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STRESS-STRAIN STATE OF WELDED AND BRAZED ASSEMBLIES OF DISSIMILAR MATERIALS WITH SOFT INTERLAYER AT TEMPERATURE-FORCE LOADING

V.V. KVASNYTSKYI[1], **M.V. MATVIIENKO**[2], **E.A. BUTURLYA**[2], **V.F. KVASNYTSKYI**[2] and **G.V. YERMOLAYEV**[2]

[1]National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute»
37 Peremohy Prosp., 03056, Kyiv, Ukraine. E-mail: kvas69@ukr.net

[2]Admiral Makarov National University of Shipbuilding
9 Geroiv Ukrainy Prosp., 54025, Mykolaiv, Ukraine

There was researched a stress-strain state (SSS) at temperature-force loading of cylinder assemblies of materials of similar strength, but different by temperature coefficients of linear expansion (TCLE), with soft (lower yield limit than in base metal) interlayer and average temperature coefficient of linear expansion. Fields and distribution diagrams of stresses and plastic deformations of assemblies were analyzed. Investigation of SSS showed that effect of mutual temperature (cooling) and force (compression) loading of assemblies with soft interlayers appears in increase of radial and circumferential stresses in both materials, increase of equivalent ones in the material with high TCLE and the interlayer and axial ones in the joined materials, and, respectively, decrease of equivalent in the material with lower TCLE. Tangential stresses at that remain virtually the same as at purely temperature loading. In change of cooling by heating the materials change their places. The value of maximum plastic deformations in the interlayer material at interface with base material close to external surface at mutual temperature-force loading reaches 2.3 %. At that, axial tension stresses in brittle materials with low TCLE (ceramics, graphite, etc.) during cooling in the assemblies with soft interlayer reduce by value of compression external stresses, i.e. risk of brittle fracture reduces. 7 Ref., 8 Figures.

Keywords: *diffusion welding, brazing, dissimilar materials, soft interlayer, stresses, deformation, computer modelling, mutual temperature and force loading*

The main problems of joining of dissimilar materials are the processes of activation of surfaces being joined and formation of residual stresses [1, 2]. Intermediate interlayers are used to solve these problems. In brazing such an interlayer is a brazed weld. Residual stresses also play important role in working capacity of fabricated assemblies after cooling [3, 4]. Therefore, investigation of such layers is relevant.

The simplest methods of evaluation of stress-strain state (SSS) are the engineering methods of calculation in limits of elasticity, based on hypothesis of flat sections, however, they do not allow considering effect of many factors even for simple assemblies. Methods of mathematical modeling are the most versatile and perspective at current stage of development of computer engineering and programming. Works [5–7] by finite element method using ANSYS computer complex have investigated the processes of SSS formation in dissimilar materials joining including metals with nonmetals. Works [6–7] studied SSS with interlayers at axial and temperature loading, respectively. Since many assemblies are subjected to axial as well as thermal loading, therefore this work investigates SSS at mutual loading taking into account plastic deformations.

Aim of the present paper is to determine effect of soft intermediate interlayers having lower yield limit in comparison with materials being joined on SSS formation in arc diffusion welding and brazing.

Main material of investigations. The investigations were carried out by the computer modeling method using ANSYS software complex. Axial symmetric problems were solved for assemblies of cylinder-cylinder type of 20 mm diameter, total height $h = 21$ mm and interlayer thickness $s = 1$ mm (Figure 1). Considering specifics of assemblies, presence of large gradients of stresses in a narrow zone close to interlayer there was used a gradient division with variable dimensions of finite elements, sizes of which in a joint zone were selected in such a way as they make not less than 10 over interlayer thickness. PLANE 183 type finite elements were used. Joined materials 1 and 2 had similar yield limits, but different temperature coefficients of linear expansion (TCLE = $20\cdot10^{-6}$ and $10\cdot10^{-6}$ 1/deg). The soft interlayer had considerably lower yield limit ($\sigma_y = 38$ MPa), than in base metal ($\sigma_y = 250$ MPa) and average TCLE ($15\cdot10^{-6}$ 1/deg). Elasticity modulus and Poisson's coefficients of all materials were taken similar and equal to $2\cdot10^5$ MPa

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and 0.3, respectively. This allows outlining the effect of particularly plastic constituent of deformation on assembly SSS. Taken properties of materials at given loading provided plastic deformation of the interlayer only. Joined materials at that were elastically deformed over the whole volume that allows using obtained results to joints of brittle materials.

