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A Study on Microstructural and Mechanical Properties of a Stir Cast Al (SiC-Mg-TiFe) Composite

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Abstract: Development of metal matrix composite is becoming widespread in most engineering applications where excellent mechanical properties are required. Mechanical and microstructural properties of aluminium reinforced with silicon carbide was investigated. Ingot of aluminium was melted in a furnace at temperature ranging between 650-700 ℃. Ferrotitanium and silicon carbide were preheated in a muffle furnace before addition to molten aluminium in a crucible furnace. Fixed proportions of magnesium, ferrotitanium and varying proportions of silicon carbide were utilized as reinforcements. Stirring was carried out manually for a minimum of 10 mins after the addition of each weight percent of silicon carbide. Resulting as-cast samples were sectioned for various mechanical and microstructural analysis. Microstructural studies from optical microscopy and scanning electron microscopy (SEM) showed the dispersion of reinforcements in the aluminium matrix. Mechanical properties which includes hardness and tensile strength of fabricated composites were observed to increase, while XRD analysis showed various phases formed from reaction between the matrix and reinforcements.

Keywords: Aluminium, ferrotitanium, silicon carbide, microscopy.

1 Introduction

There is an increase in demand for advanced engineering materials one of which is aluminium due to their multi-functionality and high performance. Aluminium matrix composites (AMCs) are therefore developed to meet these ever increasing and challenging demands. Extensive use of AMC has been reported in various industries such as automotive, armour and aerospace as a result of their good resistance to wear, excellent strength to weight ratio, high stiffness and improved corrosion resistance.

Various processing routes have been reported by different researchers for producing AMCs. These include powder metallurgy, stir casting, semi processing route, liquid state

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processing. Stir casting has been recommended as a preferred method to be utilized in the fabrication of AMCs [Prabu, Karunnamoorthy, Kathiresan et al. (2006); Kumar and Murugan (2012)]. These researchers also reported the use of nanoceramics for reinforcing aluminium matrix. Some reported nanoceramics includes titanium nitride (TIN), boron carbide (B_4C), titanium carbide (TiC) and alumina (Al_2O_3). Externally applied loads to composites are transmitted to reinforcements bonded within the matrix. There is presence of a strong interfacial bond which is formed during casting as a result of proper wettability between composite and matrix, thus essential for strengthening the reinforcements. This accounts for high strength possessed by the fabricated composites.

Nuruzzman et al. [Nuruzzaman and Kamaruzaman (2016)] investigated mechanical properties of aluminium silicon carbide metal matrix composites where volume fraction of silicon carbide and aluminium powders were varied. Observation from this study shows that increase in volume fraction of silicon carbide also increases hardness of reinforcements. Moreover, in a recent study by Marthy et al. [Murthy, Reddy, Selvaraj et al. (2016)], aluminium matrix nanocomposite was fabricated by high intensity cavitation technique. Observation from this study indicated an increase in tensile strength and wear rate with respect to the increase in weight percent of nanoceramic (SiC). A recent study by Akin et al. [Akin and Kaya (2017)] also attributed increase in oxidation resistance and fracture toughness to an increase in percentage of SiC reinforcement.

Although an extensive research has been carried out on production of aluminium matrix composite via stir casting, little or no literature is available on reinforcing aluminium matrix composite with higher weight percent of silicon carbide in addition to ferrotitanium. Ferrotitanium which is highly reactive with elements such as carbon, sulphur and nitrogen is known for its corrosion resistance in addition to high strength [Bebbington (1992)]. Therefore, the use of ferrotitanium and silicon carbide as reinforcements in the development of aluminium matrix composites is expected to improve the mechanical properties of fabricated composites.

2 Experimental

2.1 Materials

Aluminium alloy 5083 series was used as the matrix. Ferrotitanium (FeTi), Silicon carbide from Insimbi Alloy Company in South Africa were used as the reinforcement. Tab. 1 presents the elemental composition of aluminium.

