Influence of Hot Extrusion on Mechanical Characteristics of Al6063-TiC Metal Matrix Composites

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Abstract- *Of all the aluminium alloys Al 6000 series is quite popular choice has a matrix material to prepare metal matrix composites owing to its better formability characteristics and option of modification of the strength of composites by adopting optimal secondary processes. The simplest and commercially used technique is the vortex or stir casting technique for casting process. The various reinforcements that have been tried out to develop the metal matrix composites are graphite, silicon, carbide, titanium nitride, tungsten, boron Al2O3, fly ash, Zr, Si3N4, TiB2, etc. Further meager information is available in the literature as regards the Mechanical properties of TiC reinforced with Al6063 base metal matrix composites. Hence, the present investigation is aimed at developing aluminium metal matrix composite consisting of Titania reinforcement in Al6063 alloy and to characterize the effect of reinforcement on Mechanical properties in as cast and as extrusion*

Keywords- Al 6063, TiC, Tensile and Microhardness, Metal Matrix Composites and Extrusion.

I. INTRODUCTION

A Composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The two constituents are a reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. Metal matrix composites exhibit significant increase in stiffness and mechanical strength compared to matrix alloys, but suffers from lower ductility and inferior fracture toughness [2]. Metal matrix composites (MMCS) containing hard particulates offer superior operating performance and resistance to wear. In industrial processes, elements fabricated from MMC materials exhibits higher abrasive resistance leading to longer service life [3]. Metal matrix composites are gaining widespread popularity in several technological fields owing to their several advantages. Several interesting applications are piston, connecting rod, microwave filters, vibrator component, contactors, impellers and space structures [4].

1.1. Aluminium Alloy

Aluminium matrix composites have been indicated as the material having the large potential for innovation, as evidenced by increased use of these materials in sectors such as the aircraft or automotive industries. One of the first examples of applications of Aluminium matrix composite implemented for production was the piston with a composite insert reinforced with Saffil fibres, manufactured on an industrial scale by the squeeze casting method. Another field of applications of Aluminium matrix composites is the electrical engineering where, above all, the dimensional stability of radiators working at elevated temperatures is utilized [5]. The main technologies for fabrication of these materials are based on the powder metallurgy porous ceramic preform infiltration, pressure die-casting and squeeze casting methods. However, the manufacturing costs, and first of all the costs of machining, are still indicated as important limitations in the implementation of composites on a wider scale. Aluminium matrix composites have shown high mechanical properties such as high strength, high stiffness, wear resistance and good elevated temperature properties, when compared to the un-reinforced matrix alloy, which has facilitated the use of aluminium matrix composite in the following automotive drive shaft, electronic heat sinks, jet fighters, air craft firms, electronic instrument racks, ground vehicles brake rotors and satellite struts.

The Chemical Composition and Mechanical Properties of Aluminium 6063 alloy are represented in Table 1 and 2.

The Physical and Chemical Properties of Titanium Carbide are represented in Table 3 and 4.

TABLE I Chemical Composition of pure Aluminium 6063 alloy

Sl. No.	Parameters	Observed Values (Wt%)
1	Si	0.60
2	Cu	0.10
3	Fe	0.35
4	Mn	0.10
5	Mg	0.90
6	Zn	0.10
7	Ti	0.10
8	Cr	0.10
9	Al	97.65

TABLE 2 Mechanical Properties of pure Aluminium 6063 alloy

Sl. No.	Properties	Values
1	Hardness, Brinell	73
2	Hardness, Knoop	96
3	Hardness, Vickers	83
4	Ultimate Tensile Strength	241 Mpa
5	Tensile Yield Strength	214 Mpa
6	Elongation at Break	12%
7	Young's Modulus	68.9 Gpa
8	Ultimate Bearing Strength	434 Mpa
9	Poisson's Ratio	0.33
10	Fatigue Strength	68.9 Gpa
11	Machinability	50%
12	Shear Modulus	25.8 Gpa
13	Shear Strength	152 Mpa

