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Effect Of Adding SIC And TIO2 Nanoparticles To AA6061 By Stir Casting Technique On The Mechanical Properties Of Composites

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ABSTRACT: Owing to the large industrial development which the world has seen in all fields, scientists and researchers have aimed to produce new materials that have special engineering properties with a low economic cost that fits multiple industrial applications and uses. In the present article, composite materials were prepared from aluminum alloy (6061). The prepared composite was reinforced with silicon carbide (SiC) and titanium dioxide(TiO_2) nanoparticles which were added in specific weight percentages (3, 6, 9 wt%) using a stir casting technique. Cold mechanical treatment (forming with pressure) and heat-treated T6 (solution heat treatment-artificial aging) were carried out on all the specimens. The samples were later subjected to mechanical tests. From the SEM and X-RD results, the reinforced samples showed a uniform distribution of the nanoparticles within the samples matrix, indicating a successful preparation of the aluminum alloy via a stir casting technique. The results further showed an improvement in the hardness, yield strength, ultimate tensile strength, and impact toughness of the reinforced AA (6061) before and after mechanical and heat treatment (Thermo-mechanical) as the percentage of the reinforcement material increases.

KEYWORDS: Aluminum matrix composites (AMC), Nanoparticles, Mechanical properties; Stir Casting Technique (SCT)

INTRODUCTION

Among the particle-reinforced metal composites, aluminum matrix composites (AMC) have received the greatest research and engineering interest owing to their mechanical properties such as improved hardness and superior strength to weight ratio compared to those of normal Al alloys. AMCs are metals that have been strengthened using organic compounds or other metal. Among the materials used to improve the properties (such as strength, stiffness conductivity) of base metals are B_4C, SiC, TiO_2, Al_2O_3 and fly ash [1,2]. The various applications of composite materials include aircraft parts, automotive parts, mining equipment, thin and thick cylinder structural components, tool for cutting, and dies which are used for extrusion.

When aiming to optimize the mechanical characteristics of Al alloy metal matrix composites (MMCs), the process normally depends on the MMCs' microstructure [3]. This structure is characterized by various parameters of the particles used for the reinforcement; such parameters include the size, particle percentage, and shape of the particle, as well as on the grain size, processing techniques, and alloyed elements of the matrix.

The effect of B_4C & RHA on Al 7075 has been studied by S. Dayanand et al [4]. From the SEM analysis, the study found the hardness to increase as the content of the reinforcing materials (B_4C and RHA) increases.

Furthermore, Karakoç et al.[5] conducted a review of the effects of adding reinforcement particles on the properties of Al 6061 & Al 7075. From this review, stir casting was found as the best fabrication method.

The study by Ramkumar et al [6] proposed a method using a stir casting technique in which fabricated Al alloy 6061 reinforced with different percentages of Al_2O_3 particles at 5%, 10%, 15%, and 20% wt% was used. SEM techniques were used to study the microstructure of the AMMC, and it was found that the addition of different wt.% of Al_2O_3 improved the micro-hardness, tensile strength (TS), and compression strength (CS) of the material.

A review of the impact of several reinforcement materials on Al 6061 has been conducted by Verma & Rao [7]. The review reported stir casting as the best fabrication technique. They also noted that the addition of various reinforcement material into Al 6061 improved its mechanical properties.

Another study by Al-Alkaw1 & Al-Salihi [8] examined the mechanical properties of Al 6061 composites which were successfully fabricated by a stir casting technique and then reinforced by using different percentages of Al_2O_3 nanoparticles (up to 10 wt%). They found that the mechanical properties of 6061/Al_2O_3 nanoparticles are critically influenced by the concentrations of the Al_2O_3 nanoparticle since there was a substantial enhancement in the mechanical properties as the fractions of Al_2O_3 nanoparticles were increased.

In another research, Al-Alkawi et al.[9] reported the generation of nanomaterials with good mechanical properties from 6061AA-alloy. Five wt% of Al_2O_3 nanoparticles (1, 1.5, 2, 2.5 and 3 wt% Al_2O_3) were added. The nanocomposites were manufactured by a stir casting technique. The study found that all the mechanical properties of the nanocomposites were higher than that of the metal matrix.

Ashwath et al. [10] studied the production of Al alloy AA-SiC and AA- Al_2O_3 with SiC and Al_2O_3 (10 μm average particle size) using different weight percentages (3, 6, and 9). The Al alloy 2024 reinforced with 6% wt. of Al_2O_3 specimens showed improved hardness results, stress-strain, and strength behavior while Al alloy 2900 reinforced with 6 wt% Al_2O_3 showed good formability and ductility which were similar to those of AA 2024. From the literature analysis, it is obvious that higher percentages of reinforcement materials will improve the mechanical properties of the resulting composite [11,12].

Recent studies have demonstrated a level of discrepancies in the mechanical properties of superficially identical composites which only differed in their method of preparation [13]. Ramkumar & Natarajan [14] focused on the effect of different concentrations of TiO_2 nanoparticle (0 - 3 wt%) on the microstructure and strength of pure Al prepared using Accumulative roll bonding ARB method. From the microstructural characterization results, it was found that the achieved uniform distribution of the reinforcement material and ultrafine matrix grains were due to rolling after eight passes, respectively.

From the reviewed studies in the previous section, it is obvious that MMCs are mainly fabricated to combine the desirable properties of ceramics and metals. The addition of ceramic particles with high strength and high modulus to a ductile metal matrix will create a material with improved specific strength/stiffness, good wear resistance, high elastic modulus, and excellent resistance to corrosion.

The aim of this work is to study the mechanical properties, interaction of aluminum alloy (6061) containing different weight percentages (0, 3, 6 and 9Wt. %) of nanoparticles (Silicon carbide (SiC) and Titanium dioxide (TiO_2), with size (30 with ±10 nm in size) and observing the level of improvement attributed to the nanoparticles on the mechanical properties. Also, the study examines the effect of increasing the percentage of different supporting materials on the hardness, shock strength, and tensile properties of AA6061. The effect of T6 heat treatment and formation by cold pressing on the mechanical properties of AA6061 before and after reinforcement will also be studied.

EXPERIMENTAL WORK

Metal Matrix

The matrix metal used for the current work is AA 6061 following ISO 209-1 recommendation and their components (AlMgSiCu) which are widely used in different applications such as transport, automotive, aerospace, military, and electricity industries. Aluminum alloy (6061) was chosen as a metal matrix due to its good weldability, as well as its use for mechanical components due to its lightweight, good corrosion resistance and electricity conduction. Regarding its weight, it is almost twice a good conductor compared to copper [15]**.** The chemical analysis of the AA 6061 was performed at "The State Company for Inspection & Engineering Rehabilitation (SIER), formerly known as The Specialized Institute for Engineering Industries and Standard Specifications." Table 1 showed the chemical composition of the base metal while Table 2 presented the mechanical and physical properties of matrix (AA 6061). Table 3 showed the mechanical properties of the reinforcement particles **(**SiC and TiO_2).

Table 1. Chemical components of AA6061

Wt. % Max.	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Al**
Measured (SIER)	0.6	0.3	0.25	0.05	0.9	0.2	0.13	0.08	Balance

Table 2. Mechanical and physical properties of AA 6061

Material AA6061	**Density gm/cm^3**	**VHN (GPa)**	**UTS (MPa)**	**YS (MPa)**	**Poisson's Ratio (v)**	**e (%)**	**E (GPa)**
Measured (SIER)	2.8	**27**	95	55	0.3	16	75

Table 3. Mechanical and physical properties of Nano SiC & TiO_2

Nano	**Compressive strength (MPa)**	**VHN (GPa)**	**E (GPa)**	**Density gm/cm3**	**Melting point (^oC)**	**Particle size (nm)**
SiC	3009	29	415	3.1	2830	20-40
TiO_2	3118	38	431	4.23	1843	20-40

Stir Casting Technique (SCT).