Table 1: Composition of Aluminium used as the Matrix

Element	Si	Fe	Cu	Mn	Zn	Ti	V	Al
% Composition	7.17	0.59	0.01	0.01	0.01	0.21	0.02	Balance

2.2 Method

Aluminium ingot was melted in an electrical furnace lined with graphite crucible to prevent contamination of the melt. The melt temperature was maintained at a range between 670-750℃. 30 g of magnesium was added to aluminium melt to ensure wettability between matrix and reinforcement. 30 g of ferrotitanium was preheated in a muffle furnace at a temperature ranging between 850-890°C alongside with varying mass of silicon carbide. Continuous stirring was done to achieve a homogeneous dispersion of magnesium and ferrotitanium reinforcements in the aluminium matrix. Different weight percent of silicon carbide were added as reinforcements in varying proportions of 2, 5 and 7 respectively.

Samples for microstructural analysis cross-sectioned from as-cast composite were cold mounted and ground to 1200 using SiC papers. Polishing of sample surfaces was carried out using 1 µm diamond suspension till a mirror like surface was achieved, after which they were washed with acetone and dried in air. Zeiss Axioscope optical microscope and Tescan Scanning Electron Microscopy (SEM) equipped with Energy Dispersive X-ray Spectroscopy (EDS) were utilized in performing microstructural observations. Prior to analysis, samples were etched in Kellers reagent for a period of 20 s to achieve a clear microstructural detail.

XRD analysis was done using Philips X-ray diffractometer. Samples were sectioned into thin segments, ground and polished to allow a passage of rays through them. Analysis of results obtained were carried out to determine the lattice parameters.

Measurement of Vickers micro indentation hardness was carried out using Falcon 507 Innovatest microhardness testing machine at a load of 100 g and holding time of 10 s. Tensile test was performed at room temperature using computerized MKS Universal testing machine. Tests were repeatedly conducted for reproducibility purpose.

3 Results and discussion

3.1 Microstructural analysis

Fig. 1 shows the optical micrographs of as-cast aluminium and aluminium matrix composite. From Fig. 1(a), the predominant phase was that of eutectic α-Al which could be as a result of solidification from lower melting temperature of aluminium. Dendritic structures observed in as-cast aluminium was observed to disappear upon addition of reinforcements as clearly shown in Figs. 1(b), 1(d). This can be attributed to good wetting behaviour provided by magnesium between aluminium matrix and the reinforcements. Minute porosities observed in as-cast aluminium can be as a result of air entrapment during casting [Hashim, Looney and Hashmi (2001]). Manual stirring ensures homogeneous distribution of reinforcement particles in the melt, but these particles return to their initial position when stirring stops thereby leading to formation of clusters. Presence of pores in clusters keeps them afloat [Pawar and Utpat (2014)]. Analysis from SEM revealed an even distribution of intermetallic spacing within the matrix of aluminium.

