Experimental study on twin-roll strip casting of Cu-9Ni-6Sn alloy

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Abstract. A strip billet of Cu-9Ni-6Sn alloy was prepared by vacuum melting and twin-roll casting while another billet with the same chemical composition was prepared by vacuum melting and general casting. Component distribution and microstructure of the two kinds of copper alloy from different processing procedures were analysed by metallographic examination and SEM. The results showed that there were massive dendritic crystals with obvious segregation of tin in the sample prepared by general casting. The sample processed by twin-roll casting process had more fine grains with homogenous distributed tin compared to that prepared by general casting. The results demonstrated that the fine grains with homogenous distributed tin were caused by the excellent cooling ability of twin-roll casting. The extremely fast cooling speed retained the homogenous component distribution in molten condition and there was no time for grains to grow up. The experiment indicated twin-roll casting was a feasible process to produce Cu-9Ni-6Sn alloy.

1. Introduction
Cu-9Ni-6Sn alloy is one of the potential materials to supplant beryllium copper alloys because of its high strength, high hardness, good stress relaxation, excellent resistance to stress-corrosion and little time-deformation1 [1]. Cu-9Ni-6Sn alloys are widely used to manufacture relay, switch, spring, installation parts, and optical instrument and so on [2]. Cu-9Ni-6Sn alloys caused wide public concern since the 1970s. Schwartz [3] found Cu-9Ni-6Sn alloy formed the mixed organization, which is alternatively constituted by tin-rich areas and tin-poor areas with Spional decomposition of α phase in threshold of desolations of supersaturated solid solution at 300~450°C. Schwartz observed the Spional decomposition by TEM for the first time. Plewes [4] made Cu-9Ni-6Sn alloy huge deformation and distinctly improved its plastic and mechanical property.

However, Cu-9Ni-6Sn alloy is difficult to be produced by melting and casting in traditional method because of the serious segregation of tin in the process of solidification [5-7]. The segregation of tin affect the mechanical properties of Cu-9Ni-6Sn alloy and make it difficult to industrialization. The methods of rapid solidification, spray deposition and powder forming have been applied to solve this problem, but achieved little due to high-cost, complex equipment and difficulties in industrial production. In this paper, twin-roll strip casting was used to produce Cu-9Ni-6Sn alloy [8-10]. Twin-roll strip casting is a process which produces the strip products directly from molten metal by the two
counter rotating rolls as casting die. The microstructures and composition distribution of both samples processed by twin-roll strip casting and general casting were determined by OM and SEM.

2. Experimental procedure

2.1 Twin-roll strip casting

In the twin-roll strip casting experiment, copper, nickel and tin with mass percent of 85%, 9%, and 6% were put into vacuum furnace in proper order. Molten alloy were filled into the roll gap after 20 minutes of heating preservation between 1150~1250°C. The twin-roll strip casting system was shown in Figure 1.

![Twin-roll strip casting diagram](image)

Figure 1. Twin-roll strip casting diagram

Twin-roll strip casting experiment was carried out on experimental twin-roll casting mill with the roller diameter of 500mm. Process parameters obtained from the experiment were summarized as follows: Linear speed was 37.8m/min, roll-casting force was 24kN, and the gap between two rollers was 1.5mm. After the experiment, Cu-9Ni-6Sn strip with width of 110mm and thickness of 3.1mm was produced from the exit of the twin-roll casting mill as shown in Figure 2. The strip had good surface quality. There were no obvious cracks on the surface of strip. After measurement, the strip was with good flatness. The difference gauge of same plate was less than 0.01mm.

![Twin-roll casting strip](image)

Figure 2. Twin-roll casting strip

2.2 General casting

General casting experiment was also carried out in vacuum melting furnace. The same raw materials with that used in twin-roll strip casting experiment were put into vacuum furnace in proper order. Raw
materials were heated up to 1250°C and completed the solidification process in ingot mold. The cross profile of casting rod was shown in Figure 3.

