Effects of Tungsten Particle Size and Nickel Addition in DC arc Resistance of Cu-W Electrode

Bong-Seo Kim*, Hyun-Uk Jeong* and Hee-Woong Lee*

Abstract - The performance of copper-tungsten for electrodes used in an ultra high voltage interruption system was evaluated by means of an interruption test, which requires a large-scale apparatus and high cost. In this study, prior to the interruption test, the characteristics of a Cu-W electrode were estimated through the DC arc test, which is a simple, low cost procedure. The DC arc characteristics of a 20wt%Cu-80wt%W electrode were investigated with the change of tungsten powder size distribution and the addition of nickel. In specimens containing a high volume fraction of large sized tungsten particles, the relative density and hardness of sintered Cu-W electrodes increased while the electrical conductivity and the DC arc resistance decreased. Furthermore, the relative density became enhanced with the increase of the amount of nickel while the hardness and electrical conductivity diminished and the DC arc resistance worsened.

Keywords: Cu-W electrode, DC arc test, interruption system, Ni addition, tungsten particle size distribution

1. Introduction

Copper-tungsten has been commonly used for electrodes employed in ultra high voltage interruption systems. The commercial copper-tungsten electrodes for electrical contact are generally fabricated by the liquid phase sintering of tungsten and copper powder [1-3]. Copper has good electrical, thermal conductivity and arc extinction properties [4-5]. Tungsten has good arc resistance, low thermal expansion and high melting point in the electrode [6-7]. The characteristics of a Cu-W electrode may perhaps be affected by the tungsten particle size and its distribution, but the systematic data for the effect of these electrodes can hardly be found. Also, the tungsten particle size and its distribution in commercial copper-tungsten electrodes differ with each electrode maker. The additive elements like rare earth metal and noble metal are used to improve the characteristics of the electrodes. Recently, similar studies on copper-tungsten electrodes have been reported for EDM (electrical discharge machining) electrodes [8-10].

The characteristics of copper-tungsten electrodes have been evaluated using an interruption test. Through this test the electrical properties, weight change and morphology at the electrode tip have been the focus of investigation. However, as the interruption test requires a large-scale apparatus and high cost, it is very difficult to test many electrodes to determine optimal electrode conditions.

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Received October 23, 2003 ; Accepted January 19, 2004

Therefore, in this study, the DC arc test, which is a laboratory-scale test with low cost was adopted to test the Cu-W electrode before the interruption test. The effects of tungsten particle size distribution and nickel addition in DC arc resistance of Cu-W electrodes were examined.

2. Experimental procedure

The basic composition of electrodes used was 20wt%Cu-80wt%W. The compositions of 5 specimens are shown in Table 1. The mean particle sizes of tungsten powder were 4.3 and 8.3μm. Two types of tungsten powder were mixed as ratios of 7:3 and 5:5. The morphology of tungsten particles was observed by SEM (scanning electron microscope, Hitachi S-2700) as shown in Fig. 1. Nickel was added to 0.2wt% to improve the characteristics of the copper-tungsten electrodes. The copper, tungsten and nickel powder were homogeneously mixed by ball milling and then degassed at 350 C for 1h in a reducing atmosphere. The skeleton blocks composed of 10wt%Cu-90wt%W were then pre-sintered at 1150℃ for 120 min. 20wt%Cu-80wt%W-xNi electrodes were fabricated by infiltration of Cu and Cu-Ni block on 10wt%Cu-90wt%W skeleton blocks as a sintering cycle as shown in Fig. 2.

The phase of sintered electrodes was identified by XRD (X-ray diffractometer, Philips PW-1830). Hardness with a Rockwell hardness tester (H_{RB}) and electrical conductivity (%IACS) were measured. The relative density of electrodes was measured by Archimedes method. To investigate the DC arc resistance, the electrodes were mechanically worked as presented in Fig. 3. Once the electrodes attached themselves to the upper and lower part of the DC arc tester as shown in Fig. 4, they were tested under the following conditions; DC voltage of 70V and current of 70A. The DC arc resistance of electrodes was evaluated by the change of weight measured at the interval of 100, 200 and 300 cycles before and after the test. The longitudinal and cross-sectional morphologies at the tip of the electrodes were also observed by SEM following the DC arc test.

