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RESEARCH OF THE STRESS-STRAIN STATE OF A SOLDERED BIMETAL RING

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Annotation:

The influence of the cooling regime of a brazed bimetallic cathode consisting of a chromium ring inserted into a copper ring on the stress-strain state was investigated using computer simulation. Dangerous zones of tensile stresses in a brittle material were shown, which could lead to the assembly's failure. The influence of the cooling regime after brazing on the stresses and strains in the cathode was established.

Keywords: soldering, dissimilar materials, stresses, deformations, cooling regime.

Introduction.

Metal products for various purposes require the application of a protective layer to prevent their premature destruction and give them an elegant and beautiful appearance. In industrial conditions, chrome plating of parts is relevant if the object will be operated, for example, in aggressive environments, friction (steam equipment, heating networks, automobile engines, parts of sea vessels, etc.) [1]. The most common method of protecting metals from corrosion is chrome plating of parts [2]. Typically, the thickness of the chrome coating is 0.075...0.25 mm [3]. Different spraying systems use different designs and shapes of targets. The setup in question uses a cathode in the form of a bimetallic compound of a chromium and copper ring, which requires an inseparable bond between copper and chromium. The melting point of copper is 1083 °C, while chromium melts at 1907 °C. This, as well as a significant difference in the physical, chemical, and mechanical properties, makes it impossible to join these materials by fusion welding. The most suitable method for joining this part is soldering. However, the difference in the physical and mechanical properties of the materials being joined can lead to a violation of the integrity of the bimetallic unit during cooling after soldering. Pure chromium used in the cathode is a brittle metal with a hardness of 8.5 on the Mohs scale. Therefore, an important issue when joining dissimilar materials with chromium is the stress-strain state of the unit.

Aim.

To study the nature of the change in shape and the reasons for violating the integrity of a complex axisymmetric unit made of dissimilar materials after soldering, due to residual stresses under different cooling conditions.

Materials and methods.

The study used computer modeling with the ANSYS software package based on the finite element method. The stress-strain state of the units was studied under thermal loading by decreasing the temperature after soldering. The unit in the form of a bimetallic ring is designed for the ion-plasma spraying installation; it is used as a cathode, a source of material for spraying. The unit consists of chromium and copper rings (Fig. 1, a). The studies were carried out on an axisymmetric cathode model, the general view (Fig. 1, b), and the section shown in Fig. 1, c.

The unit's temperature after soldering was reduced from 900 to 20 °C in two modes: at high speed for 60 minutes, and at low speed for 480 minutes.

One of the main problems in the manufacture of the unit is the disruption of its shape and the integrity of the chromium ring after soldering due to residual stresses caused by different coefficients of linear thermal expansion of copper and chromium (Fig. 2, a). The values of the elastic modulus and yield strength of copper were taken taking into account the change in temperature (Fig. 2, b). At all temperatures, the Poisson ratio $\mu = 0.3$ and the coefficient of hardening during plastic deformation of copper, $c_h = 1 \cdot 10^2$ MPa, were taken as constant.

