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ELECTRON BEAM WELDING OF THIN-SHEET THREE-DIMENSIONAL STRUCTURES OF ALUMINIUM ALLOYS

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Variants of improvement of the technology for manufacture of three-dimensional welded structures from thin-sheet elements are considered. Examples of small-size mock-ups of specific products are presented. Recommendations for reducing residual deformations in thin-sheet welded structures are given. Variants of the welded T-joints used in manufacture of stringer panels are shown. Resistance of welded joints to intercrystalline corrosion is estimated.

Keywords: *electron beam welding, aluminium alloys, thin-sheet three-dimensional structures, dissimilar welded joints, mechanical properties, intercrystalline corrosion, crack resistance*

Wide application of aluminium alloys in different fields of industry is determined by a number of their advantages as compared to other structural materials.

Aluminium alloys are characterized by a large range of ultimate tensile strength (100–750 MPa) and high specific strength (due to small density of 2.7 g/cm^3). Besides, they have high heat and electric conductivity and corrosion resistance in different aggressive environments. Aluminium alloys are characterized by good manufacturability, easily subjected to pressure treatment, allow producing intricate shaped sections of them. Parts of aluminium alloys are widely used in different types of structures in ship, automobile and aircraft building and in transport. Here, the riveted and bolted joints are characteristic for the products of aircraft engineering, manufactured of aluminium alloys.

The riveted joint is the main type of joints in the design of a planer, aircraft and helicopter. It operates well at static, fatigue and repeated loadings and allows manufacturing products without distortions and keeping a rigid configuration.

The significant disadvantage of a riveted joint is weighting of a structure, high labor consumption in performing the operations and, as a result, high economic costs.

The application of a bolted joint in aluminium structures is caused by need in periodical dismantle

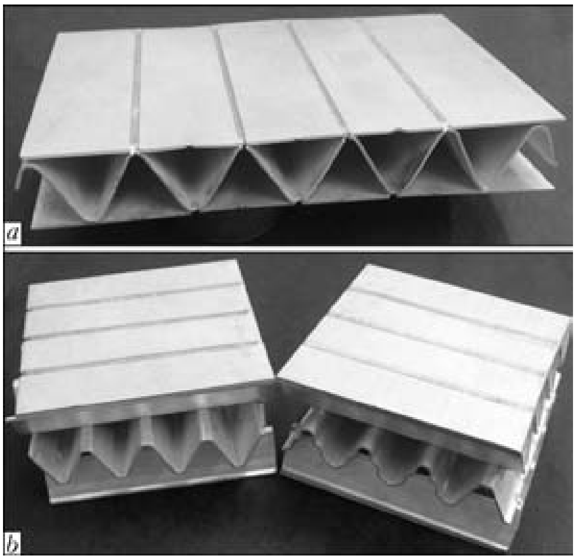

Figure 1. Appearance of mock up of thin sheet (*a*) and 3D panel of increased rigidity (*b*) manufactured of aluminium alloys by EBW

of single elements and assemblies in the process of their service. However, manufacture of bolted joint is rather labor intensive and placing one bolt is about 10 times higher by its labor intensity than installing of one rivet.

The progressive method of joining structures of aluminium alloys is welding which facilitates the process of producing metal structures and allows wide application of automation and mechanization [1].

Welding is one of the leading technological processes of manufacturing structures in different fields of national economy. Welding gains a special great importance in manufacturing different air-tight welded assemblies of long-time service. There have been already many cases of replacement of riveted and bolted joints in aircraft manufacturing by resistance spot and seam welding or such methods of fusion welding as argon arc, microplasma, plasma welding and welding using consumable electrode.

In the last decades the method of electron beam welding is developed and improved in many countries, as well as applied to manufacture of structures of aluminium alloys [2–4].

The EB-welded structures are successfully operated under the conditions of complex loadings, increased temperatures, deep vacuum, aggressive media. Applying the same equipment the electron beam can weld parts of aluminium alloys of different thicknesses: from fractions of millimeters to several tens of centimeters.

The metallurgy production of new ultra-light high-strength aluminium-lithium alloys, the application of which in welded structures reduces weight of products by 10–15 %, is developed intensively. The application of EBW facilitates expanding of application of such alloys in the structures. As it was established previously [1, 2] in EBW of heat-hardened or cold-worked aluminium alloys the ultimate tensile strength of joints is by 15–20 % higher than that using other methods of welding, and the residual welding deformations are by one order lower.