TABLE 3 Physical Properties of TiC

Sl. No.	Composition	Wt%
1	Al	0.005
2	Fe	0.152
3	Ni	0.123
4	Si	0.005
5	Na	0.005
6	Ca	0.005
7	K	0.005
8	Mo	0.005
9	S	0.005

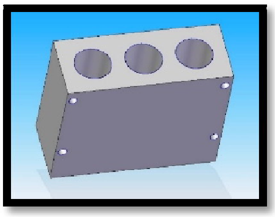
TABLE 4 Chemical Properties of TiC

Sl. No.	Properties	State/°C/Size
1	Physical State	Powder
2	Color	Black
3	Boiling Point	4300 °C
4	Melting Point	3160 °C
5	Particle Size	3.26 µm

II. METHODOLOGY

2.1 Manufacturing Route – I (Stir Casting Technique)

In order to obtain Al 6063 with TiC composite, a batch of 3kg of aluminium 6063 alloy was melted using a 6kw electric furnace. The melt was degassed using commercially available chlorine-based tablets (hexachloroethane). The molten metal was agitated by the use of mechanical stirrer rotating at a speed of 300 rpm to create a fine vortex. TiC in powder form interms of 3 to 5 microns was added slowly into the vortex while continuing the stirring process. A stirring duration of 10min was adapted. The composite melt maintained at a temperature of 710ºC was then poured into preheated metallic moulds. The extent of incorporation of TiC powder was varied from 3 to 9 % in steps of 3wt%. The Casting process is obtained for the Material having dimensions of diameter 40 mm and length 100 mm. Fig.1a) and 1b) shows the Casting die design and the Prepared Specimens of Al 6063 + 0wt% of TiC of shown in Fig. 2.



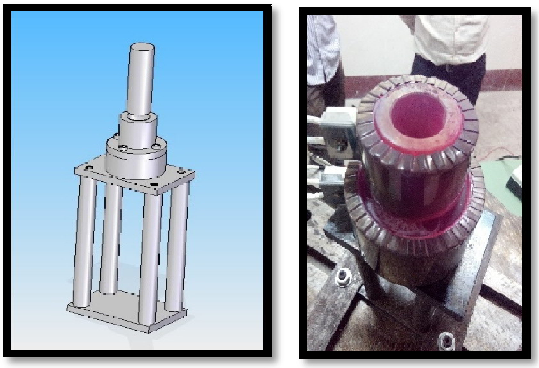
a) b)

Fig 1. Casting Die Design

Fig 2. Prepared Specimens of Al 6063 + 0wt% of TiC

2.2 Manufacturing Route – II (Hot Extrusion Technique)

In order to obtain extruded Al 6063 with TiC composite, a specimen having diameter of 35 mm and the length of 40 mm is used. The specimen is heated above 550ºC and the die temperature is maintained from 400ºC to 500ºC. Addition to that, Graphite powder and grease are mixed to act as a lubricant between the interface of the Specimen and die during Extrusion. The load was applied gradually for extrusion. Fig.3a) and 3b) shows the Extrusion Die Design assembly and Fig. 4. shows the various reinforcement of TiC in Al 6063 extruded samples.



a) b)

Fig. 3. Extrusion Die Design

Fig. 4. Extruded Specimens

2.3 Load Calculations

TABLE 3 Extrusion Ratio, and Load Calculations

Sl. No	Original Dia, d_o, mm	Final Dia, d_f, mm	Extrusion Constant, K, Mpa	Extrusion Ratio, r	P, KN
1	50	20	85	6.25	305
2	45	10		20.20	406
3	43	10		18.42	359
4	35	15		5.44	138.4

Sample Calculations for Al 6063 – 9wt% of TiC from diameter 35mm to 15mm conversion.

