

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & MANAGEMENT INVESTIGATIONS ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF TiB₂ REINFORCED ALUMINUM MATRIX COMPOSITES

Dr.G. Mallesh^{*1} and Mr.Manjunatha H.S²

^{*1}Associate Professor, Department of Mechanical Engineering, S.J.C.E- Mysuru-06, India

²Assistant Professor, Department of Mechanical Engineering, A T M E College of Engineering, Mysuru-23, India.

ABSTRACT

Aluminum based metal matrix composites plays a vital role in the present day engineering applications because it acquired good mechanical properties such as light weight, high specific strength, low density easily machinable to get variety of surface finish. Hence AMC's are widely used in aircraft structures, space shuttles, military, shipbuilding and automotive applications.

In this paper attempts are made to develop Al6061-TiB₂ composite material for light weight applications using In-situ salt reaction stir casting method by varying the weight fraction of TiB₂ (0%, 3%, 6%, 9 % and 12%).

Mechanical characterization was carried out on Al6061-TiB₂ as per ASTM Standard which includes SEM, XRD, EDAX analysis, micro hardness, and tensile strength tests. It was noticed that the developed composites exhibit superior structural properties when compared with base alloy.

Keywords: Al6061, TiB₂, Weight fractions, Microstructure and Mechanical properties.

I. INTRODUCTION

Composite is a mixture of two or more distinct constituent or phase. Both constituent have to be present in reasonable property. Constituent phases have different properties, and hence the composite properties are noticeably different from the properties of the constituents. Metal matrix has the advantage over polymeric matrix in applications requiring a long-term resistance to severe environments, such as high temperature. The yield strength and modulus of most metals are higher than those for polymers, and this is an important consideration for applications requiring high transverse strength and modulus as well as compressive strength for the composite [1]. Metal Matrix Composites (MMCs) have emerged as an important class of materials and are useful for structural, thermal, wear transportation and electrical applications. Aluminum based particulate reinforced MMCs have emerged as an important class of high performance material for use in aerospace, automobile, chemical and transportation industries [2]. The production technology and use of composites have been improved significantly in recent decades. The physical and mechanical properties of metal-matrix composites (MMCs), such as high specific modulus and thermal stability, make them particularly attractive for application in the aerospace and automotive industries [3]. Nowadays, with the increasing concern about energy saving and demands of applying advanced structures in aerospace, military, automobile and electronic area, particle reinforcement aluminum matrix composites (PRAMCs) are more and more attractive for the material scientists, because of their low density, high specific stiffness, strong wear resistance, reduced thermal expansion coefficient and high thermal conductivity [4]. Aluminum-based MMCs are excellent novel materials for applications in aerospace, automotive and transportation industries due to their high specific modulus and strength, superior wear fatigue and creep resistances. Metal matrix composites (MMCs) have become increasingly used for critical structural applications in industrial sectors because of their excellent stiffness to density and strength to density ratios [5]. Al based metal matrix composites (MMCs) reinforced with ceramic particles have received extensive attention due to their high specific strength-to-weight ratio, good wear resistance, excellent dimensional stability and superior damping capacity in comparison with the matrix alloy [6]. Al 6061 alloy is the most widely used 6xxx series aluminum alloy offering a range of good mechanical properties, good surface finish, excellent corrosion resistance and high workability. TiB₂ has emerged as an outstanding reinforcement among a wide variety of ceramics such as SiC, B₄C, Al₂O₃, TiC and graphite. This is due to the fact that TiB₂ is stiff hard and more importantly it does not react with aluminum to

