The Research of the Morphology and Mechanical Characteristics of Electric Bimetallic Contacts

Tetiana Haikova
Department of Mechanical Engineering Technology
Kremenchuk Mykhailo Ostrohradskyi National University
Kremenchuk, Ukraine
tanyahaikova@ukr.net

Ruslan Puzyr
Department of Mechanical Engineering Technology
Kremenchuk Mykhailo Ostrohradskyi National University College
Kremenchuk, Ukraine
puzyruslan@gmail.com

Dmytro Savelov
Department of Mechanical Engineering Technology
Kremenchuk Mykhailo Ostrohradskyi National University
Kremenchuk, Ukraine
dvsavelov@gmail.com

Volodymyr Dragobetsky
Department of Mechanical Engineering Technology
Kremenchuk Mykhailo Ostrohradskyi National University
Kremenchuk, Ukraine
vldrag@kdu.edu.ua

Roman Argat
Department of Mechanical Engineering Technology
Kremenchuk Mykhailo Ostrohradskyi National University
Kremenchuk, Ukraine
argat.rg@gmail.com

Roman Sivak
Department of General Technical disciplines and Labor Protection
Vinnytsia National Agrarian University
Vinnytsia, Ukraine
sivak_r_i@ukr.net

***Abstract*—The paper demonstrates that as the energy industry develops, there is a continuous process of improving the designs of contact electrical connections. Bimetallic contacts are becoming more common. Their performance depends on the morphology and strength of the connection layers. Clad workpieces with various heat treatment modes were researched. The strength of the joint of the laminated compound was also determined. With increasing temperature and heat treatment time, the concentration as well as the amount of intermetallic compounds in the weld zone increases. When the layer of intermetallic compounds reaches a certain value, the effects of increasing temperature and increasing time are weakened. Observations show that a low annealing temperature with a short heat treatment time can significantly improve the strength of the clad compound joint.**

Keywords—bimetal, workpiece, heat treatment, temperature, deformation.

I. Introduction

In the manufacture of electrical equipment, the most important role belongs to contact joints, whereupon the reliability and quality of manufactured device operation depend. With the development of power engineering, there is a continuous process of improving the design of contact joints. At the same time, unreliable contacts and those that did not prove their value during the operation of the contacts are replaced by more advanced and reliable ones [1].The process of improving contact joints has been faster in recent years due to the widespread introduction of compression and welded contact elements, the use of copper-clad aluminum, plate springs and bolt contacts [2].

The reliability of contact joints is measured by the specific number of detected defective and damaged contacts during operation [2,3]. Emergency statistics at stations and substations included in power systems shows that accidents caused by defective contact joints make up about 10% of all accidents [4].The most common cause of these accidents is deterioration of the contact in the bolted joint and, especially, in the transition contacts of inhomogeneous materials (for example, copper – aluminum) [4, 5].The main reason for the failure of bimetallic contacts is a gradual increase in electrical resistance, which contributes to an increase in the temperature of the contact zone, which results in a progressive increase in electrical resistance and the failure of the contact pair [5]. At the initial stage, this is caused by the presence of pores and various imperfections between the bimetal layers, as well as the intermetallic zone, which has an increased electrical resistance [6]. During the operation of such a bimetallic contact, the number of pores and the thickness of the intermetallic layer increase, the temperature rises. It ultimately leads to dynamic deformation instability of the conductor. However, a laminated metal composition combines high electrical and strength characteristics with a minimum consumption of expensive and scarce conductive materials (copper, silver, aluminum, etc.), which makes it possible to obtain new service properties of the material [7, 18, 19].The main ones are the following: higher electrical conductivity compared with the base metal, increased strength, reduced weight, improved corrosion protection of easily oxidized metals and lower cost [7, 8, 20].Therefore, the use of multilayer contacts is a promising practice, both in our country and abroad. This circumstance allows us to consider multilayer materials indispensable for use in the electrical engineering industry in the foreseeable future. Therefore, research related to the determination of the quality of multilayer metals, the state of the transition zone between the metals of the composition and the influence of various thermomechanical effects on an already formed contact is a topical task [9, 21].