The stir-casting technique (SCT) or Vortex Technique (VT) is a common, economical, and simple method of producing metal matrix Nanocomposites with the reinforcement particles are incorporated into the molten matrix metal (i.e., aluminum). A stirrer (impeller) is inserted into the molten metal and mechanical stirring is applied with some agitation rates to get a uniform distribution of the particles with the molten metal. This process has been extensively used to incorporate ceramic, carbon nanotubes, graphene, and metal oxide particles to magnesium and aluminum matrices [15]**.** The main challenges of this technique are:

(i) The tendency of nanoparticles clustering due to the high surface area and the resulting high van der Waals forces between them;

(ii) Poor wettability of the solid nanoparticles with the molten metal; and

(iii) High density of porosity due to possible entrapment of the air induced by the rotating stirrer [16]**.**

The stir casting, fabrication of AA6061/(SiC & TiO_2) nanoparticles with the average size of 20–40 nm nanocomposite at a specific stirring rate and temperature was done to ensure a good combination of mechanical properties; the ideal combination of stirring temperature and stirring rate was 850◦C and 500 rpm, respectively. Table 4 showed the amount of base metal and nanoparticles in weight percentage.

Table 4. Composition of aluminum alloy–nanoparticles

AA6061 (g)	**Sic (g)**	**Total weight (g)**	**TiO_2 wt.%**	**TiO_2 (g)**	**Total weight (g)**	**TiO_2 wt.%**
970	30	1000	3	30	1000	3
940	60	1000	6	60	1000	6
910	90	1000	9	90	1000	9

Fabrication of the Composite

The manufacturing of composite materials using the stir casting technique (SCT) is an economic process for the fabrication of aluminum alloy-to-composites matrix. It is mostly accepted as a low-cost method for the fabrication of AMMCs. The advantages of this operation are flexibility, applicability, and simplicity for production in large volume [17]. Stir casting method was adopted to prepare the composites as explained below.

1. AA6061 billets were shredded, placed in a graphite crucible, and melted in an electrical resistance furnace.

2. The furnace temperature was increased (850^{o}C) above the melting point of the AA6061.
3. A K-Type thermocouple was used to measure the melt temperature.
4. Prior to the introduction of the reinforcement particles into the molten Al, the melt was first degassed and refined using Hexachloroethane (C_2C_{l6}) tablets. The aim of this process is to prevent contamination and avoid oxidation.
5. Preheat reinforcement at 250°C was used to assist in removing surface impurities and changes in the surface composition.
6. The melting point of Al is around 650°C; this is the temperature where the semisolid stage of the melt is observed.
7. At the semi-solid stage of the melt, a wetting agent (pure magnesium powder at the conc. of 1 % wt.) was added to the mix. The addition of magnesium is important to increase wettability.
8. After ensuring that the aluminum is completely melted, the temperature within the furnace was reduced to a temperature close to 700^{o}C. The supporting particles (SiC&TiO_2) of known size, weight, and preheated temperature were added when the temperature of the melt was 250^{o}C. The moisture and absorbed gases were removed from the surface of the oxide layer to improve the distribution of the particle within the melt and improve the interaction and degradation between the particles and the melt, thereby reducing the surface tension between them. The reinforcements were poured manually with the help of a conical hopper. The flow rate of the reinforcements was fixed at 0.5 g per second to avoid high porosity and inclusion defect.
9. The temperature of the heater was gradually raised to 850°C in order to alter the viscosity of the liquid. For the proper distribution of the reinforcement particles within the base, as well as to create a perfect reinforcement-matrix interaction, a stirring time of 5 min was allowed.
10. The stirring was initiated at this heater temperature and was sustained for 5 minutes. A gradual increase in the stirring speed was provided using a speed controller. The speed of stirring was 450 rpm for SiC for 15 min and 550 rpm for TiO_2 for 5-10 minutes. These stirring periods were allowed to ensure the proper incorporation of nanoparticles into the alloy matrix.
11. The mold was preheated at 500°C for one hour before pouring into the mold to improve the mechanical properties of cast composite and to remove the entrapped gases from the mold. This was to ensure the maintenance of the slurry in the molten state during the pouring period.
12. The melt was purged with argon gas to prevent oxidation and reduce slag formation.
13. The stirring speed was gradually reduced to zero.
14. The pouring of the molten composite into the metallic mold was quickly done without allowing the settling of the reinforcement particles.
15. After mixing and at the temperature of 850°C, the mixture was poured into the metal mold and left to cool in the steel mold. A steady flow rate was maintained during the slur pouring to avoid air trapping; the quality of casting is mostly influenced by the distance between crucible and mold. The cast was removed from the mold after solidification.

T6 Heat Treatment

After the composite material was prepared, heat treatment was performed on the supported specimens produced, including the thermal treatment of the solution at 530°C for 1 h, followed by water cooling, then, industrial obstruction at 185°C for 6 h. The main aim is to achieve the following objectives:

1. Eliminate some plumbing defects and ensure that the phases are evenly distributed in the bulb to obtain regular structure during casting.
2. Combining internal stresses arising from thermal conditions or shrinkage during freezing.
3. Improve the mechanical properties of the spike and improve the stability of dimensions.

Mechanical processing (compression molding):

The mechanical treatment of the cold pressing form (emotional coupling) using a 20-ton piston was carried out in several stages. The main purpose of mechanical treatment was to achieve the following objectives:

1. Reinforcing the reinforced castings by introducing a new mesh of materials in the material that interferes with the continuation of the movement of importance.
2. Elimination of the pores resulting from the plumbing process.
3. Improving the mechanical properties of the cast.

The final specimens are presented in Figures 1 & 2 for SiC & TiO_2, respectively.

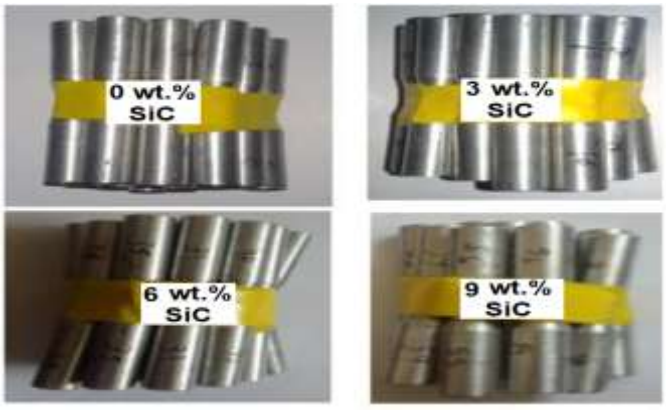


Figure 1. Nanocomposite specimens after production for SiC

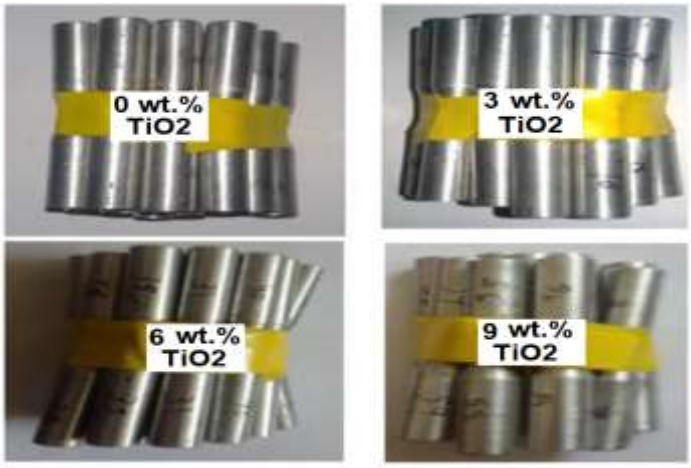


Figure 2. Nanocomposite specimens after production for TiO_2

Producing the Specimens

The sampling tests were divided into three groups according to the processes performed and operated by mechanical operations to be ready for mechanical tests. In this research, the three kinds of samples used are reinforced specimens, reinforced specimens with heat treatment, and reinforced specimens with thermal and mechanical treatments.

Specimens Preparation

The specimens' surface was polished before the test in the following way:

1. Different paper grades of wet silica (200, 800, 1000, and 1200) were used to smoothen the surface of the specimens.

2. Paste diamond (1 μm, then, 0.25 μm) was used for surface polishing.
3. Distilled water was used for cleaning, followed by alcohol.

