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Texture Evolution of Ultra-Fine Grained Commercially Pure Copper Produced by Multiple Compressions in a Channel Die

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Texture Evolution of Ultra-Fine Grained Commercially Pure Copper Produced by Multiple Compressions in a Channel Die

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Abstract

In the present study, commercially pure copper was subjected to multiple compressions in a channel die in which the specimen undergoes plain strain deformation during each pass. The specimen geometry and height reduction during each pass were chosen such that rotation of the specimen after each pass preserves the initial specimen dimensions. The copper specimens were compressed up to 8 passes (equivalent strain of 6.4). According to microstructural analysis, an ultra-fine grained copper with the mean grain size of 170 nm was produced after 4 passes of the process. Texture analysis showed that copper-type texture develops after one pass of MAF while brass-type texture establishes after 2 to 8 passes. Also, texture strength of the studied material initially increases and then decreases with increasing the applied equivalent strain. According to the texture analysis results, the produced ultra-fine grained material has a weak final texture. Therefore, it can be said that multiple compressions in a channel die can produce ultra-fine grained materials with approximately random texture after 8 passes.

Keywords: copper, multiple compressions, channel die, ultra-fine grain, texture.

Introduction

Ultrafine grained (UFG) and nanostructred metals and alloys processed by severe plastic deformation (SPD) display a number of attractive physical and mechanical properties such as enhanced strength and relative high conductivity, absence of strain hardening behavior, low temperature and/or high strain rate superplasticity [1]. Several SPD processing techniques, such as accumulative roll-bonding (ARB) [2], cyclic extrusion and compression (CEC) [3], multi-directional forging[1] (MDF) [4], equal channel angular pressing (ECAP) [5] and high pressure torsion (HPT) [6] have been developed and successfully utilized for producing sub-micron materials. Among these SPD techniques, multi-directional forging, MDF, in which the specimen is subjected to uniaxial compression along three orthogonal axes to impart SPD, is conceptually very simple. However, since after pressing the lateral sides are barreled, the use of multiple compressions along different axes requires grinding of these surfaces before the next pressing can be carried out. The need for grinding after every pass could be reduced if the sample is pressed with a constraint on two of the four lateral sides, utilizing, for example, a channel die, usually used to simulate a plane strain rolling condition [7].

Miura et al. [8] have processed AZ 61 alloy using multi-axial forging (MAF) and reported enhanced mechanical properties of this alloy. Kundu et al [7] produced ultra-fine grained pure copper using multiple compressions in a channel die. There exist few research reports about utilizing multi-directional forging

[1] MDF is also known as multi-axial forging (MAF).

and multiple compressions in a channel die. Al-3Mg-Sc(Zn) alloy was subjected to triaxial forging and its microtextural evolution was investigated. A strong texture was obtained at high temperatures (>0.4 T_m) and texture weakening was reported at low temperatures (<0.4T_m) [10]. Padap et al. [11, 12] studied variation of grain size of ferrite and mechanical behavior of AISI 1016 steel processed by warm MAF. Moreover, they observed texture weakening after 6 passes and attributed this to random rotations of grains and grain boundary sliding at large strains.

The review of the literature shows that although texture evolution during multi-directional forging has been studied, there has been no attempt to investigate texture evolution in multiple compressions in a channel die. Since the mechanical properties have a strong relationship with texture and knowledge of texture evolution facilitates understanding the mechanisms responsible for grain refinement during severe plastic deformation, studying texture evolution during multiple compressions in a channel die seems to be rational. The aim of this work is thus to investigate evolution of texture during multiple compressions in a channel die process.

Experimental procedures

The initial material was commercially pure copper blocks. From these blocks, samples with dimensions 7.5 mm × 14.8 mm ×15 mm were cut and used for the subsequent processing. The specimens were fully annealed at 723 K for 1.5 h to eliminate any effect of previous thermomechanical history. Usual metallographic procedures revealed that the mean grain size of the specimens after annealing was about 35 μm.

