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# Effect of graphite addition on mechanical behavior of Al6061/$TiB_2$ hybrid composite using acoustic emission

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ABSTRACT

The present work includes the effect of addition of graphite for improving the properties of Al6061–$TiB_2$ composite using the high-energy stir casting method. The characterization was performed with X-ray diffraction, energy dispersive spectrum and scanning electron microscope. The thermal and mechanical behaviors such as thermo gravimetric analysis/differential thermal analysis, hardness, tensile strength using acoustic emission and fatigue behaviors were investigated. The composite of composition Al6061–20% $TiB_2$ with 2% graphite shows the greatest improvement in mechanical behavior. An Acoustic Emission system was employed in all the tests to monitor the acoustic energy release during the whole deformation process and some useful conclusions were drawn.



## 1. Introduction

Aluminum-based particulate reinforced metal matrix composites (MMCs) have emerged as an important class of high performance materials known for light weight, high formability, high electrical conductivity and corrosion resistance applications. They find application in aerospace, automobile, marine, chemical, transportation, and mineral processing industries [1,2]. Normally aluminum MMCs are manufactured by liquid state, semisolid and powder metallurgy methods [3–5]. Among the manufacturing techniques of MMC, stir casting (particulate or discontinuous reinforced MMCs) is generally preferred. The advantage lies in its simplicity, flexibility and applicability to a large quantity production. It is also attractive because of the minimized final cost of the product [6]. Stir casting is a liquid state method of composite materials fabrication, in which a ceramic particle is mixed homogeneously with a molten matrix metal by means of mechanical stirring and the solidification of the melt containing suspended particles in order to obtain the desired product [7,8].

Different ceramic materials that are generally used to reinforce aluminum alloys in Al6061 MMCs are carbides (SiC, TiC, ZrC), borides ($TiB_2$, $ZrB_2$), nitrides (AlN, $Si_3N_4$), oxides ($Al_2O_3$, $SiO_2$) and aluminides ($Al_4Mo$, $Al_3Ti$, $Al_3Zr$) [9–13]. Studies have shown that $TiB_2$ particles do not react with aluminum [2,14], thereby avoiding the formation of brittle reaction products at the reinforcement–matrix interface [13–16]. Aluminum reinforced with TiC, $TiB_2$, $B_4C$, and SiC is synthesized and their behaviors were compared using the powder metallurgy route [8,15,17]. It was found that $TiB_2$ showed better mechanical property than the other reinforcements [13,14,17]. Titanium diboride ($TiB_2$) is particularly very attractive as reinforcement due to its high Young's modulus (345–409 GPa), low specific gravity (4.5), superior hardness (3400 HV) (only less than diamond, BN and B4C), good thermal conductivity (110 $W m^{-1} K^{-1}$ at 25 °C), high electrical conductivity ($22 \times 10^6\ \Omega$ cm), high elastic modulus, high melting point (3225 °C), superior wear resistance and good thermal stability [18,19]. Such unique properties made $TiB_2$ widely applicable in areas such as advanced engineering ceramics (cutting tools, wear-resistant parts, and armor materials) [20], aircraft, automotive, armaments and aerospace industry including the production of the armor of land vehicles, ships, aircrafts, helicopters, aerospace parts and parts that are exposed

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to high temperature and are characterized with high abrasion resistance [21,22].

Aluminum graphite particulate MMCs produced by solidification techniques represent a class of inexpensive tailor-made materials for a variety of engineering applications such as automotive components [23], bushes and bearings [24]. Because of this solid lubricative property, graphite in the form of particles has a wide range of applications in composite materials. It is used to make components requiring tensile, and great wear resistance such as engine bearing, pistons, piston rings and cylinder liners [25–27]. This has led to increased research interest for evaluating the effect of the type and weight fraction of reinforcement in the matrix and for different alternative procedures that are used to produce MMCs [28,29].

Fatigue property is a crucial factor in engineering design, where the cyclic load is inevitably involved [30]. MMCs in general had significantly improved in properties such as strength and fatigue life compared to the monolithic matrix material, due to the inclusion of hard brittle reinforcing particles [31]. Fatigue failure in metals accounts for 90% of all the in-service failures due to mechanical causes [32].

The acoustic emission (AE) method has been widely used to characterize the behavior of many engineering materials [33–39]. Use of an AE system to capture the energy released from a test specimen during deformation and for the study of the material behavior is more reliable than the theoretical calculations, especially when the material is heterogeneous, because the theoretical calculations are based on the assumption that suits only homogeneous specimens [40]. In addition, AE energy capturing is independent of the testing machine deformation and the related energy absorbing issues [40].

