

EFFECT OF TiO₂ AND SiC NANOPARTICLES ON THE MICROSTRUCTURE AND MECHANICAL CHARACTERISTICS OF AA7178 METAL MATRIX COMPOSITE

Nikhil Bharat  and P. S. C. Bose

Mechanical Engineering Department, National Institute of Technology, Warangal 506004, India

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Abstract

The purpose of this study was to explore the effect that stir casting has on a TiO₂ and SiC nanoparticles reinforced aluminium matrix composite. In order to study the development of ceramic particle reinforced aluminium matrix composite, density, tensile strength, hardness, and fracture analyses were carried out. The scanning electron microscope (SEM) investigation showed that the reinforcement particles were distributed consistently throughout the aluminium matrix. Electron backscatter diffraction (EBSD) study revealed the grain refinement of composites on inclusion of nanoparticles. The results of the experiments revealed that addition of 3 weight percent TiO₂ and SiC

particles to AA7178 alloy led to an increase in both the maximum strength and the hardness properties but, the elongation percentage of the manufactured composites progressively deteriorated. From the fractured surface of tensile samples, a microstructural study showed that AA7178, AA7178/TiO₂, and AA7178/SiC nanocomposites were showing both ductile and brittle behaviour because of micro-cutting and micro-voids.

Keywords: AA7178, nanoparticles, TiO₂, SiC, properties, EBSD

Introduction

Composite materials are more useful than traditional materials because they offer great balance of strength to weight ratio, high strength, and low wear loss. As a result of combining the best features of constituent parts, composite materials exhibit exceptional physical, mechanical, and tribological capabilities. Advanced technical applications that demand great strength and stiffness are increasingly relying on Al composites. Because of their low weight and high strength, Al composites may be effectively employed in the production of a wide variety of engine components, including pistons, piston pins, cylinder heads, blocks, and so on.¹ The exceptional mechanical qualities of metal matrix composites are generated by combining aluminium matrix with hard and stiff ceramic particles, such as SiC, TiO₂, BN, Al₂O₃, ZrB₂, B₄C, TiC, TiB₂, graphene, etc.^{2–9} A metal matrix composite may be fabricated using a wide variety of processes, including as conventional casting, stir casting, powder metallurgy, ultrasonic-assisted casting, and more. Stir casting is a common method of

fabricating metal matrix composites. This is essentially an advanced casting method. Conventional casting AMCs have trouble combining reinforcement into main matrix. The disparity between base matrix and reinforcement densities prevents reinforcement distribution in main matrix and encourages clustering. A stirrer in the molten mixture may check energy differences and prevent this. Stirring molten slurry before pouring it into mould cavity ensures reinforcement distribution in aluminium matrix. Stirring creates a vortex that mixes reinforced particles.^{10–12} Kumar et al.¹³ conducted an experiment to assess the impact of SiC and Mo reinforced particle fabricated by stir casting on the mechanical and morphological behaviour of metal matrix composite. In comparison to the basic alloy matrix, the composites' microhardness and tensile strength were increased by 7.14 and 8.62%, respectively. Tamilanban et al.¹⁴ used stir casting to create a composite with 12% SiC, 4% Mg, and 2% Cu reinforcing particles. It was observed that when mixing at 700 rpm, the SiC particles were more evenly dispersed throughout the matrix. Since, the SiC particles were uniformly dispersed in Al matrix at a stirring speed 700 rpm, the resulting composites had higher tensile strength. Rangrej et al.¹⁵ conducted an experimental study to investigate the impact

of stir casting method on the distribution of reinforcing particles. It was concluded based on simulation results that 60° blade angle provides a greater recirculation area than 45° and 90° blade angle. Srinath et al.¹⁶ conducted an experiment to analyse the influence of nano-SiC particle on the mechanical properties of fabricated metal matrix nanocomposite. Stir casting technique was used to produce the nanocomposite. In another study, it was discovered that the optimum results of properties were obtained at 20% nano-SiC reinforced with Al6082 with a hardness value of 93.39 N/mm² and compressive strength of 48.97 MPa. Kumar et al.¹⁷ fabricated metal matrix composite using stir casting technique. They selected SiC as a reinforcing material and Al7075 as a base matrix alloy and analysed the effect of reinforcement on the mechanical properties of the produced metal matrix composite. It was determined that the best value of ultimate tensile strength could be attained at a processing temperature of 800 °C, and that a rockwell hardness value of 96HRA could be produced at a processing temperature of 850 °C. Bommana et al.¹⁸ conducted an experiment to assess the influence of 6 wt% of (B₄C + SiC) particle on the mechanical properties of the hybrid AA6061 metal matrix composite. It was reported that the optimum value of the property was obtained at (4%B₄C + %SiC + AA6061). The BHN value was enhanced by 60% in contrast with base alloy matrix. Yu et al.¹⁹ selected Al7075 as a base material and SiC as a reinforcing material. The composites were fabricated using a stir casting process. They studied the impact of nano-SiC particles on the mechanical behaviour such as tensile and fatigue properties. In another study it was concluded that with the inclusion of 1 wt% of nano-SiC to Al7075, the tensile strength and fatigue strength were enhanced by 21.33 and 66%, respectively. Arunkumar et al.²⁰ conducted an experiment to determine how the addition of reinforcement (egg shell + SiC) affected the final hybrid composite's performance. It was concluded that with the insertion of reinforcement, hardness value increased upto 197 HV. Samal et al.²¹ fabricated AA5154 + SiC composite using a conventional stirring approach. They studied the impact of reinforcing particle on the microstructure and mechanical properties of the produced composite. From the morphological analysis, it was observed that the particles were uniformly dispersed and maintained good interfacial bonding between the reinforcement and base alloy matrix. The optimal value of the hardness and UTS were obtained at 15 wt% of SiC. The hardness and tensile strength enhanced by 37 and 35%, respectively. Bhusan²² used SiC particles as a reinforcing material and AA7075 as a base material and studied the impact of SiC on the mechanical properties. He fabricated the composites using stirring casting method and concluded that hardness increased by 10.48% with an increase in SiC particles from 5 to 15%. Bharat et al.²³ fabricated nanocomposite (AA7178 + TiO₂) using stir casting method and studied the effect of reinforcement on the microstructure and mechanical properties of the composite. It was concluded that grain

