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Modification of microstructure and properties of Ti-47Al-2Cr-4Nb-0.3W alloys fabricated by SPS with trace multilayer graphene addition

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ABSTRACT

In this paper, Ti-47Al-2Cr-4Nb-0.3W alloys with trace multilayer graphene addition were fabricated by spark plasma sintering to enhance both mechanical properties and tribological property simultaneously. With the addition of multilayer graphene, bending strength, compressive strength and tribological property of TiAl alloys are all improved. When graphene content increases from zero to 0.8 at.%, the mean grain size decreases from 14.8 ± 1.4 μm to 8.2 ± 0.8 μm. The bending strength reaches almost 1000 MPa and the fracture strength increases to 2347 ± 12 MPa, an increase of 15% compared with TiAl alloy. The friction coefficient also decreases from about 0.6 to 0.4, a decrease by 1/3 compared with TiAl alloy. The reasons for the improved mechanical properties and tribological property are the in-situ reaction plate-shape Ti_2AlC phase, fine needle-like Ti_3AlC phase as well as fine and homogeneous microstructure. The wear mechanism changes from abrasive wear to abrasive wear plus adhesive wear with the increased graphene content.

1. Introduction

TiAl alloys are potential candidates for high-temperature lightweight structural materials used in aerospace and automobiles due to their superior high temperature performance and light weight [1–5]. Furthermore, TiAl alloys are encouraged by the commercial application of low pressure turbine blade on GEnx engine, which powers Boeing 787 and 747-8 [5], subjecting to friction and wear, therefore the friction and wear properties of TiAl alloys must be known. Yet, the inadequate tribological property of TiAl alloys has been confirmed by some scholars [6–8]. Recently, research on how to improve tribological performance of TiAl alloys has received wide attention. The improved tribological properties can be achieved through the addition of higher hardness TiB_2 [9], Ti_3SiC_2 [10], MoS_2 [11] and Ag [12], as well as through nitridation and carburization [13]. But, the research does not take the demand for mechanical properties into account. The higher contents of 10 wt% Ag [14], 15 wt% Ti_3SiC_2 [10] or 20–40 vol% TiB_2 [9] are detrimental to mechanical properties. The bending strength of the TiAl-TiB_2 composites degrades obviously with the higher TiB_2 content of 20 vol% and 40 vol% and its bending strength decreases to only 488 MPa [9]. Therefore, it is still a huge challenge to choose an effective additive for TiAl alloys to enhance both mechanical properties and tribological property at the same time.

Graphene has recently received huge attention because of its outstanding mechanical and physical properties, such as high fracture strength, high Young's modulus, and extreme thermal conductivity [15,16]. Multilayer graphene possesses properties similar to that of single-layer graphene but is cheaper and easier to produce and disperse than single-layer graphene and carbon nanotubes. Besides, graphene has an excellent lubricating property, which has been examined at atomic scale [17]. In recent years, a number of studies about tribological property of graphene have been carried out. Solution processed graphene layers can effectively reduce the friction and wear on sliding steel surfaces [18]. Graphene nanoplatelets (GNP) consolidated by spark plasma sintering (SPS) can shear off and weld at higher load and provide a lubricating effect, showing that the GNP can be successfully used as a lubricating phase in ceramic matrix [19]. Therefore, it is reasonable to believe that multilayer graphene can act as both reinforcing and lubricating phases based on above studies. Furthermore, it is well established that the interstitial element carbon shows a positive effective on the creep property of TiAl alloys [20].

The powder metallurgy (PM) technique is an important approach to

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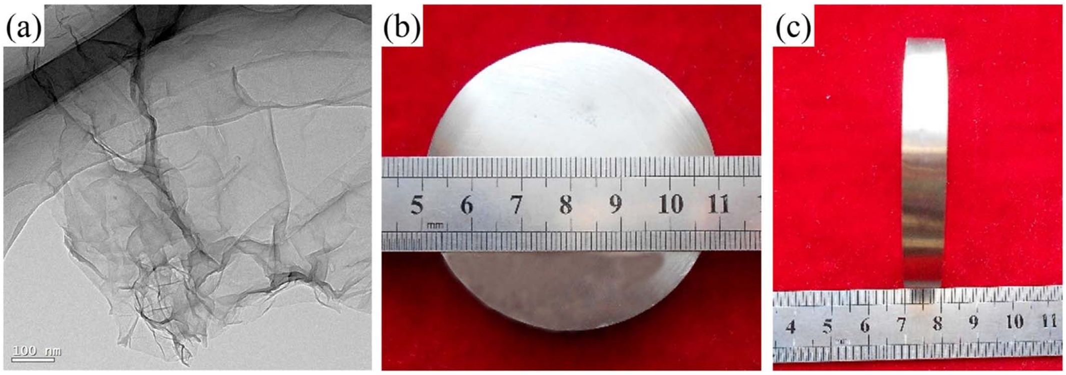

Fig. 1. (a) Morphology of graphene, (b) and (c) outer appearance of TiAl alloy sample.