Loading was performed using mutual compression by 40 MPa force and decrease of assembly temperature (after joint formation) per 100°. Obtained at such loading results are true at change of cooling by heating (in welding with thermal cycling), but materials 1 and 2, having different TCLE, change their places at that. Modeling results were compared with similar assemblies at various types of loading (only force and only temperature). Fields and distribution diagrams of all constituents of stresses and plastic deformations of assemblies were analyzed.

Analysis of modeling results showed that SSS nature in whole corresponds to general principles of mechanics and regularities set earlier in [5–7]. Effects of temperature and force loading are algebraically summed, as a result of what the fields of radial and circumferential stresses remain virtually the same as at purely temperature loading. Axial compression stresses in material 1 rise and tensile ones in material 2 reduce by value of compression load. Tangential stresses noticeably rise at the interface of «soft» interlayer with material 1 and decrease at interface with material 2 in comparison with purely temperature loading. In this case it is obviously demonstrated the algebraic summing of the effects from the difference of TCLE and plastic deformation of interlayer and significantly higher level of stresses at temperature loading in comparison with force one.

The field of equivalent stresses changes equivalently. The latter at mutual loading noticeably rises in material 1 and reduces in material 2 in comparison with purely temperature loading.

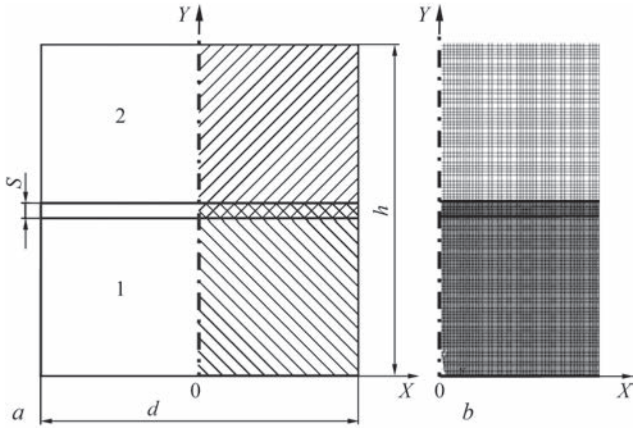

Figure 1. Physical (*a*) and FE (*b*) models of assemblies with interlayer (1, 2 — materials being joined)

In accordance with equivalent stresses there is a change of the field of plastic deformations. As in the case of purely temperature loading the maximum of the latter is accumulated close to external surface of assembly, but their distribution over interlayer thickness distinctly change. They are maximum at the interface with material 1 and reduce with distance from it.

Nature and level of distribution diagrams of radial stresses along the butt in the materials being joined at mutual temperature and force loading match with nature of corresponding distribution diagrams at purely temperature loading (Figure 2). At that the maximum radial stresses in the materials being joined reduce by 15–20 MPa. Circumferential stresses have similar to radial distribution in the materials being joined.

The pattern is completely different in the soft interlayer material. Application of pressure at temperature decrease considerably (in several times) rises plastic deformations from side of material 1 (with higher TCLE) and to lower degree from side of material 2 (with smaller TCLE) at that changing their sign (Figure 3).

The distribution diagrams of axial stresses along assembly generatrix displace to the side of compression by value of axial load of 40 MPa (Figure 4). As a