size as well as mechanical properties were enhanced with increase in the weight percentage of reinforcing particles. Bulbul et al.²⁴ conducted an experiment to assess the morphological and mechanical behaviour of Al-10Ni + TiO₂ composite produced by mechanical alloying method. It was reported that maximum microhardness value (541 +/- 20 HV) was obtained in the composite fabricated after it was milled for 20 h and sintered at 500 °C. Kumar et al.⁶ studied the impact of ZrB₂ on the morphology and mechanical properties of AA7178 metal matrix composite manufactured by stir casting method. It was observed that grains were refined with addition of reinforcing particle. Better interfacial bonding was seen between matrix and reinforcement at 10 wt% of ZrB₂. However, agglomeration of particles were seen with the inclusion of 15 wt% of ZrB₂ that leads to reduction in mechanical properties. Gajakosh et al.²⁵ investigated the mechanical behaviour of hot rolled Al7075 + TiO₂ + Gr hybrid metal matrix composite. They had also compared the properties with the cast composite. When compared to the cast composite, it was discovered that the microhardness and tensile strength of hybrid composites were improved when subjected to hot rolling. The reason for improvement in the properties was better grain refinement during the hot rolling of the composite. Padmavathi et al.²⁶ selected micro SiC and nano-TiO₂ particles as a reinforcing material and Al6061 as the base matrix. Stir casting technique was used to fabricate the hybrid metal matrix composite. It was concluded that the optimum value of mechanical strength was obtained at 1 wt% nano-TiO₂ and 10 wt% SiC. Natraju et al.²⁷ reviewed the effect of ceramic reinforced aluminium composite produced by stirring casting technique. It was concluded that with the inclusion of ceramic particles to the base matrix alloy, the properties of the composites were enhanced generally. Prasad et al.²⁸ used RSM technique to optimize and study the mechanical properties of TiO₂ microparticle reinforced AA7150 composite fabricated by stir casting method. According to the findings of analysis of variance, the stirring limitations did have an influence on each feature; however, the selected square interaction did have a significant effect at 95% confidence level. Badran et al.²⁹ conducted an experiment to assess the mechanical behaviour of fabricated (Al6061 + TiO₂) composite. It was reported that an optimal value of tensile strength was obtained at 2 wt% TiO₂. However, the optimal value of hardness was obtained at 5 wt% TiO₂. Podder et al.³⁰ fabricated hybrid (Al6063 + Cu + TiO₂ + ZrO₂) composite by stir casting technique. It was found that 10% of hybrid reinforcement showed the highest toughness compared to other hybrid reinforced combinations. The experiment was carried out by Adediran et al.³¹ with the intention of optimizing the mechanical and stir casting parameters of Al7075 + TiO₂ metal matrix composite using RSM approach. It was concluded that the model was confirmed to be statistically significant at a confidence level of 95%. The optimal conditions for stir

casting were 779.3 °C temperature, 574.2 rpm of stirring speed and 22.5 min of stirring time.

Even though research has been done recently on the production, development, and properties of composites, more research is still needed, especially on the microstructure and mechanical properties of nano-MMCs. From the literature review, it is observed that the comparative study of the effect of different reinforcements on the microstructure, properties of composites and the influence of the misorientation angle on the grain size is something that has not been investigated until recently. Hence, in the current investigation, two types of nano-MMCs with AA7178 matrix and 3 wt% of SiC and TiO₂ reinforced particles were produced by stir casting technique. Microstructural and mechanical properties of the materials were analysed and compared using scanning electron microscopy and electron backscatter diffraction.

Materials and Methods

In this work, aluminium alloy AA7178 was used as a matrix material for the manufacture of aluminium matrix composites. AA7178 is one of the Al–Zn–Mg–Cu alloys that has a wide range of applications in engineering and aviation due to its considerable mechanical qualities, ductility, and superior strength. Table 1 shows the chemical composition of AA7178.³² The specific weight proportion of TiO₂ (30–50 nm) and SiC (30–50 nm) which were used as reinforcing materials (NRL Jharkhand India) and the TEM image of nano-TiO₂ and nano-SiC particles are shown in Figure 1 along with EDS image prepared using copper grid. The base alloy matrix, AA7178/3 wt% nano-TiO₂ composite, and AA7178/3 wt% nano-SiC composite were given the designations S-0, S-1, and S-2, respectively, for the composites that were created. The diagram in Figure 2 provides an image of stir casting manufacturing equipment that is used to manufacture aluminium nanocomposite. In order to make each casting, about 1 kg of aluminium alloy AA7178 was melted down in a graphite crucible. After it was dried by being heated in a muffle furnace at 450 °C for forty-five minutes, nano-TiO₂ and nano-SiC powders were then incorporated into molten AA7178 matrix at a pouring temperature of 750 °C. A mechanical stirrer was rotated in a graphite crucible at a constant speed of 625 revolutions per minute for ten to 15 min in order to disperse nanoparticles throughout the matrix.³³ Incorporating a little amount of magnesium powder into the molten composite during the mixing

process increases the wettability of the molten material, which decreases surface tension and oxide production.³⁴ Before putting the molten slurry into the open mould, the mould was first warmed for one hour at a temperature of 500 °C. This step is essential in order to keep the slurry in a liquid state during the whole pouring process. Following the mixing step, the composite slurry was put into a permanent iron mould that had been heated beforehand, and it was allowed to cool at room temperature. In order to perform an analysis of the microstructure of the produced composites, specimens were first trimmed into the appropriate shape according to ASTM standard before being polished to a mirror finish using emery paper of varying grades as well as diamond paste. Scanning electron microscopy was used to examine the microstructure of composite specimens (VEGA3 TESCAN). The hardness behaviour of the manufactured composites was examined using a Vickers hardness tester and subjected to a 100-g force for 15 s in accordance with ASTM 384-99³⁵ standard. Vickers microhardness was measured three times, and the average result for each specimen was recorded. The ultimate tensile strength of the material was measured using a universal testing equipment (Make: FineSpray India; Model: M-50). Average results from three separate tests were used to determine the tensile strength. Scanning electron microscopy was used for fractographic investigation of tensile specimens.

