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Microstructure and physical properties of hybrid metal matrix composites AA6061-TiO₂-SiC via stir casting techniques

S. Venugopal*, L. Karikalan

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ABSTRACT

Hybrid aluminum matrix composites (HAMCs) are the second era of composites that can possibly substitute single strengthened composites because of improved properties. The present investigation used stir casting techniques to fabricate the hybrid metal matrix composites with different volume fractions Al- $\chi\%$ TiO₂- $\chi\%$ SiC (χ = 2.5%, 5%, 7.5%). This paper examines the feasibility and relevance of the growing minimum effort of hybrid composites (AA6061-TiO₂-SiC) for brake pad applications in automobile industries. An optical electron microscope (OEM) was used in HAMCs, which indicates that the reinforcement is very scattered in the Al matrix alloy and the porosity level is adopted for the stirring composites. The mechanical properties such as Tensile strength (TS), Hardness (BHN), density and impact strength of the hybrid composites have been seen as either practically identical or better than the earthenware strengthened composites. This is seen from past research that identifies the direct reinforcement of the composites due to the proximity of the hardened porcelain phases, while the indirect reinforcement arises from the thermal mismatch between the matrix and reinforcement during the solidification process. It has been reasoned that the hybrid composites offer greater flexibility and dependability in the structure of potential parts relying on the fortification's mix and organization.

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1. Introduction

Hybrid metallic matrix composites (MMC) bolstered with ceramic debris has the preferred materials for structural packages because of their first rate combination of reinforcement residences. MMCs join the houses of the metallic combinations (malleability and sturdiness) and the ceramic reinforcements (excessive first-rate and excessive modulus) prompting a rivaled profile of outstanding attributes [1,2]. These kinds of composites were discovered that important benefits compared with different traditional monolithic substances as an instance light weight, excessive corrosive resistance, high electricity and stiffness and properly put on traits [3–5]. Therefore latest researches of hybrid aluminium matrix composites are considered as most strong substances that may be utilized in shape of automotive packages such as pistons, cylinders, breaks and clutches. Aluminium is principally bolstered with exclusive types of hard phases together with SiC, TiC, TiB₂ TiO₂ and Al₂O₃ and soft phases Graphite (Gr) and

MoS₂ [6–7]. Latest researches discovered the addition SiC on Al matrix with particular promises greater with accurate wear resistance and mechanical houses [8–11]. The addition of SiC at the aluminium matrix ends in provide additives are hard to system due to its brittle assets [12]. The discovery of oxide formations shift to brittleness of SiC and develop its engineering packages. Oxides are substantially carried out for enhancing the fracture longevity of the composite materials. The usage of minerals as capability fortifications has logically emerged by thinking about the herbal views. Minerals are situation neighborly, reasonably-priced and on hand in bounty which locations them to be large fortification substances for the composites [13]. Chawla et al.'s study has proven that warmth treatment of composites increases the oblique strengthening of aluminum alloys while growing the reinforcement content material leads to reduced particle size.

Additions of TiO₂ composites are quite simply available, cheaper and feature extensive wear resistance, thermal and mechanical properties (Rama er ml 2014) [14]. Ramesh et al. QS [15] examined the impact of reinforcement (TiO₂) on aluminum (AA6061) matrix composites and completed a full-size enhancement in put on resistance and hardness homes. Chuduri et al. reported that TiO₂ Al-Mg

* Corresponding author.

E-mail address: venugopal.se@velsuniv.ac.in (S. Venugopal).<https://doi.org/10.1016/j.matpr.2020.06.462>

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and compounds show better performance compared to the base materials. Thorough study on different literary works uncovered that no definite discoveries are accessible for powder metallurgy (P/M) prepared Al – SiC – TiO₂ hybrid composites. P/M is generally adjusted for accomplishing uniform dispersion of strengthening stage inside the framework and to deliver close to net molded parts [16,17].

