Nanocrystalline and Ultrafine Grained Materials by Mechanical Alloying

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Abstract

Recent research at Harbin Institute of Technology on the synthesis of nanocrystalline and untrafine grained materials by mechanical alloying/milling is reviewed. Examples of the materials include aluminum alloy, copper alloy, magnesium-based hydrogen storage material, and $Nd_2Fe_{14}B/\alpha$-Fe magnetic nanocomposite. Details of the processes of mechanical alloying and consolidation of the mechanically alloyed nanocrystalline powder materials are presented. The microstructure characteristics and properties of the synthesized materials are addressed.

Keywords: nanocrystalline/ultrafine grained materials, mechanical alloying

1. Introduction

Nanocrystalline and ultrafine grained materials have high potential for use in both structural and functional applications in which enhanced mechanical or physical properties are required[1, 2]. Mechanical alloying/milling (MA/MM), a solid-state powder processing technique developed by Benjamin et al[3] in the late 1960s, has now been shown to be an effective approach of preparing nanocrystalline materials. In this paper, work at Harbin Institute of Technology is reviewed on the synthesis/processing, microstructure, and properties of some nanocrystalline/ ultrafine grained materials by mechanical alloying.

2. Aluminum Alloys

The progress in aerospace and automotive industries needs the development of aluminum alloys with high specific strength for applications where weight efficiency is of great importance. Since the alloying elements except for Li and Mg increases the density, the strengthening of these alloys by grain refining has attracted increasing attention.

In our work, a joint process of rapid solidification and mechanical milling (MM) was used to prepare nanocrystalline 2024 Al alloy powders. By MM for 25h, nanocrystalline alloy powders with an average grain size of 25nm and a supersaturatured solid solution microstructure were obtained[4]. After consolidation at 450℃, the alloy was characterized by a ultrafine grained structure, and its yield strength, ultimate tensile strength, and elongation achieving 510MPa, 550MPa, and 12% respectively[5]. When an in-situ quenching and aging treatment was introduced, its yield strength could be enhanced to 580MPa, while the elongation retained unchanged[6].

Al-Fe-Ni and Al-Ti alloys are strong candidates to replace conventional Ti alloys. Using elemental powders as starting materials, nanocrystalline Al-4.9Fe-4.9Ni alloy powders were prepared by MA[7]. After consolidation, the alloy presented very high mechanical strength, with its room-temperature (RT) ultimate tensile strength achieving 650MPa. Even at 300℃, the yield strength remained to be above 280MPa[8]. For the Al-Ti alloy system, as much as 8.2wt.% Ti could be solutionized by MA to form a nanocrystalline supersaturated solid solution[9]. As an example, the grain size of an Al-10wt.%Ti alloy by MA remained below 100nm after consolidation, and its RT ultimate tensile strength was as high as 700MPa[10].

3. Copper Alloy

Copper alloys with high strength and high electric conductivity are gaining increasing interest due to their wide applications as various electrode materials[11]. Morris et al [12] reported a nanocrystalline Cu-7wt.% Nb alloy with grain size of 88nm and Nb-precipitates of 5.7nm in size by MA. The yield and ultimate tensile strength of this alloy achieved 1250MPa and 1280MPa respectively. But the electric conductivity was not reported. In our studies [13, 14], a bulk ultrafine grained Cu-5wt.%Cr alloy with Cr-precipitates of about 10nm in size was prepared by MA and hot extrusion at 600-800℃. The grain size of the Cu matrix was 100-120nm. This alloy presented both high mechanical strength and good electrical conductivity, with its RT ultimate tensile strength and conductivity in the range of 800-1000MPa and 53-70% IACS respectively.

4. Mg-based Hydrogen Storage Materials

Mg-based hydrogen storage materials have attracted considerable interest because of their high hydrogen storage capacity. However, the high temperature and slow kinetics of H-absorption/desorption make them still far from practical applications. Nanocrystallization and introduction of catalytic additives are effective approaches to enhance hydriding/dehydriding kinetics. Therefore, nanocrystalline Mg-35wt.%$FeTi_{1.2}$ composite powders were synthesized by MA [15]. This material showed very fast hydrogen absorption/desorption kinetics. For example, at 3.0MPa and 673K, it only took 10 min to finish absorption. The only disadvantage was that the saturated hydrogen storage capacity was much lower compared with pure Mg. To obtain a high hydrogen storage capacity, Mg-based nanocomposites with a small amount of such additives as transition metal and transition metal oxides or chlorides were prepared by MA. The investigated materials included Mg-Ni-$CrCl_3$[16], Mg-Ni-Cu-$CrCl_3$[17], Mg-Ni-MnO_2[18], and Mg-Ni-V_2O_5[19]. These Mg-based nanocomposites showed both high hydrogen storage capacity and very fast absorption/desorption kinetics.

5. $Nd_2Fe_{14}B$/α-Fe Nanocomposites

$Nd_2Fe_{14}B$/α-Fe nanocomposites with exchange coupling are attractive as permanent magnets[20]. Such magnets are usually prepared by melt spinning followed by an annealing treatment[21, 22]. Unfortunately, the reported properties are much lower than expected, due possibly to abnormal coarse α-Fe grains developed during annealing treatment[23, 24].

To develop alternative methods of producing $Nd_2Fe_{14}B$/ α-Fe nanocomposites, we have proposed a new process which combines HDDR, a well-established process of producing Nd-Fe-B alloy powders with submicron $Nd_2Fe_{14}B$ grains[25, 26], and mechanical milling. By MM in hydrogen, the $Nd_2Fe_{14}B$ phase was disproportionated into nano-structured Nd_2H_5, Fe_2B, and α-Fe[27, 28]. By subsequent desorption-recombination at 700-760℃, $Nd_2Fe_{14}B$/α-Fe nanocomposite powders with crystallite size of about 30nm were obtained[29, 30]. The $Nd_2Fe_{14}B$/α-Fe nanocomposites prepared by this method presented good magnetic properties. For example, the remanence B_r , the coercivity H_c, and the maximum energy product $(BH)_{max}$ of the $Nd_{12}Fe_{82}B_6$ nanocomposite powders achieved 0.73 T, 610kA/m, and 110.8 kJ/m^3 respectively.

6. Summary Remarks

MA/MM is an effective processing technique for preparing various types of nanocrystalline alloy powders including those difficult to obtain by alternative routes. In general, the synthesized nanocrystalline alloy powders can be either consolidated into ultrafine grained bulk materials with unusual physical/mechanical properties or directly used in the form of powders for advanced applications. Due to its versatility in materials synthesis, simplicity in process establishment, and economy in practice, mechanical alloying appears to be of great potential for synthesis of nanocrystalline materials not only at laboratory level but also on industrial scale.

7. References

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