Developments in Microstructure and Composition of Copper-Nickel System Based on Milling Speed in Surface Mechanical Coating (SMC) Process

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1- Introduction

In most industries, failure of engineering materials imposes various problems and financial expenditures. Improvement of the structure, surface properties, and production of new alloys may play a significant role in solving this crucial issue. Materials with nanostructures, these days, have attracted many researchers' attention due to improvement of the quality and enhancement of the physical and chemical properties such as strength, hardness, resistance against corrosion and oxidation at high temperatures and pressures, electrical conductivity, etc. Thus, if these materials are created with nanocrystalline structure on the surface, surface properties will be improved. There are several ways to create nanocrystal surfaces like: severe plastic deformation, electrical deposition, chemical and mechanical alloying methods. Recently, surface coating through mechanical alloying process, as an attractive way, is taken into consideration for manufacturing a nanostructured homogeneous alloy in the solid state at room temperature. During this process, consecutive encounters of high speed balls with the powder and sample surface leads to cold welding, breaking, and recurrent welding of powder particles to each other and to the surface. In other words, the impact force of the balls in a high-energy milling creates a coating with nanocrystalline structure.

2- Methodology

Mechanical alloying in a high-energy planetary ball-mill with a single chamber was carried out in a chamber of hardened steel with a capacity of 125 ml. 15 nickel balls with 95/99% purity and a diameter of 9 mm and copper powder with greater than 99/99% purity and particle size of about 200 micrometers were used as charging materials. Nickel powder was not used in this study. While milling, nickel particles were separated from the surface of the nickel balls due to failure phenomenon and entered the copper powder which eventually led to the formation of the Ni-Cu solid solution. In this paper, in order to maintain a balance between cold welding and fracture, as well as preventing the agglomeration of the powder particles, one weight percentage of stearic acid was added to raw powders, as a process controller.

3- Results and Discussion

Fig. 1 shows X-ray diffraction patterns for group 1 and 2 samples in quick scan mode (angles of 30 to 100 degrees) and slow scan (5/41 to 5/45 degree angles). In samples at a speed of 200 rpm a small amount of nickel was isolated from the surface of the balls and entered the powder. In samples at a speed of 300 rpm, the nickel peak in the XRD patterns increased which was because of the increased applied energy to the ball and consequently isolation of larger amount of nickel layers from ball's surface. The formation of Ni-Cu partial solid solution was witnessed for both samples of 200 rpm and 300 rpm. In sample at a speed of 300 rpm, main peak intensity was dropped and widened which indicates the decrease in grain size or partially amorphous structure. Reduction of the grain size, itself, is a favorable factor for enhanced diffusion of nickel atoms in crystal structure of copper. For samples of 400 and 500 rpm, the main peak was shifted toward greater angles that indicates dissolving of larger amounts of nickel atoms in the copper network, and eventually, formation and completion of Ni-Cu solid solution. The x-ray diffraction pattern for samples of group 2 are presented in Fig. 2 (c, d). It is observed that formation of Ni-Cu full solid solution is possible at 300 rpm speed.

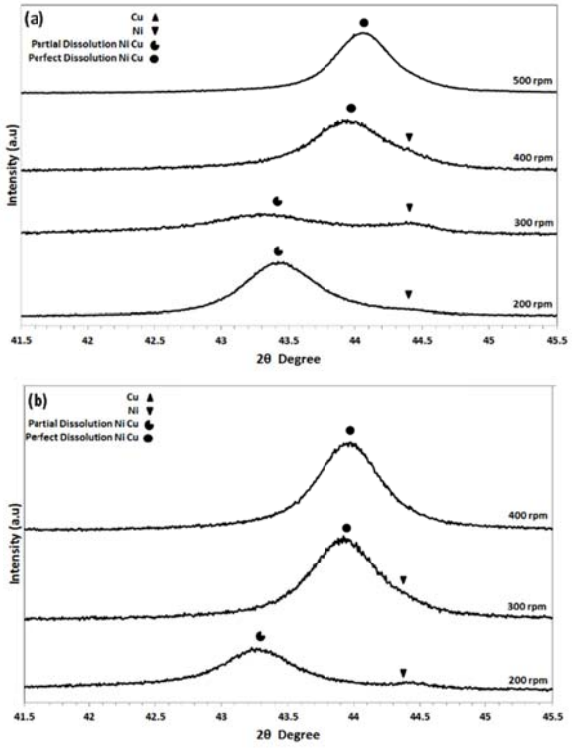

Figure 1 X-ray diffraction patterns of the remaining powder in the milling chamber in terms of milling speed at two modes of fast and slow scan b. for group 1 samples d. for group 2 samples

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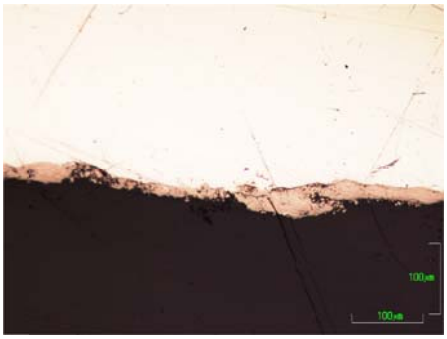

Figure 2 Optical images of the cross-section of the Ni ball for 10 h sample of group 1

Fig. 2 is related to the cross-section of coated ball which is prepared by optical microscope. According to this picture, the whole surface was coated with relatively uniform thickness.

EPMA analysis was used to study the distribution of elements of nickel and copper in the powder particles and the coating on the balls. According to the results of this analysis, the following issues are concluded:

1. By increasing milling speed, the concentration of nickel in the crystal structure of copper was enhanced.
2. In almost all cases, coarse particles of nickel were observed within the powder which indicates the isolation of nickel layers from ball's surface in different milling conditions.
3. Nickel concentration was greater in 400 rpm samples of group 2 and 500 rpm samples of group 1 than copper concentration. So that, Nickel concentration was shifted in powder particles from 15% in 200 rpm sample to 70% in 500 rpm sample of group 1 and from 15% in 200 rpm sample to 70% in 400 rpm sample of group 2.

4- Conclusions

1. Based on results obtained from XRD analysis of powder samples, the formation of solid solution was complete for 400 rpm sample in group **1** and 300 rpm sample in group 2.
2. According to the reduction of particle size from 200 rpm sample to 300 rpm in group 1 and from raw sample to 200 rpm in group 2, it is concluded that failure phenomenon of particles was dominant in SMC process of nickel-copper system, from the beginning to middle stages of the process.
3. Increasing milling energy leads to improvement of uniformity of particle morphology, coating surface, as well as, enhancement of the coating thickness and its uniformity in terms of the distribution of elements. Increasing the milling time has the same impact at lower speeds.
4. In terms of appearance, the smoothest surface was found in the 500 rpm sample in group 1 and the thickness coating to the 400 rpm sample in group 2 (about 220 µm).