The annealed specimens were compressed several times in a channel die. The pressings were carried out at room temperature using a ram speed of 25 mm s^{-1} and mineral oil used as lubricant. A specimen of height 15 mm and 14.8 ×7.5 mm^2 section was placed in the die in such a way that the 14.8 mm side just slides into the 15 mm wide channel. Fig. 1 shows the deformation scheme during multiple compressions in a channel die. The sides of the specimen are designated as A, B and C. The first pressing was carried out on face A to half of the height of the sample. This makes the side which was previously 7.5 mm to be about 14.8 mm. The specimen is then rotated such that the second pressing was carried out on face B. The 14.8 mm side slides into 15 mm wide channel and becomes the height for the next pressing. After the second pressing, the specimen was rotated such that the next pressing was carried out on face C. After each pressing, the specimen was rotated and reinserted into the channel such that the specimen dimension equal to the channel width becomes the height for the next pressing. This sequence ensures that the sample is pressed in all three directions. It is worth noting that after each pressing pass, the grinding carried out on the bulged portion of the sample to preserve its initial dimensions. The above mentioned stages were repeated up to 8 passes (ε = 6.4).

The microstructural observation by transmission electron microscopy (TEM) was done for the specimens after multiple compressions in the channel die. To prepare TEM thin foils, specimens were ground to a thickness of about 100 μm and then electropolished by a twin-jet, using a 33% HNO_3 and 66% CH_3OH solution at -30 ^oC and 20 V. EM 208 F transmission electron microscope operated at 100 kV was used for microstructural examination.

Crystallographic texture measurements were carried out on the surface of the processed samples using Cu Kα (λ=1.54056 Å) radiation and by the use of Phillips X'pert diffractometer. The texture was measured on the area of 12×8 mm^2 flat surface which had been prepared by mechanical polishing and grinding. From three incomplete pole figures {111}, {200} and {220}, orientation distribution functions (ODFs) were calculated after correction for background and defocusing using Philips X'pert texture software.

Results and discussions

Fig. 2 a-b shows the TEM microstructure of the studied material after 4 pressing passes together with the corresponding selected area diffraction pattern, respectively. It is clear that ultra fine grains are produced after 4 pressing passes based on the ring pattern of the SADs. The mean grain size of the material was measured using linear intercept method and it was found that four cycles of multiple compressions in a channel die produces an ultra fine grain material with average grain size of about 0.17 μm. Average grain size of 0.34 μm has been reported in the literature for the same material processed by the same method [7]. Average grain sizes obtained in this study and those reported in the literature are summarized in Table 1. The smaller grain size obtained in the present study can be related to the applied higer strain rate. Based on the results of the previous studies, it can be said that the formation of ultra fine grains in multiple compressions in a channel die is due to simultaneous operation of grain subdivision by deformation induced high angle boundaries and dynamic recovery [9, 13-15].

Fig. 3 a-e shows the measured {111} pole figure of the studied material subjected to various compression cycles. From this figure, it is clear that the initial material has an almost random texture. The pole figure of the processed material after one compression cycle resembles the Copper texture which occurs in most pure metals with medium to high stacking fault energy [16]. The second compression cycle changes the texture of the processed material into Brass or Silver type. It is believed that strain path change is the cause of this texture transition. This kind of texture transition has been observed during cross rolling of copper and nickel [17]. Taking a look at fig. 3-d shows that the texture of the processed material after four compression cycles is still of the Brass type. Fig. 3-e shows that imparting more SPD strains causes that the texture of the material to be more diffuse. Similar texture weakening as a result of increasing SPD strains has been reported for equal channel angular pressing in the literature [18, 19].

If the severity of the texture is interested and the details of the distribution are not important, it is appropriate to characterize the sharpness of the texture by a single parameter called texture index. This parameter is defined as follows:

$$T = \oint [f(g)]^2 dg \qquad (1)$$

Where $f(g)$ is the orientation distribution function, and integration is carried out over the whole Euler space.

Fig. 4 shows the variation of texture index with the number of compression cycles. From this figure it is clear that the texture index of initial material is 1.717 which is very close to 1, therefore, it can be said that initial material has an almost random texture. Conducting multiple compressions in a channel die up to four cycles continuously increases the texture index of the processed material to 3.762. This texture strengthening indicates that crystallographic slip might be the main deformation mechanism during these cycles [18]. Applying further strains to the samples leads to continuous decrease in texture strength. After eight compression cycles the value of texture index approaches to 1.461 indicating that using eight cycles of multiple compressions in a channel die produces an almost random texture. The above mentioned results show that after the fourth cycle of multiple compressions in a channel die the main deformation mechanism changes. It is believed that random rotation of grains/subgrains and/or grain boundary sliding are the main deformation mechanisms in this stage of deformation and are responsible for texture weakening [10, 18, 19].