![Figure 3. The cross profile of casting rod](image)

3. Results and discussion

Both Cu-9Ni-6Sn alloy samples by general casting and twin-roll strip casting were conducted OM analysis and the results are shown in Figure 4. The sample prepared by general casting showed obvious dendritic microstructure, and the primary dendrite arm spacing is about 0.5mm; The sample processed by twin-roll casting showed evident layering phenomenon: fine equiaxed grains near the surface of strip (less than 0.1mm beneath the surface); big columnar grains (between 0.1 to 0.4mm beneath the surface) and fine equiaxed grains near the surface of strip (more than 0.4mm beneath the surface). The grain size of fine equiaxed grains in surface and center of the strip is about 25μm and the grain size of big columnar grains is about 100μm.

![Figure 4 OM images of casting and twin-roll casting microstructure](image)

In order to define the components and contents of the samples, SEM analysis was conducted. Figure 5 showed the component distribution of tin by twin-roll strip casting. Figure 5 (a) and Figure 5 (b) respectively showed the components and contents in the center and surface of the sample processed by twin-roll strip casting. The colors on both images are homogenous distributed. That means tins distribute uniformly both in the center and surface in the samples. The component and content of the three regions above-mentioned in Figure 5 is shown in Table1.

| Test region | Cu, wt% | Ni, wt% | Sn, wt% |
|-------------|---------|---------|---------|
| 1           | 83.92   | 9.47    | 6.61    |
| 2           | 83.53   | 9.55    | 6.92    |

Table 1. The component and content of three test region
Figure 5 SEM images of component scanning of sample by twin-roll casting

The SEM analysis result of the sample processed by general casting is as shown in Figure 6. Three parts could be sharply separated by the shape and color of the image. In Figure 6, the first part is shown as “3” which is dull-red and without boundary; the second part is shown as “4”, which is lighter than “3” and without boundary; the third part is shown as “5”, which is bright red and with irregular shaped boundary.

Figure 6 SEM images of component scanning of sample by general casting

The component and content of the three regions mentioned above in Figure 6 is shown in Table 2. Tin in the sample processed by general casting mainly distributes in the regions marked with 3 and 4 in Figure 6.

Table 2. The component and content of three test region

| Test region | Cu, wt% | Ni, wt% | Sn, wt% |
|-------------|---------|---------|---------|
| 3           | 84.14   | 11.48   | 5.38    |
| 4           | 76.08   | 12.41   | 11.51   |

From the above table, the content of tin in region 3 is less than that in region 4. Region 4 had more tin content than matrix. The tin content in region 3 is 5.38%, which is the close to the tin mass percent in Cu-9Ni-6Sn. There was obviously segregation of tin in region 4.

According to the OM and SEM result, the microstructure of Cu-9Ni-6Sn alloy produced by general casting was made up of coarse dendrites with segregation of tin. The heterogeneous distribution of tin formed tin-poor areas and tin-rich areas. The tin content in tin-rich areas was 7 times more than that in tin-poor areas; The microstructure of Cu-9Ni-6Sn alloy produced by twin-roll strip casting was
made up of fine equiaxed grains with grain size of 25~100μm. The alloy composition was close to the set value. There was no obvious segregation of tin.

The reasons why twin-roll casting process produced fine grains and homogeneous composition are as following:

Twin-roll strip casting process had strong cooling ability. The cooling speed could reach $10^4 \degree \text{C}/\text{s}$ in the solidification process. The extremely fast cooling speed retained the homogenous component distribution in molten condition and there was no time for grains to grow up. Coarse grains could be crushed into fine grains under the influence of rolling force.

4. Conclusion

The microstructure of Cu-9Ni-6Sn alloy produced by general casting was made up of coarse dendrites with segregation of tin. The tin content in tin-rich areas was 7 times more than that in tin-poor areas; the same alloy produced by twin-roll casting was made up of several layers grains with different sizes. The size of fine equiaxed grains in the surface and center was about 25μm. The strip billet had homogeneous composition. The mass fraction of tin was about 6.2%.

The experimental results showed that twin-roll casting process was more feasible to produce Cu-9Ni-6Sn alloy strip billet. Twin-roll casting process could effectively avoid the segregation of tin because of its ultra-fast cooling speed. The appropriate reduction in twin-roll casting could crush the coarse grains into fine grains and improve the mechanical properties of the strip billet.

Acknowledgments

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