Results and Discussions

XRD Analysis

XRD (X-Ray diffraction) pattern was obtained using Cu-K type radiation. The range for 2 theta is 20°–90°. Figure 3 illustrates an XRD graph of several particle types reinforced in an aluminium matrix composite. Some significant peaks of aluminium were found in unreinforced aluminium-alloy AA7178 matrices. The TiO₂ nanoparticles reinforced aluminium matrix composite with a weight percentage of 3 shows a total of 9 main peaks. The graph reveals that there are five peaks that correspond to aluminium, and four peaks that correspond to Titanium diboride (TiO₂). The designation S-2 refers to a composite material that is reinforced with SiC particles at a weight per cent of 3 and has seven primary peaks. The graph 3 shows that there are five peaks that correspond to aluminium, and two peaks that correspond to silicon carbide (SiC).

Table 1. Elements of the AA7178 Aluminium Alloy Matrix

Element	Zn	Mg	Cu	Fe	Si	Mn	Cr	Ti	Al
Weight %	7.1	2.7	2.0	0.45	0.40	0.30	0.26	0.20	Balanced

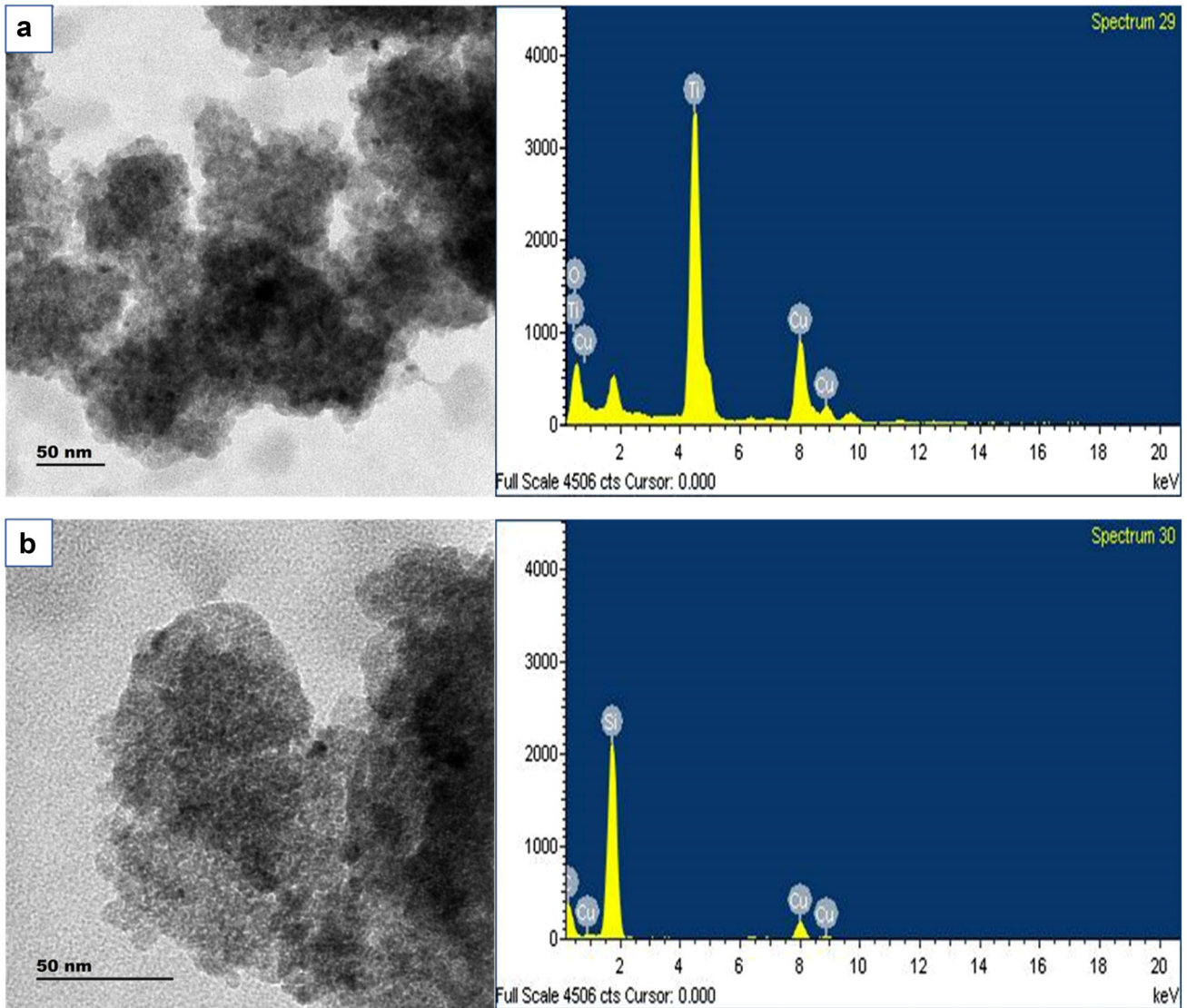


Figure 1. TEM image of (a) nano-TiO₂ particles (b) nano-SiC particles.

Microstructure Analysis

Figure 4a displays the microstructure of the aluminium alloy AA7178 in its as-cast state, without any reinforcing particles being added. It is evident that there are certain voids and clusters present in the base alloy matrix, as seen in Figure 4a. Entrapping of air during the solidification process and may be turbulence during filling process is the source of void formation, while inappropriate mixing of alloying elements during casting is the cause of cluster development. Both these phenomena may be attributed to defects in the casting process. In Figure 4b, c, it can be seen that the reinforcements of TiO₂ and SiC are distributed uniformly throughout the base alloy matrix. Grain refining is directly connected to the substance being distributed uniformly throughout the grain. As a result, the incorporation of reinforcing particles into the matrix has resulted in increased grain refinement. This is due to the fact that the reinforcing particles are functioning as a barrier, which

limits the formation of large grains and ultimately results in the production of small grains. It's clear that the connection between the reinforcement and the matrix is very strong. The development of big grains and the expansion of grains are both successfully halted by the uniform dispersion of nanoparticles. Compared to larger particles, smaller ones have greater pinning impact. However, in Figure 4b the agglomeration of TiO₂ particles can be seen. The high surface area to volume ratio of nanoparticles causes them to aggregate, reducing the surface energy available to individual particles. EDX analysis is a study that is frequently performed in order to determine the chemical composition of a substance. The EDX method involves analysing X-rays that are given off by a substance after it has been subjected to electromagnetic radiation. Figure 4d–f depicts the EDX image of base alloy matrix, TiO₂ reinforced nanocomposite and SiC reinforced nanocomposite. It is clearly seen that all the reinforcing elements are