Conclusions

Texture evolution during multiple compressions in a channel die has been extensively investigated in this study. The results of this investigation revealed that after the first cycle of the process, texture of the processed material which had initially an approximately random texture changes into Copper type. By imposing more SPD strains the texture changes into Brass type. Analyzing the variation of texture index with multiple compression cycles shows that texture strength increases by increasing the number of cycles of the process up to four, then texture weakening starts and a nearly random texture obtains after eight cycles of the process.

Tables

Table 1: Average grain sizes of the processed commercially pure copper obtained in this study and those reported in the literature.

Number of the compression cycles	Average grain size obtained in this study (μm)	Average grain size reported in the reference 9 (μm)
4	0.17	0.34

Figures

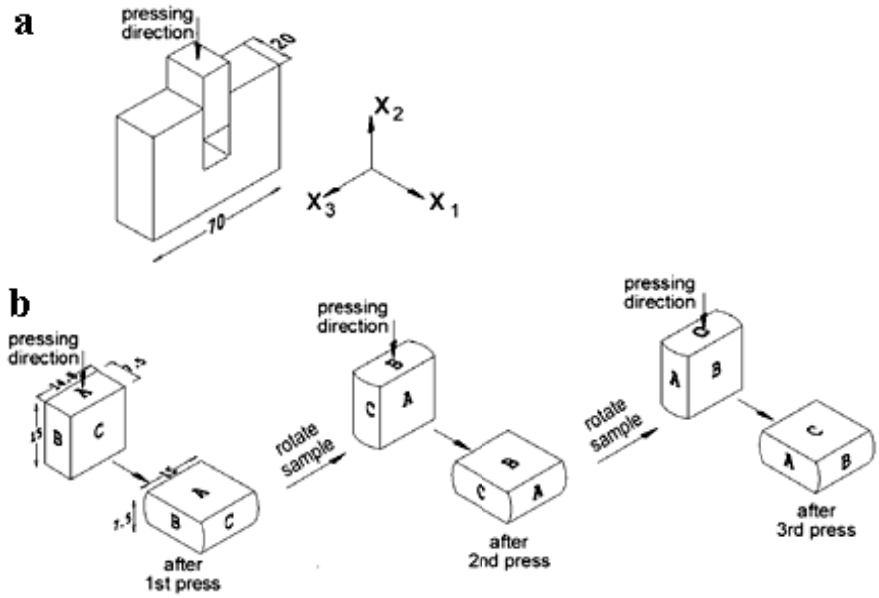

Fig. 1: (a) Orientation of channel die. (b) Scheme of multiple compression in a channel die. The orientation of the sample is the same as the die orientation in (a). Sample faces are marked A, B, C. Shown here are three pressings, after which the sequence repeats [9].

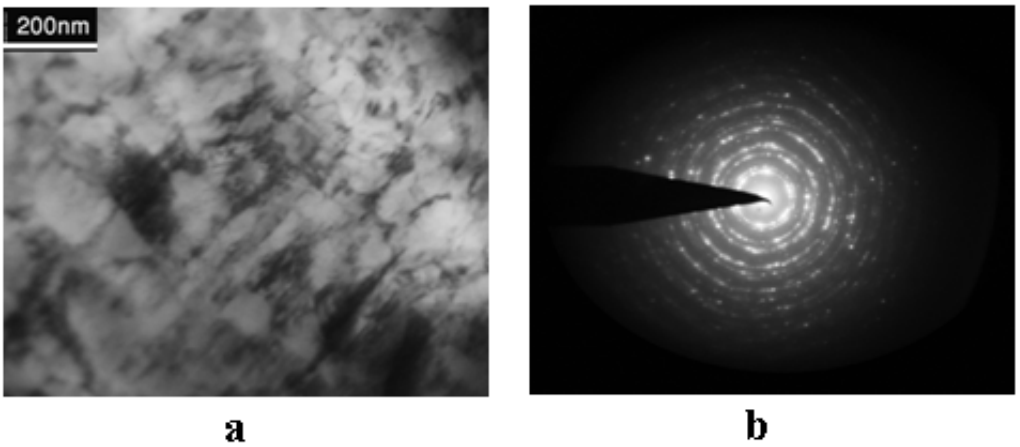

Fig. 2: TEM images of Cu samples subjected to 4 passes of multiaxial forging (a) together with the corresponding selected area diffraction pattern (b).

