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MECHANICAL PROPERTIES OF JOINTS OF 1460 ALUMINIUM ALLOY, PRODUCED BY ELECTRON BEAM WELDING USING FILLER MATERIAL FROM 1201 ALLOY

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The paper presents the results of studying mechanical properties of joints of 1460 alloy and joints of 1460 + 1201 dissimilar alloys, produced by EBW at room and cryogenic temperatures. It is shown that the strength of joints of 1460 alloy, welded using filler material from 1201 alloy at a temperature of 77 K rises by 10 %, and at a temperature of 20 K — by 20 % as compared to the joints welded without using filler material. Mechanical properties of welded joints of 1460 + 1201 dissimilar alloys at the test temperatures of 20, 77 and 293 K are on the level not lower than those of the joints of 1460 alloy, welded with the application of 1201 filler material. Welding technology is described and chemical composition of weld metal is given. 12 Ref., 3 Tables, 9 Figures.

Keywords: electron beam welding, aluminium-lithium alloys, filler material, mechanical properties, welded joints, cryogenic temperatures

Aluminium alloys of Al–Cu–Li system have higher mechanical properties and a lower specific weight as compared to traditional alloys of Al–Cu system. Russian 1460 and 1469 alloys are designed to replace 1201 alloy in welded structures of aircraft and space engineering operating at normal and cryogenic temperatures [1, 2]. Similarly, 2090 and 2195 alloys, which are produced in the USA, replaced 2219 alloy. The chemical composition of the alloys is presented in Table 1.

American aluminium 2090 and 2195 alloys of Al–Cu–Li system have long been successfully used in aircraft and space engineering [1, 3]. In particular, while replacing 2219 alloy with 2195 alloy in welded structures of fuel tanks of the Space Shattle spaceship, the weight of the product was reduced by approximately 3000 kg. There are examples of successful application of 1460 alloy for the manufacture of mockups of welded structures for cryogenic purposes [1].

The estimates of weldability of 1460 alloy are contradictory. In [4], the data are given that it is satisfactorily welded by both argon arc as well as electron beam welding. The author of [5] considers its weldability unsatisfactory. The main problems that arise during fusion welding are tendency to hot crack formation and insufficiently high mechanical properties of welded joints. The new V-1469 alloy also has reduced characteristics of weldability. In [6] it is noted that during electron beam welding in welds the formation of cracks is possible and the strength of welded joints amounts to 50 % of the strength of the base metal.

To improve the weldability of 1460 and 2090 alloys during fusion welding, filler materials of Al–Cu alloying system are used. For welding of 1460 alloy, the filler wire Sv1201 [7, 8] is used, and for welding of 2090 alloy, the filler 2319 is used [9]. During welding using these filler materials in the weld metal the copper

Table 1. Chemical composition of alloys of Al–Cu and Al–Cu–Li systems for welded structures of cryogenic purpose

Alloy grade	Alloying elements, wt.%							
	Cu	Li	Zr	Ti	Mn	Sc	Mg	Ag
1201 (USSR)	5.8–6.8	–	0.1–0.25	0.02–0.1	0.2–0.4	–	< 0.02	–
2219 (USA)	5.8–6.8	–	0.1–0.25	0.02–0.1	0.2–0.4	–	–	–
1460 (USSR)	2.6–3.3	1.9–2.3	0.1	0.1	0.05–0.1	0.06–0.1	0.06–0.1	–
2090 (USA)	2.4–3.0	1.9–2.6	0.1	0.15	0.05	–	0.25	–
B-1469 (Russia)	3.2–4.5	1.0–1.7	0.02–0.26	0.05–0.07	0.05–0.08	0.02–0.28	0.01–0.5	0.45
2195 (USA)	3.7–4.3	0.8–1.2	0.12	0.1	0.25	–	0.25–0.8	0.25–0.6