Table 1 Composition of specimen. (wt%)

Specimen	W		Cu	Ni
	4.3μm	8.3μm		
1	56	24	20	0
2	56	24	20	0.1
3	56	24	20	0.2
4	40	40	20	0
5	40	40	20	0.1

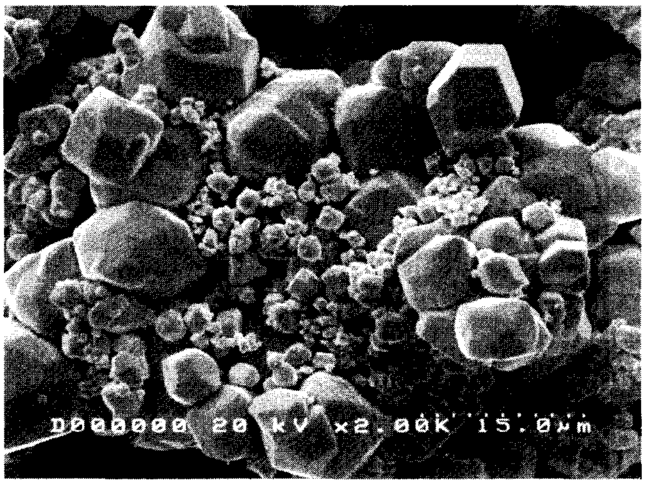


Fig. 1 SEM micrograph of tungsten powder

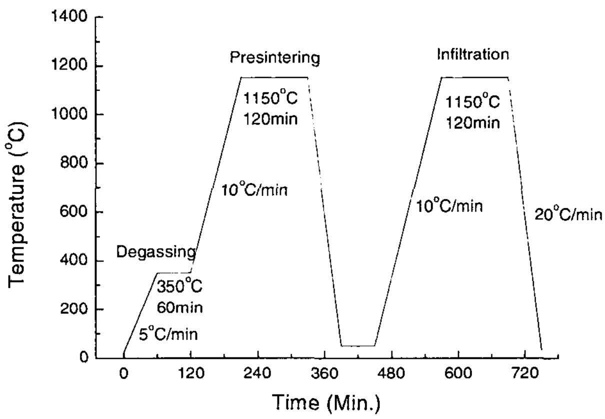


Fig. 2 Sintering cycle of electrode

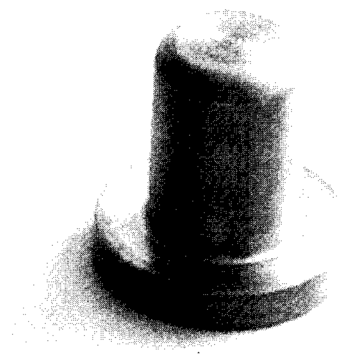


Fig. 3 Electrode for DC arc test

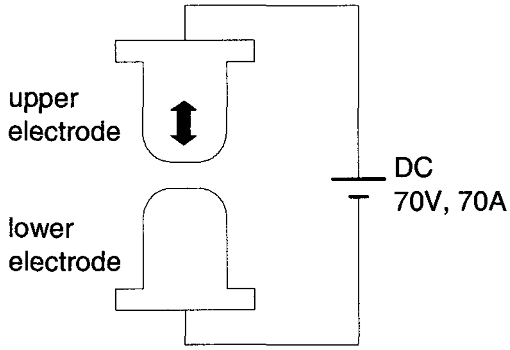


Fig. 4 Apparatus for DC arc test of electrode

3. Results and discussion

3.1 Microstructure

Copper and tungsten are completely insoluble due to a very positive heat from mixing in solid and liquid states [11]. Therefore, copper-tungsten electrodes are generally fabricated by infiltration using capillary phenomena after fabrication of the pre-sintered skeleton. Due to the good solubility of nickel with copper and tungsten, nickel has been adopted as an additive element to improve the characteristics of copper-tungsten electrodes [12, 13]. In addition, it has been reported that Ni retains its protective coating during cyclic exposure to high temperatures, such as those in the DC arc [14].

