2-TiC powder mixture, a higher degree of wear was observed in the composite than in the case of a composite where a 10% fraction of powder mixture was applied.

Mahendra and Radhakrishna [11] characterized the stir cast Al-4.5%Cu- (fly ash + SiC) hybrid metal matrix composites. The fly ash and SiC were added in 5%, 10%, and 15% by weight (equal proportion) to the molten metal. The density of the composite decreases with the increase in fly ash and SiC content. The tensile strength, compression strength, and impact strength increase with the increase in fly ash and SiC. *Boopathi et al.* [12] fabricated the aluminium-SiC-fly ash hybrid metal matrix composites through the conventional stir casting method. In the presence of silicon carbide and fly ash [SiC (5%) + fly ash (10%) and fly ash (10%) + SiC (10%)] with aluminum, it was fairly observed that the density of the composites was decreased, and the hardness was increased. Correspondingly, the increase in tensile strength was also observed but the elongation of the hybrid metal matrix composites in comparison with unreinforced aluminium was decreased

Moorthy et al. [13] fabricated a hybrid composite of Al-2218 with the 5, 10, 15 wt% of fly ash and 4 wt% of talc by stir casting method. It was found that the accumulation of both fly ash and talc particles into the matrix improves the wear resistance of the composite with the increasing volume of fly ash. Even at a higher load, 4% weight of talc exhibits better lubricity, which causes the reduction in the coefficient of friction and wear rate. *Rao et al.* [14] optimized the mechanical properties (impact strength, hardness, and tensile strength) of Al-7075 based hybrid metal matrix composite using a non-dominated sorting genetic algorithm (NSGA-II). The optimum combination of SiC and TiO2 obtained under the best compromise solution has been found to be 9.513% and 0.487%, respectively. The results also indicate that among the two, SiC and TiO2, the fraction of SiC particle is the most influencing parameter to all the three mechanical properties.

Vinod et al. [15] fabricated the A356 alloy RHA-Fly ash reinforced hybrid metal matrix composites by the double stir casting process and investigated the physical and mechanical properties of composites. It is found that the mechanical properties of composites are improved due to the addition of both organic and inorganic particles. Uniform dispersion of reinforcement particles helps to improve the mechanical properties of composites. Lower porosity is also found in composites due to the reinforcement of ceramic hybrid particles.

These investigations emphasize that the use of multiple reinforcements in aluminum matrix hybrid composites yield better mechanical, physical, and tribological properties. The Al-4032, the aluminum-silicon alloy having a composition of silicon of about 12%, is widely used as the material for sliding components in automobiles, aviation, and other sectors. The research on Al-4032 alloy matrix-based composites is going on to reduce weight and improve the mechanical, chemical, and tribological properties of components used in industrial machinery.

In the present study, Al-4032 alloy with different weight fractions of SiC and GP reinforced hybrid composites have been fabricated using the bottom pouring stir casting technique. The ceramic particles (reinforcement materials) have been used in equal proportion, making the net hybrid reinforcement at 0, 3, 6, 9 weight%. The morphological and mechanical properties of the aluminum matrix hybrid composites (AMHCs) have been investigated to assess the effect of composition, and usefulness for industrial application. The mechanical properties of the AMHCs have been observed to be better than the unreinforced alloy.

Background Theory – Characterization of the AMHC

The characterization of the AMHC sample has been carried out under two heads – viz. morphological characterization, and mechanical characterization

Morphological characterization

The morphological characterization refers to the broad and general process by which a material's structure and properties (grain structures, grain boundaries, grain size, etc.) are assessed. It is an important step for the scientific understanding of engineering materials. Microstructure characterization of advanced materials involves qualitative and quantitative analysis of surface topography, porosity, crystal defects, and interfaces. SEM offers the ability to visually inspect the surface morphology for the detection of pores, fissures, and other surface materials/deposits. X-ray diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions.

The morphological characterization of the Al-4032 alloy-based metal matrix hybrid composites has been done through an optical microscope, X-ray diffraction, and scanning electron microscope. Before characterization, the samples are processed by some traditional method of polishing. To analyze the microstructure, a specimen of size ϕ15mm×5mm was cut from the cast composite. Polishing of the samples has been done using the emery paper ranging from 100 to 3000 grit size i.e. 100, 200, 400, 600, 800, 1000, 1200, 1500, 2000, 2500, 3000 grits. After the polishing on emery papers, the diamond paste has been used for attaining the ultrafine mirror-like finishing using the velvet cloth. This follows the application of Keller's etchant (for the aluminum or aluminum base alloy/composites) for etching. These polished samples are tested on different microstructural machines – optical microscope, X-ray diffraction, and scanning electron microscope.