form any reaction product at the interface between the reinforcement and the matrix [7]. Al 6061 alloy is the most widely used 6xxx series aluminum alloy offering a range of good mechanical properties, good surface finish, excellent corrosion resistance and high workability. In recent past researchers have used wide variety of ceramic dispersoids such as SiC, B₄C, Si₃N₄, Al₂O₃ and TiO₂ as reinforcement material in Al 6061 based MMCs. However compared to these dispersoids TiB₂ stands out as an outstanding reinforcement, owing to the fact that it possesses high hardness, high strength to density ratio and refractory nature to avoid formation of interfacial reaction products with aluminum. [8]. Al6061 is widely used in numerous engineering applications including transport and construction where superior mechanical properties such as tensile strength, hardness etc are essentially required [9]. Titanium diboride is a ceramic material with high strength, melting point 2790° C, hardness (960 HV), modulus (530 GPa) and corrosion resistance. The combination of its excellent properties has made TiB₂ increasingly important for a wide range of applications in erosive, abrasive, corrosive or high-temperature environments [10]. Compared with other ceramic particles such as SiC, TiC, Al₂O₃, SiO₂, titanium diboride (TiB₂) is a new ceramic material with relatively high strength, melting point, hardness and wear resistance, which is an attractive strengthening agent for aluminum-based composites. It is worthwhile to note that TiB₂ particle can be in-situ formed in the aluminum matrix by means of the chemical reaction processing method [11]. Among wide variety of reinforcements, TiB₂ has gained considerable importance because TiB₂ is stiff, hard and does not react with aluminum to form reaction products at the interface of reinforcement and matrix [12]. TiB₂ ceramic particle do not react with molten aluminum, thereby avoiding formation of brittle reaction products at the reinforcements-matrix interfaces. Also aluminum reinforced with TiB₂ is known for its high wear resistance property [13]. TiB₂ also has no interface reaction with aluminum. As a widely used in-situ process, the salt-metal reaction route is based on the aluminothermic reaction between two kinds of potassium fluoride salts and aluminum to form in-situ TiB₂ particles [14].

The AMCs reinforced with ceramic particles are currently fabricated using various established methods and some specific patented methods. The conventional methods are powder metallurgy, mechanical alloying, stir casting, squeeze casting, compo casting and spray deposition. The processing method influences the mechanical behavior of the AMCs [15]. The manufacturing techniques of the aluminum metal matrix composites are classified in to three types' namely (1) liquid state methods, (2) semisolid methods and (3) powder metallurgy methods. [3] In liquid state methods, the ceramic particulates are incorporated into a molten metallic matrix and casting of the resulting MMC is done [16]. Normally aluminum-based MMCs are manufactured by liquid state, semisolid and powder–metallurgy (P/M) methods [17]. However, the ex-situ method of preparation of particle-reinforced MMCs have certain technological challenges, e.g., non-uniform particle distribution [1], formation of undesirable interfacial reaction products, inherent casting defects and poor bonding at the matrix/reinforcement interface[18]. In situ method has been found to be one of the most important techniques in the fabrication of MMCs in the middle 1980s. One of the most important advantages of the MMCs produced by the In situ processes is the thermodynamic stability of the particulate phases [19]. The composites processed using the conventional methods suffer, in common, from matrix reinforcement interfacial thermodynamics instability, thus limiting their ambient and high temperature mechanical properties. In order to overcome this limitation and to ensure good matrix to reinforcement compatibility, micro structural homogeneity efforts have been made to synthesize and fabricate the MMC in a single stage from its raw materials. In-situ process represents one such category of technique used to synthesize MMC [20]. However, there still exist challenges in producing high quality metal matrix composites, the major issues are achieving excellent bond between matrix and reinforcement and reducing interfacial reaction between reinforced particles and matrix alloy. The above problems that are associated with metal matrix composites can be addressed by adopting in-situ method of fabricating metal matrix composites [21]. In situ processes involve the synthesis of composites such that desirable reinforcement, matrices and interfaces are formed during processing. The successful synthesis of in situ composites involves a good understanding of thermodynamics and reaction kinetics in order to obtain the desirable end product [22]. In situ composites reinforced with particulates have advantages over ex-situ composites in grain refinement, uniform distribution of reinforcements, excellent bond between the reinforcement and matrix, and economy of fabrication [23]. Recently, in situ fabrication techniques have been developed to produce metal matrix composites (MMC). Since the formation and growth of reinforcement take place within the matrix, in situ preparation of composites provides advantages including uniform distribution of finer particles, excellent bond at the interface, thermodynamically stable reinforcements that overwhelm the conventional ex situ processes, yielding better mechanical and tribological properties [24].

