Influence of Er on Microstructure and Properties of Al-0.2%Zr-0.06%B Heat-resistant Alloy Conductor Prepared by Continuous ECAE Forming

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Abstract. By using OP，SEM，double arm direct electric bridge, electronic universal material testing machine and electric heating high temperature drying box instrument. The effect of Er on the properties and microstructures of Al-Zr-B alloy electric conductors was studied. The results show that additive Er can refine the grain of the alloy, increase the strength of the alloy and heat resistance and conductivity after a reasonable heat treatment. Er can react with impurity elements existing in aluminum matrix to form precipitated phase, thereby the effect of impurity elements on the conductivity of aluminum was reduced, their corresponding the electric conductivity and tensile strength improved. When the Al-0.2Zr-0.06B-0.2Er alloy soaked in the temperature of 220℃for 8h, its tensile strength and equivalent conductivity is 218MPa and 59.8%IACS respectively. The complicated properties of Al-Zr resistant alloy wires are improved, this study is of significance.

Introduction

Electric power is the indispensable important energy of national economic development. With the rapid development of economic in our country, the demand for power is greatly increased. Sources of Electricity in our country are mostly concentrated in the west region, but the power needed in the eastern region. So large-scale electric powers must be transmitted with long distance from western china to the eastern, exchange of electric power between south and north and interconnection in the whole country has high demands for wires with saving energy, heat resistance and freeze-proofing. High strength heat resistant aluminum alloy wires with high electric conductivity were used to meet the increase of overhead conductors. However, the resistivity of heat resistant aluminum alloy conductor is too high to fit for the electric power long-distance transmission, so development of high strength with high conductivity heat resistant aluminum alloy wire has become a major task in our country[1-2]. Studies have shown that adding suitable amount of Zr element can effectively improve the recrystallization temperature of aluminum and increase the heat resistance of aluminum. Al-Zr alloy conductors with low content of Zr are not fit for strength requirement for long distance electric power transmission. With the increase of content of Zr, the strength of Al-Zr alloy conductors can be increased with electric conductivity of heat-resistant alloy wire decreased rapidly. It is reported that Er can refine the grain and restrain recrystallization of aluminum alloy[3-6], reduce the effect of impurity elements on conductivity of aluminum substrate, then improved the electrical conductivity. Experiments showed that adds the right amount of Zr and B elements at the same time can improve the thermal stability and electrical conductivity of aluminum alloy wire[7]. Al-Zr-B-Er alloy was selected as experimental electric conductive material in this study, followed by continuous ECAE process. It is hoped to find a new method to produce high electrical conductivity -strength Al-Zr resistant heat aluminum alloy conductor.

The Experimental Materials and Methods

99.7% industrial pure aluminum is used in experiment, its chemical composition as shown in Tab.1. Al-Zr-B-Er alloy was preparing by adding Al-5%Zr, Al-3B% and Al-20Er master alloys, the mass fraction of Er in the alloy were 0, 0.1, 0.2 and 0.3 respectively. Crucible furnace is used in this experiment to melt aluminum alloy. Firstly, the temperature of the crucible was preheated to

730℃ with half an hour holding to make the crucible dry, and then industrial pure aluminum was put in clean crucible to be melted completely, then Al-5%Zr master alloy, Al-3%B master alloy and Al-20Er alloy added one by one with each melted completely. After degassed by using nitrogen, slag was removed, and impurity removed. When the temperature reach to 730℃, liquid alloy were poured into the steel die to produce aluminum alloy bars with water-cooled. After then the bars were homogenized with soaking temperature 510℃ for 6h.Then square samples with a cross section of 12mmx12mm and length of 60mm alloy rods were extruded by using homogeneous bars. Finally, the square bars were extruded by using continuous ECAE extrusion die with the B_C path, the samples were prepared by 3 passes, 4 passes and 5 passes respectively. Specimens observed by using optical microscope and scanning electron microscopy (SEM). the resistance of the samples wrer measured by Using SB2230 type dc digital resistance tester, then it is converted to electrical conductivity of 20℃. the tensile strength of the sample with the extrusion of 4 passes by using SANS CMT5105 testing machine with tensile speed 30 mm/min. Using the JCT-1 type high temperature electric heating oven insulate sample for 1h, the annealing temperature is 230℃, to test the tensile strength of samples under the high temperature and then calculate the survival rate of intensity of the samples.

