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Formation Study of Aluminum and Copper Nanocomposites

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Abstract

Solid solutions of Al-Cu were prepared via ball milling for about 30 h. The solid solubility level increased with the initial solute content in the mixture. By heating up to 423ºC, the nanocrystalline supersaturated solid solution Cu (Al) alloy decomposed to nanophase composite of Al and Cu. Then nanocomposite was investigated by X-ray diffraction technique and DTA. XRD pattern showed that the grain size of Al and Cu phases increases after heating but remained grain size is in range the nanometer.

Keywords: *Mechanical alloying, Nanocomposites, Copper, Aluminum, Heat treatment*

1. Introduction

Mechanical alloying process has become a widely used technique to form powder materials and to synthesize a large range of non-equilibrium phases, from amorphous materials to nano-crystalline phases, and extended solid solutions [1-3]. Solid solubility extensions have been achieved in many alloy systems by non-equilibrium processing methods such as RSP and vapor deposition. Similarly, mechanically alloyed powders also exhibit extension of equilibrium solid solubility limits. In addition to synthesizing stable (equilibrium) solid solutions, it has also been possible to synthesize metastable (non-equilibrium) supersaturated solid solutions by mechanical alloying starting from blended elemental powders in several binary and higher order systems [3-6]. The amorphization is observed in alloy systems whose heat of mixing is negative and is interpreted as the metastable melting from the mixture of elemental powders which are energetically in a higher state. However, metastable or non-equilibrium crystalline phase formation has been examined well in the alloy systems whose heat of mixing is positive [7-13]. As clearly demonstrated by Klassen and coworkers, [14] low temperature milling results in the stabilization of the solid solution, whereas elevated temperature milling results in the coexistence of two terminal solid solutions. This temperature effect is best explained by considering such alloys during milling as driven systems, where thermal diffusion tends to promote phase separation because of the positive heat of mixing, this dynamic competes with an atomic mixing forced by the sustained plastic deformation of material [15-18]. Nanocomposites are of great interest due to their novel structures, properties, and applications compared to their equilibrium counterparts. In the present study, the formation of aluminum and copper nanocomposites in Al-Cu system via mechanical alloying process was investigated.

2. Experimental procedure

Cu (MERCK Art No.102703) and Al (ALDRICH Art No.32707-7) powders were used as starting materials. The powder mixture of Cu-20at% Al and Cu-3.64at%Al and hardened steel milling balls were placed in stainless steel vials hermetically sealed and were milled in a planetary ball mill. The weight ratio of the powders to the balls (BPR) was kept 1:15 for all experiments. Handling of powders and the milling were performed under protection of a pure argon gas atmosphere. The vials were rotated at 300 rpm. Differential thermal analysis (DTA) measurements were made to determine decomposition temperature at a rate of 10 K/min. The mechanically alloyed powders were heated at 423ºC for 1 hour under pure argon gas and were characterized by X-ray diffraction using CuKα radiation. AverAle grain sizes of Cu and Al phases were estimated by the peak broadening of the X-ray diffraction patterns by using the Wiliamson Hall method [17].

3. Result and discussion

Increasing the milling time of pure aluminuim and copper powders breaded the X-ray diffraction peaks and reducing

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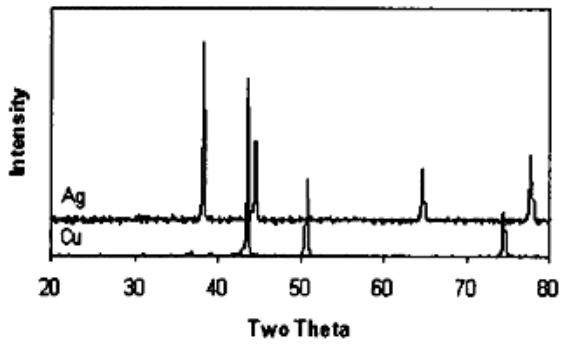
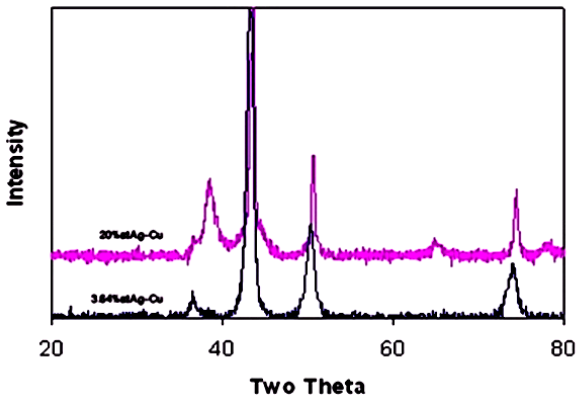
the intensity of certain peak such as (111). However, the peak positions of aluminuim and copper hardly changed with milling time. The usual decrease of the intensity of diffraction peaks and their broadening consequent to the formation of nanometer-sized coherent diffraction domains and the accumulation of lattice defects were initially observed. Local mutual dissolution processes formed a new face-centered cubic (fcc) phase with its (111) peak positioned between the (111) reflections of Al and Cu, as shown in Fig.1. A shift in the diffraction peaks of Cu towards lower angles was the result of an increase in lattice constant, by the dissolution of Cu into Al the owing to smaller atomic radius of Cu compared to Al are (0.128) nm and (0.144) nm. In contrast, the diffraction peaks of Al shifted toward upper angles, indicating a decrease of lattice constant due to dissolving of Cu into Al, as shown in Fig. 2.



