Study on the property of Al-Sn-Pb and its bush material clad with steel strip by liquid-solid bond rolling

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Abstract: $AlSn_8Pb_2Si_{25}Cu_{0.8}Cr_{0.2}$(ASP) is a new bush material with high performance, but its bad plasticity limits its application. By studying the effect of silicon content on the performance of this bush material, it was found that the alloy performance and the distribution of tin and lead were affected by the silicon content. When the silicon content was 2.5%, most of the silicon precipitated along the grain boundary, and most of the lead and tin located along the grain boundary continuously, this resulted in the decrease of the bush material's performance. When the silicon content decreased to 1.0%, it distributed more uniformly, the tin and lead phases were spheroidized and became discontinuous, the performance of ASP material was then greatly increased.

Keywords: bush material; aluminum-tin-lead alloy; spheroidization

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1. Introduction

Babbitt alloy, copper-lead alloy, aluminum-tin alloy and aluminum-lead alloy are well known bush materials[1-6]. As the progress in automobile industry, there arises a big demand of high speed and long life bush materials. A new bush material $AlSn_8Pb_2Si_{2.5}Cu_{0.8}Cr_{0.2}$ (ASP) was developed to satisfy the demand in America [7]. This material has many advantages, such as good antifriction behavior, high strength, high wear resistance, good friction consistency and high load-bearing ability, but it has bad plasticity and it is difficult in forming. In the manufacturing process, ASP alloy strip was first fabricated by powder metallurgy or rapid solidification, and rolled into strip by wrapping -rolling with aluminum, then the strip was clad with steel strip by rolling. This complex and expensive manufacturing process limited the application of this material. Also, the bonding strength was not high enough for some harsh applications. The low shear strength resulted from the pure aluminum that existed in the interface between ASP and steel will decrease the service life of the bush.

In China, the development of ASP is slow and lags behind until the liquid-solid roll bonding technology was found. The new technology greatly increases the bonding strength of the interface between aluminum alloy and steel, and succeeds in manufacturing stainless steel strip clad by aluminum and other composite bush materials that composed of steel and ASP alloy [8,9]. However, this ASP alloy is brittle, and it is easy to be broken during the forming process, therefore, it is important to improve the formability of ASP alloy.

2. Experimental process and materials

In this experiment, aluminum alloy samples were prepared by cast-rolling, in which the aluminum alloy solidified during the liquid-solid bond rolling. Figure 1 is the schematic of cast-rolling process. This equipment is also used in liquid-solid bond rolling.

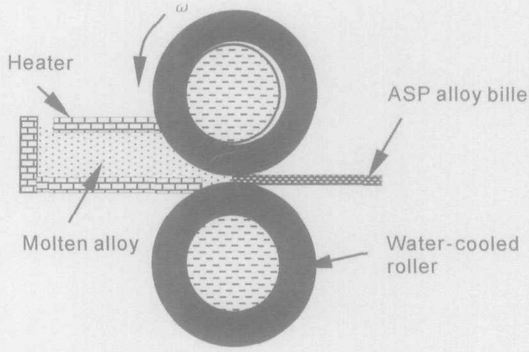

Fig.1 Schematic of cast-rolling process

Experimental aluminum alloys were prepared by melting aluminum, tin, lead, copper, aluminum silicon intermediate alloy, and aluminum chromium intermediate alloy in an induction furnace. Chemical compositions of the experimental alloys are listed in Table 1. After the

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aluminum alloys were rolled into strip by cast-rolling, some samples were prepared from the strip for measuring strength and hardness.

Table 1 Chemical composition of the super-high strength Al alloys (%)

Sample No.	Composition
1	$AlSn_8Si_{2.5}Pb_2Cu_{0.8}Cr_{0.2}$
2	$AlSn_8Si_{1.0}Pb_2Cu_{0.8}Cr_{0.2}$
3	$AlSn_8Pb_2Cu_{0.8}Cr_{0.2}$
4	$AlSn_8Si_{2.5}Pb_2Cu_{1.2}Cr_{0.2}$
5	$AlSn_8Si_{1.0}Pb_2Cu_{1.2}Cr_{0.2}$
6	$AlSn_8Pb_2Cu_{1.2}Cr_{0.2}$
7	$AlSn_8Si_{2.5}Pb_2Cu_{1.6}Cr_{0.2}$
8	$AlSn_8Si_{1.0}Pb_2Cu_{1.6}Cr_{0.2}$
9	$AlSn_8Pb_2Cu_{1.6}Cr_{0.2}$

3. Results and discussion

3.1 Mechanical performance

Figure 2 shows the relationship of hardness to copper content and silicon content, and the relationships of tensile strength and elongation to chemical contents are shown in Figs.3 and 4, respectively.