The XRD peaks of sintered Cu-W-Ni electrodes are shown in Fig. 5. The electrode (specimen 1) containing no nickel displayed a typical XRD peak. However, the Cu and W peaks in specimen 5 shifted slightly due to the formation of the solid solution of Cu-Ni and W-Ni during sintering [12]. The peak shift signifies the change of lattice constant due to the substitution of nickel atoms in the copper and tungsten matrix. However, the change of lattice constant by slight shift in specimen 5 is too small to be ignored in this study.

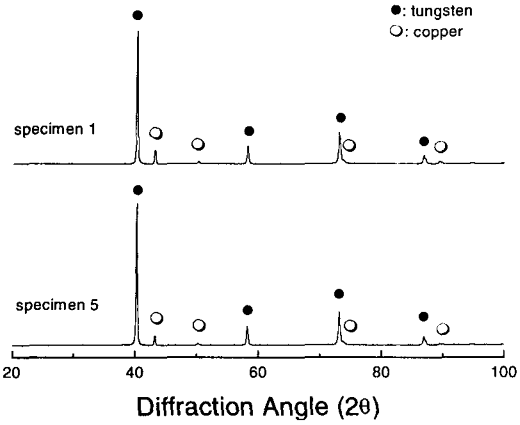
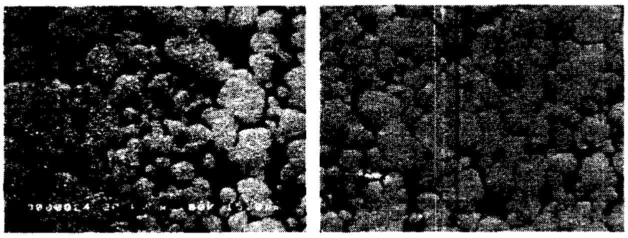


Fig. 5 XRD peaks of sintered Cu-W-xNi electrode

Fig. 6 shows the microstructures of sintered specimens 1 and 4 as observed by SEM. Tungsten preserved the initial particle morphology and copper was liquid phase sintered by infiltration. It is assured that those of other specimens also have a very similar to specimen 1. As the particle size is significant in liquid phase sintering, the characteristics of electrodes can be changed accordingly. Small particle size reduces the diameter of the capillary tube in the skeleton with the increase in capillary force, which in turn increases the densification of sintered materials [9, 15]. Therefore, it has a direct affect on the density of the electrodes.



(a) (b)

Fig. 6 SEM micrographs of tungsten particle distribution in sintered Cu-W electrode.
(a) specimen 1 (4.3μm:8.3μm=7:3) (b) specimen 4 (4.3μm:8.3μm=5:5)

The relative density changes of Cu-W electrodes with tungsten particle size and nickel addition are shown in Fig. 7, with a range of 97.5~99.5%. In two kinds of specimens 1-3 and 4-5 whose ratio of tungsten particle size distribution was 4.3μm :8.3μm=7:3 and 5:5, the relative density of electrodes increased in conjunction to the increasing amount of additive nickel. Specimen 4 and 5 with high ratios of tungsten particles (4.3μm:8.3μm =5:5) have higher relative density than that of 7:3. In specimens 4 and 5 with a high volume fraction of large tungsten particles, the void in the electrodes is reduced relatively so that copper in a liquid state could be easily infiltrated to the skeleton. Also, since nickel can form a homogeneous solution with copper improving the sintering ability, it is considered that the density of electrodes increases with the increase in the amount of additive nickel.

