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INFLUENCE OF THE EXTRUSION PROCESS ON THE GRAIN SIZE OF COPPER MICRO-ALLOYED WITH IRON AND PHOSPHORUS

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Abstract

The aim of this work is to analyze the process of obtaining and thermal treatment on the grain size of copper microalloyed with iron and phosphorus (0,003 wt%Fe i 0,014 wt%P). Microalloyed copper was obtained in two ways: by melting cathode copper and prealloys CuFe0,1 and CuP6,42 in an induction furnace followed by the casting of the same raw materials and the up-casting process, followed by extrusion. The samples obtained in this way were subjected to thermomechanical treatment, which involved cold plastic deformation by rolling with 70% reduction, followed by annealing at 470°C for 80 minutes. Based on the microphotographs and the ImageJ software, the average grain size and grain size distribution were determined for each tested sample. The results showed that the average grain size of the extruded sample was smaller, and the microstructure was more uniform and had a higher degree of recrystallization, which can be attributed to severe plastic deformation (extrusion).

***Keywords**: extrusion, microalloying, "up-cast" process, microstructure.*

1. INTRODUCTION

Research in the field of severe plastic deformation (SPD) has grown significantly in recent years due to the numerous properties that can be achieved in different materials [1]. The main goal of the severe plastic deformation (SPD) method is to achieve a unique combination of high strength and ductility [2], as well as to achieve ultrafine-grained materials with improved properties [3].

Copper represents an ideal model of material for studying deformation processes and microstructure development due to its low cost, unique FCC structure, medium stacking fault energy and long history of research on this material.

Many researchers have studied the mechanical and structural properties of pure copper in the extrusion process [4-6]. Shalini et al. [7] conducted microstructural analyzes of copper products before and after deformation (extrusion). Their results showed that the hardness of the extruded products is higher and that finer and more uniform grains are obtained during extrusion. Zhao et al. [8] studied the effect of strain rate on the microstructure and mechanical properties of AA6063 during a continuous extrusion process. Their results showed that variations in the speed of the extrusion wheel directly affect the deformation of the material and significantly affect the maximum extrusion temperature. They concluded that there is an optimal wheel speed for extrusion that produces products with good mechanical and structural properties.

In this work, the microstructure of samples from the same alloy obtained by different technological procedures will be analyzed, as well as the confirmation that the extrusion process has a significant influence on the grain size.

2. EXPERIMENTAL

Experimental research included the production of cast samples from micro-alloyed copper with 0.003 wt%Fe and 0.014 wt%P obtained by different procedures.

The first sample was obtained by melting, in an induction furnace, cathode copper of purity 99.99% (GRADE A quality produced by AURUBIS) and pre-alloys CuFe0.1 and CuP6.42 under a layer of charcoal as a covering agent, followed by casting in a graphite mold. After hardening in the mold, the casting was removed from it and tempered in a mixture of water and alcohol. The second sample was obtained by melting the same raw materials and casting with the "up-cast" process, followed by extrusion. The samples thus obtained were subjected to thermomechanical treatment, which involved cold plastic deformation by rolling with 70% reduction, and then annealing at 470°C for 80 min.

The metallographic preparation of the samples was performed on a device for electrolytic polishing and etching. An aqueous solution of phosphoric acid and alcohol was used as an electrolyte for polishing the samples, and for better structure development, the samples were also etched with a solution of ferric chloride. Microstructural analysis of the prepared samples was performed using optical microscopy, and the average grain size, profile diagram and grain size distribution were determined using ImageJ software.

3. RESULTS AND DISCUSSION

Figure 1 shows optical microphotographs of microalloyed copper obtained by different methods, after thermomechanical processing. The grain distribution shows that there is a visible difference in grain size between the sample that was extruded (Figure 1b) and the one that was not (Figure 1a).

In the case of the extruded sample, the grains are visibly smaller with clearer boundaries, and the inconsistency in grain size is reduced, resulting in a more homogeneous structure.

