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EFFECT OF TWO KINDS OF WELDING WIRE ON MECHANICAL PROPERTIES OF COPPER JOINTS

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Abstract. In this paper, aiming at the problems of solidification crack and strength loss, special experiments for copper welding were employed depending on the deoxidation characteristics of the HS201 filler metal and excellent high-temperature performance of Ni-contained B30 welding wire. Through investigating the plasticity, high-temperature strength and ductility of the two kinds of filler metal, the effects of the different filler metal on the T2 copper joints are compared and analyzed, meanwhile, the analysis of the bending property, high temperature tension performance and microstructure of the two joints shows that the strength and ductility of the joints with B30 filler metal are superior to the ones with HS201, for the former, there does not exit defect such as welding cracking, in addition, the welded seam is well fused with the parent metal, thereby problems such as welding joint strength loss and hot cracking have be solved, which provides an effective way of obtaining high-quality copper joint.

1. INTRODUCTION

Due to high thermal conductivity and eutectic, fusion difficulty and hot crack are the main technological bottlenecks for copper welding. The both problems are particularly prominent in the case of thick and large pieces welding. Currently, the main way of solving the problem is preheating, and usually, the preheat temperature is over 500°, which causes not only poor welding conditions, long manufacture cycle and high cost, but also coarse grain and strength loss [1]. The hot cracking susceptibility of copper is closely associated with oxygen content to a large extent. The interaction between copper and oxygen starts at room temperature, the black CuO coating is formed on the copper surface when copper is heated up to 100 °C, and then at high temperature, the oxidation ratio increased sharply and dense red Cu_2O oxidation film is formed on copper, meanwhile, CuO would not exist which decomposes into Cu_2O and Cu completely at high temperature. Cu_2O and Cu can form eutecticCu_2O+Cu of which the eutectic temperature is 1065 °C and below the melting point of Cu 1083 °C. Due to the eutectic distributed in grain boundaries during weld metal solidification, intergranular bonding force of copper is weakened greatly, therefore, the plasticity of the joint decreases significantly. In addition, copper has high coefficient of linear expansion and shrinkage rate, hence, rather large tensile strain would be generated during cooling and solidification process, and then result in solidification crack which would also degrade the mechanical performance of the joint remarkably [2-6].

Based on the problems of solidification crack and strength loss, in this paper, the deoxidization

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Table 1. Chemical composition and melting point of HS201.

Element	Si	Mn	Sn	Cu	Melting point
Content (wt.%)	0.3	0.3	1.0	Rem.	1050 °C

Table 2. Chemical composition and melting point of B30.

Elenemt	Cu	Ni	Fe	Ti	Melting point
Content (wt.%)	60	27	trace amount	trace amount	1238 °C

Table 3. Welding parameters for HS201 and B30.

Filler metal	Welding method	Current I/A	Protecting gas flow Q/L•min^{-1}	Groove type Type V
HS201	Manual TIG	220	5	70°
B30	Manual TIG	210	5	45°

character of HS201 filler metal and excellent high-temperature behavior of Ni-contained B30 filler metal were employed to conduct the special experiments for copper welding. Through investigating the plasticity, high-temperature strength and ductility of the two kinds of filler metal, mechanical property characteristics of the two kinds of joints were analyzed carefully, and the strengthening mechanism of the joint by fracture morphologies analysis and microstructure observation were interpreted. Finally, an effective way of obtaining high-quality copper joint was provided.

2. EXPERIMENTAL MATERIAL

The base metal used for this work is T2 type copper, the filler metals are HS201 and B30, and the chemical composition of the two wires are given in Table 1 and Table 2, respectively.

The size of specimen was 220 mm×120 mm×48 mm, as illustrated in Fig. 1 by means of multi-pass weld, and preheat temperature was 650~800 °C for HS201. Welding parameters for HS201 and B30 are shown in Table 3.

3. EXPERIMENTAL METHOD

3.1. Bending test

Comparison of bending test of HS201 and B30 welded joints were shown in Fig.2, from which crack can be detected for HS201 welded joints when the joint was bended to about 70°, while the B30 welded joint was bended to 180°, there was a small crack on the joint, which showed that plasticity for B30 welded joint is much better than that for HS201 welded joint.

