Experimental Study on the Properties of Copper Base Alloy by Laser Cladding on the Surface of Pure Copper Contact

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Abstract. Arc ablation is the main reason for the failure of pure copper switches. In order to improve the electric ablation resistance of pure copper contacts, Cu-W-Ni alloy cladding layers with different tungsten contents were prepared on the surface of pure copper matrix by laser cladding technology. The microstructure, composition distribution, hardness and corrosion resistance of the cladding layer were analyzed. The results show that the surface of the cladding layer and the pure copper matrix is metallurgical, without holes, cracks and other defects, and the dilution rate is low, and the average hardness is significantly increased. On the whole, the comprehensive properties of CuW10Ni3 cladding layer are slightly better than the other two Cu-W-Ni cladding layers. Compared with the pure copper matrix, the contact hardness is significantly improved under the premise of ensuring the electric conductivity of the inner pure copper matrix.

Keywords. Laser cladding, pure copper matrix, microstructure, hardness, corrosion resistance.

1. Instruction
Disconnecting switch is one of the most widely used electrical equipment in power system. The failure of disconnecting switch often leads to a large range of power failure, which seriously affects the operation safety of power grid. The electric contact is the key part of the high voltage switching appliance. When the switch is closed, the gap of the contact produces high temperature and high energy arc, which erodes the surface of the contact. Every year due to the defects such as contact hair heat and overheating, resulting in the isolation switch damage to the power grid large area of power outage accidents occur from time to time, which will not only cause a lot of economic losses, but also cause a great threat to the lives of substation workers [1, 2]. Contact damage mainly occurs in the arc ablation process and is mainly composed of the following three parts: first, the evaporation and sputtering of existing surface attachments and low-melting copper; second, the dynamic balance of melting, splashing and cooling and solidification of copper; last, the surface is uneven and strongly ablated [3].

At present, pure copper contacts are commonly used, which have good electrical conductivity, but in the process of use, they will fail due to decreased strength and low deformation resistance. Oxide film is easily formed on the surface of copper, leading to the increase of resistance and rapid temperature rise. Moreover, pure copper is poor in corrosion resistance, temperature, strength and other aspects. A lot of research work is being done on contact materials at home and abroad. From the
perspective of research direction, there are mainly three aspects as follows: first, developing new contact materials; second, to find a new preparation process without changing the material; third, under the condition that the main material remains unchanged, new alloying elements or non-metallic compounds are added to improve the performance of the material. In this study, the comprehensive properties of contact materials were improved mainly through the latter two approaches.

According to the research of Wang Yanming et al. [4], under the same current and current breakdown times, the higher the tungsten content in copper-tungsten alloy, the stronger the copper-tungsten alloy's resistance to arc erosion.

Laser cladding is a new type of surface technology. This cladding layer often has excellent properties that the matrix does not, such as good wear resistance, corrosion resistance, heat resistance, oxidation resistance and other properties [5].

In this paper, the laser cladding technology is used to prepare the copper based cladding layer with wear resistance and corrosion resistance on the surface of pure copper contact. The microstructure, composition distribution, hardness and corrosion resistance of the three copper based cladding layers prepared are studied.

2. Experimental Materials and Methods

2.1. Experimental Materials
The experimental matrix is pure copper plate of 20×20×8mm (same as GW5-35 high voltage disconnector contact material). The composition of cladding materials is shown in table 1. It has a grain size range of 325-140 mesh.

Table 1. The composition of cladding materials.

| Composition/wt. % | W   | Ni | Cu allowance |
|------------------|-----|----|--------------|
| CuW10Ni3         | 10  | 3  | allowance    |
| CuW20Ni3         | 20  | 3  | allowance    |
| CuW40Ni3         | 40  | 3  | allowance    |

Cu has good thermal and electrical conductivity, while W has high density, high strength, high melting point and low expansion coefficient. The two substances are not mutually soluble and cannot form intermetallic compounds. However, the increase of copper significantly reduces the porosity of the alloy, but the agglomeration tendency of copper is more obvious, the distribution of W element in the copper is uneven, and the interface between the alloy and the infiltrating copper liquid is loose. Tungsten-copper composite is a pseudo alloy composed of tungsten with high melting point and high hardness and copper with high conductivity and thermal conductivity. With the advantages of Cu and W, Cu-W material has good thermal conductivity, high density and small expansion coefficient, so it is widely used as an electrical contact material [6-8]. At the same time, a small amount of Ni is added to the Cu-W alloy to increase the hardness and corrosion resistance of the material [9].

2.2. Laboratory Equipment
The laser cladding equipment used to prepare the cladding layer is RFL-C3300W laser. Testing equipment includes EVO 18 Special Edition scanning electron microscope and energy dispersing spectrometer, FM-300 hardness tester, XRD tester.