Original Area, Ao = $\Pi d_0^2/4 = \Pi * 35^2/4 = 961.62$ mm^2

Final Area, Af= $\Pi d_f^2/4 = \Pi * 15^2/4 = 176.6$ mm^2

Extrusion Constant, K = 80 to 90 Mpa or N/ mm^2 for temperature range from 400 °C to 500 °C from ASME Data hand book.

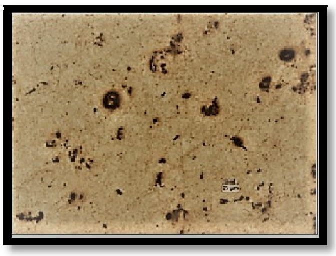
Extrusion Ratio, r = Ao/Af =5.44

Force Required, P = K Ao In [Ao/Af] = 138.4 KN.

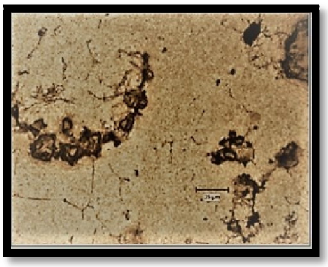
III. RESULTS & DISCUSSIONS

3.1 As Cast

3.1.1 Optical Microscope Studies



a) Al6063 + 3wt% TiC Composite



b) Al6063 + 6wt% TiC Composite

c) Al6063 + 9wt% TiC Composite

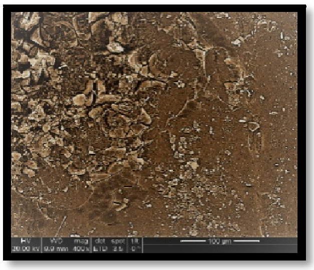
Fig.5a), b) and c) Optical Microphotographs of as cast Al6063-TiC Composites

Fig.5a), b) and c) shows the optical microphotographs of casted Al6063 alloy and Al6063-TiC composites. It is observed that there is homogeneity in the distribution of the reinforcement in the matrix alloy. There exists a good bond between the matrix and the reinforcement in by adding 9 wt% of TiC with Al 6063 compared to 3 wt% and 6 wt% of TiC.

3.1.2 Scanning Electron Microscope Studies

a) Al6063 + 3wt% TiC Composite

b) Al6063 + 6wt% TiC Composite



a) Al6063 + 9wt% TiC Composite

Fig.6a), b) and c) Scanning Electron Microphotographs of as cast Al6063-TiC Composites

Fig. 5a), 5b), 5c), 6a), 6b) and 6c) shows the optical microphotographs and SEM of as cast Al6063-TiC composites.

It is observed that there is homogeneity in the distribution of the reinforcement in the matrix alloy.

There exists a good bond between the matrix and the reinforcement in by adding 9 wt% of TiC with Al 6063 compared to 3 wt% and 6 wt% of TiC.

The intense plastic deformation and exposure to elevated temperature cause dynamic recrystallization which refines the grains of aluminium alloy Al6063. The average grain size of friction stir processed Al6063 is about 3.26 microns.

Dynamic recrystallization resulted in an extensive grain refinement.

The distribution of TiC particles is fairly homogeneous in the AMMC's. During the initial stages of the formation of the AMMC's, the plasticized aluminium alloy flows into the groove at the back of the tool.

The rotating action of the tool provides a vigorous stirring which causes the packed TiC particles in the groove to be uniformly distributed in the aluminium matrix. Segregation reduces mechanical and Tribological properties of the AMMC's.

Since the AMC is formed in the solid state, the free movement of particles due to density gradient is absent. However, an agglomeration of TiC particles was observed at few places.

The dark regions in the microstructure exhibit bonds of TiC particles with Al 6063.

Those regions were present close to the center of the AMMC's. It causes a vertical flow might have formed the agglomeration of the plasticized composite shown in Fig 7. and the EDAX Pattern shown in Fig. 8.