3.2. Measurement of elevated temperature mechanical properties

The weldability of the material is closely related to the elevated temperature mechanical properties, hence the mechanical properties of copper weld metal in brittle temperature range(BTR) is crucial to hot cracking, and elevated temperature strength and ductility are the most critical performance criterions, therefore, tensile test at high temperature for the two kinds of welded joints were performed under seven temperature: 200, 300, 400, 500, 600, 700, 750 °C, three samples were taken for each temperature, and the three series of experiments results from the tests were averaged and compared. The elevated temperature strength of copper can be obtained from literature [1], 80% of which can be taken as the comparison data(In many areas of

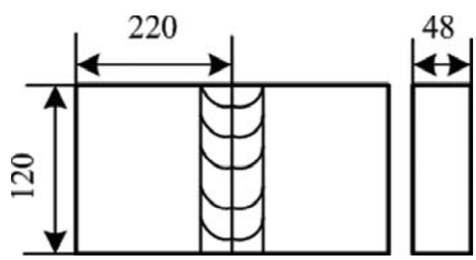

Fig. 1. Dimension of workpiece.

Table 4. High-temperature tensile strength test results of base metal and HS201 and B30 welded joints.

Filler metal		Tensile strength /MPa							
		20 °C	200 °C	300 °C	400 °C	500 °C	600 °C	700 °C	750 °C
B30	1	220.1	168.2	160.2	116.8	104.9	63.6	37.5	29.1
	2	226.7	187.6	160.8	130.8	101.0	64.0	36.3	26.1
	3	225.0	181.3	153.8	132.8	108.8	57.2	37.1	27.9
	mean value	223.9	179.0	158.3	126.8	104.9	61.6	37.0	27.7
HS201	1	defects	defects	117.5	defects	32.2	43.8	21.1	14.5
	2	defects	defects	127.3	46.3	defects	defects	35.6	18.4
	3	181.9	151.0	defects	102.2	85.3	19.3	38.0	27.2
	mean value	181.9	151.0	122.4	74.2	58.5	46.5	31.6	20.0
T_2	1	215.0	185.0	150.0	123.0	75.0	50.0	35.0	20.0
$0.8\ T_2$	1	172.0	148.0	120.0	98.4	60.0	40.0	28.0	16.0

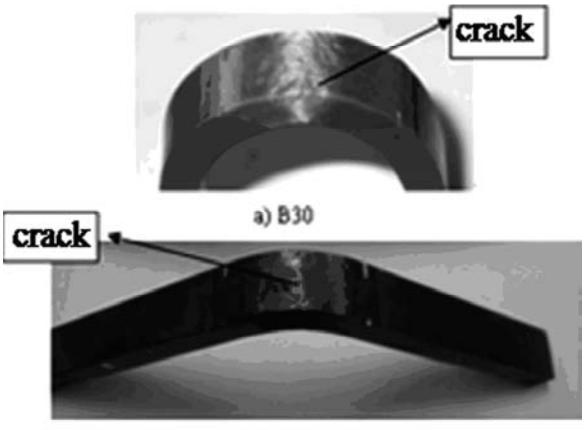

Fig. 2. Comparison of bending test of HS201 and B30 welded joints.

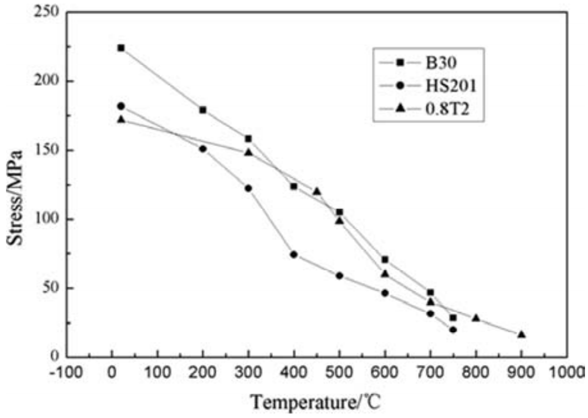

Fig. 3. Curves of tensile strength with temperature for base metal and HS201 and B30 welded joints.

engineering application, when tensile strength of copper welded joint reaches 80% of that of base metal, the acceptance criteria will be accepted.). The experiment results are listed in Table 4, and comparison of the curves for the three cases are illustrated in Fig. 3.

