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ARTICLE

Influences of Ytterbium on Microstructure and Properties of BAg30 Filler Metals and Brazed Joints

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Abstract: The effects of ytterbium (Yb) on the thermal behavior, wettability, and microstructures of Ag30-Cu-Zn-Sn (BAg30) filler metals were investigated. The shear strength and fracture morphology of brazed joints were analyzed to optimize the filler composition. Results reveal that the addition of 1wt% Yb in BAg30 filler metal can significantly decrease the temperature difference between solidus temperature and liquidus temperature, improve the wettability of filler on the steel substrate, and refine the microstructures. However, the excessive addition of Yb (more than 1wt%) can degrade the properties and coarsen the microstructure. According to the shear strength tests, the BAg30-1wt% Yb brazed joint shows obvious superiority in shear strength and fracture morphology: its shear strength is higher than that of the original BAg30 brazed joint, and the fracture mechanism is ductile fracture, presenting the homogeneous and fine dimples.

Key words: filler metal; brazed joint; wettability; shear strength

Ag-based filler metals have the advantages of moderate melting point (600~790 °C), superior strength, excellent toughness, outstanding electrical conductivity, good thermal conductivity, and fine corrosion resistance, especially the BAg40CuZnCd filler metals, which are widely used in the fields of aerospace, automobile manufacturing, appliance, electric power, and super-hard tools[1,2]. However, the toxicity of Cd can cause adverse effects on human body and environment. Thus, the Ag-Cu-Zn-Sn filler metal becomes one of the ideal substitutes for Ag filler metals containing Cd due to its low melting temperature, good wettability, and fine mechanical properties[3]. Nevertheless, the brazing properties and comprehensive properties of Ag-Cu-Zn-Sn filler metal are inferior to those of the traditional Ag filler metals containing Cd.

Rare earth elements generally have a positive effect on the mechanical properties of metals[4,5]. The effect of rare earth elements on Ag-Cu-Zn-Sn filler metals has been widely studied. Li et al[6] investigated the effect of La content on the shear strength of 20Ag-Cu-Zn-Sn-P brazing joints, and found that La can improve the shear strength of joints. Particularly, when the content of La is 0.5wt% , the maximum shear strength of brazed joints can be obtained. Ma et al[7] studied the influence of Ce on the wettability of Ag17CuZnSn filler metal, and found that a trace amount of Ce can improve the wetting behavior of filler metals on H62 brass and 304 stainless steel. For the molten filler metals, the active Ce can gather on the surface of liquid Ag-based filler metals, which decreases the surface tension. Lai et al[8] also found that Ce can refine the microstructure of Ag30CuZnSn3Ga2In filler metal. In the solder matrix, Ce exists in the form of rare earth phase and acts as the "heterogeneous nucleation" particle, which refines the microstructure of filler metal. In addition to rare earth elements, Ga and In can also affect the microstructure and properties of the Ag-based filler metal. Ga can refine the microstructures of Ag-Cu-Zn-Sn filler metals[9] and accumulate on the solid/liquid interface, leading to the exacerbation of the constitutional supercooling of filler metal. As a result, more secondary dendrite forms and the dendritic spacing reduces. With the addition of 1.5wt%~2wt% In[10], the microstructures become more homogeneous and finer, and the

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wettability of Ag-based filler metals and mechanical properties of brazed joints can be enhanced obviously.

In this research, the effects of Yb on the thermal behavior, wettability, and microstructures of Ag30-Cu-Zn-Sn (BAg30) filler metals were investigated. Besides, the microstructures and shear strength of brazed joints of BAg30-Yb filler metals were also analyzed.

1 Experiment

The pure Sn, Ag, Zn, Cu, and Yb were used as the raw materials, and the filler metals of different components were obtained. Table 1 shows the composition of BAg30 filler metals with different Yb contents. The 315T-type extrusion was used to prepare BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) wire of 3 mm in diameter. The Q235 steel with the dimension of 40 mm×40 mm×2 mm was selected as the substrate.

The STA449 F3 comprehensive thermal analyzer was used to analyze the melting characteristic of the filler metals. The temperature range of the test was 0~900 °C, and the heating rate was 10 °C/min. The filler metals of 0.2 g were placed in the center of the Q235 stainless steel substrate. Then they were put into the vacuum furnace for wettability test. Before the wettability test, the hydrochloric solution was used to remove the oxides from the surface of stainless steel. The spreading areas were analyzed and calculated by Image-J software. Five groups of experiments were conducted and the average value was recorded. The scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS) were used to analyze the microstructure of the BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) filler metals and brazed joints.

