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Micro structural characteristics and mechanical behaviour of aluminium matrix composites reinforced with Titanium carbide

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ABSTRACT

In this study titanium carbide particles reinforced in aluminium alloy (A 6063) composites were fabricated successfully using stir casting method. Titanium carbide was added in 2, 4, 6, 8 and 10 percentages by weight in the aluminium alloy. Density, hardness, impact and tensile tests were conducted to assess the mechanical properties of composites. Scanning electron microscopy and X-ray diffraction techniques were employed to study the fracture mechanism and phase identification respectively. Increase in addition of titanium carbide decreased the impact strength and elongation of composites to a maximum of 31% and 35% respectively. The density, hardness and tensile strength of composites increased to a maximum of 7.8%, 20% and 19.55 respectively while adding titanium carbide particles. X-ray diffraction results indicated that Al and TiC were the principal elements in composites and are free from intermetallics. Microstructures of the fractured composite specimen are characterized by ridges, voids, cracks, dimples, particle fracture and ridges.

Keywords: Composites, Mechanical properties, Microstructure, Aluminium, Titanium carbide

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1. INTRODUCTION

Aluminium matrix composites have drawn immense interest in diverse applications including aerospace and automobile components due to their light weight, high strength to weight ratio, high stiffness, low cost and high dimensional stability. Aluminium is used as a key metal matrix constituent in production of composite materials. There is an increased petition for low cost, lightweight material with excellent mechanical and tribological properties in aerospace and automobile industries. Rana et al. [1] fabricated Al/SiC composites by ultrasonic assisted stir casting and observed that the tensile and compressive strength of composites increased with increase in addition of SiC particles. Pardeep Sharma et al.[2] reinforced graphite particles into aluminum matrix by stir casting process and observed a non-uniform mixture of graphite, while the hardness of composites decreased with increase in addition of graphite particles. K.Shirvanimoghaddam et al. [3] studied the influence of stir casting temperature on mechanical properties of $ZrSiO_4$, TiB_2 and B_4C composites and reported an increase in hardness and tensile strength by 125% and 52% respectively with increase in temperature. Zhiyong Cai et al. [4] fabricated aluminum/SiC/ copper composites by liquid phase hot pressing and reported that the formation of Al_2Cu (θ) phase increased with increase in copper content. The fracture mechanism of Al/Sip composites is dominated by Si phase cracking, while the ductile rupture of Al matrix reduced with increase in Cu content. Rong Tu et al. [5] prepared B_4C-HfB_2 composites by arc melting process and observed that HfB_2 content increased the thermal and electrical conductivity of the composites. Harichandran et al. [6] added boron carbide particles to aluminium and reported that increase in B_4C beyond 6% leads to porosity and particle agglomeration, thereby decreasing the strength and ductility of composites. Wenming Jiang et al. [7] fabricated aluminum/iron bimetallic composites by hot-dip galvanizing and aluminizing method and observed a comparatively consistent and dense reaction layer in composites. Veysel Erturun et al. [8] Al 6061/SiC contrived composite by powder metallurgy followed by reciprocating extrusion and observed a decrease in grain size and hardness with increase in number of extrusion passes. Yu Li et al. [9] reported that addition of Ti in Al-B_4C composite resulted in denser TiB_2, coarse Al_3Ti and uniform distribution of B4C. Fadavi Boostani et al. [10] used graphene sheets during ball milling to encapsulate SiC particles in aluminium-based composite and reported an increase in yield strength and ductility by 45% and 84%, respectively. Lei Yu et al. [11] fabricated Al/ZrB_2/ SiC composites by situ reaction hot-pressing and reported that the oxidation resistance of composites increased with increase in SiC and is characterized by grain pull-out and grain refinement strengthening. Hanqing Xu et al. [12] prepared $Ti/Al_2O_3/Pr_6O_{11}$ composites by vacuum hot pressing at a pressure of 30 MPa and observed new phases of $AlTiO_2$, $Pr_2Ti_2O_7$ and $PrAlO_3$ characterized by intergranular and transgranular fracture behavior. Linlin Yuan et al. [13] fabricated AlB_2 reinforced aluminum composites by powder metallurgy technique followed by hot rolling and reported that an extreme addition of AlB_2 aluminium alloy declined the mechanical properties of composites. Syed Nasimul Alam and Lailesh Kumar [14] fabricated Al composites reinforced with exfoliated graphite nano platelets by powder metallurgy and reported that addition of graphite nano platelets beyond 3 wt.% decreased the hardness of the composites due to graphite agglomeration. Kenneth Kanayo Alaneme et al. [15] reported that the hardness of Al/rice husk ash/ graphite composites fabricated by liquid metallurgy decreased with increase in the presence of graphite and rice husk ash, while the tensile strength and toughness of composites increased with addition of graphite and rice husk ash. Shuai Wang et al. [16] reinforced Ti_3AlC_2 in aluminium alloy by hot-press sintering approach and observed poor wettability of Ti_3AlC_2 leading to deprived bonding between Al and Ti_3AlC_2 leading to the formation of Al_2Cu layer. Qiyao Hu et al. [17] processed $B_4C/Al_3Ti/Al$ hybrid composite by a two-step stir casting process and observed the formation of TiB_2 layer at the interface. Ruixiao Zheng et al. [18] fabricated metallic glass particles reinforced aluminium composites by powder metallurgy and observed that the metallic glass acts as a good binder that reduces the porosity in composites. Jianjun Sha et al. [19] doped Ti and carbon nano tubes in ZrC by hot pressing and observed the formation of TiC, crack deflection, crack branching and crack bridging in composites. Zichuan Lu et al. [20] synthesized intermetallic Al_3Ti alloys with residual aluminum by reactive foil sintering and found that the compression failure strain of composites increased by the distribution of ductile Al phase along the grain boundaries. Yunhe Zhang et al. [21] studied the effect of steel pins in aluminum alloy composites fabricated by pressure infiltration method and observed the formation of continuous interfacial layers of $FeAl_3$ providing tough interfacial bonding. Kenneth Kanayo Alaneme et al. [22] reported that an increase in presence of ground nut shell ash in aluminium/ silicon carbide composites decreased the tensile strength, hardness and specific strength of composites. Kang Wang et al. [23] observed some pores, particle agglomerates and SiO_2/Al in-situ reaction in aluminium composites reinforced with SiO_2 and Al_2SiO_5 fabricated by stir casting. Long Xia et al. [24]

fabricated B_4C/ Lithium alumina silicates glass-ceramic composites by hot-pressing and reported that high crystallinity, high relative density and fine grain size are the main factors influencing the mechanical properties of composites. Ravikumar et al. [25] reported that the brittle fracture of Al/tungsten carbide composites was characterised by cracks and particle fracture. Manu sree et al. [26] reported that the Al_2O_3 formed at the interface, between the Al and aluminosilicate matrix improved the bonding strength of composites.