In this investigation various Al6061 composites were prepared by reinforcing different weight fractions of $TiB_2$ and graphite and their mechanical and thermal properties of hybrid composite were investigated. Literature from previous works in the field of Al6061–TiB2–graphite composite showed that no work had been carried out for determining the tensile test using AE in Al6061–$TiB_2$–graphite hybrid composite. So, this article mainly focuses on the study of tensile testing using AE and also emphasizes on hardness, fatigue and thermal behavior of Al6061–$TiB_2$–graphite hybrid composites.

## 2. Material and methods

### 2.1. Materials

Commercial grade aluminum Al6061 was used as the base material and the details of the composition are given in Tables 1–3, . The Al6061 reinforced hybrid composites, containing 2 wt% graphite particle size 20–25 μm and $TiB_2$ particle size 1–5 μm were prepared by the stir casting process. In this stir casting Al6061 rods were placed in a coated graphite crucible and heated to 700 °C using an electrical furnace as shown in Fig. 1(a). The $TiB_2$ powder was preheated at 900 °C and the graphite particles were preheated at 1000 °C in a separate muffle furnace as shown in Fig. 1(b). In this preparation process, stirring was carried out in the graphite crucible for ensuring homogeneous distribution of the mixture of composites. Al6061 was melted in a crucible by heating it in a blower furnace at 700 °C for fifteen minutes to melt the Al6061completely. Then preheated $TiB_2$ and graphite powder were slowly added to Al6061. The stirring was carried out with the help of a drilling machine for about 20 min at the stirring speed of 450 rpm. The mixture was poured into the mold cavity and allowed to cool by keeping the mold at room temperature. The same procedure was repeated for all the other compositions [14].

**Table 1**
Chemical composition of Al6061.

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

**Table 2**
Chemical composition of $TiB_2$ powder.

| Element | Ti | B | O | C | Fe | N |
|---|---|---|---|---|---|---|
| Weight % | 67.60 | 31.04 | 0.45 | 0.25 | 0.09 | 0.26 |

**Table 3**
Chemical composition of graphite powder.

| Element | Carbon | Sulfur | Iron |
|---|---|---|---|
| Weight % | Min 95 | Max 0.1 | Max 0.5 |

The size of the composite casting was designed based on the requirement of all microstructural and mechanical tests.

### 2.2. SEM–EDS analysis with elemental distribution

Fig. 2(a–h) shows the scanning electron microscope (SEM) image and energy dispersive spectrum (EDS) pattern of the various composites. Fig. 2(a) indicates the topographical SEM image of the Al6061 alloy and (b) shows the EDS of an Al6061 alloy. The elemental peaks of aluminum and the functional elements like magnesium, silicon, manganese and ferrous are identified with high intensity peak. The extra elements like carbon, nitrogen and oxygen are identified as very low peaks. The microstructure and EDS analysis of $TiB_2$ particles are shown in Fig. 2(c, d). The shapes of the processed crystals are flat, irregular, hexagonal platelets. Fig. 2(e, f) shows the topographical SEM image of the graphite particle. It is observed that the powder particles are agglomerated, exhibiting irregular shapes that take the form of flakes of different sizes. Fig. 2(g, i) shows the topographical SEM image of the Al6061–10% $TiB_2$ and Al6061–20% $TiB_2$–2% graphite composite. It is seen that $TiB_2$ particles were mostly hexagonal in shape. Common casting defects such as porosity and shrinkages were not found in the micrographs. Fig. 2(h, j) shows the EDS spectrum of the Al6061–10% $TiB_2$ and Al6061–20% $TiB_2$–2% graphite composite with peaks of aluminum, titanium, boron and graphite. EDS elemental analysis confirmed the presence of boron, aluminum, titanium and graphite. The micrograph shows that there is no agglomeration of the $TiB_2$ and graphite particles in the mixture [14].

### 2.3. X-ray diffraction analysis

X-ray diffraction (XRD) shows the elements present in the composite. Fig. 3 shows the XRD results of the prepared composites with their intensity peaks for the composites with designed 5, 10, and 20 wt% of $TiB_2$ with 2 wt% graphite. These results indicate the presence of aluminum (in the largest peaks), and the presence of titanium diboride particles and carbon (indicated by minor peaks), which are identified through JCPDS software. A clearly visible carbon peak can be observed in the hybrid composites. The increase in the intensity of the $TiB_2$ peaks with the increasing titanium diboride content of the composite is evident [14,41]. Fig. 3 also shows that the relationship is directly proportional to the increase in the intensity of titanium diboride and graphite and with the increasing of the composites peak is