

Investigations On Hardness And Tensile Behavior Of Micron Sized Titanium Carbide Particles Reinforced Al2014 Alloy Composites

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Abstract

The current research focuses on investigating the microstructural and mechanical properties of Al2014 reinforced with both titanium carbide particles. The composite material was produced using a novel casting method. In this study, TiC content was varied at levels of 3 and 6 wt. %. Employing scanning electron microscopy (SEM) tool, microstructural analyses were conducted, revealing a uniform dispersion of ceramic TiC particles within the Al2014 composites. Mechanical testing, following the ASTM standards, was carried out on the composites, specifically assessing hardness, tensile strength, yield strength, and percentage elongation to evaluate the properties of the Al-based MMCs. The findings of this study indicate a significant enhancement in both tensile and yield strength values for the fabricated composites. However, it is important to note that the percentage elongation decreases as the reinforcement content in the composite increases.

Keywords: Al2014 Alloy, TiC Particles, Stir casting, Hardness, Tensile Properties

INTRODUCTION

Composite materials are synthesized through the combination of two or more materials that possess separate properties and are incapable of dissolving into one another. Composite materials are created by mixing elements with distinct characteristics, resulting in a distinctive property that surpasses the individual properties of the constituent materials [1, 2].

Constituents maintain their identity while also combining in a way that produces new traits that are superior to the sum of their individual parts. As technology continues to improve, there is an increased need for materials that are energy-efficient, lightweight, and affordable in the aerospace, defense, aviation, automation, and many other sectors [3, 4]. Therefore, the principal applications revolve on reducing weight while simultaneously preserving improved mechanical and other tribological qualities, for which aluminum composites are best suited [5-7]. Aluminium is suitable for usage because it is resistant to corrosion is high as compared to the magnesium and other alloys, especially for aerospace applications. When its surface reacts with air, it forms oxides that provide protection against erosion caused by rubbing between two surfaces in an application. Therefore, it is often utilised in aircraft applications where it lacks significant inherent wear resistance [8, 9]. Hence, there is a pressing want for substantial improvements on the properties.

The use of contemporary materials with greater qualities in the automotive and aerospace industries has led to a steady advancement of MMCs [10, 11]. A MMC is made up of reinforcements like ceramics and a matrix material like meta or an alloy. At the microscopic level, composites are heterogeneous, yet at the macroscopic level, they are homogeneous.

The crucial aspect is in the assessment of a material's macroscopic characteristic, wherein the components produced by these composites may be seen identified without the aid of magnification. At a macroscopic level, different types of materials are joined, such as alloys of metals. These materials appear to be homogeneous to the naked sight, meaning that their pieces cannot be distinguished and they clearly work together [12-14].

The fundamental benefit of composites is that a good design shows off the premium attributes of its constituent parts. Both naturally occurring and man-made composites exist. Among the former are wood, where lignin serves as the matrix and is reinforced by cellulose fibers. The human body is also made up of composites, with soft collagen being strengthened by bone-salt of calcium and phosphate ions. Utilising a composite material by integrating two or more substances requires more effort compared to using conventional monolithic steel and aluminium components. Essentially, these metals and their alloys consistently fail to fulfil the demands of modern advanced technology. Required performance is achieved solely through the utilisation of diverse material combinations. Currently, the aircraft industries have experienced an increase in acceptability due to the use of new materials [15].

Due to their outstanding properties such as low ductility, good thermal conductivity, good damping characteristics, and excellent thermal expansion, aluminium matrix composites (AMCs) have garnered a lot of attention in recent decades and are seen as the most promising materials to encounter the ever-increasing demands of current technology [16-18]. For as long as composites have been around, aluminium and its alloys have been the go-to matrix material. Reasons for this include the inexpensive production cost of AMCs and the wide variety of excellent mechanical and thermal qualities already stated [19-21].

Because it directly affects the overall performance of aerospace vehicles, a component's weight is extremely important in the aerospace industry. Advanced aluminium alloys had to be improved as a result. In order to improve performance characteristics, this work uses a novel stir casting technique to create Al2014 alloy composites that are reinforced with 3 and 6 weight percent of TiC particles, which are 15-20 microns in size. An inventive two-stage stir casting method was used to create the Al2014- TiC composites in order to improve the wettability between the particles and the matrix. To evaluate the impact of adding TiC particles to the Al2014 alloy, a variety of metals were examined.