Mechanical characterization

Mechanical characterization of the AMHCs is carried out to study the effect of the reinforcing material on the mechanical properties of the base material. If the bonding between the matrix and the reinforcement is good, the mechanical properties of the composite obtained will also improve. The mechanical characterization includes the testing of tensile strength, microhardness, and impact strength of the AMHC samples.

(a) Tensile test

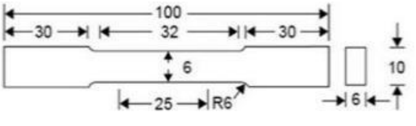
The tensile test has been carried out to obtain the ultimate tensile strength and ductility of the material (percentage elongation). The tensile test specimens were prepared as per the ASTM E-08 standards (Figure 1) on a wire-cut electron discharge machine. The tensile tests were performed on the Universal Testing Machine. An average of three readings has been taken to reduce the variability in the results,

(b) Micro-hardness Test

The samples for the micro-hardness test have been prepared as per the ASTM E-92 standards. The samples were polished up to 1500 grit size to make the surface free from irregularities. A Vickers microhardness tester was used. An average of five readings has been taken along the length of the specimen as the final hardness value of the AMHCs.

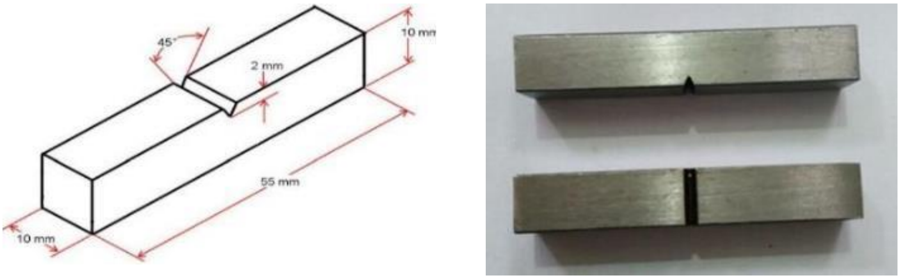
(a) Impact Test

The Charpy impact test was performed on the aluminum metal matrix composite. A sample size 10x10x55 mm^3 was prepared with a V-notch depth of 2mm at 45^0 according to the ASTM A-370 standards (Figure 2). The impact test for each type of composition has been five times and the average has been taken as the final impact strength for the composition.



(a) *(b)*

Fig. 1. (a) Tensile test specimen as per the ASTM E-8 standards (b) Machined tensile specimen.



(a) *(b)*

Fig. 2. (a) Standard Charpy impact specimen dimensions as per ASTM A370, (b) machined impact specimen.

Experimental work

The experimental work involves fabrication/processing of the Al-4032/SiC/GP hybrid composites, preparation of samples, followed by morphological and mechanical characterization. The details of the experimental work are given below.

Processing of the hybrid composites

The aluminum matrix hybrid composite has been fabricated with the Al-4032 as the base matrix (purchased from Gravita India Pvt Ltd.) and the combination of SiC (conventional reinforcement, purchased from Chawri market New Delhi) and granite powder (industrial waste particles, obtained from the Shri Ram Marble, Ajmer) ceramic particles as the reinforcement material in equal proportion. The hybrid reinforcement has been used at various weight fractions i.e. 0, 3, 6, 9 %. The reinforcement particles size has been up to 54µm. The chemical composition of the Al-4032 alloy is shown in Table 1. Silicon present in the base alloy imparts high fluidity and low shrinkage, which results in good castability and weldability. The presence of silicon also improves casting characteristics by improving feeding and hot tear resistance [16].

Table 1. Chemical composition (fraction—percentage by weight) of the Al-4032 alloy.

Component	Si	Cu	Mg	Cr	Ni	Zn	Mn	Al
Weight%	11.53	0.9	1.00	0.10	0.8	0.25	0.415	Rest

The stir casting process with the bottom pouring vacuum stir casting setup has been adopted for mixing the reinforcement with the molten metal using mechanical stirrer blades [17]. Following are the steps for fabrication of the AMHCs followed in the experiment.

