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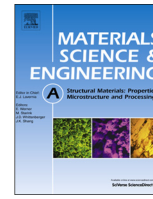

Mechanical behavior and failure analysis using online acoustic emission on nano-graphite reinforced Al6061–10TiB_2 hybrid composite using powder metallurgy

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ABSTRACT

The present paper includes the mechanical behavior of Al6061 alloy, Al6061–10TiB_2 composite and Al6061–10TiB_2–1Gr and Al6061–10TiB_2–2Gr hybrid composite prepared using a powder–metallurgy method. The samples were characterized by the Scanning Electron Microscope, Energy Dispersive Spectrum, X-ray Diffraction, Particle Size and Transmission Electron Microscope. Normally for Gr reinforced hybrid composite, the hardness and tensile strength decreased with increased Gr content. However, in this present study, the addition of TiB_2 with nano-Gr particle improved the hardness and tensile strength up to some extent. The tensile fractured specimens were also analyzed using SEM. An acoustic emission (AE) technique was employed in all the tensile test specimens to monitor the acoustic energy released during the deformation process and for the early crack detection.

1. Introduction

Aluminum-based particulate reinforced Metal Matrix Composites (MMCs) have been receiving worldwide attention on account of high performance materials known for light weight, superior strength and stiffness. They find applications in aerospace, automobile, marine, chemical, transportation, and mineral processing industries [1,2]. Normally aluminum- based MMCs are manufactured by liquid state, semisolid and powder–metallurgy (P/M) methods [3–8]. Among the manufacturing techniques of MMC, the P/M method is a low cost method, suitable for high volume production of complicated shapes. It is widely used for the manufacturing of aluminum-based composite materials. The P/M processing includes mixing, pressing and sintering [9]. The advantages are simplicity, flexibility and applicability for a large quantity production. It is also attractive because of the minimized final cost of the product [10]. One of the main advantages of P/M when compared to casting is better control over the microstructure and better distribution of the reinforcement in P/M compacts [11,12]. Different ceramic materials that are generally used to reinforce aluminum alloys in Al6061 MMCs are SiC, TiC, ZrC, TiB_2, ZrB_2, AlN, Si_3N_4, Al_2O_3, SiO_2, Al_4Mo, Al_3Ti and Al_3Zr [13]. Studies showed that TiB_2 particles do not react with aluminum and helps to avoid the formation of brittle reaction products at the reinforcement–matrix interface [13–16]. Aluminum, reinforced with TiC, TiB_2, B_4C and SiC, was synthesized and their behaviors were compared using powder–metallurgy route [8,15,17]. It was found that Titanium Diboride (TiB_2) possesses better mechanical property than the other reinforcements [13,14,17]. 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 × 10^6 Ω cm), 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].

The reinforcement materials are embedded into the matrix in the hybrid composite [21–24], which is characterized by greater light weight, higher strength, higher stiffness, better toughness and desired wear resistance than those of conventional materials [25]. Aluminum-graphite particulate MMCs produced by P/M

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techniques represent a class of inexpensive tailor-made materials for a variety of engineering applications such as automotive components [26], bushes and bearings [27]. Due to solid lubricative property, graphite has a wide range of applications in composite materials. Graphite is used to make components requiring tensile, and great wear resistance such as engine bearing, pistons, piston rings and cylinder liners [28]. Mechanical properties of aluminum-based MMCs are the essential functions of manufacturing processes. Surface state and the type of matrix reinforcement and heat treatment influence the mechanical behavior of the MMCs in service conditions [29,30].

The acoustic emission (AE) technique is one of the powerful non-destructive techniques for real-time structural health monitoring of damage in composite structures under quasi-static and dynamic–cyclic loading [31]. The AE method has been widely used to characterize the behavior of many engineering materials [32,33]. 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 [34]. In addition, AE energy capturing is independent of the testing machine deformation and the related energy absorbing issues [35].

Even though many researchers attempted Al6061 with TiB2 and Gr, literatures confirm that no work is done on the mechanical behavior of Al6061 with TiB_2 and nano-Gr as reinforcement materials produced in the solid and liquid phase method. In this investigation, various Al6061-based hybrid composites were prepared by reinforcing 10TiB_2 and nano-Gr and their mechanical properties of hybrid composite were investigated. The previous works in the field of Al6061–TiB_2–Gr P/M composite [5,21,25,30] showed that no work was carried out for determining the tensile test using AE in Al6061–TiB_2–Gr hybrid nano-composite. The transient wave released in materials undergoes permanent deformation and fractures have been widely utilized for the study and characterization of metals and composites. So, this article is mainly focused on the study of tensile testing using AE and also it emphasizes the hardness of Al6061–TiB_2–Gr hybrid nano-composite.