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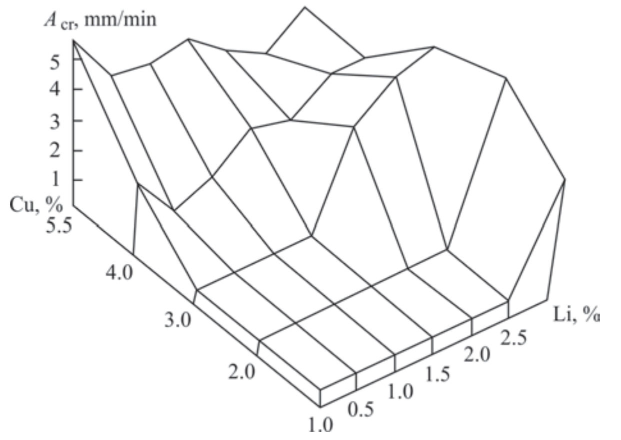

Figure 1. Dependence of weldability A_{cr} of alloys of Al–Cu–Li system on copper and lithium content [10] (with an increase of A_{cr} susceptibility to hot crack formation decreases)

content is increased and the lithium content is reduced. Such a change in chemical composition helps to improve mechanical properties and reduce the susceptibility to hot crack formation in the weld metal.

In [10], the susceptibility of alloys of Al–Cu–Li–0.12Zr system to hot crack formation during welding depending on the content of copper and lithium in them was investigated. It was found that with a decrease in the content of copper <3 % and lithium <1.5 %, the susceptibility to crack formation increases sharply. The results of these studies (Figure 1) should be taken into account during welding of Al–Cu–Li alloys using filler material.

The aim of this work is to show the possibility of improving mechanical properties of Al–Cu–Li system alloys at cryogenic temperatures by changing the chemical composition of the weld metal due to the use of filler material from 1201 alloy on the example of EBW of 1460 alloy.

Welding of all semi-finished products was carried out after a full heat treatment (hardening + artificial aging). Parameters of welding conditions were selected in such a way as to provide a full penetration of a butt in a one pass with the formation of reinforcement and a reverse weld bead. To control the shape of the penetration zone, a system of program distribution of electron beam power density within the spots and heating was used. Mechanical properties of welded joints were investigated at the temperatures of 293, 77 and 20 K. Ultimate tensile strength at room and cryogenic temperatures was determined by tensile testing of standard round specimens (GOST 11150–84, type 1) with a working part diameter of 4 mm. To determine the sensitivity to stress concentrators, round specimens with a notch were tested on tension. The impact toughness was determined on specimens with a Charpy notch throughout the weld metal. All the test specimens were cut out across the weld, placing the weld in the center of the specimen. The hardness of the weld metal and the heat-affected-zone was measured with a Rockwell instrument with a load on a steel ball of 600 N on a B-weighted scale with a ball diameter of 1 mm.

At the first stage, the strength of the base metal and welded joints of Al–4 % Cu–1 % Li alloys and 1460 alloy at temperatures of 20, 77 and 293 K was investigated. Specimens for tests were cut out from the joints welded previously by EBW method while studying weldability of these alloys [11]. The test results are shown in Figures 2 and 3.

From Figure 2 it is seen that the ultimate tensile strength of the base metal of Al–4 % Cu–1 % Li alloy and its welded joints at a decrease in the test temperature from 293 to 20 K rises by 180–190 MPa and reach-

