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Development and Evaluation of Fracture Characteristics and Microstructure Analysis of Al6061 Reinforced with TiB_2

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Abstract
Weight to strength ratio of composites plays a very important role in modern industries. Hence to overcome the limitations of conventional materials, Particle reinforced metal matrix composites (MMCs) can be used in situations where polymer composites cannot be utilized. In the recent years, MMCs were fabricated with Aluminium as the matrix material and ceramic particles like SiC, Al_2O_3, SiO_2, TiO_2, AlN, Si_3N_4, TiC, WC, ZrB_2, etc., using In-Situ, Ex-Situ and powder metallurgy techniques. In the present study, manufacturing of Aluminium alloy Al6061 reinforced with 1.5% of magnesium with different weight fractions of (0, 3, 6, 9 and 12 wt. %) TiB_2 particles were developed by In-Situ process using inorganic K_2TiF_6 and KBF_4 salts. The microstructure studied using scanning electron microscopy revealed that In-Situ formed TiB_2 particles were consistently distributed with clear interface and good bonding in the Aluminium matrix. Fracture analysis of the composite revealed that stress intensity factor decreases with increase in percentage of reinforcement.
Keywords:MMC, Reinforcement, Composite, Fracture

1. INTRODUCTION
Composite materials are the combination of two or more materials which are different in form and chemical composition. These composites are gaining more importance as a structural material in the present-day engineering design and development activity. This is because they offer very attractive mechanical properties such as high strength to weight ratio, higher thermal and corrosive resistance etc. Examples includes cemented carbides, plastic molding compounds containing fillers, rubber mixed with carbon black and wood etc., These materials consist of primary phase and secondary phase.

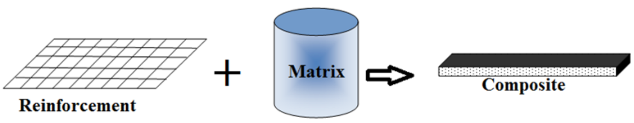

FIGURE 1.1 Composite material

The advent of advanced reinforced composite materials has been called the biggest technical revolution since the jet engine. This claim is very striking because the tremendous impact of jet engine on military aircraft performance is readily apparent. The impact on commercial aviation is even more striking because the airlines switched from propeller driven planes to all jet fleets within a span of just few years.
Advanced composites have two major advantages, among many others, improved strength and stiffness, especially when compared with other materials on a unit weight basis. For example, composites can be made to have same strength and stiffness as steel, yet are 70 percent lighter.

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Other composites are as much as three times strong as Aluminium, the common structural aircraft material, yet weighs only 60 percent. Composite materials can be tailored to meet design requirements of strength, stiffness and other parameters all in various directions. The advantages of composite materials are so compelling that research and development is being conducted across broad fronts instead of down the most obvious paths whole organizations have sprung up to analyze, design and fabricate parts made of composite materials.
Fracture mechanics deals with the study of how a crack or flaw in a structure propagates under applied loads. Cracks and flaws occur in many structures and components, sometimes leading to disastrous results. The engineering field of fracture mechanics was established to develop a basic understanding of such crack propagation problems.

2. EXPERIMENTATION

2.1 In-Situ Processes

In this technique, the reinforcement phase is formed In-Situation, by adding different salts to form required combination of composite system. In this work Al 6061 reinforced with Magnesium by varying different weight fractions of TiB_2 (In-Situ) are used to prepare composite material to study the wear behaviour. All these materials were used throughout experiment.

FIGURE 2.1 Raw materials for manufacturing of composites system

Table 2.1 Chemical Composition of Al6061 alloy

Element	Weight %
Mg	1.08
Fe	0.17
Si	0.63
Cu	0.32
Mn	0.52
V	0.01
Ti	0.02
Al	Balance

Table 2.2 Calculated Weights of Salts per Casting

Sl.No.	Weight of Salts		TiB_2 (wt. %)
	K_2TiF_6 (g)	K_2TiF_6(g)	
1.	10.36	10.87	3%
2.	20.72	21.74	6%
3.	31.08	32.61	9%
4.	41.45	43.48	12%

Aluminium alloy Al6061 reinforced TiB_2 particulate composites were successfully synthesized by the In-Situ reaction of K_2TiF_6 and KBF_4 salts to molten Aluminium.

