DEVELOPMENT OF THE RECRYSTALLIZATION TEXTURE IN COPPER HEATED BY LASER BEAM

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Development of the recrystallization texture in copper heated by laser beam

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Introduction

The effects of the heating rate on recrystallization texture were investigated in some papers 1, 2, 3. Whereas the materials and the heating methods adopted in the previous investigations were different, the results obtained were not identical. Alexandrov and Davies [3] heated OFHC copper by means of transverse flux induction heating (TFIH) and found that the recrystallization texture consists mainly of {110}<112>, {112}<111> and cube components, which is obviously different from that observed in conventional annealing. Up to now, the process and physical mechanisms controlling the recrystallization textures during fast annealing remain unclear.

One of the significant characteristics of laser beam heating is that the heating rate is very high and the heating time may be controlled by a proper choice of some heating parameters. It is the aim of this paper to examine the development of the annealing texture in commercial pure copper heated by laser heating technique.

Experimental

Three pieces of commercial pure copper sheets of different thickness, with chemical composition given in Table 1 , were used in the present investigation. Two sheets with an average grain size of about 35μm were cold rolled to 70% reduction (Sample I) and 92% reduction (Sample II), respectively. Another sheet with a grain size of about 15μm was cold rolled to 88% reduction (Sample III). The final thickness of all the three samples was 0.30mm and each was cut into the size of 20 × 40mm for annealing by laser heating.

TABLE 1. Composition of Commercial Pure Copper, % (impurities, not more than).

Cu	Bi	Sb	Pb	As	S	O	Bal.
99.90	0.002	0.002	0.005	0.002	0.005	0.06	0.005

In order to increase the efficiency of energy absorption, the upper surfaces of the samples were blackened. A 2kW CO_2 laser generator was used and the light spot diameter was adjusted to d = 3.0 mm. The samples were then heated by means of laser beam scanning with the working power 600W. The distance between the scanning lines was 2.0mm and the heating time t was controlled by the scanning speed v (t = d/v). The Schulz back reflection technique [4] was adopted to measure {111}, {200} and {220} incomplete pole figures (χ_f = 70°) and the ODF analysis was performed by the two-step method [5].

Results

The ODFs of cold rolled samples show the typical copper texture which consists of α and β tubes, i.e. mainly {112}<111> (C), {110}<112> (B) and {123}<634> (S). Fig. 1 (a) gives the constant ψ (Δψ = 10°) sections of the ODF of Sample III, where the orientation intensities of the C, B and S components are each 8 times random units (tru). The C component in Sample I and II has the peak value of 11 and 4 tru, respectively.

