Powder Metallurgy of Nanostructured High Strength Materials

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Abstract

Nanostructured or partially amorphous Al- and Zr-based alloys are attractive candidates for advanced high-strength lightweight materials. Such alloys can be prepared by quenching from the melt or by powder metallurgy using mechanical attrition techniques. This work focuses on mechanically attrited powders and their consolidation into bulk specimens. Selected examples of mechanical deformation behavior are presented, revealing that the properties can be tuned within a wide range of strength and ductility as a function of size and volume fraction of the different phases.

Keywords : Nanostructured materials, solid-state processing, mechanical properties

1. Introduction

In recent years, nanostructured materials have attracted much attention due to their scientific and engineering significance [1]. In particular, substantial increase in strength, along with good ductility, has been observed in a number of alloys with multiphase nanoscale microstructures [1]. Such composites can be produced by processing routes based on rapid quenching from the melt (e.g. melt spinning) and powder metallurgy (e.g. mechanical attrition, MA). These synthesis routes may directly lead to a nanostructure or, in other cases, additional heat treatment has to be employed to create or optimize the desired nanostructure, such as in the case of (partial) devitrification of metallic glasses [2]. However, materials in powder form, such as MA powders, have to be subsequently consolidated to achieve bulk specimens [1]. Consolidation of nanocrystalline powders into fully dense bulk specimen is thus of primary interest in the development of near-net shape parts for technological applications [1].

In this work, results concerning the formation and the mechanical properties of nanostructured materials in Al- and Zr-based alloys are presented. Such materials may contain crystalline, quasicrystalline or amorphous phases and their mechanical properties are very encouraging regarding the combination of high strength and good ductility at room temperature.

2. Experimental and Results

Mechanically attrited powders were produced using a planetary ball mill and hardened steel balls and vials. All sample handling was carried out in a glove box under purified argon atmosphere (less than 1 ppm O_2 and H_2O). The phases and microstructures were characterized by X-ray diffraction (XRD) (Co K_α radiation) and by scanning electron microscopy (SEM). The thermal stability of the samples was investigated by differential scanning calorimetry (DSC) at 40 K/min heating rate under a continuous flow of purified argon.

2.1 Al-based alloys

The interest in new Al-alloys is due to the discovery of melt-spun Al-based ribbons with amorphous or quasicrystalline/fcc-Al composite structure, which exhibit good ductility and tensile strength of about 1000 – 1340 MPa [3,4[. Although these ribbons reach a strength exceeding that of conventional Al alloys [1], their small size prevents engineering applications. For that reason, powder metallurgical methods such as gas atomization or MA have been used to create powder particles with the desired microstructure [1]. Such quasicrystalline or glassy powders can be consolidated into nearly full density bulk specimens by extrusion or hot-pressing [5]. A typical example is gas-atomized and extruded Al-Cr-Cu-Mn powder [5], which displays a strength of about 600 MPa and a ductility exceeding 15 %.

A different approach to obtain high-strength materials is to use metallic glass as reinforcement in metal matrix composites (MMCs) through infiltration casting or sintering techniques. In order to prevent the glass from crystallization, a metallic glass reinforcement with a crystallization temperature higher than the melting point of the metal matrix can be selected [6]. Yet, most of the currently available metallic glasses exhibit crystallization temperatures that are lower than the melting points of Al and Mg, two of the most used matrix materials for MMCs. A different strategy is to develop some techniques by which the metallic glass-reinforced matrix composites are produced at temperatures below the melting temperature of the matrix. For example, Ni-Nb metallic glass reinforced Al-based MMCs have been produced by sintering at a relatively low temperature [7]. $Ni_{70}Nb_{30}$ glassy powders were first produced by mechanical alloying and subsequently combined with pure Al as matrix. The powder mixture was then cold-pressed to form a low density green compact and consolidated by sintering below the melting point of Al. The $Ni_{70}Nb_{30}$ glass was chosen because it has a rather high crystallization temperature (however lower than the melting temperature of Al) [7] and, therefore, it is quite stable during the sintering process. In addition, Ni-Nb-based glassy alloys are characterized by a strength higher than 2000 MPa and a Vickers hardness of about 800. Thus, they are suitable as reinforcements in Al-based MMCs. Mechanical tests reveal that the bulk specimens sintered at low temperature exhibit enhanced yield and fracture strength by about 8 an 16 %, respectively, compared with monolithic Al [7].

2.2 Zr-based alloys

Besides quenching from the melt, glass formation has also been achieved by MA for several multi-component Zr-based systems [8]. Depending on the milling intensity, MA can lead to glass formation or to the formation of nanoscale phases directly during milling. For example, $Zr_{57}Ti_8Nb_{2.5}Cu_{13.9}Ni_{11.1}Al_{7.5}$ glassy powders [9] can be produced at low milling intensity whereas at higher intensity a composite consisting of particles with fcc-Ti_2Ni-type structure embedded in an amorphous matrix can be achieved. The fcc particles in the as-milled powder are in the nanoscale regime (less than 10 nm), as indicated by the extremely broad diffraction peaks shown in Fig. 1(a). The material is partially amorphous and the corresponding DSC curve [Fig. 1(b)] reveals a distinct glass transition (T_g), followed by a supercooled liquid region before two exothermic events due to crystallization occur at higher temperature. When the powder is heated up to the completion of the first crystallization event (800 K), the diffraction peaks belonging to the fcc phase increase in intensity. This indicates grain growth of the fcc particles, which nevertheless are still in the nanometer regime (below 100 nm). The formation of a glassy-matrix composite containing nanoscale crystalline particles directly upon MA combined with the presence of a distinct glass transition and a rather wide supercooled liquid (SCL) region opens the possibility to produce large amounts of material by a relatively simple route and to consolidate and shape the composite powders into bulk parts at relatively low temperature and pressure using the viscous flow of the supercooled liquid [1,8]. In addition, the particle size can be varied by proper heat treatment, giving the opportunity to tune the microstructure of the composite material.

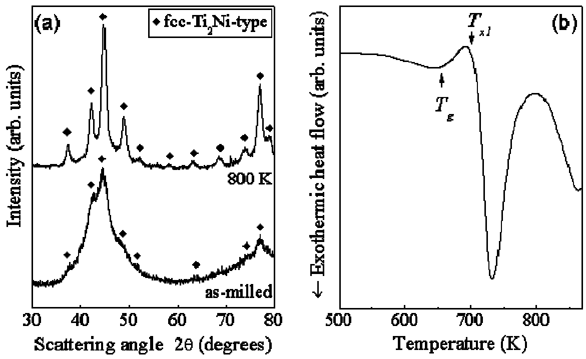

Fig. 1. (a) XRD patterns of as-milled $Zr_{57}Ti_8Nb_{2.5}Cu_{13.9}Ni_{11.1}Al_{7.5}$ powder and after heating up to the first DSC exothermic event and (b) DSC scan for the MA $Zr_{57}Ti_8Nb_{2.5}Cu_{13.9}Ni_{11.1}Al_{7.5}$ glassy powder.

3. Summary

Results on the formation of Al- and Zr-based mechanically attrited powders containing amorphous or nano-(quasi)crystalline phases and their consolidation into bulk specimens have been reported. This class of materials not only offers a new scope for applications due to promising mechanical properties but also provides the possibility of discovering and developing new materials with interesting properties.

4. References

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