SANS universal testing machine was used to measure the strength of BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) brazed joints. The average value of tested results was calculated and used to evaluate the effect of Yb addition. The fracture micrographs of brazed joints were observed by SEM.

2 Results and Discussion

2.1 Effect of Yb on melting temperature of filler metals

Fig.1 shows the thermal behavior of BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) filler metals. The results indicate that the temperature difference between the solidus temperature and liquidus temperature is decreased with increasing the Yb content. Compared with that of BAg30 filler metal, the temperature difference of BAg30-1Yb filler metal is decreased by 29.5%. It is known that the decrease in temperature difference is beneficial to the wetting behavior of the filler metal.

Table 1 Composition of BAg30-*x*Yb filler metals (wt%)

Specimen	Ag	Cu	Zn	Sn	Yb
30Ag-Cu-Zn-Sn	30	Bal.	31	1	0
30Ag-Cu-Zn-Sn-0.5Yb	30	Bal.	31	1	0.5
30Ag-Cu-Zn-Sn-1Yb	30	Bal.	31	1	1
30Ag-Cu-Zn-Sn-2Yb	30	Bal.	31	1	2
30Ag-Cu-Zn-Sn-5Yb	30	Bal.	31	1	5

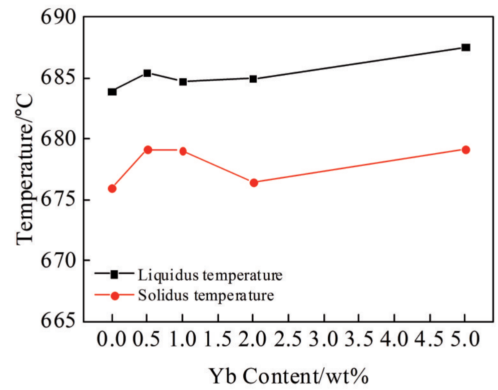

Fig.1 Thermal behavior of BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) filler metals

According to Fig.1, adding 1wt% Yb can obviously decrease the temperature difference of BAg30 filler metal, which can improve the wettability of BAg30 filler metal on substrates. However, when the Yb content is 2wt% and 3wt%, the temperature difference is increased obviously.

2.2 Effect of Yb on wettability of filler metals

Fig.2 reveals the spreading area of BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) filler metals. It is found that the proper Yb addition can enhance the spreading area of BAg30 filler metal. When the Yb content is 1wt%, the spreading area of filler metal is increased by 3.5% (from 285 mm^2 to 295 mm^2), indicating that the optimal wettability of filler metals can be obtained with the addition of 1wt% Yb. Doped Yb reacts with Sn, forming tiny $YbSn_3$ particles inside the filler metal. The tiny $YbSn_3$ particles can change the liquid-solid-gas three-phase balance of the liquid solder, thereby reducing the surface tension[11]. With increasing the Yb content, the spreading area of BAg30 filler metal is decreased linearly. Meanwhile, compared with that of BAg30 filler metal, the spreading area of BAg30-5Yb filler metal is decreased remarkably from 285 mm^2 to 218 mm^2. During the brazing process, the excessive Yb can easily react with oxygen to form the oxide films or oxide slags, thereby reducing the fluidity of the filler metal.

2.3 Effect of Yb on microstructure of filler metals

Fig.3 shows the microstructures of BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) filler metals. As shown in Fig.3a, the microstructure of

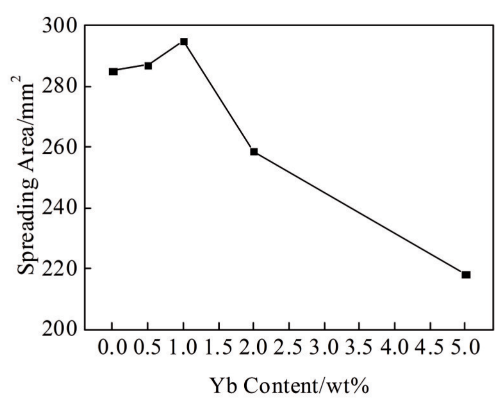

Fig.2 Spreading areas of BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) filler metals