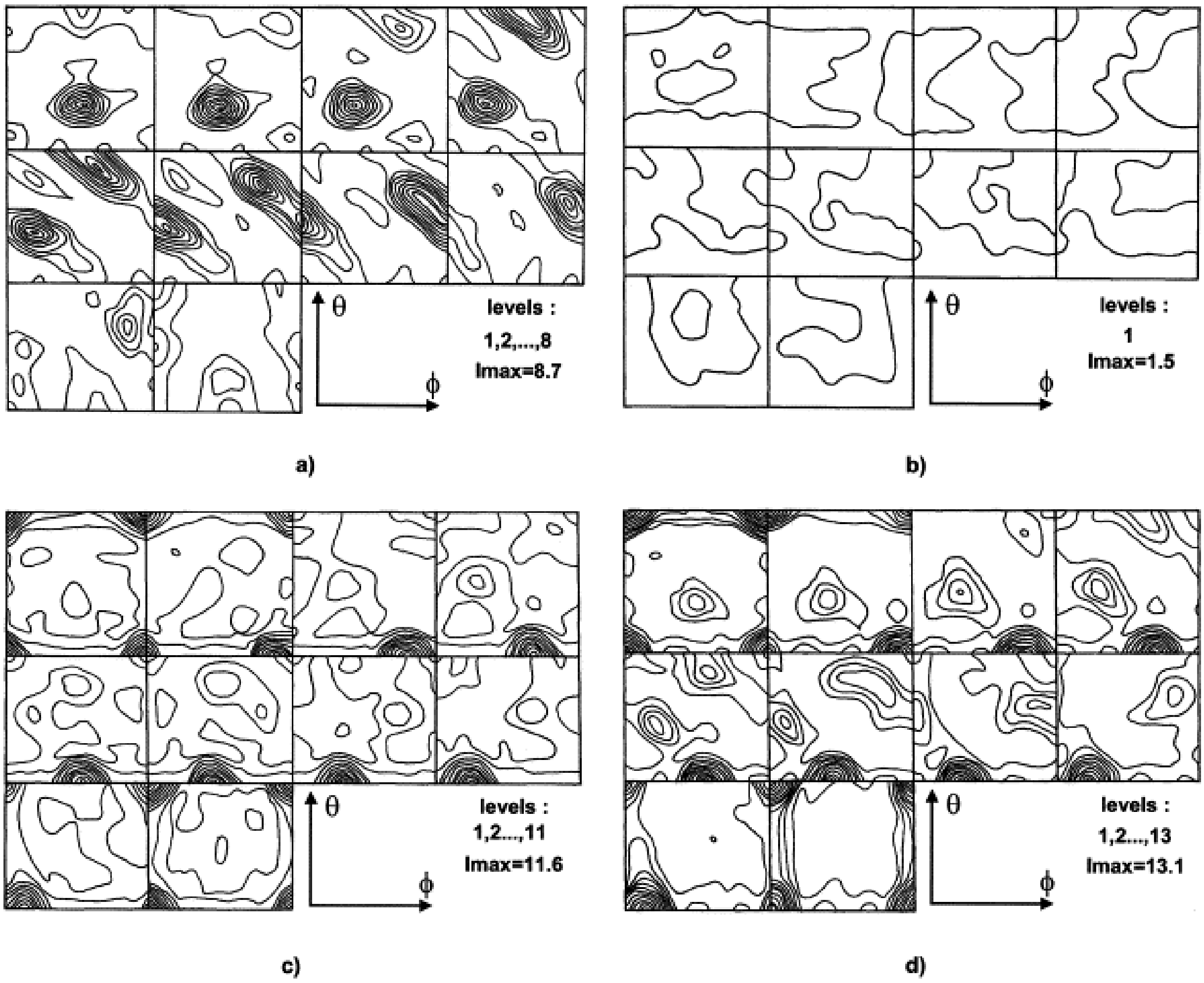

Figure 1. Constant ψ sections (Δψ = 10°) of the ODFs of (a) as-cold rolled Sample III, (b) annealing Sample I (t = 15.0ms), (c) annealing Sample II (t = 15.0ms) and (d) annealing Sample III (t = 15.0ms).

In the present work, the heating time during annealing process was chosen as t = 9.0, 11.2, 13.2, 15.0, 22.5, 45.0 (ms). As t increases, recrystallization occurs in Sample I, II and III. The optical microscopy observation showed that the recrystallization processes are the same as those found in conventional annealing. When t = 15.0ms the recrystallization completes in all the samples (see Fig. 2), but different texture components were formed. In Sample I the grain orientation distribution is almost random (Fig. 1(b)), whereas a strong cube component and a weak {122}<221> component are evident in Sample II (Fig. 1(c)). For Sample III the strong cube and relatively weak rolling components are seen (Fig. 1(d)). As t increases further, grains grow and the intensity of the cube component increases in all the three samples. The development of the C and cube components versus the heating time is shown in Fig. 3. It is noted that, for all the samples, the intensity of the rolling texture component {112}<111> (the

B and S components as well) decreases considerably and there is no obvious increase of the cube component at the initial stage of heating. Indeed, no new grains could be observed by optical microscopy.