2.3. Experimental Methods
In this experiment, laser cladding was carried out on the substrate surface of pure copper plate by means of synchronous powder feeding. Before laser cladding, the surface of pure copper plate should be pretreated to prevent the cladding effect from being affected. The pretreatment method is as follows:
polishing the surface of the plate with 200-600 mesh sandpaper to remove the impurities and oxide scale on the surface, then cleaning with acetone to remove the impurities, and finally fixing it on the cladding workbench. The plate is fixed and the laser head is moved for laser cladding. The alloy powder with three components in table 1 was dried at 100℃ for 1 hour and then filled into the powder feeding equipment. The laser cladding equipment uses RFL-C3300W laser, and the experimental parameters of each cladding layer are shown in table 2.

Table 2. Preparation parameters of each cladding layer.

| Powder type | Output power | Scanning speed | Spot diameter | Powder supply gas | Protection gas | Powder supply rate | Lap rate |
|-------------|--------------|----------------|---------------|-------------------|----------------|--------------------|----------|
| CuW10Ni3   | 2970W        | 6cm/s          | 1.5cm         | N₂                | Ar             | 1-4kg/h            | 50%      |
| CuW20Ni3   | 3000W        | 5.5cm/s        | 1.5cm         | N₂                | Ar             | 1-4kg/h            | 50%      |
| CuW40Ni3   | 3036W        | 6cm/s          | 1.5cm         | N₂                | Ar             | 1-4kg/h            | 50%      |

The thickness of single layer cladding layer can reach 450 μm. The average thickness of the cladding layer is about 1300~1400μm after three times of cladding in the same way. The prepared cladding layer was polished flat and polished to obtain a corrosion and wear resistant cladding layer with good morphology. Through wire cutting, the test samples required for hardness test, salt spray test (using GB/T10125-2012 <Artificial Atmosphere Corrosion Test salt Spray Test> standard).

The test method of hardness of the cladding layer section is ‘S-shaped dot test method’. Starting from the surface of the cladding layer, dot to the matrix, take three points in the horizontal direction of the cladding layer, the distance between each point is 50μm, and the distance between each point in the vertical direction of the cladding layer is 150μm. The load is 200g/N, and 0 is the position of the matrix.

The corrosion resistance test was based on the neutral salt spray test designed according to the test standard (GB/T 10125-2012). 5% NaCl solution (50 g/L) was prepared to control the pH value of the spray solution collected in the salt spray chamber between 6.5 and 7.2. The solution was configured with new boiling water to reduce the carbon dioxide in the solution and avoid the change of pH value. The indoor temperature of salt spray was set at 35℃, the pressure barrel temperature was set at 45℃, the humidity was greater than 95%, the fog reduction amount was 1 mL/(h·cm²), the nozzle pressure was 70 kPa, and the spray was carried out continuously. Samples were taken out every 24 h for observation and test. The total duration of the experiment was 120 h.

3. Experimental Results and Analysis

3.1. Microstructure of Cladding Layer
Among them, the surface of CuW10Ni3 cladding layer is smooth and flat, the overall thickness is uniform, and there is no obvious hole. However, with the increase of W element content in the cladding layer, the surface morphology gradually deteriorates, as shown in figure 1. Compared with CuW10Ni3, the other two kinds of cladding layer surface began to appear a small number of holes, while CuW40Ni3 surface morphology is poor, with more holes. The surface of the three cladding layers is not cracked by nondestructive testing with the dye penetrant.

Figure 1. Macroscopic morphology of the three cladding layers. (a. CuW10Ni3; b. CuW20Ni3; c. CuW40Ni3)
Figure 2 respectively shows the cross section morphology and element distribution of the three cladding layers. It can be found that the three kinds of cladding layers are metallurgically bonded with the matrix, and they are closely bonded. The matrix is a single gray phase, and the cladding layer contains white and gray phases. With the increase of W element content, the content of white phase gradually increases.

![Figure 2. Section morphology and element distribution of cladding layer. (a) CuW10Ni3; (b) CuW20Ni3; (c) CuW40Ni3.](image)

The composition of different positions of each cladding layer is shown in Table 3.

|                | White phase | Gray phase |
|----------------|-------------|------------|
|                | W/wt.%      | Cu/wt.%    | Ni/wt.%    |
| CuW10Ni3      | 100         | 96.29      | 3.71       |
| CuW20Ni3      | 100         | 96.95      | 3.05       |
| CuW40Ni3      | 100         | 97.05      | 2.95       |

It can be seen that the white phase is composed of W element, and the gray phase is composed of Cu and Ni elements. The content of Cu element is much higher than Ni element, and the cladding layer produces the segregation of W element. The content of W in CuW10Ni3 and CuW20Ni3 cladding layers is less, which is 10wt.% and 20wt.% respectively. In contrast, the distribution of W element in the CuW20Ni3 cladding layer is the most uneven, with both small granular segregation and large agglomeration segregation. However, in the CuW40Ni3 cladding layer, the content of W element is significantly increased and more uniformly distributed in the gray matrix phase. Similar to the CuW20Ni3 cladding layer, there is still both small granular segregation and large agglomeration segregation.

