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N_2-Ar Gas Tungsten Arc Welding of Copper Plates Using Cu-xTi Welding Alloys

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Abstract: The N_2-Ar Gas Tungsten Arc (GTA) welding of copper plates without preheating using Cu-xTi welding alloys was investigated. The microstructure of the welds was observed and mechanical performance of weld metal was tested by using Cu-xTi welding materials with different ratio of Ti. The numerical simulation of temperature and stress distribution of the copper plates by using N_2-Ar and Ar shielding arc welding was carried out. And it can be found that the N_2-Ar GTA welding of copper thick plates without preheating can be carried out successfully. The addition element Ti in welding materials can eliminate the nitrogen porosities in the weld metal which is caused by N_2 in the shielding gas. Element Ti reacts with nitrogen ions which dissolved in weld metals at higher temperature to form TiN and TiN particles flow up to the surface of the welding pool and exist in weld slag after solidification. It can also be found that the elimination degree of nitrogen porosities, the distribution of the second phases and the mechanical properties of the welds are associated with the change of the Ti content in the welding alloys. And when Ti 5.5 wt (%) is selected, nitrogen porosities are eliminated completely and the second phase are distributed dispersedly, the tensile strength and impact ductility of the welds achieve the best result, which almost reaches the lever of the base metal.

Key words: Copper, N_2-Ar mixed gas, Cu-xTi welding alloys, nitrogen porosity

INTRODUCTION

Copper materials which have been widely used in thermal exchangers, electric wires, containers and conduit pipes have the advantages of high thermal and electrical conductivity, perfect plastic property and high corrosion resistance. Gas Tungsten Arc (GTA) welding is the most popular welding technique to weld copper compared with electron beam welding, laser welding (Biro *et al*., 2002) and friction stir welding (Lee and Jung, 2004). It is necessary to preheat the copper plates up to 400°C when using Ar-GTA welding (Wegrzyn, 1993) and preheating is also needed using He-GTA welding of the thickness of 5 mm and more (Dawson, 1973).

N_2-Ar mixed gas was selected as shielding gas to realize thick copper plates welding without preheating and found that many of holes increased with the increasing ratio N_2 in shielding gas (Kuwana *et al*., 1986). Former research draw a conclusion that these holes were generated by the N_2, which named as nitrogen porosity. Then, in order to eliminate the nitrogen porosities, Kuwana used Cu-Ti welding materials to weld copper plates and the nitrogen porosities decreased at some degree. But some further explanations such as how to eliminate the nitrogen porosities, the temperature and stress distributions of the joints by using the mixed shielding gas during welding, the microstructures and mechanical performance of the weld metals were not carried out yet (Zuo *et al*., 2012).

As the N_2 has the advantages of high thermal input and low cost, the N_2-Ar gas selected as shielding gas during arc welding without preheating were carried out and Cu-xTi welding alloys were used as filler materials. This work emphatically investigates the influence of Ti in welding metal on the macro and micro structures and mechanical performance of the welds. In this research, the numerical simulation of temperature distribution and transverse stress by using Ar and N_2-Ar shielding arc are calculated firstly and the mechanical performances were carried out finally.

EXPERIMENTAL PROCEDURES

The materials used in this research were the copper plates in the size of 25×10×1 cm. The joints were single V-groove types of 30°C. The filler metals, HS201 and HS201+Ti_6Al_4V in form of 3 mm rods, were selected and the Ti content in HS201+Ti_6Al_4V composite wire is 3, 4, 5.5 and 8%. And N_2-Ar mixed gases were used and the ratio of N_2:Ar is 9:1.

The cross-sections of the welds were prepared for metallographic analysis by the standard polishing technique. The microstructures of the welds were examined by light microscopy (Olympus-PMG3), scanning electron microscopy (S-570) equipped with an energy dispersive X-ray spectrometer (TN5500). The tensile strength of the welds was evaluated by method of an electron tension testing machine (Instron-5569).

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Furthermore, the impact ductility of the welds was also measured and at least the values of three samples were reported.

