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INFLUENCE OF THE YIELD LIMIT OF THE INTERLAYER ON THE STRESS-STRAIN STATE OF UNITS DURING BRAZING OF A HEAT-RESISTANT ALLOY

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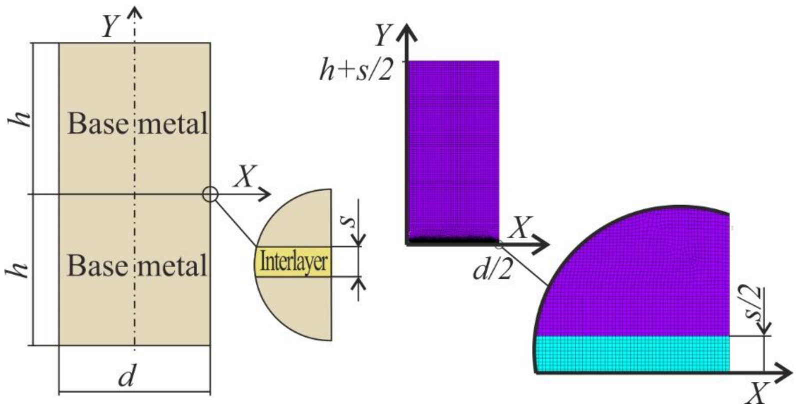
Introductions. Brazing is the primary method of joining cast heat-resistant alloys, which cannot be welded by fusion. When brazing, the solder acts as an intermediate gasket, which has physical and mechanical properties different from the material being joined before and after interaction with the base material. Such an interlayer changes the nature of the stress-strain state in the joint zone, which was established analytically in the 20th century by O. A. Bakshi [1]. The development of computer technology and software packages makes it possible to model the stress-strain state (SSS) of joints, considering virtually all active factors and the dynamics of processes. The formation of a volumetric stress state can significantly affect the performance of soldered joints. In this regard, it is necessary to be critical of various assessments of the performance of connections and nodes, if given without considering their SSS [2].

The beginning of the research into the features of the formation of the SSS of joints of heterogeneous and homogeneous materials with intermediate interlayer was laid by V.I. Makhnenko, which made it possible to develop a soldering technology with controlled stress-strain state [3].

The work [4] considers the modeling of SSS during the soldering of metals with graphite. The work [5] SSS of soldered units made of homogeneous metals with a soft layer under axial load. The influence of the thickness of the intermediate interlayer and its rigidity on the stress-strain state of the joint in an elastic state was investigated in [6]. Considering the high temperatures of joining heat-resistant alloys, the role of plastic deformations cannot be ignored.

Aim. Study the influence of plastic deformations on the formation of the stress-strain state of a unit during cooling after brazing.

Materials and methods. The study of the influence of the cooling mode and the combination of the properties of the interlayer and the base metal was carried out on cylindrical models (Fig. 1), with an interlayer thickness of 0.08 mm. The stress-strain state of the units was studied under thermal loading by decreasing the temperature from 1270 to 1100 °C.



a **b**

Fig. 1. General view of the sample with an interlayer (a) and finite element model (b)

The properties of the base metal, except for the yield strength, were assumed to be the same in all variants, constant at temperature: elastic modulus $E_{bm}=0.5\cdot10^5$ MPa, Poisson's ratio μ = 0.4, coefficient of hardening during plastic deformation of the material $c_h=0.5\cdot10^2$ MPa, coefficient of linear thermal expansion $\alpha_{bm}= 21\cdot10^{-6}$ 1/deg. Yield strength (conditional) $\sigma_{0.2}$ was assumed to decrease linearly from 150 MPa at 1100 °C to 0 at 1270 °C.

The investigated variants of units with interlayers 0.08 mm thick, having a coefficient of linear expansion of strain of 2 times less (10.5 10^{-6} 1/deg, variants 1 and 2) and 2 times greater (42 10^{-6} 1/deg, variants 3 and 4) compared to the base metal; yield strength of 0.85 (variants 1 and 3) and 0.7 (variants 2 and 4) of the yield strength of the base metal, with a Poisson's ratio of 0.4. The modulus of elasticity of the interlayer material in all variants was assumed to be the same as the base metal