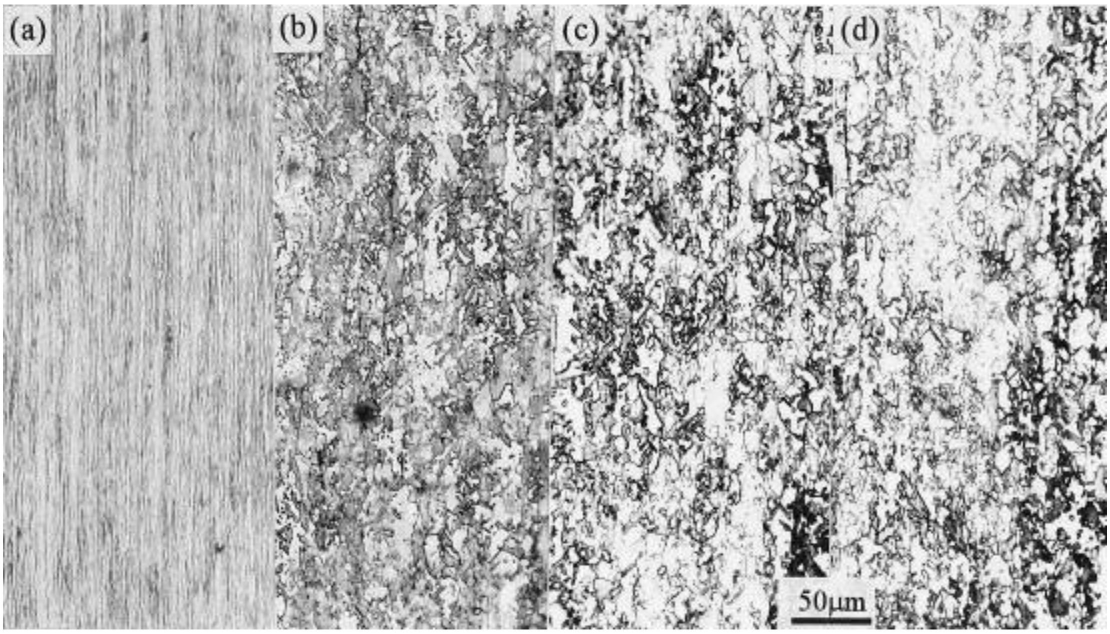

Figure 2. Microstructures of copper samples cold rolled and annealed by laser beam. (a) As-cold rolled Sample III (88%Re.), (b) Sample I (t = 15.0ms), (c) Sample II (t = 15.0ms), (d) Sample III (t = 15.0ms).

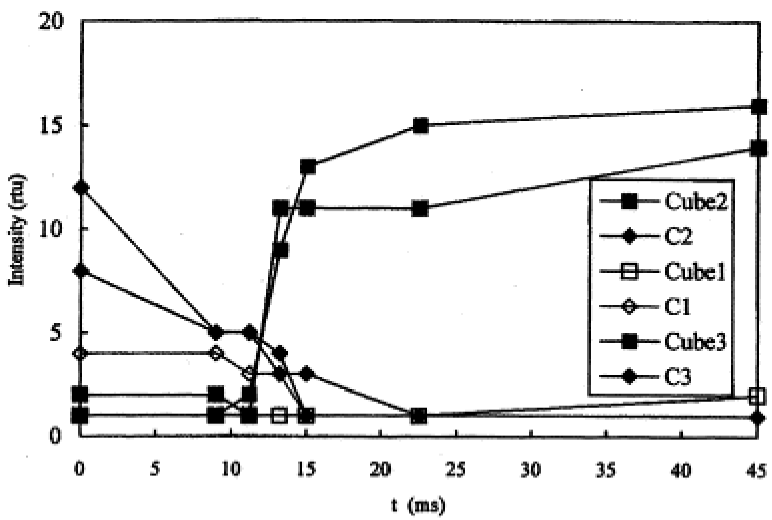

Figure 3. Orientation intensity versus the laser beam heating time t. C1, C2 and C3 are the C components of Sample I, II and III, respectively; Cube1, Cube2 and Cube3 are the cube components of Sample I, II and III, respectively.