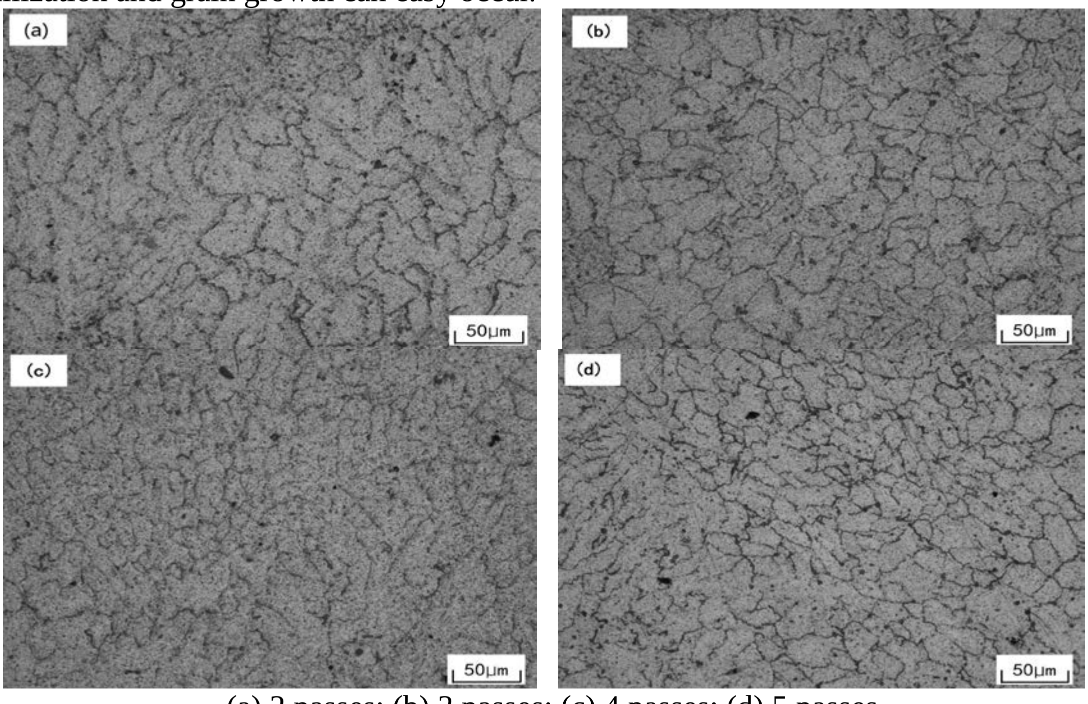
Tab.1 Chemical composition of Al99.70 industrial purity aluminum ingot(Wt,%)

Element	Si	Fe	Cu	Mg	Cr+Mn+V+Ti	Al
Content	0.08	0.13	<0.05	<0.05	<0.022	Bal.

Experimental Results and Analysis

The Influence of Extrusion Times to Al-Zr-B Alloy Grain with the Continuous ECAE

The microstructures of the Al-Zr-B-Er alloy prepared by different ECAE extrusion passes are shown in Fig.1. It can be seen that their grain size decrease with the ECAE forming passes increase, the homogeneity of the grain increase with the ECAE forming passing increase, equiaxed grains of alloy can be obtained by using 4-pass ECAE forming process. The main reason is that the material was seriously sheared by multi-pass EEAE to provide enough energy, so the secondary recrystallization and grain growth can easy occur.

