Structural features of V-1469 alloys compounds produced by friction stir welding

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Abstract. This article is about the distribution of hardness, texture, phase composition, and residual stresses in various zones of the joint of sheets of alloy V-1469 obtained by friction stir welding (FSW).

An important problem in the manufacture of large-sized welded structures from high-strength aluminum-lithium alloys is their softening during fusion welding, for which the ratio of the weld strength to the strength of the base material is lower than 60%. It is possible to increase the operational characteristics of welded joints due to the use of FSW, for which this ratio reaches 75–80% [1].

In figure 1 hardness measurement results are shown depending on the distance from the center of the weld for two sections located at 3.5 and 7 mm from the surface.

Figure 1. Distribution of hardness over the cross section of the welded joint at a distance of z = 3.5 (a) and z = 7.0 mm (b) from the surface: X is the distance from the center of the weld.

The hardness distribution has a W-shaped shape, while the nature of this dependence does not change for different sections of the welded joint. It should be noted that the minimum hardness values correspond to the transition zone between the mixing zone and the heat affected zone.

The results of a quantitative phase analysis (figure 2) show that the FSW is accompanied by phase changes as a result of the thermal effect of welding, which are characterized by a decrease in the
amount of the $T_1$ phase, which is the main hardening phase in alloys of the Al-Cu-Li system. At the same time, an increase in the amount of the $\delta'$-phase cannot compensate for the decrease in the amount of the $T_1$ phase and, as a result, the weld hardness decreases (figure 1).

![Graph](image1.png)

**Figure 2.** Distribution of the phase composition in the cross section of the welded joint at a distance of $z = 0$ (a) and $z = 6$ mm (b) from the surface: X is the distance from the center of the weld.

In [3], it was shown that the B-1469 alloy containing ~8% $\delta'$-phase and ~6% $T_1$-phase has a yield strength ~200 MPa higher than alloy 1441 with ~18% $\delta'$-phase and close to zero by the content of the $T_1$ phase. This explains the decrease in hardness in the welded joint compared to the base material, but does not explain why the minimum hardness is located in the transition zone, although the minimum of the $T_1$ phase corresponds to the mixing zone, in which the hardness is higher than in the transition zone (figure 1).

It should be noted that the nature of the distribution of the phase composition varies with depth and these changes are nonmonotonic. The most pronounced gradient of the phase composition is observed in the subsurface layers, regardless of whether it is from the front or back surface. The least pronounced gradient is observed in the central zone.

Measurements of the residual stresses in the direction transverse to the weld as a function of the distance from the weld center for various sections of the welded plates showed [2] that the stress level does not exceed 60 MPa (figure 3), and for some sections the residual stresses do not exceed 30 MPa. This is significantly lower than the value of residual stresses during fusion welding, when the level of residual stresses closely approaches the value of yield strength.

Features of the stress distribution changes significantly with distance from the surface of the welded joint. In the surface layer (figure 3a), compressive stresses dominate in the mixing zone and the adjacent heat affected zone, while peak compressive stresses form in the transition region between them. At a distance of 3.5 mm from the surface (figure 3b), the nature of the distribution of residual stresses changes sharply. Here, tensile stresses dominate, which are characterized by an “M”-shaped dependence, which is considered characteristic of the distribution of residual stresses in the FSW joints. In fact, the distribution on the surface of the compound (figure 3a) can be considered as a mirror-symmetric or “inverted” “M”-shaped relationship. Between these sections, the stress distribution is intermediate.

Significant changes in the FSW process occur in the texture of the material. The texture of the initial plates is characterized by the texture of "brass" {011} <211>, which in the mixing zone as a result of intense shear deformation occurs is converted to a state close to non-texture. It is important to note here that in the region between the mixing zone and the heat affected zone, which experiences the strongest changes in the phase composition and mechanical properties, the texture of the material does not differ from the texture of the base metal. This is natural, since phase changes are stimulated by thermal influence, and texture changes only by shear deformation in the mixing zone.
Figure 3. Distribution of residual stresses in the cross section of the welded joint at a distance of \( z = 0 \) (a) and \( z = 3.5 \) mm (b) from the surface: \( X \) is the distance from the center of the weld.

Studies of the compound made of alloy B-1469 obtained by friction stir welding allowed us to find an explanation for the effect of softening of the weld material, which is caused by a decrease in the amount of the \( T_1 \) phase from 4–5% to 0–2%, with an increase in the proportion of \( \delta' \)-phases from 8–9% to 11–13% cannot compensate for the decrease in the amount of the \( T_1 \) phase, since the latter is a much stronger hardener than the \( \delta' \) phase.

In the surface layer of the FSW joints, compressive stresses dominate in the mixing region and the adjacent heat affected zone region, and tensile stresses dominate in the subsurface layers, with peak compressive stresses (47–54 MPa) and tensile (53 MPa) stresses forming in the transition zone between mixing region and heat affected zone.

Texture changes in the FSW compound occur only in the mixing zone, where the texture of the “brass” as a result of intense shear deformation is converted to an almost textureless state.

References
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