IMPROVEMENT OF FATIGUE STRENGTH OF OVERLAP JOINTS OF SHEET ALUMINIUM ALLOYS MADE BY FUSION WELDING

V.V. KNYSH, I.N. KLOCHKOV and **I.V. BEREZIN**
E.O. Paton Electric Welding Institute, NASU
11 Bozhenko Str., 03680, Kiev, Ukraine. E-mail: office@paton.kiev.ua

Overlap joints have the advantage of simplicity of their preparation and fit-up for welding, however, because of a number of technological factors, they are characterized by low values of cyclic fatigue life. The influence of structural eccentricity and overlap value on fatigue strength of overlap welded joints of sheet aluminium alloys AMg6 and 6061-T6 made by consumable electrode gas-shielded pulsed-arc welding was shown experimentally. Application of high-frequency mechanical peening of the zones of weld-to-base metal transition was proposed as cold straightening technique to lower the values of structural eccentricity and improve the values of welded joint fatigue strength. Low-intensity high-frequency peening from one side results in plastic deformation of the surface metal layer in the treatment zone, leading to formation of a system of residual stresses, the impact of which causes bending-out in the joint plane. Treatment mode is selected so that the angle of misalignment relative to load application in the treated joints was close to zero. It is found that strengthening by high-frequency mechanical peening of fillet sections of fusion zones of two fillet welds in sheet overlap joints of the studied aluminium alloys leads to increase of their limited fatigue limits on the base of fatigue lives from $5\cdot10^3$ up to 10^6 cycles of stress alternation, thus increasing their cyclic fatigue life up to 30 times at zero-to-tension loading. 10 Ref., 4 Figures.

Keywords: *arc welding, sheet aluminium alloys, overlap welded joints, fatigue strength, structural eccentricity, high-frequency mechanical peening, strengthening*

Application of overlap welded joints of aluminium alloys is due to their high adaptability-to-fabrication. In view of the simplicity of preparation and fit-up for welding, they are often applied for welding sheet blanks. Another advantage of overlap joining of sheets also is no need for edge preparation at any thickness and smaller shrinkage stresses compared to butt welding. However, overlap welded joints, made by two one-sided fillet welds, feature a high stress concentration that is mainly due to the effect of structural eccentricity. Simultaneous action of eccentricity and stress raiser, which is due to geometrical shape of the joint, considerably lowers the fatigue strength of overlap joints [1].

To reduce postweld angular deformation of sheet welded elements various methods of hot and cold straightening of the entire structure and its individual components [1–8] are applied, which are based on application of nonuniform local or bulk plastic deformation. Such methods of straightening the structural elements include: hammer peening, postweld rolling of the weld, as well as bending along the weld and vibrational treatment of structural element [3]. The main disadvantage of cold straightening at high treatment intensities is formation of high tensile residual stresses, nonuniformly distributed across the thickness. In addition, cold straightening does not always improve the profile geometry in the zone of weld-to-base metal transition [5, 9]. At straightening of sheet material surface, treatment by a jet of steel shot from one side is used [9, 10]. Plastically deformed surface layer of metal in the zone of such treatment makes an impact on lower-lying plastically undeformed metal layers, as an off-center force, and causes their elastic deformation. A system of residual stresses balanced across the thickness is formed, namely compressive stresses in the active work-hardened layer, tensile stresses in the lower-lying and central layers of metal and compressive stresses on the surface from the reverse side of the element. Low intensity shot blasting induces low levels of tensile residual stresses in the metal central layers, and compressive residual stresses induced on the surface promote a significant improvement of fatigue strength of the element in the straightening zone.