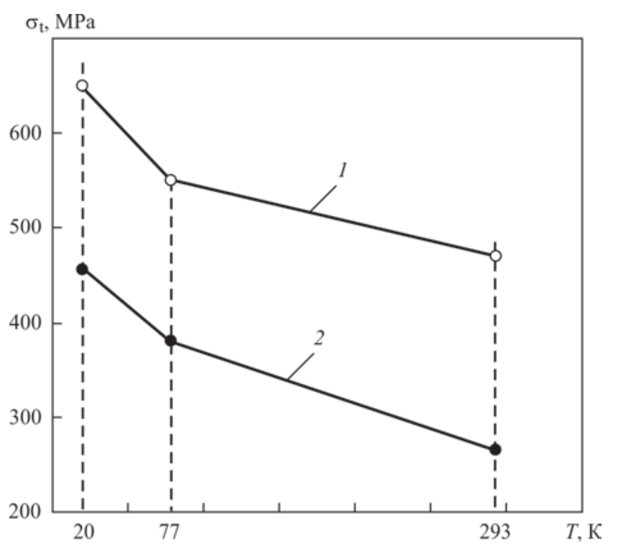

Figure 2. Ultimate tensile strength of specimens made of base metal (*1*) and welded joints (*2*) of plates of Al–4 % Cu–1 % Li alloy with a thickness of 40 mm depending on test temperature

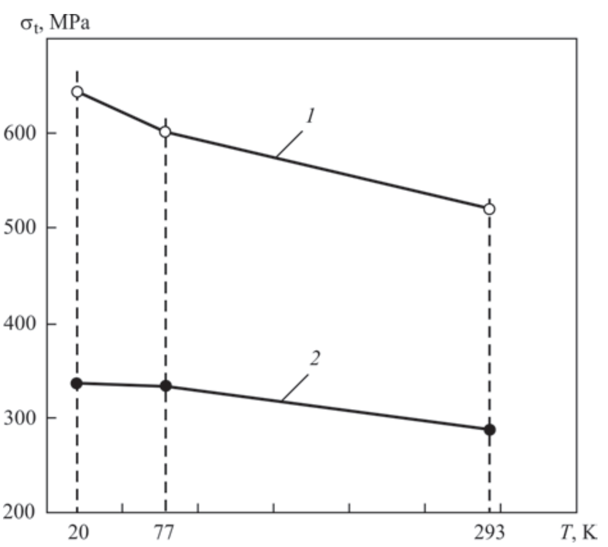

Figure 3. Ultimate tensile strength of specimens made of base metal (*1*) and welded joints (*2*) of rolling rings of 1460 alloy with a thickness of 72 mm depending on test temperature

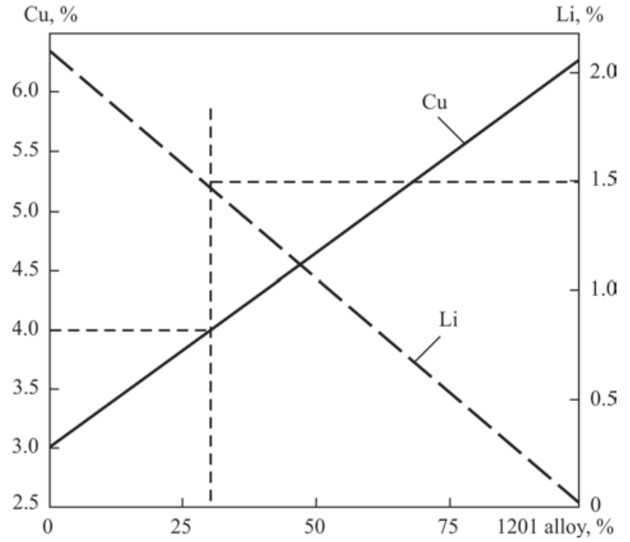

Figure 4. Dependence of calculated copper and lithium content in weld metal of 1460 alloy on the amount of 1201 alloy which participates in the welding pool formation during EBW of 1460 alloy with 1201 filler and during EBW of dissimilar 1460 + 1201 alloys