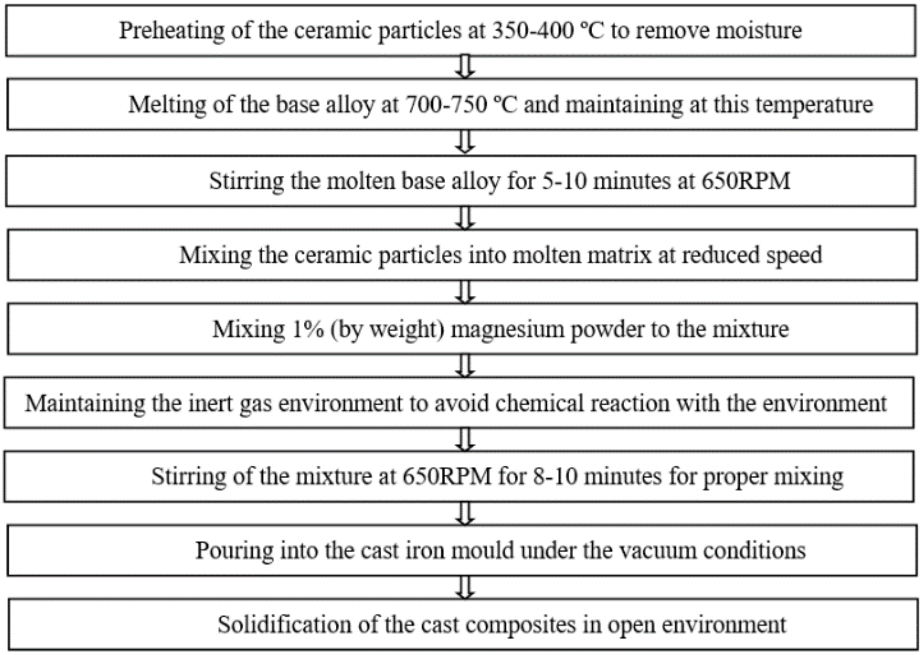


Fig. 3. Step for the processing of the AMHC.

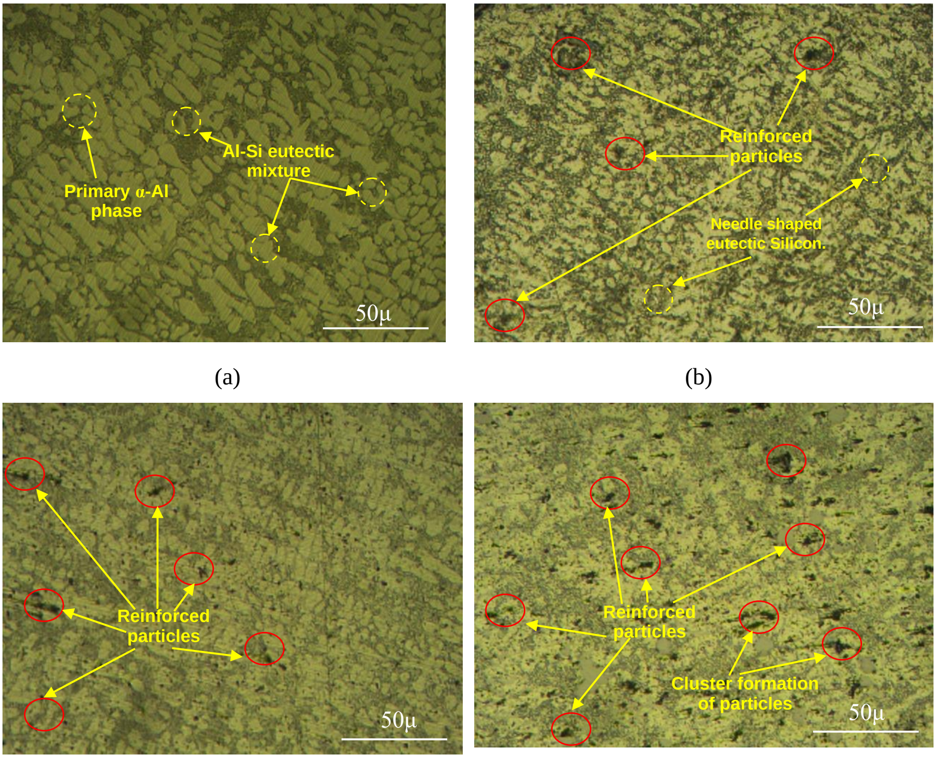
Results and Discussion

The Al-4032 alloy-based hybrid composites have been fabricated, using SiC and GP as hybrid reinforcement at 0-3-6-9% by weight in equal proportion, using the bottom pouring stir casting method. The morphological and mechanical characterization of the AMHC samples has been attempted to investigate the effect of hybrid reinforcement. The results obtained from the characterization have been discussed in this section.

