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High-entropy alloy particle reinforced Al-based amorphous alloy composite with ultrahigh strength prepared by spark plasma sintering

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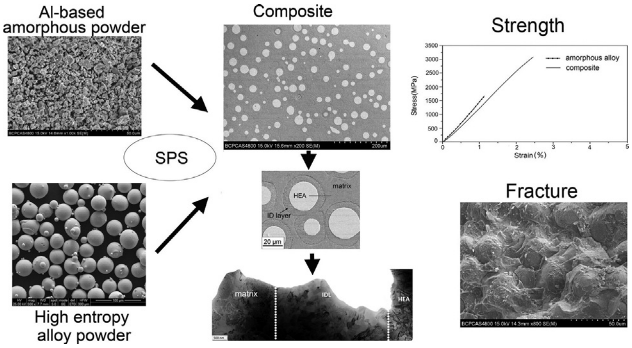
HIGHLIGHTS

- The high-entropy alloy particles reinforced amorphous alloy composite was prepared.
- The composite exhibits outstanding yield strength3120 ± 80 MPa.
- There is an interdiffusion layer between the HEA particle and the matrix.
- The propagation of microcracks could keep stable within the interdiffusion layer.

GRAPHICAL ABSTRACT



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ABSTRACT

An $Al_{0.6}CoCrFeNi$ high-entropy alloy (HEA) particle reinforced $Al_{65}Cu_{16.5}Ti_{18.5}$ amorphous alloy composite was prepared by spark plasma sintering (SPS). There is an interdiffusion (ID) layer between the HEA particle and the matrix. The yield strength of the composite is as high as 3120 ± 80 MPa, which was attributed to the combined action of the stable propagation of cracks, the significant increase of fracture surface energy, and the relative low content of sintering defects in the matrix.

1. Introduction

Al-based amorphous alloys have attracted much attention in the last two decades due to their extremely high specific strength. However, only thin Al-based amorphous alloy could be prepared due to the low glass-forming ability (GFA). Thus, powder metallurgy such as spark plasma sintering (SPS) was employed to prepare bulk Al-based amorphous alloy [1–3].

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The strength of the sintered Al-based amorphous alloy or amorphous/crystalline alloy could be as high as 1000 MPa [4–6]. However, most of these alloys fail by brittle fracture, which might stem from the inherent brittleness of the amorphous phase and/or the precipitated intermetallic compounds. Once the cracks formed, those cracks would propagate fast without barriers, leading to a brittle fracture.

Particle-reinforced composites (PRCs) have been developed in the last decades due to higher elastic modulus, increased strength/hardness, improved ductility/toughness, higher resistance to crack propagation, etc. [7,8]. Thus, adding the second phase particles into the Al-based amorphous alloy may inhibit the unstable propagation of cracks and increase the fracture resistance of the alloys.

In general, the metal particles with good ductility (such as copper and aluminum particles) generally have low strength by comparison with the Al-based amorphous alloy, thus these metal particles may deteriorate the strength of the composites [9]. Some other particles such as W, although exhibiting high strength, the density is so high that may deteriorate the advantage of low density of Al-based amorphous alloy. High entropy alloys (HEAs), a new type of advanced metal materials, are composed of five or more principal elements with concentrations ranging from 5 to 35 at.% [10–12]. HEAs mainly consist of simple solid solutions or a mixed structure of solid solutions and intermetallics [13–16]. HEAs with a single FCC structure are known to possess good plasticity but low strength, whereas those with single BCC and its derivative structures (intermetallics) tend to exhibit high strength but poor ductility. Accordingly, dual-phase HEAs may have the potential to exhibit high strength and good plasticity, and a mixture of FCC and BCC structures tends to form in $Al_{0.6}$NiFeCrCo HEA [17–22]. Thus, the $Al_{0.6}$NiFeCrCo HEA particle was selected as the second reinforced phase.

As a consequence, the present research attempted to prepare $Al_{0.6}$CoCrFeNi HEA particle reinforced $Al_{65}Cu_{16.5}Ti_{18.5}$ amorphous alloy composite by SPS. The microstructure and mechanical properties of the composite were investigated.