Microstructure Test (SEM)

During microstructure analysis or microscopic examination, the material structure was studied under enlargement. Proper preparation of the specimen and the surface of the material requires that a small sample of the material is selected accurately and subjected to the microstructure analysis. Then, mounting, pounding, polishing, and etching was performed to reveal accurate content and microstructure. The specimen must be free from scratches, stains and other imperfections that tend to mark the surface.

Mechanical Testing

Tensile Tests

All the samples were machined using a programmable milling machine (CNC). Figure 3 showed the tensile specimen. This testing was performed in accordance with ASTM (E8/8M-09) 2017 [18] on samples measuring 82 mm long and 12 mm in diameter. After obtaining the tensile designs, the values of UTS were determined. Surface finishing and residual stress reduction in the samples were considered during the work.

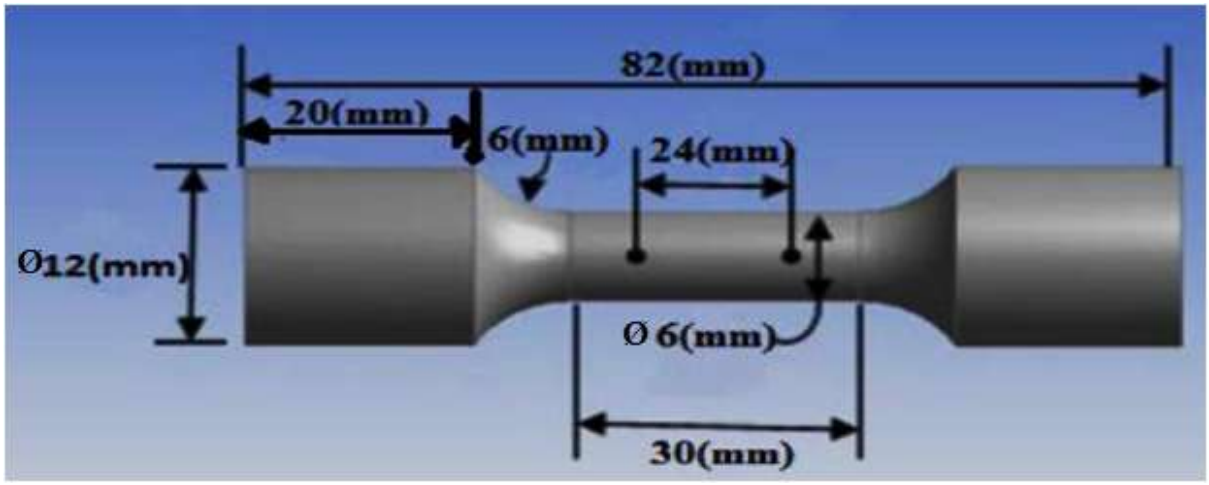


Figure 3. Specimens' dimension for tensile test

Hardness testing

Vickers hardness (VH) testing was implemented in accordance with [19-21]. The hardness test was done by polishing the specimens with different papers of wet silicon carbide, starting with 200 to 1200 μm.

Impact Toughness Test

The Charpy impact test or Charpy V-notch test is a standardized high strain-rate test performed for the determination of the amount of energy a material absorbed during fracture. It is normally performed following the ASTM E23–18[22]. The energy absorbed by the material at fracture is an estimate of the notch toughness of the material; it serves as a way of studying the ductile-brittle transition which is dependent on temperature. It has a wide industrial application owing to the ease of its performance; its results can easily be obtained, and it is cheap as well. However, a major problem is that its results only for comparative use. This test is a mechanical way of testing specimens used in the impact toughness value determination (Figure 4).

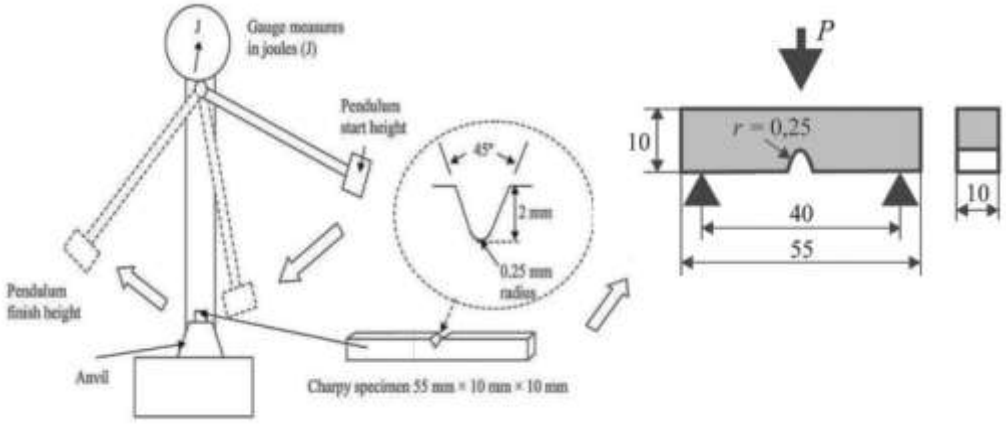


Figure 4. The Charpy V-Notch impact test (55 mm); 10 x 10 mm sample cross-section.

The sample medium is operated V-notch, 2 mm deep, with 45° angle, and 0.25 mm radius along the base on the wire cutting machine

XRD Test

The crystalline phases in the material were identified using an X-ray diffraction test to facilitate the identification of the chemical composition. Phase identification was achieved by comparing the acquired data to a reference database [23]. XRD helps in the analysis of the mineral content of materials, polymers, unknown materials, and corrosion products. Most times, the samples are analyzed via powder diffraction; this involves the use of finely ground sample powders.

RESULTS AND DISCUSSION

Microstructure Analysis via SEM

The specimens for mechanical and microstructural characterization were machined from the castings. The surfaces of the specimens were polished based on the recommended metallographic technique, starting with 220 grit SiC paper, then proceeded to 1200 grit SiC paper; next with diamond paste for fine polishing and Keller's reagent etching. The prepared composites were subjected to microstructural studies under SEM equipment to determine the morphology and formation of (Sic & TiO_2) compounds in the composite. During the microstructure analysis, the optical micrographs of AA6061 with 0, 3, 6, and 9 wt % SiC particles were captured as presented in Figures 5 (a, b, c and d) while those of AA6061 with 0, 3, 6 and 9 wt % TiO_2 particles were presented in Figures 6 (a, b, c, and d). Furthermore, Figures 5 & 6 (a) showed the microstructure of as-cast AA6061 while Figures 5 & 6 (b, c, d) showed the feature of the nanocomposites with 3, 6, and 9 wt %, respectively. Evidently, there was a uniform grains distribution throughout the region.

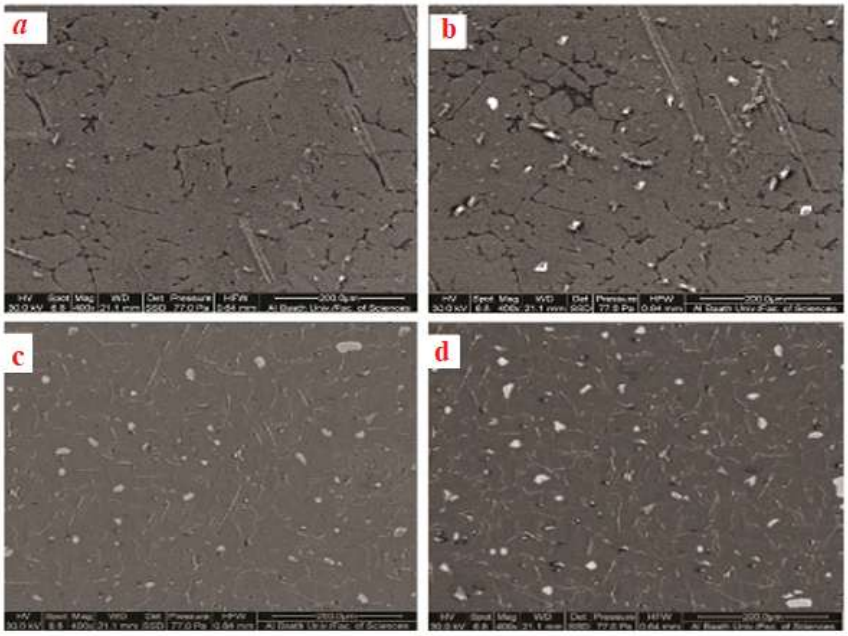


Figure 5. SEM of 6061Al alloy as reserved and with nano SiC: (a) SEM of AA6061 (400X for all), (b) SEM of AA6061 with 3wt. % nano SiC, (c) SEM of AA6061 with 6 wt. % nano SiC, (d) SEM of AA6061with 9 wt. % nano SiC.