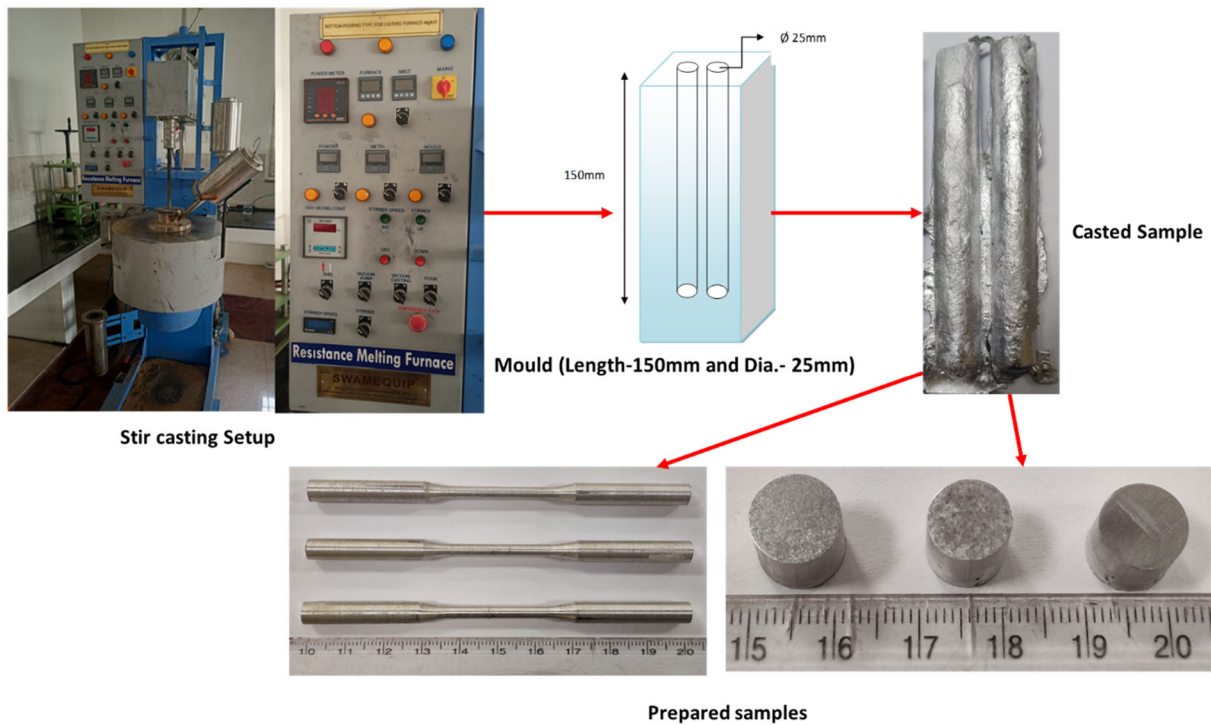


Figure 2. Image of the stir casting setup with prepared samples.

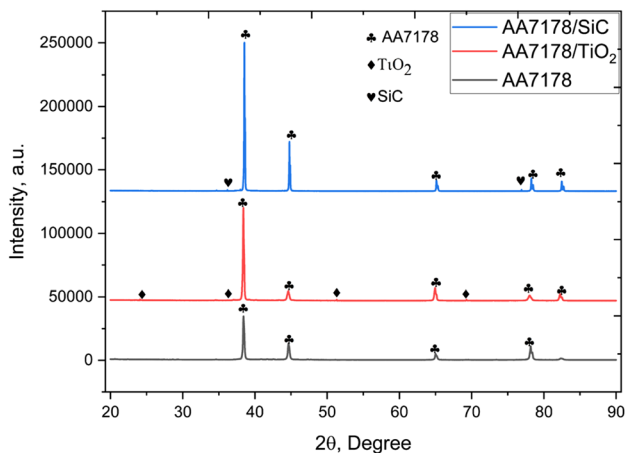


Figure 3. XRD plot of nanocomposites.

present in the fabricated nanocomposite, i.e. titanium, silicon, carbon, aluminium, etc.

EBSD Analysis

Inverse pole figure (IPF) maps were used to describe the grain size as well as the crystallographic orientation of the material. Crystallographic orientations are associated with each of the numerous colours that appear on the IPF maps. These orientations enable the calculation of grain size and the investigation of the process of texture development. These maps are helpful in bringing attention to the microstructural aspects of the area.³⁶ Figure 5a–d shows

the inverse pole figure maps of the base alloy matrix, TiO₂ reinforced nanocomposite, and SiC reinforced nanocomposite. The misorientation angle represented by each colour in these maps ranges from 0° to 15°. Grain boundaries are classified as either high (crystallographic misorientation >15°) or low (crystallographic misorientation <5°) based on the angle of the misorientation relative to the crystal growth direction. It is seen from Figure 5a that a more significant number of low-angle grain boundaries (around 66.8%) are present, resulting in a large grain size of the composite. The possible reason may be the absence of reinforcing particles which act as a barrier to restrict further formation of grains. However, in Figure 5b, c the grain size is smaller than base material because of higher angle grain boundaries (54 and 57%) due to the presence of nanoparticles which restricted the increase in the grain size. Inverse pole figures showed that nanoparticles modify the crystallographic orientation of nanocomposites relative to unreinforced samples. When compared to the samples that did not include reinforcement, the nanocomposites had a texture that was very consistent.