(a)



(b)

Fig .1: X-ray diffraction patterns of, a) As received Al and Cu powders, b) Cu-20 at %Al and Cu-3.64at.% Al at milling times 30 h.

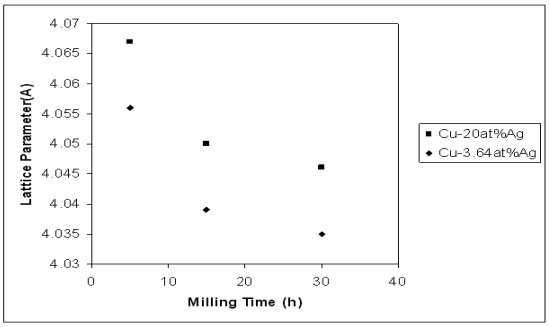
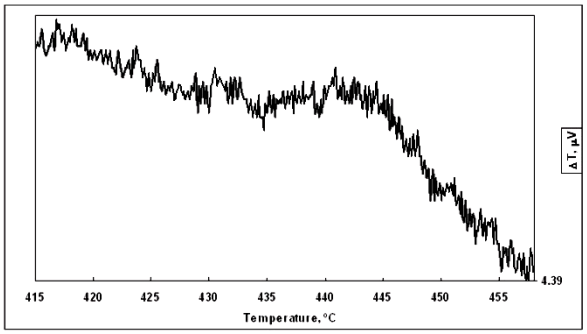
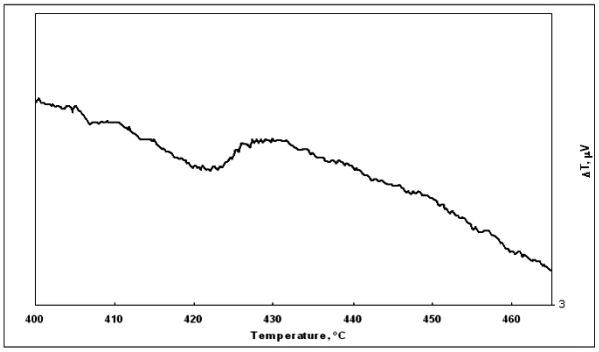


Fig.2: Decreased of lattice parameter due to dissolving of Cu into Al lattice as a function of milling time.

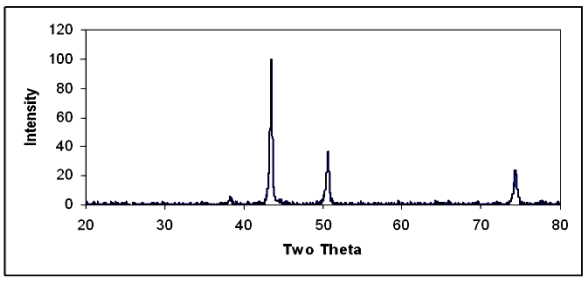


(a)

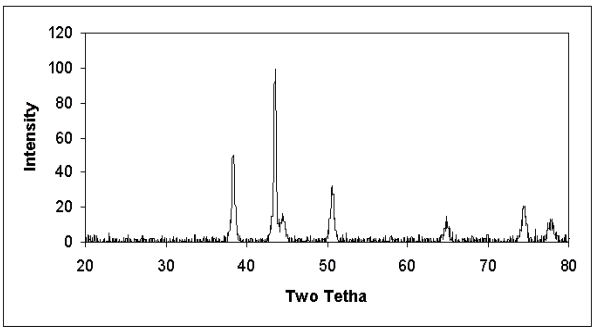


(b)

Fig .3. DTA traces for milled powder at 30 h for, a)3.64 % at Al–Cu, b) 20 %at Al-Cu



(a)



(b)

Fig.4: X-ray diffraction patterns of powder heated at 423ºC after 30 h of milling, for: (a) 3.64%atAl-Cu, and (b) 20%atAl-Cu

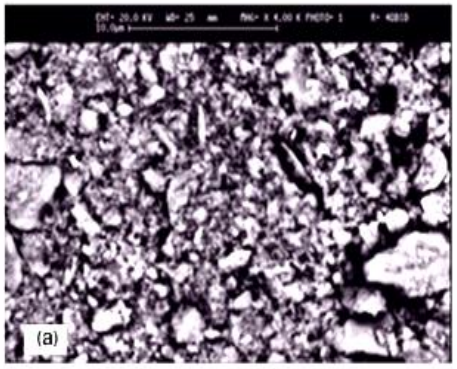
Figure 3 shows DTA heating traces of samples milled for 30 with a single exothermic peak at about 423ºC. In order to reveal the origin of exothermic event, as milled powders were heated in DTA with a heating rate of 10 K/min. The peak of 20%Al – Cu sample was clearer than the peak of 3.64 %atAl-Cu sample. Thus, by heating up to 423ºC the nano crystalline supersaturated solid solution of Cu(Al) alloy decomposed into a nano phase composite of Al and Cu.

