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FABRICATION AND PROPERTIES OF FeCrC REINFORCED COPPER ALLOYS BY MECHANICAL ALLOYING

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ABSTRACT
In this study, properties and fabrication of FeCrC reinforced copper alloys by mechanical alloying were examined using mechanical grinding, optical microscopy, energy dispersive spectroscope, X-ray diffraction, and hardness testing. Mechanical alloying (MA) was the technique available to mix Cu-FeCrC particles. High FeCrC provided more cold work during milling. Thus, smaller crystallite size and greater internal stress occurred in Cu alloys. High performance Cu was further strengthened by a combination of fine grain and alloying. $C_{23}C_6$, Cr_7C_3, and α–Cu were detected in the structure. The hardness of Cu increased significantly after grinding with FeCrC.

Keywords: *Mechanical alloying, Cu matrix alloy, morphology, hardness*

1. Introduction

Metal matrix composites (MMCs) are preferred in industrial areas where abrasion resistance and plastic forming are required due to their high mechanical properties and ductility [1–2]. Pure copper has ductility, electrical and thermal conductivity properties. It is used in electricity, electronics and plastic sector. Cu alloys are produced to increase the mechanical performance of Cu. Cu-Cr materials are highly used in automobiles, catalysts, electrodes and electronic industries due to their high electrical-thermal conductivity, mechanical and corrosion performance [3–6]. Cu-Cr alloying is difficult with the traditional technique as there is no total solubility between Cu and Cr under equilibrium conditions [7,8]. Due to solid solution occur and higher precipitation of Cr in Cu matrix, it has increased the preference rate to produce copper matrix composite. Melting and casting processes, powder metallurgy, sol-gel, and high-energy ball grinding methods are used to produce copper composites [9].

Mechanical alloying (MA) is a process of cold welding, fragmentation and re-welding for the internal diffusion of elements. MA is a special form of production in the manufacture of copper composites due to the environmentally friendly process and homogeneous distribution of the phases. In mechanical alloying, the intense deformation created in the particles forms crystal faults such as dislocation, voids, and grain boundaries. Also, mechanical alloying produces nano-crystalline materials, structure differences, phase transformations [10,11]. She et al. manufactured Cu-Cr alloys by reducing the reaction of Cr_2O_3 with Cu-Mg melt. A good combination of 171HV microhardness and 475 MPa tensile strength resulted [12]. Sauvage et al. investigated the effect of interphase boundaries on grain size reduction mechanisms by subjecting the Cu-Cr composite to severe plastic deformation. Interphase boundaries played a notable role in the grain size reduction mechanism [13].

In this study, the effect of FeCrC on the properties and fabrication of Cu-based FeCrC reinforced composites fabricated by MA were investigated.

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2. Experimental Procedure

FeCrC (65%Cr-25%Fe-6%C-2%Si, size 45 μm) and Cu (99.9%, 45 μm) powders were used as test powders. Production conditions of test samples are presented in Table 1. Stainless steel balls of 10 mm were used as grinder. The ball/powder ratio of elemental powders was chosen as 10/1. Powders in distinctive percentages were blended and ground using a high energy grinding equipment in a stainless steel crucible under argon shielding (99.9%) at room temperature for 4 h. Ar was at a flow rate of 0.6 l/min. The ground powders were cold pressed using a press at a stress of 200 MPa. Sintering was done at 1000 °C. The surfaces of the samples were polished with 1 μm diamond paste after sanding with 180-1200 mesh abrasives.

The samples were etched with 95% $FeCl_3$ and 5% HCl solution. Surface microstructure features of the samples and main element distributions were analyzed using an optical microscope (OM: LEICA DM750) and an energy dispersive spectroscope (EDX). Hardness rates were determined on a QNESS Q10M microhardness machine using a 50 g load at 1 mm interspaces on the Vickers scale. The resulting phases in the samples were detected on a Rigaku X-ray diffraction (XRD) apparatus with Cu Kα radiation, λ= 0.15416 nm at 40 kV and 40 mA.

