Effects of rare-earth Y addition on microstructure and mechanical properties of lead-tin bronze

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Abstract: Piston pump rotor is one of the indispensable parts of hydraulic machinery, whose performance and quality determine the drive efficiency and service life of the piston pump. This paper mainly studies the effect of rare-earth yttrium (Y) on the microstructure and properties of the wear layer in piston pump rotor. The material of the wear layer is composed of lead-tin bronze. By adding different contents of rare earth Y, observe the change of microstructure and properties of lead-tin bronze. Through comparison, the addition of rare-earth Y can improve the tensile strength and elongation of lead-tin bronze, and the organization of lead particle morphology has become much smaller and uniformer than that without rare-earth. However, if the amount of rare-earth is too high, the tensile strength and elongation decrease, and the lead particles in the organization also have the tendency to grow up. Finally, it is concluded that when the amount of rare earth is 0.04%, the comprehensive performance is the best.

Key words: lead-tin bronze; rare-earth yttrium (Y); piston pump rotor; hydraulic machinery

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0 Introduction

Copper and copper alloys are widely used in air-conditioning and refrigeration tubes, building pipes, electronic and electrical equipment, aerospace and other fields because of their high thermal conductivity, favorable corrosion resistance properties, good mechanical properties and good processibility[1-3]. However, China suffers from a shortage of copper resources. Therefore, impure copper has been attracting increased attention because of their relative abundance and the urgent need for energy conservation[4]. Yttrium (Y) is the first rare-earth element found in earth, which is always symbiotic with other heavy rare-earth elements in nature. The abundance of Y is higher than mostly heavy rare-earth elements, expect cerium, lanthanum, neodymium[5].

In recent years, the mechanism of rare earth Y in the casting of pure copper has been studied in depth[6]. Rare-earth Y not only can refine the matrix, purify the matrix, remove oxygen, sulfur and other impurities, but also can change the impurity morphology and distribution, and its alloying effect on the improvement of copper performance has been getting more and more attention. The addition of rare-earth Y can improve the high temperature performance and thermal processing properties of copper, reduce the hot cracking tendency of copper, improve the thermoplastic, heat and corrosion resistance[7]. At the same time, the addition of rare earth Y can improve the tensile strength, elongation and hardness of copper, and improve the copper processing performance and weldability. Domestic and foreign researches show that the role of rare earth in the mechanism of copper has not yet been fully understood, and some results for the production also appear to be mature and stable. Therefore, this study is very necessary.

1 Experiment

1.1 Experimental materials

According to the above literature parameters, different contents of Y in the experiment are studied to analyze the effects of rare-earth on the properties of pure copper and copper alloy. However, there were few studies about the effect of rare-earth on

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lead-tin bronze. In this paper, the effects of rare-earth Y on the microstructure and properties of lead-tin bronze are studied. The parameters used in the experiment are mainly based on the parameters in the literature.

In the course of the experiment, domestic $ZCuPb_{20}Sn_5$ alloy is used, whose composition and performance are referred in Tables 1 − 2. The ingredient number is similar to the international brand $CuPb_{20}Sn_5$ and the German brand G-$CuPb_{20}$Sn. The rare-earth Y is added in the form of copper-Y alloy (Y content of 10%).

Table 1 Chemical composition of lead bronze (wt. %)

Cu	Pb	Sn
69.0—76.0	18.0—23.0	4.4—6.0

Table 2 Performance of lead bronze

Density (g/cm^3)	Tensile strength (MPa)	Hardness (HB)	Elongation (%)
9.3	≥150	≥50	≥5

1.2 Experimental methods

A well resistance furnace and graphite crucible for smelting are used in experiment. The 12# graphite crucible is preheated in the furnace (first in furnace temperature of 600 ℃ for 1 h, then 400 ℃ for 1 h, and finally 200 ℃ for 1 h). When using the graphite crucible, it is preheated in a furnace at 600 ℃. The temperature of melting furnace is adjusted to 1 150, 1 200, 1 250 ℃ in turn, so that the furnace temperature rises slowly. Put the pure copper together with the preheated crucible into the melting furnace. When all the copper is melted, add pure nickel into the liquid. After the interval of 5—7 min, half of the phosphor bronze alloy is added into copper liquid to exclude oxygen, and then stir it 30 s with the graphite rod which is preheated at 300 ℃. Then Zn, Pb and Sn are added in the order of the melting point of the alloying element, and add the latter metal after the former one is completely melted. Then the copper-Y rare earth alloy is added in addition to put the refinement for 3—5 min. At last, the remaining 1/2 of the phosphorous copper is added and stirred. After about 3 − 5 min until the temperature reaches to 1 150—1 230 ℃, begin to pour and cast. After placing it for 5 min, the mold is picked up.