Experimental Details

Materials Used

For the creation of metal composites, Al2014 alloy ingots were purchased from FENFE Metallurgical, Bengaluru, India. The alloy composition and the TiC reinforcement particles, which range in size from 15 to 20 μm and are obtained from MatRICS Laboratories, India, are shown in Table 1. The characteristics of the reinforcements and matrices are listed in Table 2. The scanning electron microscopy (SEM) of the TiC particles used to create the Al2014-TiC composites is shown in Figure 1.

Table 1 Chemistry of Al2014 alloys by weight. %

Si	Fe	Cu	Mn	Mg	Ti	Cr	Al
1.20	0.70	5.00	1.20	0.80	0.10	0.10	Balance

Table 2 Properties of Al2014 alloy and TiC particles

Material	BHN	Modulus (GPa)		Tensile Strength (MPa)
		Density (g/cm ³)		
Al2014	50	2.80	70-80	180
TiC	3200	4.60	380	3900 (C)

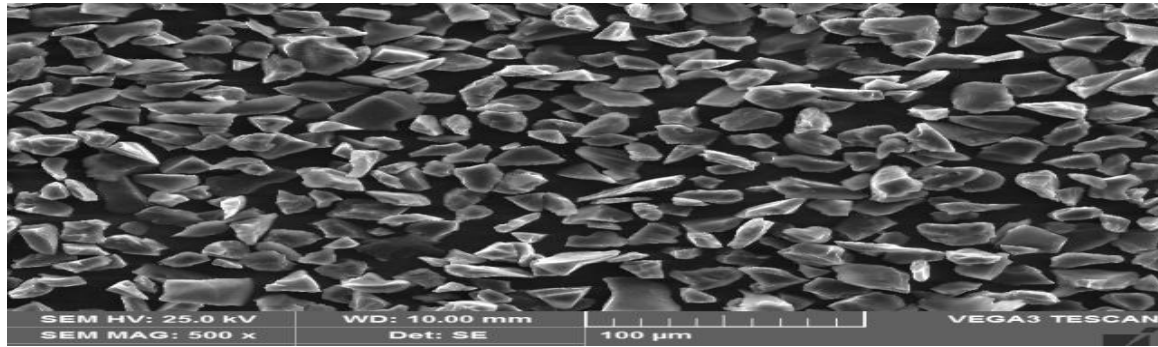


Figure 1: 15-20 micron sized TiC particles SEM Image

2.2 Composites Preparation and Testing

By using liquid metallurgy, Al2014 alloy with various weight rates of TiC composites are created. Al2014 composite metal pieces weighing a certain amount were placed into the electric furnace and heated till liquid metal stage. The temperature of Al2014 compound liquid metal is raised to 750°C. The correct thermocouples are used to measure and record the superheated and dissolving temperatures. For around three minutes, potassium titanium fluoride (K_2TiF_6) [22, 23] is used to degas the superheated liquid metal in the crucible. To blend the metal in the liquid, a shaft stirrer is utilised in conjunction with a zirconium-coated steel rotor. For the purpose of creating vortices, the stirrer is spun at a speed of around 300 rpm while submerged in the crucible's liquid metal to a depth of approximately 65%. The reinforcement particles were included in two stages into the molten metal. The molten metal of Al2014 alloy with TiC was stirred for 5 minutes. The process of blending is prolonged until the overall wettability of Al2014 composites with particles reaches a certain level at which interfacial strength is recognized. At that time, the cast iron molds with the requisite dimensions are filled with the liquid metal mixture of Al2014 composite and TiC particulates. Fig. 2 is indicating Al2014-TiC composites.

Figure 2 Al2014-TiC composites prepared



In order to determine whether the Al2014 contains reinforcing particles TiC, a scanning electron microscopy analysis is performed on the specimen after casting. Al2014 alloy and Al2014-TiC composites have their microstructures photographed. The microstructure specimen has a 15 mm dia., and a 5 mm height. Paper with grits of 300,600, and 1000 is used to grind the surface of the specimen. After that, the surface is polished using polishing paper with a thickness of 3 μ m to get an even smoother finish on the polishing machine.

To conduct the hardness test, the specimen is prepared by grinding it in line with the ASTM standard E10 [24, 25]. A Brinell hardness tester is employed for the purpose of quantifying hardness. The sample exhibits a smooth and impeccable surface. Upon exerting a force of 250 kg on the specimen, a 5-millimeter depression was created by a ball. The specimen's surface exhibits five depression marks, which are subsequently analysed.