It is revealed from the literature review that intensive research were carried to expose the microstructure and mechanical properties of aluminium matrix composites reinforced with different reinforcement particles. Aluminium alloy (A 6063) having good surface finish, high corrosion resistance and weldability are a potential matrix material in engineering applications. Literature study reveals that studies were not carried using Titanium Carbide (TiC) as reinforcement material. Titanium carbide normally used for manufacturing wear-resistant tools, cutting tools, protective coatings and carbide steel having good chemical inertness and thermal conductivity is a prominent reinforcement material. In this study an attempt was made to investigate the mechanical properties like impact strength, density, hardness, tensile strength and elongation of aluminium (A6063) matrix composites reinforced with TiC particles fabricated by stir casting. The fractured surfaces and microstructures of the composite samples were studied using scanning electron microscopy (SEM) and X-ray diffraction analysis (XRD).

2. MATERIALS PREPARATION

The chemical composition of aluminium alloy (A6063), obtained using spectrometer test is shown in Table.1. Mechanical properties of A6063 aluminium alloy used in the present study are shown in Table.2. Aluminium alloy was reinforced with Titanium carbide (TiC) having particle sizes in the range of (53-75) µm is fabricated by stir casting. Uniform distribution of reinforcement particles in the matrix metal melt can be achieved by having a proper control of stirring. Preheated TiC particles (400^{o}C) were mixed with molten aluminium matrix at 800^{o}C in a graphite crucible. Stirring is carried out at a speed of 500 rpm for 5 min to ensure uniform distribution of TiC particles in the aluminium matrix. Sodium hexa fluoro aluminate (10 gm) was added to the molten melt to prevent formation of slag and improve the casting efficiency. Magnesium was added in 1 wt % to improve wettability.The molten mix is then poured and solidified in a split die to attain a composite specimen of 130 mm in length and 20 mm in diameter. The composite samples were subjected to optical microstructure and X-ray diffraction (XRD) studies to evaluate the distribution of particles and phases present in the composites. It can be observed from the optical microstructure (Fig.1) that a fair uniform distribution of TiC exists in the composites. XRD images are used to spot the existence of any other phases in the composites after casting. Increase in TiC also shows an increase in intensity of TiC peaks in the XRD pattern. XRD results (Fig.2) shows that Al and TiC are the principal elements present in the composites specimen indicating that the composites are free of intermetallics and impurities.

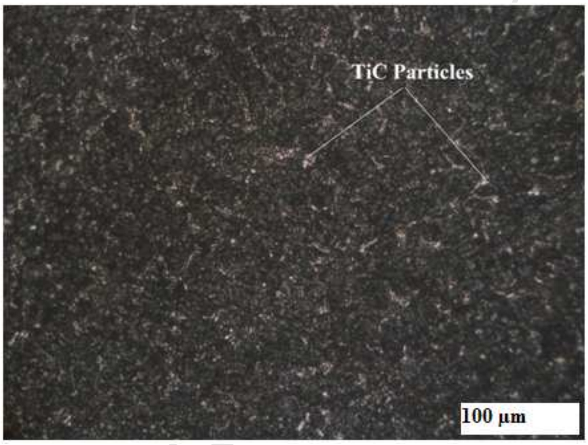

Fig 1: Microstructure of the composite sample

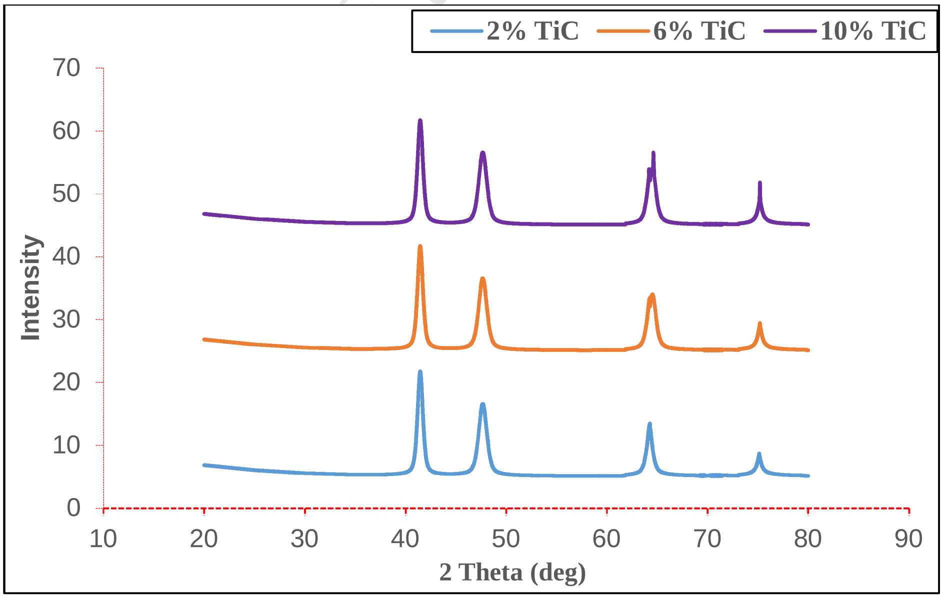

Fig 2. XRD Pattern of composite samples

Table 1. Chemical Composition of Aluminium 6063 alloy

Elements	Si	Fe	Cu	Mn	Cr	Mg	Zn	Ti	Others	Al
Weight %	0.35	0.17	0.05	0.07	0.06	0.69	0.02	0.04	0.085	Bal

Table 2. Properties of 6063 Aluminium alloy

Sl.No.	Properties	
1	Density	2.68g/cm^3
2	Poisons ratio	0.33
3	Young's modulus	75 GPa
4	Elongation	16 %
5	Yield strength	75 MPa
6	Hardness	25 BHN
7	Tensile Strength	126MPa

3. EXPERIMENTAL PROCEDURE

Aluminium/Titanium carbide specimens were depicted for tensile test to study the effect of TiC on aluminium composite using TUE-C make computerized 20 KN Universal Testing Machine. Tensile tests were carried out using circular specimens machined as per ASTM E-8 standards with a gauge diameter of 6mm and length 120 mm. Tensile tests were conducted at a strain rate of 0.001/sec at atmospheric conditions and the data is recorded by a computer. In order to minimize the possibilities of error each test were carried using three specimens and the average value is used for study.

Izod and charpy impact tests were conducted using a 184 J capacity standard impact pendulum type testing machine (ASI make, AMT-8 model) to evaluate the impact strength of composites. The impact specimens were machined for a cross section of 10×10 mm^2 as per ASTM standards.

Brinell hardness tests were conducted in a standard Brinell hardness tester with a load of 200 kgf and a ball diameter of 5mm. The test specimen surfaces were polished using emery paper to ensure accurate hardness value.

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Density of aluminium alloy and composites were measured to assess the porosities present in the composites. Density of the specimen is calculated using a standard polished specimen of 100 mm height and 10 mm diameter. An electronic weighing machine with accuracy of 10^{-3} mg is used to find the mass of the specimen. Volume of the composite is evaluated by using a vernier with a least count of 0.001 mm. Density is calculated by dividing volume against mass.