$K_2TiF_6 + 13/3Al = Al_3Ti + 4/3AlF_3 + 2KF$
$2KBF_4 + 3Al = AlB_2 + 2AlF_3 + 2KF$
$Al_3Ti + AlB_2 = TiB_2 + 4Al$

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The sequence of TiB_2 formation can be summarized as follows. The introduction of K_2TiF_6 and KBF_4 to molten Aluminium forms inters metallic compounds namely Al_3Ti and AlB_2 respectively, which act as source for Ti and B atoms.

- Boron atoms move towards Al_3Ti particles
- Reaction takes place between Ti and B atoms in a gap from Al_3Ti surface to form TiB_2.
- Owing to smaller size, boron atoms start diffuse through TiB2 particles.
- Dissolution of Al_3Ti particles due to natural cracking and fragmentation of Al_3Ti particles which lead to increased rate of TiB_2 formation after complete reaction.
- It is evident that there is no trace of Al_3Ti or AlB_2 which indicates that the reaction is complete. Sufficient holding time and proper mole ratio of inorganic salts are required for complete reaction.

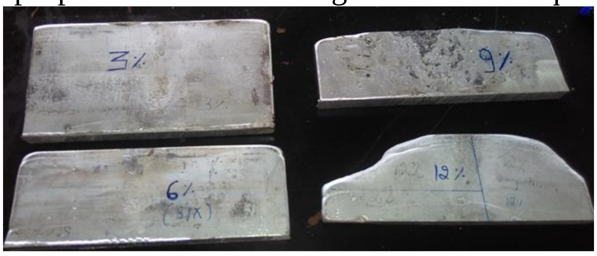

FIGURE 2.2 Different weight fractions of TiB_2 reinforced MMC's

Equipment used for fracture toughness test range from simple, hand-actuated devices to complex, servo-hydraulic systems controlled through computer interfaces. Common configurations involve the use of a general-purpose device called a universal testing machine. Modern test machines fall into two broad categories: electro mechanical and servo hydraulic.

The most commonly used specimen for fracture toughness testing is the compact test specimen, tests were conducted using UTM (TUE-600C) as shown in figure 2.3 for different weight fractions of TiB_2 reinforced composites. Fracture toughness tests were conduct on pre-cracked specimens to create a sharp crack tip.

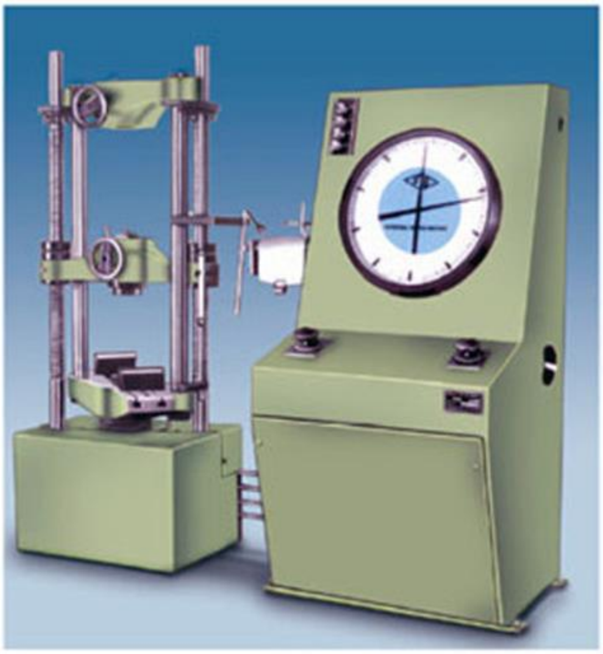

FIGURE 2.3 Universal Testing Machine (TUE-600C)

The test procedure involves the manufacture of fixtures which depends on the geometry of test specimen, pin and clevis fixture is used to hold the specimen between upper and lower jaws. A pre-cracked specimen held between the fixtures is as shown in figure 2.4 to the fracture point or to a predetermined load or displacement point.

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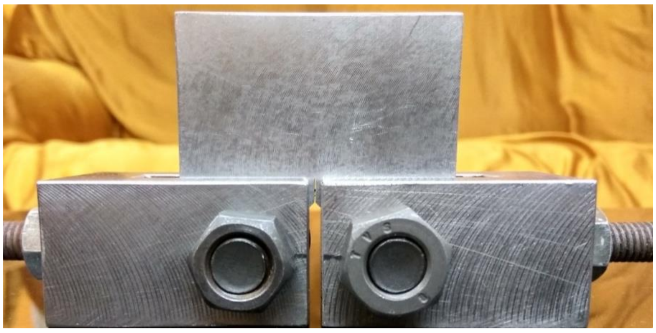

FIGURE 2.4 Specimen position in a fixture

During the test, the load and displacement for different weight fractions of TiB_2 specimen were recorded to determine stress intensity factor.