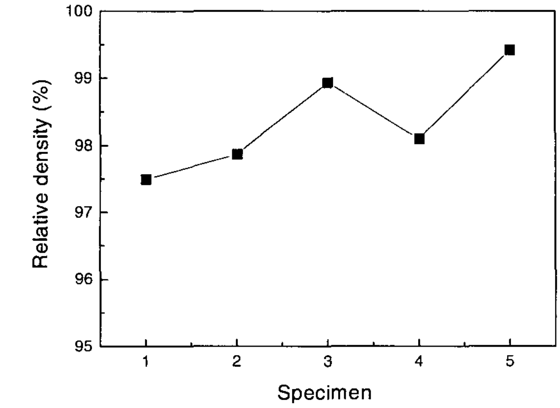


Fig. 7 Relative density change of Cu-W-xNi electrodes

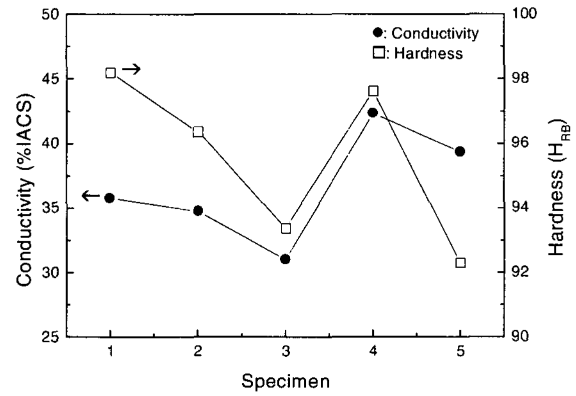


Fig. 8 Electrical conductivity (%IACS) and hardness changes of Cu-W-xNi electrodes

The electrical conductivity of electrodes with the ratio of tungsten particle size distribution and the amount of additive nickel is shown in Fig. 8. The electrical conductivity of electrodes decreased with the increasing amount of additive nickel. Nickel has a lower electrical conductivity than copper. The electrical conductivity of electrodes increased with the increase in the high volume fraction of large tungsten particles. Large tungsten particles in the electrodes create a short path for electrical conduction at the same composition. Therefore, the additive nickel and low volume fraction of large tungsten particles decrease the conductivity of the electrodes.

The hardness change according to the composition of each specimen is also shown in Fig. 8. The hardness decreased with the increasing amount of additive nickel and the volume fraction of large tungsten particles. The hardness of copper-tungsten electrodes mainly depends on the composition, particle size and distribution of the tungsten. The small particle size and uniform distribution of tungsten at identical composition powder increases the hardness of the electrodes.

3.2 DC arc test

The characteristics of DC arc resistance under DC 70V and 70A using an arc tester are shown in Fig. 4. They were investigated by measuring the weight change of electrodes after arc testing at 100, 200 and 300 cycles as shown in Fig. 9. The weight changes of electrodes by DC arc were increased with the increasing amount of additive nickel and the volume fraction of large tungsten particles. Compared with two kinds of specimens 1-3 (4.3μm :8.3μm =5:5) and 4-5 (4.3μm :8.3μm =7:3), the weight change of specimens 1-3 was smaller than that of specimens 4 and 5.

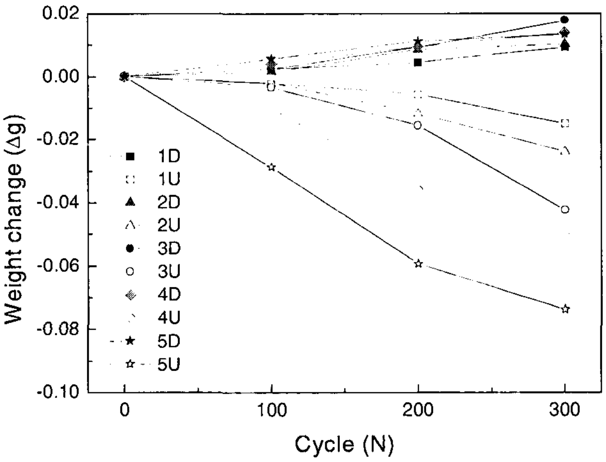


Fig. 9 Weight change of electrode with DC arc test cycle (D: lower part electrode, U: upper part electrode)

The longitudinal and cross-sectional morphologies of electrodes after DC arc test of 300 cycles are shown in Fig. 10 as observed by SEM. With the increase in the amount of additive nickel and the volume fraction of large tungsten particles, the particles consisting of molten copper and tungsten particles at the tip of the electrodes were partially melted and flied away and dispersed in all directions by the arc. Some particles adhered to the surface of the lower part electrodes. With the increase in the amount of additive nickel, the quantities of particles flied away by the arc at the tip of the electrodes increased. Therefore, the thickness of the adhered layer at the tip of the lower part electrodes increased. In all upper part electrode tips, the melted and flied away particles by the arc made voids around the electrode surface. As the number of particles flied away in specimens 4 and 5 was much greater than that of specimens 1, 2 and 3, the cracks formed at the tip of the upper part electrodes in specimens 4 and 5 are deep and long.