The ceramic reinforcements acquire superior strength than other types of reinforcement's materials and because of the fact, there are used as primary reinforcements for the development of hybrid composites. Ceramic reinforcements receive superior strength than other types of reinforcement materials and, in fact, are used as primary reinforcements for the development of composite alloys. Although secondary reinforcements reduce the cost, these are readily available and have a lower density weight of hybrid composites [18]. The enhancement properties of hybrid composites can be combined to achieve the optimization of the material properties. In addition, the utilization of mix throwing strategy for manufacture of AMCs lessens the cost the composites, as it is conservative, easy to perform and profoundly gainful technique [19–21].

The present investigation therefore intended to study the impact of TiO₂ composites on the mechanical properties such as tensile strength, impact strength, hardness and density measurements. That study exhibited the characterization of aluminium matrix composites by stir casting techniques [22–24]. The capability of a wide scope of optional fortifications has been investigated for the advancement of HAMCs and the application region of these composites has been proposed. The emphasis is on the improvement of parameters for different properties of composites [25]. Further, the impact of support's sort and substance on the material properties has additionally been investigated and reported.

2. Materials and methods

2.1. Materials

The AA6061 features precipitation hardened alloys, exhibits good mechanical properties and wears the most widely used properties in the aerospace and automobile industries. It also includes high magnesium and silicon as the main melting elements. The physical and chemical properties of the matrix and reinforcement materials are shown in Tables 1 and 2. Therefore, the reinforcement of SiC and TiO₂ of the average particle sizes is 25 μm and 50 μm, respectively, used in aluminum matrix composites with different fractions.

3. Experimental setup

Likewise, a basic four-edge alumina-covered solidified steel liner was brought into the conditioner to start the liquefying of the aluminum to 850 °C and to corrupt the amalgam with nitrogen. The ratio of stirrer is set 2/3rd of the path down the liquid metal. Pre-warmed fortification assets SiC and TiO₂ are in harmony when the vortex is shaped in the liquid metal. The preheating temperature was furthermore kept up at 500 °C. The tensile tests were carried out on Universal Testing Machine (UTM) characterized by stress–strain behaviour of the hybrid composite materials. For each type of volume fraction combination, three samples are prepared

and the mean values are taken as the optimal value. The specimen dimension was prepared according to the ASTM E8M guidelines as shows in Fig. 1. The test was practiced at the room temperature (23 °C) for the crosshead feed rate 0.002 m/s. Servo hydraulic machine instron 25 KN load cell limit. While the tensile test fractured surfaces was characterized by using Scanning Electron Microscope (SEM). Fig. 2.

Hardness test were performed by using Brinell Hardness Number (BHN) and the specimen was designed based on the ASTM E10 standards. The Brinell hardness utilizing the ball having 5 mm distance across and a load capacity 250 kg, which make an expansive and strong indentation following all the more precisely of the normal hardness esteem got over the more extensive surfaces with numerous grains and consistency of the material in unpredictable surfaces.

The hybrid composites of impact strength were directed by utilizing Izod impact testing machine. The prepared samples has arranged by the ASTM E23 guidelines with the measurement 75mmx 10 mm × 10 mm as appeared in Figure 3.17. The square cross sectional zone comprises of 2 mm depth and 450 indent edge upgraded by the crossover composites. The testing machines have limit of the vitality level 0 to 160 J. The schematic portrayal of the Izod sway testing machine as appeared in Figure 3.16

After the tensile specimen's metallurgical characterization of fractured surfaces morphology such as interfacial bonding, homogeneous distributions, and porosity defects were analyzed by using Scanning Electron Microscope (SEM). These specimen surfaces have been used for polishing using Keller's regeneration, which contains (2 mL HF + 3 mL HCl + 20 mL nitric acid + 190 mL distilled water).