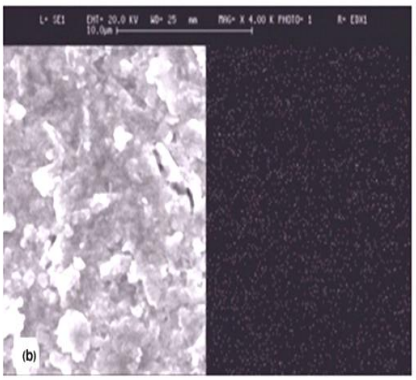
Figure 4 reveals the diffraction peaks of Cu significantly shifted toward higher angles, indicating that Al solutes dissolved in Cu began to precipitate by heating up to 423ºC. The diffraction peaks of Al phase appear in the X-ray diffraction and the positions of Cu peaks almost coincided with those of the un-milled Cu powders, which meant that Al atoms dissolved in Cu almost completely precipitated. The diffraction peaks of both Cu and Al phases become narrow upon further heating, as shown in Fig 4, which indicates an apparent grain growth of both Cu and Al phases. Table 1 shows the aver Ale grain size of Cu and Al phases after heat treatment, which shows that the grain size of Al and Cu phases increases obviously after heating but grain size is in range nanometer.(As shown table 1).

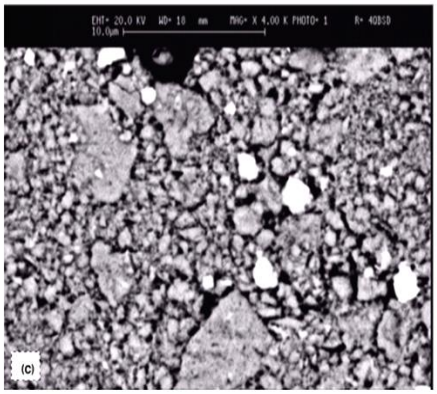
Table 1
Grain sizes of aluminuim and copper (nm)

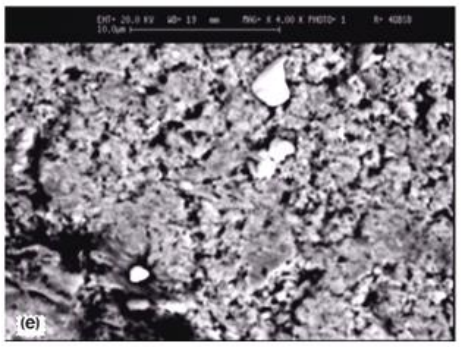
Conditions	Composition	d_{Ag}	d_{cu}
After 30h milling	3.64%atAl-Cu	8.35	18
After 30h milling	20%atAl-Cu	5.68	16
After heating	3.64%atAl-Cu	58.72	46.2
After heating	20%atAl-Cu	48.5	37.46

Figure 5 is SEM impales that Fig.5a and Fig.5b show the formation of the solid solution and Fig 5c and Fig5d show the formation of nanocomposite for 3.64%atAl-Cu sample and Fig.5e and Fig.5f show the formation of nanocomposite for 20%atAl-Cu sample.









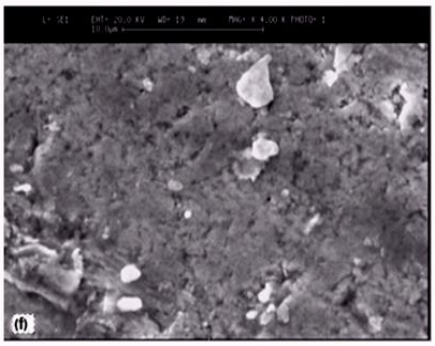


Fig. 5: Scanning electron microscopy (SEM) and dot map after heating after 30 h milling 2o% at Al-Cu, a) BS, b) SE and Cu dot map after heating 3.64%atAl-Cu, c) BS, d) Al dot map after heating 20%atAl-Cu, e) BS, f) SE.

4. Conclusions

Mechanical alloying process was performed in the Al-Cu system. It was shown that the solid solubility level rose by increasing the initial solute content in a powder mixture. The shifts in the position of peaks in the X-ray diffraction patterns were utilized to determined changes in the lattice parameter values and calculated the solid solubility levels. The diffraction peaks of Cu significantly shifted toward higher angles, indicating that Al solutes dissolved in Cu begin to precipitate by heating to 700 K and the diffraction peaks of Al phase appear in the X-ray diffraction.

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