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Remarkable promotion of mechanical tensile strength of $Mg_{1\text{-}x}A_xB_2$ superconductor via additions of ultra-high - ductile AZ61-alloy

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ABSTRACT

Extruded Mg–(6%Al)–(1%Zn) ~ (AZ61) alloy powder was applied as softener matter and grains sizes promoter in narrow range to replace on magnesium sites of $Mg_{1\text{-}x}A_xB_2$ superconductor (where, $x = 0.0,0.025,0.050,0.075$ and 0.1 mol and A = AZ61) alloy) . Samples were synthesized via high temperature solid state reaction technique depending upon diffusion mechanism of Mg -vapor ions through added A-boron-matrix at 760 °C. Microstructural features and grains sizes averages were estimated and monitored by both of 3D-AFM and SE-microscopy. Mechanical tensile was recording promising results with maximum tensile value of 52.3 MPa is for sample with $x = 0.075$ mol which is better than pure MgB_2 (33.8 MPa.) by promotion ratio ~ 54.73%.

1. Introduction

Magnesium di-boride ~ is well known as 39 K unconventional superconductor [1,2],it introduces remarkable progress in the material synthesis and processing as well as in understanding of their physical properties [3–8] .Many of inorganic diborides crystallize in the same hexagonal-type of structure as MgB_2 these compounds have been already known and investigated before carefully. Promoting mechanical, microstructural and superconducting features of MgB_2 were performed via magnesium site substitutions [9–13]. Numerous numbers of scientists were investigated dopants such as Al, Mn, Os, Hf and Ir which were showing good substitutions to enter the structure unambiguously [14–17] although it was successfully only for a limited concentration range .For boron site substitutions a number of trials with different elements were made including, (C, Zn, Zr, Si and F),Carbon substitution was reported in several publications [5,6]. Cava et al. [19] have proposed the minimal criteria for judging a successful chemical doping/ or substitution in MgB_2 superconducting system .

It is well known that one of the most common disadvantages of nonconventional magnesium diboride superconductor is poor mechanical features so the major goal of the present article is to achieve remarkable increase on the mechanical tensile features of magnesium diboride without damaging its superconducting features by certain narrow range of additions from one of most common ductile alloy to promotes microstructure features and consequently its applications will be remarkably enhanced.

2. Expriments

2.1. Samples preparation

Superconducting samples were synthesized via high temperature solid state reaction technique depending upon diffusion mechanism of Mg -vapor ions through added A-boron-matrix at 700° Extruded Mg–6%Al–1%Zn (AZ61) alloy powder was applied as softener matter in narrow range to replace on magnesium sites of $Mg_{1\text{-}x}A_xB_2$ superconductor (where, $x = 0.0,0.025,0.050,0.075$ and 0.1 mol and A = AZ61) alloy). Alloy additives was added as powders with molar ratios of the nominal compositions of starting materials (Mg, alloy + B).The average particle size of boron and alloy additives powders used was ≤ 50 µm . All powders are with purity grade ≫ 99.9%., Powders were mixed, ground together and were placed into Ta-ampule under argon pressure, the Ta-tube carefully sealed in goodly way and forwarded to tubular quartz furnace at 1050 °C sintering temperature. The thermal cycle of preparation pure MgB_2 and alloy-added- MgB_2 included intermediate fixation step at 700 °C for 2 h and details of thermal cycle was described therein [12].

2.1.1. Sonication process for samples powders

The pure MgB_2 and alloy added samples were ground each individually and dispersed on 30 ml of acetone/tetra-hydro-furane (THF) mixed solvent by ratio 2:1 accompanied with intensive sonication for 4 hrs with two intervals stops of stirring was applied .Sonication of the dispersion process was performed via a (WiseClean WUC-DIOH 200 W,

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40 kHz,).The purpose of sonication is to split small aggregates and at the same time prevent aggregation and association of grains. Microwave assist was applied for ten minutes to dry and avoid presence of tracers from applied mixed solvent.

2.2. Structural measurements

The X-ray diffraction (XRD) measurements were carried out at room temperature on the ground samples using Cu-K_α radiation source and a computerized Shimadzu (Japan) diffractometer with two theta scan technique. High-resolution Atomic Force microscopy (AFM) is used for testing morphological features and topological map (Veeco-di Innova Model-2009-AFM-USA).Scanning Electron Microscopy: the morphological features and bulk grain size calculations were carried out by using high resolution SEM (Philips-USA).

2.3. Electrical measurements

2.3.1. The DC-electrical resistivity measurements

DC-electrical resistivity of the synthesized materials were measured as a function of temperature using the modified four-probe technique and the temperature was recorded in the cryogenic temperature zone down to 30 K using liquid helium refrigerator .

2.4. Mechanical measurements

Samples were cut from the bulk by certain dimensions $6 \times 6 \times 6$ mm^3,to make as possible the longitudinal loading direction of the specimens parallel to *a*- or *b*-direction and perpendicular to the *c*-direction of the bulk. Tensile tests were carried out at room temperature 295 K and details of loading was described by Tomita and Murakami [20],the displacement speed of the actuator of testing machine was in between 0.1 to 0.2 mm/min. and observation of fracture morphology of the samples was carried out using digital camera.