RESULTS AND DISCUSSION

The copper plates were welded using HS201 by Ar shielding arc without preheating. It can be seen that the longitudinal hot cracking on the surface of the welds. And this hot cracking originated in the crater expands along the center of the welds against the welding direction. In the cross-section of the weld the micro hot cracking were existed shown in Fig. 1. From former research results (Li *et al*., 2012), the generate reason of the hot cracking in welding copper is described as follows. The low melting eutectic film (Cu_2O+Cu, 1050°C) locate among the grain boundary and this may weaken the final strength of the solidifying weld metal. The solidifying weld metal tends to contract by a combination of solidification shrinkage and thermal contraction. When tensile stresses developed across adjacent grains exceed the strength of the semi solid weld metal, the grain boundary fails and the hot cracking is originated. In this study, the influence of content element Ti in Cu-xTi filler materials on the macro and micro structures and mechanical performance of the welds are researched emphatically based on the numerical simulation and experimental researches.

The numerical simulation of the temperature distribution and the transverse stress of the welds surface perpendicular to the welding direction using HS201 by Ar shielding arc without preheating were calculated and shown in Fig. 2a and 3. It can be observed that temperature gradient from the welds center to base metal has a large change. In the welds center the temperature is higher than melting point and in the vicinity of the weld zones the temperature is down to 400°C below. This large temperature gradient inevitably leads to increase the transverse tensile stress. And this large transverse stress inevitably leads to crack along the center line of the welds. When preheating to 400°C, the longitudinal hot cracking will be disappeared by using Ar shielding arc. Then the numerical simulation of the temperature distribution of the welding joints by Ar shielding arc preheating to 400°C and N_2-Ar shielding arc without preheating were also calculated and shown in Fig. 2b and c. Compared with Fig. 2a the sizes of the welding pool are increased and the temperature gradients are decreased when preheating 400°C by Ar shielding arc and without preheating by N_2-Ar shielding arc. The energy density of the N_2 arc is larger than that of Ar arc and the temperature distribution using N_2-Ar shielding arc without preheating is closed to the temperature distribution using Ar shielding arc preheating 400°C, as the result of comparison the arc static characteristic of Ar and N_2. From Fig. 3, it can be found that the transverse stress in the center of the welds using N_2-Ar shielding arc is lower than that using Ar shielding. Then this simulation indicate that hot cracking will be disappeared by using N_2-Ar shielding arc without preheating. It should also be noticed that the zone above 800°C during Ar shielding arc is the widest and that during N_2-Ar shielding arc is the narrowest. The temperature of 800°C exceeds the re-crystallization temperature of copper, it can be concluded that the heat-affected zone of Ar shielding arc is wider than that of N_2-Ar shielding arc and preheating is the main reason that makes wider the heat-affected zone of Ar arc. Consequently, thick copper plates can be welded theoretically by using N_2-Ar shield gas without