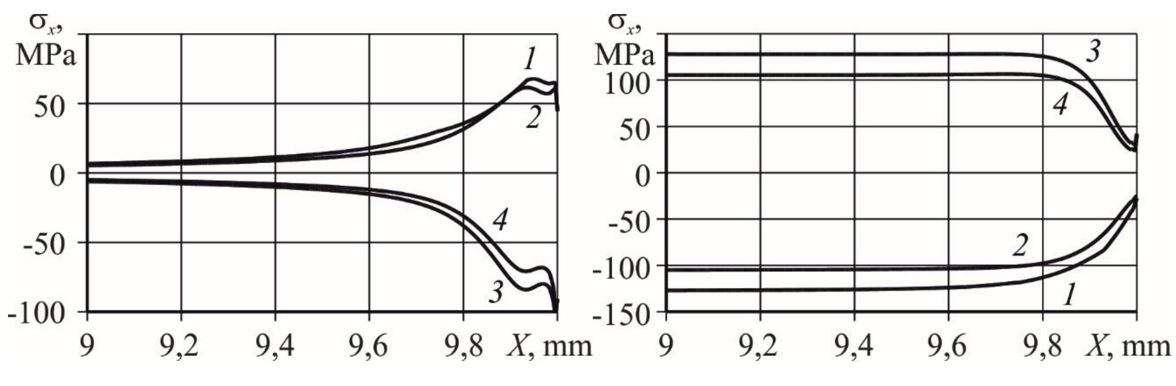
E_{in} = 0.5 10^5 MPa.

The possibility of plastic deformation of the interlayer and the base metal was considered according to the von Mises condition.

Results and discussion. An analysis of the fields of all components and equivalent stresses showed that there are no stresses on most of the joint, and only in a small zone located near the interlayer at the edge of the joint (at the outer surface of the cylinder) and in the interlayer itself a complex stress-strain state is created, caused by the difference in the coefficient of linear expansion of the metal being joined and the interlayer.

Analysis of the stress distribution along the joint according to the diagrams (Fig. 2...5) shows that all components and equivalent stresses in the base metal are absent over most of the joint, and only in a small zone near the outer surface, about 1 mm long, do they appear and increase sharply.

Radial stresses in the base metal are tensile in variants 1 and 2 and compressive in variants 3 and 4 (Fig. 2, a). Remaining close to zero over most of the joint, they reach a maximum value of about 65 and – 100 MPa at the joint edge in variants with interlayers with minor (variants 1 and 2) and large (variants 3 and 4) CLTE, respectively. In the interlayer material, radial stresses are compressive in variants 1 and 2 and tensile in variants 3 and 4 (Fig. 2, b).



a **b**

Fig. 2. Diagrams of radial stresses along the joint in the base metal (a) and the interlayer (b) near its outer edge, variants 1, 2, 3, 4

On the greater part of the joint, they are at the level of about – 128 and –

105 MPa (variants 1 and 2) and 128 and 105 MPa (variants 3 and 4), i.e., they are the same in magnitude in the nodes with layers with small and large CLTE. At the edge of the joint (Fig. 2, b), the radial stresses decrease significantly to ±30 MPa in all variants. The circumferential stresses are distributed similarly to the radial ones.

In the interlayer, axial and tangential stresses are also absent over most of the length of the joint (Fig. 3). Only near the edge, they appear and increase sharply, axial stresses up to 68 and 55 MPa in variants 1 and 2, and –69 and –59 MPa in variants 3 and 4, tangents up to -44 and -38 MPa and 51 and 43 MPa, respectively.

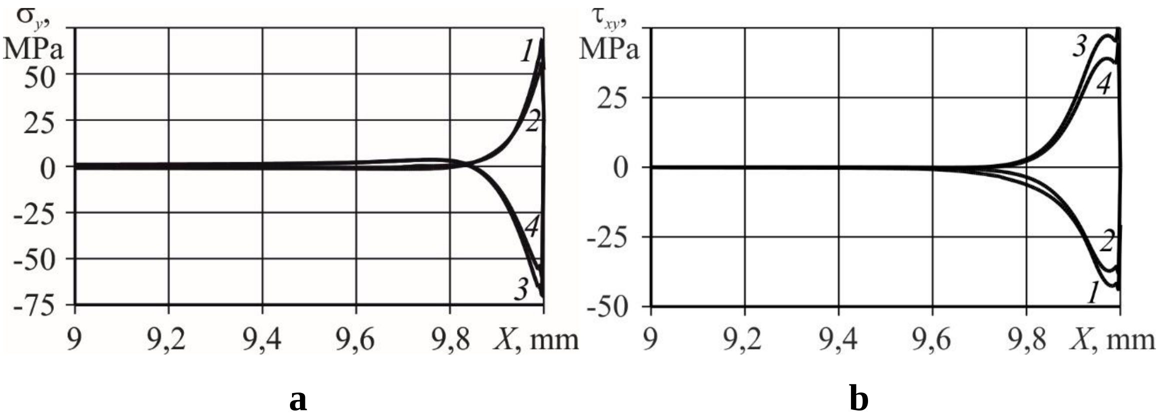
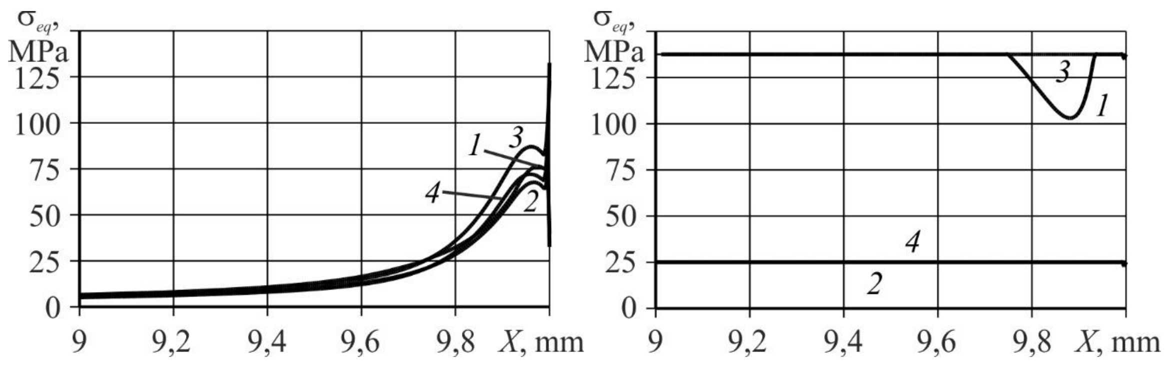


