Cu-Hf-Al amorphous/nanocrystalline composite particles produced by milling

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Abstract
Cu_{95}Hf_{5}Al_{10} amorphous/nanocrystalline composite particles were prepared by ball-milling. Crystalline master alloys were prepared by induction melting under purified argon atmosphere. During the mechanical amorphization the ground ingots were milled for different durations of time and with several interruptions in order to analyze the structure of the powders. The mechanical milling was performed in a Pulverisette 5 high energy planetary ball-mill under argon atmosphere using stainless vial and balls with diameters of about 3 mm, 5 mm and 10 mm. The ball-to-powder ratio was 20:1. The milled powders were analyzed by XRD to determine the amorphous fraction, by SEM to characterize the microstructure and by DSC to observe processes in the powders during heating. After milling for 20 h, an amorphous structure appeared and the amorphous fraction was 95%.

Keywords: amorphisation, milling, planetary ball-mill

1. Introduction
The materials of bulk metallic glasses (BMG) attract tremendous attention because they offer unique mechanical properties such as ultrahigh strength or high hardness [1-5]. Copper-based amorphous alloys are particularly interesting for practical applications as new structural materials due to their significant advantages, including their low cost, high fracture strength of around 2 GPa, often coexisting with visible ductility, and feasibility for the formation of BMG based composites [5-10].

The new types of Cu-Hf-Al alloys are suitable structural materials in engineering and motorcar industry owing to their excellent mechanical properties such as strength as well as corrosion and wear resistance. The Cu_{95}Hf_{5}Al_{10} alloy was developed by Jia et al. [6] and shows a critical diameter value higher than the values obtained earlier, that is, it can be cast in a bulk amorphous form with a diameter of 10 mm. Ball-milling (BM) is a well-known process producing a wide range of materials with unique properties [12].

The present work reports about Cu_{95}Hf_{5}Al_{10} amorphous/nanocrystalline composite particles prepared by ball-milling.

2. Experimental
The crystalline master alloys were prepared by induction melting under purified argon atmosphere. The master alloy ingots were ground to particles with size below 320 μm before the mechanical milling. The particles were milled for different periods of time during the mechanical amorphization.

The procedure was interrupted after arbitrarily selected milling times in order to analyze the structure of the powders. The mechanical milling was performed in a Pulverisette 5 high-energy planetary ball-mill under argon atmosphere using stainless steel vial and balls with diameters of 3 mm, 5 mm and 10 mm. The ball-to-powder ratio was 20:1. The optimal parameters of the milling were determined in a previewed work of the Materials Science Research Group [1-2].

The microstructure of the powders was characterized using a 1830 I Amray Scanning Electron Microscope equipped with an EDX DX4 and a Zeiss EVO MA Scanning Electron Microscope. The ball-milled powders were analyzed by X-ray diffraction (XRD) using a Philips PW 1830 diffractometer with Cu Kα radiation (λ = 0.1542 nm). The glass transition and crystallization temperatures of the amorphous phase were measured with a Netzsch 204 DSC with alumina container. The particle size was measured by a Quantimet Image Analyzer using Leica Software.

![Fig. 1. Backscattered SEM image of the Cu_{95}Hf_{5}Al_{10} master alloy with the XRD diffractogram](image-url)
3. Results and discussion

Figure 1 shows the Cu$_{54}$Hf$_{36}$Al$_{10}$ crystalline master alloy with three identified intermetallic compounds: Cu$_8$Hf$_7$ (orthorhombic, $a = 1.2587$ nm, $b = 0.9238$ nm, $c = 0.9265$ nm [13]), CuHf$_2$ (tetragonal, $a = 0.3170$ nm, $c = 1.1133$ nm [14]) and the ternary compound CuHfAl (hexagonal, MgZn$_2$-type Laves-phase, $a = 0.5155$ nm, $c = 0.8381$ nm [15]). Confirmed by element analysis using EDX, the needle shape crystalline phases (lighter) were identified as CuHf$_2$, the dendrites (dark gray) as CuHfAl and the matrix Cu$_{10}$Hf$_7$ intermetallic compounds, respectively.

Figure 2 shows the XRD patterns of Cu$_{54}$Hf$_{36}$Al$_{10}$ powders after different milling times. 10 h milling resulted in broadening the crystalline diffraction peaks and reduction of their intensity; however, there was no significant change in the position of diffraction peaks. Increasing the milling time beyond 10 hours led to the appearance of a broad diffuse diffraction maximum between $2\theta = 32^\circ$ and $46^\circ$, which implies the formation of an amorphous phase. After milling for 20 h, an amorphous structure appeared and the amorphous fraction was 95%.

The scanning electron images show the structure of the Cu$_{54}$Hf$_{36}$Al$_{10}$ powders as a function of milling time (Figure 3). After 10 hours milling CuHf$_2$ phase remains in the powder, as seen in Figure 3 (a). Figure 3 (b) shows 15 hours milled powder. The needle shape crystalline phases (lighter) were identified as CuHf$_2$. The particles are coalescent with gaps encompassed between them. Figure 3 (c) shows 20 h milled powder in lower magnification, while Figure 3 (d) – in higher magnification. The structure of the particles can not be observed, an amorphous structure appears and the amorphous fraction is 95% During the high-energy milling the particles were repeatedly attended, cold welded, fractured and rewelded. Figure 4 shows the Cu$_{54}$Hf$_{36}$Al$_{10}$ particle size distribution as a function of milling time measured by Quantimet Image Analyzer. The average size of the particles decreases with increasing milling time. The majority of the particles in the starting powder were 200 μm in size. As the milling time increases, the range of particles size distribution narrows. While the average particle size in the starting powder was 200 μm, after 20 hours of milling it was only $\sim 10$ μm.

Thermal data of the Cu$_{54}$Hf$_{36}$Al$_{10}$ alloy were obtained by DSC measurements with the first crystallization temperature at $T_x = 572$ °C and the crystallization peak temperature being at $T_p = 618$ °C.

4. Conclusions

Within the frames of this work Cu$_{54}$Hf$_{36}$Al$_{10}$ powders were produced by ball-milling with the milling time varying between 5 and 20 h.

The results can be summarized as follows: increasing the milling time resulted in an increase of the amorphous fraction. After milling for 20 h, an amorphous structure appeared and the amorphous fraction was 95%. Thermal data of the Cu$_{54}$Hf$_{36}$Al$_{10}$ alloy were obtained by DSC measurements with the first crystallization temperature at $T_x = 572$ °C and the crystallization peak temperature being at $T_p = 618$ °C.
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References


Cu-Hf-Al amorf/nanokristályos szerkezetű por előállítása örökessel

Cu_{Hf_{1-x}}Al_{x} amorf/nanokristályos szerkezetű port állító- tunk elő gőzös malamolból. Kristályos mesterötvözet készíttetünk indukciós elviszást alatt argon atmoszférában. Az öröléshez Fritsch által gyártott Pulverisette 5 golyós malommal dolgoztunk. Az amorf térfogathányad 95%-os volt. Az általunk előállított kiváló minőségű az acél tégelyében és acélból készített 20:1 gőzfűrészanyaganyagot dolgoztunk.

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