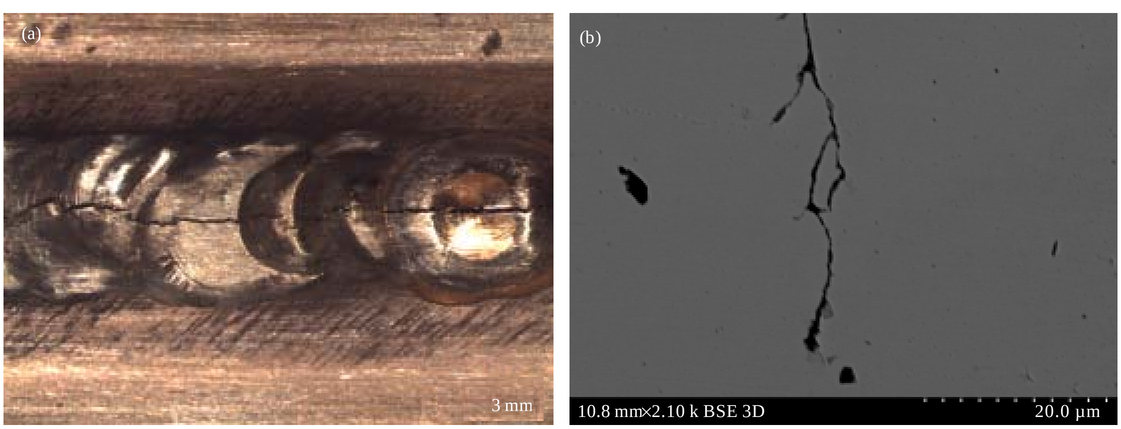

Fig. 1(a-b): Hot crack in the joint using HS201 by Ar shielding arc welding without preheating, (a) Longitudinal hot cracking and (b) Micro-cracking

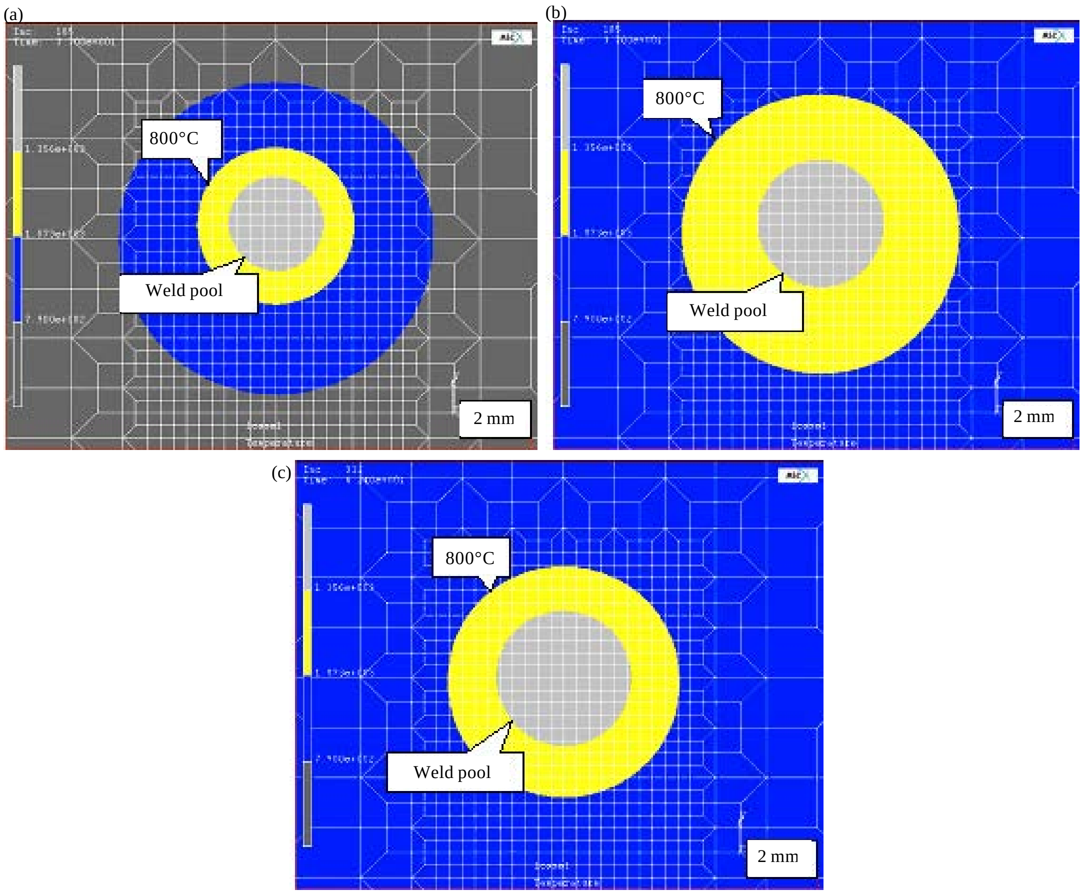

Fig. 2(a-c): Profiles of temperature distribution pattern of gas tungsten arc welding joints using Ar and N_2 shielding arc welding, (a) Ar 20°C 400A, (b) Ar 400°C 280A and (c) N_2-Ar 20°C 280A