4. RESULTS AND DISCUSSION

4.1 Influence of TiC on density

Theoretical densities and the actual measured densities of composites with standard error bar is presented in Fig.3. It can be inferred that the measured values are closer to the theoretical values indicating that the composites are free from pores which is a sign of good casting. Small variation in densities between the actual and measured value is probably because of the fact that some of the reinforcements may shift into the slag. Density of TiC is 4.93 g/cm^3 against a density of 2.68g/cm^3 for the base aluminium alloy (A6063). The density of the composites increased up to 7.8% showing a maximum density of 2.89 g/cm^3 for the composite reinforced with 10% TiC. Porosity of the composites increased to a maximum of 1.39 % while reinforcing TiC in aluminium alloy. Increase in density is due to the higher density of the TiC reinforcement compared to that of the aluminium alloy. Researchers have observed different values for composites reinforced with different particles. Shirvanimoghaddam et al. [3] reported that the density of composites reinforced with $ZrSiO_4$ and TiB_2 increased, while the density of composite reinforced with Al-B_4C decreased. This is due to the higher and lower value densities of the reinforcement. Pardeep Sharma et al. [2] observed that the density of aluminium composites increased with increase in addition of Si_3N_4 and the porosity increased up to 1.43% due to the presence of impurities in the aluminium material.

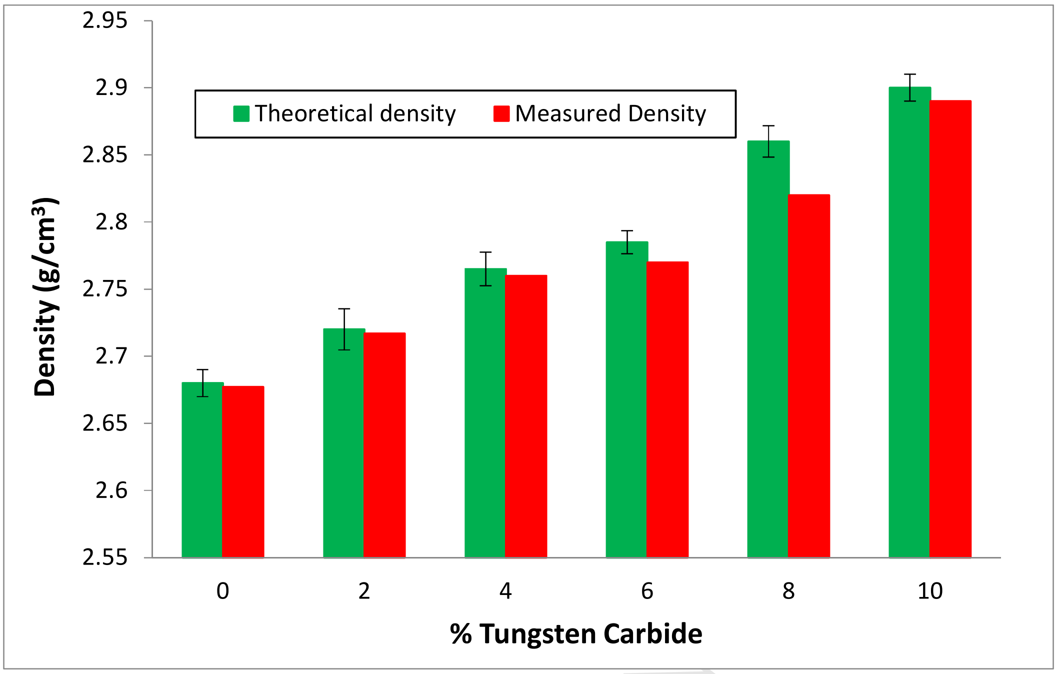


Fig 3. Influence of TiC on density

4.2 Influence of TiC on strength and elongation

Effect of ultimate tensile strength (UTS) and yield strength of TiC aluminium alloy composite with standard error bar is shown in Fig.4. Addition of TiC particles increases the UTS and yield strength of the composites. UTS increased to a maximum of 19.5% and yield strength increased to about 18% while adding 10% titanium carbide particles in aluminium alloy. Increase in tensile strength is generally attributed to the strong interfacial bonding between the aluminium matrix and TiC. Absence of pores in composites is also a reason for the increase in tensile strength. Similar kind of increase in tensile strength while adding particles like SiC, B_4C, B_4C-HfB_2, Al_3Ti, were reported by researchers [1, 6, 5]. However addition of $ZrSiO_4$ in aluminium alloy decreased the tensile strength of composites [3]. Multidirectional thermal stress and grain refinement at the matrix/reinforcement interface induces the strengthening effect of composites, thereby increasing the tensile strength of composites [1]. High dislocation density and thermally induced stress formed due to the variation in thermal expansion between the TiC and aluminium alloy also increases the tensile strength of composites [6]. Thermodynamically unstable reinforcement particles bear reaction at the TiC/Al interface and increase the strength which in turn depends on the processing temperature. [10]. Presence of dimples, micro cracks and micro voids formed due to debonding are the major factors influencing the tensile strength of composites [15]. Addition of TiC in aluminium alloy decreases the elongation of composites as shown in Fig.5. Elongation of composites decreased to about 35% while adding 10% TiC to the aluminium alloy. Addition of TiC particles increases the interfacial bonding between the TiC particle and aluminium matrix. Presence of hard TiC particles decreases the ductility of composites, thereby encouraging the plastic deformation and hence decrease in elongation of composites.