1.3 Experimental procedures

Chose the melting temperature under about 1 200 ℃, and the deviation should not exceed 20 ℃. Because the melting point of rare-earth Y is 1 526 ℃, which is lower than the melting point of copper, if add it alone, it is not easy to dissolve, so rare-earth Y is joined in the form of Y alloy. According to the scope of the literature, the initial sets for the experiment are shown in Table 3.

Table 3 Experimental factors and levels

Factor	Added amount of rare-earth Y (%)	Melting temperature (℃)
0	0	1 200
1	0.03	1 200
2	0.04	1 200
3	0.05	1 200

2 Results and analysis

2.1 Mechanical properties analysis

The tensile strength, hardness and elongation at each level measured by the experiment are shown in Table 4.

Table 4 Experimental results of mechanical properties

Content (wt. %)	Casting temperature (℃)	Hardness (HB)	Tensile strength (MPa)	Elongation (%)
0.00	1 200	83.28	213.49	11
0.03	1 200	74.78	239.07	11.05
0.04	1 200	81.66	247.33	16
0.05	1 200	81.5	233.77	10

It can be seen from the experimental data that the tensile strength and elongation of lead-tin bronze are relatively low in the absence of rare-earth elements. With the addition of rare-earth, the tensile strength and elongation increase obviously, which indicates that the addition of rare-earth elements has improved the mechanical properties of lead-tin bronze. When the added contents of rare-earth Y are different, its effects are different. When the amount is 0.03%, the tensile strength and elongation are increasing; When the amount is 0.04%, the tensile strength and elongation continue to increase. Tensile strength increases from 213.49 MPa to 247.33 MPa, and the elongation increases from 11% to 16%. When the amount is 0.05%, the tensile strength and the elongation are lower, and the hardness is also lower. It is shown that when the amount of rare-earth Y is more than 0.04%, the tensile strength and elongation begin to decrease while the hardness is still increasing.

2.2 Metallographic microstructure analysis

Lead-tin bronze is a high-lead bronze, and the distribution of lead particles in its organization directly determines the size of the tensile strength. The smaller the particle size, the better the tensile strength and the higher the elongation. So this experiment is carried out to improve the shape of lead particles. Fig. 1 shows the XRD scanning of the lead-tin bronze.

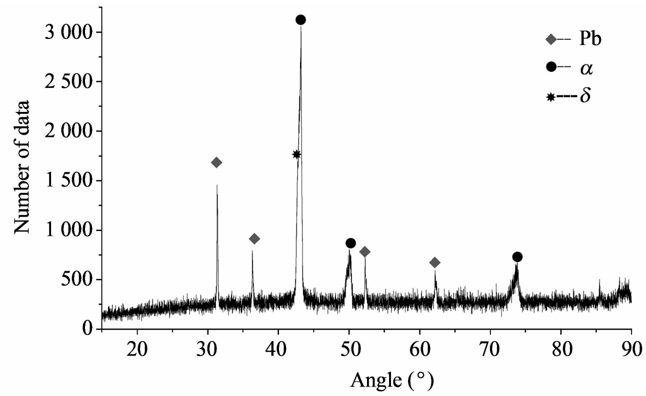
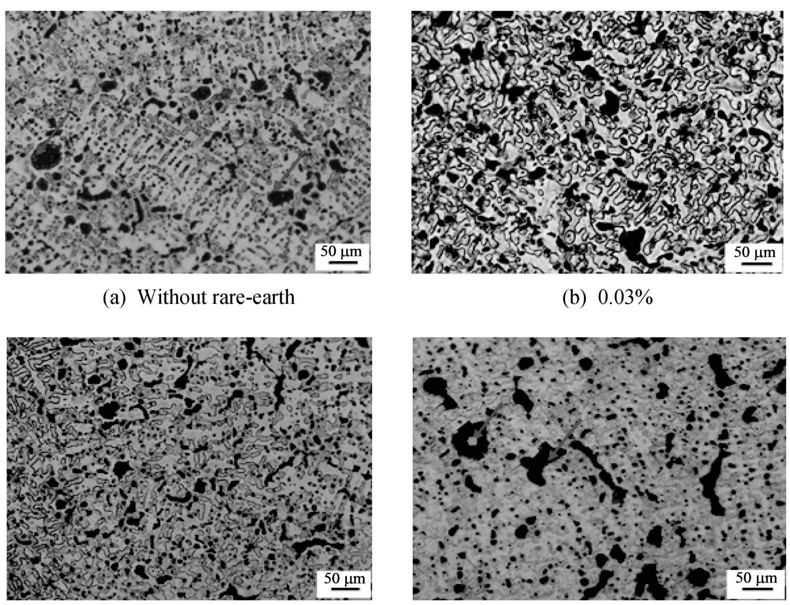