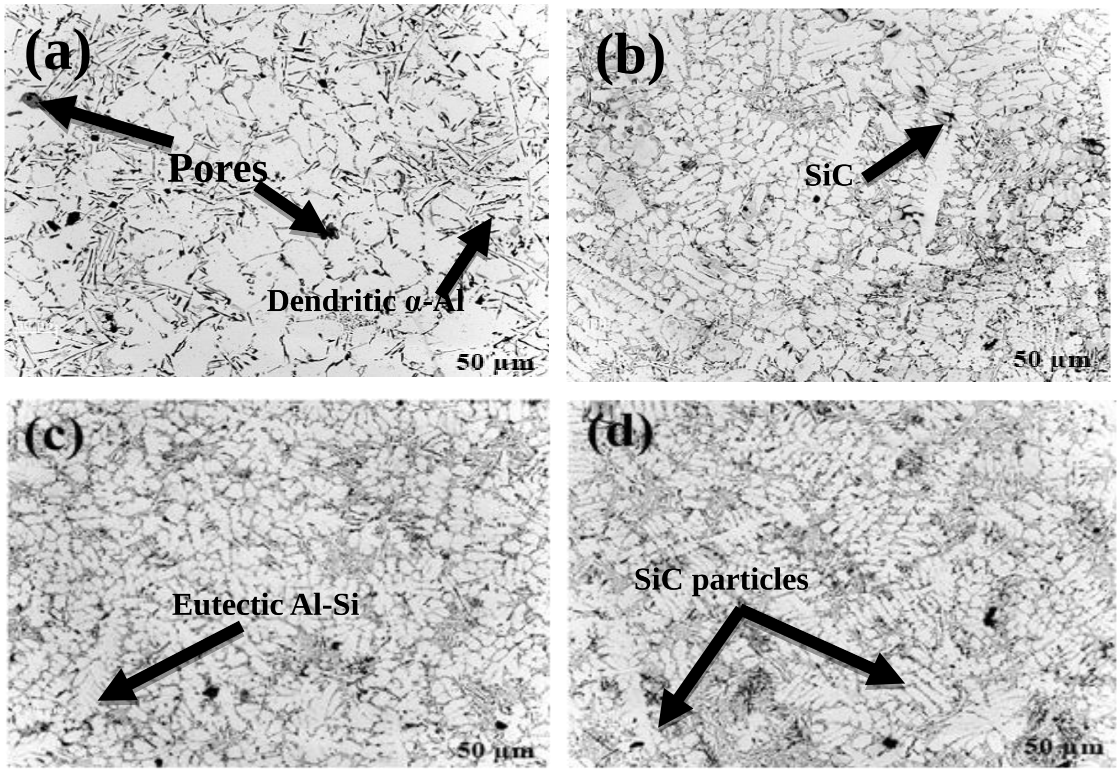
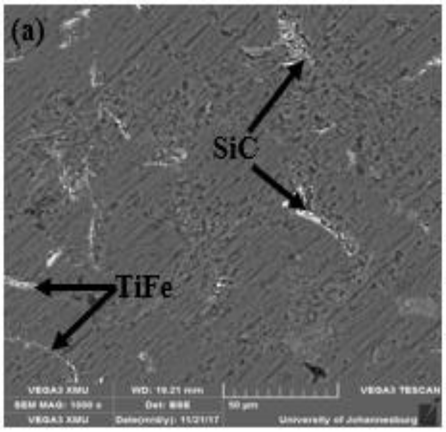
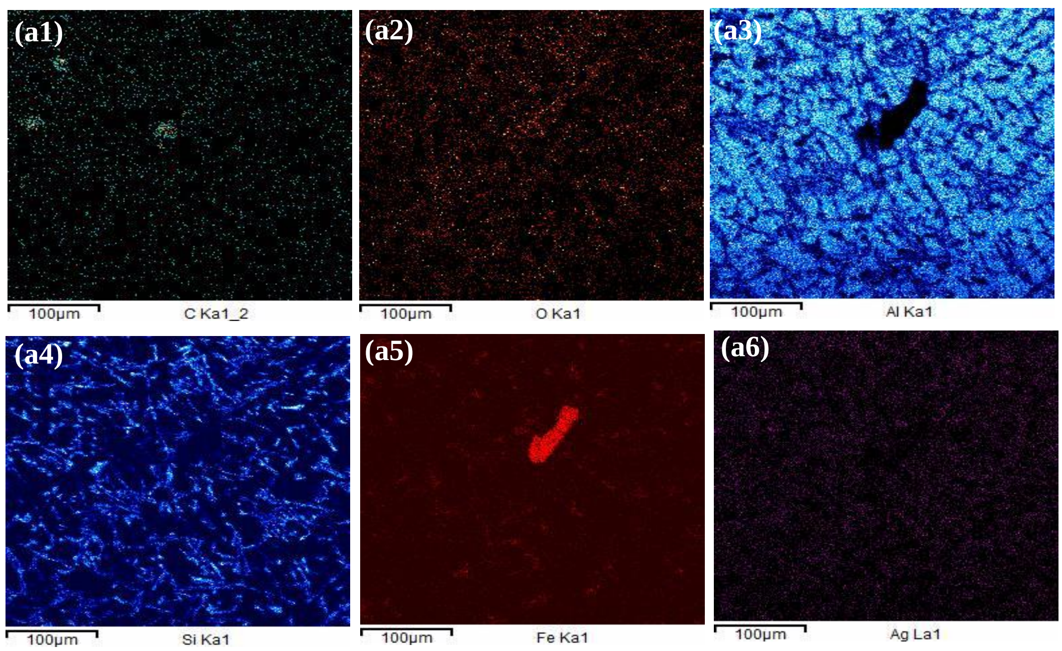


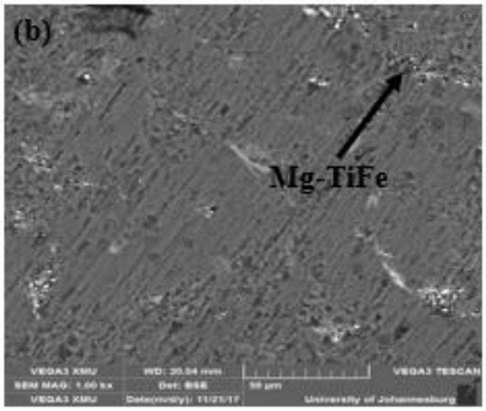
Figure 1: Optical micrographs of (a) Aluminium (b) Al + TiFe+2% SiC (c) Al +TiFe+ 5% SiC (d) Al + TiFe+7% SiC