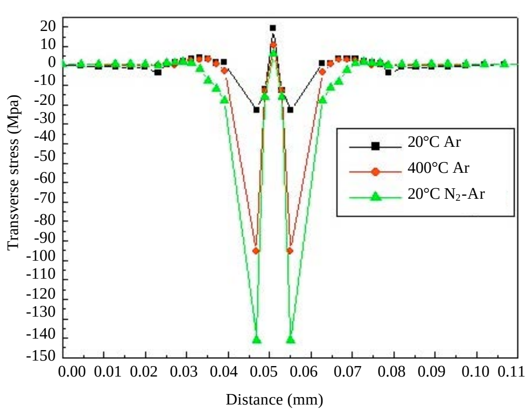

Fig. 3: Transverse stress of the welds surface perpendicular to the welding direction in different welding condition

preheating. The N_2-Ar mixed gas shield was selected to weld thick copper plates as the arc stability of N_2 arc is not as good as that of Ar arc.

The copper plates were welded using HS201 by N_2-Ar shielding arc welding and the macrostructure of welding joint is showed in Fig. 4a. Non-cracking weld formation can be acquired by using Ar-N_2 mixed shield gas without preheating, but it can be found that some defects such as gas porosity and incomplete fusion exist in the weld metal. From further observation, it can be seen that there are too many nitrogen porosities caused by N_2-Ar shield gas in the welds (Fig. 4b). And the tensile strength of the welds is only about 80 Mpa which is far below the level of base metal. The main cause of nitrogen porosity formation and low tensile strength is that HS201 which is widely used in Ar GTA welding of copper can't

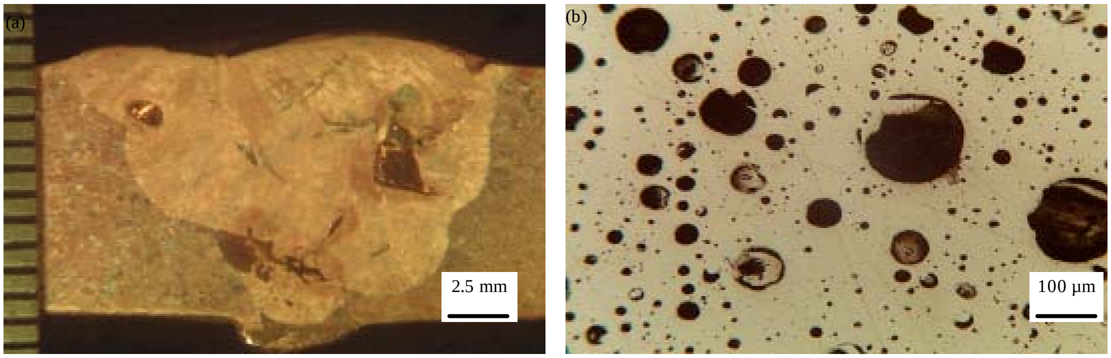

Fig. 4(a-b): Profiles of joint using HS201 By N2-Ar shielding arc welding, (a) Cross-section of the welds and (b) Nitrogen porosity