The trapped TiC particles during the vertical flow might have formed the agglomeration while the particles in groove were mixed with plasticized aluminium. The grains are not clearly visible because they are ultrafine in nature.

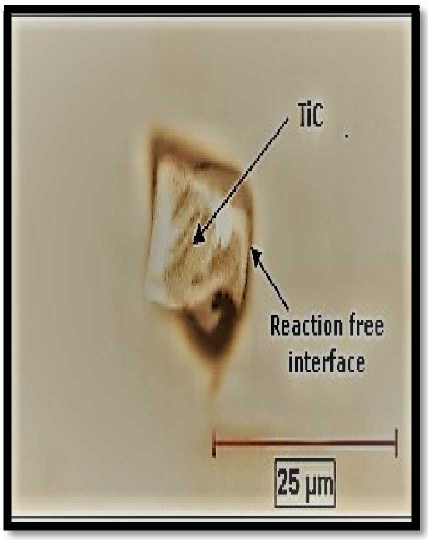


Fig. 7 Reaction interface of TiC with Al6063 of as Cast

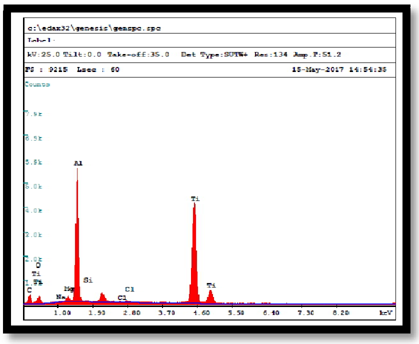


Fig. 8 EDAX Pattern of as Cast

3.1.3 Mechanical Properties

3.1.3.1 Microhardness

TABLE 4. Microhardness Test Results

Sl. No	AMMCs	VHN, 5 Kg
1	Al 6063 + 0 wt% of TiC	65
2	Al 6063 + 3 wt% of TiC	74
3	Al 6063 + 6 wt% of TiC	83
4	Al 6063 + 9 wt% of TiC	93

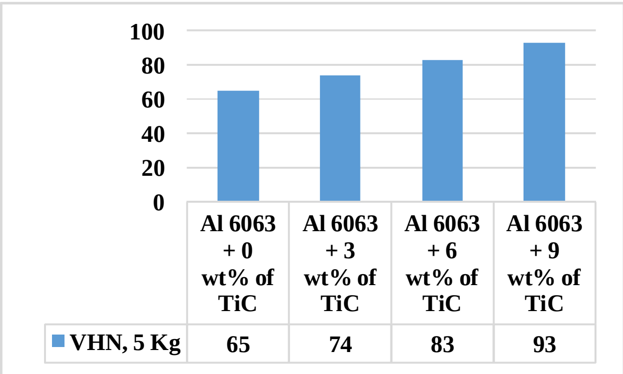


Fig. 9 Variation of Microhardness of as cast for Al6063-TiC composites with percentage of reinforcement.

Fig. 9 shows the variation of Microhardness of as Cast Al6063 alloy and composite.

TiC particles have been spontaneously incorporated in to commercial available Al6063 alloy a melt using fluxing agents which remove the melt surface oxide and promote contact between clean, wetting surface.

TiC particle addition significantly refines the grain structure which increase of the strength of the composite.

At higher composition better properties are exhibited which can be explained by stronger interfacial bonding in the TiC system due to wetting of the reinforcement by the liquid and particle engulfment into the solid phase caused principally by the increased tendency for nucleation of solid on the particle surface

3.1.3.2 Ultimate Tensile Strength

TABLE 5. Ultimate Tensile Strength Results

Sl. No	AMMCs	UTS, Mpa
1	Al 6063 + 0 wt% of TiC	100.82
2	Al 6063 + 3 wt% of TiC	117.56
3	Al 6063 + 6 wt% of TiC	133.25
4	Al 6063 + 9 wt% of TiC	161.50