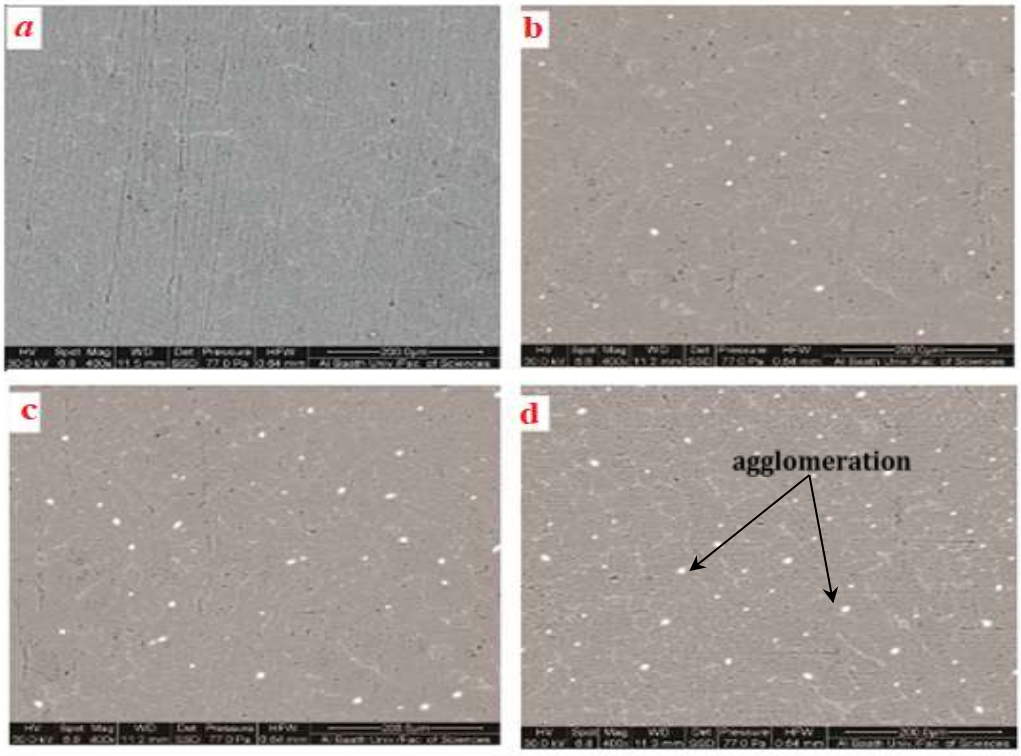


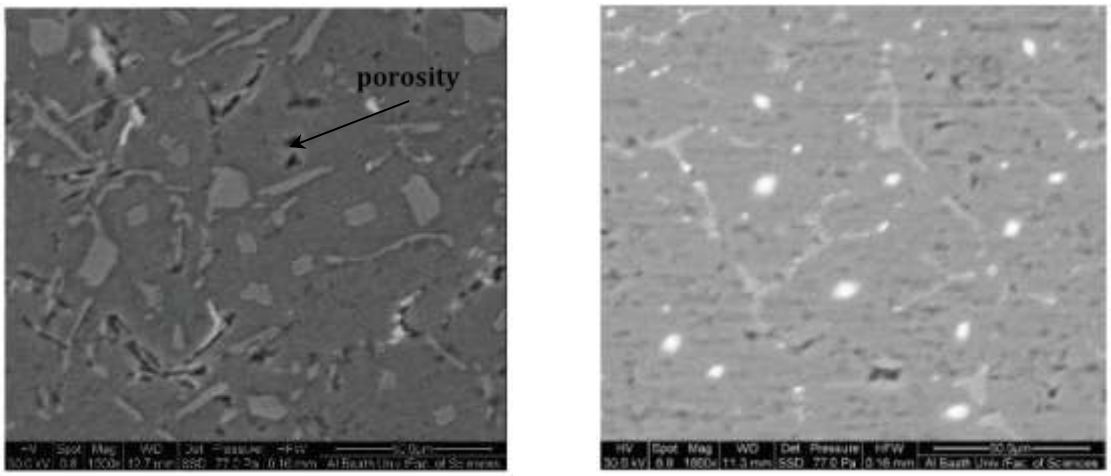
Figure 6. SEM of 6061Al alloy as reserved and with nano TiO_2: (a) SEM of AA6061 (400X for all), (b) SEM of AA6061 with 3 wt. % nano TiO_2, (c) SEM of AA6061 with 6 wt .% nano TiO_2, (d) SEM of AA6061with 9 wt.% nano TiO_2.

The as-cast AA6061 showed a typical dendritic microstructure due to solidification. The formation of the dendritic structure was facilitated by the high cooling rate. The composite lacked such dendritic structures in its microstructure as depicted in Figures 5and 6 (b, c, d). The microstructural study revealed good interfacial integrity between the reinforcement particles and the matrix, with a clear formation of SiC & TiO_2 as shown in Figure 6(b). This is an indication of the homogenous distribution of SiC & TiO_2 within the base alloy. There were also some

instances of agglomeration in the composite produced with 9 wt % (Figure 6d). The formation of SiC & TiO_2 was more evident when viewed in a higher magnification as presented in Figure 7 (a) and (b) for SiC and TiO_2, respectively. The Sic & TiO_2 particulates were observed to exhibit different shapes, ranging from spherical to cylindrical and hexagonal. These shapes of the reinforcement particles have a pronounced implication on the properties of AMCs.

The microstructure of the casted AA6061 revealed the existence of porosity while the microstructure of the composite showed minimum porosity; this porosity can be a result of the following:

1. Shrinkage during solidification.
2. Particle injection may lead to the trapping of gas in the melt.
3. The gap between the mold and the crucible.
4. Growth in the contact surface with air.
5. Trapped gas due to the stirring process.



a b

Figure 7. Higher magnification (1600X) of (a) SiC, and (b) TiO_2

Mechanical Properties

Hardness testing

A load of 4 Kg was applied for 20 sec before taking five rare readings of the hardness of each sample from different regions to determine the mean hardness value. Figures 8 & 9 showed the variation of hardness (VH) of the base alloy and the composites with different SiC & TiO_2 contents. Evidently, the value of the hardness increases with the percentage of SiC and TiO_2. The thermal treatment and thermal-mechanical processing helped in achieving high hardness values. Figures 10 and 11 revealed the effect of the amount of SiC and TiO_2 on the hardness of the composites. Clearly, the introduction of SiC and TiO_2 particles significantly increased the composites' hardness value. The hardness was found to be 58.46% and 59.7% when the percentage of the particles were increased 3-9 weight%. The hardness value of the composite subjected to heat treatment was 66.25% and 68.6% when the percentage of SiC and TiO_2 was increased from 1% to 9%, but with mechanical heat treatment, the hardness values were 71.58% and 72.45% after increasing the particles' percentage from 1% to 9%. The observed increase in hardness value could be due to the high dislocation density surrounding the SiC and TiO_2 particles owing to the variation in the thermal expansion coefficient between the base alloy and the particles. The hardness may also be due to the matrix phase refinement and the integration of hard (SiC & TiO_2) particles within the matrix of the base alloy.