The purpose of the paper is to study various heat treatment modes for the morphology and mechanical characteristics of the contact layers of the conductor with two components aluminum + copper.

II. Methods of Research

The development of modern industry is associated with the production of new materials with unique properties and combining contradictory mechanical characteristics, for example, such as good electrical and thermal properties of a particular material. Therefore, clad metals, consisting of two or more layers, are becoming more widespread due to their unique properties. [10, 35]. Currently, there are various methods for manufacturing multilayer metals, such as explosion welding, rolling, self-propagating high-temperature synthesis, extrusion, drawing with thinning of the wall and friction welding [11, 33]. Among these

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methods, the explosion welding method occupies a special place due to its efficiency and economy. Its advantages include simplicity of equipment and the possibility of manufacturing parts of large overall dimensions, removing contamination from the layers during joining by the cumulative jet that precedes the detonation wave [12, 21, 36]. Since explosion welding is based on a high degree of deformation, the joined metals will receive a high degree of hardening, especially in layers adjacent to the weld zone. Therefore, subsequent processing of such a workpiece for electrical contact is difficult. The composition must undergo heat treatment for relaxation of the deformations that arose at the stage of joining dissimilar metals.

Multilayer metals based on copper and aluminum are widely applied. [13, 35]. For example, a clad sheet with two layers of aluminum / copper can reduce the weight of a product with equivalent electrical and thermal conductivity by almost 40 % compared with copper or copper alloy. Savings make about 60 % of copper alloy. For these reasons, Al / Cu bimetal is often used to armor cables, winding clamps in televisions, cooling plates, and buses for joining conductors. [15, 31, 37].

However, research aimed at studying the morphology and strength of the joint of aluminum with copper, obtained by explosion welding, are still not sufficiently covered in the literature. [17, 29].The strength of the composition joint, as well as the presence of air pores and intermetallic inclusions, has a decisive influence on the quality of the electrical contact element.

In this paper, we studied the composition and mechanical characteristics of a two-layer metal sheet consisting of copper (M2) and aluminum (AD35), which was produced by explosion welding. Explosion welding technology is described in detail in the papers [14, 30] and is not discussed here.

Annealed aluminum sheet (AD35) is used for the production of ingots, bars, rolled wire, band; wires for leads and cables, as well as wires for welding and other purposes, for the manufacture of semi-finished products by hot or cold deformation. The copper strip (M2) is used for high-quality semi-finished products and alloys based on copper, processed by pressure, for the manufacture of electrical products [16, 22].The thickness of the sheets is 11 mm and 0.8 mm, respectively. We used microsections of thermally untreated bimetal, heated to temperatures of 160º C, 320º C for 1.5 hours, 4.5 hours, 18 hours, respectively.

The applied equipment: laboratory electric oven SNOL 7.2/1100, tensile machine UME-10 tm, scanning electron microscope REM–106I, optical microscope OLYMPUS GX41, dispersion spectrometer Smart Raman DXR.

The morphology of the microsection of a copper / aluminum sheet with different annealing temperatures is shown in Fig. 1. It can be seen that the aluminum / copper joint that has not undergone heat treatment is uneven, and aluminum and copper are embedded in each other. Low annealing temperature levels the contact area as shown in Fig. 1b. This phenomenon must be caused by the temperature equalization between aluminum and copper [23, 24]. With an increase in the heat treatment temperature, a layer of the transition zone appears along the Al / Cu boundary, as shown in Fig. 1c and d. In addition, the width of the transition layer increases with temperature growth.