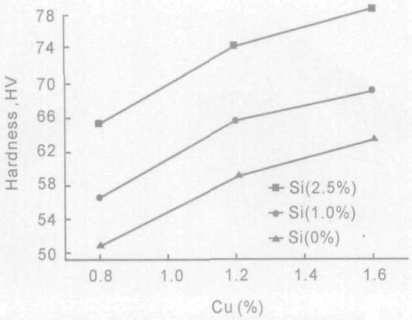


Fig.2 Relationship of hardness to contents of copper and silicon

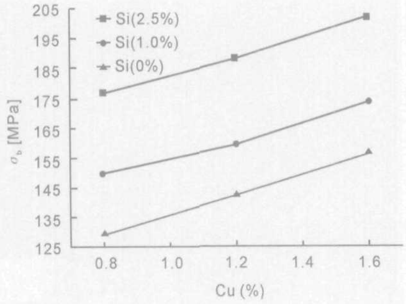


Fig.3 Relationship of tensile strength to contents of copper and silicon

From Figs.2 and 3, we can see that the hardness and tensile strength of the aluminum alloy increased with the increment of silicon and copper contents. On the contrary, the elongation decreases with the increment of copper and silicon content. Results show that $AlSn_8Si_{1.0}Pb_2CU_{1.2}Cr_{0.2}$ has the best general performance among these aluminum alloys. It has the highest elongation while, its hardness and tensile strength are close to those of the other alloys.

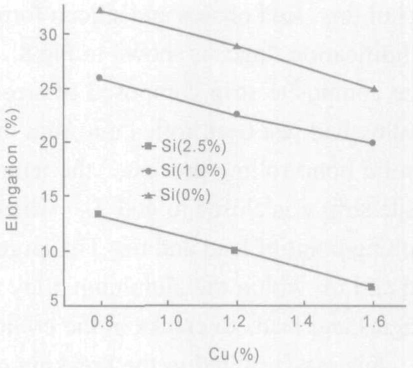


Fig.4 Relationship of elongation to contents of copper and silicon

3.2 Microstructure and distribution of elements

The bad plasticity of $AlSn_8Pb_2Si_{2.5}Cu_{0.8}Cr_{0.2}$ is related to the microstructure of the alloy. Figure 5 is the microstructure of $AlSn_8Pb_2Si_{2.5}Cu_{0.8}Cr_{0.2}$ alloy after clad with steel. From Fig.5, we can see that the microstructure of the alloy contains three zones. The surface zone is composed of fine grains caused by fast cooling of the water-cooled roller, the middle zone close to the surface zone consisted of columnar grains, and the middle zone near the interface is composed of equiaxed crystal grains.

Due to the high silicon content, most of the silicon solidified as eutectic and only very small amount of silicon dissolved in the matrix (see Fig.6), this silicon distribution reduces the alloy performance greatly.

The non-uniform silicon distribution resulted in non-uniform tin and lead segregation. Tin and lead grew around the silicon particles, as shown in Fig.7, and many

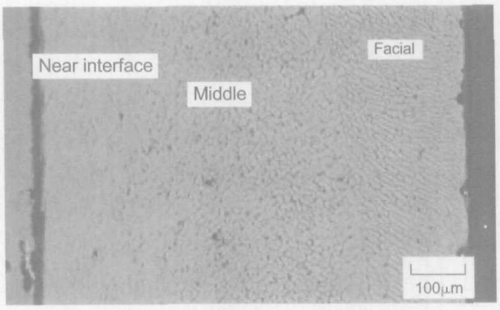


Fig.5 Microstructure of $AlSn_8Si_{2.5}Pb_2Cu_{0.8}Cr_{0.2}$

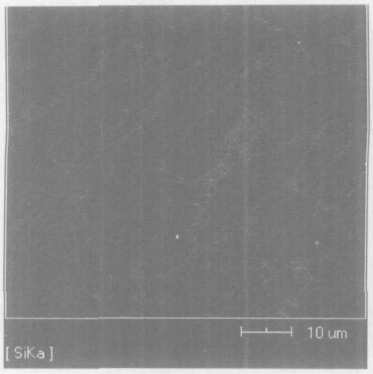


Fig.6 Silicon distribution in the alloy

large blocks of tin, lead phases and silicon formed during the later solidification stage, as shown in Fig.8.