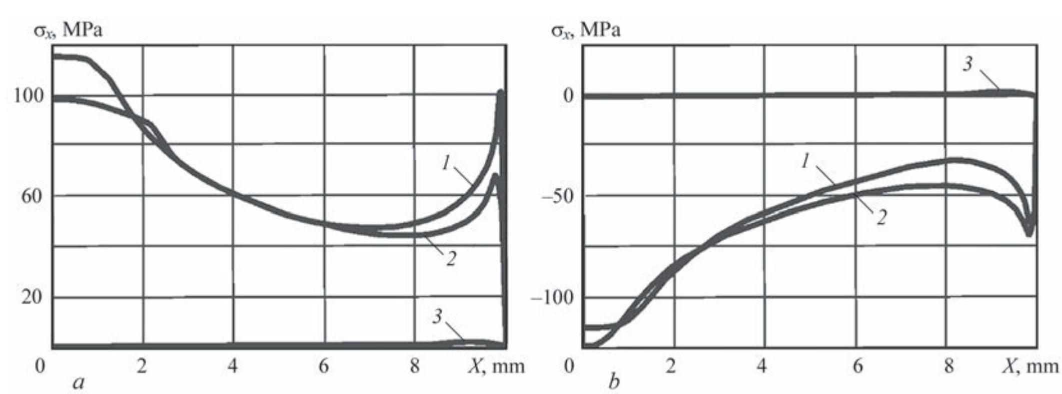

Figure 2. Distribution diagrams of radial stresses in materials 1 (*a*) and 2 (*b*) along butt with «soft» interlayer at temperature-force (*1*), temperature (*2*) and force (*3*) loading

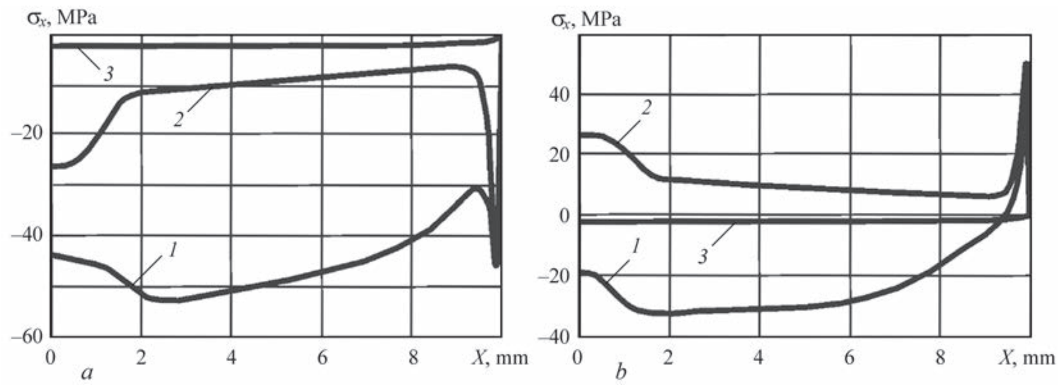

Figure 3. Distribution diagrams of radial stresses in material of «soft» interlayer on butts with material 1 (*a*) and 2 (*b*) at temperature-force (*1*), temperature (*2*) and force (*3*) loading

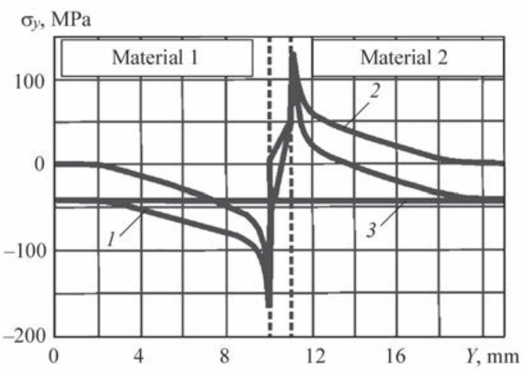

Figure 4. Distribution diagrams of axial stresses on generatrix of assembly with «soft» interlayer at temperature-force (*1*), temperature (*2*) and force (*3*) loading

result tensile stresses in material 2 (with small TCLE) decrease reducing the risk of its brittle fracture.

Tangential stresses being unchangeable on the largest part of the butt increase in the vicinity of external cylinder surface rising from side of material 1 by 10 MPa (Figure 5, *a*) and decreasing by 10 MPa from material 2 side (Figure 5, *b*).

There is a respective change of the distribution diagrams of equivalent stresses. Level of these stresses rises by value of applied pressure 40 MPa in material 1 (Figure 6, *a*) and decreases by 40 MPa in material 2 (Figure 6, *b*). Their distribution in both materials being joined remains close to uniform.

In the material of «soft» interlayer being plastically deformed the value of equivalent stresses in the bigger part of the butt keeps the level of around 40 MPa from material 2 side with smaller TCLE (Figure 7, *b*). From the side of material 1 with larger TCLE the distribution is nonuniform, there is a clearly expressed stagnation zone close to assembly axis, in which equivalent stresses reduce to 10 MPa. In the vicinity of external surface of assemblies they vice-versa rise up to 80 MPa (Figure 7, *a*).