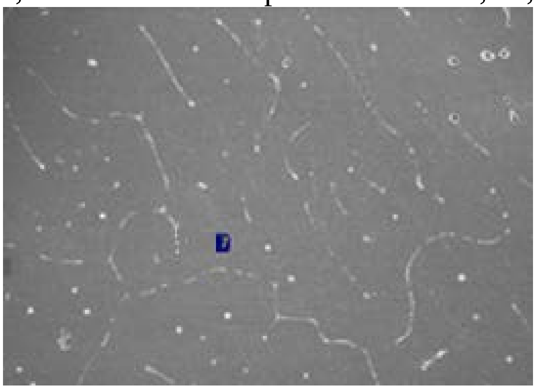


(a) 2 passes; (b) 3 passes; (c) 4 passes; (d) 5 passes

Fig.1 The microstructures of the Al-Zr-B-Er alloy prepared by different ECAE extrusion passes

The Form of the Er

The solid solubility of Er in aluminium alloy is very small, small solid solubility leads to precipitate phase easy to precipitate and there are also many mass fraction of precipitated phase. Fig.3 and Tab.2 are the mass fraction of 0.3% Er which enrichment at grain boundary under SEM and the elements quality score table of EDS. By spectrum Fig.7 point can be seen, this position of Er's mass fraction have reached to 2.935%, far higher than the average mass fraction of 0.3% in the aluminum substrate .Which can be speculated that after Er is added to the Al-Zr-B alloy, when the content of the Er above the solid solubility limit, Er atoms will enrich to the solid-liquid interface which atomic arrangement is irregular. At the same time from Tab.3 can be seen , this position of the Fe's mass fraction is 0.323%, higher than the average mass fraction of 0.13% in aluminum matrix. May be due to the Er has strong surface activity, easy adsorb Fe and other elements of the aluminum substrate and increased the content of Fe and other elements in liquid phase near the interface. So in Al-Zr-B alloy organization, quite a few of the Er supersaturated solid solution in the aluminum substrate, the rest of the compound such as Al, Fe, Er phase exists in the form of grain boundary.



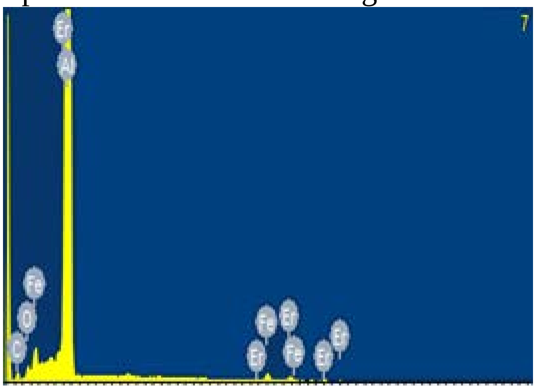


Fig.3 Mass fraction of 0.3% Er enrich at grain boundary under SEM

Tab.2 The energy spectrum analysis of elements composition(Wt,%)

Element	Mass fraction
C	0.051
O	0.057
Al	0.966
Fe	0.323
Er	2.935

The Effect of Er on the Properties of Al-Zr-B Alloy

Tab.3 shows the main chemical composition of specimens, it can be seen that the chemical composition of Zr of specimen1, specimen2, specimen3 and specimen 4 is zero, 0.1%, 0.2% and 0.3% respectively. Fig.3 shows the effects of Zr on the tensile strength (TS) and equivalent electrical conductivity (EEC) of wires respectively. It can be seen that the tensile strength of the wires increases rapidly as the artificial aging starts. As the aging prolongs, the value increases until peak tensile strength, and then the tensile strength decrease (see Fig.3a). However, EEC (see Fig. 3(b)) increases from the beginning of the artificial aging. Because the properties of Al-Zr-B-Er alloy are determined by the hardening-precipitation phases, and the precipitation phase grows with a protracting aging time[8]. The mechanical properties (TS) can be explained by Orowan dislocation mechanism, and the EEC increases due to the diffusion of the solution elements on the free electronics, solution elements precipitated from the Al-Matrix to form hardening phase distributed in grain boundary, hardening phase weakening the diffraction to the electronic movement. It can be seen that the effect of ECAE aging process on TS changes is different from the traditional aging.