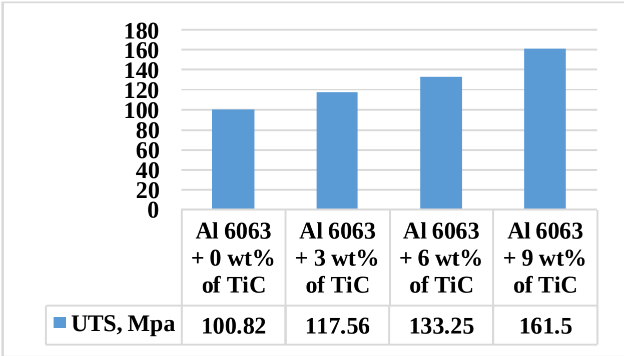


Fig. 10 Variation of Ultimate Tensile Strength of as cast for Al6063-TiC composites with percentage of reinforcement.

Fig. 10 shows the variation of ultimate tensile strength of as Cast Al6063 alloy and composite. An increase in ultimate tensile strength is observed with increased percentage of TiC. Use of TiC in developing the composite has significantly increased the ultimate tensile strength. This can be attributed to the fact that TiC results in lowering the surface tension and there by promotes better wettability of the reinforcements with the molten metal matrix.

3.2 As Extrusion – A Comparative Study with as Cast

3.2.1 Scanning Electron Microscope Studies

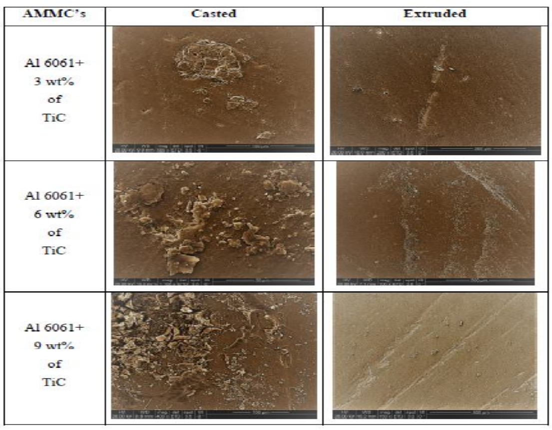


Fig.11. Casted and Extruded Specimens with different wt% of TiC with Al 6063.

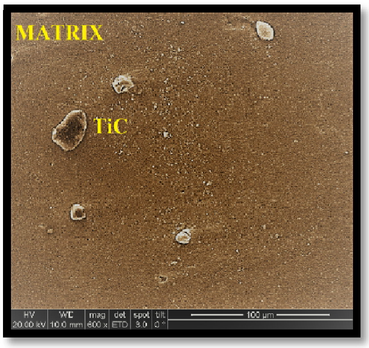


Fig. 12 Reaction interface of TiC with Al6063 of as Extrusion

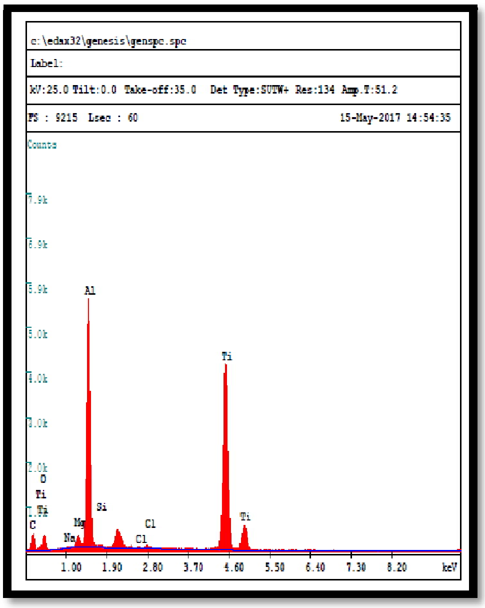


Fig. 13 EDAX Pattern of as Extrusion

Fig. 11 shows the SEM microphotographs of as cast, as hot extruded matrix alloy and its composites and Fig. 12 shows the EDAX pattern of Hot Extruded Al 6063-TiC AMMC's. Microstructure clearly indicates the homogeneity in the distribution of reinforcement in the matrix alloy. The distribution of titanium carbide particles in the matrix alloy is highly influenced by good wettability of TiC particles in molten metal.

