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ELECTRON BEAM WELDING OF ALUMINIUM 1570 ALLOY AND MECHANICAL PROPERTIES OF ITS JOINTS AT CRYOGENIC TEMPERATURES

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ABSTRACT

The features of electron beam welding of the 1570 alloy were studied and mechanical properties of its welded joints in the temperature range of 20–293 K were investigated. It was found that during electron beam welding in the 1570 alloy, the width of the heat-affected-zone does not exceed 4 mm from the fusion line, which is 4 times lower than in the AMg6N alloy. In the weld, fusion zone and HAZ cracks, clusters of eutectic interlayers and other defects were not detected. The ultimate strength of the joints of the 1570 alloy at a decrease in the test temperature from 293 to 20 K increases from 325 to 525 MPa. The yield limit is also increased from 210 to 270 MPa, and the ductility changes slightly. At the same time, the impact toughness decreases from 38 to 9 J/cm^2. The strength coefficient of welded joints with a decrease in the test temperature from 293 to 20 K increases from 0.85 to 0.95. In general, the 1570 alloy is well welded by electron beam and the method of electron beam welding can be recommended in the manufacture of welded structures of rockets and spacecrafts.

KEY WORDS: electron beam welding, aluminium alloy, mechanical properties, welded joints; cryogenic temperatures

INTRODUCTION

The high-strength 1570 alloy of the Al–Mg system is designed to replace the AMg6 alloy in welded structures of rockets and spacecrafts. The use of the AMg6 alloy is explained by its advantages such as high ductility and corrosion resistance at a satisfactory weldability. The main disadvantage of this alloy is its relatively low strength [1]. The difference between the 1570 and AMg6 alloy is that it is additionally doped with the scandium element in the amount of 0.17–0.27 % and has higher mechanical properties. For alloys of the Al–Mg system, the most effective hardener is scandium [2]. High mechanical properties of the alloy are predetermined by the formation of fine-dispersed reinforcing particles of the $A1_3Sc$ phase, precipitated during heating and deformation from the supersaturated solid solution. In terms of yield strength, semi-finished products from the 1570 alloy are 1.5–2.0 times higher than similar semi-finished products from the AMg6 alloy, depending on the type of semi-finished product. The use of the 1570 alloy instead of the AMg6 alloy gives an advantage in weight by up to 20 % [1].

The addition of scandium to alloys of the Al–Mg system improves their weldability. For example, their resistance to hot crack formation during fusion welding significantly increases [1, 3]. The strength coefficient of welded joints of the 1570 alloy is 0.85–0.95 depending on the type of semi-finished product. It was found that short-term heating of the near-weld zone of the 1570 alloy to 450 °C is not accompanied by a decrease in hardness [4]. Even at long-term heating (2–10 h), recrystallization processes in the 1570 alloy begin at the temperatures above 400–500 °C, depending on the type of semi-finished product [5]. This is explained by a high thermal stability of the nonrecrystallized structure, predetermined by the precipitation of secondary particles of the $A1_3Sc$ phase from the supersaturated solid solution during thermomechanical treatment of the alloy.

One of the main ways to join the structural elements of rocket engineering from aluminium alloys is electron beam welding (EBW). The aim of this work is to study the features of EBW of the 1570 alloy and study the mechanical properties of its welded joints in the temperature range of 20–293 K.

RESEARCH METHODS AND EQUIPMENT

The research was carried out on stamped semi-finished products of the 1570 alloy with a thickness of 30, 40 and 60 mm. Semi-finished products were welded in the electron beam welding machine UL 209M

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with a power source ELA 60/60 with an accelerating voltage of 60 kV. Hardness measurements were used to evaluate changes in the strength of the weld metal and the width of the heat-affected-zone (HAZ). The Rockwell device was used with a load on a steel ball of 600 N on the scale B. The microstructures of welded joints were examined on cross-sections with the use of the Neophot optical microscope.

The mechanical properties of the stamped semi-finished product of the 1570 alloy and its welded joints were determined at temperatures of 20, 77, 196 and 293 K. Standard specimens of GOST 11150–84 type 1 No.2 (for tests at low temperatures) and specimens with a notch of the same diameter of the working part were tested. Impact strength was determined during tests of specimens with Charpy notch.