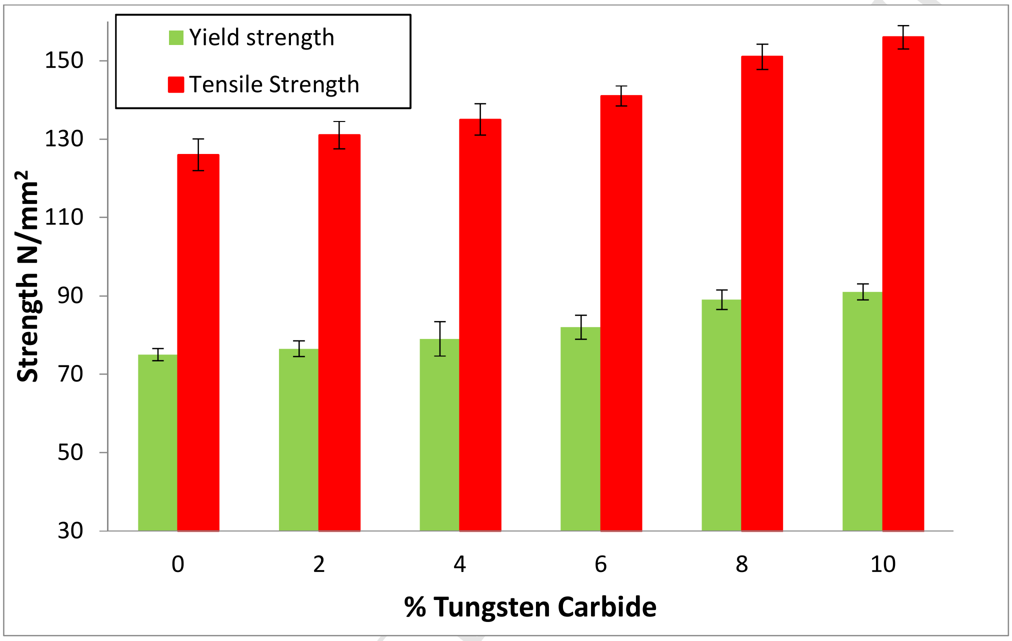


Fig 4. Influence of TiC on Tensile Strength

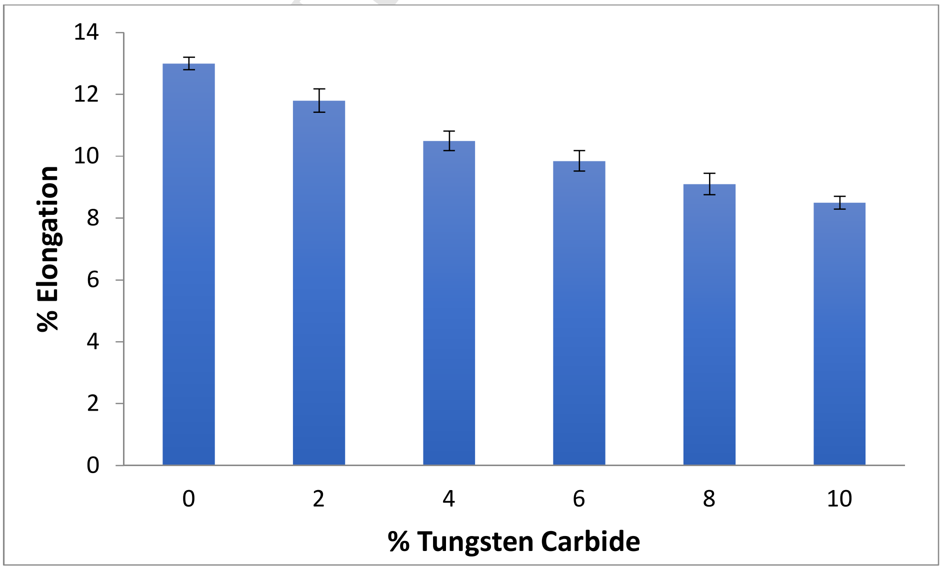
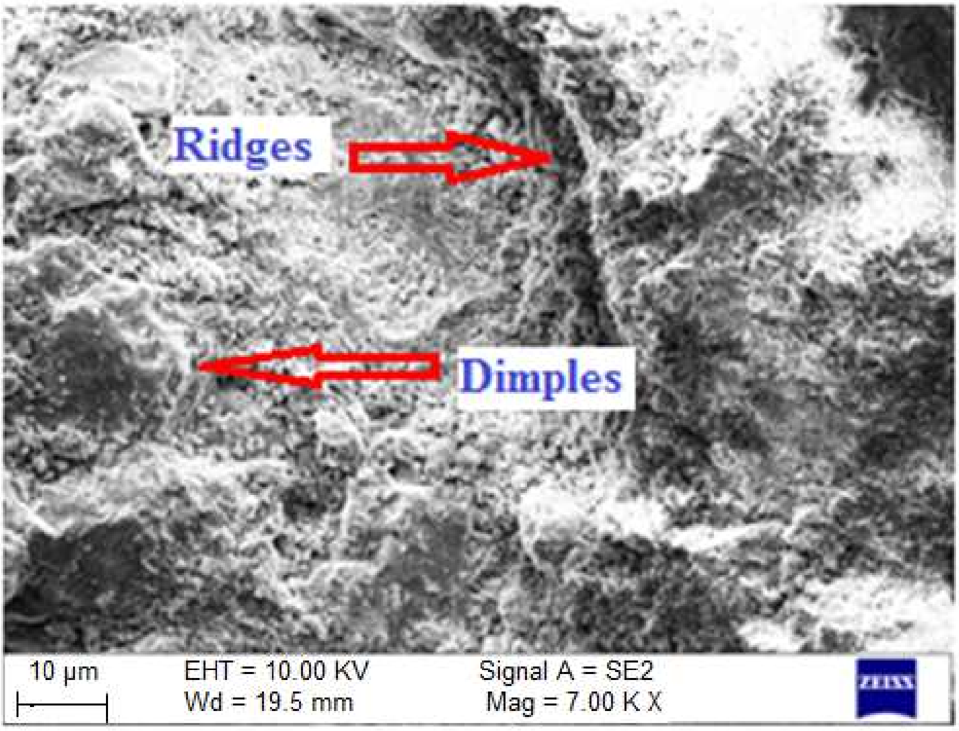
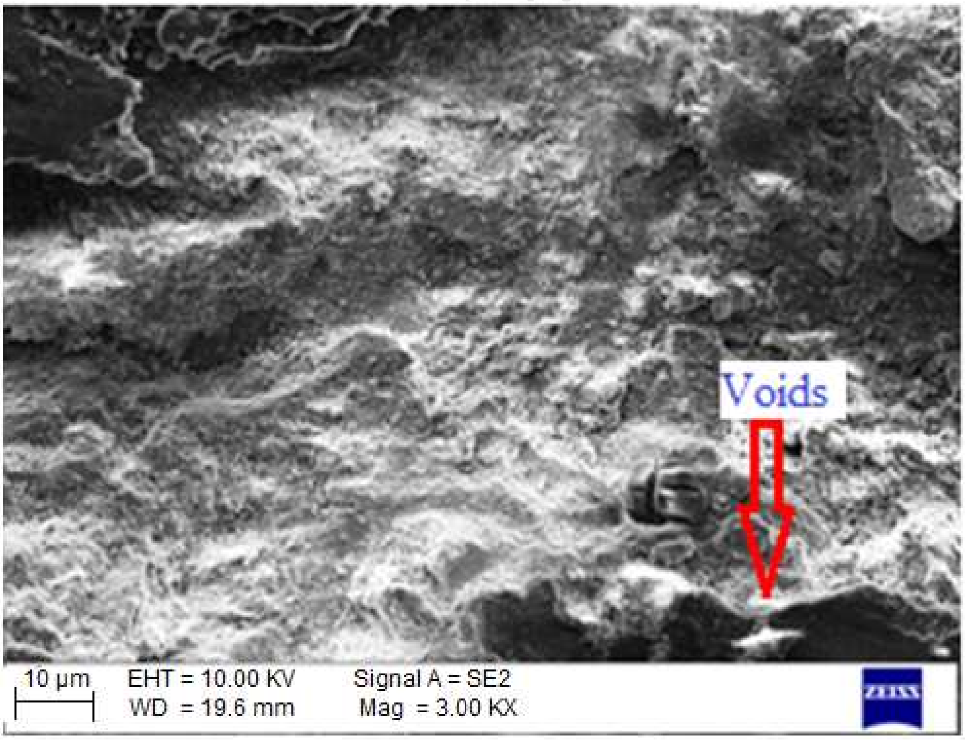