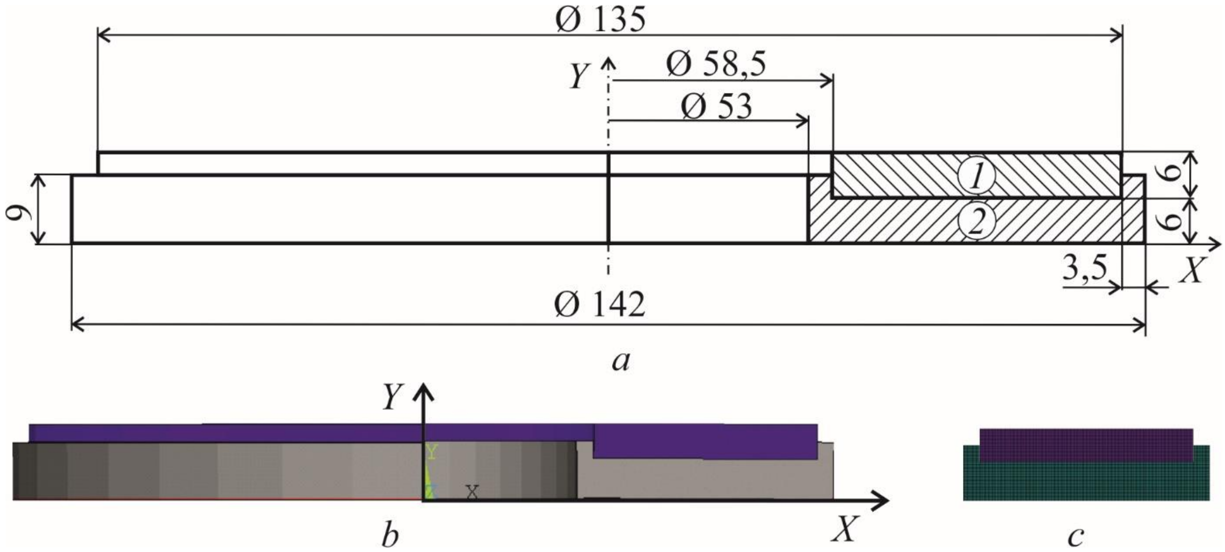
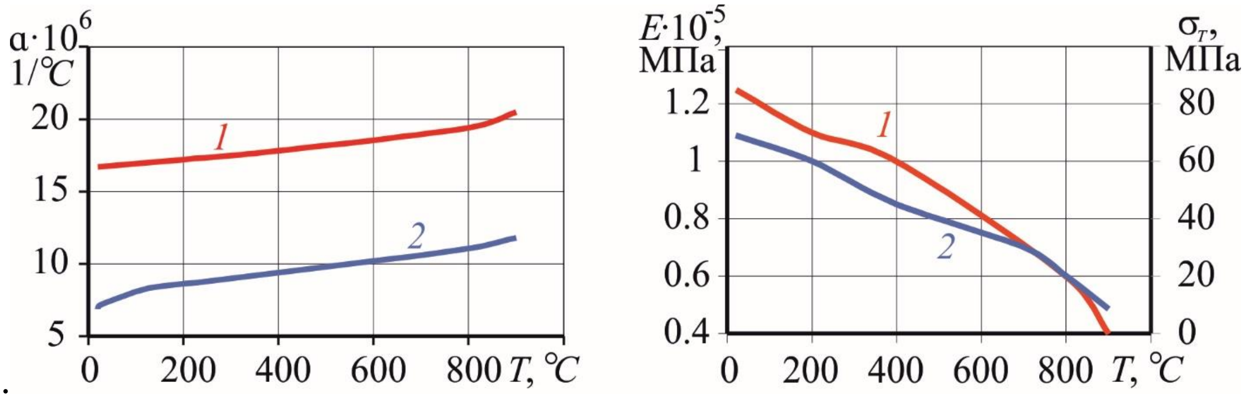


Fig. 1. General view of the cathode (a) made of chromium (1) and copper (2), general view of the cathode model (b), and section of the axisymmetric finite element model (c)



a b

Fig. 2. Dependence of the coefficients of linear thermal expansion (a) of copper (1) and chromium (2), and the modulus of elasticity (1) and yield strength (2) of copper (b) on temperature

Creep deformations of copper were calculated using the equation:

$$\dot{\varepsilon}_{cr} = C_1 \cdot \left[\sinh\left(C_2 \cdot \sigma\right)\right]^{C_3},$$

where creep coefficients were taken into account, taking into account temperature (Table 1).

Table 1

Creep coefficients of copper depending on temperature

T, °C	C_1	C_2	C_3
200	9,81e-6	6,7e-9	3,93
400	6,8e-6	1,51e-8	3,57
450	7,8e-6	2e-8	3,36
500	6,1e-6	2,79e-8	3,39
550	4,2e-6	3,26e-8	3,38
730	1,3e-6	5,71e-8	2,66
900	9e-7	9,35e-8	2,26

For chromium, the mechanical properties are assumed to be constant: elastic modulus E = 2.9 105 MPa, Poisson's ratio μ = 0.3. The coefficient of linear thermal expansion depending on temperature is shown in Fig. 2.

Results and discussion. Analysis of stress fields after cooling showed that the highest values are reached by radial and circumferential tensile stresses on the upper (outer) surface of the chromium ring (Fig. 3).