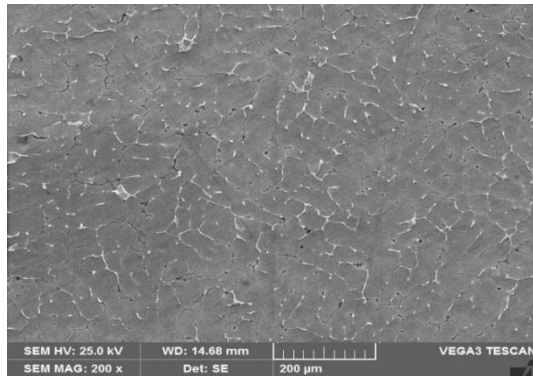
To analyse the tensile properties of Al2014 alloy and TiC reinforced composites, it is necessary to use specimens that have been prepared following the guidelines specified in ASTM standard E8 [26, 27]. To obtain the most accurate findings, the tensile strength is tested by using three specimens. In order to examine the response of Al2014-TiC composites to unidirectional tension, assess the influence of uniform distribution, and determine the tensile strength, a computer-controlled tensile machine is utilised. Figure 3 exhibits the sample of the tensile test specimen.



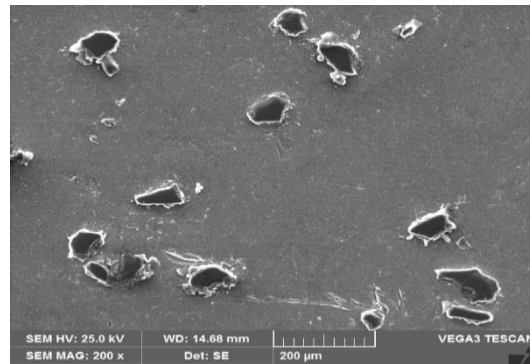
Figure 3 Tensile test specimen

RESULTS AND DISCUSSION

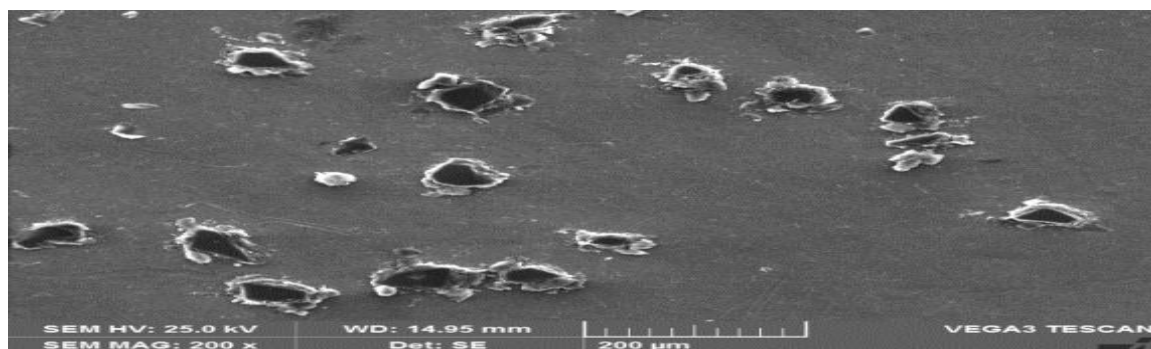
Microstructural Analysis



(a)



(b)

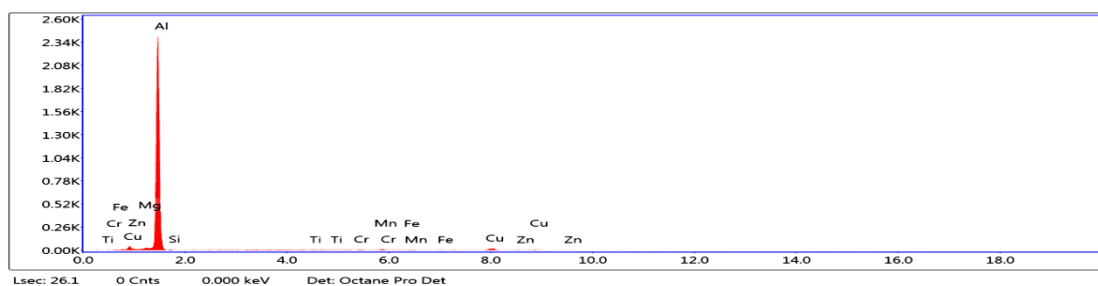


(c)

Figure 4 SEM microphotographs of (a) Al2014 alloy (b) Al2014 - 3 wt. % of TiC (c) Al2014 - 6 wt. % of TiC composites