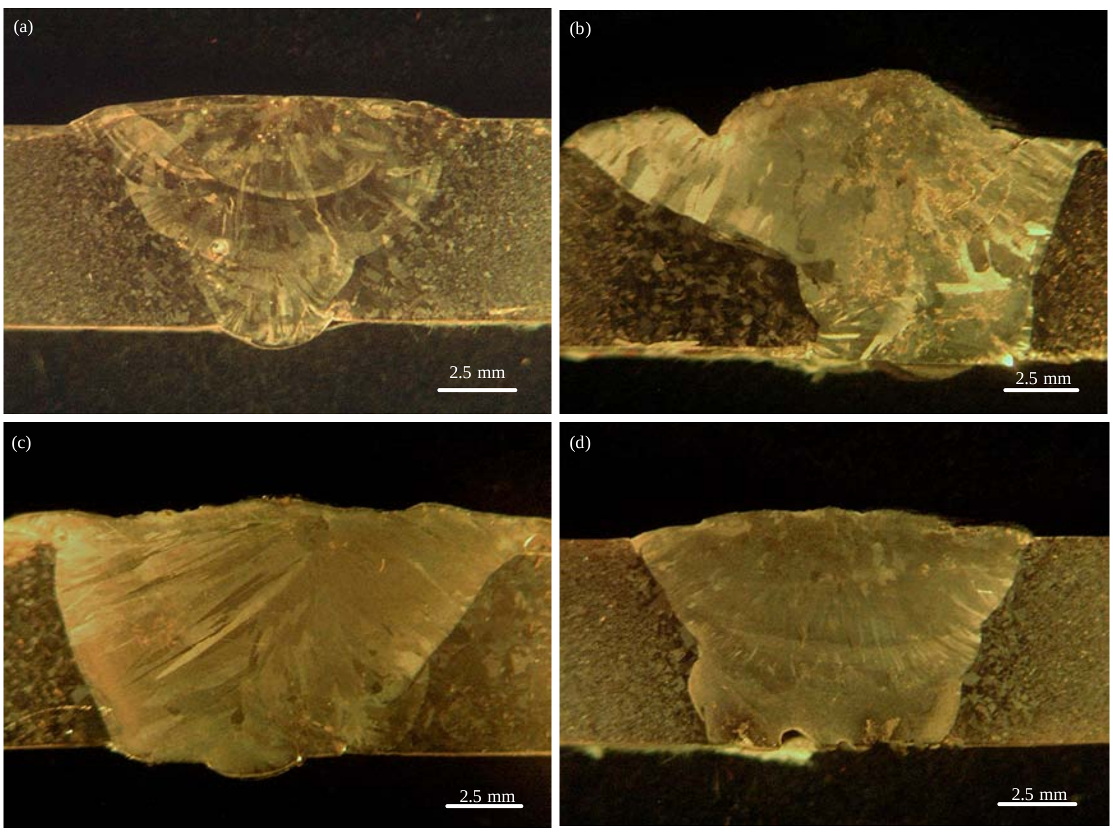

Fig. 5(a-d): Cross-section of joints with different Ti contents (wt%), (a) 3%, (b) 4%, (c) 5.5% and (d) 8%

meet the requirement of N_2-Ar shielding arc welding without preheating. So, different ratios of element Ti acted as denitriders combined with HS201 to eliminate the nitrogen porosities and improve the mechanical performance of the welds when using N_2-Ar shielding arc welding.

The copper plates were welded by N_2-Ar shielding arc welding with different ratio of Ti and the cross-section of the welding joints were shown in Fig. 5. It can be seem that weld penetration and width using Cu-xTi welding alloys is larger than that only using HS201. And the common defects such as incomplete penetration are avoided. And it can be found that the large-sized nitrogen porosity is eliminated completely in the joints using Cu-xTi welding alloys.