3. RESULTS AND ANALYSIS

3.1 Fracture test result

Fracture test on different weight fractions of TiB_2 was conducted to determine the fracture toughness and stress intensity factor. The maximum load carrying capacities of each specimen are noted to estimate stress concentration factor.

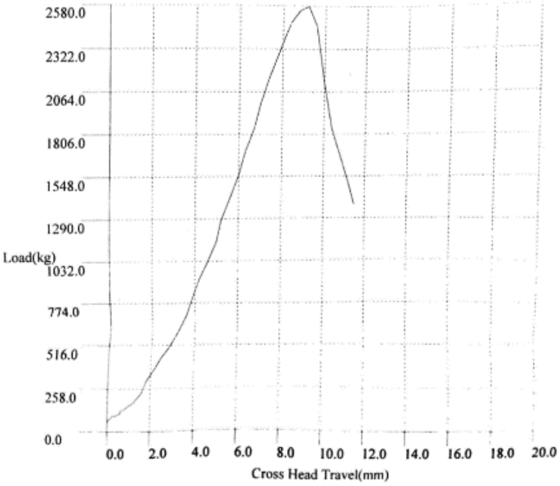

FIGURE 3.1.1 (a)

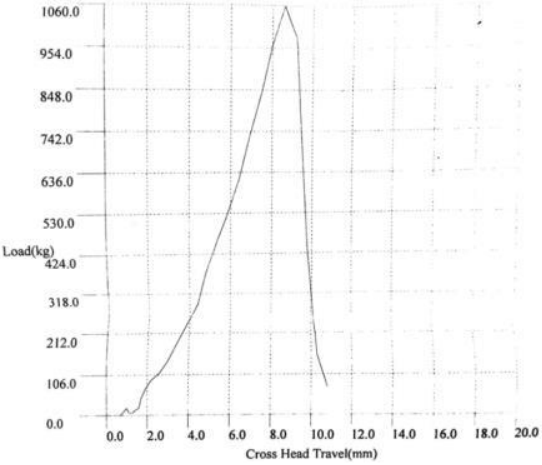

FIGURE 3.1.1 (b)

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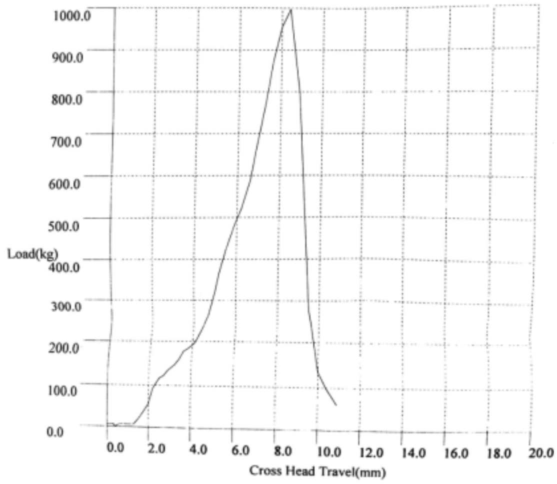

FIGURE 3.1.1 (c)

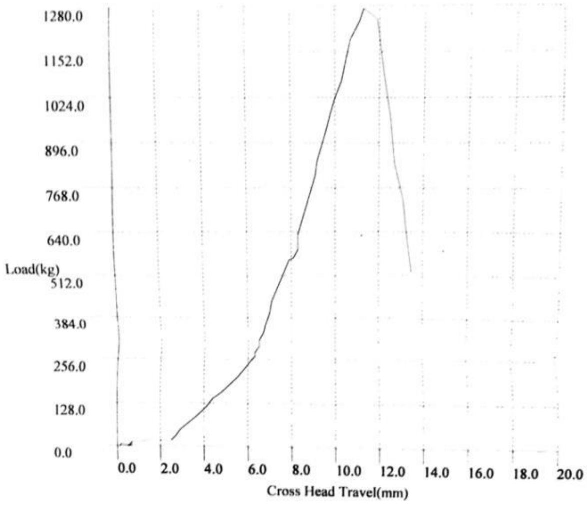

FIGURE 3.1.1 (d)