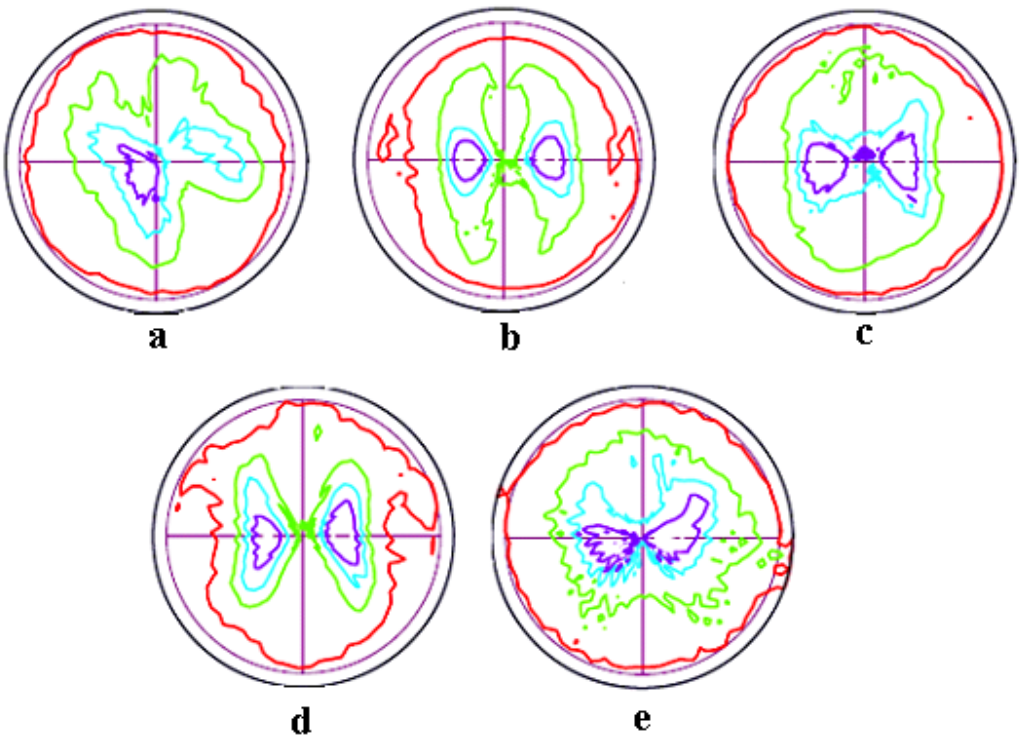

Fig. 3: {111} pole figures of Cu samples subjected to different passes of multiple compressions in a channel die; a) initial material, b) after 1 pass, c) after 2 pass, d) after 4 pass and e) after 8 pass.

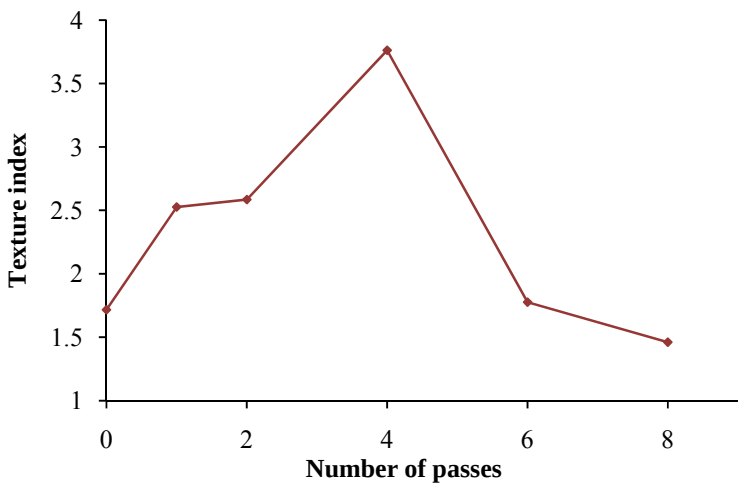

Fig. 4: variation of texture index with the number of compression cycles.

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