SEM and EDX images shown in Figs. 2(a) and 2(b) displayed a clear dispersion of major elements present in ferrotitanium and silicon carbide in matrix of aluminium. Further observation reveals absence of further reactions between particles of reinforcements (SiC and TiFe) and the matrix. This can be ascribed to experimental procedure utilized in stir casting of composites. Clear interface and good bonding between matrix and reinforcement can increase the load bearing ability of fabricated composites. Distribution of reinforcement particles were observed in the grains which in turn promotes the mechanical properties of composites [Moses, Dinaharan and Sekhar (2014)].



Element	Weight(%)	Atomic(%)
C	9.42	18.96
O	4.09	6.18
Mg	0.35	0.35
Al	65.18	58.43
Si	17.36	14.92
Ti	0.15	0.08
Fe	1.47	0.64
Ag	1.97	0.44





Element	Weight(%)	Atomic(%)
C	6.45	13.38
O	3.93	6.13
Mg	0.52	0.54
Al	64.33	59.44
Si	22.13	19.64
Ti	0.13	0.07
Fe	1.06	0.47
Ag	1.45	0.34

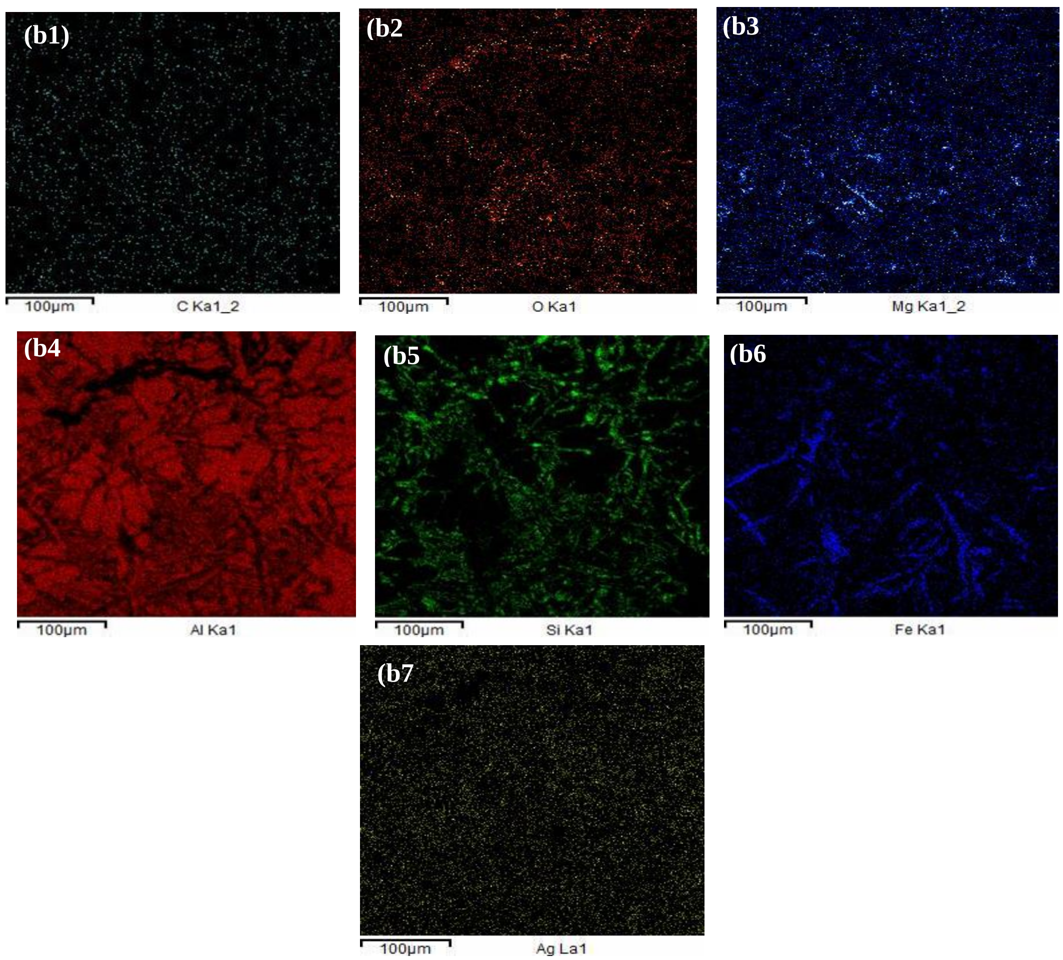


Figure 2: SEM and EDX mapping of (a) Al +TiFe+ 5% SiC (b) Al + TiFe+7% SiC

3.2 XRD analysis

Results from XRD analysis for aluminium matrix and fabricated composites are presented in Fig. 3. Different intermetallic phases with varying two theta values were formed. Peak positions for different phases are formed at corresponding two theta values of 28, 38, 44, 56, 65, 79 and 83. Highest peak shift was observed in Ni_3Ti phase in the sample with 5 wt.