3.2. The XRD Results

Figure 3 shows the XRD results of the three cladding layers. It can be found that the diffraction peaks of the three cladding layers are almost identical, and they are all composed of phase 3. W is insoluble with Cu and Ni, while Cu and Ni are infinitely soluble. This is also verified in the XRD results. In addition to Cu and W phases, a third phase, Cu3.8Ni, appeared.
3.3. Hardness Analysis

Figure 4 shows the hardness curve from the cladding layer to the substrate. It can be seen that there is a gradient of hardness growth in the transition region from the substrate to the cladding layer. In the cladding layer region, the overall hardness value is significantly higher than that of the substrate. From 60-70HV of the matrix to over 90HV; compared with the cladding layer of the three components, the hardness value of the cladding layer increases with the increase of W content. The average hardness of the CuW40Ni3 cladding layer increases to about 130HV, which is 1.5-2 times higher than that of the substrate.

According to XRD results, due to the presence of Ni, Cu3.8Ni phase is formed in the cladding layer, which also plays a role in the increase of hardness to some extent [10]. It was also found that the hardness of CuW10Ni3 and CuW20Ni3 fluctuated greatly. Combined with the scanning electron microscope, the enrichment and uneven distribution of W may lead to this result. On the other hand, the laser cladding technology itself is characterized by rapid melting, expansion and solidification (the cooling rate usually reaches 102 ~ 106 ℃/s), and the microstructure of the cladding layer is generally very fine and compact, which can effectively improve the hardness of the cladding layer [5].

3.4. Salt Spray Test

The macroscopic morphology of the three cladding layers after salt spray corrosion at different times is shown in figure 5.
Figure 5. The macroscopic morphology of the three cladding layers.

It can be obviously found that, in contrast, the surface of CuW10Ni3 cladding layer is relatively smooth, almost no corrosion products on the surface. Obviously, with the increase of W content in the cladding layer, the surface morphology gradually deteriorates, especially the surface of CuW40Ni3 cladding layer is covered by corrosion products and has very obvious holes. The three cladding layers of Cu-W-Ni have different degrees of weight loss, while the cladding layer of CuW40Ni3 has weight gain due to more surface holes and difficult to remove corrosion products. Figure 6 shows the weight loss curves of CuW10Ni3 and CuW20Ni3 cladding layers.

Figure 6 shows the relationship between weight loss and corrosion time. After 120h salt spray corrosion, the total weight loss of CuW10Ni3 cladding is 1.5621 mg/cm\(^2\), and the total weight loss of CuW20Ni3 cladding is 3.7247 mg/cm\(^2\). As can be seen from the figure, the weight loss curves of CuW10Ni3 and CuW20Ni3 cladding layers are approximately parabolic. It shows that the corrosion product surface has protective effect in the corrosion process of the two cladding layers. The weight loss rate of CuW20Ni3 cladding layer is 2.4 times that of CuW10Ni3 cladding layer. The results show that the corrosion resistance of cladding decreases with the increase of W element content.

Figure 6. The weight loss curve.

The weight loss curves of CuW10Ni3 and CuW20Ni3 cladding layers were fitted, and the fitting formulas were respectively obtained as shown in table 4.

Table 4. Fitting formula of weight loss curve.

| Cladding Layer | Fitting Formula         | R\(^2\)  |
|----------------|-------------------------|----------|
| CuW10Ni3      | y=0.01001x\(^{1.04796}\) | 0.98915  |
| CuW20Ni3      | y=0.10193x\(^{0.74949}\) | 0.99842  |
It can be seen from table 4 that the weight loss curves of CuW10Ni3 and CuW20Ni3 cladding layers are similar after the addition of Ni element, both of which are approximately parabolic. XRD analysis shows that a new Cu3.8Ni phase appears in addition to Cu and W phases after adding a small amount of Ni element in the cladding layer [9]. Therefore, the corrosion resistance of Cu-W-Ni cladding is greatly improved due to the addition of Ni element.

4. Conclusions and Remarks

(1) The cladding layer of CuW10Ni3, CuW20Ni3 and CuW40Ni3 was prepared by laser cladding. The cladding layer and the matrix are well fused and metallurgical. The composition distribution of cladding layer is uniform, and W element has a certain degree of segregation.

(2) The hardness of the three Cu-W-Ni cladding layers is significantly higher than that of the pure copper matrix, and the hardness values show a rising trend with the increase of the content of W element.

(3) The SEM and XRD results of the cross section of the cladding layer show that the third phase Cu3.8Ni exists in the cladding layer besides Cu and W phases. The corrosion resistance of the coating was significantly improved.

(4) Overall, the comprehensive performance of CuW10Ni3 cladding layer is slightly better than the other two Cu-W-Ni cladding layers, but the cladding process parameters need to be further optimized to obtain higher performance.

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