Table 1. Process conditions of samples.

Sample no	**S1**	**S2**	**S3**
Cu (wt.%)	Bal	Bal.	Bal.
FeCrC (wt.%)	3	6	9
Sintering (ºC)	1000	1000	1000

3. Experimental Results

3.1. Mechanical alloying of samples

In the MA process, hard FeCrC was severely deformed, broken. FeCrC was dispersed among the Cu powders and inserted in the Cu powders. Due to close contact, an alloy formed between them. The higher alloying ratio increased the lattice defects that lead to work hardening. Undissolved brittle particles were evenly separated in the ductile matrix. Welding is assumed to occur only in the zone of close metal-to-metal contact. Crystallite sizes were associated with dislocation formations produced by plastic distortion. Excessive plastic distortions enhanced the dislocation intensities that would create the cell wall and structure [14]. The increment of dislocations can cause an increase in the stress field and lattice strain. Fine and hard particles prevented plastic deformation and diffusion during pressing. Therefore, the particle-reinforced metal matrix composite could not be fully densified by sintering.

3.2. Morphology of samples

Fig. 1 shows the morphological changes of samples. The hardness of metals significantly affected morphological changes. Cr less than 9% in the Cu-FeCrC alloy formed intense dislocation, providing intense work hardening. Thus, the crystallite dimension of the ground powders is reduced. Increasing FeCrC percentage made the effects of cold forming more pronounced and crystallite sizes became smaller. In grinding, the intense strikes of the steel balls on the Cu-FeCrC powders advanced the mechanical touch between the powders. The heat of the powder surfaces can improve due to energy transmission. A sharp temperature rise reduces crystal dislocation density and recrystallization [15]. The capillary stress created by the fine crystals that appeared in the crushed powders provided the diffusion of solute atoms and solid phase solubility. The ultra-temperature of cold working can relax the dissolution of Cr in Cu crystals [16]. The high FeCrC ratio increased to the concentration rate of Cr in the Cu structure. The reduction in crystallite dimension incremented the grain boundary field, which procured more spread pathways for Cr to diffuse into the Cu lattice. The rise in internal energy caused by multiple defects declined the activation energy needed for Cr spread. Fe and Cr could not concentrate side by side. Fe and Cr have high chemical proximity. They are completely soluble in each other at high temperature. But they could not react to form intermetallic compounds [17]. 9wt.% FeCrC provided more cold work during milling. It promoted the breakage of powder particles, and the crystallite size was reduced. As the Cr content decreases, the temperature difference between liquefaction and solidification decreases. Most Cr atoms can be dissolved in solid solutions rich in Cu. As Cr increases, a larger duplex region is passed through before solidification. More chromium phases occur before the formation of copper-rich supersaturated solids. With the increase of Cr, the chromium-rich particles become coarser, their size and density increase.