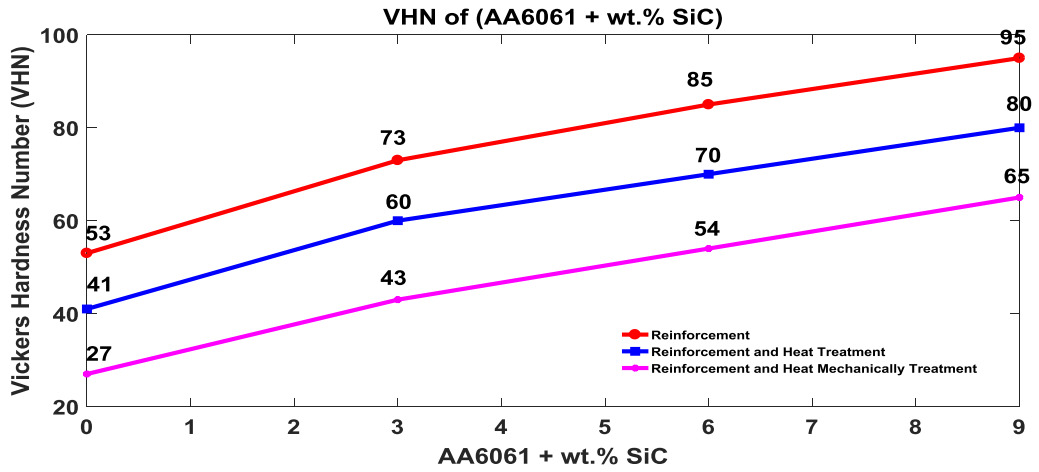


Figure 8. The effect of increasing the percentage of reinforcement in SiC with heat treatment and mechanical heat treatment on hardness values.

Another factor that may contribute to the better interaction between the particles and the matrix is the clean and clear interface between them, conferring the composite an increased load-carrying capacity.

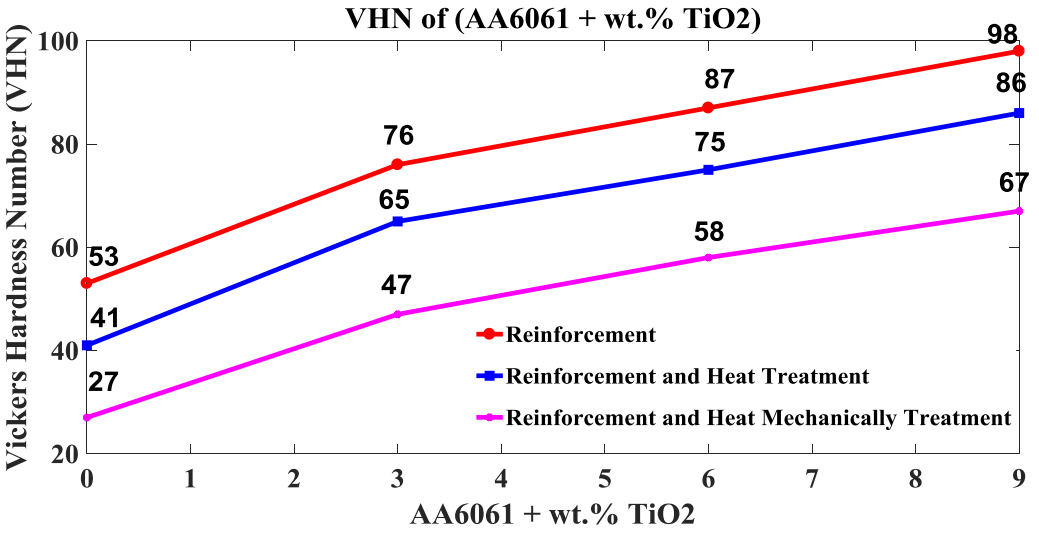


Figure 9. The effect of increasing the percentage of reinforcement in TiO_2, with heat treatment and mechanical heat treatment on hardness values.

Impact Toughness Test

The results were shown in Figures 10 and 11; the impact toughness of aluminum was found to increase with the percentage of SiC and TiO_2 that was strongly dispersed and strongly attached to it. Heat treatment and mechanical treatment were also observed to improve the toughness value of aluminum. The introduced SiC and TiO_2 particles significantly enhanced the composites' impact toughness. When the percentage of the particles added in the base metal was improved from 1-9wt%, the impact toughness increased from 77.27% to 79.17% but when subjected to heat treatment, the impact toughness increased from 82.14% to 85.29% for 1-9wt% increase in the particles' concentration. Upon mechanical heat treatment, the impact toughness values increased to 86.49% and 87.8%.

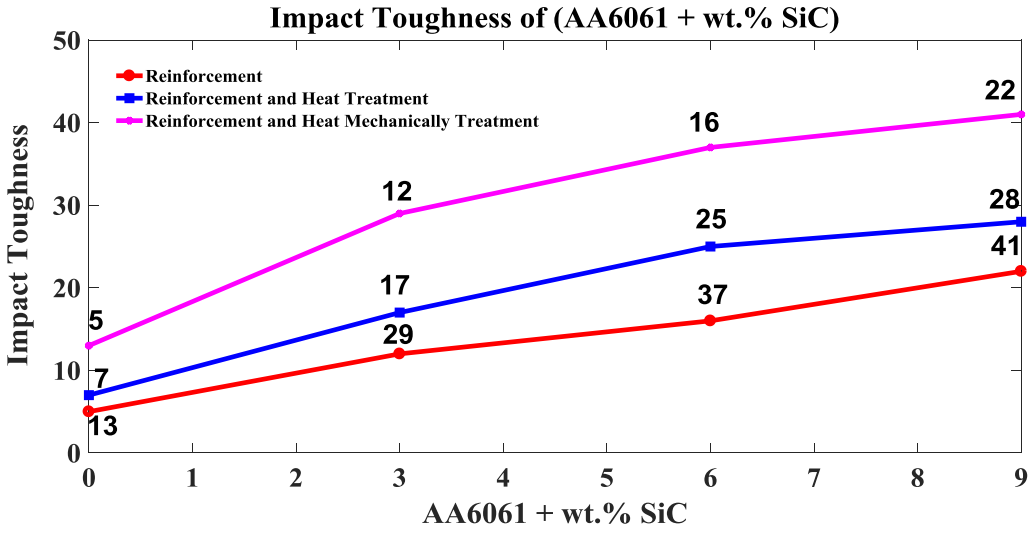


Figure 10. The effect of increasing the percentage of SiC, coupled with heat treatment and mechanical heat treatment on impact toughness values.

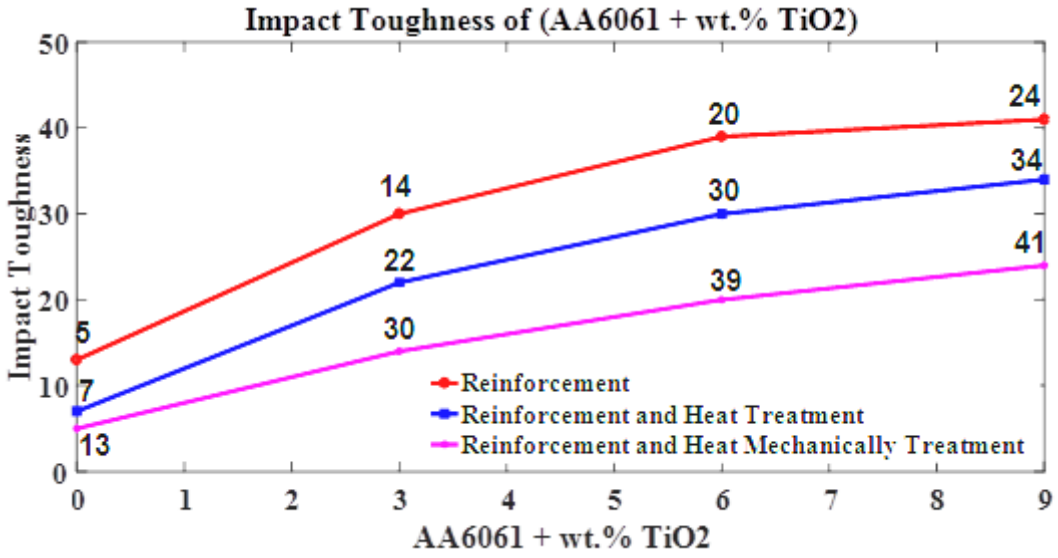


Figure 11. The effect of increasing the percentage of TiO_2, coupled with heat treatment and mechanical heat treatment on impact toughness values.