Among various Al matrix composites, the in-situ TiB₂ particles reinforced Al alloy composite prepared using an exothermic reaction process with K₂TiF₆ and KBF₄ salts has been the highlight of research interests in recent years, since the interfaces between TiB₂ particles and Al matrix alloy are clear and well bonded, and reaction products are easy to remove [25]. Metal matrix composites with AA 2219 Al alloy as the matrix and different amounts of TiB₂ particles (5wt % and 10wt %, respectively) as the reinforcement introduced in-situ by the salt metal reaction technique [26]. Earlier, Wood et al. had synthesized A356/TiB₂ composites via a salt route technique involving K₂TiF₆ and KBF₄ salts. [27]. Metals like aluminum that have been combined with a high percentage of other elements such as TiB₂ are called a master alloy [28].

The present investigation focuses on fabrication of TiB₂ reinforced with aluminum matrix using in-situ method was carried out, the morphological study of the composites were investigated and the mechanical properties such as hardness, tensile strength and ductility were analyzed.

II. EXPERIMENTAL PROCEDURE

Al 6061 reinforced with TiB₂ by varying different wt fractions are used to prepare composite material to study the mechanical properties of the composites developed using In-situ technique.

In this technique, the reinforcement phase is formed in situation, by adding different salts to form required combination of composite system.

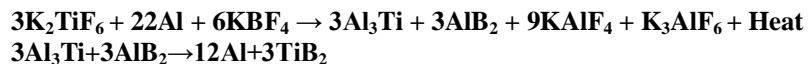
Table.1 Chemical Composition of Al 6061 alloy

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

Al 6061 rods were placed in a coated graphite crucible and heated using an electrical furnace. The chemical composition of Al 6061 aluminum alloy is presented in Table 1. A coating was applied inside the crucible to avoid contamination. The temperature of the molten aluminum was maintained at 850⁰C. The measured quantities of premixed salts K₂TiF₆ and KBF₄ were added into the molten aluminum alloy and thoroughly stirred using a graphite rod at intervals of every 10 minutes. A total reaction time of 1 hr was allowed at 850⁰C and the melt was later poured into a cast iron metal mould. After solidification process castings were obtained as shown in figure 1. Machining of the composites was carried out as per ASTM standards to conduct morphological analysis and various mechanical tests.

Aluminum alloy Al6061 reinforced TiB₂ particulate composites were successfully synthesized by the in situ salt metal reaction of K₂TiF₆ and KBF₄ salts. During in-situ reaction process, the elements Ti and B are introduced from the two salts into the molten aluminum and made to react within it.

As the salts are mixed stoichiometrically to form TiB₂, TiB₂ is the only intermetallic phase to be formed by the reaction which is given below



