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Characteristic and formation mechanism of matt surface of double-rolled copper foil

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ABSTRACT

Copper foils for flexible printed circuit boards were prepared by double rolling, and the matt surface of double-rolled copper foil was characterized by atomic force microscope, scanning electron microscope, 3D optical interferometer, optical microscope and surface profiler. The morphology characteristics of matt surface were studied, and the formation mechanism of matt surface was discussed. The results showed that the matt surface of the double-rolled copper foil presented rough and relatively homogeneous morphology, and the morphologies of upper and lower matt surfaces were practically coincident. As the copper strips just entered into the deforming zone, the roughening of laminated surface occurred, but the roughness was relatively small. When the copper strips passed through the neutral plane, the roughness of the laminated surface increased significantly. In the backward slip zone, the initial micro-dimples between the two laminated surfaces were connected in the rolling direction, which led to the formation of larger and airtight dimples; when the copper strips moved toward the neutral plane and entered into the forward slip zone, the pressure of fluid in the airtight dimples increased rapidly, which enhanced the depths of the dimples; meanwhile, the depression corrugations with certain depth and larger width were formed on the laminated surface because of the dimple connection in the width direction. The copper foils with thickness of 36–54 μm were fabricated by double rolling, and the R_z value of their matt surfaces was 1.0–1.3 μm, which meet the requirements for directly using as adhesive surface of resin substrate, and therefore multiple roughening treatments during the traditional production process of flexible printed circuit board might be omitted. The formation mechanism of the matt surface of double-rolled copper foil proposed on the basis of the metal flow and deformation mechanics theory could explain the representative characteristics of the length direction of corrugations on matt surface being perpendicular to the rolling direction, several corrugations within a grain on the matt surface and the coincident morphologies of the upper and lower matt surfaces.

Introduction

The rolled copper foils have wide application in electronic industry due to their advantages of small volume, favorable ductility, excellent electrical conductivity and bending property. The rolled copper foils used for flexible printed circuit board usually possess the structure of different roughness on two surfaces. The smooth surface of copper foil can meet the requirement of beautiful appearance and high-frequency conductivity, and the rough surface can satisfy the demands of high bonding strength between copper foil and resin substrate. So far, the copper foils used for flexible printed circuit board have been usually produced by monolayer rolling, and a rough surface of the foil can be obtained by subsequent electroplating roughening treatment. Matsuda and Kataoka (2003) obtained a kind of rolled copper foil with surface roughness of 1.0 μm (one side) by monolayer rolling and electroplating roughening treatment, and the increased contact area between foil and resin substrate led to a higher bonding strength. For the ultra-thin and high-precision rolled copper foil, the surface roughness of foil after single electroplating roughening treatment is still quite low, and multiple roughening treatments are needed to meet the requirement of roughness for adhesion, which results in the problems of long process, heavy environmental burden and high production cost.

Double rolling is a kind of deformation method, wherein two stacked sheets of material are rolled at the same time, and its schematic diagram is shown in Fig. 1. Kerth et al. (1975) reported that the aluminum foils fabricated by double rolling possessed a

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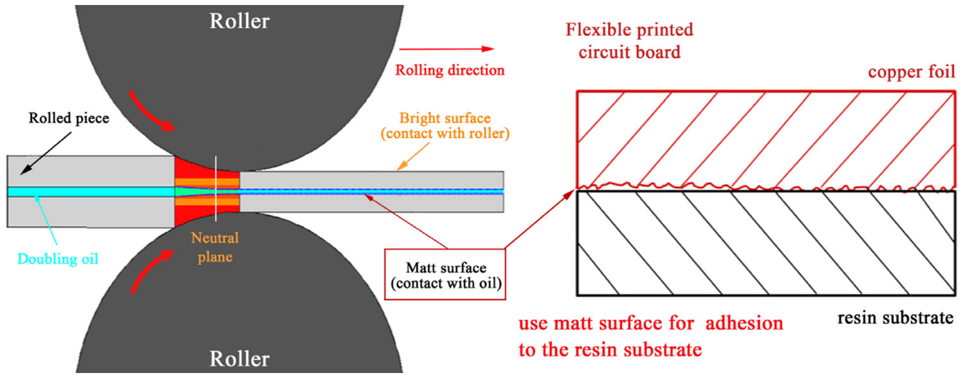

Fig. 1. Schematic diagrams of double rolling process and the idea of using matt surface for adhesion to the resin substrate.

rough surface (i.e., interface between the two rolled pieces) and a smooth surface (i.e., the external surface in contact with the bright steel rolls) simultaneously. It is well known that due to the adverse effect of surface roughness on the strength and other service performances of aluminum foils, the matt surface roughness has been paid more attention for the ultra-thin double-rolled aluminum foil. Utsunomiya et al. (2004a,b,c, 2005, 2006) investigated the matt surface roughness of double-rolled aluminum foil systematically and established an analysis model of matt surface roughness based on the crystal plasticity and strength theory. They also proposed a formation mechanism of matt surface and analyzed the influence factors and laws of the matt surface roughness. Their studies can provide significant guidance to decrease the matt surface roughness and realize the production of thinner aluminum foils.