Tensile Test Results

Ultimate Tensile Strength (UTS)

The evaluation of the tensile properties of the composites and the base alloy was done at ambient temperature, with the UTS and elongation percentage evaluated from the engineering stress-strain plot. Figures 12 and 13 showed is a progressive improvement in UTS for composites produced with SiC and TiO_2, respectively. The UTS of the composites were observed to continuously improve as the percentage of the particles was increased. This improvement continues with thermal treatment and thermal-mechanical treatment. The observed increase in UTS could be due to the increased contents of SiC and TiO_2 in the base alloy. Composites with 9 wt. % SiC and TiO_2 presented the maximum improvement in UTS value (46.93%, 58.7% & 64.15%, respectively, for SiC and 49.47%, 61.22% & 65.07% respectively, for TiO_2 compared to the base alloy. Another possible reason for the improved UTS value could be the interaction between the particles and dislocations when the composites are under load; could also be due to the existence of several appending dislocations around the particles owing to the variation in the thermal expansion coefficient between the particles and the base matrix. The mismatch in thermal expansion

coefficient between the matrix and the particles will also strengthen dislocation at the grain boundary based on the level of mismatch[24].

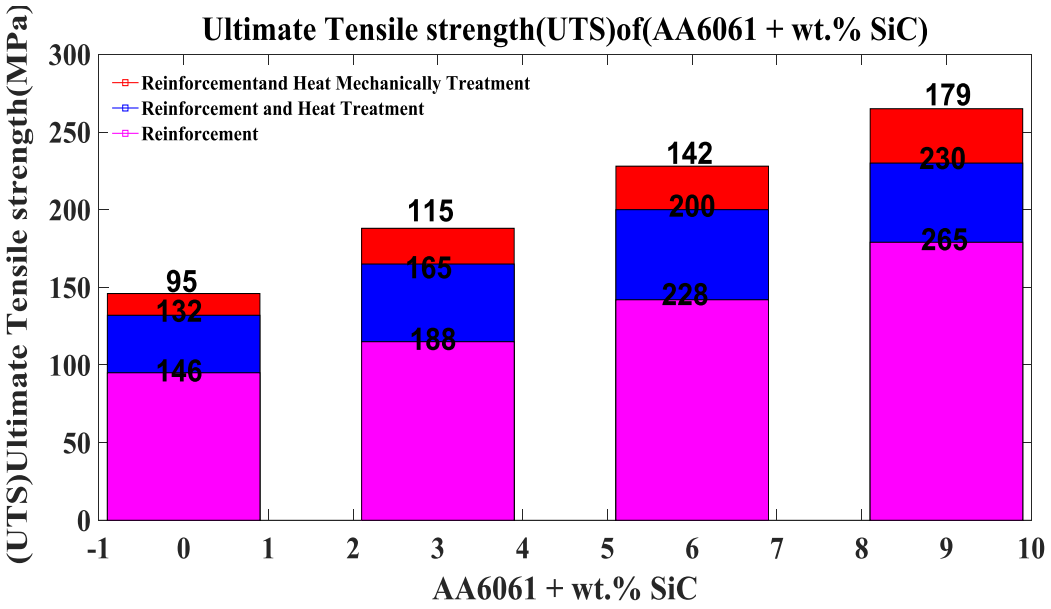


Figure 12. The effect of increasing the percentage of SiC, coupled with heat treatment and mechanical heat treatment on UTS values.

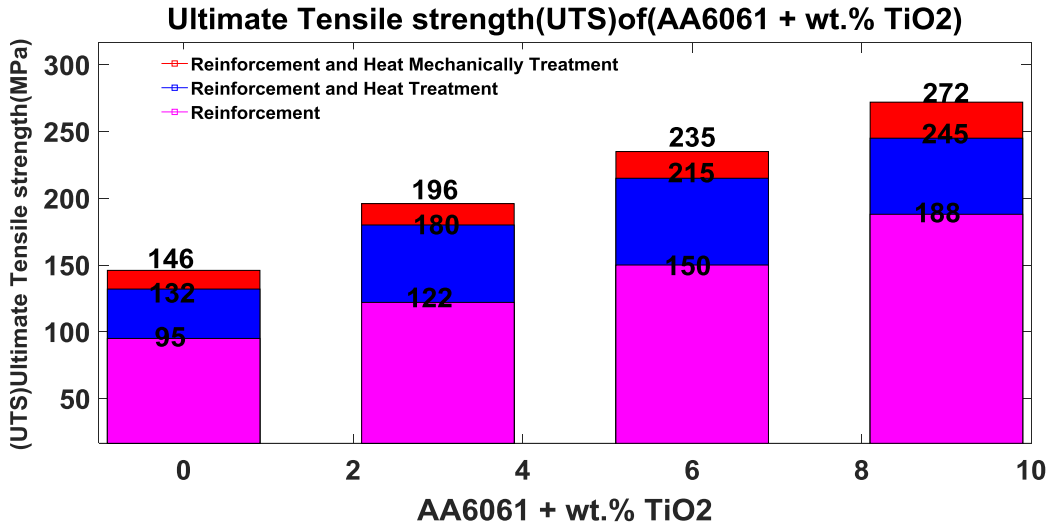


Figure 13. The effect of increasing the percentage of TiO_2, coupled with heat treatment and mechanical heat treatment on UTS values.

Yield Stress (YS)

The increase in yield stress (YS) was due to the decreased inter-particle spacing between the SiC and TiO_2 particles as the particles are harder than the base alloy. Figures 14 and 15 showed that the YS was gradually improving with increasing percentages of SiC and TiO_2. This percentage increases progressed with thermal treatment and thermal-mechanical treatment. It showed that composite with 9 wt. % of SiC and TiO_2 exhibited the maximum values of YS (60.71%, 66.67% & 72.64%, respectively, for SiC) and 61.27%, 69.1% & 73.17%**,** respectively for TiO_2) compared to the base Al6061 alloy.

The addition of SiC and TiO_2 to the base alloy suppressed stress deformation, thereby improving the CS of the composite. However, the incorporation of hard SiC and TiO_2 particles into the base alloy shifted the nature of the

composite from ductile to brittle. Furthermore, the aforementioned mechanical properties were improved by thermal treatment and thermal-mechanical treatment[14].

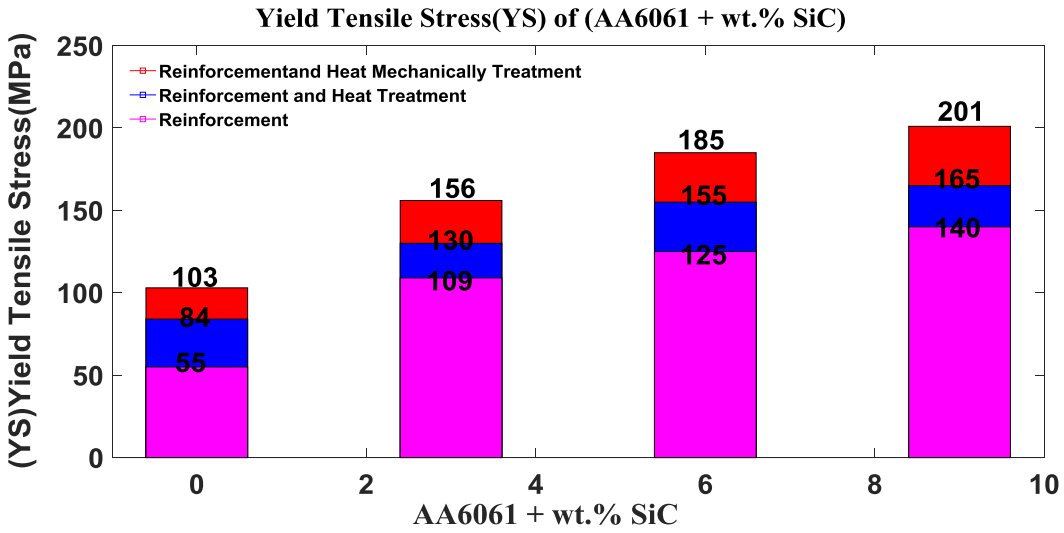


Figure 14. The effect of increasing the percentage of SiC, coupled with heat treatment and mechanical heat treatment on YS values.