Fig. 1 XRD of lead-tin bronze alloy

From Fig. 1, it can be seen that there are three main phases in the organization, namely α phase, lead phase and the solid δ ($Cu_{31}Sn_8$) phase. The α phase is mainly composed of copper particles, and the δ phase is a solid solution of copper and tin.

Fig. 2 shows the microstructure of lead-tin bronze alloys with different rare-earth contents.

Fig. 2(a) is the microstructure without adding rare-earth, from the the picture magnified 200 times, it can be seen that the organization is fairly uniform, but the columnar crystal area is large. Due to the presence of tin, a large amount of gray massive ($\alpha+\delta$) blocks appear on the white α phase matrix, showing the dendritic arrangement. Black dot particles are unevenly distributed lead particles. Arrows are irregularly shaped holes that are slightly loose. In tin bronze, lead is distributed in the free state between the dendrites or filled with tin bronze that is easy to appear in the micro-loose place, which enhances the casting density.



(a) Without rare-earth (b) 0.03%

(c) 0.04% (d) 0.05%

Fig. 2 Metallographic structure of lead-tin bronze alloy with different rare earth contents

Fig. 2(b) is the microstructure with addition 0.03% of rare-earth Y, from which we can see a large area of lead particles distribution. The size is uneven, but the obvious dendritic segregation can not be seen, and the organization is relatively uniform. The performance has improved, but it is not ideal.

Fig. 2(c) is the microstructure with addition 0.04% of rare-earth Y. The white matrix is the α solid solution, gray segregated dendrites is the tin-rich solid solution, where the white island is $\alpha+\delta$ eutectoid mixture from the columnar region into a small equiaxed crystal. Fine grayish black lead can be seen, and most of the lead particles become smaller, the whole organization is much uniformer.

Fig. 2(d) is the microstructure with addition 0.05% of rare-earth Y. It can be clearly seen that lead particles grow up, and appears a large number of microscopic loose holes. The organization becomes no longer uniform, which results in decreased performance.

From the organization point of view, when adding 0.03%-0.04% of the rare-earth Y, the performance is relatively better, and the content of 0.04% is the best tissue.

3 Conclusion

1) Rare-earth in the high-lead bronze alloy mainly exists in the form of rare-earth lead compounds. It can effectively prevent the proportion of lead in the alloy segregation and reverse segregation, making the lead particles refined and even uniformly distributed, meanwhile improving the tensile strength of the alloy and elongation.

2) Studies have shown that the combination of rare-earth to prevent lead segregation is better than alloying elemental nickel. The addition of rare-earth to the alloy can basically eliminate the columnar crystal region and make it into a small equiaxed crystal structure. However, the excessive addition of the ingot has a decrease in performance.

3) When the amount of rare earth Y is 0.04%, the tensile strength is 247.33 MPa and the elongation is 16%. The morphology of lead particles is relatively small and uniform in the organization form, and there is no columnar crystal region. By experimental analysis, its comprehensive performance is the best.

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稀土钇的添加对铅锡青铜组织性能的影响

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摘　要： 柱塞泵转子是液压机械中不可或缺的重要零件之一，其性能和质量决定了柱塞泵的传动效率和使用寿命。本文主要研究稀土钇对柱塞泵转子中的耐磨层的组织和性能的影响，耐磨层的材质是由铅锡青铜组成，通过加入不同含量的稀土钇，观察铅锡青铜组织和性能的变化. 通过对比得出，稀土钇的添加对铅锡青铜的抗拉强度和延伸率都能有所提高，而且组织中铅颗粒形态也比不加稀土时更加细小、均匀。但是，加入量过高，抗拉强度和延伸率反而有所下降，组织中的铅颗粒也有长大的趋势. 最后得出稀土的最佳添加量为 0.04%时，其综合性能最好。

关键词： 铅锡青铜；稀土钇；柱塞泵转子；液压机械

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