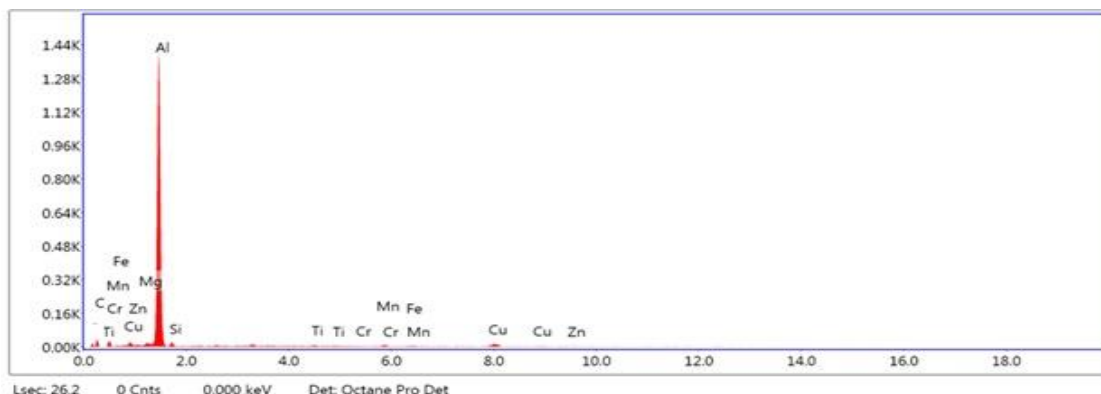
Scanning electron microphotographs in Figure 4 (a-c) display composites that have been strengthened with 3 to 6 weight percent TiC particles. Figure 4 (a) displays a scanning electron micrograph of the Al2014 alloy. The lack of particles is indicated by the pristine grain boundaries. The micrograph does not exhibit any discernible voids or casting defects. Figure 4 (b) and Figure 4 (c) display microphotographs of composites containing Al2014-3% TiC and Al2014-6% TiC, respectively.

The micrographs clearly show that the TiC particles are present in the reinforced composites at 3 and 6 weight percent. The innovative two-step casting method used to create the composites ensures that the



particles do not clump together or agglomerate [28]. In addition, the microstructure surface of Al2014 composites with 6 weight percent TiC comprises a greater number of TiC particles that are dispersed throughout the matrix Al2014 alloy.

(a)



(b)

Figure 5 EDS analysis of (a) Al2014 alloy (b) Al2014 - 6 wt. % of TiC composites

Figure 5 (a-b) displays the EDS analysis of composites that are reinforced with Al2014 alloy and include 4 wt. % of B₄C particles. Figure 5 (a) clearly illustrates that Cu is a prominent alloying element in the Al2014 alloy, along with Si, Cu, Fe, and Mg. Additionally, Figure 5 (b) displays the EDS spectra of composites that have been strengthened with Al2014 and 6 weight percent TiC particles. The presence of titanium and carbon particles in the Al2014 alloy was identified using the EDS spectra of composites. The presence of Ti and C elements, along with Cu, Fe, Cu, Mn, and Si, confirms the integrity of the casting procedure employed in the production of the composites.

3.2 Hardness Measurements

Table 2 Hardness of Al2014-B₄C composites

Sl No.	Material	Hardness (BHN) Standard Deviation	with Improvement (%)
1	Al2014 Alloy	69.30 ± 0.88	~
2	Al2014 - 3 wt.% of TiC	78.09 ± 0.32	12.68
3	Al2014 - 6 wt.% of TiC	90.21 ± 0.75	30.16