As shown in Fig. 3, it can be seen that the change of elevated temperature mechanical properties of T2 type copper, HS201 welded joints and B30 welded joints are similar, all of them increase as temperature rising. When temperature is under 350 °C, B30 welded joints demonstrate excellent strength, and exceed the one of base metal, while over 350 °C, strength of the two cases are close. When temperature is between 200-600 °C, tensile strength of HS201 welded joints decreases quickly, that is far smaller than B30 welded joints, which can reach the anticipated 80% strength of base metal. When over 600 °C, however, elevated temperature strength of the three decrease greatly and the strength is between 20-50 MPa, and the one of HS201 welded joints is the lowest, about 6 MPa and 10 MPa lower than B30 welded joints and 80% strength of base metal, on average, respectively. In conclusion, elevated temperature strength of B30 welded joints is far greater than HS201 welded joints, and closes or even exceeds 80% strength of base metal.

3.3. Analysis of fracture and contraction

Fig. 4 shows fracture of HS201 and B30 welding joints at room temperature. As it can be seen in Fig. 4, fracture of B30 welding joints located in base metal, and accompanied with necking, however HS201 welding joints fractured at the welded seam

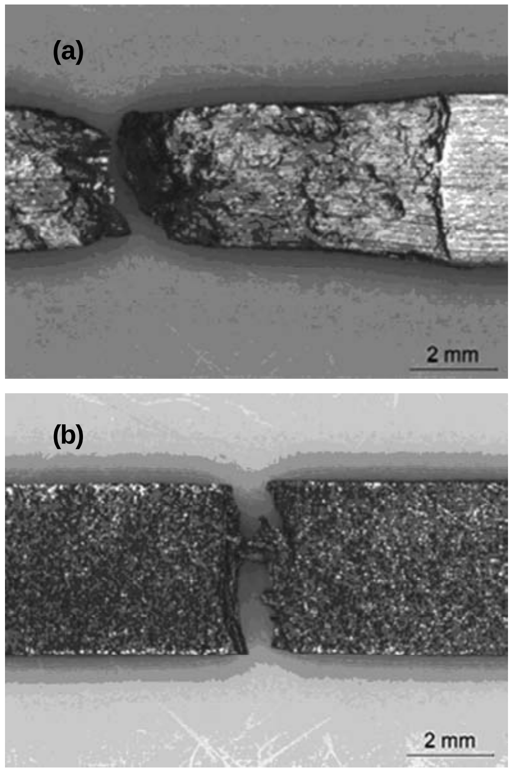

Fig. 4. Fracture of B30 and HS201 welding joints at room temperature: a) B30 welding joint; b) HS201 welding joint.

without necking. Macro-fracture of HS201 and B30 welding joints at 500 °C was illustrated in Fig. 5, which demonstrated that B30 welding joints fractured at base metal also, similarly, fracture of HS201 welding joints occurred in welded seam. Fig. 6, which shows micro-fracture of HS201 and B30 welding joints at 500 °C, it is can be seen that when B30 welding joints fracturing at base metal, severe necking occurred in copper, while there is not apparent necking observed. There are similar cases for the other temperatures.

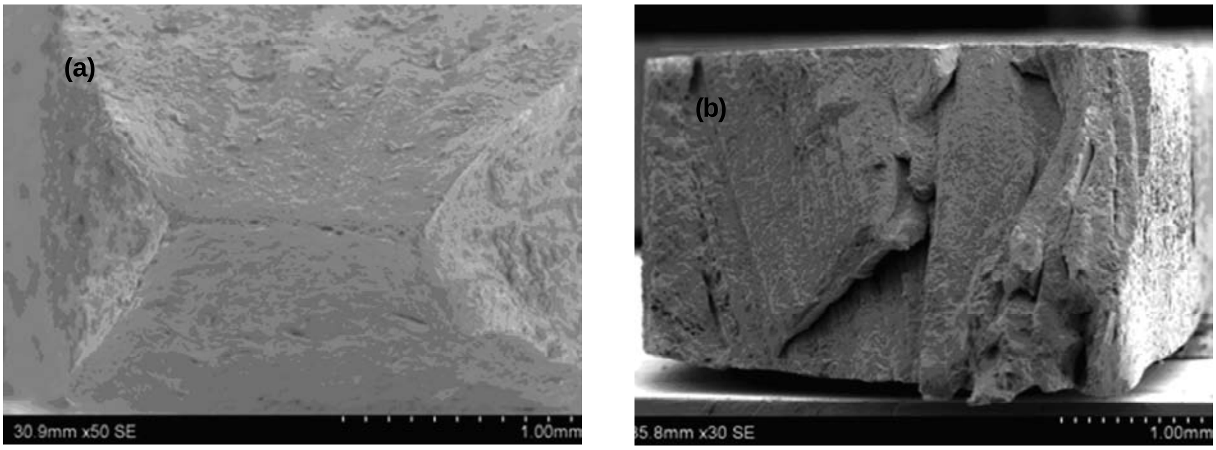

Fig. 5. Macro-fracture of B30 and HS201 welding joints at 500 °C: a) B30 welding joint; b) HS201welding joint.