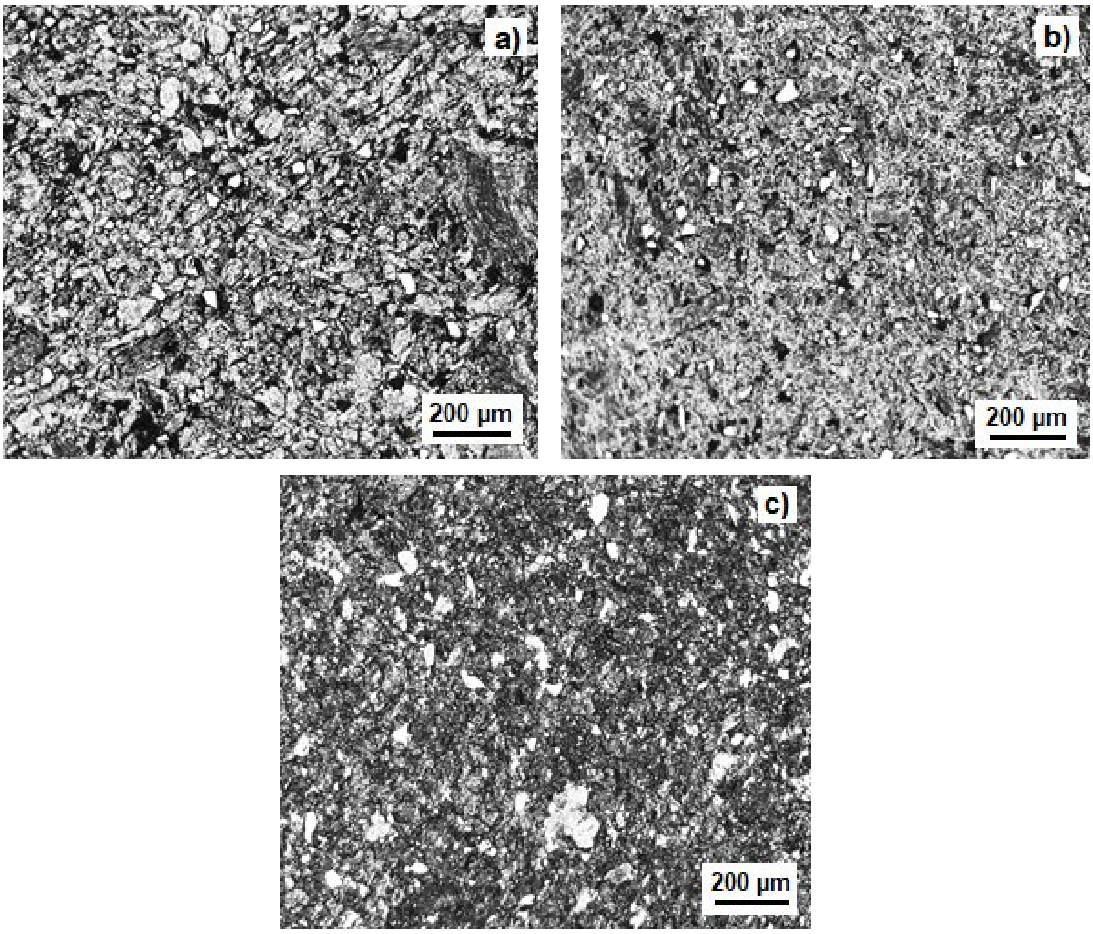

Figure 1. Optic micrographs view a) S1, b) S2, c) S3 samples.

Cr was more reactive than Cu. Therefore, when the powder is sintered, excess Cr is combined with the oxides on the surface. The subsequent loss of the oxide layer releases more active Cu atoms. It reduces the activation energy of diffusion [18]. It speeds up the bonding between Cu powders. Some liquid phase was seen in the samples sintered at 1000 °C. The pores and voids in the alloy were filled. High sintering temperature is more suitable for diffusion and mass transfer process through various ways such as lattice, grain boundary and defect/dislocation. High temperatures provide excessive energy for atoms to join and facilitate the separation of gases from the alloy. The ratio of Fe and Cr in the alloy determined the compactness of the sintered alloys. X-ray diffractions of the S3 sample are given in Fig. 2. $Cr_{23}C_6$, Cr_7C_3, and α–Cu were detected in the structure.

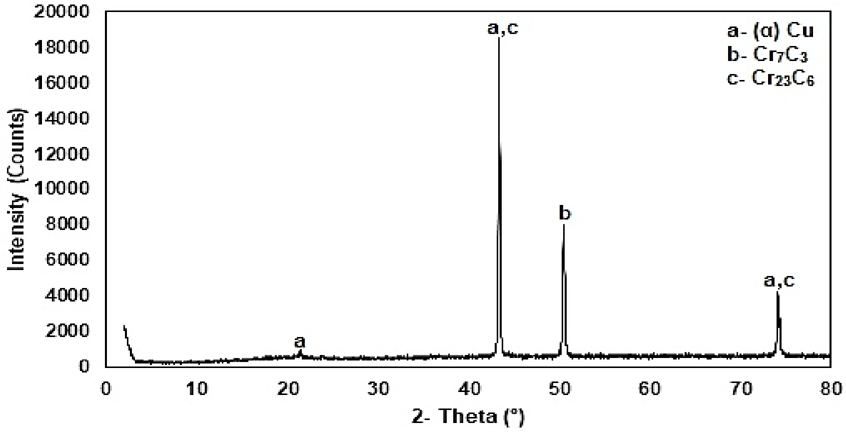

Figure 2. XRD diffractions of S3 sample.