2. Materials and methods

2.1. Materials

The materials used for the present study were Al6061, TiB_2 and Gr, and the details of their compositions are given in Tables 1–3 separately. The Al and the reinforcing ingredient of the received TiB_2 powder has the particle size of 30–50 μm and 1–10 μm, and the graphite particle size varies from 25 μm to 50 μm. Fig. 1 shows the SEM images of the received powders (a) Al (b) TiB_2 and (c) Gr powders and also the properties of the TiB_2 and Gr powders listed in Table 4.

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	Remaining

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 Gr powder.

Element	C	S	Fe
Weight %	95.00	0.10	0.50

2.2. Ball milling and powder characterization

The Gr powder was pulverized into nano-scale and mixed with TiB_2 and Al6061 powders using high energy ball mill (Planetary mono mill, Fritsch, Germany-Pulverisette-6) with tungsten carbide vials using 10 mm diameter tungsten carbide balls. The ball to charge weight ratio was 20:1. Milling was done at 300 rpm in a wet medium, in the presence of toluene to prevent oxidation and agglomeration of the charges as explained in [10]. The milling effect in the Gr particles was characterized by using the SEM, Transmission Electron Microscope (TEM) and particle size analyzer image. Fig. 2 (a) shows the SEM image of the Gr powder after 10 h. Fig. 2(b) is the particle size analyzer image of the Gr powder after 10 h. It confirms that the average particle is 750 nm. Fig. 2(c) shows the TEM image of the Gr powder after 20 h. Fig. 2(d) is the particle size analyzer image of the Gr powder after 20 h. It confirms that the average particle is 60 nm. The particle analyzer inset shows the initial wide diffraction peaks of Gr getting sharpened and reduced in intensity, when reduced in size.

2.3. Mixing

The Al6061 and hybrid composites of Al6061 were prepared by the P/M method by adding 10 wt% of TiB_2 and 1 and 2 wt% of nano-Gr after mechanical alloying. The mechanical alloying was performed for 2 h. During the mixing Al, TiB_2 and nano-Gr were mixed in the same bowl. Fig. 3(a) is the SEM image of the Al6061–10TiB_2–1Gr nano-powder composite after mechanical alloying at 2 h and Fig. 3(b) is the SEM image of the Al6061–10TiB_2–2Gr nano-powder composite after mechanical alloying at 2 h.

2.4. X-ray diffraction analysis

X-ray Diffraction (XRD) investigations of the prepared powder composites were carried out using (PANalytical, Model: XPERT-PRO). The XRD results of the prepared Al6061, Al6061–10TiB_2–1Gr hybrid nano-composite and Al6061–10TiB_2–2Gr hybrid nano-composite are shown in Fig. 4(a)–(c). Peak values were collected over the 2θ range of 10–100° with a step size of 0.0170° and step time of 20.3142 s. All the samples showed wide diffraction peaks, which could be indexed to the structure of Al6061, TiB_2 and Gr. They revealed that the characteristic peaks in the XRD patterns which consistent with JCPDS files no. 89-2837, 07-0275 and 89-8487 for Al6061, TiB_2 and Gr respectively [29].

Fig. 4 shows the XRD results of the prepared powder composites with their intensity peaks at Al6061 and Al6061 with 10 wt% of TiB_2 with 1, 2 wt% Gr. Fig. 4(a) shows the XRD paten of the Al6061 powder. Fig. 4(b) shows XRD paten of the Al6061–10TiB_2–1Gr nano-powder composite and Fig. 4(c) is the XRD of the Al6061–10TiB_2–2Gr nano-powder composite. Fig. 4(b) and (c) reveals that the intensity of TiB_2 was greater in the (101) plane (2θ=44.6714°, JCPDS 07-0275). In addition, the intensity of TiO_2 and CuO was observed at different peaks and confirmed through JCPDS software, notably at 2θ=65.0960°, JCPDS 89-4746 (TiO_2 1 2 5), 2θ=38.3029°, JCPDS 89-2531 (CuO 111) and 2θ=44.5010°, JCPDS 39-1483 (AlB_2 101). Fig. 4(b) and (c) shows the presence of