EXPERIMENTAL STUDIES AND RESULTS

During welding, the beam current and the focusing lens current were selected from the condition of a guaranteed penetration and formation of the back weld bead. EBW modes for semi-finished products of different thicknesses are shown in the Table 1.

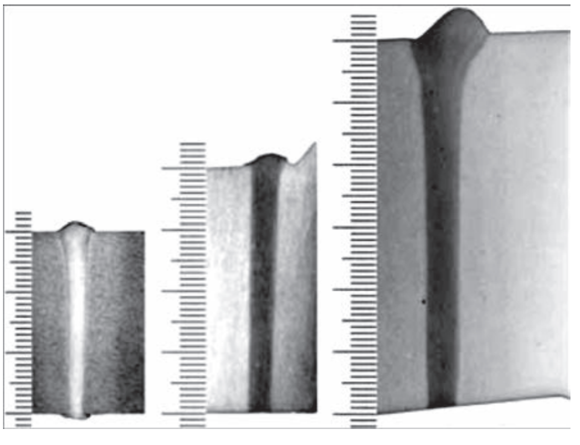

Figure 1. Macrosections of joints of semi-finished products of the 1570 alloy with a thickness of 30, 40 and 60 mm

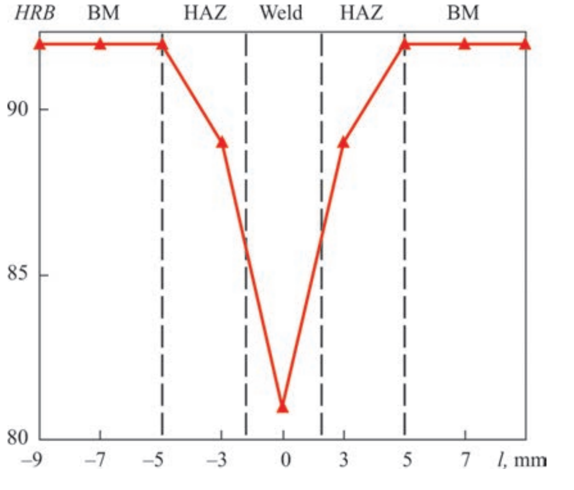

Figure 2. Distribution of hardness in the cross-section of joints of stamped semi-finished products of the 1570 alloy

Table 1. EBW modes for welding of semi-finished products of the 1570 alloy of different thickness, mm

Thickness of semi-finished product, mm	EBW modes for the 1570 alloy			
	U_{acc}, kV	v_w, mm/s	I_{beam}, mA	Beam scan amplitude, mm
30	60	14–17	220–280	1.0–1.5
40		14–17	270–330	1.0–1.5
60		10–12	360–420	1.5–2.0

Welds had a width from 3 to 5 mm with almost parallel boundaries of the penetration zone in the central and lower part (Figure 1). Spraying, splashing and leaking of liquid metal during EBW process were not observed.

During EBW of the 1570 alloy, the width of the HAZ does not exceed 4 mm from the fusion line (Figure 2) regardless of the thickness of the welded semi-finished products (see Table). This is 4 times less than in EBW of the AMg6N alloy [6].

The weld metal has a homogeneous highly-dispersed cellular-dendritic structure (Figure 3). In the weld, fusion zone and HAZ no cracks clusters, of eutectic interlayers and other defects were found.

With a decrease in the test temperature from 293 to 20 K, the ultimate strength of the base metal of the 1570 alloy increases from 385 to 535 MPa (Figure 4). The yield limit also increases from 245 to 310 MPa. The relative elongation decreases from 24 to 15 %