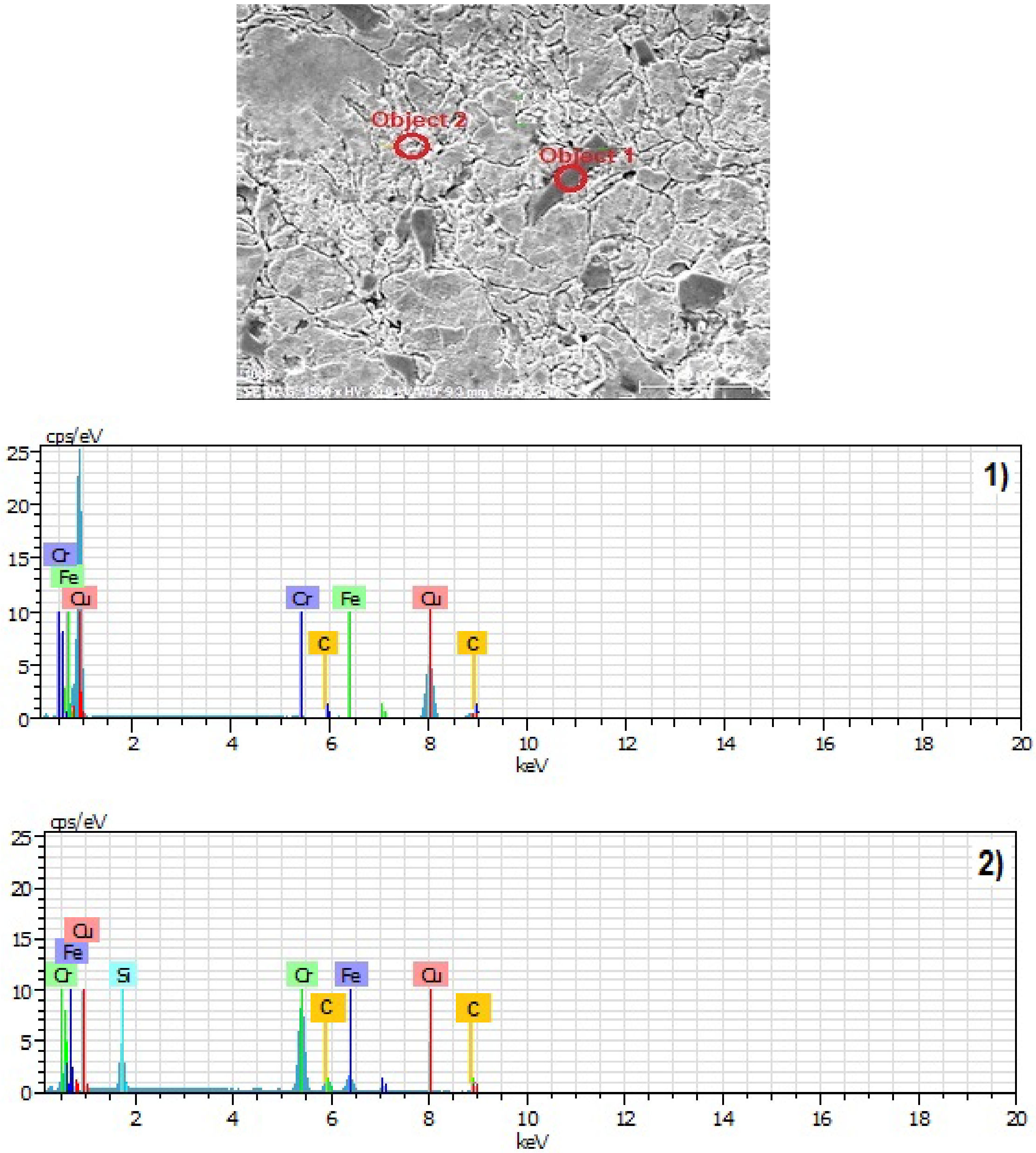

Figure 3. EDS analysis of S3 sample.