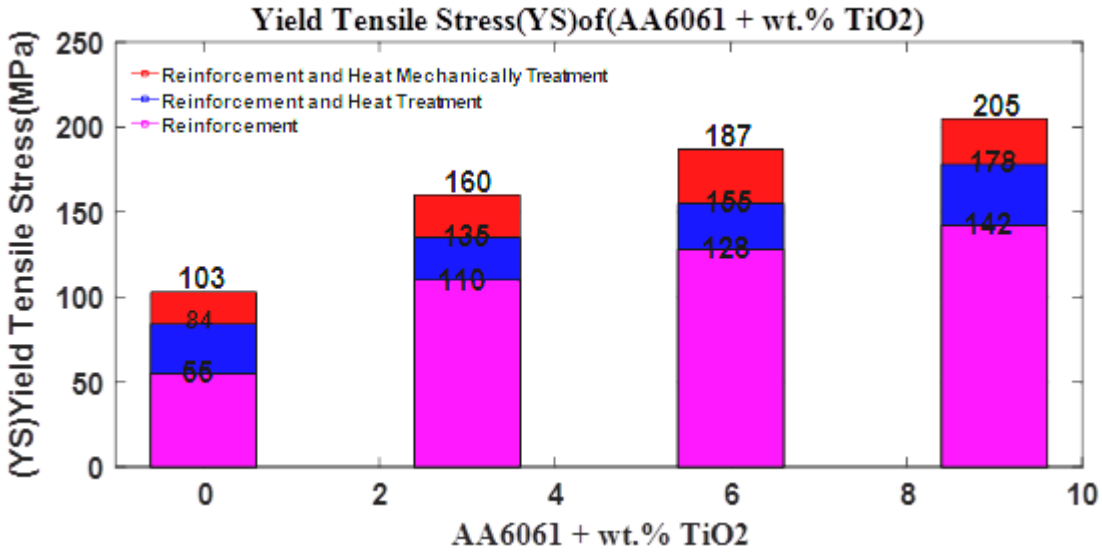


Figure 15. The effect of increasing the percentage of TiO_2, coupled with heat treatment and mechanical heat treatment on YS values.

Ductility

The ductility of the unreinforced Al alloy and its in-situ composites is presented in Figures 16 and 17. The figures showed a decrease in the ductility of the composites as the weight percent of the reinforcement particles increases compared to the unreinforced base alloy Al6061. This decrease also persisted with thermal treatment and thermal-mechanical treatment. The composite prepared with 9 wt. % of the particles showed the highest ductility values (improved by about 39%, 50% & 55.56%, respectively, for SiC and 44.45%, 55.56% & 61.12%, respectively for TiO_2) compared to the base Al6061 alloy.

The differences in the shape and size of the SiC & TiO_2 particles within the composites caused a decrease in SiC & TiO_2 elongation when the weight percentage of SiC & TiO_2 is increased. The decrease in the ductile matrix content, as well as the grain refinement upon the increment of the weight percentage of the particles, is due to the decrease in the ductility of the AMCs. All the composites showed lower ductility values compared to the matrix

metal due to the hindering of the reinforcement particles upon grain deformation. However, the ductility can be improved by ensuring a homogenous distribution of SiC & TiO_2 particles and minimizing large agglomerations.

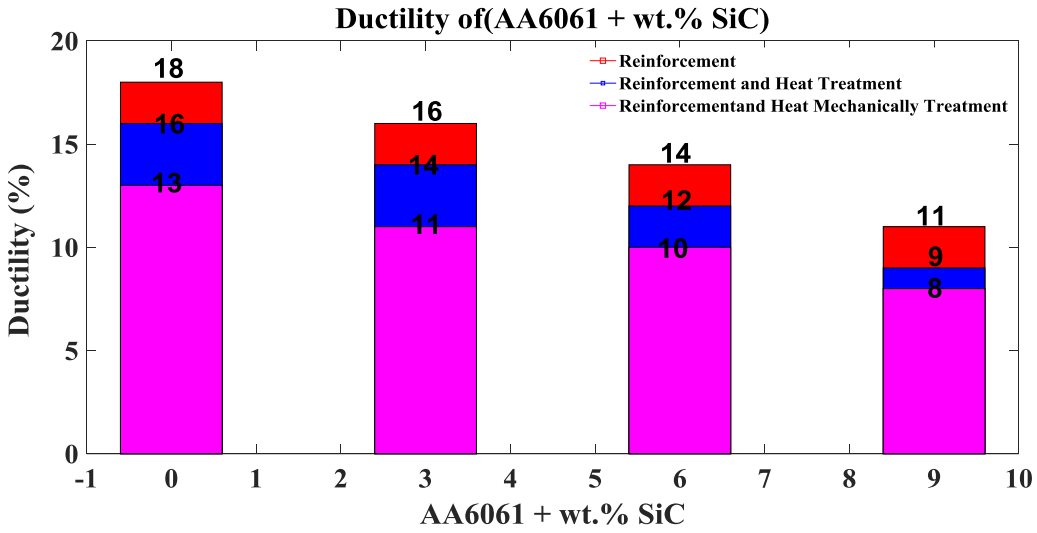


Figure 16. The effect of increasing the percentage of SiC, coupled with heat treatment and mechanical heat treatment on the ductility values.

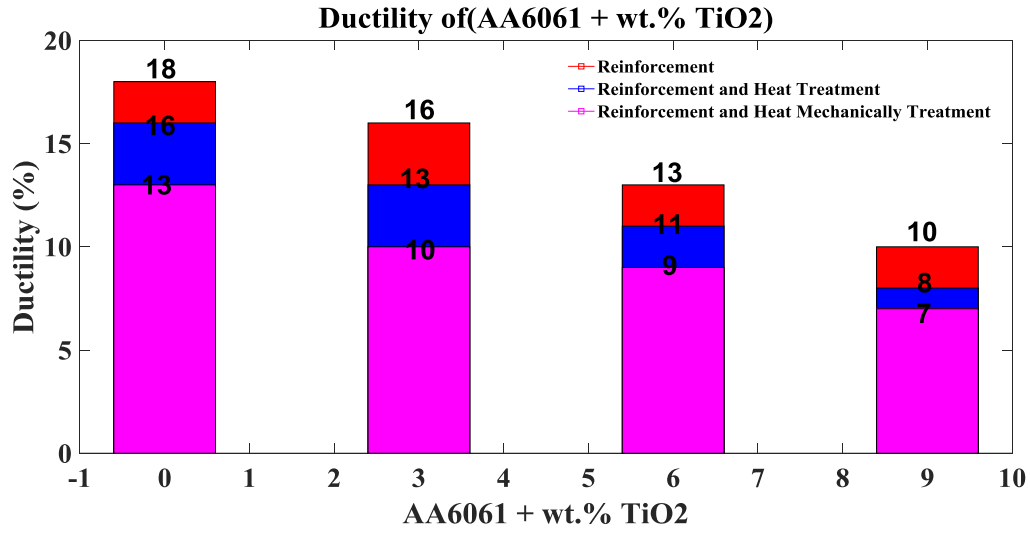


Figure 17. The effect of increasing the percentage of TiO_2, coupled with heat treatment and mechanical heat treatment on the ductility values.