3. Results and discussion

3.1. Structural measurements

Fig. 1(a–e) displays XRD diffraction patterns for investigated samples with general formula $Mg_{1-x}A_xB_2$ (where, $x = 0.0$, 0.025, 0.050, 0.075 and 0.1 mol and A = AZ61 alloy).

The analyses of XRD patterns indicated that all samples are mainly belong to hexagonal phase with P6/mmm space group confirming that all samples within investigated narrow range of additions still keeping their original superconducting hexagonal crystal form of $Mg_{1-x}A_xB_2$ [5–8]. It is known that, MgB_2 has AB_2 structure type which is commonly found for many metals diborides .This structure, consisting of interleaved graphite-like layers of boron and triangular layers of metal atoms. This kind of graphite-like layers structure allows for alloy additives in narrow range as in present investigations to insert successfully without problems in between layers [5–7].

3.2. Nano-and micro-structural features

Fig. 2(a–e) explains 3D-AFM images and SEM-micrographs captured for pure and different alloy-added samples. From the analyses of These-images and EDX elemental analysis for many spots on each sample we deduced the following facts;

1st (MgO/or Zn/Al phases) does not noticeable at the inter-grain-layers specially in sample with lower $x = 0.025$ mol meanwhile sample (e) with maximum additions ratio ($x = 0.1$ mol) it begins to appear in

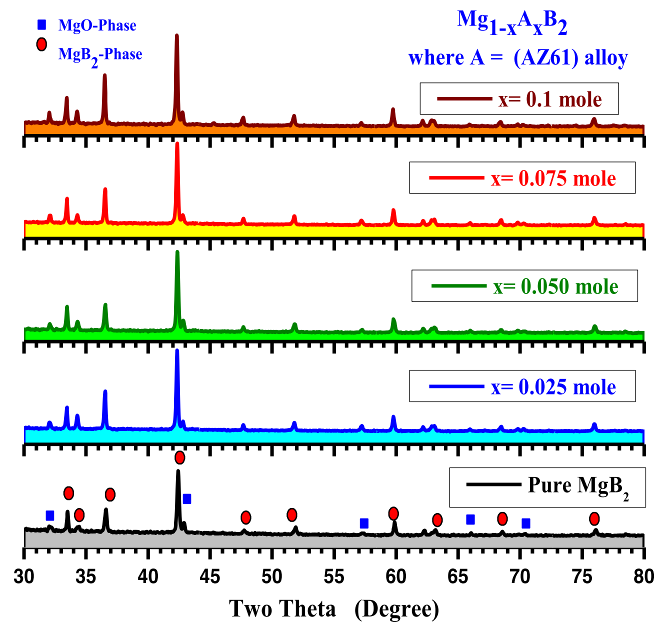

Fig. 1. X-ray diffraction patterns recorded for pure and alloy-added-MgB_2 superconductor; (a): $x = 0.00$ mol, (b): $x = 0.025$ mol, (c): $x = 0.050$ mol, (d): $x = 0.075$ mol and (e): $x = 0.100$ mol.

between layers in very small segregations, 2nd -the average estimated grain size is in between 0.28 and 1.49 µm and 3rd 3D-AFM-tapping noncontact mode images confirmed that the surface topology of all samples are regular arrays shapes, unified in heights gradient with heights average of 1.6 µm except sample (e) with maximum addition ration has irregular heights average with random arrays due to impurity phases and appearance of added alloy segregations in random distribution zones.

3.3. Superconducting measurements

Fig. 3(a–e) shows the DC-electrical resistivity measured as a function of absolute temperature for pure MgB_2 and different added samples with general formula $Mg_{1-x}A_xB_2$ (where $x = 0.025$, 0.05, 0.075 and 0.1 mol). It is clear that,the Tcs-offsets decrease regularly (38.2,38, 36.4,36.1 and 35.5 K) as concentration x increases from $x = 0$ to 0.1 mol respectively as clear in Fig. 3(a–e). From these results, the depression of Tcs-offsets is mainly due to two factors 1st is the hole band filling caused by alloy components(Aluminum Tri-valence /Zinc) [11,12] and the 2nd factor is increasing the impurity phases make as random pinning centers can scattered and restrict super-current flow inside the bulk of the sample decreasing superconducting fraction ratios [13,14,18,19].

3.4. Mechanical properties

The mechanical tensile strengths were measured as a function of displacement of the actuator (stroke mm) at the fracture at 298 K. As it clear in Fig. 4 the maximum averages of tensile strength increase as AZ61-alloy additions increases within the range of $0 \geq x \leq 0.075$ mol recording maximum tensile average 53.2 *M*Pa with stroke ~0.3 mm is for sample with addition $x = 0.075$ mol respectively, meanwhile the mechanical tensile strength decrease again with addition $x = 0.1$ mol. These results confirmed that additions x with 0.075 mol is the optimum additions ratio from AZ61-alloy.