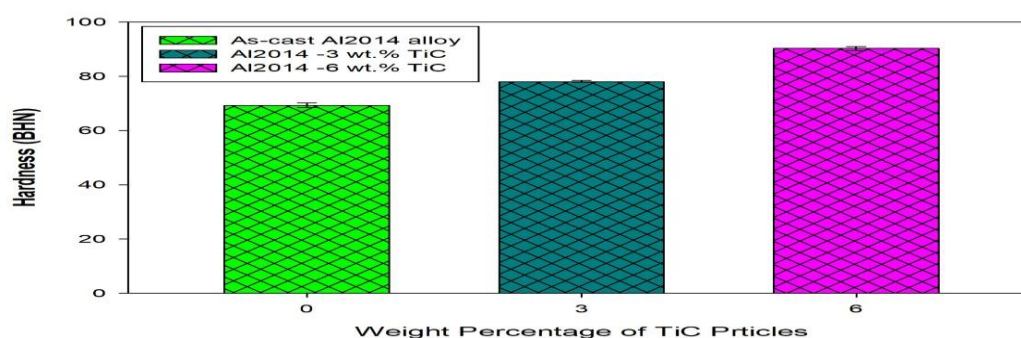


Figure 6 Hardness of TiC reinforced Al2014 alloy composites

Table 2 and Figure 6 show the hardness values of Al2014 alloy, Al2014 - 3, and 6 wt. % of TiC composites. As the plot shows, the hardness of Al2014 alloy improves from 3 to 6 wt. % TiC particles. The hardness of the cast alloy is 69.30 BHN, but it increases to 78.09 BHN and 90.21 BHN after adding 3 and 6 wt. % of carbide particles, respectively. A hardness enhancement of 30.16% was seen in TiC composites with an Al2014 alloy content of 6 weight percent. Because of the hard TiC particles that are present in the ductile matrix, the hardness of Al2014 alloy is enhanced. Incorporating carbide particles, which have a hardness of 3200 BHN, into a soft matrix helps to increase the hardness. As a result of the dislocation density caused by the thermal coefficient mismatch between the Al2014 alloy and TiC particles, this

procedure also increases strain hardening in the composites [29, 30]. The composites get harder due to the strain hardening phenomenon.

3.3 Tensile Properties

Figure 7 show the consequence of TiC on strength of Al2014 alloy. The strength of the Al alloy has been upgraded as the wt.% of TiC particles in the soft Al2014 matrix increases, as shown in Figure 7. Al2014 alloy has an ultimate tensile strength of 214.1 MPa. In addition, the UTS of composites made of Al2014 with 3% TiC and 6% B₄C are 235.4 MPa and 262.5 MPa respectively. The addition of 6 weight percent of TiC particles ranging in size of 15 to 20 microns improved the UTS of Al2014 alloy by 22.6%
 Figure 7 UTS of TiC reinforced Al2014 alloy composites

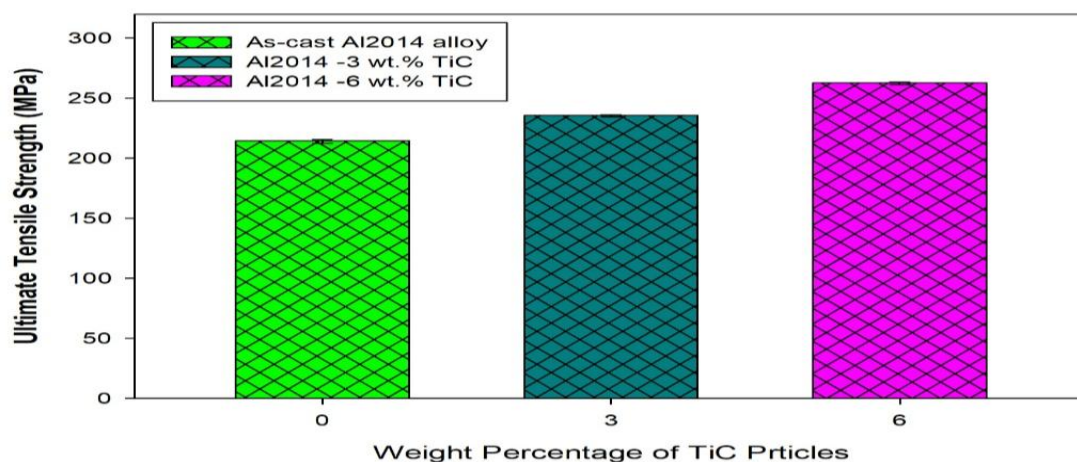
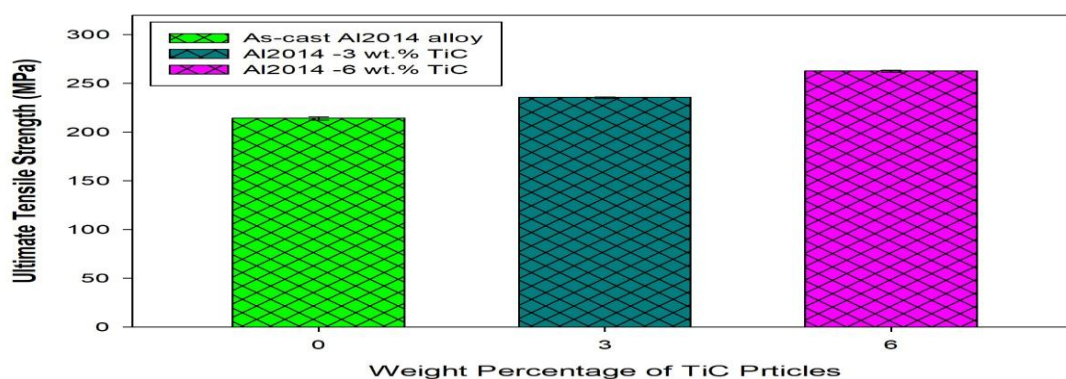