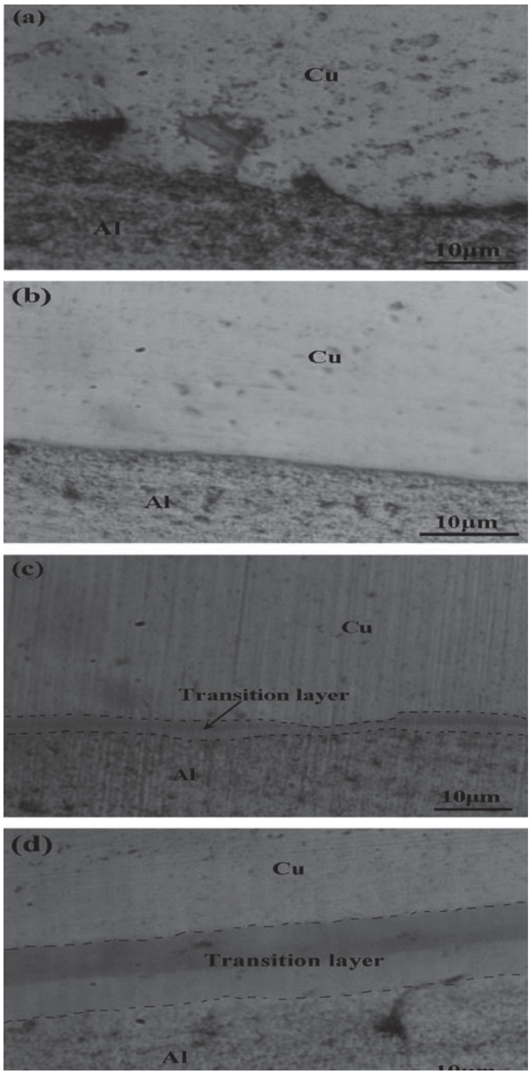

Fig. 1. The morphology of the boundary layer of a copper-aluminum compound with different heat treatment: (a) – after explosion welding, (b) – 160ºC/1.5 h, (c) – 320ºC/1.5 h, (d) – 420ºC/1.5 h

III. EXPEREMENTAL RESEARCH

The clad workpiece was subjected to heat treatment at different temperatures and with different heating times to study the change in the size of the contact layer and the concentration of elements in the joint zone of the Cu / Al composition. Graphs of the concentration of Al and Cu elements in the contact layer at a heating temperature of 160º C and 320º C are shown in Fig. 2.

The following conclusions can be drawn from the photographs of microsections: processing at a temperature of 160º C, 18 h led to the formation of an interlayer intermetallic layer. The interlayer width increases with the growth of the heat treatment time. In addition, the concentration of elements changes over time, as shown in Fig. 2b. At a temperature of 320 ° C and 1.5 hours, the formation of interlayer intermetallic compounds also occurs, but their concentration is not uniform. When the heating time increases to 18 hours, the thickness of the layer of intermetallic compounds almost doubles, but the increase in the thickness of the layer practically stops with a further increase in heating time to 48 hours.

The morphological structure of the contact layer and its composition during annealing with a temperature of 320º C for 18 hours are shown in Table 1. Tests on a dispersion spectrometer show that the interlayer band consists of several types of layers. The layer adjacent to aluminum has a large amount of copper in the proportion of aluminum: copper – 2:1. Thus, we can conclude that with an increase in the heat treatment time, the number of layers in the band increases significantly and the chemical composition of the formed compound becomes inhomogeneous.