Morphological characterization

<u>Microscopic characterization</u>

The microstructure study of the Al-4032/SiC/GP composites has been carried out through an optical microscope at 200x (Figure 4). The study reveals that the base matrix contains typically Al-Si eutectic mixture and primary silicon phase (Figure 4a). It is observed that the hybrid ceramic particles are almost uniformly distributed throughout the Al-matrix and form a good bonding. Significant microstructural differences have been observed in the three samples of different weight fraction AMHCs. As the weight percentage of the hybrid ceramic particles increases beyond 6%, the coagulation/cluster formation starts (Figure 4d). It is due to the increase of particulate interaction and settling velocity that results in a non-homogeneous distribution of ceramic particles. The cluster formation takes place during the mixing and stirring processes [18].



(c) (d)

Fig. 4. Microstructure images by optical micrographs of AMHC samples at 200x (a) base alloy, (b) 3% hybrid, (c) 6% hybrid, (d) 9% hybrid.

<u>SEM characterization</u>

The SEM characterization study of the Al-4032 matrix-based hybrid composites has been conducted using JUIL (JSM) IT-100 scanning electron microscope, situated at NITTTR, Chandigarh. The presence of dendritic pro-eutectic α-Al and plate-like structured eutectic-Si has been observed through SEM characterization for the base matrix. The density of the GP material is similar to that of the base matrix and this might be the possible reason for insufficient bonding at the interface of the matrix and ceramic particulates leaving voids [16]. The agglomeration of particulates while solidifying may create intra-particulate voids because of insufficient bonding with the matrix material [19]. A clear interface between matrix and reinforcement can increase the load-bearing ability of the AMHCs. These hybrid ceramic particles have a high melting point, so, no further reaction has been noticed with the matrix material. The GP particles appear to be surrounded by the α-Al phase (Figure 5).

From the SEM characterization, it is observed that an almost uniform distribution of the reinforcement throughout the matrix has been achieved. But at a higher weight percentage, the homogeneity of the samples appears to be disturbed due to the clustering and agglomeration of the ceramic particles at some points. The wettability also affects the bonding between the matrix and ceramic particles. The dispersion of these reinforcing particles is influenced by the wettability of the hybrid ceramic particles, and interfacial bonding between these particles and Al–4032 alloy. It is also observed that increasing the weight percentage of the hybrid particles above 6% creates a slurry and disturbs the homogeneity of the composite material.