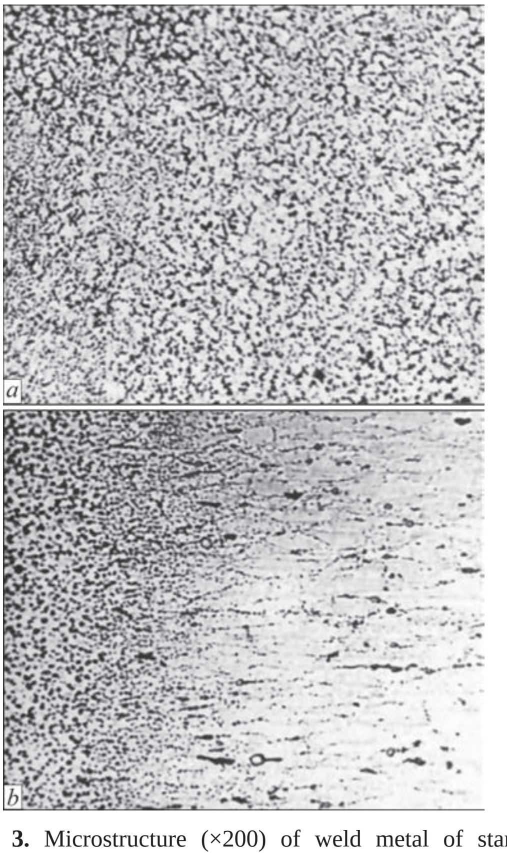

Figure 3. Microstructure (×200) of weld metal of stamped semi-finished product of the 1570 alloy: *a* — central part of the weld; *b* — fusion line

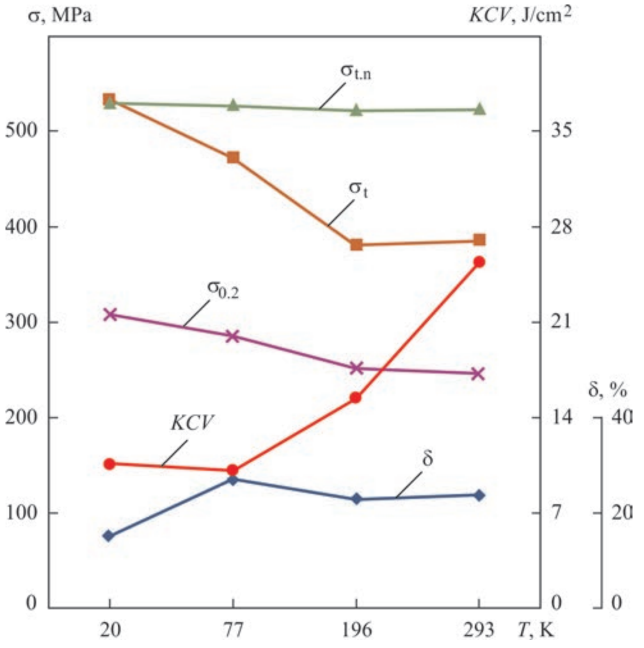

Figure 4. Dependence of mechanical properties of stamped semi-finished product of the 1570 alloy with a thickness of 60 mm on the test temperature

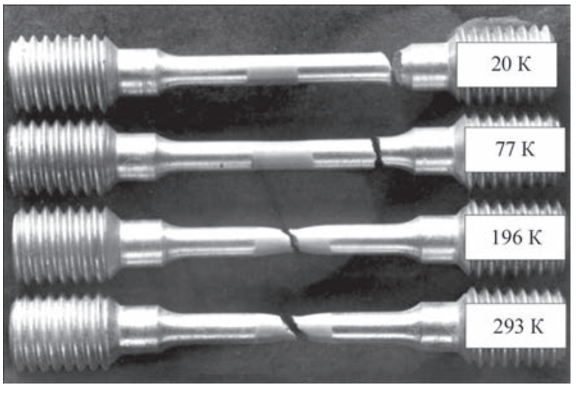

Figure 5. Nature of destruction of specimens cut from welded joints of stamped semi-finished product of the 1570 alloy at different test temperatures

and the impact toughness decreases from 25 to 10 J/cm^2. The ultimate strength of the notched specimens is about 525 MPa and is almost independent of the test temperature.

The peculiarity of the tests of welded joints of the 1570 alloy is that at the test temperatures of 20 and 77 K, the specimens are destroyed over the base metal outside the HAZ (Figure 5). The ultimate strength of the smooth specimens becomes higher than the ultimate strength of the specimens with a notch and at 20 K it reaches 525 MPa (Figure 6). At the same time, impact toughness of the weld metal decreases from 38 to 9 J/cm^2. The ultimate strength of the rupture specimens with a notch of the weld metal amounts to about 443 MPa at all test temperatures.