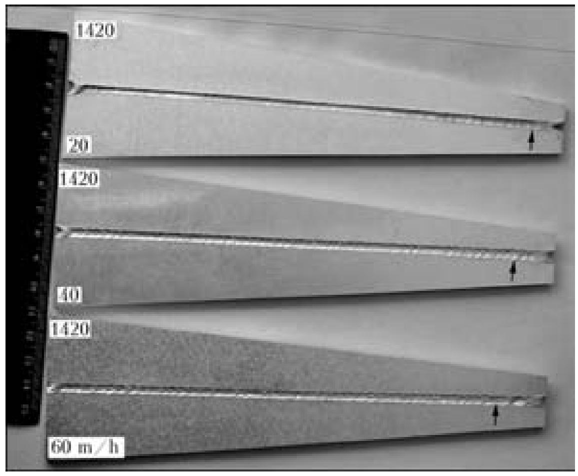

Figure 2. Appearance of welded specimens of alloy 1420 after their test on crack resistance in the range of speeds 20–60 m/h

In our work the first attempts to apply technology of EBW were made during manufacture of three-dimensional structures of thin-sheet elements of aluminium alloys of different alloying systems. The structures of aluminium alloys are designed of rolled sheets, stamped bent and pressed profiles, shaped stampings and forgings. Application of such semi-products in the structures produced using arc welding methods is connected with a number of difficulties both at the stage of preparation for welding, and also in assembly and welding of joints. First of all this is overcoming the welding using the methods on prevention of their appearance or further removal. In this situation more problems occur in application of overlap joints or joints for upper sheet penetration in structure of thin sheet elements.

The examples of EBW application in manufacture of 3D panels of thin-sheet elements, where there are joints being hard-to be performed by arc methods, are given in Figure 1. To achieve high quality of joints and accuracy in keeping the geometric shapes in EBW of similar structures one must strictly fulfill a number of design-technological requirements. The assembly of fragments for welding is performed using assem-

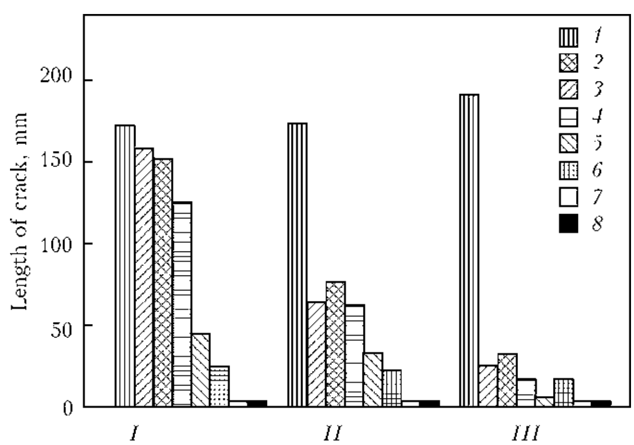

Figure 3. Influence of speed of EBW on tendency of aluminium alloys towards hot cracks: *1* — alloy D16; *2* — AD0; *3* — 1460; *4* — 1201; *5* — AMts; *6* — 1420; *7* — 1570; *8* — AMg6; *I* — v_w = 20; *II* — 40; *III* — 60 m/h

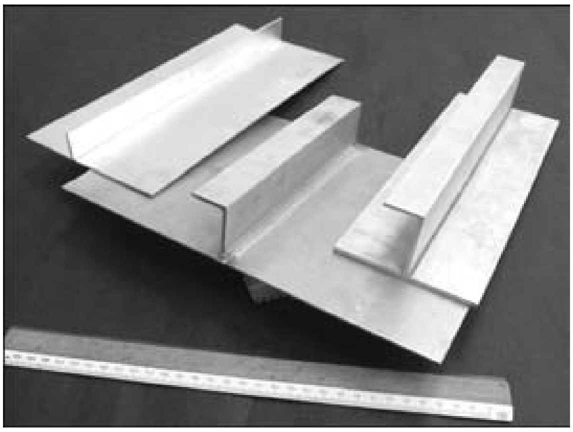

Figure 4. Fragments of thin-sheet stringer panels manufactured using EBW of single- and two-sided fillet welds

bly-welding device which should guarantee the absence of gaps between contacted surfaces of elements to be welded. Besides, in device the heat dissipating elements are provided, positioned on the both sides along the entire weld. Here, the weld formation with a small reinforcement is provided. Any distortions (of buckling or burn-out type) are also absent. Welding condition parameters should be previously preset within such limits that during its performance the lower part would be penetrated for not more than 0.5 of the thickness. In these structures both similar and dissimilar aluminium alloys can be applied.