4. Results and discussions

4.1. Impact strength

The impact strength of the hybrid composite materials was performed to look at the durability and score affectability of the composites upgrade with the different engineering materials. In Figure shows the impact strength of the hybrid composites with different volume fractions. The addition of SiC and TiO₂ on AA6061 matrix of impact strength has increased while increasing particulate reinforcements as reported by Senthil Murugan *et al* (2014). On this conflicting, while expanding the level of SiC support particles added at the same time to the AA6061 composites, it was credited to build up the effect quality of the composites. These outcomes are recommends that the AA6601 matrix is appropriate for the auxiliary applications because of effect quality of the hybrid composites. In any case, the present test work depicted the AA6061 reinforcement composites of impact strength which is less than the AA6061/7.5%TiO₂ /7.5% SiC composites as a result of the brittle happened in the Intermetallics segments (Amanda McKie *et al* 2011). Among the hybrid composites impact strength 110 N/mm was obtained for AA6061/7.5%TiO₂ /7.5% SiC hybrid composites.

4.2. Hardness

The composite composites were reinforced with different volume fractions using stir casting techniques, in which the sample

Table 1
Physical properties of aluminium Alloy AA6061.

Material Properties	Tensile strength (MPa)	Density (g/cm ³)	Thermal conductivity (W/m-K)	Modulus of Elasticity (GPa)
AA6061	300	2.70	167	68.9
SiC	137.86	3.22	120	90

Table 2
Chemical Composition of Matrix Alloy AA-6061.

Chemical	Si	Fe	Cu	Mg	Mn	Zn	Cr	Ni	Pb	V	B	Al
Percentage	0.483	0.648	0.082	0.077	0.687	0.211	0.013	0.024	0.028	0.2	0.007	Bal

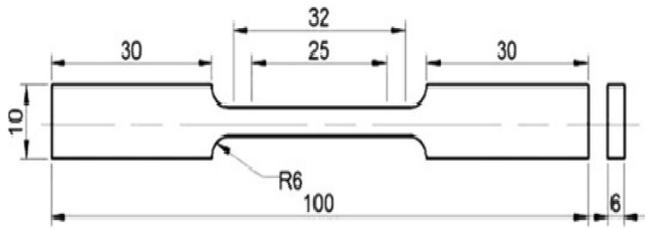


Fig. 1. Dimension of the Tensile Specimen (ASTM E8M-04).

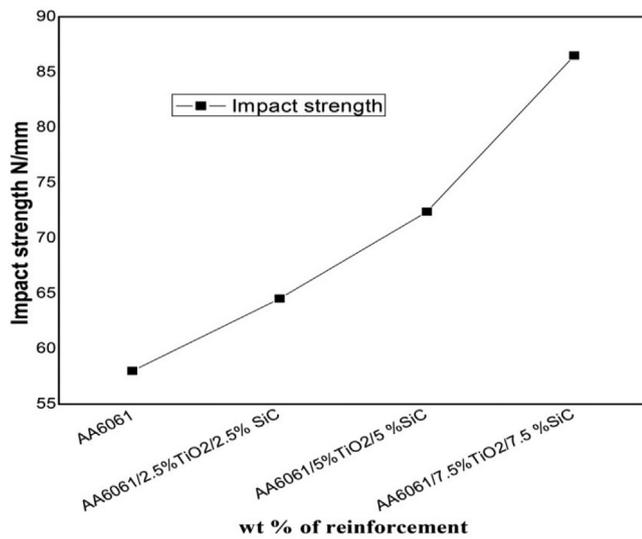


Fig. 2. Impact strength.

was tested at a Brinell hardness (BHN) of 250 kg load. The graphical representation of BHN curve for the different volume fractions while the addition of SiC has improved on the aluminium matrix shows in Fig. 3. From the exploratory aftereffects of hardness were watched no deformities during the ball space on composite surfaces because of the homogeneous circulation particles contrasted and the unreinforced AA6061 matrices. The substances of SiC reinforcement on aluminium AA6061 matrix with different volume fractions are opposed in which against the surfaces during the ball indentation. Hence the solid bond affected between the matrix and reinforcements. It has been demonstrated the refinement of grain sizes are acquired by utilizing mix throwing manufacture strategy. Fig. 4.

The expansion of reinforcements fundamentally improved the hardness of the hybrid composite materials. The dislocations of particles and different deformities are acquired because of the uniform dispersion of particles. The higher hardness esteems are acquired for AA6061/7.5% TiO₂/7.5% SiC (60 BHN) with the correlation by unreinforced composite.