At a decrease in the test temperature from 293 to 20 K, the strength coefficient of welded joints increases from 0.85 to 0.95 (Figure 7). The sensitivity of the

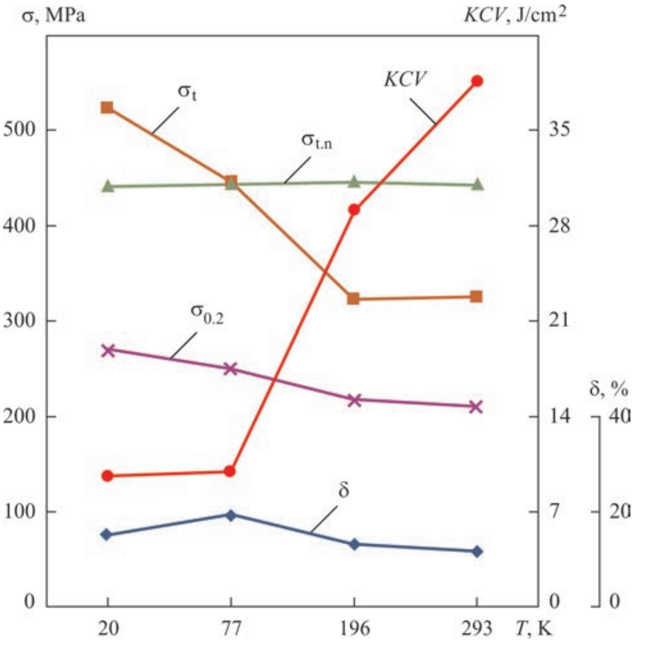

Figure 6. Dependence of mechanical properties of welded joints of the 1570 alloy, made by EBW method, on test temperature

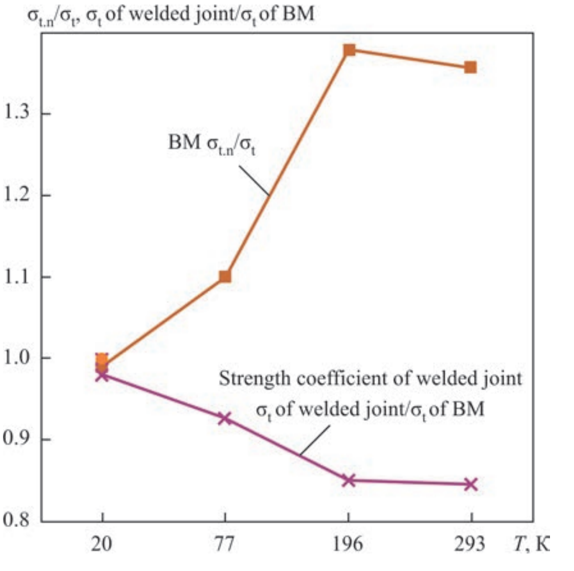

Figure 7. Effect of test temperature on strength coefficient of joints and sensitivity to stress concentrators of stamped semi-finished product of the 1570 alloy

metal to stress raisers is evaluated by the ratio of the ultimate strength of the specimen with a notch to the ultimate strength of the smooth specimen ($\sigma_{t.n}/\sigma_t$). The sensitivity to the notch of the base metal and the weld metal is low. The ratio $\sigma_{t.n}/\sigma_t$ at temperatures of 293 and 196 K is not lower than 1.3. With a decrease in temperature, the sensitivity of the base metal to the notch increases, but even at a temperature of 20 K the ratio $\sigma_{t.n}/\sigma_t$ amounts to about one.

CONCLUSIONS

The investigations of microstructure and mechanical properties of joints of stamped semi-finished products of the 1570 alloy, made by EBW method, were carried out. No defects were found in the welded joints. The width of the HAZ amounts up to 4 mm from the fusion line and almost does not depend on the thickness of the semi-finished product to be welded. At a decrease in the test temperature from 293 to 20 K, the strength coefficient of welded joints increases from 0.85 to 0.95.

Thus, it was found that the 1570 alloy is well welded by electron beam and the EBW method can be recommended in the manufacture of welded structures of rockets and spacecrafts.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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