% silicon carbide with a shift from two theta values 42 to 45. This could be due to reaction between ferrotitanium and slightly higher weight percentage of silicon carbide. Other detected peaks are listed in Fig. 3, but peaks of major constituents belong to Ni_3Ti. Crystallite sizes and lattice strain were calculated using Scherer's calculator. Crystallite sizes were observed to decrease with increasing weight percent of silicon carbide. Increase in lattice strain can be attributed to breakdown of crystallite which may be ascribed to presence of iron and carbon in ferrotitanium and silicon carbide reinforcements respectively [Kamrani, Riedel and Reihani (2015)].

Table 2: Crystallite and lattice strain for as-cast pure aluminium and composites

Sample	Crystallite size (nm)	Lattice strain (%)
Al	68.7	0.331
Al+Mg+TiFe+2% SiC	54.8	0.432
Al+ Mg+TiFe+5% SiC	51.83	0.574
Al+ Mg+TiFe+7% SiC	45.08	0.575

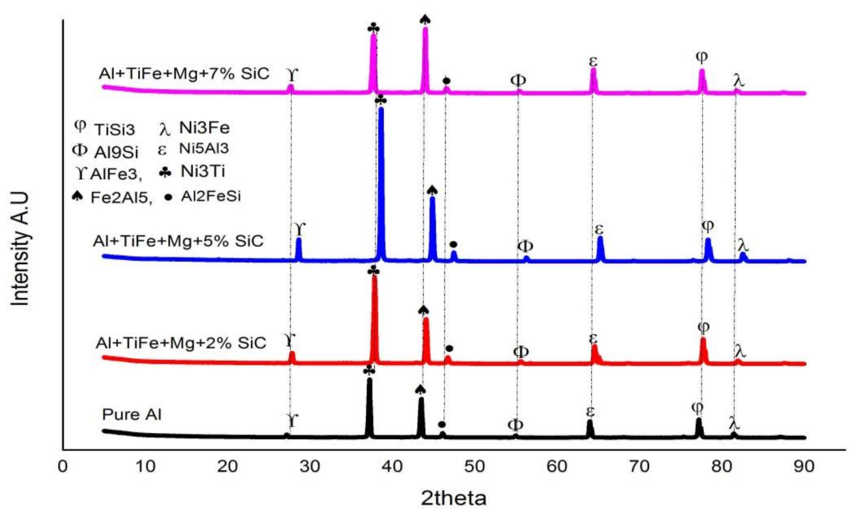


Figure 3: XRD analysis of aluminium and aluminium matrix composite

3.3 Hardness

Fig. 4 shows the plot for effect of different weight percent of silicon carbide and fixed weight of ferrotitanium on hardness of fabricated aluminium and aluminium matrix composite. From the plot, increase in weight percent of silicon carbide was observed to improve the microhardness values of composites lowest value of 88.18 HV was recorded by as-cast aluminium while highest value of 117.83 $HV_{0.1}$ was attained by sample with 7 wt.% silicon carbide. Improvement of hardness value can be attributed to impediment of dislocation movement by silicon carbide and iron present in ferrotitanium. Similar observation was observed in a study by Karthikeyan et al. [Karthikeyan and Nallusamy (2017)].

Table 3: Hardness values for aluminium and aluminium composites.