The reinforcements get oriented along the extrusion direction. Further, a good bond exists between the matrix and the particle. It is also observed that there is no pull out of the particle reinforcement from the matrix even after extrusion although they experience damage. This fact supports good bond between the matrix and the reinforcement

3.2.2 Mechanical Properties

3.2.2.1 Microhardness

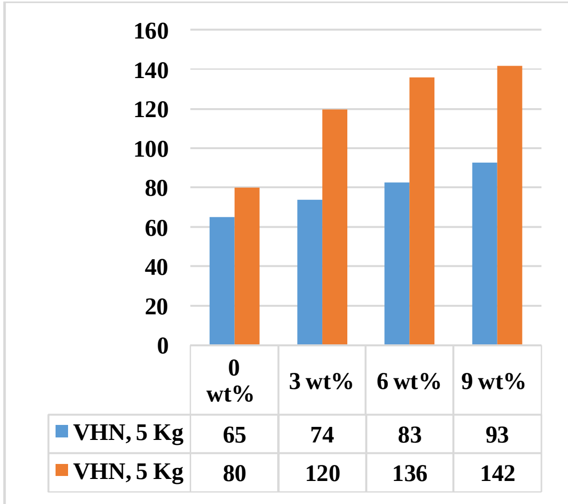


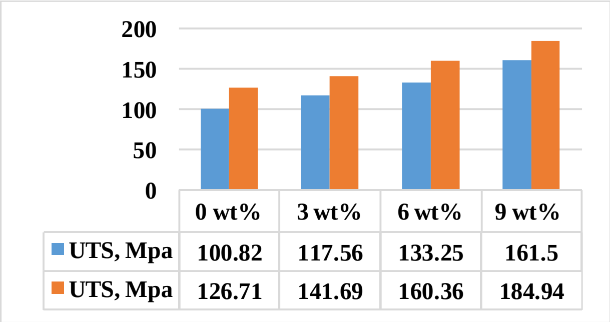
Fig. 14 Variation of Microhardness of as cast and extruded Al6063-TiC composites with percentage of reinforcement.

Fig.14 shows the variations of microhardness of as cast and hot extruded Al6063 alloy and Al6063-TiC composites conditions. It is observed that microhardness increases with increase in percentage of TiC particles in the matrix alloy, in both as casted and hot extruded conditions. A maximum of 12.30% improvement is noticed in as hot extruded Al6063-0 wt% TiC composite when compared with as casted matrix alloy. Increased microhardness with increase in percentage of TiC particles in matrix alloy can be attributed to following reasons.

- Higher hardness of TiC particles. Hard reinforcement in a soft and ductile matrix always enhances the hardness of the matrix alloy in general.
- Increased content of reinforcement in matrix alloy leads to increased dislocation densities during solidification due to thermal mismatch between 6063 alloy and TiC particles leading to retardation in plastic deformation.
- Excellent bond between matrix alloy and reinforcement and minimum micro porosities.
- During hardness test of the composite, the indentation pressure is partially accommodated by plastic flow of material and largely by localized increase in concentration of TiC particles.

A maximum of 45.77 % improvement is noticed in hot extruded Al6063-9wt% of TiC composite when compared with as casted matrix alloy. It is also observed that, hot extruded has profound influence on microhardness of hot extruded Al6063 alloy and Al6063-TiC composites. All the hot extruded samples exhibit higher microhardness values when compared with as casted alloy and its composites. This can be attributed to the formation of intermetallic precipitates namely Mg_2Si from super saturated solid solution.