Physical and Mechanical Properties

In terms of material properties, density significantly influences the strength-to-weight ratio and material features. The matrix alloy AA7178 (S-0) has a 2.81 gm/cc density. The density of TiO₂ reinforcement particles is 4.23 gm/cc, whereas the density of SiC reinforcement particles is 3.21 gm/cc. Archimedes' principle was used to determine

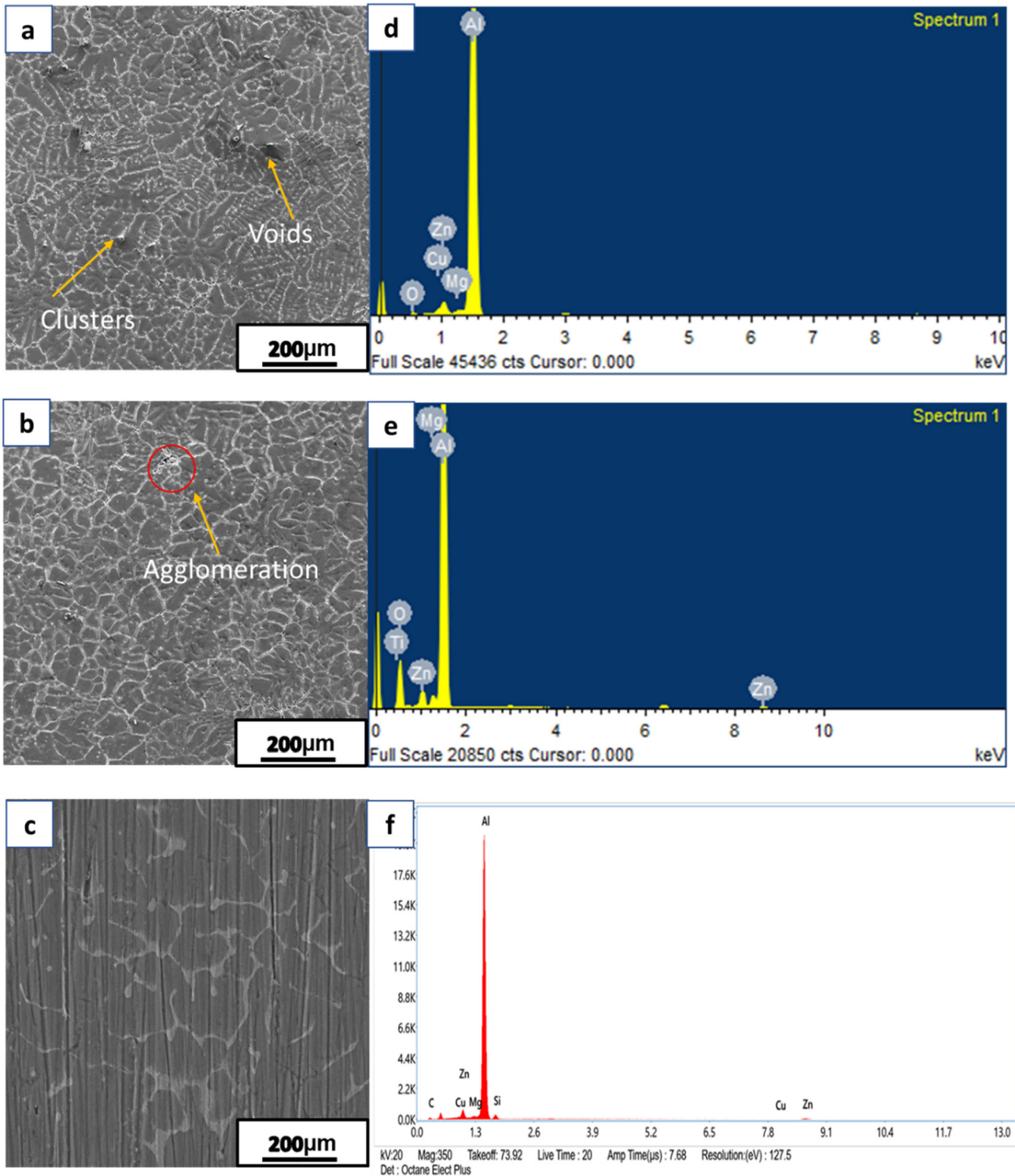


Figure 4. SEM micrographs of (a) base alloy matrix, (b) TiO₂ (wt%) reinforced nanocomposite and (c) SiC (wt%) reinforced nanocomposite along with EDAX image.

the true density of manufactured composites by taking the average of three test. TiO₂ reinforced nanocomposite (S-1) had a greater theoretical density than SiC reinforced nanocomposite (S-2) as shown in Figure 6. The unreinforced alloy had a higher void content than TiO₂ and SiC reinforced composites, which have a smaller void content.

When comparing TiO₂ reinforced composite (S-2) with SiC reinforced composite (S-3), it can be seen that TiO₂ reinforced composite (S-2) reported smaller void %, shown in Figure 7. The developed void material comes from a variety of sources. It is anticipated that the presence of dispersive substances in the molten matrix, in combination

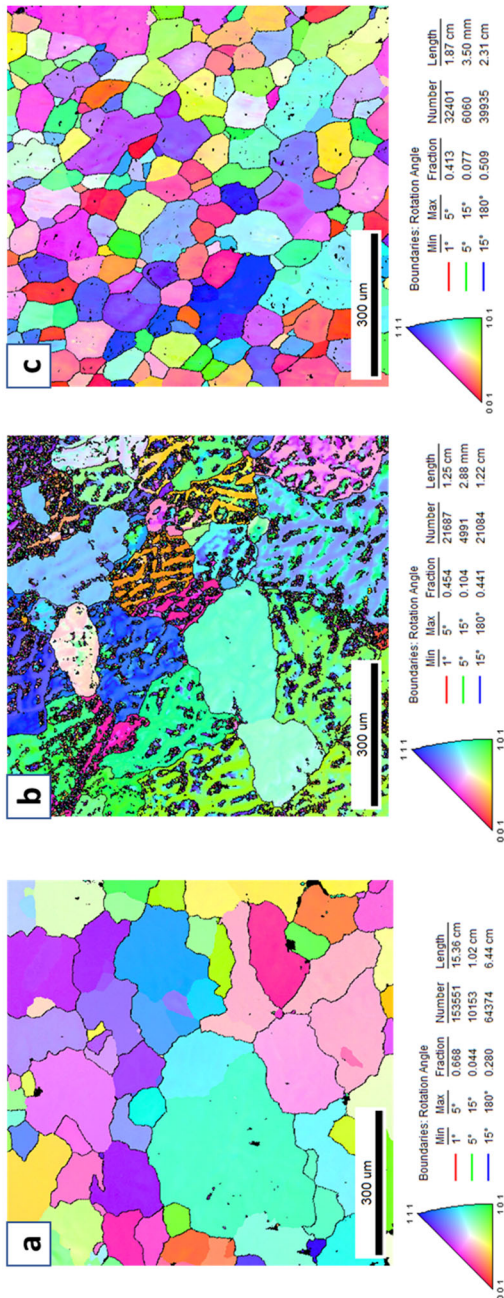


Figure 5. Inverse pole figure map of (a) base matrix alloy, (b) AA7178 + 3 wt% TiO₂ and (c) AA7178 + 3 wt% SiC.