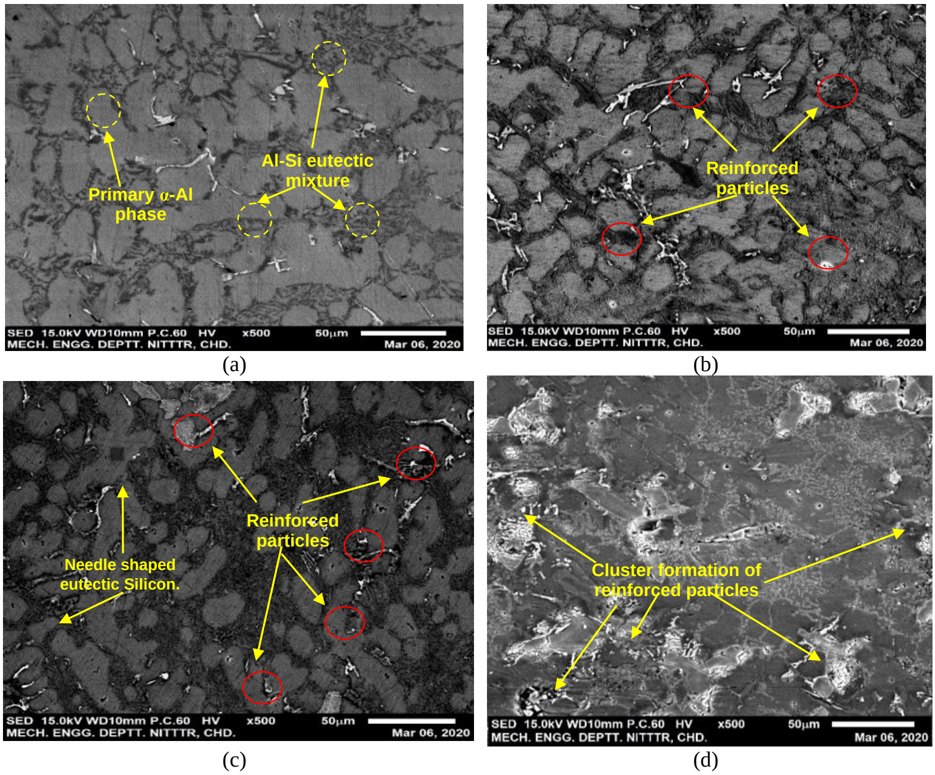


Fig. 5. Scanning electron microscope (SEM) characterization at 500x- 50μm of the AMHC (a) base alloy, (b) 3% hybrid, (c) 6% hybrid, (d) 9% hybrid.

X-Ray Diffraction (XRD) characterization

Figure 6 shows the XRD patterns attained for the Al-4032/SiC/GP hybrid composites. The XRD reports confirm the presence of SiC and GP reinforcement within the matrix alloy. Different peaks have been observed for different samples at 3, 6, 9 % reinforcement by weight. As the weight percentage of both, SiC and GP particles increases, the height of the peaks of the ceramic also increases (Figure 6). But on the other hand, the peaks of Al-4032 slightly reduce in height.

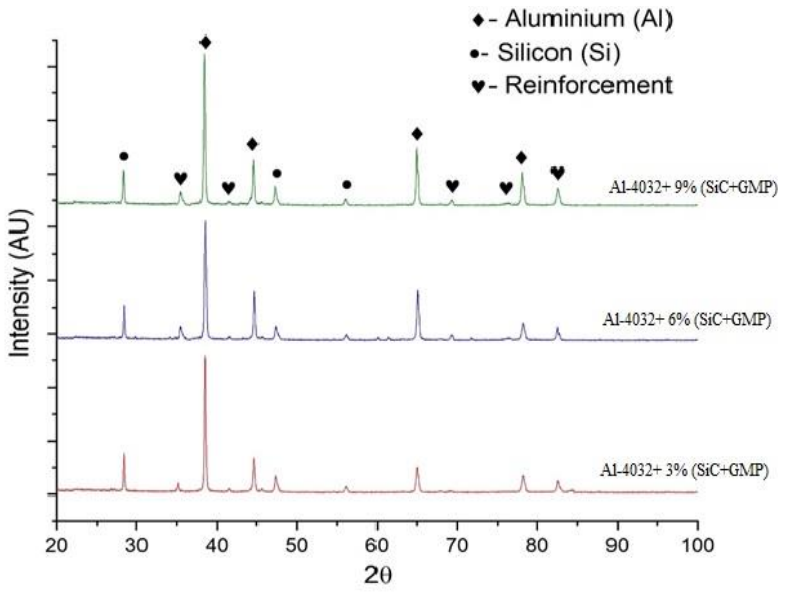


Fig. 6. XRD pattern for Al-4032/SiC/GP hybrid composites.

Mechanical Characterization

Tensile test

The result of the tensile test conducted on the AMHC samples is presented in Table 2. With the increase in the reinforcement ratio of the hybrid ceramic particles, the UTS value of the AMHC samples tends to increase up to the weight fraction of 6%. But, after that, it starts decreasing. The maximum value of the UTS is 146 MPa, obtained at the 6%. With increasing weight fraction, more load is transferred to the reinforcement material which results in higher yield strength of the composite material. During loading, ceramic particles absorb the load and enhance the strength of the fabricated composite.

On the other hand, the percentage elongation shows the opposite behavior to the UTS. The elongation percentage of any material represents its ductility behavior. As the UTS value increases, the brittle behavior of the AMHCs sample also increases and causes a decrease in the percentage elongation value of AMHCs. The increasing-decreasing trend of the UTS and percentage elongation for AMHC is shown in Figure (7-8).

Table 2. Tensile test of the AMHCs.