When the composite strip composed of steel strip and **aluminum** alloy had just been rolled out from the roller in the liquid-solid bond rolling process, the temperature of the composite strip was closed to 400 °C, which is higher than the melting point of lead and tin. The large blocks of molten lead and tin within the aluminum alloy may acted as crack origins and leads to cracks in the coiling process (see Fig.9), this may resulted in the breaking of the strip during the bending deformation at ambient temperature, as shown in Fig. 10

From the above results, we can see that the distribution of silicon is important in controlling the distribution of lead and tin. When the composition of the aluminum alloy changed to $AlSn_8 Si_{1.0} Pb_2 Cu_{1.2}Cr_{0.2}$, the silicon distribution became more uniform when compared with those in $AlSn_8Pb_2Si_{2.5}Cu_{0.8}Cr_{0.2}$.

The silicon distribution in $AlSn_8Si_{1.0}Pb_2Cu_{1.2}Cr_{0.2}$ is shown in Figure 11. We can see from Fig. 11 that silicon precipitated uniformly. This silicon distribution will resulted in the spheroidization and better dispersion of tin and lead in ASP alloy, (see Fig. 12).

The better dispersion and the spheroidization of tin and lead will increase the deformation performance of the alloy. Also, the spheroidizated tin and lead precipitated near the surface will enhance the lubrication property of the bush material.

Figure 13 is the microstrucrure of the steel strip clad ASP alloy, from this picture we can see that no obvious precipitation block of lead and tin appeared in ASP alloy layer. Due to the improvement of the microstrucrure, deformation performance of the alloy improved greatly, as shown in Fig. 14. The samples can sustain bending for several times and the best sample broke after bending for 8 times at 180 degree.

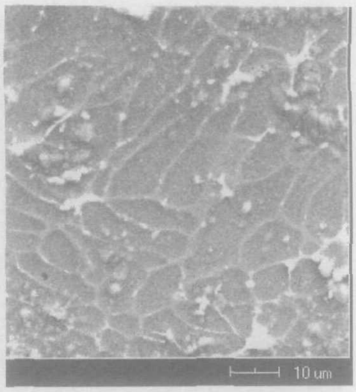


Fig.7 Precipitation of lead and tin

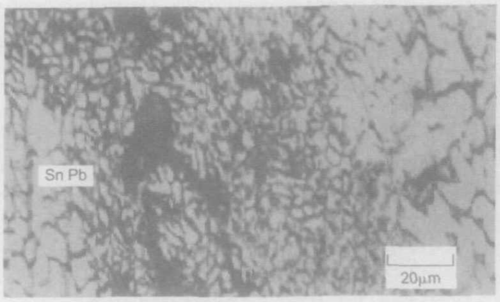


Fig.8 Large segregation block of tin and lead

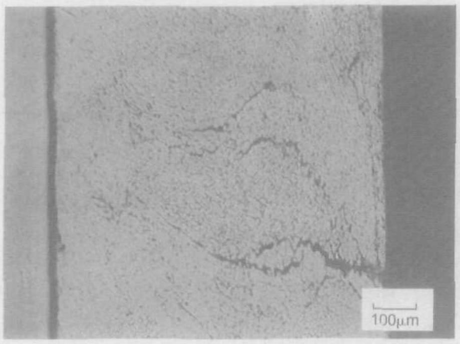


Fig.9 Cracks in the alloy layer when coiled at elevated temperature

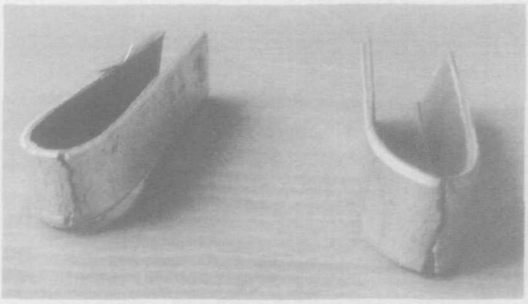


Fig. 10 Bending fractures of $AlSn_8Pb_2Si_{2.5}Cu_{0.8}Cr_{0.2}$ / steel strip at ambient temperature