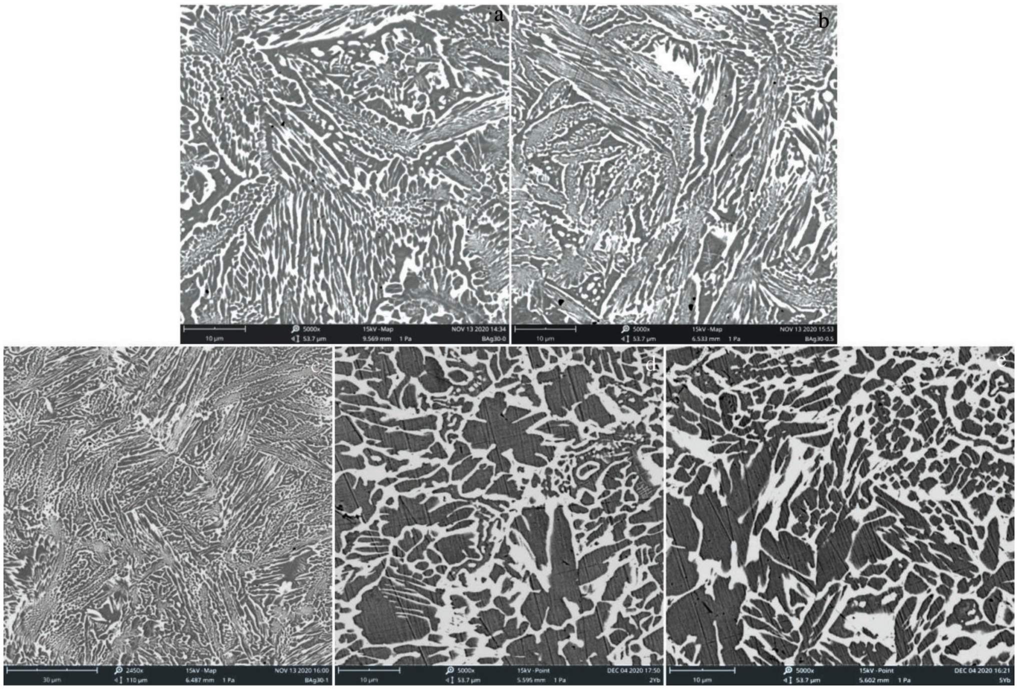

Fig.3 Microstructures of BAg30-*x*Yb filler metals: (a) *x*=0, (b) *x*=0.5, (c) *x*=1, (d) *x*=2, and (e) *x*=5

BAg30 filler metal is composed of Ag solid solution, Cu solid solution, and Cu-Zn compound phase. The matrix structure of original BAg30 filler metal is relatively coarse, the distribution of Ag-based solid solution and Cu-based solid solution is uneven, and obvious eutectic particles can be observed in the local areas. After the Yb addition, Fig.3b and 3c show that the Cu-Zn compound phases gradually become fine and dispersive. Particularly, the BAg30-1Yb filler metal shows a uniform and fine structure, which can be explained by the absorption of Yb with a high surface free energy on the grains during solidification[12]. Moreover, when the Yb content exceeds 1wt%, the microstructures of Ag-based filler metal become coarser, as shown in Fig.3d and 3e.

2.4 Microstructure of brazed joints

Fig.4 illustrates the microstructures of the BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) brazed joints. The microstructure of the BAg30 brazed joint is composed of Cu-Zn compound phases, which is similar to the results in Ref.[13]. As shown in Fig.4a and