Sr. No	Samples	UTS (MPa)	% Elongation
1	Base matrix	69.4	18.4
2	Al-4032/SiC/GP (3%)	103	13.2
3	Al-4032/SiC/GP (6%)	146	7.8
4	Al-4032/SiC/GP (9%)	118	11.7

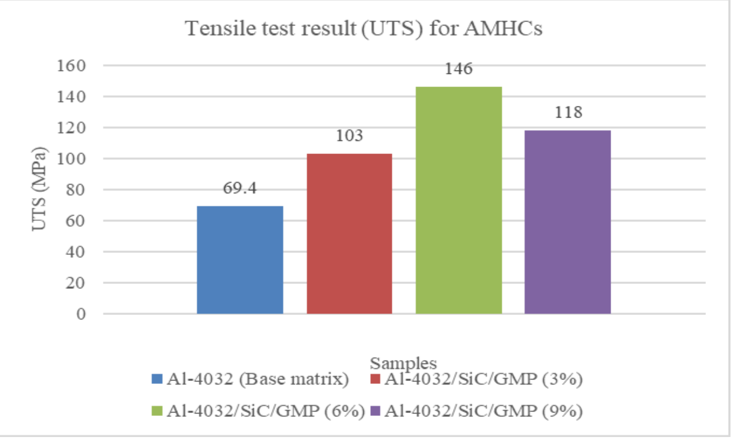


Fig. 7. Graphical representation of ultimate tensile strength of AMHCs.

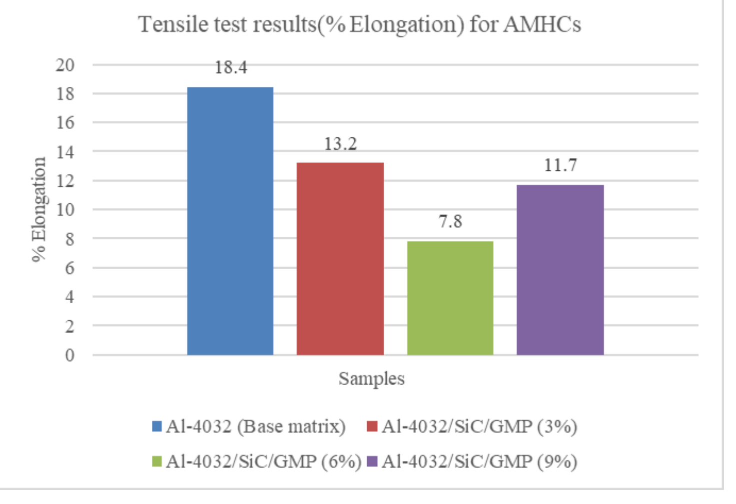


Fig. 8. Graphical representation of % Elongation of AMHCs.

Micro-hardness test

The effect of reinforced particulate weight fraction on the Vickers micro-hardness value has been investigated and the results have been presented in Table 3 and Figure 9. The micro-hardness of the AMHC samples has been found to improve with the addition of the hybrid ceramic particles. It may be because of the higher hardness of the ceramic particles than the base matrix, and the good bonding interface between the reinforcement and the matrix [18] (also confirmed by SEM studies, Section 5.1.2). Figure 9 shows that the Vickers microhardness of the AMHCs is a function of the reinforcement weight fraction.

However, with the addition of the reinforcement beyond 6% of the weight fraction, the micro-hardness follows a decreasing trend. This may happen due to coagulation of reinforcement occurring at the high weight fraction, resulting in voids at the interface

[21]. The maximum value of micro-hardness obtained corresponding to the 6% weight fraction of reinforcement is 190.2 HV.

Table 3. Micro-hardness test of AMHCs.

Sr. No	Samples	Microhardness (HV)
1	Al-4032 (Base matrix)	131.4
2	Al-4032/SiC/GP (3%)	160.4
3	Al-4032/SiC/GP (6%)	190.2
4	Al-4032/SiC/GP (9%)	173.3

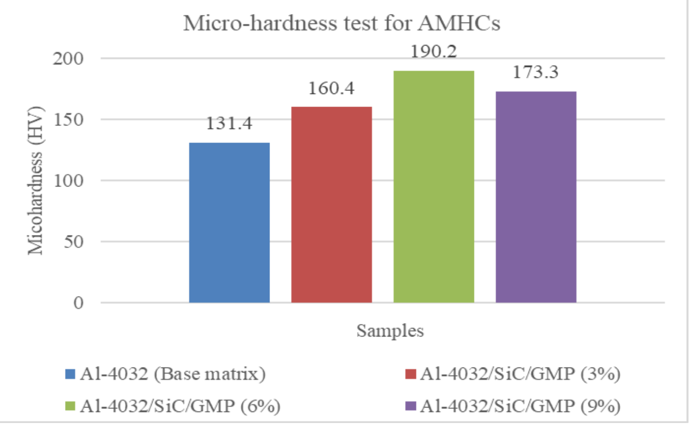


Fig. 9. Graphical representation of micro-hardness test results for AMHCs.