4.3. Density

Fig. 5 shows the correlation between the experimental and theoretical density of the hybrid composites with the invention of reinforcement materials. The results were found with the rein-

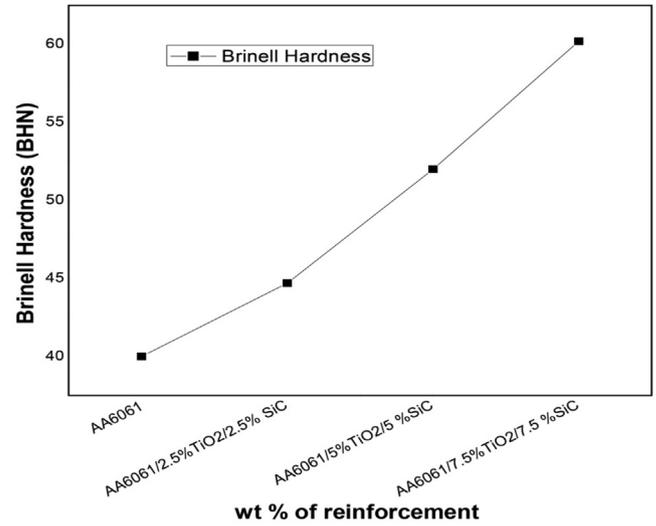


Fig. 3. Hardness.

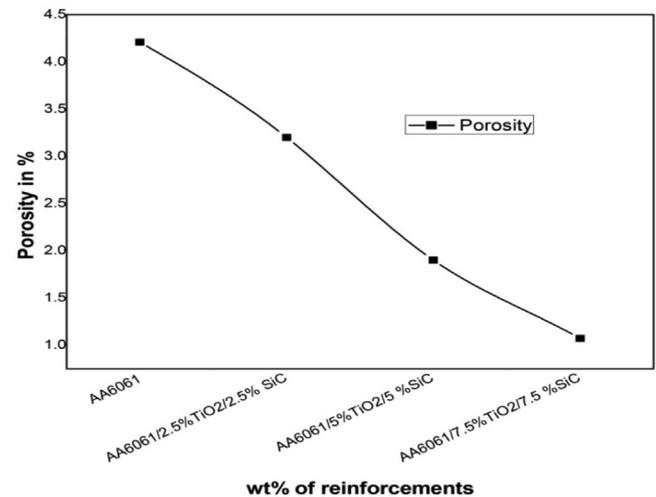


Fig. 4. Porosity.

forcement of the three phases by adding SiC content, reducing the theoretical density of the hybrid composites. The development of pores and throwing abandons the hypothetical density can't be utilized for the exploratory examinations. The density of TiO₂ which is less than the matrix alloys (AA6061) and SiC reinforcements. Because of the SiC molecule and the fixed substance decreases the density of composites reduces of the structure has appeared in Fig. 5. The watched aftereffects of hypothetical density and experimental density contrasts demonstrates that little measure of porosity displayed lower than 2.5% of presence of the composites. The past researches are revealed the porosity of hybrid composites which is higher than 4% is not used in the aluminium matrix. However, optimizing the aluminum matrix developed with any reinforcement does not measure with the porosity of the hybrid composites. This competent degree of porosity must be inhabited hybrid composites relying on the handling strategies,

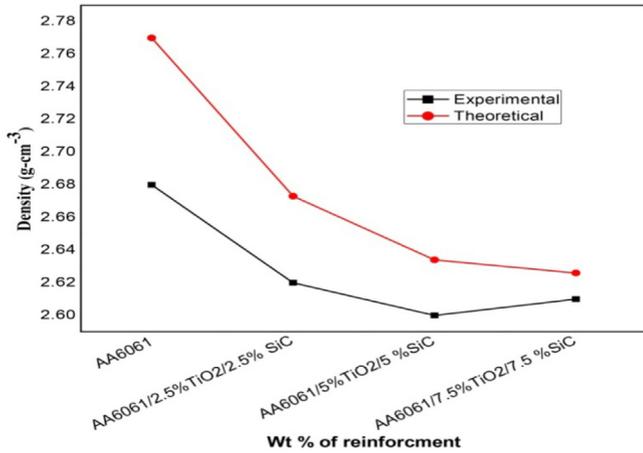


Fig. 5. Density (Experimental V_s Theoretical).