Fig. 3. Diagrams of axial (a) and tangential (b) stresses at the joint of the base metal and the interlayer near its edge in variants 1, 2, 3, 4

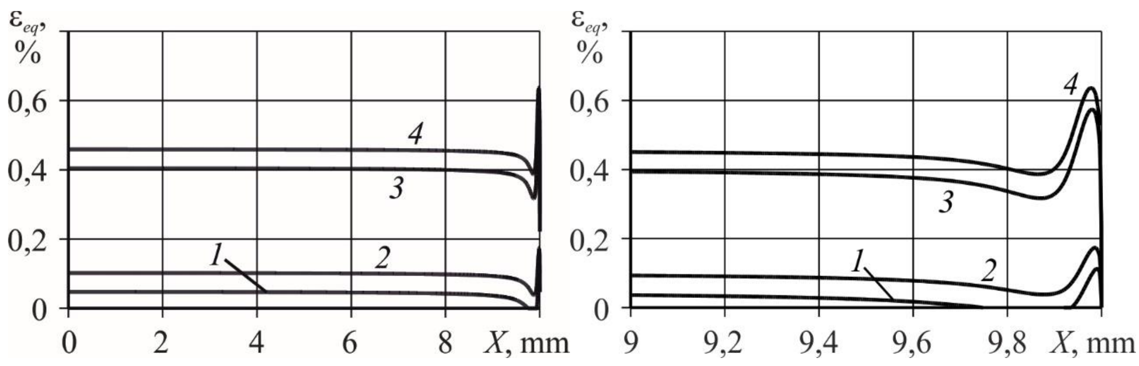
In accordance with all components, the stresses are distributed and equivalent (Fig. 4). In all variants, a constant stress level is maintained over most of the joint in the materials being joined and in the interlayer. At the same time, mainly in the metal, they can practically lead to changes only in a small volume at the edge of the joint. In the interlayer, the equivalent stresses over most of the length of the joint remain at a constant level of 127 (variants 1 and 3) and 105 MPa (variants 2 and 4), close to the yield strength of the interlayer material, along the entire length of the joint (Fig. 4, b).

The plastic deformations in the interlayer are distributed accordingly (Fig. 5). Equivalent plastic strains are constant over most of the joint length, increasing significantly as the yield strength of the interlayer decreases and the difference between the CLTE of the interlayer and the base metal increases. Near the outer edge of the joint, they first decrease and then increase again.



a b

Fig. 4. Diagrams of equivalent stresses σ_{eq} along the joint in the base metal (a) and the interlayer (b) near its edge in variants 1, 2, 3, 4



a b

Fig. 5. Diagrams of equivalent plastic ε_{eq} deformations along the joint in the interlayer along the entire length of the joint (a) and near its edge (b) in variants 1, 2, 3, 4

Conclusions. Under thermal loading in cylindrical units made of heat-resistant alloy with a solder layer having a CLTE lower or higher than that of the base metal, and a yield strength lower than that of the base metal, the appearance of plastic deformations does not change the nature of the stress-strain state in comparison with the elastic deformation of the unit. Hanging the ratio of the CLTE values and the yield strength of the interlayer and the base metal does not affect the nature of the stress-strain state, changing only the sign and level of stresses and deformations. Short-term plastic deformations are small in variants with a smaller difference in CLTE of the interlayer and the base metal. Short-term plastic deformations increase significantly in variants with a larger difference in CLTE of the interlayer and the base metal. The appearance of plastic deformations in the interlayer has little effect on the rigidity coefficient and the degree of hardening or softening of both the base metal and the interlayer material. The softening of the base metal in the middle part of the joint and the interlayer near its edge must be considered when designing such assemblies and choosing the properties of the interlayer material.

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