However, at the stage of designing the products, using different types of aluminium in the structure, it is necessary to dispose information on their tendency towards formation of crystalline cracks. Considering that such welds are produced without application of filler materials and there are no conditions to perform modifying of weld metal due to alloying elements in the filler, the alloys should be previously selected in such a way that their crack resistance was the best. However, if cracking occurs during welding, then measures to prevent cracks should be preset in the technological process.

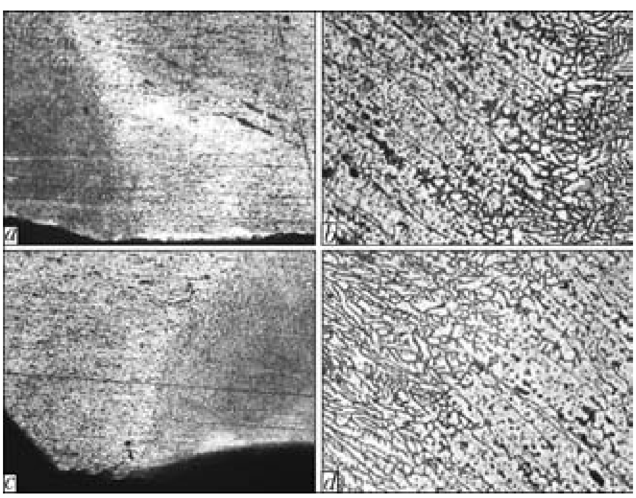

Figure 5. Microstructures of specimens of alloy D16 welded joints, produced by EBW, after the tests on microcrystalline corrosion: *a*, *b* — reference specimen; *c*, *d* — specimen 1 (*a*, *c* — ×100; *c*, *d* — ×500)

Figure 2 shows specimens of the alloy 1420 after their tests on crack resistance in the range of speeds 20–60 m/h. This alloy has short cracks only at the beginning zone of the specimen where it has a thinning shape. The generalized results of investigations of resistance of aluminium alloys to formation of crystalline cracks are given in Figure 3 [5]. It is seen from the Figure that similarly to the alloy AMg6, the cracks are absent in a new high-strength alloy 1570 alloyed by scandium. Besides, the lower the speed of welding and, consequently, the lower the rate of crystallization of weld metal, the higher is the tendency to crack formation.

The category of 3D thin-sheet structures can include welded stringer or stiffened panels (Figure 4). During their manufacture with account for specifics of aluminium alloys, and also the arrangement of welds, the EBW is the most rational method of joining [6, 7]. The process of preparation of elements, their assembly and welding are also characterized by high requirements to performance of all operations. The welding-on of stiffeners can be performed both by one-sided fillet welds, as well as layout of fillets on both sides of the stiffener. As a rule, the application of filler materials is not practiced as both in the first and the second case the fillet of 1.5–3.0 mm is formed on joints. The parameters of welding condition are usually selected so that the penetration of the lower panel did not exceed 50 % of its thickness. For this purpose the inclination angle of electron beam to the panel plane is usually 25–30° in the process of welding. To avoid considerable residual deformations of welded panels, as the authors of the work [6] showed, it is

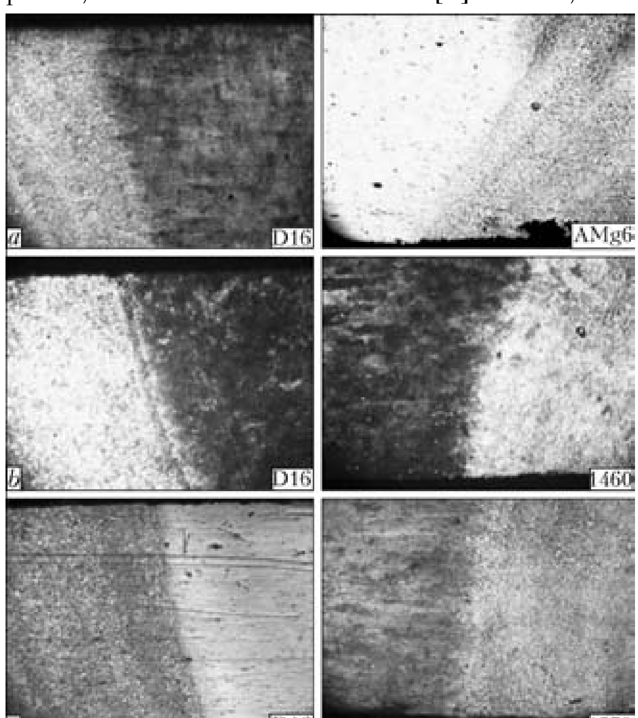

Figure 6. Microstructures (×100) of specimens of EB-welded joints of dissimilar aluminium alloys after tests on intercrystalline corrosion: *a* — alloy D16 + AMg6; *b* — D16 + 1460; *c* — D16 + 1570