This work is devoted to experimental determination of the effectiveness of application of the technology of high-frequency mechanical peening (HFMP) of sheet overlap welded joints as a method of cold straightening, in order to increase the fatigue strength. Results of fatigue

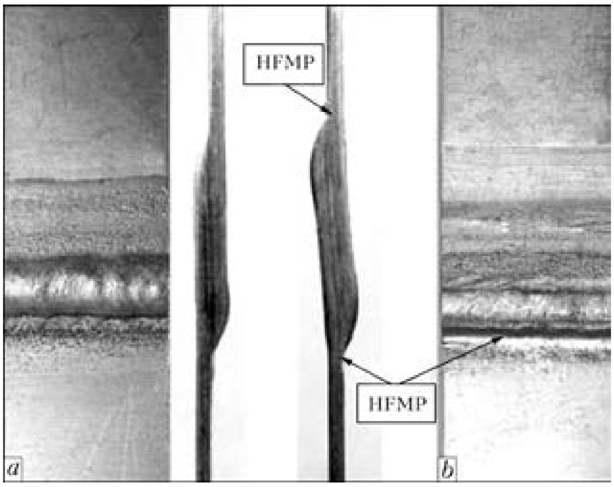

Figure 1. Samples of overlap welded joint in as-welded condition (*a*) and after HFMP of fusion zones (*b*)

testing are given for welded joints of aluminium alloys AMg6 (Al–Mg–Mn) and 6061-T6 (Al–Mg–Si) made by consumable electrode inert-gas pulsed-arc welding in as-welded condition and after HFMP.

At one-sided strengthening by HFMP technology of the zone of weld-to-base metal transition of overlap welded joints of the studied aluminium alloys, the effect of bending-out of welded joint plane is manifested, similar to the one found at low intensity shot blasting of the base metal. This promotes elimination of angular residual deformation in sheet overlap welded joints and, consequently, minimizes the undesirable moments of forces arising at loading of joints with structural eccentricity. Samples of overlap welded joints of AMg6 alloy 2 mm thick in the as-welded condition and after HFMP are given in Figure 1.

To perform experimental studies, blanks of overlap joints in the form of plates of 250 × × 500 mm size with 2δ and 5δ overlap (mm) were welded from rolled sheets of aluminium AMg6 and 6061-T6 alloys 2 and 3 mm thick, respectively. Welding was performed by two welds with consumable electrode in a mixture of argon and helium. In welding the plates were rigidly fixed in the jig.

The angle of misalignment φ of application of force *F* in overlap joints was determined through the ratio of the value of eccentricity *e* to joint width as follows:

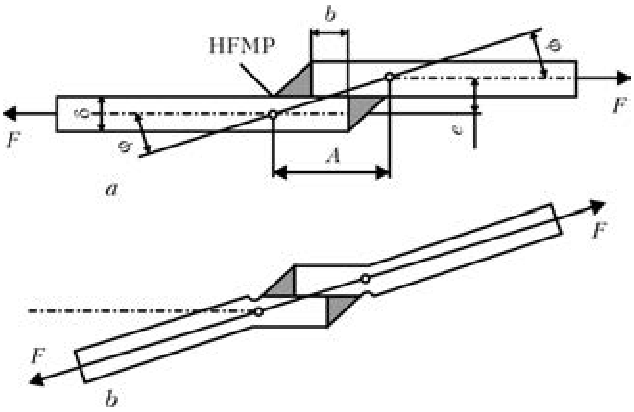

Figure 2. Schematic of overlap joint: *a* — as-welded condition; *b* — after HFMP

$$\varphi = \mathrm{arctg}\left(\frac{e}{A}\right).$$

Width of joint *A* (Figure 2, *a*) was taken to be equal to the sum of overlap size and two sizes of weld leg, equal to base metal thickness δ. For overlap joints of base metal plates of the same thickness δ, eccentricity *e* was equal to plate thickness, respectively. At HFMP strengthening of two fusion zones of overlap joints of the studied aluminium alloys treatment modes were selected so that the angle of misalignment φ in strengthened joints was close to zero (Figure 2, *b*).

Fatigue testing of samples of overlap joints 250 mm long with 40 mm width of the working section (Figure 3) in as-welded condition and after local HFMP was conducted in servohydraulic testing machine MTS 318.25 with digital control at zero-to-tension cycle asymmetry. Samples were cut out normal to the joint from large-sized welded blanks.