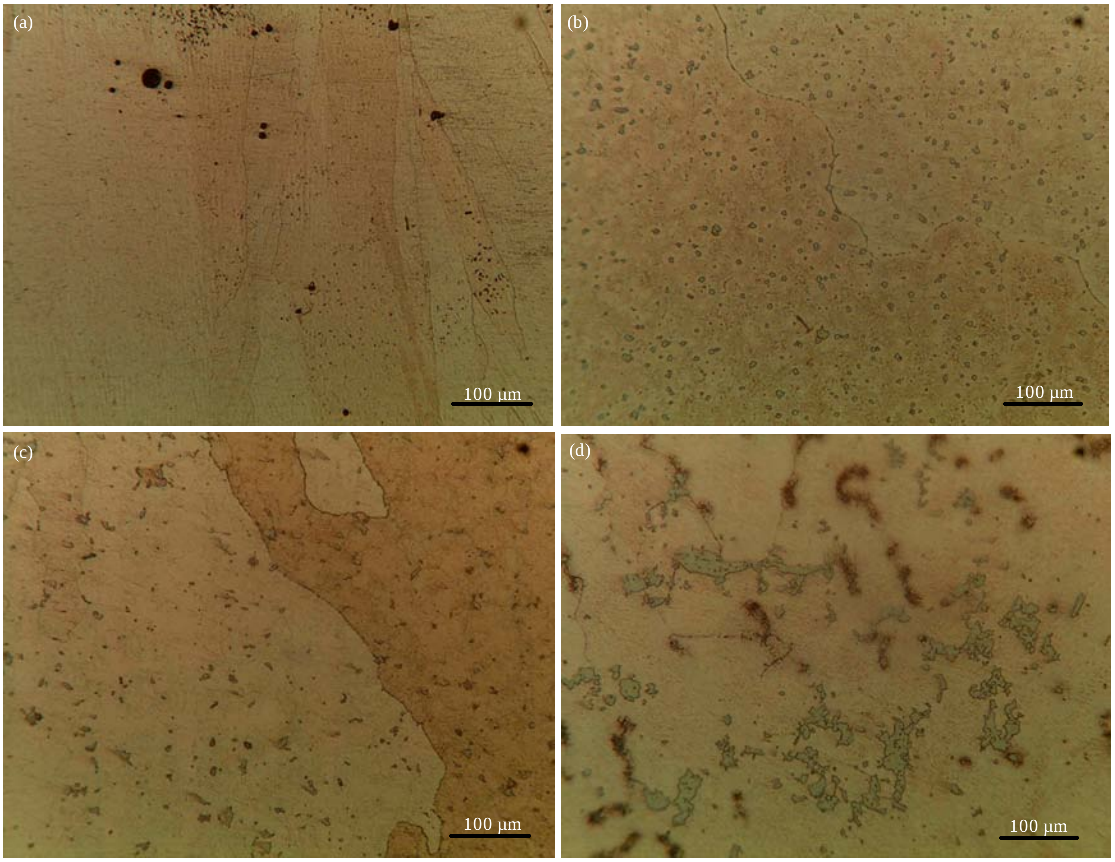

Fig. 6(a-d): Microstructure of joints and weld metal with different Ti contents (wt%), (a) 3%, (b) 4%, (c) 5.5% and (d) 8%

Table 1: Atom percent of element content in the second phase and the matrix respectively in the welds (at%)

Element	N	O	Al	Ti	V	Cu
Second phase (at%)	20.93	14.17	2.25	38.80	0.61	23.15
Matrix (at%)	6.75	5.12	1.29	2.07	0.28	84.49

Figure 6 shows the microstructure of weld metals using Cu-xTi welding alloys. It can be seen that the microstructure is very homogeneous without any nitrogen porosities except 3 wt (%) Ti specimen. The nitrogen porosities distribute in the up side of welds and welding bead when 3 wt (%) Ti is used. And this is because that the content of Ti is too low to eliminate nitrogen porosities. Nitrogen ions dissolve into weld pool in high temperature area and nitrogen ions haven't enough time to precipitate from weld pool during the cooling, then nitrogen porosities form in top of weld metal and welding bead. It is noteworthy that there are many grey microstructures in the weld metals. And these grey structures are mainly in form of second phase with dispersive distribution in subgrain boundary when content of Ti is 3, 4 and 5.5 wt (%), while are formed as second phase segregation when content of Ti reached 8 wt (%).

Figure 7 shows the different microstructure of the second phase and the matrix in the welds. Compared with EDS analysis between second phase and matrix, the obvious difference lies in the atom percent of Cu, Ti and N. The content of Cu is much lower while the contents of Ti and N are increased significantly in second phase than in matrix (Table 1). The grey second phase is judged preliminarily as inter-metallic compounds of copper titanium or inter-metallic compounds of titanium nitrogen. The content differences of Ti and N between matrix and second phase show that the elimination of nitrogen porosities is directly related to the addition of element Ti.