2. Material and methods

The elemental powders of Al, Cu, and Ti (purity >99.9 wt.% and 50 μm in average particle size) were mixed in the desired nominal compositions (at.%) of $Al_{65}Cu_{16.5}Ti_{18.5}$ followed by ball milling. The milling experiments were performed on a high-energy vibrating ball mill (SPEX 8000D) using hard alloy vials and balls with diameter of 10 mm and 5 mm, the weight ratio of the ball to the powder is 10:1. To avoid oxidation, all of the powders were handled in a glove box under argon atmosphere. To prevent the strong agglomeration of powder, ball

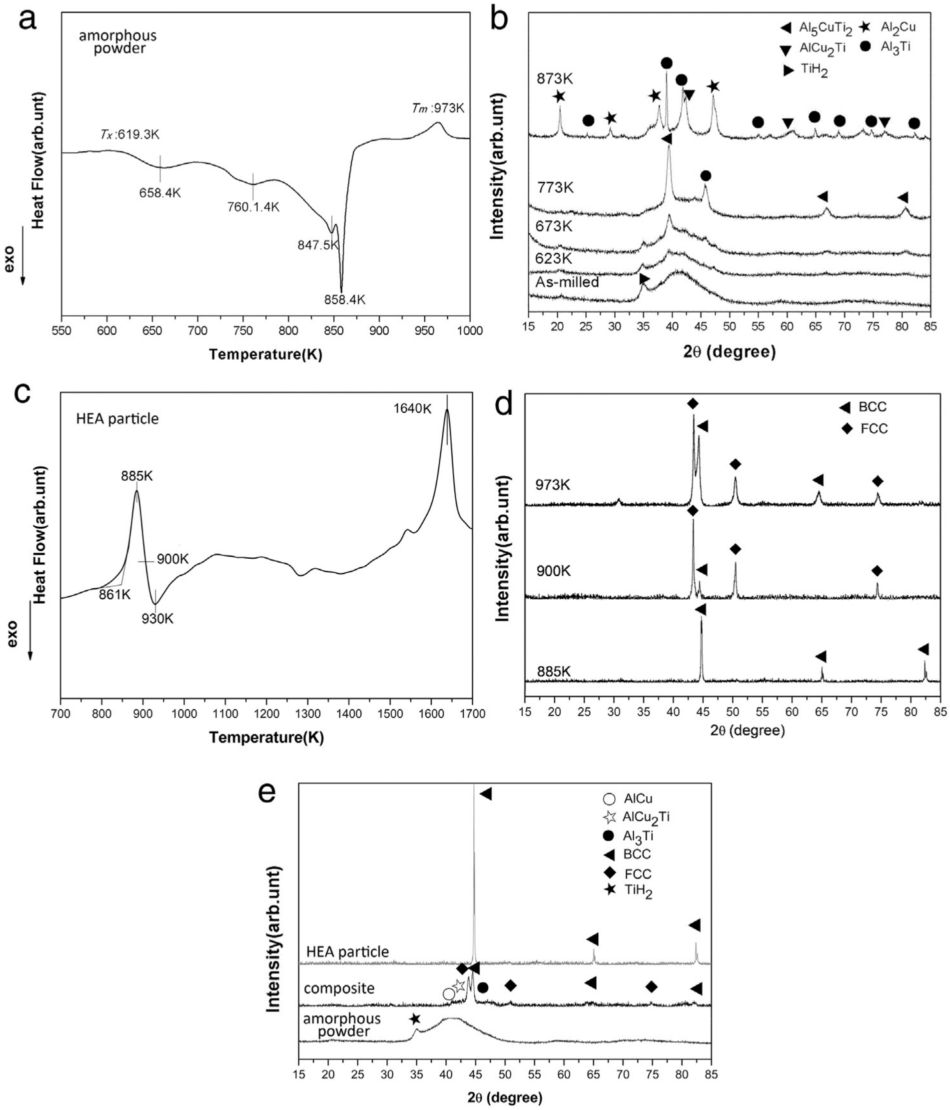

Fig. 1. DSC plots of the as-milled amorphous powder (a) and the HEA particle (c); XRD patterns of the amorphous powder (b) and the HEA particle (d) after heating at different temperatures; (e) XRD patterns of the composite along with the as-milled amorphous powder and the HEA particles.