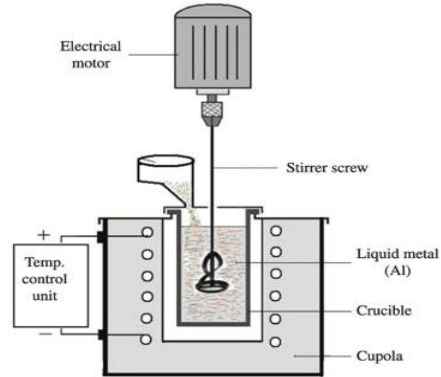


Figure 1: Melt stirring test apparatus for the production of composite



Figure 2: Aluminum Rods



Figure 3: Metal Mould



Figure 4: Molten metal in the Mould



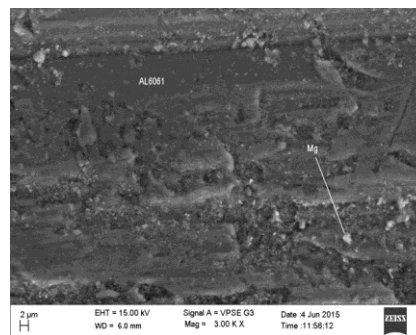
Figure 5: Casted specimens

III. RESULTS AND DISCUSSION

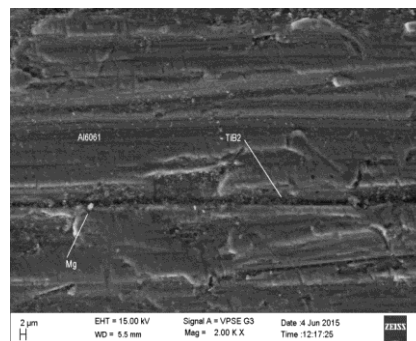
Microstructure

The SEM micrographs of the fabricated AMCs are presented in Figure.6 the micrographs shows no common casting defects such as porosity, shrinkages or slag inclusion which showcases the quality of castings. The in situ formed TiB_2 particles are distributed homogeneously in the aluminum matrix. Such kind of particulate distribution is an essential requirement to achieve better mechanical properties and solidification process dictates the uniform distribution of TiB_2 particles in the matrix.

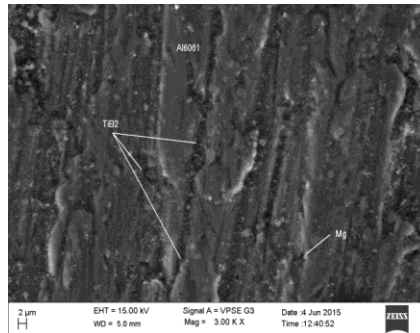
It appears that a more uniform distribution of TiB_2 particles with less porosity can be achieved at 6% of TiB_2 . Beyond 6% weight fraction of TiB_2 leads to clustering of particles, which indicates the formation of hard brittle Al_3Ti intermetallic phase, thereby decreases the ductility. The in situ formed TiB_2 particles exhibit various shapes such as spherical, hexagonal and cubic. Some investigators observed the shape of TiB_2 particles to be hexagonal, while some other reported spherical and cubic structure [33].



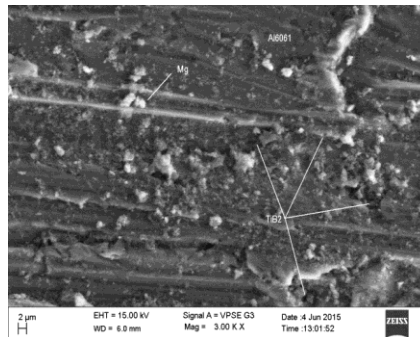
Al6061



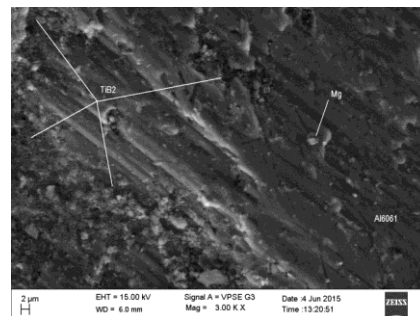
Al6061+ 3% TiB₂



Al6061 +6 % TiB₂



Al6061 + 9% TiB₂



Al6061 + 12% TiB₂

Figure 6: Microstructure of Al 6061 with different weight fractions of TiB₂ In-Situ composites.

X-ray Diffraction Analysis

X-ray diffraction pattern of the composite obtained are presented in Figure.7. It is evident from the figure that the composite is consisted of aluminum and TiB₂.

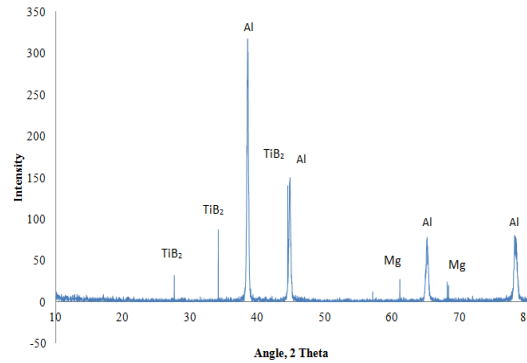


Figure 7: XRD pattern of Al 6061 -6% TiB₂

Micro hardness

The results of the micro hardness test of the base metal and the composites are presented and observed that the micro hardness of the base alloy increased with addition of TiB₂ particulate.