<u>Impact test</u>

The effect of hybrid ceramic particle reinforcement on the impact strength has been investigated. The results obtained have been presented in Table 4 and Figure 10. The addition of the hybrid reinforcement ceramic particles appears to improve the impact strength of the AMHC samples, with the maximum value of 34.3 J occurring at a 3% weight fraction.

Beyond 3%, the toughness energy follows a decreasing trend. This may be due to the brittle nature of the reinforced ceramic particulates. Also, the tendency of segregation of the reinforcement particles at some specific locations at higher reinforcement fractions may not improve the strength significantly. On application of load, decohesion at the interface between hybrid ceramic particles and ductile matrix may be a reason for lower impact strength at a higher weight fraction of reinforcement [20].

Table 4. Result of impact strength test for AMHCs

Sr. No	Samples	Impact energy (J)
1	Al-4032 (Base matrix)	22.4
2	Al-4032/SiC/GP (3%)	34.3
3	Al-4032/SiC/GP (6%)	29.8
4	Al-4032/SiC/GP (9%)	24.8

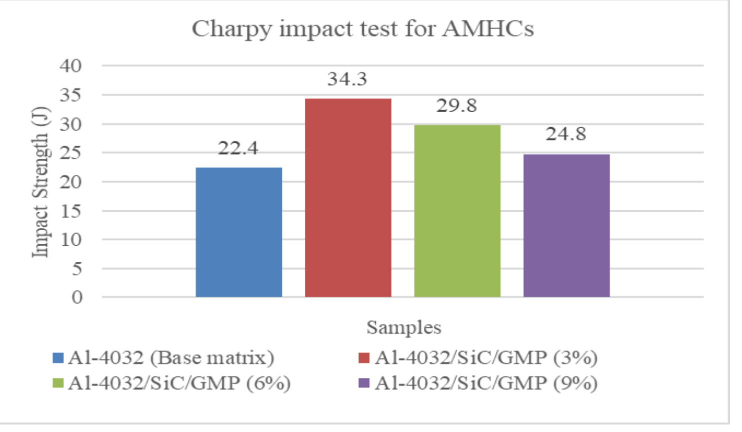


Fig. 10. Graphical representation of impact strength test results for AMHCs.

Conclusion and future scope

In this work, Al-4032/SiC/GP composites have been fabricated through a stir casting route for different reinforcement ratios (0-3-6-9%) by weight. The SiC (conventional reinforcement) and granite powder (industrial waste ceramic particles) have been utilized to form the Aluminium-alloy based hybrid composites. The morphological and mechanical characterization has been conducted to study the effect of the addition/ variation of the hybrid ceramic particles on the properties of the AMHCs. The following conclusion can be drawn from the study.

The hybrid ceramic particles are almost uniformly distributed all over the matrix phase, for AMHC samples up to 6% reinforcement. However, localized coagulation of the reinforcement (harming the homogeneity) has been noticed at a 9% weight fraction, indicating the formation of the composite is satisfactory only up to 6% reinforcement.

Addition of the hybrid ceramic particles to the matrix in general results in an improvement in mechanical properties of the AMHC. The tensile strength and microhardness of the AMHC sample increase with the increase in the reinforcement ratio up to 6% (by weight). Beyond this, the properties start decreasing, possibly be due to coagulation of the reinforcement, and weak interfacial bonding at higher weight fractions.

The impact strength of the AMHCs appears to be higher than that of the Al-alloy matrix. The highest value of the impact strength occurs corresponding to a 3% weight fraction of the reinforcement. The impact strength follows a decreasing trend beyond this value, possibly due to an increase in brittleness of the composite with the increase in the reinforcement fraction.

In this work, the fabrication of the hybrid AMHC (SiC + GP in equal proportions) has been attempted using a 0-3-6-9% (by weight) reinforcement ratio. The work can be extended for other weight fractions of the reinforcement (in the range of 2-8%) for more useful results. The inclusion of torsion and fatigue tests of the AMHCs may be beneficial for industrial application.

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