XRD Analysis

The composites were analyzed via the XRD method and the results of the analysis are shown in Figures 18 &19 for SiC and TiO_2 reinforced composites, respectively. The presence of SiC or TiO_2 peaks in the acquired XRD pattern demonstrated the successful incorporation of SiC or TiO_2 in the composites. The intensity of SiC and TiO_2 peaks was also found to increase as their respective weight percentage increases. The figures also showed that SiC and TiO_2 particles existed only in one phase within the composites. When the weight percent of SiC or TiO_2 particles increases, the atomic weight of the composite also increases. The XRD spectra of the produced composites suggested the successful integration of SiC and TiO_2 particles in the base matrix, indicating the completion of the in-situ reaction.

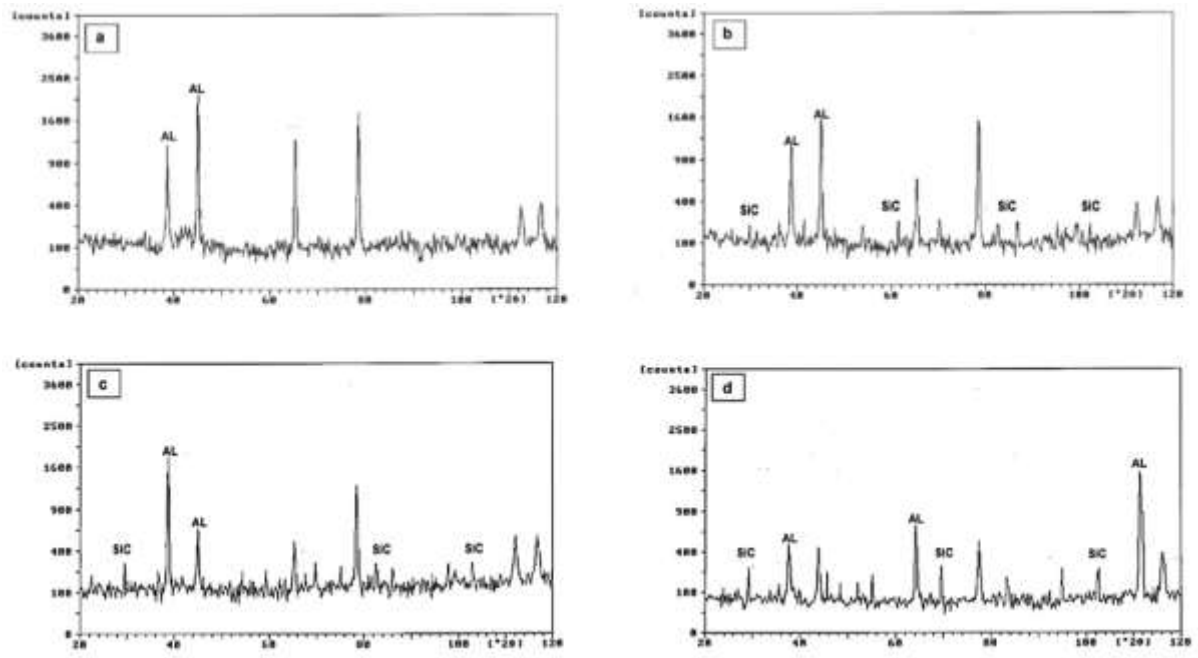


Figure 18. XRD analysis for Al6061 + wt. % SiC (a). AA6061, (b) AA6061+3w t. % SiC, (c) AA6061+6wt. % SiC, (d). AA6061+9wt. % SiC

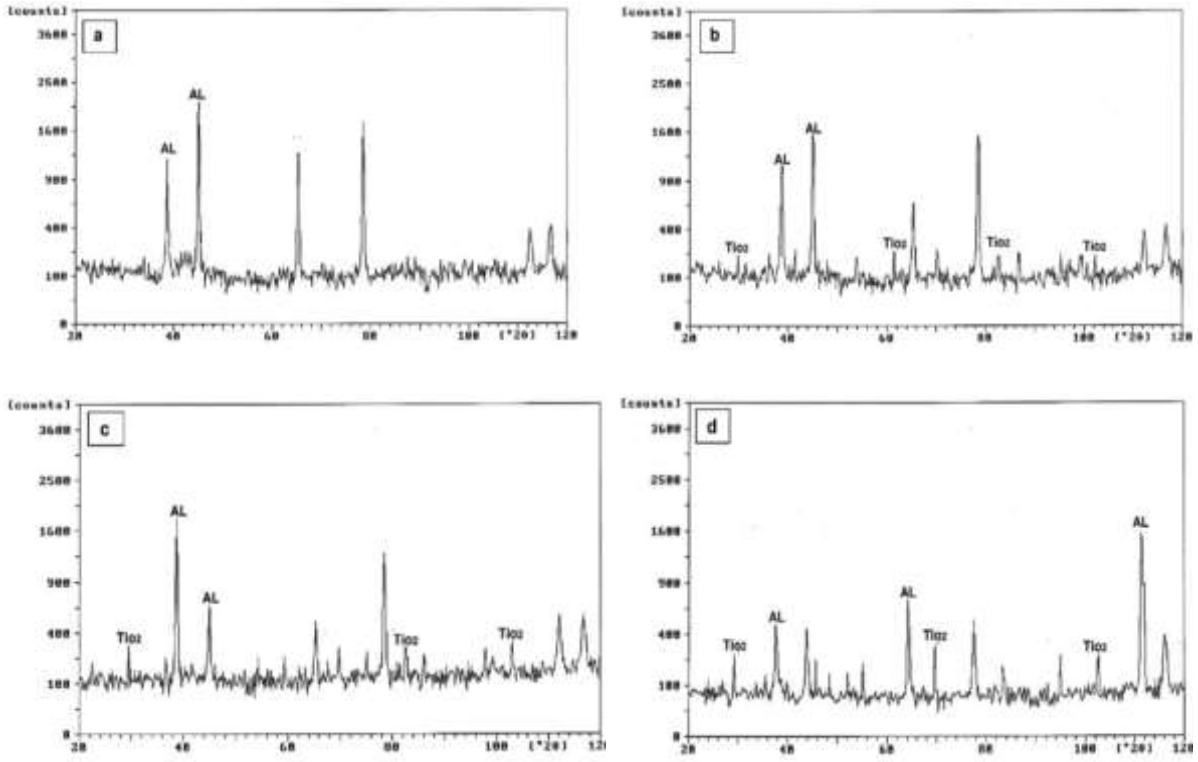


Figure 19. XRD analysis for AA6061 + wt. % TiO_2 **,** (a) Al6063, (b) Al6063+3wt% TiO_2 (c) Al6063+6wt% TiO_2, (d) Al6063+9wt% TiO_2

CONCLUSIONS

The following conclusions are derived from the experimental results that have been obtained in the present work.

1. Al6061/(SiC or TiO_2) composites containing different weight percentages of SiC or TiO_2 can be produced via chemical reactions between molten aluminum alloy and SiC or TiO_2 particulates using Stir Casting Technique (SCT).
2. The incorporation of SiC or TiO_2 in Al6061 confers better mechanical properties than as-cast Al6061 in all cases, but the addition of TiO_2 to the metal matrix gave better results compared to the addition of SiC in all cases.
3. The microstructure (by SEM) of the produced composites showed a clean and uniform dispersion of SiC or TiO_2 particulates in the aluminum matrix (AMC). Regular distribution for the SiC or TiO_2 nanoparticles was observed through the microstructure analysis of the samples; a low level of porosity was also noticed.
4. In-situ SiC or TiO_2 particulates formation enhanced the mechanical properties of the composite, such as the hardness value compared to the unreinforced aluminum alloy. The improvement in mechanical properties of the composites persisted even after heat treatment and mechanical heat treatment.
5. The best improvement percentage in impact toughness, UTS, and YS were observed when using 9% by weight of SiC or TiO_2 particles as reinforcement compared to the unreinforced base alloy Al6061.
6. An increase in the weight percentage of the reinforcement particles decreased the Particle of the produced when compared to the normal base alloy; this decrease in ductility persisted even after thermal treatment and mechanical thermal treatment.
7. The XRD spectra of the composites suggested the successful incorporation of SiC or TiO_2 particles within the base matrix, indicating successful completion of the in-situ reaction.

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