Sample	Hardness value ($HV_{0.1}$)
A=Al	88.18
B=Al+TiFe+2% SiC	111.47
C=Al+TiFe+5% SiC	114.64
D=Al+TiFe+7% SiC	117.83

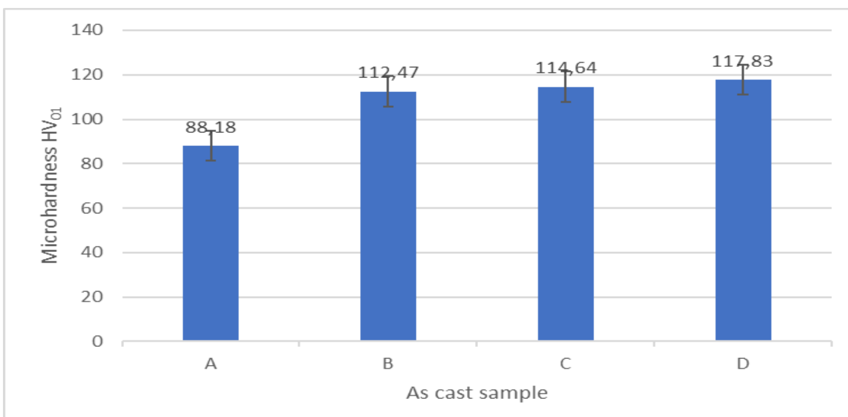


Figure 4: Hardness error plot for Aluminium matrix composites

3.4 Tensile strength

The relationship between tensile strength and weight percentage of silicon carbide in addition to ferrotitanium is shown in Fig. 5. Improvement in tensile strength accompanied with increase in elongation is observed in fabricated composite. Increase in elongation can be ascribed to decrease in ductility which is a function of increasing weight percent of silicon carbide [Pichumani, Srinivasan and Ramamoorthi (2018)]. Composites with 5 and 7 wt.% SiC reinforcement were also observed to deform plastically at close stress values which serves as an indication that further increase in weight percent of SiC might lead to decrease in tensile strength of composites. During solidification, strain fields that could lead to dislocation are created around ferrotitanium and silicon carbide reinforcements. Reactions between dislocation and reinforcements inhibit the propagation of cracks during tensile loading. Orowan strengthening which induces more strength on aluminium matrix is present when silicon carbide and ferrotitanium are dispersed in aluminium matrix, thereby strengthening the resulting composite [Ravi, Naik and Prakash (2015)]. Load bearing capacity (strength) of composites improved by higher dislocation density in the aluminium matrix, results from thermal mismatch between the matrix and reinforcements [Toptan, Kilicarslan, Karaaslan et al. (2010)].

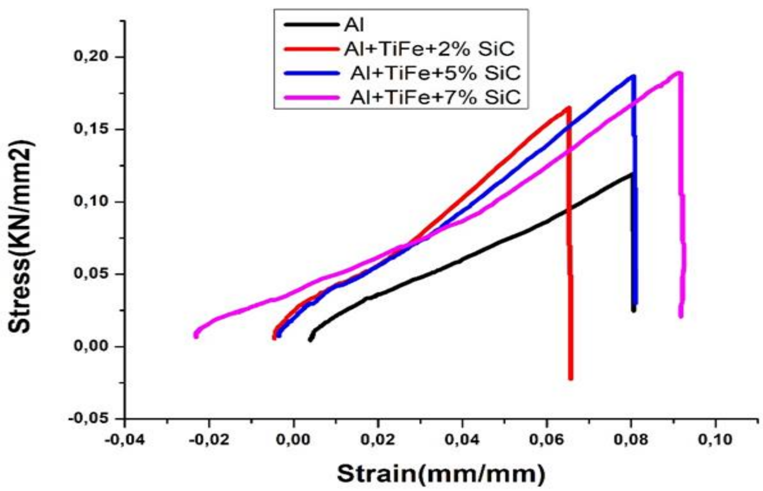


Figure 5: Tensile test for aluminium matrix composites

3.5 Fractography

Fig. 6. shows the SEM micrographs of fractured surface from tensile testing of specimens. Smaller voids and presence of larger dimples are observed in the fracture morphology from Fig. 6(a). Particles of SiC and TiFe could be seen on the surface of fractured specimens as shown in Figs. 6(b) and 6(c). Interestingly, this gives a good evidence of adequate bonding between matrix and reinforcements. Reduction in dimples formed on the surface of sample with the highest reinforcement could be attributed to proper settling of ferrotitanium and silicon carbide particles within the grain of aluminium matrix, thereby causing reduction in shear deformation along tensile direction. Formation of cracks in Fig. 6(a) can be because of hard ferrotitanium particles, or coarse intermetallic formed in the composite. It is therefore essential to reduce formation of voids which can result in formation of clusters and control coarse intermetallic formation in composites [Ranganath, Sharma, Krishna et al. (2002)].