EDS analysis of the S3 sample are given in Fig. 3. At high temperature, Fe atoms diffused into the Cu matrix. Due to the atomic radius of Fe and Cu, iron dissolved in the Cu matrix. The addition of sufficient FeCrC prevented the addition of more Fe to the alloy matrix. The fractured fine FeCrC were dispersed in Cu matrix and promoted the break of Cu powders. The finer powders created a larger surface for the large number of Fe to spread into the copper. The high FeCrC ratio affected the grinding process. At the high FeCrC ratio, the powders became flaky and largely.

3.3. Hardness

The microhardness of the samples is given in Fig. 4. MA was a very good technique for mixing Cu-FeCr. It increased the hardness of materials. The average hardness of CuFeCrC alloys is 68 HV. 9 wt.% FeCrC increased the hardness from 50 HV to 78 HV. FeCrC and work hardening increased the hardness of Cu. Cu was very ductile and broken faster than FeCrC. Hard FeCrC was an effective reinforcing alloy for Cu-based composites. The hardness of Cu increased significantly after grinding with FeCrC. Smaller grain sizes and greater defect density resulted in higher hardness [19].

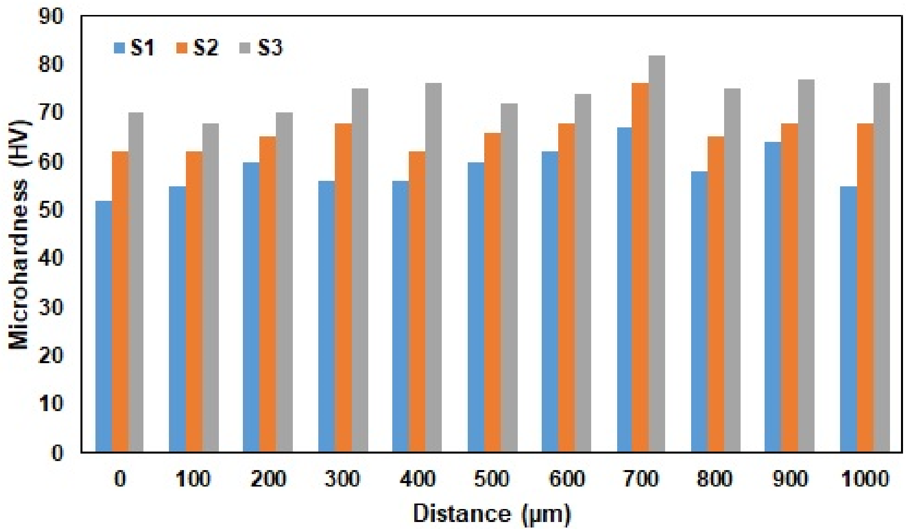

Figure 4. Microhardness variation of samples.

4. Conclusion

The effects of FeCrC on properties of Cu-based FeCrC reinforced alloys fabricated by MA were studied. The results obtained are as follows. MA was the technique available to mix Cu-FeCrC.
The crystallites of FeCrC were refined more efficiently due to the ductility of Cu. 9wt.% FeCrC provided more cold work during milling. It promoted the breakage of powder particles, and the crystallite size was reduced. The collision between powders and balls became weaker as the FeCrC ratio increased. Hard FeCrC was a powerful reinforcing alloy for Cu. MA created a major impact in rising the hardness. The increased amount of reinforcement rate increased the hardness.

Disclosure statement

No potential conflict of interest was reported by the authors.

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