with deep nucleation of ceramic particles, would result in enhancement of the contact area, and lead to specific void associates of various particles. Ceramic reinforcement was added to the void, which resulted in its enhancement. In addition, the increase in the vacancy content of composites was accompanied by a reduction in the grain size of the reinforcing particle. It is related to the maximal contact zone between the ceramic particles and the molten matrix in the case of reduced particulate size. Increasing casting temperature increases void content because of gas trapping during metal mixing. Large casting temperatures improve the wettability of the reinforcement, which leads to uniform dispersion of ceramic particles throughout the molten matrix. This results in a considerable reduction in the amount of void space that is present in the cast samples. The overall outcome of the physical and mechanical properties is listed in Table 2. It is observed from Table 2, that with an increment in wt% of nanoparticles, hardness as well as tensile strength of the composite also increased in contrast to what was observed with base alloy matrix.

Figures 8 and 9 show the results of mechanical testing (average of three test) on TiO₂ and SiC reinforced aluminium matrix composites. The Vickers microhardness test resulted in a significant advancement of the microhardness of the material. When compared to base matrix alloy, the hardness of a nanoparticle-reinforced composite is much higher. The hardness of the material was determined by placing intense stress on a specific location, and dispersion density was increased to encourage the load to remain below the indentation area. When compared to base aluminium matrix alloy, the micro hardness of S-1 and S-2 rises by about 56.55 and 51.70% respectively due to the insertion of hard and stiff TiO₂ and SiC nanoparticles as shown in Table 2. The rise in the hardness of the composites that have been created might have been caused by several factors. To begin with the hardness of nanoparticles is greater in comparison to the hardness of the matrix alloy, and the incorporation of these reinforcements into the matrix in an even distribution leads to an increase in the matrix's overall hardness. Second, the addition of hard ceramic particles refines the grains of aluminium alloy, which increases the dislocation density of the matrix reinforcement interfaces and, as a result, increases the hardness values of the composites that are generated. Last but not least, the addition of reinforcing particles causes an increase in the mass of the manufactured composites. This mass increase leads to densification, which in turn produces an increase in the composites' hardness.

The outcome of nanocomposites' ultimate tensile strength and percentage of elongation is shown in Figure 10. The tensile specimen S1 before experiment and after experiment is shown in Figure 9. It has been observed that the addition of a few different kinds of dispersive nanoparticles causes an increase in the ultimate tensile strength from 95.62 to 210.45 MPa for TiO₂ reinforced nanocomposite

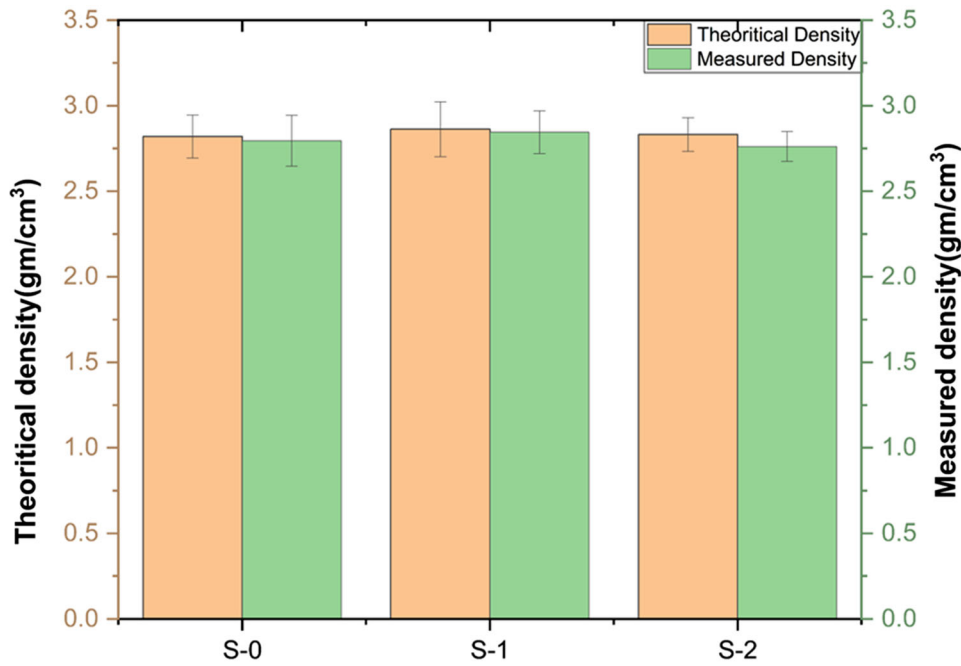


Figure 6. Variation of density of nanocomposites.