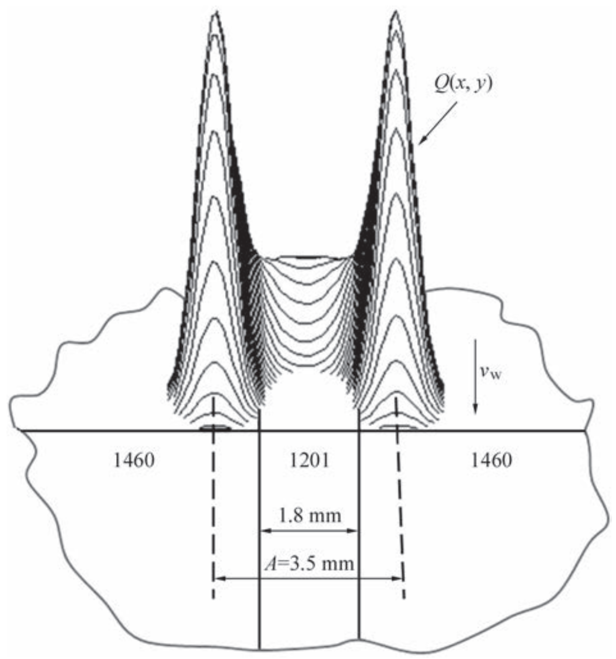

Figure 5. Scheme of EBW of butt joint of plates of 1460 alloy with filler of 1201 alloy ($Q(x, y)$ — distribution of beam density power; V_w — welding direction; A — amplitude of beam scanning)

es 650 and 455 MPa, respectively. The ultimate tensile strength of the base metal of 1460 alloy (see Figure 3) increases from 520 MPa at a temperature of 293 K to 645 MPa at 20 K. In the welded joints of 1460 alloy low-temperature hardening is extremely small. In this regard, during further investigations it was decided to increase the strength of welded joints of 1460 alloy at cryogenic temperatures to reduce the content of lithium and increase the content of copper in the weld metal. It should be noted that during EBW of Al–4 % Cu–1 % Li alloy, the weld metal was proned to microcrack formation [11], which is agreed with the data presented in [10]. Therefore, in order to increase the low-temperature hardening of the joints and at the same time not to provoke the formation of hot cracks in the weld metal, it was decided to increase the content of copper to 4 % and limit the content of lithium to 1.5 %.

The conventional method of changing the composition of weld metal during fusion welding is the use of filler materials. In our case the most suitable filler material from the existing aluminium alloys is 1201 alloy because as compared to 1460 alloy it has an increased content of copper (5.8–6.8 %) and do not have lithium in its composition.

Plates of 1460 alloy with a thickness of 40 mm were welded both with the use of filler material from 1201 alloy, as well as without it. Without a filler, horizontal butts joints were welded using a horizontal beam, and in case of using filler material, welding was performed by a horizontal beam in an uphill mode. The filler material was introduced into the welding pool using a molten insert made of 1201 alloy of 1.8 mm thickness. As was previously determined, the welding pool should contain about 4 % of copper and about 1.5 % of lithium. From Figure 4, it follows that to obtain such a chemical composition in the formation of the weld, about 30 % of the filler from 1201 alloy should be involved.

Taking into account a high elasticity of lithium vapors in vacuum, and as a consequence, its inevitable evaporation losses, it was decided to limit the share of 1201 alloy in the welding pool formation to 25 %. Therefore, with an insert width of 1.8 mm, the width of the weld with parallel side walls should be about 8 mm. EBW conditions are given in Table 2.

In order to exclude preliminary melting and leakage of the insert material from the butt, a beam scanning trajectory in the form of a semicircle while directing the branches of the semicircle in the direction of welding was used. The scanning amplitude was 3.5 mm. The power density of the electron beam was distribut-

Table 2. Conditions of EBW of plates of 1460 alloy and plates of dissimilar 1460+1201 alloys

Material	Thickness, mm	EBW conditions			
		Welding speed, mm/s	Accelerating voltage, kV	Scanning amplitude, mm	Beam current, mA
1460	40	11	60	1.5	320
1460 with 1201 filler	40	5.5	60	3.5	250
1460 + 1201	18	11	30	2.0	350