Discussion

It is evident that the texture development for Samples I and III is different from that reported by Liu et al. [6], where the fast salt bath heating was used and almost the same process of texture development as in conventional annealing was found. Such a difference may be attributed to the different heating rates. In the present experiment the annealing rate is much higher than that of the salt bath heating. Now the question arises, what are the differences of texture formation mechanisms between conventional and ultrarapid annealing?

From Fig. 3 we can see that when the heating time t increases (but less than 13.2ms), the intensity of the cold rolling component C in all the samples decreases but there are no increases in the intensity of the cube component. The optical microscopy observation has confirmed that there were no microstructural differences between the annealed samples and the cold rolled samples at the time. This may indicate that at the early stage of recrystallization, there exist a larger number of nuclei with random orientation and the growth of these nuclei governs the further texture development process.

It is generally admitted that the recrystallization driving forces are mainly the stored energy, including the energy of defects such as vacancies, dislocations, grain or subgrain boundaries. In recrystallization, the grain boundary migration depends on both the difference of stored energy between two neighboring grains and the grain-boundary energy. A grain (or subgrain) which is in favour of the above two aspects would grow selectively. Recently, Vatne and Nes [7] cited Gibbs-Thomson relation for the critical radius R_C of nuclei, (1)

$$R > R_c = \frac{2\gamma}{P_D} \quad (1)$$

where γ is the grain boundary energy, P_D the driving pressure. All grains fulfilling Equation (1) will become successful in terms of further transformation with a growth rate G given by [7] (2)

$$G = M\left(P_D - \frac{2\gamma}{R}\right) \quad (2)$$

where M is the mobility of a grain boundary. The grain boundaries having 38.21°<111> (Σ = 7) relation are known to have lower energy γ_{111} than random grain boundaries. As the cube component has a 40°<111> relation with the S component, it is easier to nucleate according to Equation (1). On the other hand, if assuming $M_{111} = M_{random} = M$, one may deduce from Equation (2) that the growth rate of the cube component is higher than that of the others.

For ultrarapid annealing, because of the relative short time at the low temperature stage, the thermal kinetics process occurs mainly at high temperature. Thus the pressure P_D is higher and the grain boundary energy γ is relatively lower than that in the conventional annealing. According to , , grains with different orientation would have more chance to nucleate and grow. Therefore, the cube formation is less favoured as compared to the conventional annealing case. A deduction is made that, when recrystallization just completes, the resulting textures may be quite different depending on the nucleation and growth rates of all components which are affected by the γ and P_D. In fact, the smaller the grain size and the higher the rolling reduction, the higher the pressure P_D. This makes the differences in the recrystallization texture development for Samples I, II and III. As for the increase in the density of the cube component with further grain growth after 15.0ms, this may be due to the fact that the cube grains have a relatively large size and they can swallow small grains of other orientations. Consequently, it leads to the cube texture strengthening.

Conclusions

1.The development of texture in commercial pure copper annealed by laser beam is affected by both the rolling reduction and the initial grain size prior to rolling. For the coarse grained sample I with 70% reduction, the recrystallization texture is nearly random when recrystallization just completes. However, the cube component is evident in the sample II with 92% reduction. For the fine grained sample with 88% reduction, the recrystallization texture consists of the cube component and the cold rolling components at the just full recrystallization state. As grains grow further, the cube component in all the samples increases and the cold rolling components disappear.

2.For the samples heated by laser beam with short time (<13.2ms), no new grains could be observed and the cold rolling components decrease considerably. There is no obvious increase of the cube component. It may be deduced that at the initial stage of recrystallization, there exist a larger number of nuclei of different orientations including the cube and cold rolling components. The further texture development are mainly controlled by the growth competition of all these components.

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