Figure 8 is the effect that TiC particles have on the yield strength of Al2014. Figure 8 shows that the strength of the Al2014 has been enhanced with an increase in the weight percent of TiC particles in the Al matrix. Al2014 alloy yields its full strength is 181.25 MPa. In addition, the YS of composites made with Al2014 and 3 weight percent TiC is 204.3 MPa, while that of composites made with Al2014 and 6 weight percent TiC is 228.4 MPa. The addition of 6 weight percent of TiC particles ranging in size 15-20 microns improved the YS of Al2014 alloy by 26%.

Figure 8 YS of TiC reinforced Al2014 alloy composites

Plots 7 and 8 demonstrate that the inclusion of 3 and 6 weight percent of minuscule TiC particles into the Al2014 alloy resulted in an increase in its ultimate and yield strengths, respectively. Incorporating TiC into the matrix enhances the tensile strength of the Al alloy. Due to the particle's hardness, the matrix material becomes more fragile and is able to endure higher directed loads. Within the realm of composites, these resilient particles function as load-bearing elements, hence enhancing the strength of the composites. Furthermore, as per the Hall-Petch strengthening mechanism, the incorporation of minuscule particles into the aluminium matrix leads to a decrease in grain size. Consequently, the strength of the composites is enhanced. The presence of density dislocations in the Al2014 alloy is attributed to the significant difference in expansion coefficients between the alloy and the TiC particles,



as explained by the Orowan principle [31, 32]. Strain hardening takes place in the Al-TiC melt due to the presence of density dislocations, resulting in enhanced strength.

Figure 9 show the ductility of Al2014 and Al2014 alloy composites reinforced with 3 and 6 weight percent of tiny TiC particles, respectively. The graph shows that the ductility of the matrix drops as the percentage of TiC particles rises. The presence of TiC in the matrix is responsible for the decrease in ductility. The material is able to resist further elongation due to the significant multidirectional stresses at the interface of the Al2014 alloy and TiC. Thanks to the strong bonding between the Al and TiC particles, the applied load is effectively transferred to the evenly distributed micro TiC particles, and the overall performance is improved. All things considered, the Al2014 alloy-6% TiC composites exhibit lower elongation than the base amalgam.