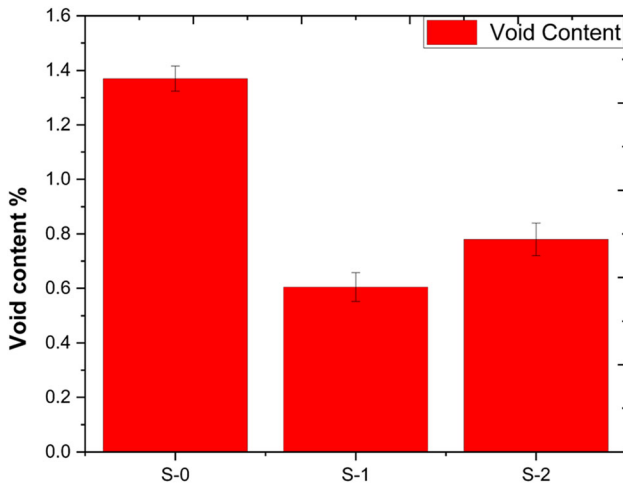


Figure 7. Void content nanocomposites.

and 206.12 MPa for SiC reinforced nanocomposite as depicted in Table 2. TiO₂ reinforced composite (S-1) and SiC reinforced composite (S-2) clearly demonstrate greater strength in comparison to base alloy matrix. The presence of ceramic particles in the matrix alloy causes dislocations to be produced over the whole of the lattice range. Furthermore, mismatches in the coefficients of thermal expansion of the base alloy and reinforcement induce the production of dislocations at the interface, which facilitates the diffusion of alloying elements, and boosting the nucleation and growth rate of precipitates. The dislocation movement is governed by direct contact between dislocation particles or by the matrix structure. Because of these interactions, dislocations tend to clump together at the grain boundaries or the matrix-particle contact, which

ultimately results in the material being more resistant. As seen in Figure 9, the proportion of elongation that occurs drops by a substantial amount as the final tensile strength rises because of addition of hard ceramic nanoparticles which makes the composite brittle in nature. In conclusion, it has been discovered that TiO₂ and SiC reinforced aluminium matrix composites have lower ductility in comparison to unreinforced AA7178 matrix alloy.

Fractography

The kind of fracture that happened during the tensile test was determined using fractureography analysis on fragmented tensile specimens. In general, the manner of fracture in tensile specimens was classified as ductile or brittle. At room temperature, the fracture microstructure of specimens subjected to tensile test of base alloy matrix, AA7178/3 weight per cent TiO₂ nanocomposite, and AA7178/3 weight per cent SiC nanocomposite is shown in Figure 11. The stir casting process has a significant influence on the formation of a variety of interfaces between the matrix and the reinforcement, which facilitate the production of cracks and their propagation.

The microstructural study of base AA7178 matrix shown in Figure 11a displays smaller dimples that are dispersed evenly. These dimples indicated the matrix's ductile characteristics. Morphologies of base alloy matrix show equiaxed dimples, indicating ductile fracture with large permanent deformation and localized maximal stresses. It can be seen in Figure 11b, c that the material failed in a

Table 2. Physical and Mechanical Properties of Nanocomposites

Specimen (average of 3 tests)	Theoretical density (g/cm ³)	Measured density (g/cm ³)	Void %	Hardness HV	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
7178 Alloy	2.82 ± 0.126	2.7952 ± 0.149	1.37 ± 0.0456	123 ± 4.25	95.62 ± 3.45	84.36 ± 2.75	4.249 ± 0.235
7178 + 3% TiO ₂	2.8623 ± 0.160	2.845 ± 0.1255	0.604 ± 0.0526	192.56 ± 3.98	210.45 ± 4.26	178.14 ± 3.12	0.9353 ± 0.145
7178 + 3% SiC	2.8317 ± 0.098	2.7614 ± 0.087	0.78 ± 0.0601	186.6 ± 2.974	203.12 ± 4.68	167.65 ± 3.42	0.985 ± 0.125

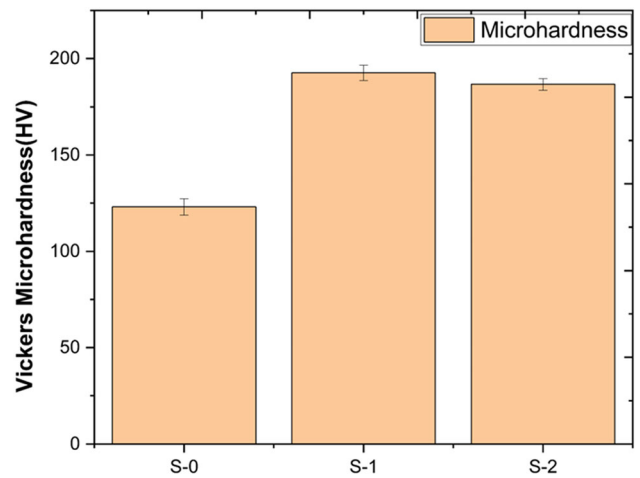


Figure 8. Microhardness value of nanocomposites.

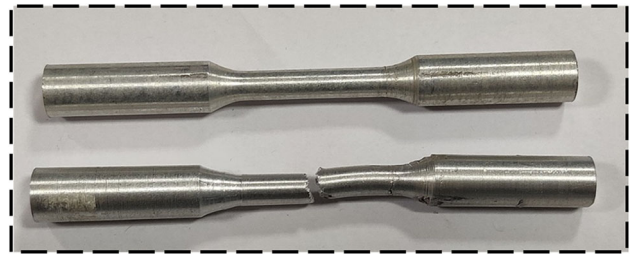


Figure 9. Tensile specimen (S1) before and after.

hybrid manner, meaning that it fractured in both ductile and brittle manner. As a result of the rising tensile stress causing the composite to flex, the load was no longer transferred to the reinforcement in an acceptable manner, resulting in a degradation of grain boundaries. Following this, intergranular fractures emerge and spread inside the grains; hence, fracture manifests itself in both these modes of failure.

Conclusion

- I. Stir casting was used to successfully produce TiO₂ and SiC nanoparticle-reinforced aluminium matrix composites. Nano-sized TiO₂ and SiC powder was found to be reinforcing the whole molten matrix, as demonstrated by the XRD patterns.
- II. The nanoparticles in stir-cast composites were uniformly distributed in the aluminium base alloy matrix, and the composite's porosity was kept to a minimum by carefully controlling the pouring temperature, operating temperature, stirring speed, and stirring time throughout the solidification duration, all of which influence the cast product's volume and surface area.
- III. When compared to nano-TiO₂ and nano-SiC reinforced aluminium matrix composite,