3.2.2.2 Ultimate Tensile Strength



	0 wt%	3 wt%	6 wt%	9 wt%
UTS, Mpa	100.82	117.56	133.25	161.5
UTS, Mpa	126.71	141.69	160.36	184.94

Fig. 15 Variation of ultimate tensile strength of as cast and extruded Al6063-TiC composites with percentage of reinforcement.

Fig.15 shows the variations of ultimate tensile strength of as cast and hot extruded Al6063 alloy and Al6063-TiC composites conditions. Wettability is one of the dominating factors to ensure good bond between matrix and reinforcement. A good bond between the matrix and reinforcement always favours an improvement in the ultimate tensile strength of metal matrix composites. Further, dispersion of hard ceramic particle in the soft ductile matrix results in improvement in strength.

The hard-ceramic particle obstructs the advancing distraction front, there by strengthening the matrix. This may be attributed to large residual stress developed during solidification and to mismatch of thermal expansion between hard ceramic particles and soft Al matrix. The improvement in the composite strength can also be attributed to the synergetic effect of microstructural changes in the matrix, such as grain refinement, porosity reduction and particle break down of the reinforcement during extrusion process. The compressive stresses during extrusion do result in large degree of reduction in TiC particle sizes. Smaller the size of the reinforced particles and higher its homogeneity in its distribution within the matrix alloy result in significant improvement of strength of the composites.

3.2.2.3 Fractography Studies

a) Before Extrusion **b) After Extrusion**

Fig. 16 Fractography of Extruded Al 6063 alloy and Al6063-TiC Composites.

Fig 16a) and 16b) shows the Fractured surfaces of the extruded Al6063 and TiC reinforced Al6063 composites. The particle have not got detached from the matrix alloy, however, they appear to have got damaged as shown in Fig. 16.a)

The EDAX pattern of the cracked particle is shown in Fig. 17. It confirms that the cracked particle is TiC. The fracture surface of MMC's at room temperature, are generally characterized by a modal distribution of large voids associated with the particle reinforcement debonding, due to high localized stress concentration at the interface and small dimples.

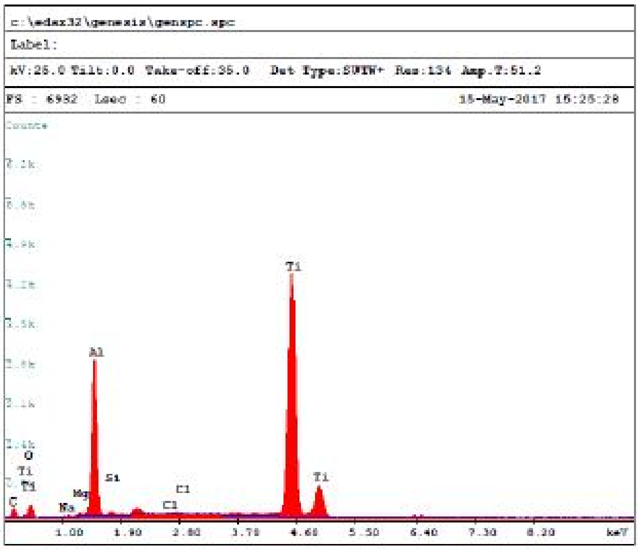


Fig. 17 Al6063-TiC composite and its EDAX pattern of as Extrusion in Fractured Surfaces

Fig. 17 shows the EDAX pattern of Al6063-TiC composite and its EDAX pattern of as Extrusion in Fractured Surfaces.

However, the test result shows that even though the material exhibits ductile characteristics, there is a drop in ductility as the percentage of reinforcement is increased, which leads to differences in deformation mechanisms hence causing a tri-axial stress state in the soft and ductile metal matrix.

This favours the initiation and growth of voids in the matrix as well as debonding at the particle matrix interface. It can be observed from the micrographs that the sizes of voids have decreased on heat treatment in both Al6063 matrix & Al6063 TiC composite.

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