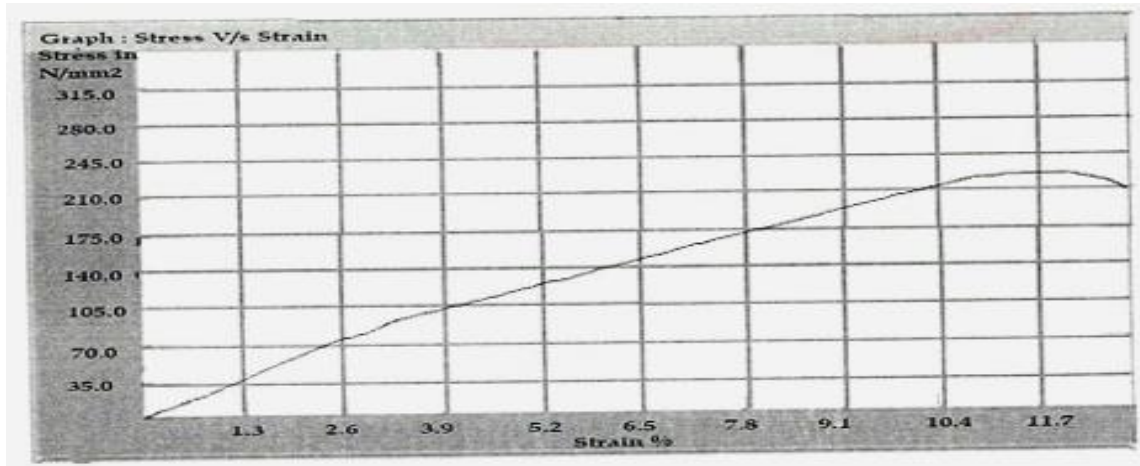
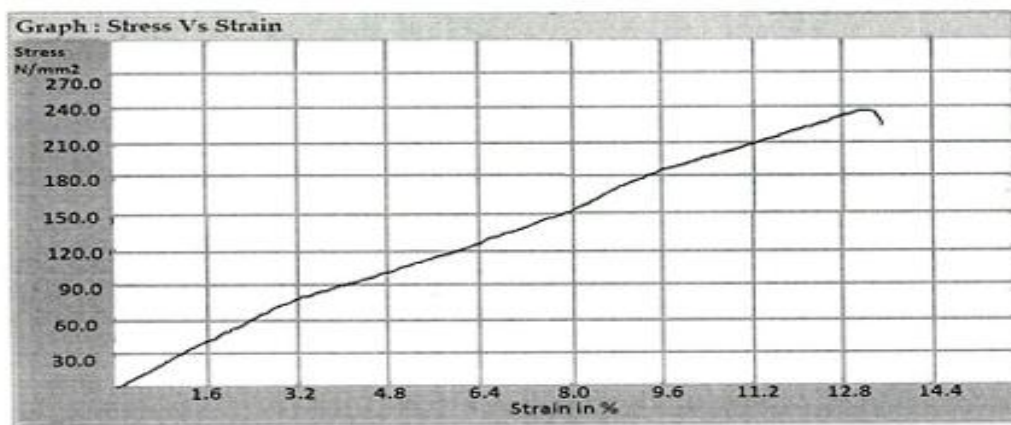
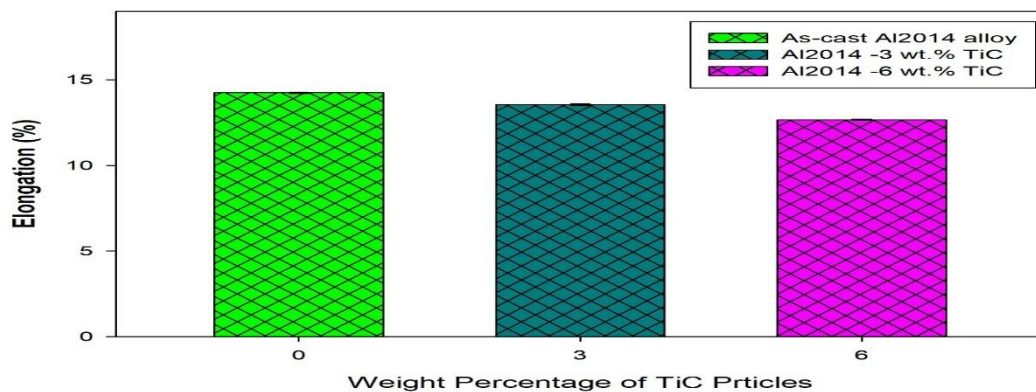
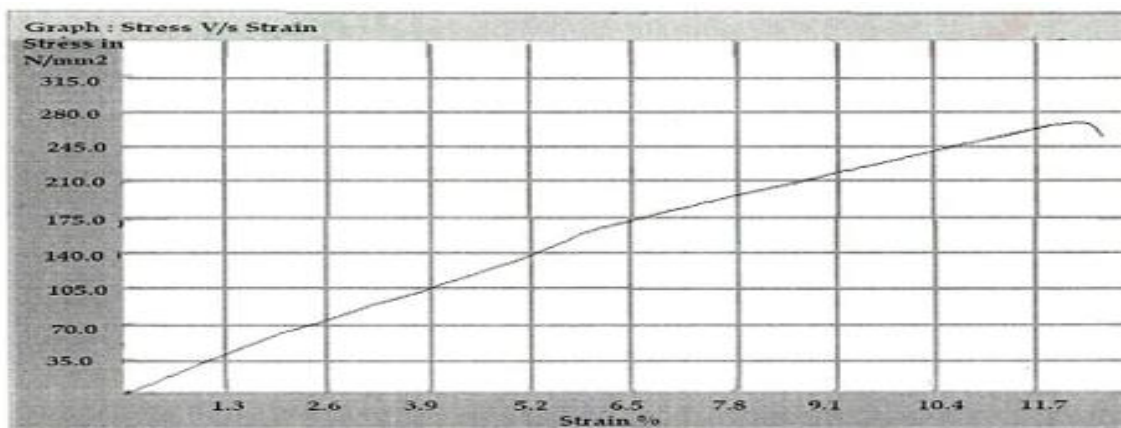


Figure 9 Percentage elongation of TiC reinforced Al2014 alloy composites



(a)



(b)

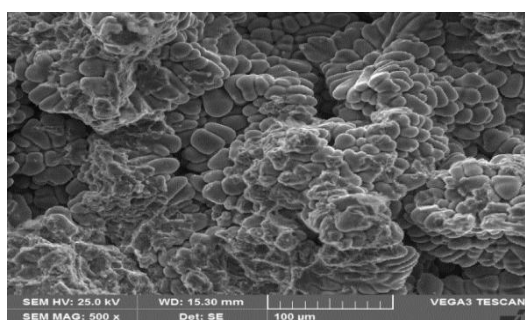
Figure 10 Stress-strain plots of (a) Al2014 alloy (b) Al2014 - 3 wt. % B₄C (c) Al2014 - 6 wt. % B₄C composites