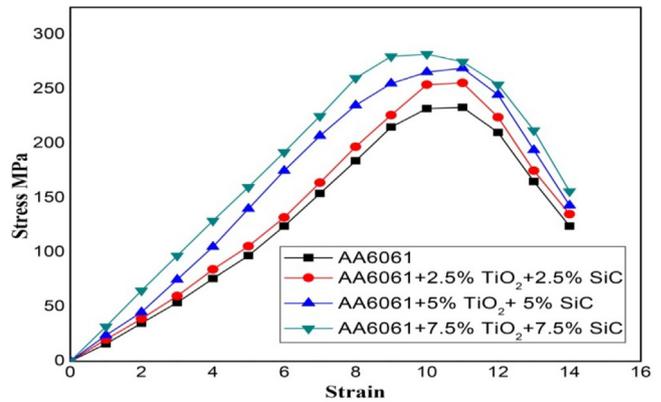


Fig. 7. Stress MPa.

size and dispersion of particles. The SiC substance and porosity both are go about as controlled factor for the estimation of densities. Figs. 6,7.

Typically SiC a molecule comprises of the experimental density diminished contrasted and the base amalgam. The density decreases from 2.604 g/cm³ AA6061/7.5%TiO₂ /7.5% SiC to 2.6 g/cm³ (AA 6061). Although the porosity have been controlled with that experimental density for increasing levels 3.3% to 4.76% during the addition of SiC content on aluminium matrix. Then again expanding with the fortifications for the experimental density directly expanded because of diminishes the porosity level. Be that as it may, the density of the composites diminished up to 1% and lessens 45% porosity on the prepared hybrid composites. The essential significance of hybrid composites accomplished the better mechanical properties improved with the controlling variables, for example, the porosity and SiC content. The found outcomes showing the lower thickness level happened in the fortifying composites contrasted and the customary combination.

The determined estimation of hypothetical density arranged in Table 3 by utilizing the accompanying conditions. The manufacture of new hybrid composites of density has estimated by the Archimedes principle. The inferred scientific condition for density calculation by the condition followed as

$$\rho_{hc} = \frac{m}{m - m_1} \rho_w$$

Where m - Mass of the composites measured from the air

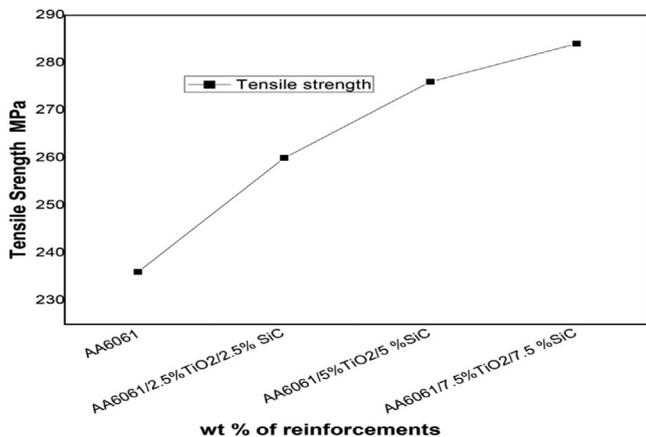


Fig. 6. Tensile Strength.

Table 3

Comparison Theoretical and Actual Density of Composites.