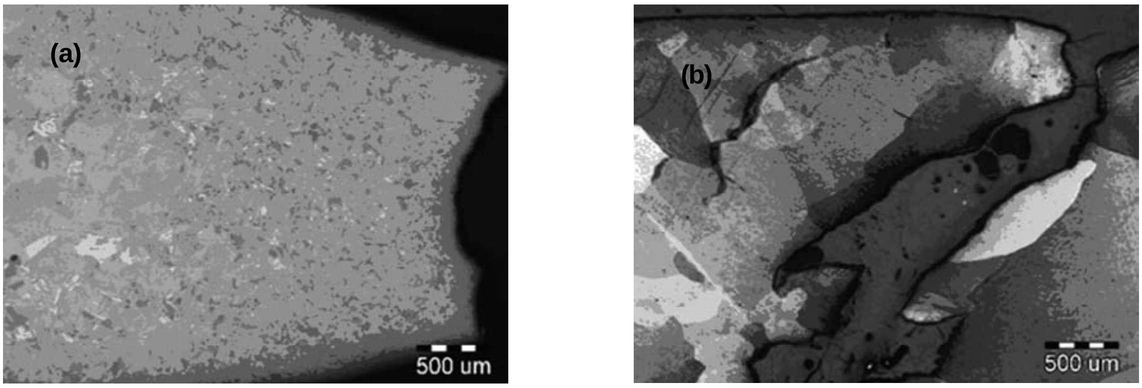

Fig. 6. Micro-fracture of B30 and HS201 welding joints at 500 °C: a) B30 welding joint; b) HS201 welding joint.

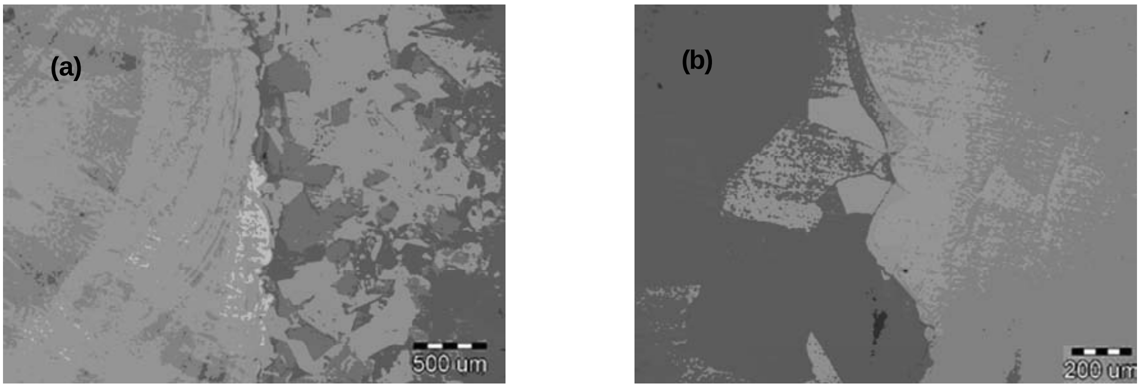

Fig. 7. Microstructure of B30 welding joint in fusion zone: a) Low magnification; b) High magnification.

From above analysis, no matter what temperature is, room temperature or high temperature, strength of B30 welding joints are larger than that of base metal, and deformation concentrated in base metal and HAZ during tensile process, while little deformation occurred in B30 welding seam. Regular fracture of HS201 welding joints located in welding seam with no plastic deformation. It is verified that strength and plasticity of B30 welding joints are superior to HS201 welding joints

4. MICROSTRUCTURE OF B30 WELDING JOINTS

Microstructure of B30 welding joint in fusion zone is shown in Fig. 7, and Fig. 7b is the magnification of Fig. 7a. As shown in Fig. 7, the welded seam is well fused with the base metal, no defect such as crack and inclusion are observed, and Fig. 8 illustrates microstructure of B30 welding joint in weld zone, from which lack of fusion, crack and inclusion can be detected.