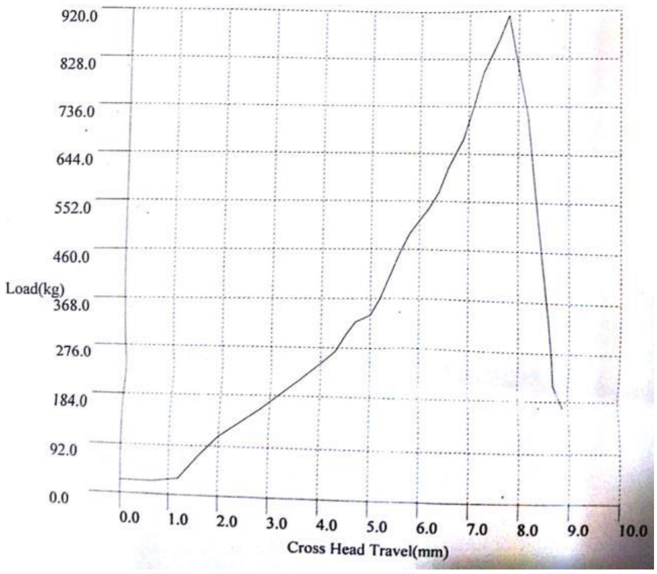

FIGURE 3.1.1 (e)

FIGURE 3.1.1 (a) to 3.1.1 (e) shows the Load and displacement plot for Al6061- for base, 3%, 6%, 9% and 12% TiB_2reinforced composite respectively.

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Figure 3.1.1(a) to 3.1.1(e) shows the maximum load carrying capacity and it is observed that maximum load taken by Al 6061 alloy compared to TiB_2 reinforced composites also noticed that with the addition of TiB_2 load carrying capacity decrease till 6% of reinforcement because of the presence of TiB_2 hard particles leads to the formation of voids. Further increase in the % of reinforcement load carrying capacity enhance this is the reason that sound castings were manufacture using In-situ technique.
Further adding the % of reinforcement beyond 9% brittle phase has been formed hence a load carrying capacity decrease which is clearly observed in the figure 3.1.1(d).Fractured test specimens are observed after conducting the test, it is noticed that crack propagation takes place almost perpendicular to the load application direction it is true for all conventional materials. The composite developed with TiB_2 reinforcement seems to be a homogeneous material, it indicates that TiB_2 particles are distributed uniformly throughout the casting. Failure pattern for Al6061 alloy and 9% reinforced TiB_2 is almost same and crack path for different weight fractions of TiB_2 are as shown in figure 3.1.2.

FIGURE 3.1.2 Fractured specimens of Al6061 and TiB_2 Reinforced(Base, 3%, 6%, 9% and 12%) composites.

Table 3.1 The stress intensity factor for different weight fractions is tabulate in table

Percentage of reinforcement	Peak Load P_{max} (kg)	Cross head travel (mm)	K_{IC} (MPa.$m^{1/2}$)
0	2575.8	9.2	35.364
3	1058.47	8.6	14.5321
6	997.28	8.4	13.6920
9	1272.61	11.3	17.47

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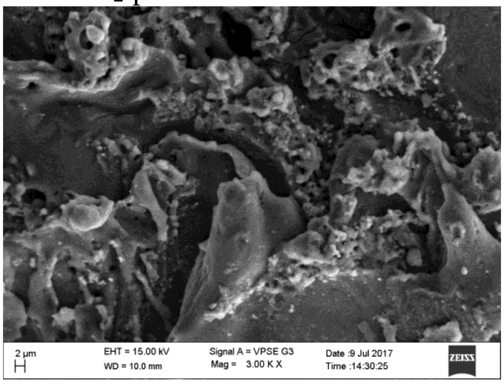
12	977.63	7.8	13.4222

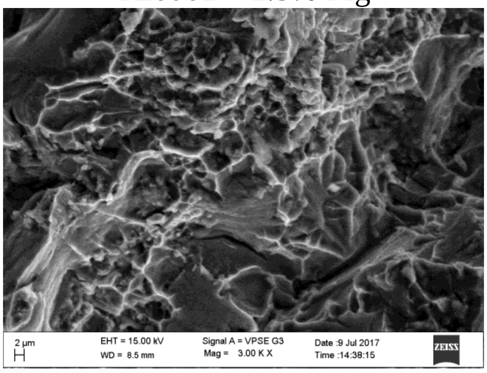
From the table it is observed that Al 6061 base alloy has K_{IC}value as 35.364 whereas 12% TiB_2 reinforced composite material has K_{IC} value as 13.422 for same test conditions. It indicates that stress concentration near the vicinity of the crack tip decrease around 62% with the addition of the reinforcement hence the stress level in the components decreases with reduction in stress intensity factor.