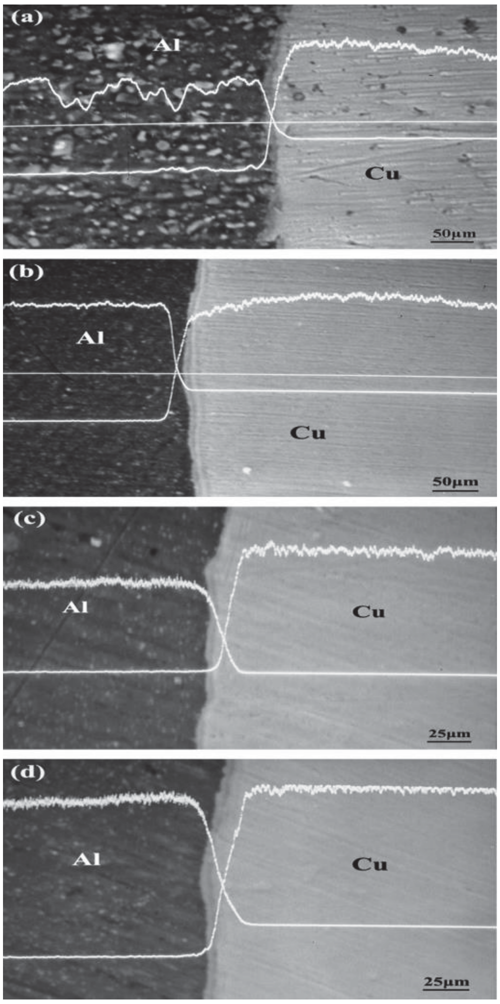

Fig. 2. Profiles of electronic microanalysis of aluminum - copper elements in the contact layer of a clad sheet workpiece with various heat treatment: (a)–160ºC/1.5 h, (b)–160ºC/18 h, (c) – 320º/1.5 h, (d) – 320º/18 h.

TABLE I. THE COMPOSITIONS OF THE VARIOUS LAYERS ALONG THE JOINT IN AL/CU (BY %)

Test state	Cu	Al
A	32.21	67.79
B	18.52	81.48
C	23.77	76.23

To assess the heat treatment influence on the strength of aluminum and copper joint, we used the standard method for testing multilayer metals for shear (GOST Standard 10885-64), [25, 33] The research has shown that joint strength depends on the selected annealing mode. The highest joint strength is observed for clad sheet subjected to heating of 160º C for 1.5 hours. The lowest shear resistance between layers has a composition that has undergone heat treatment of 320º C for 18 hours. There is a decrease in joint strength with hanging temperature and processing time. According to the observations made above, a higher temperature and a long heat treatment time can lead to a rapid increase in the volume of intermetallic compounds along the layer boundary.

As research [32, 34] reveals, the intermetallic composition has high strength but low ductility. In addition, the resulting compounds have large differences in the sizes of Al and Cu crystals, which leads to high residual stresses along the boundary and reduce the bond strength of the compound. Therefore, it is necessary to conduct heat treatment at low temperature with a short period of time to improve the strength characteristics of the joint zone of the clad metal.

IV. CONCLUSION

The stability of contact bimetallic compounds depends on the quality of their manufacture. For the formation of the final product for electrical contact, it is necessary to carry out additional machining or plastic deformation on the bimetal billet obtained by welding. If the workpiece is processed in a hot state, then the time of the entire cycle of the workpiece-finished product should not exceed 2 hours. During this time, the boundary of the metal compound is leveled, but the intermetallic layer does not have time to form. If the sheet is subsequently processed in a cold state, then due to the hardening of the composition after explosive stamping, it is necessary to conduct annealing of the first kind for it. This type of annealing is used to relieve hardening and residual stresses for parts made of monometall. To select the necessary annealing intervals for aluminum-copper bimetal in order to remove hardening, on the one hand, and not to break the formed metal joint, on the other hand, and to eliminate the excessive growth of the intermetallic layer, was part of this study. The best heat treatment option has been obtained: heating to a temperature of 160 ° C and holding for 1.5 hours. This annealing mode prevents the formation of an intermetallic layer in the contact zones and bimetal has the best joint strength of the layers. This will provide reduced electrical resistance of the aluminum-copper contact, as well as dynamic deformation stability during its operation.

The following points are also confirmed [26, 28]: temperature has a greater effect on the growth of the intermetallic phase than the heat treatment time; when the layer of intermetallic compounds reaches a certain value, the effects of increasing temperature and time are weakened; low annealing temperature with a short heat treatment time can significantly improve the strength of the clad composition joint.

The prospect of further research in this direction is caused by the need to measure the electrical resistance of bimetallic annealed contacts. This will allow one to simulate a contact pair operation in conditions close to real ones and to predict normal operation intervals.

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