Fig. 10 (a-c) are demonstrating the stress-strain plots of as cast Al2014 alloy, Al2014 with 3 and 6 wt. % of TiC composites respectively. The ultimate strength of base Al2014 alloy is 214 MPa with 14.2% of elongation. The composites with 3 and 6 wt.% of TiC particles are exhibiting the higher strength compared to the Al2014 alloy with slight reduction in the ductility. The increased strength with addition of carbide particles helps in the decline of the surface area in the real time applications, which further contributes in decreasing the weight of the component [33, 34].

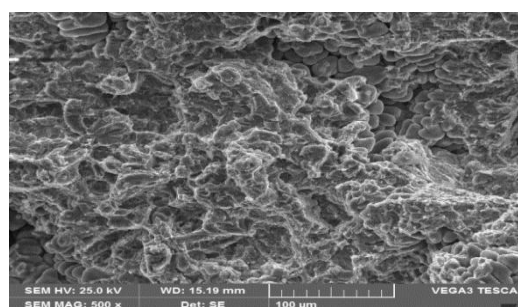
3.4 Tensile Fractography

The micrographs of the fracture surfaces of Al2014 and Al2014 with 3 and 6 weight percent TiC composites are shown in Figure 11 (a-c). The tensile fracture micrographs show that the matrix alloy and TiC reinforcement are well-bonded. Figure 11 (a) shows the surface of the Al2014 alloy that has broken in pictures taken at 500X magnification. The visible grains on the cracked surface of the cast alloy indicate a ductile fracture.

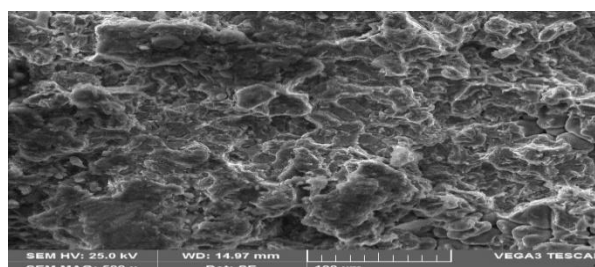
Also, the fractured surfaces of the Al2014 - 3 wt. % TiC and Al2014 - 6 wt. % TiC composites can be seen in Figure 11 (b-c). The micrographs show that the composites become more brittle with increasing amounts of TiC reinforcement. The surface of tensile fractured Al2014 - 3 wt. % TiC composites shows this increased brittleness clearly. This brittle fracture also occurs in tandem with the composites' elongation. There is a decline in composite ductility with increasing wt.% of TiC particles, as mentioned in the percentage elongation section.



(a)



(b)



(c)

Figure 11 SEM images of tensile fractured surfaces (a) Al2014 alloy (b) Al2014 - 3 wt. % TiC (c) Al2014 - 6 wt. % TiC composites

CONCLUSIONS

Al2014 alloy with 3 and 6 wt. % of TiC composites were produced by stir casting and following conclusions were made

- The microstructures of the produced Al2014 and Al2014 composites with 3 and 6 weight percent TiC were examined by SEM and EDS. The elemental analysis indicates the existence of titanium carbide in the Al2014 composites.
- The hardness of Al2014 alloy found 69.3 BHN, with 3 and 6 weight percent of TiC composites, it was 78.9 BHN and 90.2 BHN respectively.
- The improvements in the ultimate strength of the Al2014 alloy was obtained with the occurrence of TiC particles. The strength of Al2014 matrix increased to 262.5 MPa with 6 wt.% of TiC particles. The increased strength is due to strong bonding existence between the Al2014 alloy and TiC.
- The improvements in the yield behaviour of the Al2014 alloy was obtained with the presence of TiC particles. The strength of Al2014 matrix increased to 228.4 MPa with 6 wt.% of TiC particles.
- The stress-strain plots indicated the impact of TiC on the strength and ductility of the Al2014 alloy and its TiC composites.
- By adding 3 and 6 weight percent of carbide particles, the ductility of the aluminium alloy was reduced. The existence of hard carbide particles decreases the elongation of soft Al2014 matrix.
- Ductile mode fracture was seen in unreinforced material on tensile fractured surfaces. Additionally, brittle mode of fracture was noted in the composites as the reinforcing amount increased to 6 wt. %.

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