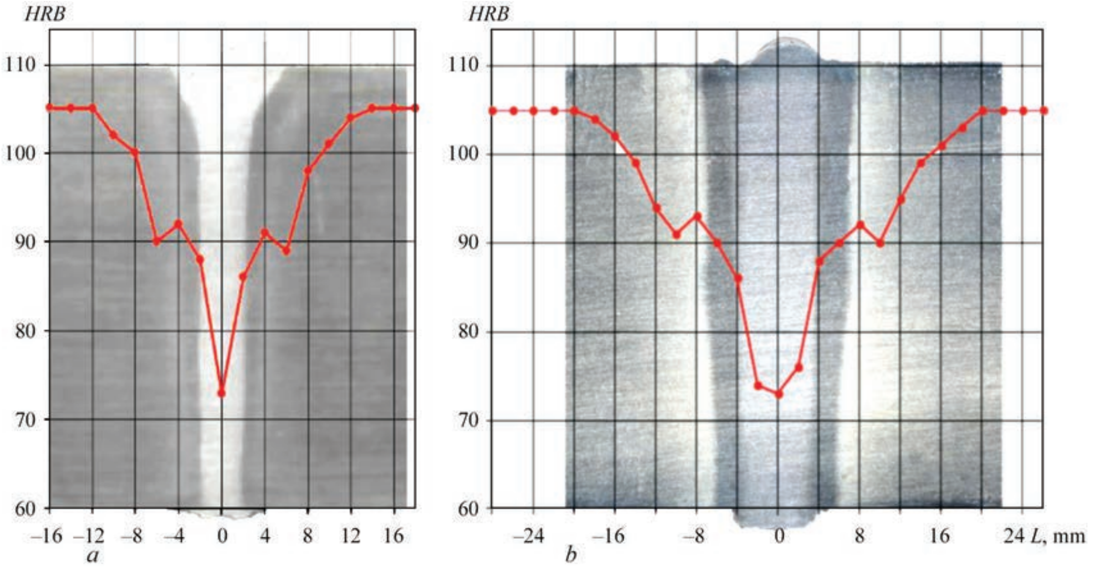

Figure 6. Cross-sections and distribution of hardness in the joints of plates of 1460 alloy of 40 mm thickness welded without filler (*a*) and with filler material of 1201 alloy (*b*)

ed along the scanning trajectory in such a way that the edges to be welded amounted to about 85 % of the total power and about 15 % for the tail part of the pool. The scanning parameters of the electron beam were calculated according to the procedure described in [12]. The welding scheme is shown in Figure 5.