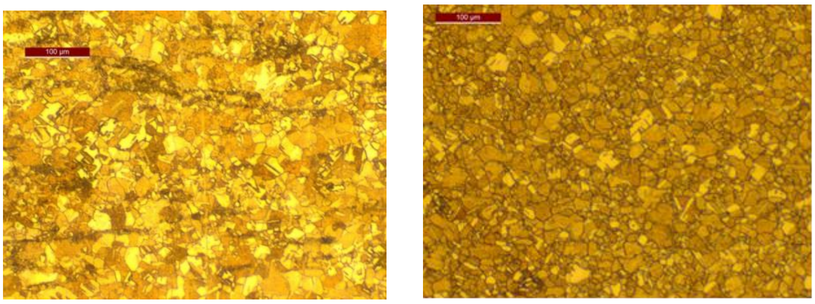

Figure 1. *Optical microphotographs of samples after rolling with 70 % deformation and annealing for 80 min at 470 °C a) obtained in an induction furnace, b) obtained by "up-cast" process and extrusion*

Average grain sizes, profile diagram and grain size distribution for the tested samples were obtained based on optical microphotographs, using ImageJ image analysis software. The grain size was measured along the longest axis, and in both samples the average grain size was determined in three fields of view. Figure 2 shows the average grain size and grain size distribution of samples obtained by different methods. It can be seen from the picture that the microstructure of the extruded sample is much finer and more uniform with an average grain size of 15.96 μm.

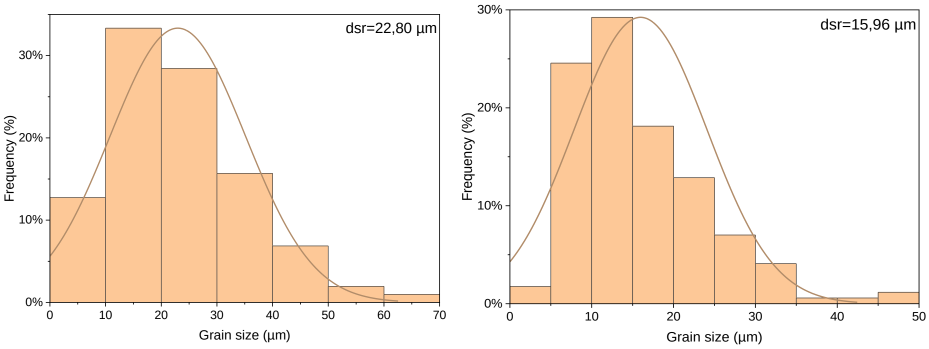

Figure 2. *Average grain size dsr and grain size distribution for sample a) obtained in an induction furnace, b) obtained by "up-cast" process and extrusion*

The extrusion process is realized under the influence of active friction processes that occur between the workpiece and the working wheel. By rotating the wheel, the rod is pulled into the filling chamber, where due to high compressive stresses and shear deformation, the metal is heated and the temperature in the deformation zone reaches 450-600°C, so the extrusion process takes place without pre-heating the bar. During extrusion, thermal deformations of the bar were achieved, during which dynamic recrystallization occurred. Therefore, the grain is significantly refined during the extrusion process [9,10].

The extrusion process proved justified in terms of grain comminution, because the finer the grain before deformation, the finer the recrystallized grain will be. A smaller starting grain causes a higher accumulated energy and density of dislocations during deformation, so that conditions are created for the formation of nucleus in many more places inside the grain. The extrusion process, in combination with rolling and heat treatment, proved to be justified in the tasks of forming a fine-grained structure, whereby the set of mechanical properties of the material is improved.

4. CONCLUSION

The paper presents the results of the influence of the obtaining procedure on the grain size of micro-alloyed copper. Based on the obtained results, it can be concluded that the extrusion process proved justified in terms of grain comminution. During extrusion, thermal deformations of the bar were achieved, during which dynamic recrystallization occurred, and therefore the grain was significantly refined during the extrusion process. The combination of extrusion and cold rolling not only reduced the grain size, but also reduced the heterogeneity of grain distribution in the workpiece.

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