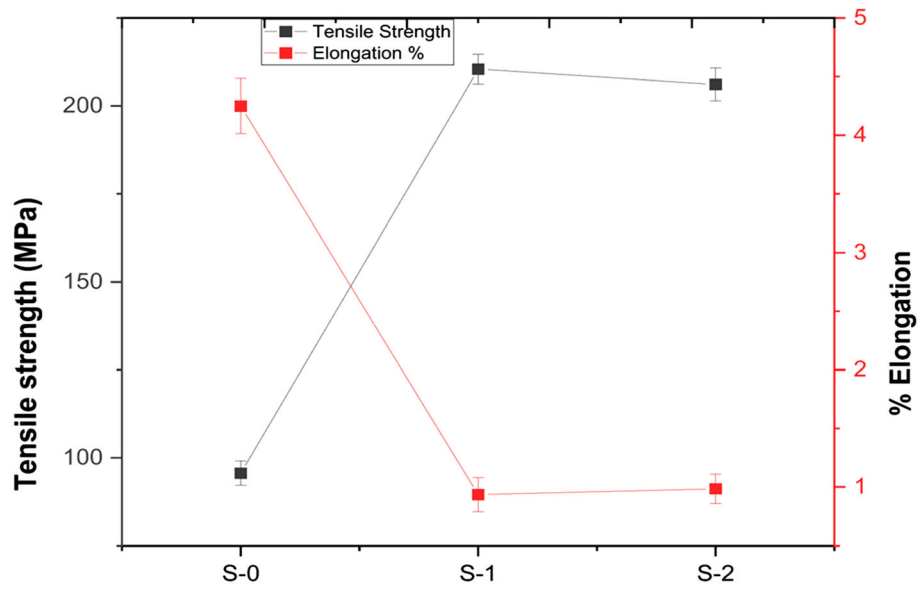


Figure 10. Tensile strength and % Elongation of nanocomposites.

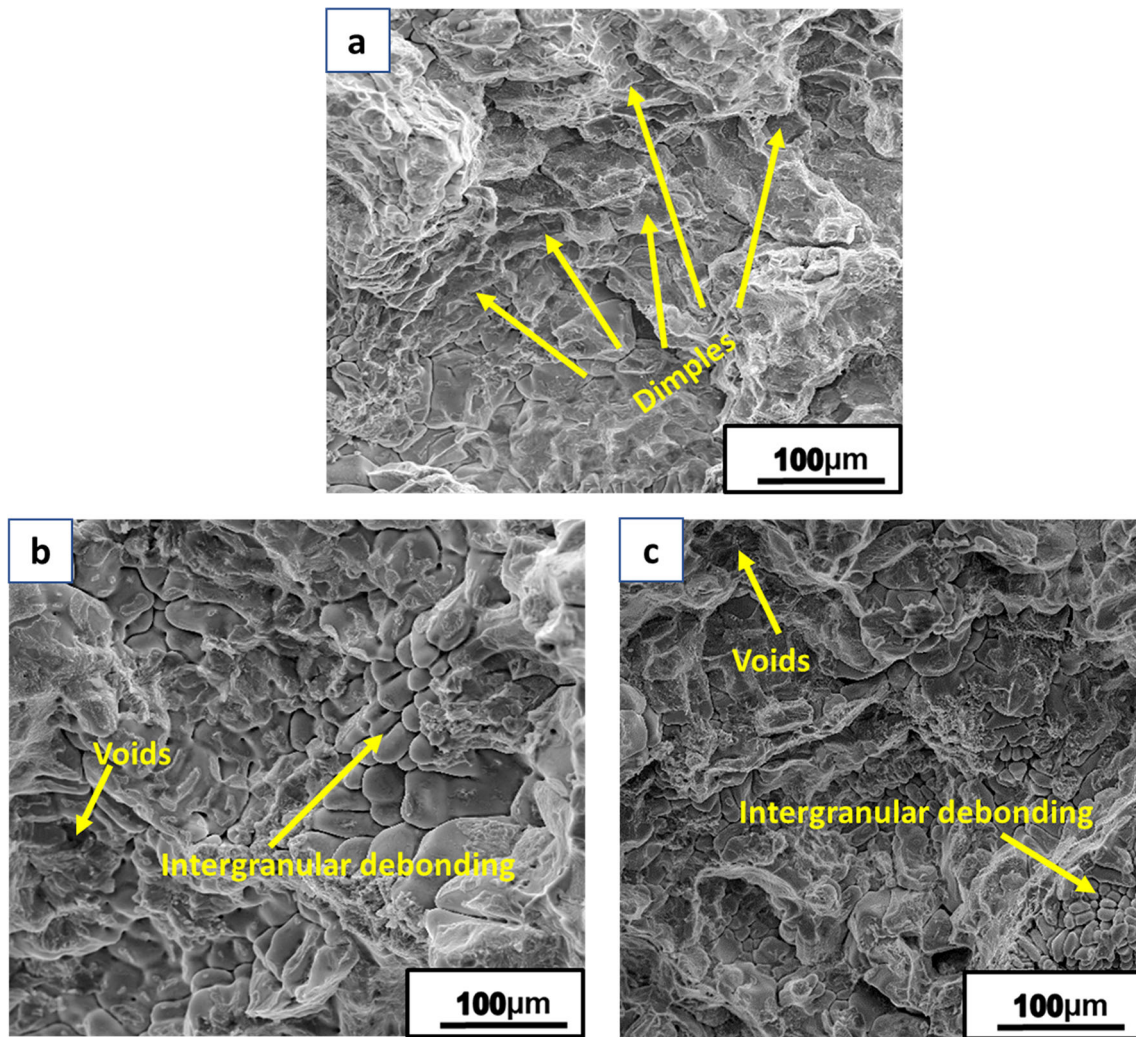


Figure 11. SEM micrograph of fractured specimen (a) base matrix alloy (b) AA7178 + 3 wt% TiO_2 and (c) AA7178 + 3 wt% SiC.

unreinforced aluminium alloy 7178 exhibits lower levels of both strength and hardness. In addition to this, it was found that TiO₂-reinforced nanocomposite had a strength that was 2.05% higher and a hardness that was 3.09% greater than that of SiC-reinforced nanocomposite.

- IV. EBSD analysis revealed that inclusion of reinforcing particles to the base alloy reduces the grain size due to the presence of more high angled grain boundaries than low angled grain boundaries which restricts further formation of grains.
- V. Analysis of fracture revealed that unreinforced composite has equiaxed dimples, indicating the ductile behaviour. However, reinforced nanocomposite showed intergranular debonding with some voids that indicate both mode of failure, i.e. brittle and ductile.

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Conflict of interest The authors declare no conflict of interest

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