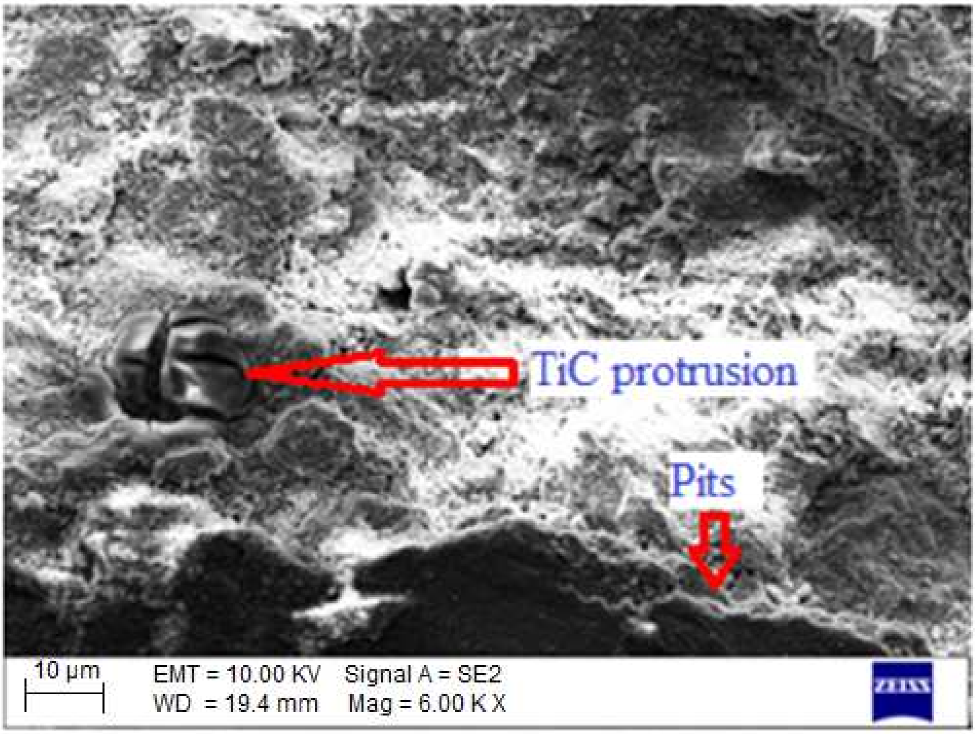
Fig 5. Influence of TiC on elongation



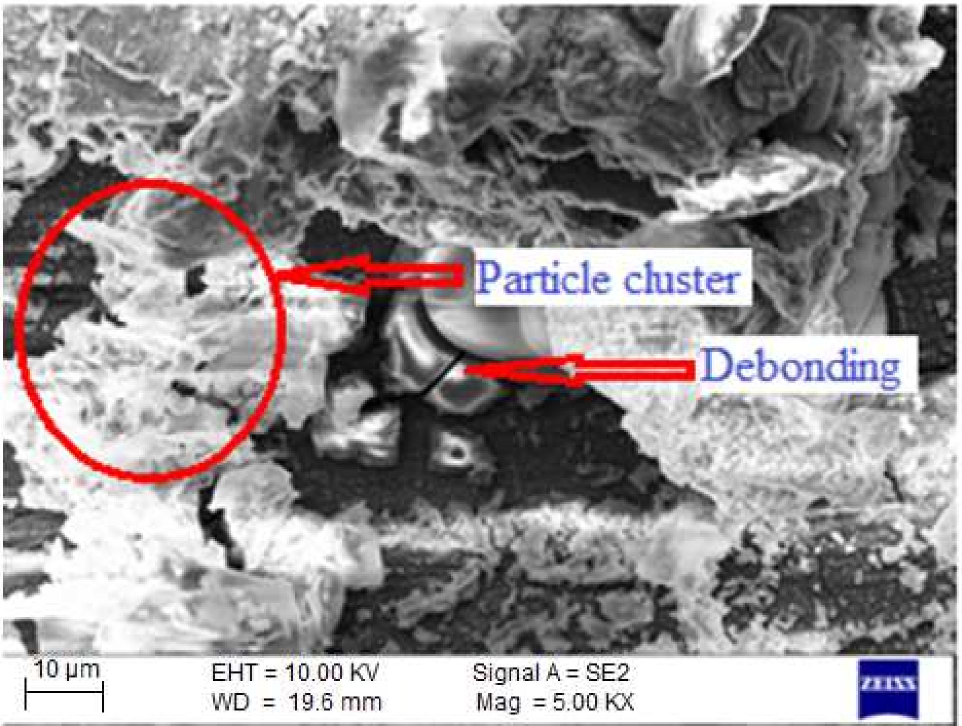
(a) Aluminium alloy (A 6063)