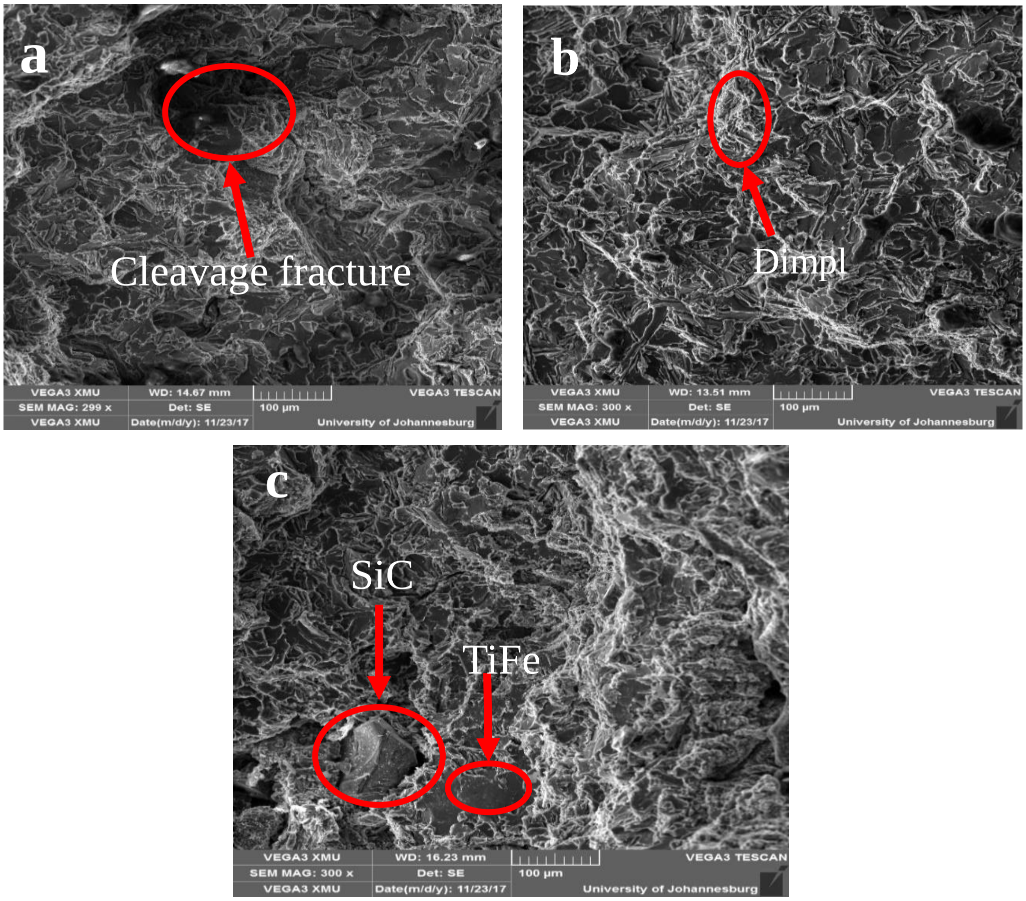


Figure 6: SEM images of fractured surface for (a) Al+Mg +TiFe + 2% SiC (b) Al+Mg +TiFe + 5% SiC (c) Al+Mg +TiFe + 7% SiC

4 Conclusion

The mechanical and microstructural properties of aluminium fabricated through stir casting was investigated. Micrograph from optical and scanning electron microscope reveals dispersion of reinforcement in the matrix Hardness and tensile strength were observed to be improved in samples reinforced with higher weight percent of silicon carbide. Samples with higher addition of reinforcements in aluminium were observed to have a reduced dimple sizes, thereby increasing the tensile strength during tensile testing. Different peak shifts observed at various values of two theta are because of proper wettability provided by magnesium addition between the reinforcements and aluminium matrix.

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