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Original Research

Mechanism of surface texture evolution in pure copper strips subjected to double rolling

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Abstract

Developing ultra-thin copper foils with different surface roughness and microstructure has important significance for improving the service performance and reducing the production cost of high-end circuit boards. In this paper, pure copper strips with initial cube texture were subjected to a double rolling process (deformation amount ranges from 50% to 95%), and the surface textures evolution law and mechanism of double-rolled strips were studied by an X-ray diffraction technique. The results show that when a deformation amount increased from 50% to 70%, the grains of two surfaces rotate away from the cube orientation, and the formed textures of two surfaces mainly consisted of C, S and B orientation components. The orientation density values for these three components on bright surface only had slight difference; the orientation density values for C and S components were much larger than that for B components on a matt surface. When the deformation amount increased to 90%, the increase extents of orientation density values for C and S components were obviously larger than that for B components on a bright surface; the increase extents of orientation density values for these three components were almost the same on the matt surface. It has been found that when deformation amount reaches 95%, the grains orientation of bright surface were relatively concentrated, and the orientation density value for C texture obviously increased to 11.68 and that for B texture was only 3.15; the grains orientation of matt surface were relatively dispersed, and the orientation density value for C texture increased to 9.26 and that for B texture obviously increased to 6.35, and the density values of these two textures had less difference. For the condition of strong compressive and shear stress on the bright surface, grains were mainly rotating to C texture orientation; compared with the bright surface, “semi-free” deformation condition on the matt surface is beneficial to promote much more grains to rotate to the B texture orientation.

Keywords: Pure copper strips; Double rolling; Surface texture; Evolution law; Mechanism

1. Introduction

Microstructure and texture were key features to relate the processing of metal with their final properties [1]. An ever-increasing interest has been shown to improve mechanical/physical properties by obtaining desired microstructure or texture of materials. Double rolling is the process where two stacked metal strips with doubling oil between them are rolled at the same time. The main purpose of this forming method is to decrease the elastic flattening value of rollers, and then get strips with smaller minimum reliable thickness. Double rolling is widely used in the final process during manufacture of thin aluminum foils with thickness less than 10 μm [2]. So far, there is not any research or production report about fabricating copper foils by the double rolling method. During the double rolling process, the deformation conditions on the two surfaces of a monolayer rolled piece exihibit some differences, thus may lead to a difference of surface roughness, grain size and texture strength.

The crystal grain orientation changes during a different plastic deformation process. When crystal plane and crystal direction of many grains tend to line up to some certain direction, the grains

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orientation exhibit ordered structure, which made texture formed. The textures of metal are closely related to its deformation history [3] and the mechanical properties [4,5]. Commonly, initial texture types, deformation amount, lubrication condition and deformation mode are the main influencing factors of deformation textures. The typical cold rolling textures of face-center cubic metals mainly consist of Brass {110} < 001 > (B), Copper {112} < 111 > (C) and S {123} < 634 > three components. Volume fraction of these three texture components is different under different deformation conditions. For example, the orientation density values of these three components are almost the same for the rolled polycrystalline aluminum with initial randomly distributed texture, while the orientation density values of C and S components are much larger than B components for the rolled polycrystalline aluminum with initial cubic texture [6]. With the increase of deformation, the deformed grains usually rotate from C to B orientation, but it is still unclear that the reason of the texture transformation is caused by cross-slips or mechanical twinning [7,8]. The lubrication condition could affect the deformation uniformity of rolled piece during a cold rolling process, and the compressive and shear stress that grains suffered is changed by the distance to the surface of rolled piece. The distribution of grain orientation in the thickness direction is uniform; especially the texture types of surface and center region are quite different [9–12]. The distribution of stress and strain of rolled piece for composite rolling or accumulative roll-bonding is much more complicated than that for monolayer rolling, which could also result in different types and strength of textures in different regions, and the shear texture components are usually in surface region, while plane-strain compression texture components are in the center region [13–15].

During the process of double rolling, one surface (bright surface) of the monolayer rolled piece contacts with the rigid roller, and the other surface (matt surface) located in the central rolling region contacts with the doubling oil. The grain orientations of the two surfaces may have some difference under this kind of asymmetrical deformation condition, and this may lead to different recrystallization textures [16,17] and properties of bending resistance, etching, and so on [18,19]. Along with the rapid development of high-accuracy in the electronic industry, the comprehensive quality requirement for pure copper foils becomes higher and higher. Developing ultra-thin copper foils with different surface textures and reasonable utilization of the superior properties endowed with different texture components, which could offer a possible way to improve the whole performance of copper foils.

In the present work, the characteristics of surface textures in thin copper strips subjected to double rolling under different deformation amount conditions were studied. The evolution law and mechanism of surface textures were discussed based on the orientation distribution functions and orientation line analysis, and the analysis results could also help to provide the theory basis for analyzing the relationship between structures and properties of double-rolled copper foils.

2. Experimental

Cold rolled copper strips with thickness of 1.0 mm were used for double rolling deformation, and the chemical compositions of the strips are listed in Table 1. The strips were annealed at 500 °C for 10 min in an Ar atmosphere, and complete recrystallization occured. Before double rolling, the deep refining mineral oil with viscosity of 3 mm^2/s was taken as doubling oil, and the oil was uniformly coated onto the surfaces between the upper and lower strips. The machine oil was adopted to lubricate the contact surface between rollers and rolled pieces. The two layers of copper strips were subjected to double rolling with deformation amount of 50%, 70%, 90%, and 95% on a four high mill.

The surface textures of double-rolled copper strips were observed by an X-Ray diffractometer type D5000. Copper powders with the same compositions were taken as the non-textured standard sample. In order to remove the effect of stress, the powders were treated at 700 °C for 10 min in H_2 atmosphere. Using a reflection method to get the pole figures of (111), (200), (113), and (220), and adopt Textools software for the data analysis and calculation of grains orientation, then the orientation distribution functions of double-rolled copper pieces could be obtained.

3. Results and discussion

3.1. Evolution law and mechanism of bright surface textures

Fig. 1 shows the grain orientation distribution function (ODF) map of the annealed copper strip. It can be seen clearly in the section map of φ2 = 45°, the main texture of strip is cube texture {001} < 100 > and its orientation density value is 7.4. The orientation density values of other rolling textures are quite low, thus it can be considered that the orientation of initial undeformed grains of annealed strips is nearly cube texture.

Fig. 2 shows the experimental complete ODF maps of bright surface textures of double-rolled copper strips under different deformation amount. With the increase of deformation, the orientation of deformed grains changes significantly. When deformation amount is 50%, some grains already rotate away

Table 1
Chemical compositions analysis of the copper strips used in the present investigation (wt%).

Cu	Ag	As	Zn	Te	Sn	P	Fe
99.99	< 0.0003	< 0.0001	< 0.0002	< 0.0002	< 0.0005	0.0013	0.0009
Pb	Sb	Bi	Ni	Si	As	S	Cd
0.0003	< 0.0002	0.0002	< 0.0005	< 0.0005	< 0.0001	0.0016	0.0002