3.2Microstructure Analysis

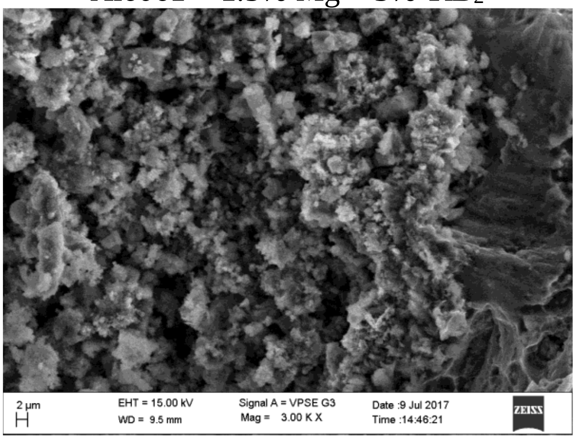
The SEM micrographs of the fracture AMCs is presented in Figure 3.2.1. The in situ formed TiB_2 particles are distributed homogeneously in the aluminium matrix with interface and good bonding of the TiB_2 particulates in the base Al alloy matrix. Such kind of particulate distribution is an essential requirement to achieve better fatigue and fracture properties and solidification process dictates the uniform distribution of TiB_2 particles in the matrix.



Al6061 + 1.5% Mg



Al6061 + 1.5% Mg + 3% TiB_2



Al6061 + 1.5% Mg +6 %TiB_2

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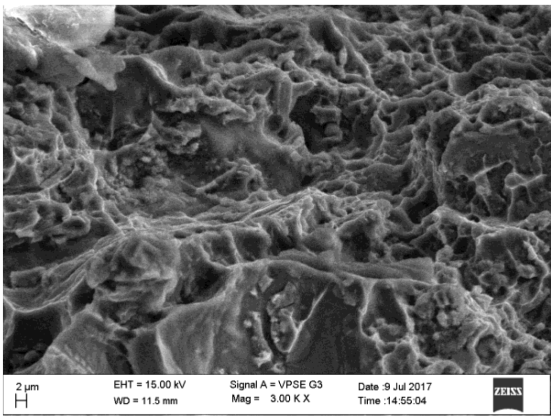
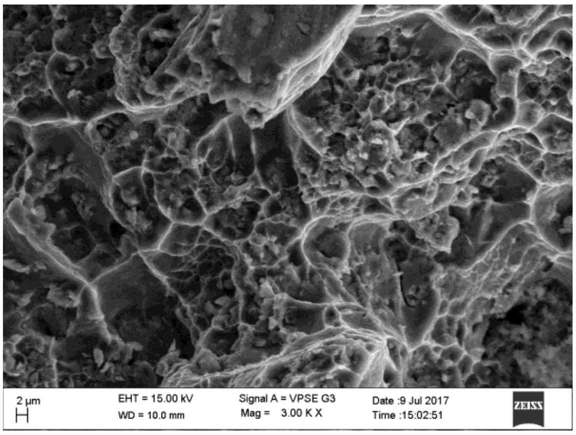


Al6061 + 1.5% Mg + 9%TiB_2



Al6061 + 1.5% Mg + 12% TiB_2

FIGURE 3.2.1 Microstructure Images of Fracture Test Specimens

Fracture mechanism in composite with 6wt% of TiB_2 particles was due to ductile rupture and decohesion of particle-matrix interface while in case of composite with 9wt% of TiB_2 particles fracture mechanism occurred due to matrix brittle rupture by particle fracture.

CONCLUSION

The Al 6061 based metal matrix composite containing 3%, 6%, 9% and 12% TiB_2 particulates were successfully developedby employing the In-Situ reactive processing technique with the addition of 1.5% of Mg. Compact test specimenwere machined using CNC machines.Fracture behaviour of TiB_2 reinforced composite hasanalysed and found that stress intensity factor decreases with increase in the addition of % of reinforcement. SEM analysis of the composites showed the uniform distribution, clear interface and good bonding of the TiB_2 particulates in the base aluminium alloy matrix.

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