Figure 8a shows the weld slag formed at the weld surface and organization structure of which is very complicated. The lath phase is mainly composed of TiN generated at higher temperature region through XRD analysis (Fig. 8b). Element Ti reacts with element N dissolved in welding pool at higher temperature and the solid particles of TiN have low density compared with

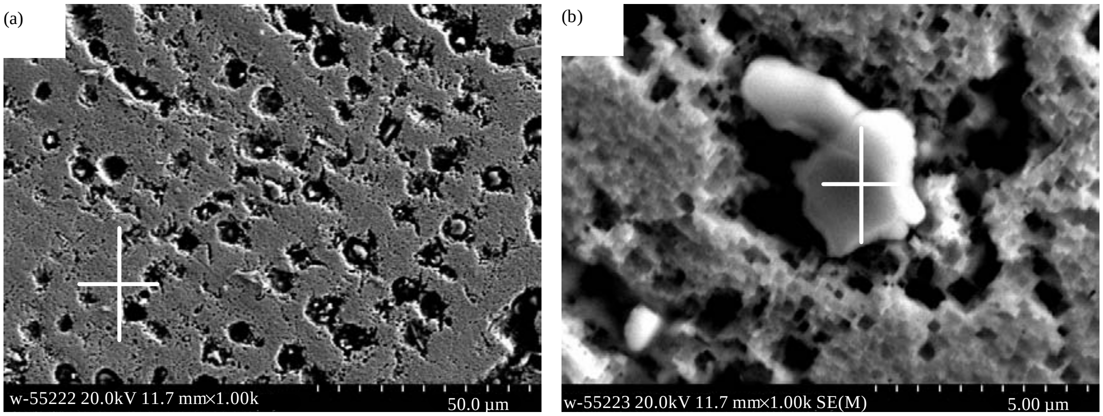

Fig. 7(a-b): SEM Images test of second phase and matrix in the welds, (a) Microstructure of the welds and (b) Second phase

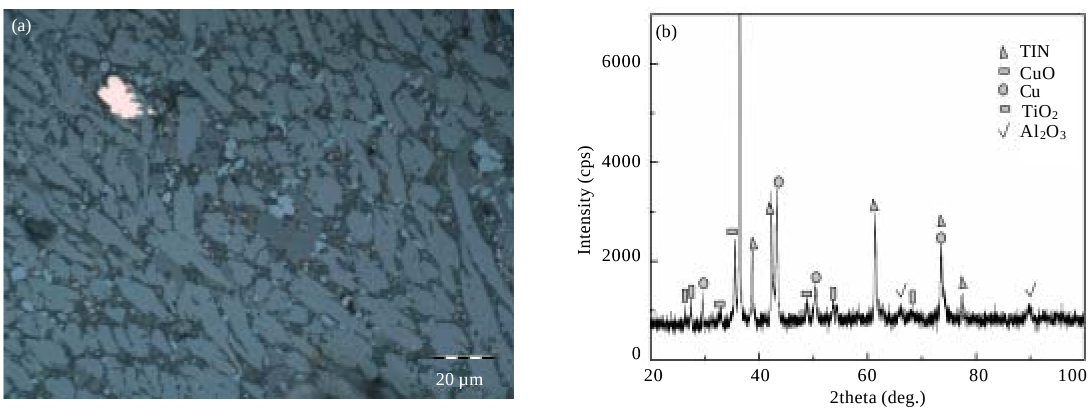

Fig. 8(a-b): Image and the XRD analysis of weld slag on the surface of the welds, (a) Microstructure of the slag and (b) XRD results of the slag

liquid copper molting pool and float upward to the surface of molting pool. After solidification, the weld slag which mainly is composed of TiN is formed at the surface of the welds.