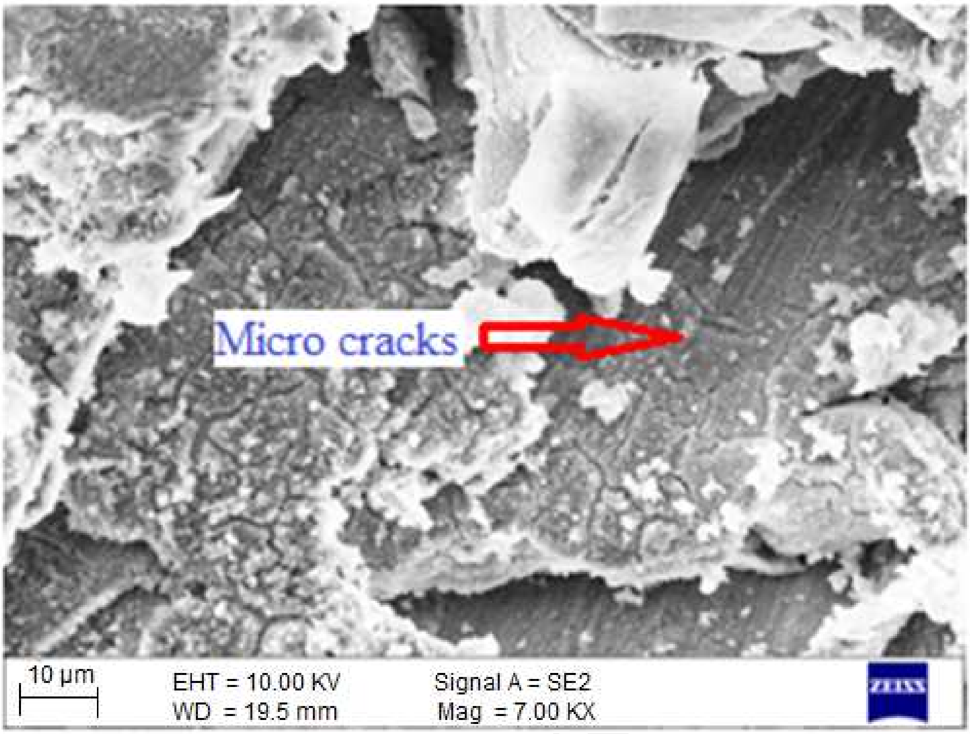
(b) Al+ 2% TiC



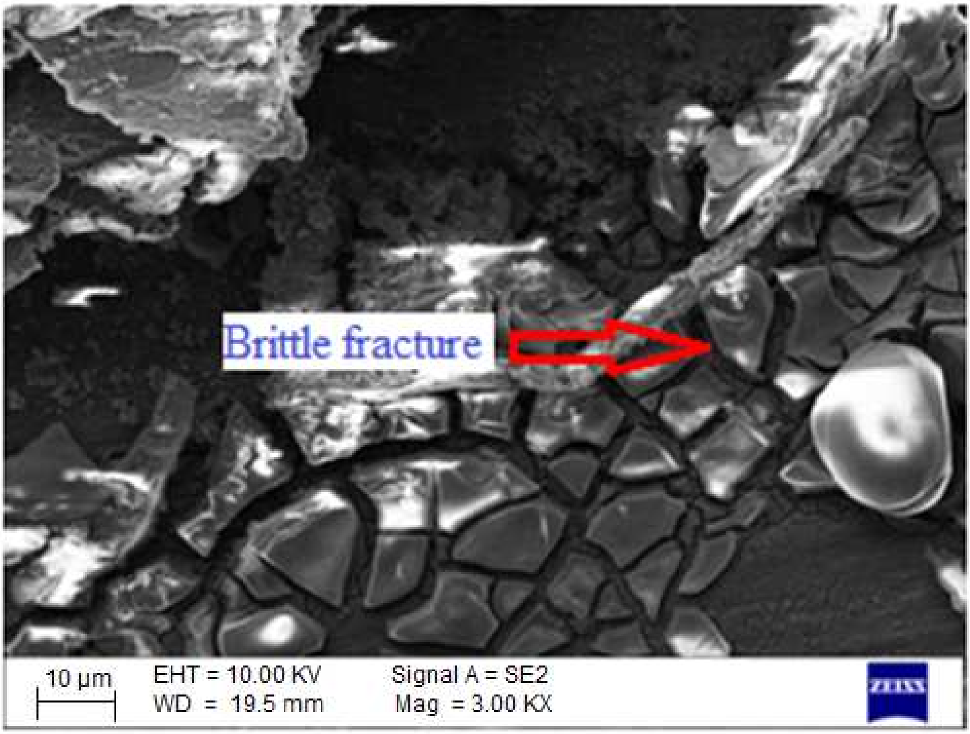
(c)Al+ 4% TiC



(d) Al+ 6% TiC



(e)Al+ 8% TiC



(f) Al+ 10% TiC

Fig 6. SEM of the fractured composites after tensile test

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Scanning electron microscopy structure of the fractured composite sample is shown in Fig.6. Presence of dimples and ridges due to shearing can be observed along the surface of aluminium alloy (Fig.6a) indicating a ductile mode of fracture. Fig.6b shows the presence of voids and ridges due to elastic deformation along the surface. The mechanism of failure mode is mostly delamination and ductile fracture at this stage. No debonding of TiC from the matrix was observed at this stage clearly indicating a ductile fracture. Increase in presence of TiC reduces the presence of voids and dimples representing a decrease in elastic deformation. Presence of pits observed in Fig .6c may be due to the defects in the casting. Protrusion of particles can be found in Fig.6c due to the interfacial toughening mechanism. Presence of TiC in the form of clusters due to the plastic deformation is absorbed along the surface of the composites with 6% of TiC (Fig.6d). Debonding of the particles is also observed (Fig.6d) due to the increase in hard and sharp TiC particles. With further increase in TiC, micro cracks and fracture of TiC particles are observed along the surface representing a brittle mode of fracture (Fig.6e). Propagation of cracks and particle fracture are evidenced along the surface indicating an increase in brittle nature of composite with higher TiC content (Fig.6f). Increase in crack may be due to the strong interface strength between TiC and aluminium resulting in brittle mode of fracture. In summary the failure of aluminium alloy is elastic and ductile in nature and is characterised by dimple and voids. With increased presence of TiC the failure is predominantly brittle in nature characterised by cracks, debonding and particle fracture.

4.3 **Influence of TiC on hardness**

Influence in hardness of composites with increase in TiC with standard error bar is depicted in Fig.7. It can be observed that addition of TiC in aluminium alloy increased the hardness of composites. Hardness of composites increased to about 20% when compared to that of the base aluminum alloy. Hardness of the composites increased with increase in addition of TiC particles. Similar trend was reported by other researchers that addition of SiC, B_4C, AlB_2 particles increased the hardness of composites [1, 6, 13]. However addition of graphite particles decreased the hardness of composites [2]. Increase in hardness may be attributed to the variation in plastic deformation of composites due to the presence of hard TiC particles. Absence of porosity may also be the reason for the increase in hardness of composites. Microstructural changes taking place at higher processing temperature also influences the hardness of composites

[3]. Hardness of composites also increases due to Orowan and Hall–Petch strengthening mechanisms in addition to the interface between the reinforcement and matrix [2]. Linlin Yuan et al. [13] reported that the hardness of composites depends on the processing method and heat treatment process involved after processing.