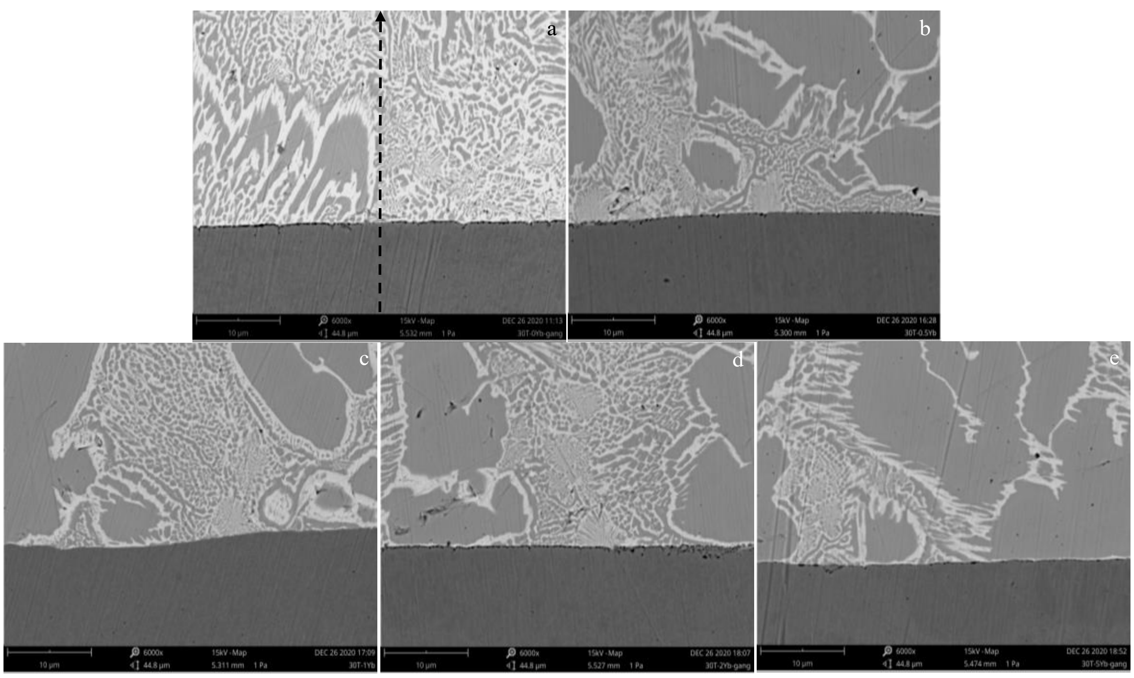

Fig.4 Microstructures of BAg30-*x*Yb brazed joints: (a) *x*=0, (b) *x*=0.5, (c) *x*=1, (d) *x*=2, and (e) *x*=5

4b, some pores can be found at the filler metal/substrate interface, which has a passive effect on the mechanical properties of brazed joints. No pores can be observed at the interface between BAg30-1Yb filler metal and substrate, indicating a reliable connection between BAg30-1Yb filler metal and steel substrate. It is clear that no intermetallic compounds can be found in the interface layer. The EDS line scanning was used to detect the components at interface between BAg30 filler metal and steel substrate, as indicated by the arrow in Fig. 4a. According to Fig. 5, it can be concluded that no remarkable element diffusion occurs between the filler metal and the steel substrate. However, due to the existence of Fe and Mn elements in Q235 steel and that of Cu and Zn elements in filler metal, Mn is solid-soluble in Cu, Zn is solid-soluble in Fe, and a small amount of Fe and Cu is solid-soluble into each other. Thus, during the long-term service, the solid solutions will appear in the interface. The interface microstructures are important for brazing[14] and soldering[15], which should be further discussed.

2.5 Effect of Yb on mechanical properties of brazed joints

Fig. 6 reveals the influence of Yb on the shear strength of BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) brazed joints. It can be seen that 0.5wt%, 1wt%, and 2wt% Yb can improve the shear strength of BAg30 brazed joints. After the addition of 2wt% Yb, the maximum shear strength of 182.2 MPa can be achieved. However, when the Yb content exceeds 2wt%, the shear strength of BAg30-*x*Yb brazed joints is decreased obviously. This phenomenon is related to the fracture mode of brazed joints. Fig. 7 shows the fracture morphologies of BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) brazed joints. According to Fig. 7a, a cleavage structure can be observed, suggesting the typical cleavage fracture of BAg30 brazed joint. Many uniform dimples appear in the fracture morphology of BAg30-*x*Yb joints, indicating that the fracture mode changes with the Yb addition.