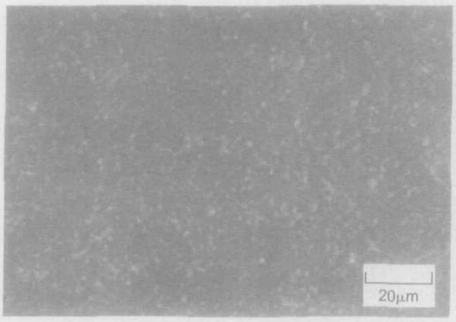
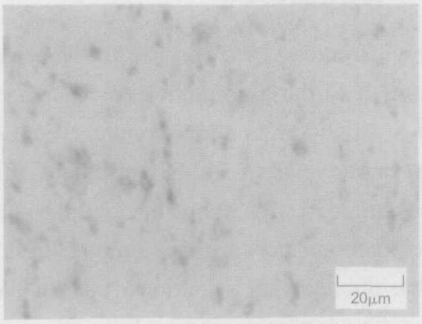
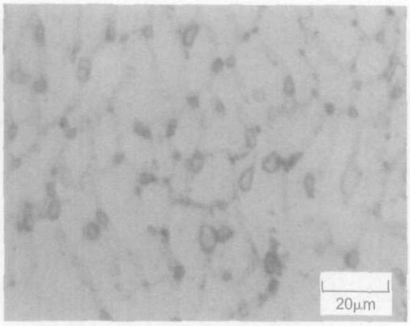


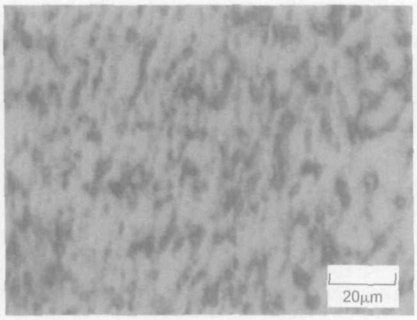
Fig.11 Silicon distribution in $AlSn_8Si_{1.0}Pb_2Cu_{1.2}Cr_{0.2}$



(a) Near the interface



(b) At the middle of the alloy layer



(c) At alloy surface

Fig.12 Microstructure of $AlSn_8Si_{1.0}Pb_2Cu_{1.2}Cr_{0.2}$

Fig.13 Microstructure of the new ASP alloy

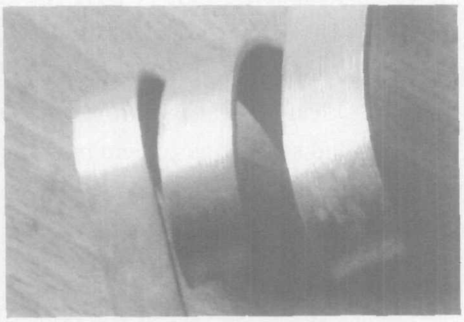


Fig.14 New bush composite strip after bending test

4. Conclusions

By studying the microstructure and performance of ASP alloys, optimal composition of the alloy was determined, and conclusions were drawn as the following:

(1) As the silicon and copper contents increased, the hardness and tensile strength of the alloy increased, meanwhile, the elongation decreased.

(2) The performance of $AlSn_8Si_{1.0}Pb_2Cu_{1.2}Cr_{0.2}$ was better than that of $AlSn_8Si_{2.5}Pb_2Cu_{0.8}Cr_{0.2}$.

(3) The growth of tin and lead phases was based on the core of silicon. In $AlSn_8Si_{2.5}Pb_2Cu_{0.8}Cr_{0.2}$, silicon precipitated as eutectic, and resulted in segregation of large blocks of tin and lead. In $AlSn_8Si_{1.0}Pb_2Cu_{1.2}Cr_{0.2}$, the dispersed silicon precipitation will resulted in the spheroidization and better dispersion of tin and lead in ASP alloy.

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