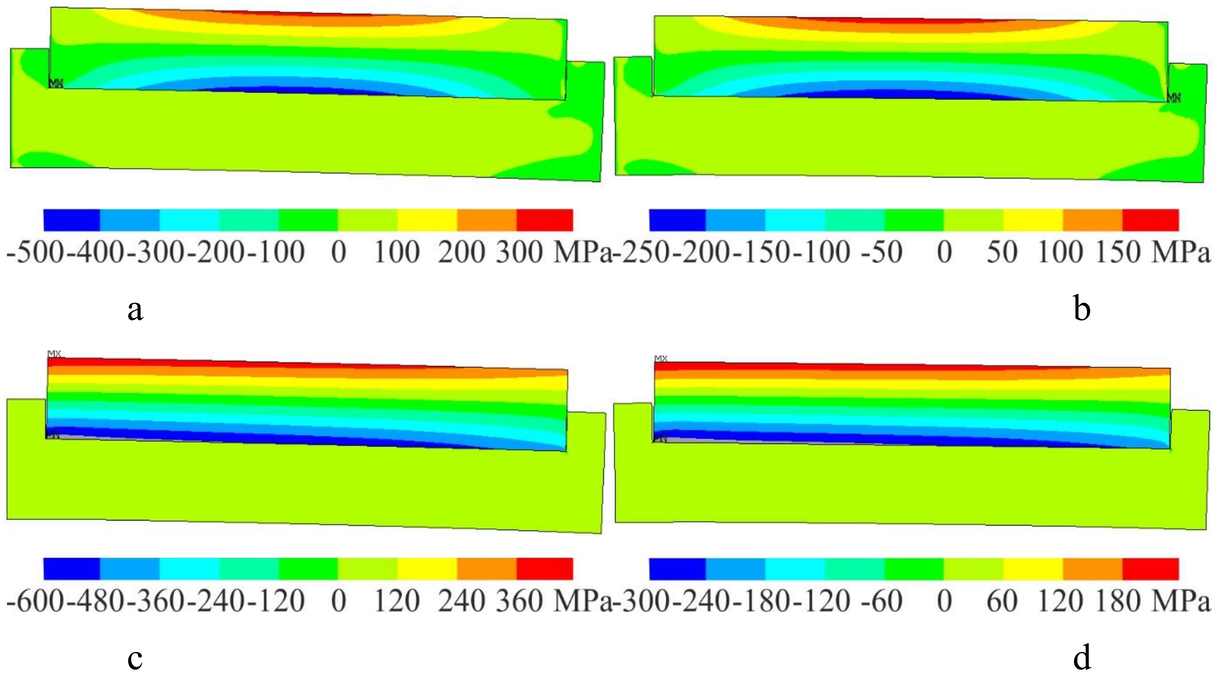


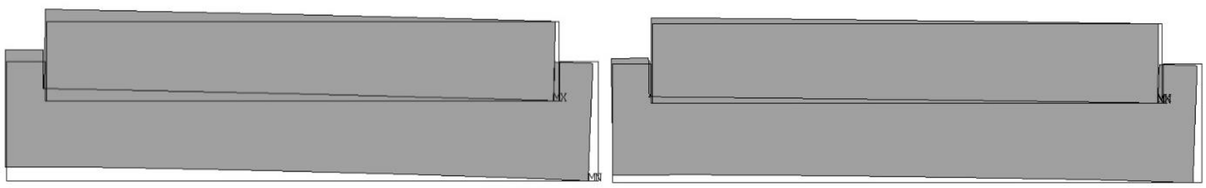
Fig. 3. Fields of radial σ_x (a, b) and circumferential σ_z (c, d) stresses after cooling with a high (a, c) and low cooling rate (b, d)

On the upper surface of the chromium ring, as a result of its bending, large tensile stresses arise in both the radial (above 200 MPa) and circumferential (above

300 MPa) directions. This can lead to the occurrence of cracks, most likely across the ring near its inner edge under the action of maximum circumferential stresses, and less likely along the circumference of the ring, in the middle part of its width under the action of maximum radial stresses.

The maximum axial tensile stresses are concentrated in a small area of the cylindrical part of the chromium-copper joint. Cracks may also occur here. The maximum shear stresses of up to 40 MPa are also concentrated at the joint, but on a flat part near the outer surface.

Unlike chromium, stresses arising during cooling in the copper ring lead to the formation of plastic deformations. Analysis of the modeling results showed that short-term plastic deformations are small during slow cooling, while creep deformations are significant. Along the copper joint at the extreme points, short-term plastic deformations of up to 1...15% and creep deformations of up to 2% in most of the joint and up to 16...27% at the extreme points occur, which can also cause failure. The resulting stresses and deformations distort the cross-sectional shape of the soldered ring after cooling. This distortion is visible in Fig. 4. The copper ring cross-section rotates and bends noticeably. In contrast, the chromium ring rotates, bending less due to its greater rigidity and strength.



a b

Fig. 4. Change in the contour of the node after cooling with a high (a) and low cooling rate (b)

When cooling at a high temperature decrease rate, the maximum displacement of the points of the upper surface of the chrome ring in the axial direction reaches 0.93 mm. The lower edge of the copper ring is 1.03 mm. When cooling at a lower rate, due to the influence of creep deformations, these values decrease, for chrome to 0.45 mm, for copper to 0.6 mm. Thus, the stress-strain state of the copper-chrome unit after soldering causes a fairly noticeable violation of its shape and size, fairly large stresses in chrome and plastic deformations in copper, which can lead to its destruction. A significant effect of the cooling mode on the picture of the stress-strain state in the soldered cathode is noted.

Conclusion: Due to the difference in copper and chromium's physical and mechanical properties, a complex stress-strain state occurs in the soldered unit after cooling. The tensile stresses that arise in chromium are dangerous for the integrity of the cathode. Reducing the cooling rate after soldering minimizes the risk of unit destruction.

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