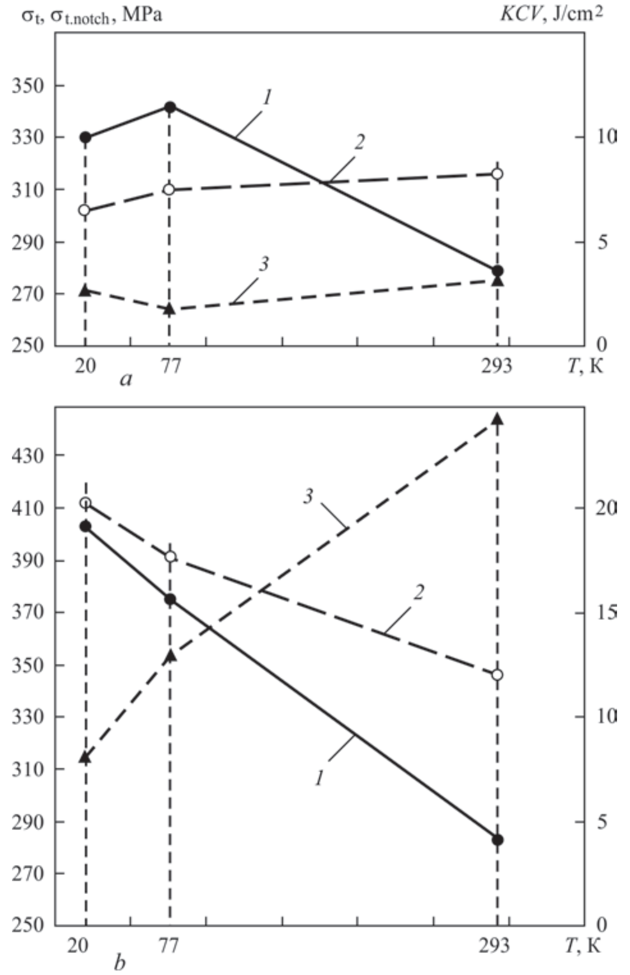

Figure 7. Dependence of mechanical properties of joints of 1460 alloy, welded without filler (*a*) and with filler from 1201 alloy (*b*) on test temperature: *1* — ultimate tensile strength of plane specimens (σ_t); *2* — ultimate tensile strength of specimens with a notch ($\sigma_{t.notch}$); 3 — impact toughness (*KCV*)

Cross-sections of joints and the results of hardness measurements are presented in Figure 6.

The welding process both using filler material as well as without it proceeded steadily without spattering and without leakage of liquid metal. The width of the weld produced without filler material was about 4 mm, and that with a filler was about 8 mm. The welds had almost parallel fusion lines with a slight expansion in the upper part. The hardness of the weld metal was *HRB* 73–76 and did not depend on chemical composition of the weld. The width of the heat-affected-zone (HAZ) for the weld without filler was about 12 mm. The weld produced with the filler of 1201 alloy had a HAZ width of about 20 mm, which is predetermined by the expansion of the molten zone and a lower welding speed. Cracks in the welds and in the HAZ were not detected. The chemical composition of base and filler metal, as well as welds is presented in Table 3.

Mechanical properties of the joints of 1460 alloy at room and cryogenic temperatures of tests are shown in Figure 7.

During welding without filler material, the ultimate tensile strength of the joints rises from 280 to 330 MPa when the test temperature is reduced from 293 to 20 K. The ultimate tensile strength of the specimens with a notch is reduced from 315 to 285 MPa. This indicates an increase in the sensitivity of the weld metal to stress concentrators. The impact toughness of the weld metal is low and is at the level of 2–3 J/cm^2 in the entire range of tests.

Reduction in the content of lithium and increase in the content of copper in the weld metal during weld-

Table 3. Chemical composition of weld metal and base metal during EBW of 1460 alloy using filler material and without it, as well as dissimilar 1460 + 1201 alloys

Location of determination	Chemical composition, wt.%			
	Base	Cu	Li	Sc
1460 alloy	Al	3.0	2.15	0.08
1201 alloy	Al	6.3	–	–
Weld of 1460 alloy, produced without filler	Al	3.0	2.10	0.08
Estimated chemical composition of weld metal during EBW using filler of 1201 alloy	Al	4.0	1.5	0.056
Weld of 1460 alloy, produced using filler of 1201 alloy	Al	3.80	1.45	0.06
Weld of dissimilar 1460 + 1201 alloys	Al	4.05	1.35	0.05

ing using filler made of 1201 alloy allows a significant improvement in mechanical properties of joints at cryogenic temperatures. The strength of joints welded using filler material at a temperature of 77 K, rises by 10 %, and at a temperature of 20 K, it sies by 20 % as compared to the joints welded without filler. Thus, the ultimate tensile strength of the joints at a decrease in the test temperature from 293 to 20 K, rises from 285 to 405 MPa. The specimens without a notch during testing at temperatures of 20 and 77 K fractured along the fusion line. The ultimate tensile strength of the specimens with a notch is everywhere higher than the ultimate tensile strength of plane specimens. When using filler of 1201 alloy, the impacct toughness of the weld metal increases by 3–10 times. It amounts to 25 J/cm^2 at a temperature of 293 K and 7.6 J/cm^2 at 20 K.

Also, experiments on EBW of dissimilar 1460 + 1201 alloys were performed. The welding conditions are given in Table 2. In order to control the degree of participation of alloys to be joined in the formation of the weld, the shift of the electron beam relative to the butt line is usually used. During EBW of butts from 1460 + 1201 alloys, the beam was not shifted relative to the butt, and the distribution of beam power density was controlled along the scanning trajectory in such a way that in the weld formation 75 % of 1460 alloy and 25 % of 1201 alloy took part. At such a ratio, it was expected to obtain about 4 % of copper content and about 1.5 % of lithium content in the weld metal.