The peak strength of specimen prepared by dynamic ECAE can be very quickly and their following TS decrease relatively slowly as aging time prolonging. The reason is that precipitate speed of solution element from Al-Matrix can be accelerated or completely, as well as the nuclei rate and growing speed of hardening phase. For example, the isothermal temperature 220℃, aging for 8h, the TS and EEC of Al-0.2%Zr-0.06B%-0.2Er% alloy conductors(specimen3) is 228 MPa and 58.3% IACS respectively.

Compared with those Al-Zr resistant heat alloy prepared by traditional forming process, the TS and IACS% of the wire prepared by CDECAE followed by a final aging process are higher than that of them. Table 3 shows that with the increase of content of Er, the tensile strength of the alloy increase obviously. with the increase of the content of Er, the conductivity of alloy increase till the content of Er reach 0.2%, the conductivity reach maximum, further add the content of the Er, the conductivity of the alloy reduce instead. Show that when content of Er was 0.2%, the effect of Er on the conductivity of alloy is the most obvious, and the conductivity of alloy is the highest.

Tab.3 Main chemical composition of specimens (Wt, %)

Alloy No.	Er	Zr	B
1	0	*0.2*	0.06
2	0.1	*0.2*	0.06
3	0.2	*0.2*	0.06
4	0.3	*0.2*	0.06

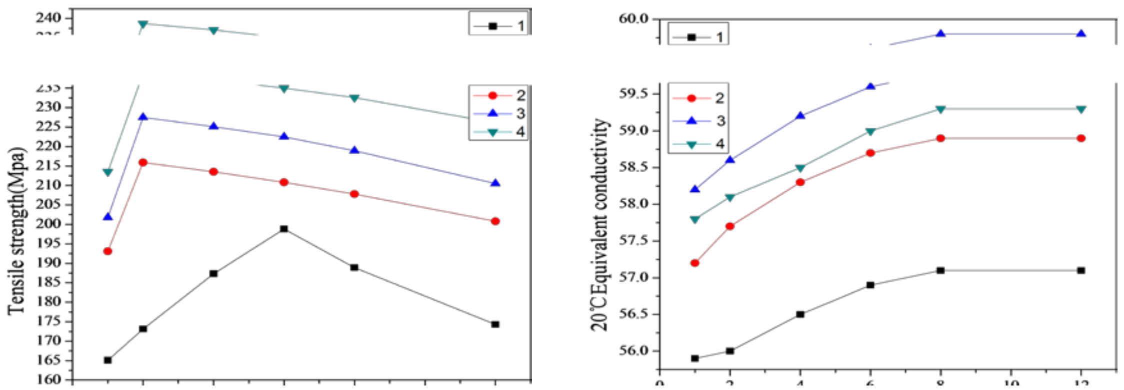


Fig.4 The effect of ageing time on Al-Zr-B-Er alloy performance at 220℃

Tab.4 Electrical conductivities of Al-Zr-B-Er alloy aged at 220℃ for 8h

Style No.	20℃Electrical conductivity/IACS	Tensile strength/MPa	The survival rate of intensity /%
1	57.1	188.9	89.1
2	58.9	207.8	90.7
3	59.8	218.9	91.3
4	59.3	232.6	91.5

It may be found that Er can react with impurities such as Fe, Si, Cr within alloy, then generate sediment precipitate to the bottom of the furnace, reduced the effects of impurity elements on electrical conductivity of aluminum alloy and improved the conductivity. Redundant Er can react with Al forming Al_3Er precipitated phase, Al_3Er precipitate from the alloy firstly, Al_3Zr and $Al_3(ZrEr)$ will also gradually precipitate in the subsequent heat treatment, so EEC of specimens increase with the aging time prolonged.

Conclusion

1) The grain size of Al-Zr-B-Er alloy wires decrease with the ECAE forming passes increase, the homogeneity of the grain increase with the ECAE forming passing increase, equiaxed grains of alloy can be obtained by using 4-pass ECAE forming process.

2) The optimization process for producing Al-Zr-B%-Er% alloy conductors is obtained in this study. When the isothermal temperature 220℃, aging for 8h, the TS and EEC of Al-0.2%Zr-0.06B%-0.2Er% alloy conductors is 218 MPa and 58.3%IACS respectively.

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