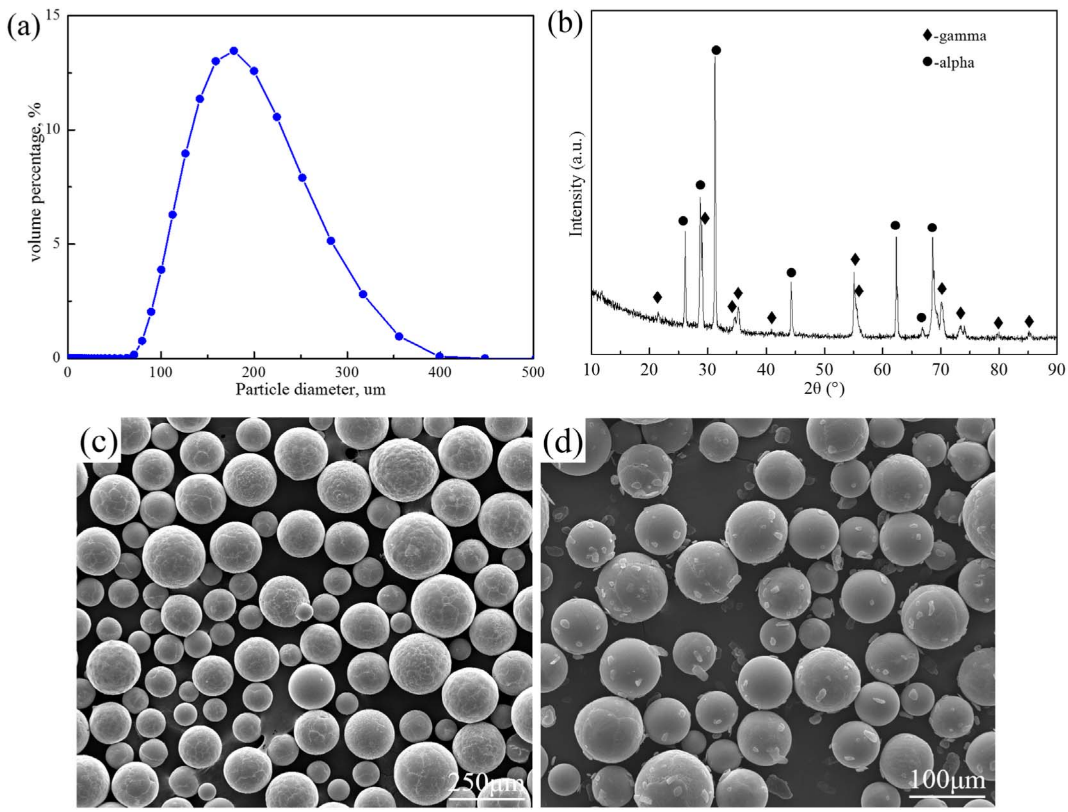

Fig. 2. (a) Particle size distribution of pre-alloyed TiAl powders; (b) XRD pattern of pre-alloyed TiAl powders; (c) SEM images of pre-alloyed TiAl powders and (d) 0.8% graphene uniformly distributed on the surface of pre-alloyed TiAl powders.

produce TiAl alloys, and appears to be more attractive since a high degree of chemical homogeneities can be obtained and macro-segregations are avoided [21]. The PM process comprises elemental powder metallurgy (EPM) and alloying powder metallurgy (APM). The mechanical properties of EPM TiAl alloys are often reduced by the concentrations of impurities such as oxygen and nitrogen [22]. Thus, many experiments have been conducted on microstructure and properties of APM TiAl alloys. Powders made from plasma rotation electrode process (PREP) contain a more uniform and spherical morphology [23]. In numerous preparation methods of TiAl alloys, SPS is able to consolidate powders by the application of direct current pulses of high intensity and uniaxial pressure in a short time, achieving refined microstructure, high purity and high density [21,24]. The excellent comprehensive properties including yield strength, elongation, and high-temperature creep of Ti-47Al-2Cr-2Nb can be obtained by SPS [25]. Additionally, the addition of graphene to alumina did not have adverse effects from the SPS processing [26], indicating that adding graphene to TiAl alloys maybe also feasible.

Therefore, in this paper, APM TiAl alloys containing trace graphene contents, namely, TiAl-xG alloys, were fabricated by mixing the TiAl pre-alloyed powders with trace multilayer graphene, and then consolidated using SPS. The microstructure, mechanical properties and tribological property of TiAl and TiAl-xG alloys were compared and discussed.

2. Experimental

The pre-alloyed powders were prepared by PREP, and their nominal composition was Ti-47Al-2Cr-4Nb-0.3W (at.%) in this study. Unless otherwise noted, alloy contents are shown in at.%. The typical morphology of starting multilayer graphene is presented in Fig. 1(a). The graphene was dispersed by ultrasonic treatment and then mixed with TiAl pre-alloyed powders in V-type powder mixer in argon atmosphere. The mixing time and mixing speed were 16 h and 20 rpm, respectively.