Plastic deformations in the «soft» interlayer material have nonuniform distribution, gradually rising from ones close to 0, in the stagnation zone, up to 1 % and more in the vicinity to the external surface. At that on the interface with material 1 in this zone at mutual loading they are several times higher than at purely temperature loading (Figure 8, *a*). On the interface with material 2, vice versa, distribution is more uniform than at purely temperature loading (Figure 8, *b*), but their level is lower.

Mutual force (compression) and temperature (cooling) loading create more favorable conditions for development of plastic deformations in the «soft» interlayer than purely temperature. Their value and nonuniformity of distribution rise from the side of material 1(with higher TCLE) and they reduce, but distribution becomes more uniform from the side of

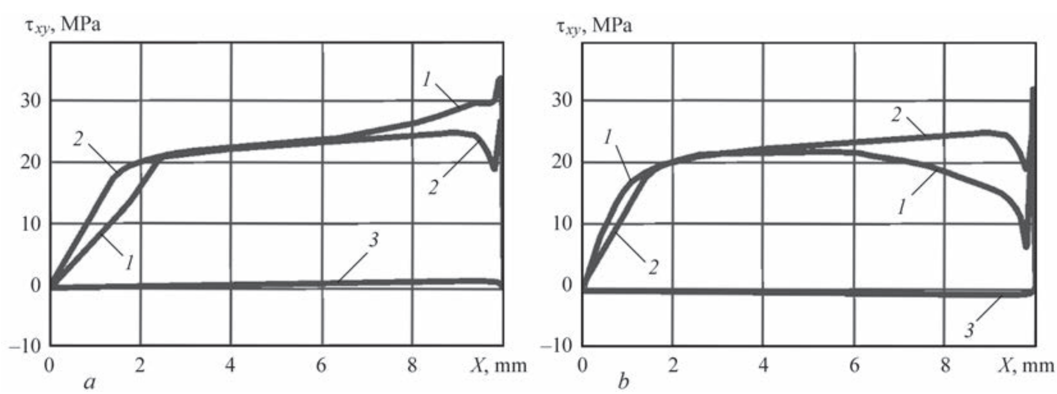

Figure 5. Distribution diagrams of tangential stresses on butts of materials 1 (*a*) and 2 (*b*) with «soft» interlayer at temperature-force (*1*), temperature (*2*) and force *(3)* loading

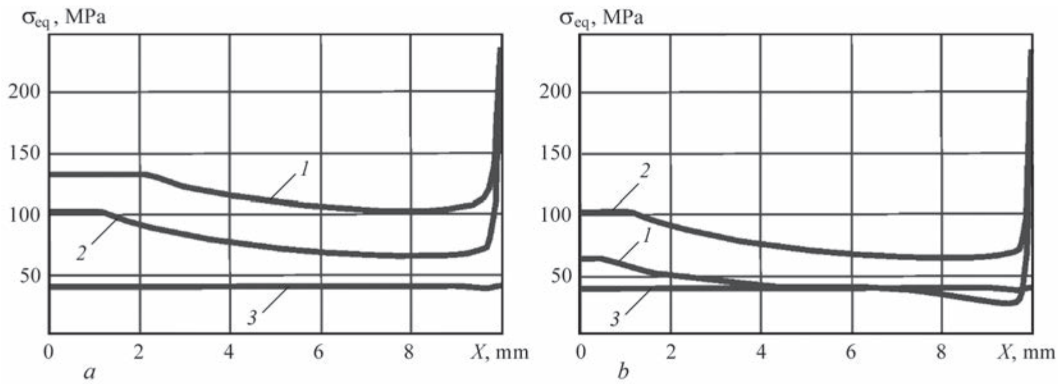

Figure 6. Distribution diagrams of equivalent stresses in joined materials 1 (*a*) and 2 (*b*) on butt with «soft» interlayer at temperature-force (*1*), temperature (*2*) and force (*3*) loading