The mechanical performance including tensile strength and impact ductility of the welds using Cu-xTi welding alloys were carried out and shown in Fig. 9. It can be seen from Fig. 9a that the tensile strength of weld joint is very poor, which is less than 30 Mpa when the Ti content 3 wt (%) is selected. The main reason of the poor mechanical properties is due to the nitrogen porosities exist in the welds, where the phenomena of stress concentration are easy to be formed. And the stress concentration will cause the break firstly in the tension test of the welds. When the Ti content 4 wt (%) is used, the tensile strength and impact ductility (Fig. 9b) are both non-uniform, the maximum value of the tensile strength reaches to 265 Mpa and the minimum down to about 70 Mpa. The values of impact ductility are changed in a wide range also, the maximum value is up to 140 Mpa and the minimum value is only about 24 Mpa. It is worth notice that the tensile strength and impact ductility of the welds present the best quality in these four welds in different Ti ratio, which has the uniform values and almost reaches the lever of base metal when 5.5 wt (%) Ti is selected. When content of Ti increased to 8 wt (%), the mechanical performances are decreased as the second phase segregated together in the welds. So, it can be concluded that the obvious difference mechanical performances with different ratio of Ti are directly related to elimination of nitrogen porosities and distribution of second phase. Compared with these welds using Cu-xTi

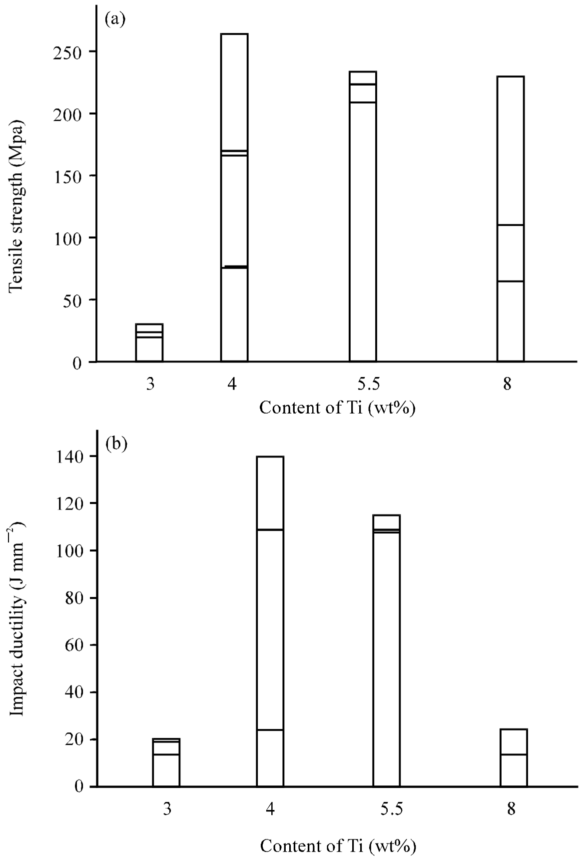

Fig. 9(a-b): Mechanical performance of the welds with different Cu-xTi filler, (a) Tensile strength of the welds and (b) Impact ductility of the welds

welding alloys, the mechanical properties are better when nitrogen porosities are eliminated completely and the second phase distribute dispersedly, while the mechanical properties are poor when a few nitrogen porosities residue and segregation of second phase forms in the welds.

CONCLUSION

The numerical simulation results show that the temperature gradient and the transverse stress of the welds center are decreased using N_2-Ar shielding arc welding compared with the welds using Ar shielding arc welding. But the welding defect-nitrogen porosities locate in the welds when HS201 is selected as welding material using N_2-Ar shielding arc welding.

Using Cu-xTi welding alloys to weld copper plates can eliminate the nitrogen porosities using mixed Ar-N_2 shielding gas tungsten arc welding. Element Ti in the welding alloys react with N dissolved in welding pool at higher temperature, after solidification the weld slag which mainly are composed of TiN is formed at the surface of the welds.

When content of Ti is 5.5 wt (%), the nitrogen porosities are disappeared completely and IMCs are mainly formed as second phase in dispersive distribution. Mechanical performances of the welds present the best quality in different Ti ratio welds, which almost reaches the level of base metal.

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