Composition	Theoretical Density (g cm ⁻³)	Actual Density (g cm ⁻³)	Porosity (%)
AA6061	2.68	2.77	4.21
AA6061/2.5%TiO ₂ /2.5% SiC	2.62	2.673	3.2
AA6061/5%TiO ₂ /5% SiC	2.630	2.634	1.9
AA6061/7.5%TiO ₂ /7.5%SiC	2.625	2.626	1.07

m_1 - Mass of the composites measured from the distilled water
 ρ_w - Density of the distilled water (Generally 998 kg/m³ at 20 °C)

The electronic equalization machine 0.001 mg in the water and air was utilized to decide the mass of the all prepared samples. The porosity additionally determined by the accompanying condition

$$p = \frac{\rho_{th} - \rho_{hc}}{\rho_{th}}$$

Where ρ_{th} -Theoretical density

ρ_{hc} -hybrid composites measured density

The hybrid composites of hypothetical density esteem determined by utilizing rule of mixtures

$$\rho_{th} = \rho_{Al6061} V_{Al6061} + \rho_{TiO_2} V_{TiO_2} + \rho_{SiC} V_{SiC}$$

ρ - density

V -Volume fraction

So also, the hybrid composites of volume fraction has determined by utilize the accompanying conditions

$$V_r = \frac{\rho_{Al6061} - \rho_{hc}}{\rho_{Al6061} - \rho_r}$$

V_r - Volume fraction

ρ_{Al6061} -Density of AA 6061 alloy

ρ_{hc} -Density of reinforced composites

ρ_r - Individual density of the reinforcements such as TiO₂ and SiC.

4.4. Theoretical calculation

In Table 4 shows the young's modulus of casted alloys. The young's modulus of the hybrid composite materials have been determined by utilizing hypothetical conditions, which dependent on the molecule plans of fortifying materials. The current materials of young's modulus assessed by utilizing rule of blends (ROM)

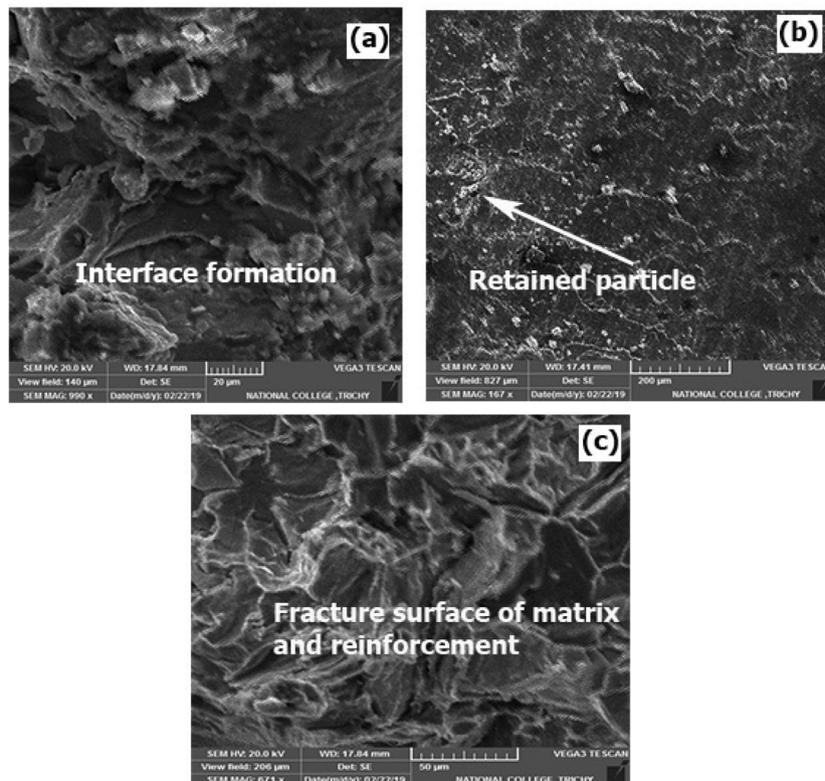


Fig. 8. Fractured surface morphology.