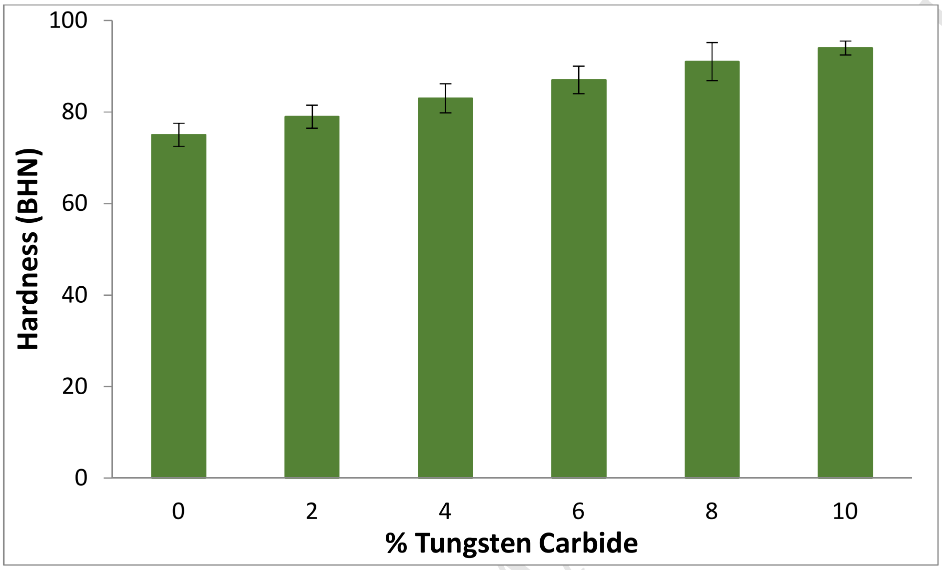


Fig 7. Influence of TiC on hardness

4.3 **Influence of TiC on Impact Strength**

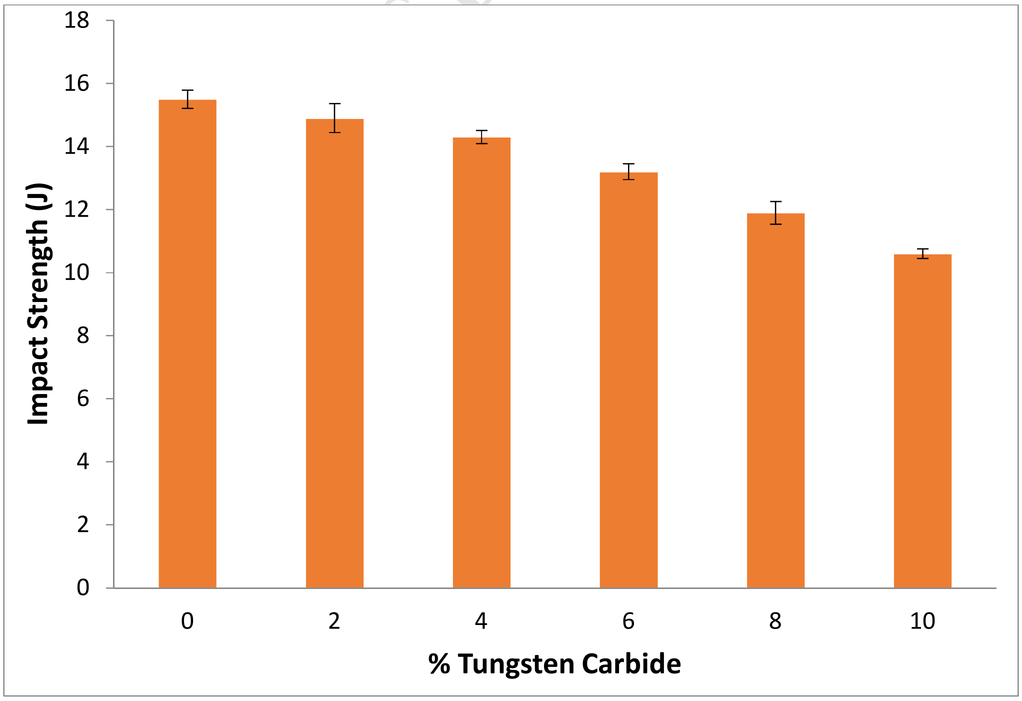
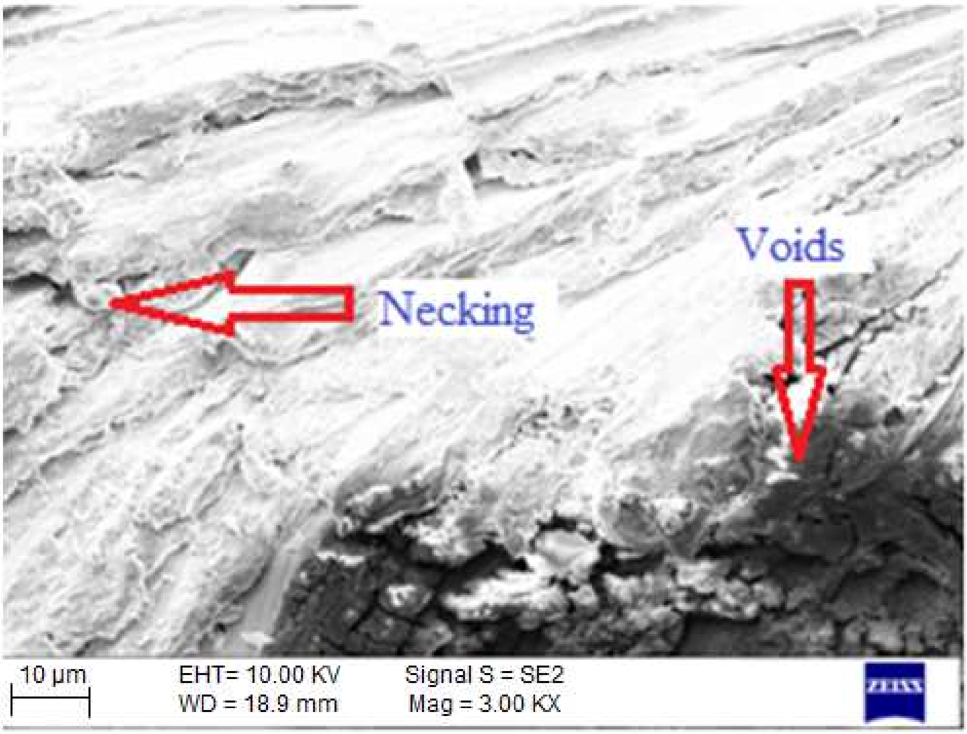
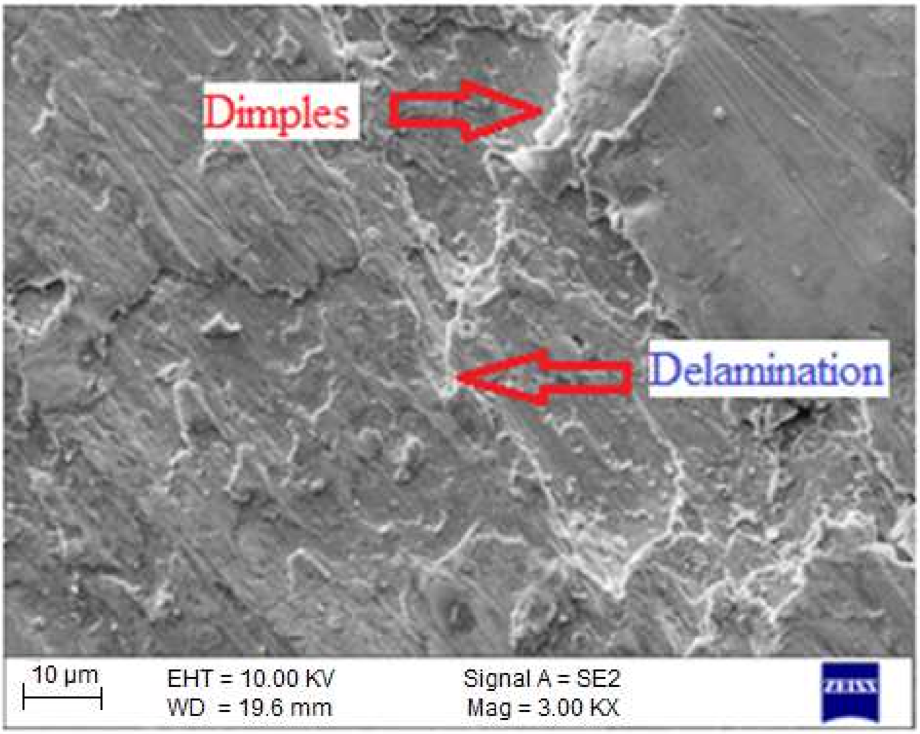