As the copper particles located around the electrode tips were preferentially melted and flied away, the tungsten particles surrounding the copper were simultaneously flied away with the melted copper. As well, the ionized particles by DC arc moved to the negative electrodes located in the lower part. Therefore, the surface of the upper part electrode tips was so severely affected that cracks were formed and grew with repeated arc cycles.

As some particles flied away from the tip of the upper part electrodes adhered at the surface of the lower part electrodes, the weight and thickness of the lower part electrodes increased according to the increase in the arc test cycles. However, the weight of the upper electrodes was decreased and that of the lower electrodes was increased. The adhered layers at the tip of the lower part electrodes have completely different microstructures as compared with that of the typical Cu-W electrodes as shown in Fig. 6.

The electrodes with large tungsten particles show generally good arc resistance. However, the results of DC arc resistance in this study were contrary to those of previous studies [3, 6]. It is considered that this is owing to the high volume fraction of large tungsten particles (4.3μm:8.3μm=5:5) in specimens 4 and 5 as compared with commercial electrodes.

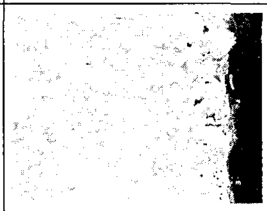
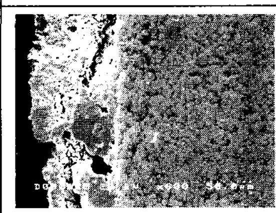
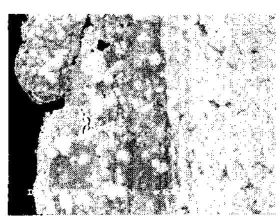
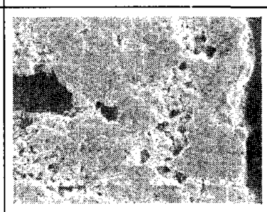
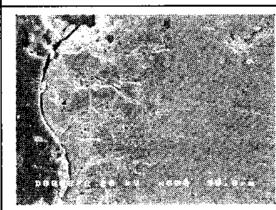
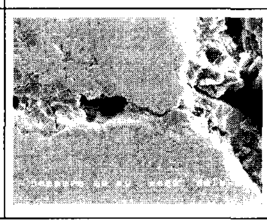
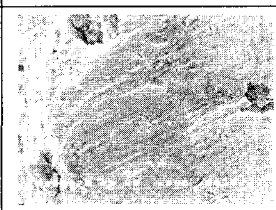
specimen	upper part electrode	lower part electrode
1		
3		
4		
5		

Fig. 10 Cross-sectional morphologies at electrode tip after DC arc test 300 cycles

4. Conclusions

The 20wt%Cu-80wt%W-xNi electrodes having both ratio of tungsten particle 4.3μm:8.3μm=7:3 and 5:5 were fabricated by liquid phase sintering. The amounts of additive nickel were 0.1 and 0.2wt%. The effects of tungsten particle size and nickel addition in the DC arc resistance of Cu-W electrodes for the interruption system were studied. With the increase in the amount of additive nickel, the density of electrodes was increased, while the hardness and conductivity were decreased. Furthermore, with the increase of volume fraction of large tungsten particles, the density and conductivity of electrodes were increased, while the hardness was decreased. The DC arc resistance lessened with the increase in the amount of additive nickel and the volume fraction of large tungsten particles.

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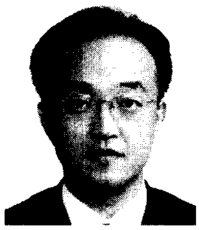

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