A significant increase in hardness of the alloy matrix can be seen with addition of TiB₂ particles. Higher value of hardness is clear indication of the fact that the presences of particulates in the matrix have improved the overall hardness of the composites. This is true due to the fact that aluminum is a soft material and the reinforced particle especially ceramics material being hard, contributes positively to the hardness of the composites.

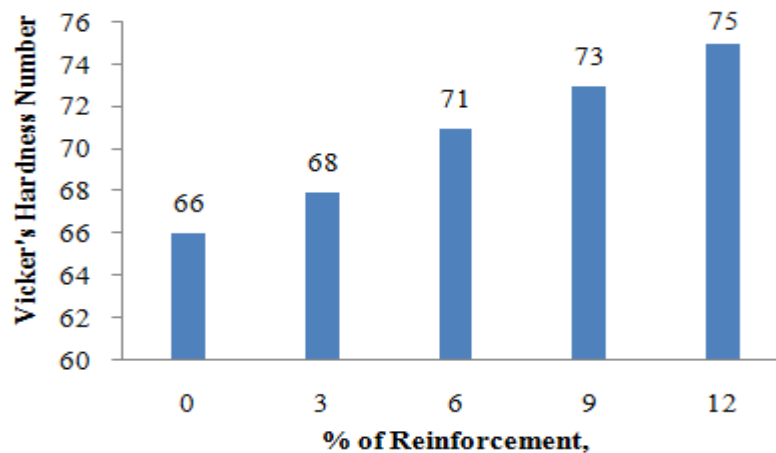


Figure 8: VHN for different weight fractions of TiB₂

Tensile Strength

The tensile strength and % ductility of Al 6061 and Al-TiB₂ composites are presented and the results of tensile tests confirm that addition of ceramic reinforcement to the aluminum matrix alloy increases tensile strength. As could be seen from the results of the tensile test, the tensile strength of the composite registered an increase with addition of TiB₂ particulates from 3 to 12 %. This is due to the strengthening of Aluminum alloy matrix by the particulates. It is also seen that % ductility of the composites got reduced with addition of particulates



Figure 9: Tensile strength for different weight fractions of TiB_2

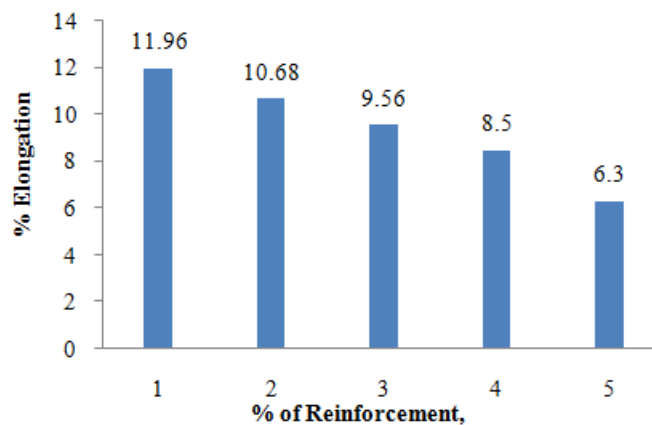


Figure 10: Percentage Elongation for different weight fractions of TiB_2

However, the composite materials exhibited lower elongation than that of unreinforced specimens. It is obvious that plastic deformation of the mixed soft metal matrix and the non-deformable reinforcement is more difficult than the base metal itself. As a result, the ductility of the composite drops down when compared to that of unreinforced material.

IV. CONCLUSIONS

The mechanical characteristics of Aluminum 6061 alloy composite reinforced with TiB_2 particles was successfully synthesized by In-situ reaction using halide salts. The study reveals that SEM micrograph and XRD patterns clearly indicate the presence of TiB_2 particles with a favorable good bond between the matrix and the reinforcement. But beyond 6 % Agglomerations of the TiB_2 reinforcements of varying size and shape were observed. From the result, it is concluded that increase in the amount of TiB_2 will certainly increase the Micro hardness and ultimate tensile strength of the composite was considerably higher than matrix alloy. However, composites exhibited lower ductility when compared with matrix alloy.

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