(Clyne, T.W). The general recipe can be communicated as the accompanying condition

$$E_C = E_F V_F + E_m V_m$$

$$V_F + V_m = 1$$

4.5. Tensile strength

The current material research businesses concentrated on to lessen their thickness of the composites utilizes in aviation and automobile. The elasticity of AA6061 hybrid composites strengthened with TiO_2 (2.5%, 5% and 7.5%) and SiC (2.5%, 5% and 7.5%) molecule assessed by Universal Testing Machine (UTM). The hybrid composites have improved for the upgrade the impact of support on AA 6061 contrast and the base compound. Each wt % of composites structured dependent on the ASTM standard measurements and during the tensile test the load meter was broadly spread to the fortification by utilizing the matrix component. Generally the strength of the hybrid composites were characterized by strengthening mechanism, due to the presence of TiO_2 and SiC particles of homogeneous distribution on the matrix. Accordingly the quality was improved contrasted and the unreinforced amalgam and made the great interfacial bond between the reinforcements and particles. The uniform dispersion of blends causes the separation of

matrices because of diminished the crack. The addition of SiC and TiO_2 on aluminium matrix both are improved strength of the hybrid composites and decrease the fracturing while the stress transformations for the corresponding displacements as shows in Figure xxx.

The SiC on aluminium matrix attributed a important role in Metal Matrix Composites (MMC_s) for developing the interfacial strength compared with other elements (L.M. Tham *et al*). The hard phases of particles SiC and TiO_2 facilitate the good interfacial strength were the load transfer adequate to make the quality of the hybrid composites. Therefore, increases volume fractions their leads to improve the strength of the hybrid composites. The experimental result produces tensile strength of comparison for AA6061 (230 MPa), AA6061/7.5% TiO_2 /7.5% SiC (280 MPa), it is found to be that addition of SiC particles leads to increases the strength other than not compensated while increasing strength of the composites. These types of composites obtained reasonable ductility characteristics and elongation those attained by SiC and TiO_2 reinforcements. Be that as it may, the expanding tensile strength during the load transfer because of bonded strength with the SiC and the refinement of grain structures as fortifying mechanism. It is conceivable to close the expansion SiC support to improve the rigidity so as to additionally expanding the weight rate upgrade the sufficient flexibility and optimized strength.

4.6. Fractured surfaces

Fig. 8 shows the tensile fractured surfaces of hybrid composites with different volume fractions obtained for maximum load limits. The difference between the reinforced and unreinforced alloys of fractured surfaces have established by using Scanning Electron Microscope (SEM). The surface morphologies characterized based on the size of cracks, defects and dimples forming in the AA6061 matrix. However, the microstructure analysis revealed brittle

Table 4

Calculation of Young's Modulus (GPa).

S. No	Percentage of reinforcement	Young's Modulus (GPa)
1	AA6061	68.9
2	AA6061/2.5% TiO_2 /2.5% SiC	72.3
3	AA6061/5% TiO_2 /5 %SiC	74.6
4	AA6061/7.5% TiO_2 /7.5 %SiC	112.3

behaviour for the existence of SiC particles due to fractured surfaces are provide a important role in tensile fracture analysis. The brittle fracture of SiC, splits are shaped in AA 6061 due the support showed the lamentable interface bonding. This behaviour were attributed that crack propagation near to the dendrites boundaries are formed as fracture surfaces as intergranular type. It was the outcomes demonstrated where the expanding the level TiO₂ including the matrix of SiC particle sizes also increments homogenously for to diminish the deformities.

5. Conclusion

1. The density of the manufactured composite is higher than that of the matrix material because of the nearness of high density of SiC particles.
2. Hardness and tensile strength are enhanced with increasing of content of SiC and TiO₂ particles in the composite, at the expanse of ductility. The hardness of the composites is improved by 40 BHN for AA6061 to 62.3 BHN for AA6061/7.5% TiO₂/7.5 SiC.
3. The tensile strength was obtained 280 MPa for AA6061/7.5% TiO₂/7.5 SiC which is higher than the base materials.
4. It has been noticed that density and porosity of the composites are diminished with the expansion in the TiO₂ content. The elasticity of the half and half composites is expanded with the expansion in SiC content (5%–20%) and the maturing time (0–24 h).
5. The SEM studies revealed the effects if interfacial bonding and that failure of the composites gradually shifted from ductile to brittle behaviour with an increased content of SiC particles in the hybrid composites.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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