rational to use method of preliminary elastic tension of fragments being welded (panels and stiffeners) before welding. The tension forces should not exceed the conditional yield strength of alloy to be welded.

However, from the position of providing reliable performance of welded structures the welding-on of stiffeners, as is shown in Figure 4, is not rational, as the welds are in the zone of concentration of stresses at loading of products. Relocation of welds to the zone, remote from sharp transitions, increases greatly their reliability and performance during loadings.

As the many-year practice showed, one of the factors of latent nature of reduction of terms of reliable and long-time service of welded aluminium structures is their tendency to intercrystalline corrosion, from the sources of which the catastrophic fracture of products begins. In our developments welded joints of alloy D16 and joints of dissimilar aluminium alloys produced using EBW were tested.

To conduct investigations, four specimens of 10 mm width, 20 mm length and 2.5 mm thickness were cut out from welded joints perpendicularly to welds. The investigations were conducted using chemical method according to GOST 9.021–74 «Aluminium and aluminium alloys. Methods of accelerated tests for intercrystalline corrosion».

The temperature of working solution was 30±5 °C, the composition of solution was as follows: solution of sodium chloride plus 0.3 % of peroxide (58 g/l NsCl + + 10 ml/l of 33 % solution H_2O_2), the duration of tests was 6 h with subsequent metallographic analysis of sections at the depth of etching between grains according to GOST 6032–89 «Corrosion-resistant steels and alloys. Methods of tests on resistance against intercrystalline corrosion» using metallographic microscope «Neophot-21» (according to GOST 6032–82 the value of depth of fracture of grain boundaries should be not more than 30 μm).

The preliminary visual inspection of specimens showed that their condition was satisfactory. The results of investigations and photos of microstructure of sections of the D16 alloy welded specimens on the tendency to intercrystalline corrosion are given in Figure 5.

The analysis of obtained results proves that specimens of welded joints of aluminium alloy D16 produced using EBW are not tended to intercrystalline corrosion.

The investigations on tendency to intercrystalline corrosion of joints of dissimilar aluminium alloys D16 + AMg6, D16 + 1460 and D16 + 1570, made using EBW, were performed according to the methods given above and in the solution of the same composition. Having compared the depth of damage of intergranular etching of specimens being tested (three pieces each) with the reference specimen, the estimation of resistance of joints to intercrystalline corrosion was carried out.

The results of investigations and measurements are given in Figure 6 and in the Table.

Mechanical properties of welded joints of dissimilar aluminium alloys (place of fracture of specimens — along the weld)

Number of specimen	Grades of alloys welded	σ_t, MPa
1	D16 + AMg6	294–312 / 308.5
2	D16 + 1570	302–316 / 314.3
3	D16 + 1460	296–311 / 309.2

As is seen from the analysis of obtained results of investigations, all joints of dissimilar aluminium alloys D16 + AMg6, D16 + 1460, D16 + 1570 produced using EBW in vacuum are not tended to intercrystalline corrosion.

The carried out mechanical tests (see the Table) showed that ultimate tensile strength of joints of dissimilar aluminium alloys is at the level of properties of joints of homogeneous aluminium alloys of the lower strength. Thus, in case of using aluminium alloys of different grades in the structure of welded product, the decrease of strength characteristics will not almost occur.

CONCLUSIONS

1. The design-technological solutions have been developed during creation of welded 3D structures and stringer panels of increased rigidity using thin-sheet elements or shaped rolled metal.

2. It was established that welded joints of alloy D16 and dissimilar butt joints of alloys D16 + Mg6, Mg6, D16 + 1460 and D16 + 1570 made using EBW are not subjected to intercrystalline corrosion under the conditions of their tests according to GOST 9.021–74.

3. Results of performed experimental-search works and investigations can be used in selection of materials and variants of joints for further tests on determination of characteristics of fatigue, fracture toughness, stress corrosion, vitality and residual strength of welded structure elements.

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