SOFTENING OF MATERIAL DURING FRICTION STIR WELDING OF ALUMINUM ALLOY 2219-T81

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When friction stir welding high-strength aluminum alloy 2219-T81, a material softening effect was observed. The presence of a softening zone was confirmed by hardness measurements and mechanical testing of samples of the base material and welded joints. A model of material softening from the maximum heating temperature during welding was proposed, which is advisable to use in mathematical modeling of residual welding stresses. Not taking into account the softening effect leads to an increase in residual stresses by 30%.

Keywords: aluminum alloy, friction stir welding, softening, residual stresses, mathematical modeling, experimental measurement

Introduction. At welding heat-treated aluminum alloys, the effect of softening of the welded joint material due to heating [1] can significantly affect the structural integrity of the welded joint, as well as the distribution of residual stresses.

The results of mechanical tests of samples of the base material and welded joints showed that in the heat-affected zone (HAZ) of aluminum alloy 2219-T81, the Yield Strength decreases from 350–370 MPa to 140–160 MPa. Based on the results of Rockwell hardness measurements in the cross section of the test sample (Fig. 1), it was also determined that in the welded joint zone there is a zone of material softening approximately 20 mm wide, where the hardness characteristics are reduced by almost half, on average from 70 HRB to 35 HRB.

A comparison of the calculated distribution of maximum temperatures in the cross section of a welded joint of δ=6 mm plates made of alloy A2219-T81 (Fig. 2), as well as on the top and bottom surfaces (Fig. 3) with the hardness measurement results (Fig. 1) showed that the width of the zone of initial softening of 40 mm corresponds to a temperature of Ts=240°C, and the zone of maximum softening on the top surface with a width of approximately 20 mm and on the bottom surface with a width of 10 mm determines the temperature of the end of softening at T_e=450°C of material heating during welding.

In mathematical modeling of stress-strain behavior at FSW [2], the following parameters of the material softening model were adopted: the Yield Stress of the softened material σ_{soft}, as well as the onset temperature Ts and completion temperature Te of softening. Fig. 4 shows the model of softening of alloy A2219-T81 from the maximum heating temperature [3]: σ_{soft}=160 MPa, Ts=240°C, Te=450°C, taking into account which, the distributions of the Yield

Stress of the material at 20°C on the bottom and top surfaces of the FSW welded joint will differ significantly (Fig. 5).

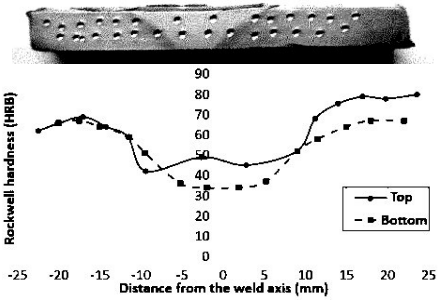

Fig. 1. Hardness distribution in the FSW joint of 2219-T81 alloy plates.

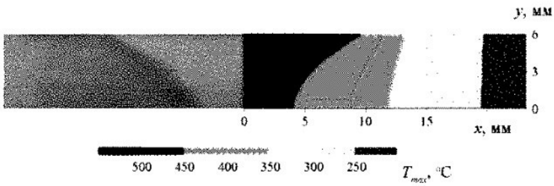

Fig. 2. Calculated maximum temperatures in the cross section of a welded joint compared to the shape of the HAZ on a macrograph.

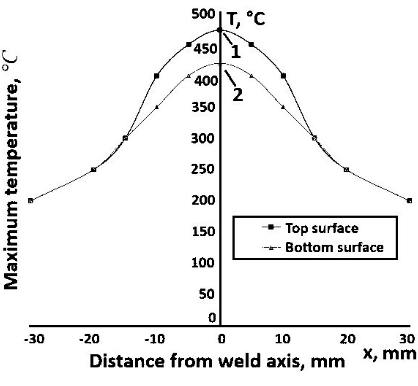

Fig. 3. Distribution of maximum heating temperature on the bottom and top surfaces of the welded joint FSW.

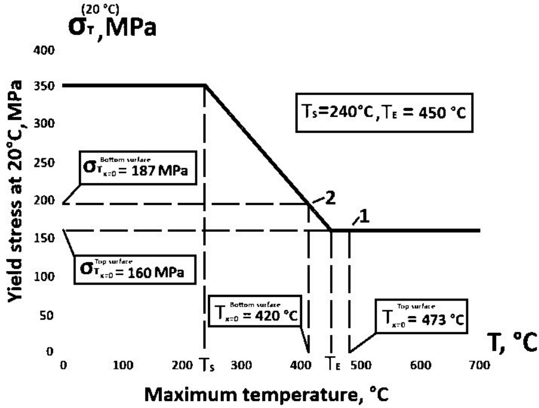

Fig. 4. Model of softening of alloy 2219-T81 versus maximum heating temperature.

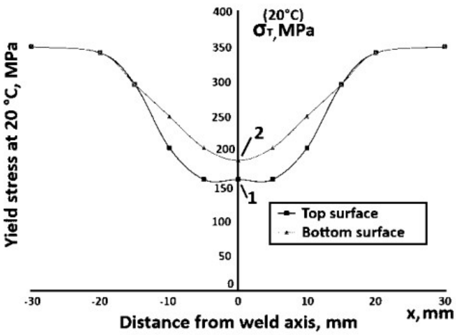

Fig. 5. Distribution of the Yield Stress at 20°C on the bottom and top surfaces of the welded joint of the FSW.

The results of calculating residual stresses, taking into account material softening from maximum heating temperature, showed satisfactory agreement with experimental measurements (Fig. 6). Not taking into account the softening effect leads to a significant increase (by 30%) in maximum residual longitudinal stresses. It should be noted that the longitudinal residual stresses on the bottom surface are greater than on the top surface. This is due to the fact that the maximum temperature from the heat flow of the tool is higher on the top surface than on the bottom surface (Fig. 3). Therefore, the material on the top surface of the welded sample is more softened than on the bottom (Fig. 5). As is known, the more softened the material, the lower the residual stresses.

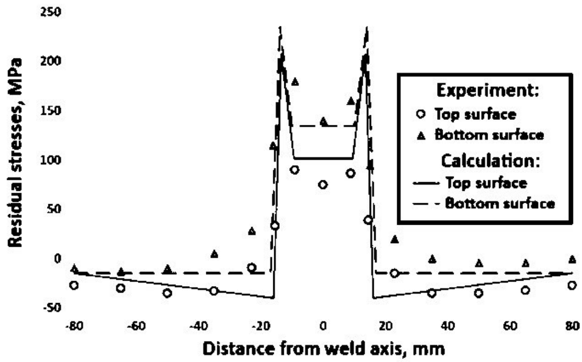

Fig. 6 Distribution of residual longitudinal stresses

Conclusions. The results of mechanical tests and hardness measurements of samples of the base material and welded joints made of aluminum alloy 2219-T81 showed that in the weld zone there is a significant softening of the metal and a decrease in the yield stress.

The results of mathematical modeling of residual stresses in aluminum alloys during friction stir welding are significantly influenced by the consideration of material softening in the weld heat-affected zone. The results of mathematical modeling showed that during friction stir welding, the level of residual longitudinal tensile stresses is high, close to the Yield Stress of the 2219-T81 aluminum alloy in the annealed state (up to 150-180 MPa), which is consistent with the results of experimental measurements. Failure to take into account the softening of the material can lead to a significant increase (more than 30%) in the maximum residual longitudinal stresses.

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