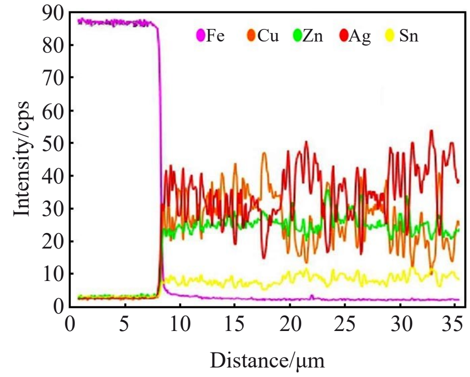

Fig.5 EDS line scanning along the arrow marked in Fig.4a

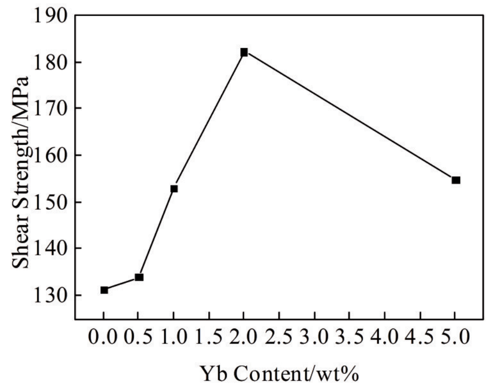

Fig.6 Shear strengths of BAg30-*x*Yb (*x*=0, 0.5, 1, 2, 5) brazed joints

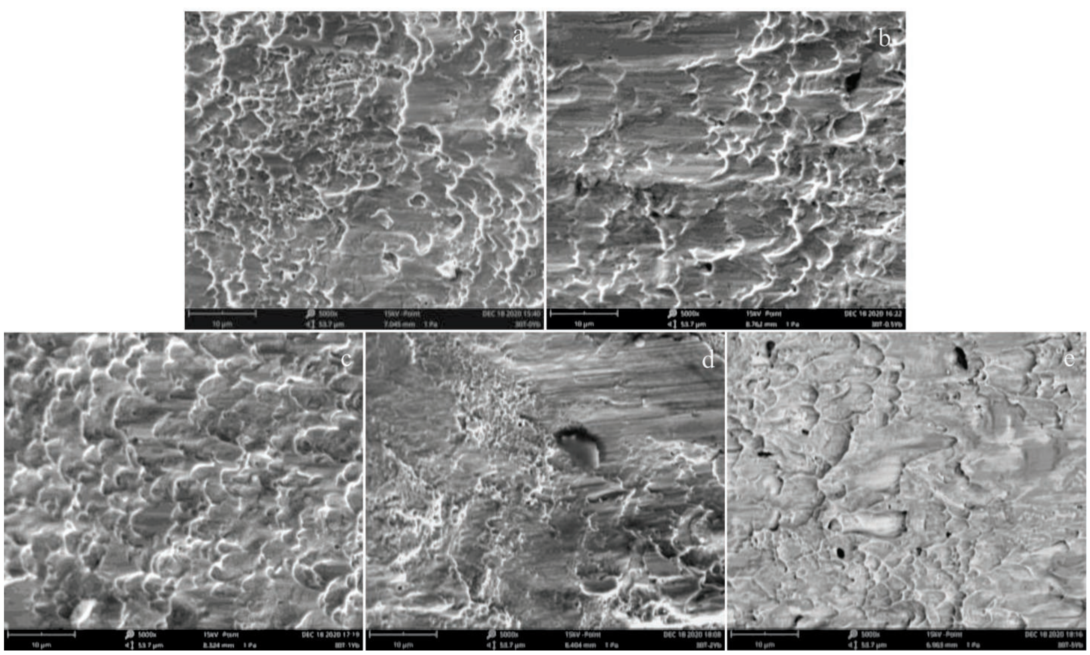

Fig.7 Fracture morphologies of BAg30-*x*Yb brazed joints: (a) *x*=0, (b) *x*=0.5, (c) *x*=1, (d) *x*=2, and (e) *x*=5

3 Conclusions

1) The addition of 1wt% Yb can decrease the temperature difference between solidus temperature and liquidus temperature of Ag30-Cu-Zn-Sn (BAg30)-Yb filler metals. The wettability of BAg30-Yb filler metal on steel substrate is improved after the addition of 1wt% Yb.

2) The microstructures of BAg30 filler metals can be refined after addition of 1wt% Yb. The matrix microstructure is composed of Ag solid solution, Cu solid solution, and Cu-Zn compound phase.

3) After the Yb addition, the fracture morphology of BAg30-Yb brazed joints changes and shows uniform dimples. The BAg30-2Yb brazed joint has the maximum shear strength.

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Yb元素对BAg30硬钎料及焊点组织与性能的影响

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摘　要：研究了Yb元素对Ag30-Cu-Zn-Sn（BAg30）钎料热性能、润湿性和微观组织的影响，分析了焊点的剪切强度和断口形貌，优化了钎料组分。结果表明，BAg30钎料添加1%（质量分数，下同）Yb后可以显著降低钎料液相线-固相线差值，促进钎料在钢基板表面的润湿性，细化微观组织。然而，当Yb添加量超过1%后，过量的Yb元素会降低钎料的性能，粗化微观组织。通过焊点剪切测试，BAg30-1% Yb钎料的焊点抗剪切强度和断裂形貌表现出明显的优越性，抗剪切强度相较于BAg30钎料焊点明显提高，断口形貌出现均匀细小的韧窝，表现为韧性断裂机制。

关键词：硬钎料；焊点；润湿性；抗剪切强度

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