According to the feature that the double-rolled aluminum foil has a rough matt surface, Wang et al. (2013) first proposed an idea that double rolling method was used to prepare the copper foil which could have enough large matt surface roughness and meet the requirement of firmly bonding with resin substrate (from Fig. 1), in order to omit the multiple roughening treatments during the traditional production process of copper foils, shorten the production process of copper foils, improve the matt surface quality and reduce the cost and environmental burden. In addition, the formation mechanism of matt surface, influence factors and laws of the matt surface roughness for the double-rolled copper foils may be not the same as that for the double-rolled aluminum foils due to their different materials. Clarify the above questions is a key to realize the idea that a high quality copper foil could be directly prepared by double rolling. Thus, from the view of rolling process, this paper mainly studied the laminated surface morphology evolution during the double rolling process of copper foil and the effect of doubling oil between laminated surfaces on the morphology characteristic of matt surface, and analyzed the formation mechanism of matt surface. Furthermore, the possibility of using the matt surface as adhesive surface with resin substrate and therefore omitting the electroplating roughening treatments was discussed to design the rolling parameters correctly and control the matt surface quality accurately.

Experimental

Materials and double-rolling processing

Commercial purity copper strips (0.18 mm in thickness, 300 mm in length and 50 mm in width) were subjected by double rolling on a four-high mill with work rollers of 40 mm in diameter. The arithmetical average deviation (R_a) value of the original copper strip is 0.05 μm and the micro-inequality for ten points (R_z) value is 0.09 μm. In order to analysis the influence factors of reduction and kinematic viscosity of doubling oil on matt surface roughness, the copper strips were double rolled with the reduction ranging from 25% to 80%. Before rolling, the refining mineral oils with five different kinetic viscosities (1.21, 1.73, 2.20, 2.76, and 3.11 mm^2/s at 313 K), as doubling oils, were uniformly smeared on the surfaces (laminated surfaces) between the upper and lower strips, respectively.

For obtaining enough length of deforming zone and observing the morphology evolution of laminated surface clearly, the 1.0 mm thick copper strips were subjected by double rolling with the reduction of 50% on a two-high mill (roller diameter of 260 mm), and the initial R_a and R_z values of copper strip are 0.16 and 0.35 μm, respectively. By the method of abruptly stopping rollers during double rolling process, here named by rolling stop, the double-rolled copper strips with undeformed zone, deforming zone and deformed zone were obtained. Meanwhile, two different deformation cases were considered during the rolling stop experiment: (1) the case of with doubling oil (viscosity of 3.11 mm^2/s) smeared on the laminated surfaces; (2) the case of without doubling oil smeared on the laminated surfaces.

Evaluation and characterization

Surface morphologies of the double-rolled copper foils were characterized by atomic force microscope (Agilent Technologies 5500), the measurement areas were about 100 μm × 100 μm, and the roughness values were evaluated by Digital Nanoscope software. The overall morphology and microstructure of the matt surface in the same region were observed by scanning electron microscope (Cambridge S-360) and optical microscope (Nikon Eclipse Lv150) respectively. 3D optical profilometry measurement (NT 9800) was used to observe the morphologies of the upper and the lower matt surfaces, and the measurement areas of 300 μm × 400 μm were selected at the same position of the upper and lower matt surfaces. The morphology evolution of laminated surfaces in the deforming zone was characterized by scanning electron microscope and surface profiler (Dektak 150). In the roughness measurement process with surface profiler, the sampling length is 1000 μm and the interval of sampling points is 1 μm.

Results

Surfaces of double-rolled copper foils

The surface morphologies of the double-rolled copper foil with a thickness of 90 μm (reduction of 50%, doubling oil viscosity of 1.21 mm^2/s) are shown in Fig. 2(a) and (b). The morphologies of the two surfaces were quite different. The bright surface was flat and smooth, and its R_a and R_z values were 0.045 and 0.069 μm,