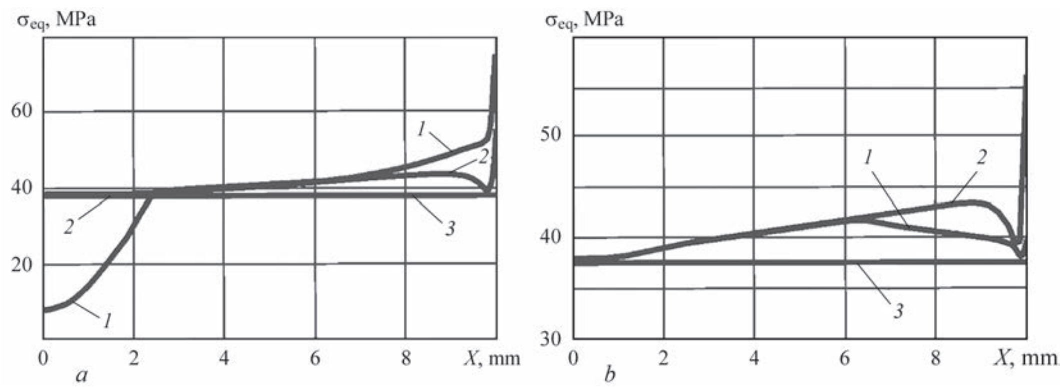

Figure 7. Distribution diagrams of equivalent stresses in material of interlayer on butt with materials 1 (*a*) and 2 (*b*) at temperature-force (*1*), temperature (*2*) and force (*3*) loading

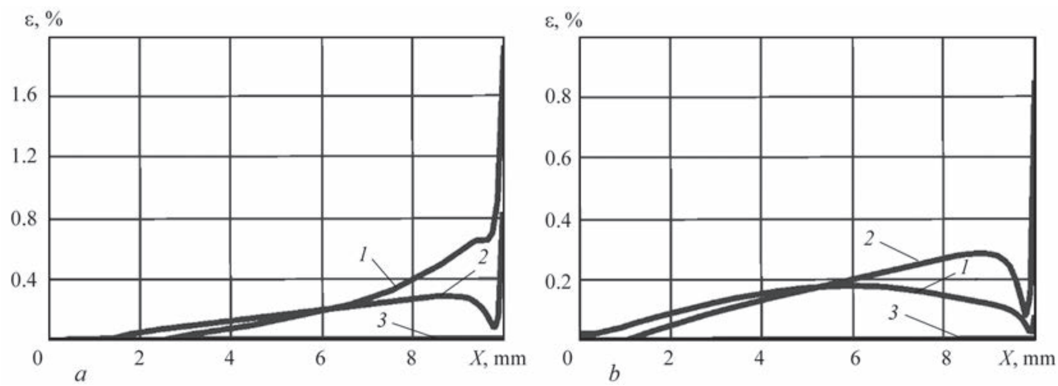

Figure 8. Distribution diagrams of plastic deformations in material of interlayer on butt with materials 1 (*a*) and 2 (*b*) at temperature-force (1), temperature (2) and force (3) loading

material 2 (with lower TCLE). Obviously that the materials change places in alteration of cooling by heating, i.e. thermal cycling under pressure shall promote formation of physical contact and activation of processes of joint formation.

Analysis of the results of SSS investigation showed that effect of mutual temperature and force loading of assemblies with soft interlayers appears at some increase of radial and circumferential stresses in both materials, rise of equivalent ones in material 1 and interlayer and axial in materials being joined and, respectively, decrease of equivalent ones in material 2, tangential stresses at that remain virtually the same as in purely temperature loading.

The value of maximum plastic deformations in the interlayer material on the interface with base materials in the vicinity of external surface at temperature-force loading significantly rises and makes around 2.3 %.

Conclusions

1. At mutual loading by compression and cooling (cooling under pressure) the axial tensile stresses in the brittle materials with low TCLE (ceramics, graphite, etc.), responsible for their fracture in cooling after welding

(brazing) in the assemblies with «soft» interlayer, reduce by the value of compression load. It means that risk of brittle fracture in the assemblies with «soft» interlayer reduces in cooling under pressure.

2. Tangential and equivalent stresses in the butt zone (on interface), determining formation of metallic (physical) contact and activation of process of joint formation in diffusion welding, at mutual loading by compression and cooling of assemblies with soft interlayer noticeably rise in material with higher TCLE in cooling and material with lower TCLE in heating. At that, distribution of equivalent stresses is close to uniform. Thus, thermal cycling under pressure shall promote formation of physical contact and activation of processes of formation of joint in assemblies with «soft» interlayer.

3. Plastic deformations in the material of «soft» interlayer on the interface with material having lower TCLE at mutual loading on cooling stage are more uniformly distributed, but their level is lower than in purely temperature loading. At mutual compression and heating the same takes place on the interface with material having higher TCLE. It can be assumed that welding with thermal cycling under pressure provides in the assemblies with «soft» interlayer more uniform distribution of plastic deformations in the interlayer.

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