It is experimentally established that HFMP of the zone of weld-to-base metal transition increases the limited fatigue limit of overlap joints over the entire testing base from $5\cdot10^3$ up to 10^6 cycles of stress alternation of sheet aluminium alloys AMg6 and 6061-T6 (Figure 4). On the base of 10^6 cycles of stress alternation their conditional fatigue limit increases by 40 to 45 MPa, that is by 2.3–2.5 times for AMg6 alloy and by 2.7–3 times for 6061-T6 alloy (see Figure 4). Such an improvement of fatigue strength at application of HFMP of overlap joint is due primarily to elimination of structural eccentricity, as well as provision of a smother transition from weld to base metal and strengthening of the sur-

Figure 3. Sample of overlap joint for fatigue testing

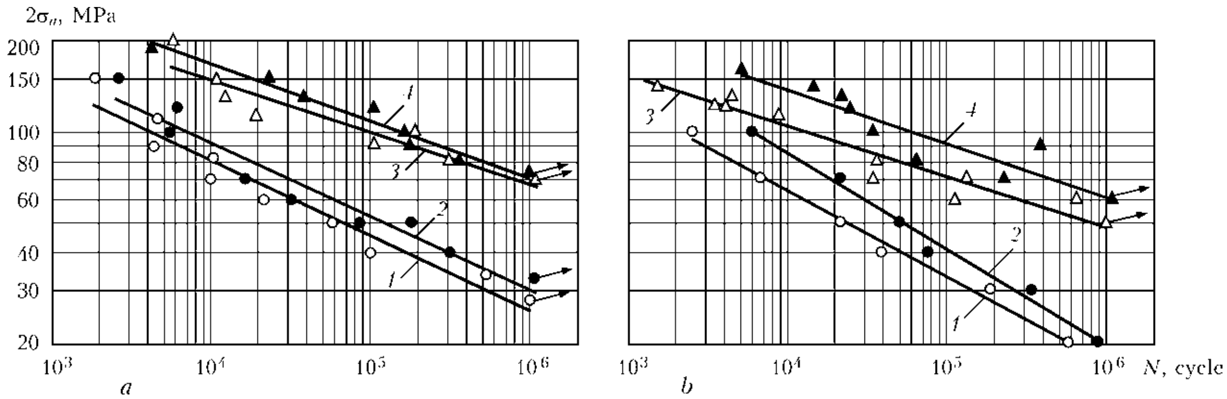

Figure 4. Fatigue curves of overlap joints: *a* — AMg6 alloy 2 mm thick; *b* — 6061-T6 alloy 3 mm thick; *1*, *2* — as-welded condition with 2δ and 5δ overlap, respectively; *3*, *4* — after HFMP with 2δ and 5δ overlap, respectively

face layer. Reduction of overlap size leads to lowering of joint fatigue life both in as-welded condition and after HFMP. This is related to the fact that at small overlap dimensions the value of angle φ increases, and in joints with a small overlap size it can be decreased by spending more time for HFMP performance.

Thus, eccentricity or angular misalignment of force application in overlap welded joints of sheet aluminium structures can be eliminated with simultaneous formation of a more favourable profile of weld-to-base metal transition by treatment of fusion zones by HFMP technology.

Conclusions

1. Fatigue curves of overlap joints of AMg6 alloy 2 mm thick and 6061-T6 alloy 3 mm thick with overlaps of two and five thicknesses, made by consumable electrode inert-gas pulsed-arc welding, in as-welded condition and after strengthening by HFMP, were determined.

2. It is experimentally established that HFMP of the two fusion zones of sheet overlap joints of aluminium alloys AMg6 and 6061-T6 improves the limited fatigue limits of the joints on the base of fatigue lives of $5\cdot10^3$ up to 10^6 cycles of stress alternation, increasing their cyclic life by 25–30 times for AMg6 alloy and by 10–20 times for 6061-T6 alloy.

3. HFMP strengthening of fillet regions of fillet welds in sheet overlap joints improves the limited fatigue limit on the base of 10^6 cycles of stress alternation for AMg6 alloy up to 2.5 times, and for 6061-T6 alloy — up to 3 times at zero-to-tension alternating loading.

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