Fig 8. Influence of TiC on Impact strength

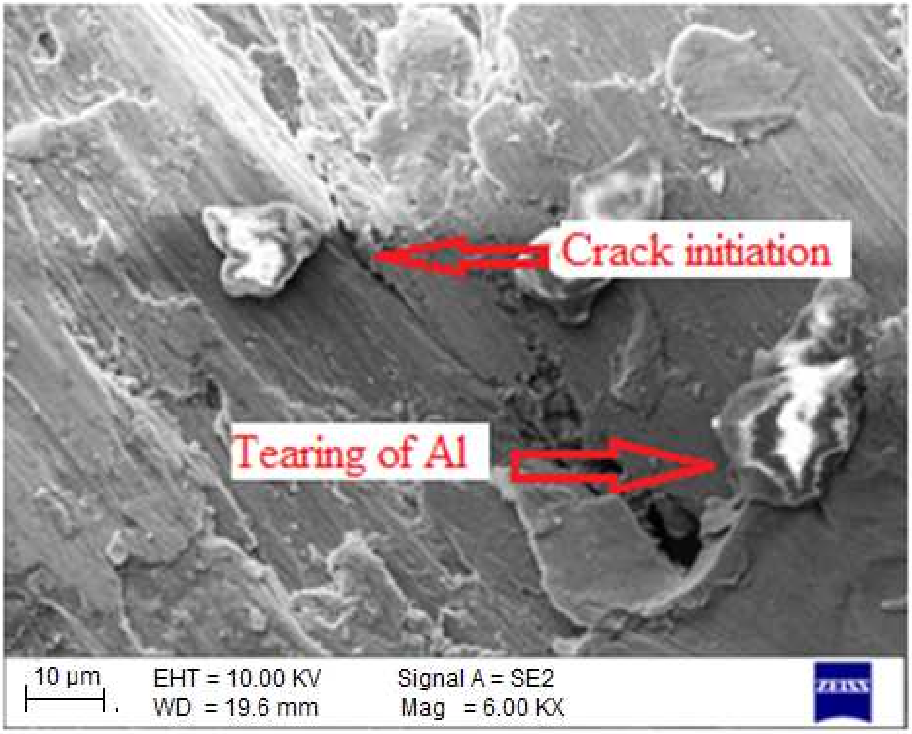
Fig 9. Fractured impact composite specimen



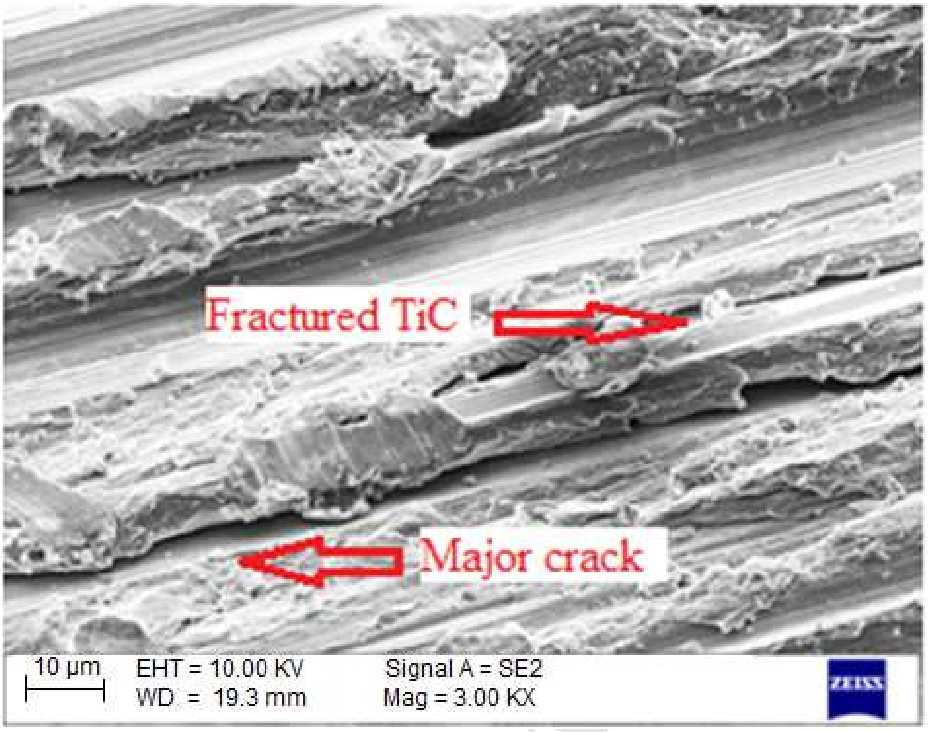
(a) A 6063 aluminium alloy



(b) Al+ 2% TiC



(c) Al+ 6% TiC



(d) Al+ 10% TiC

Fig 10. SEM of the fractured composites after impact test

Influence in impact strength while adding titanium particles in aluminium alloy and standard error bar is shown in Fig.8, and the fractured composite samples are shown in Fig.9. Increase in the presence of TiC decreased the impact strength of aluminium matrix composites. Similar kind of decrease in impact strength was observed and reported by other researchers [5, 15, 26]. Impact strength decreased to a maximum of 32% while adding 10% of titanium carbide particles. Decrease in impact strength can be attributed to the brittle nature of composites due to the addition of TiC particles. An increase in TiC decreases the ductility of aluminium alloy and also increases the stress concentration areas thereby favoring the formation of minor cracks and subsequent propagation of those cracks. The increased stress concentration areas at the interface results in debonding of Al and TiC at the interface thereby reducing the impact strength [26]. The thermal mismatch between TiC and Al alloy leads to the formation of high dislocation density at the Al-TiC interfaces, thereby decreasing the impact strength [15]. A mismatch in elastic modulus and thermal expansion at the interface region of Al-TiC directs an increase in elastic strain and decreases the impact strength [5]. The impact plastic deformation energy stored in the aluminium alloy is higher before failure. Reduction in deformation energy in composites due to debonding also reduces the impact strength.

Scanning electron microscopy of the fractured specimen after impact test is shown in Fig.10. It can be observed from Fig 10a that the failure of the aluminium alloy is characterized by voids and necking. This is mainly due to the soft aluminium matrix subjected to elastic deformation due to the impact load. Evidence of voids is also seen along the surface resulting in some casting defect. Addition of 2% of TiC (Fig.10b) to the aluminium alloy does not have a major impact on the failure mechanism. Failure at this stage is also ductile in nature which is characterized by delamination mode of fracture. Higher impact strength may be due to the presence of dimples formed as a result of ductile mode of failure. Increase in TiC shifted the mode of failure from ductile mode to brittle fracture. This can be correlated to the formation of minor cracks as shown in Fig.10c. Formation of crack is probably due to the plastic deformation. Fig.10.d shows that a further increase in TiC promotes that propagation of crack and fracture of TiC particles. At high strain, the strong interfacial bonding between the aluminium and TiC induces the formation of these types of cracks. It can be concluded that higher impact strength of aluminium alloy is due to the ductile mode of failure characterized by delamination and dimples. At higher TiC content, the failure is brittle in nature characterized due to plastic deformation, cracks and particle fracture.

5. CONCLUSIONS

Investigations were carried out to study the influence of reinforcing TiC into Al (A6063) and the following conclusions are inferred:

- Stir casting technique is employed to fabricate the composites with a fairly uniform dispersion of TiC.
- XRD analysis states that aluminium and TiC are the primary elements present in the composite indicating that the composites are free from impurities.
- Density of the composite was higher than that of the base alloy because of the higher density of TiC.
- Increase in addition of TiC increased the density, hardness and tensile strength of the composite, while decreased the elongation and impact strength of the composites.

- SEM analysis revealed that the failure of the aluminium alloy is ductile in nature due to elastic deformation. Increase in addition of TiC gradually shifted the failure to brittle mode of due to plastic deformation.
- The mechanical properties and characterization of TiC reinforced aluminium will provide a technical database in the field of composites for commercial, automotive, military and aerospace applications.

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Highlights

- TiC particles reinforced in Al alloy composites was fabricated by stir casting method.
- Addition of TiC increased the density, hardness and tensile strength of composites.
- Elongation and impact strength of the composites decreased.
- Ductile failure of composites is characterised mainly by dimple and voids.
- Brittle failure is characterised by cracks, debonding and particle fracture.

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