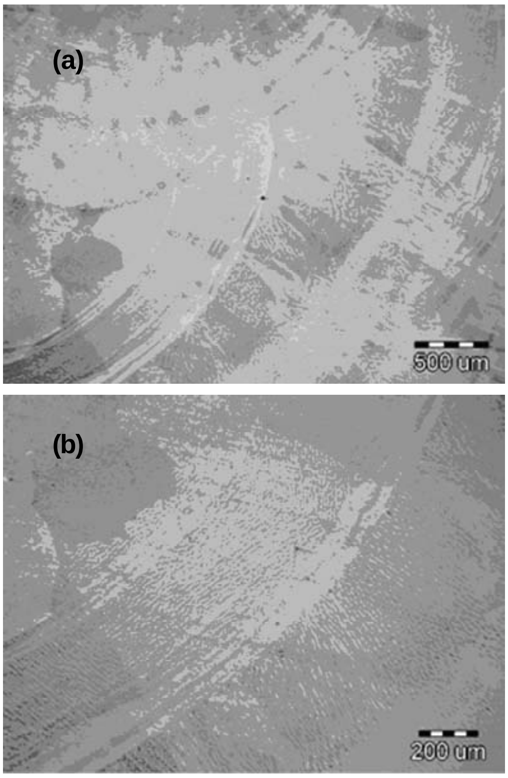

Fig. 8. Microstructure of B30 welding joint in weld zone: a) Low magnification; b) High magnification.

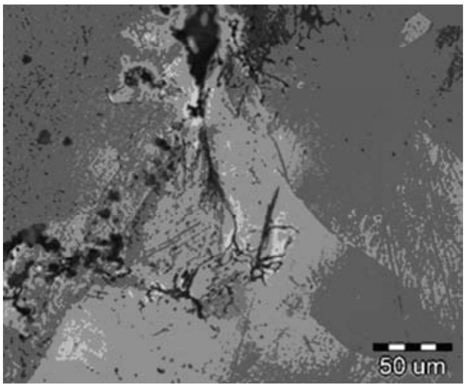

Fig. 9. Hot cracking in HS201 welding joint.

Following explanation may be reasonable for the results. For B30 welding joint, there is not the conditions of forming more eutectic (Cu_2O+Cu) during welding process, compared with HS201 welding joint, B30 welding joint has better weld crack sensitivity, and coupled with the strengthening effect of Ni, therefore the welding joint has better resistance to plastic deformation both at room temperature and elevated temperature. Due to the high strength of B30 welding joint, deformation and fracture are far away from welding seam under stretching at different temperature, and the weak areas disappear, so crack would not initiate. However, the case for HS201 welding joint is different. Owing to Cu which is the main element in welding seam, although additional small amounts of deoxidizing elements, oxygen can't be effectively avoided to get into the high temperature molten metal, it is easy to form eutectic (Cu_2O+Cu) during solidification which weakens grain boundary. Under tensile stress, many microcracks initiate, even generate larger macro hot crackings, hence, welding seam becomes the weakest zone in the joint. For such joints, strength, plasticity and ductility are difficult to ensure, necking would only occur in good-plasticity and crack-free welding joints.

5. CONCLUSIONS

(1) When welding copper with B30 filler metal, strength of the joints approximates to or even exceeds 80% of high temperature strength of base metal, and are much better than HS201 welding joints.
(2) Bending test results of welding joints show that ductility of B30 welding joint is far higher than HS201 welding joint at room temperature, and corresponding cold-bending angles reach 180 and 70 °C respectively.
(3) High temperature tension test results show that B30 welding joints fracture at base metal with apparent necking, and strength of B30 welding joint is superior to base metal apparently, however, for HS201 welding joint, fracture locates in welding seam or fusion line, and no apparent necking is observed, high temperature strength of welding seam is inferior to base metal.
(4) Microstructure of B30 welding joint is fine enough, no crack is detected, and the joint processes good performance. However, it is a different case for HS201 welding joint. Due to Cu which is the main element in welding seam, although additional small amounts of deoxidizing elements, oxygen can't be effectively avoided to get into the high temperature molten metal, it is easy to form eutectic (Cu_2O+Cu) during solidification which weakens grain boundary. Under tensile stress, many microcracks initiate, meanwhile, lack of fusion and inclusion exists hence, welding seam becomes weakest zone in the joint.

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