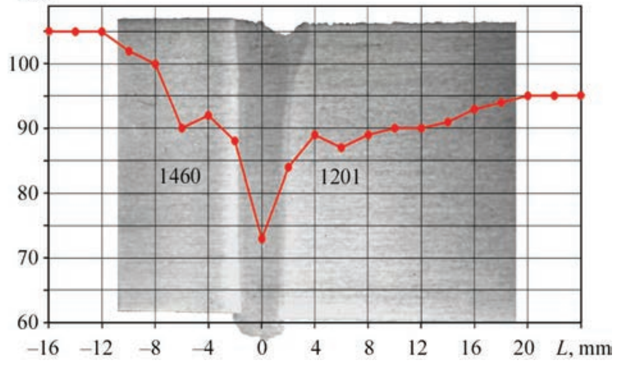

Figure 8. Cross section and hardness distribution in welded joint of plate of 1460 alloy with a thickness of 18 mm with the plate of 1201 alloy

The parameters of the beam scanning were calculated according to the procedure described in the work [12].

Cross-sections of joints, results of hardness measurements and mechanical properties of joints of 1460 + 1201 alloys are shown in Figures 8 and 9.

The hardness of the base metal of 1460 alloy is 105 *HRB* and 95 *HRB* for 1201 alloy at 73 *HRB* of a weld metal hardness. The width of HAZ on the side of 1460 alloy does not exceed 12 mm, and on the side of 1201 alloy it is 20 mm. In the weld metal, individual pores with a diameter of up to 0.5 mm were detected. Lacks of fusion and cracks were not detected. The chemical composition of the weld metal is given in Table 3.

The ultimate stength of 1460 + 1201 joints at a room temperature is at the level of 285 MPa and increases to 445 MPa when the temperature decreases to 20 K. The impact toughness decreases from 26 to 8 J/cm^2. At all test temperatures, the ultimate stength of specimens with a notch is higher than that of plane specimens, i.e. the sensitivity to stress concentrators in the weld metal is negligible.

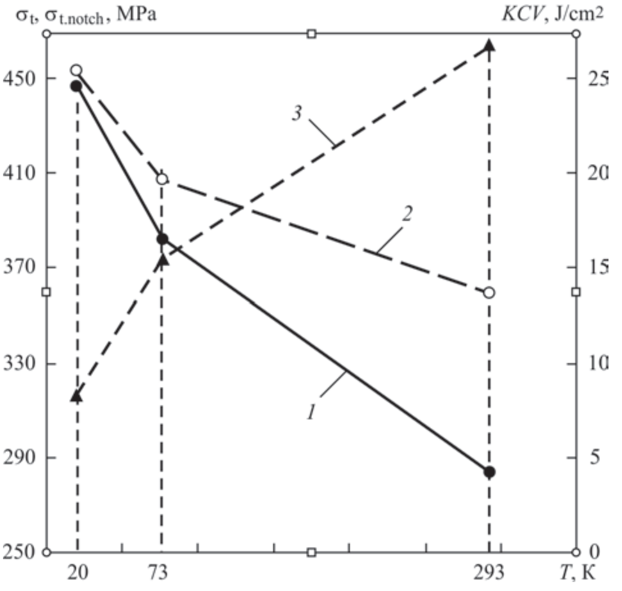

Figure 9. Dependence of mechanical properties of joint of plate of 1460 alloy with plate of 1201 alloy on test temperature: *1* — ultimate tensile strength of plane specimens (σ_t); *2* — ultimate tensile strength of specimens with a notch ($\sigma_{t.notch}$); *3* — impact toughness (*KCV*)

Conclusions

1. Mechanical properties of welded joints of 1460 alloy at room temperature and especially at cryogenic temperatures depend on the content of copper and lithium in the weld metal. As the copper content increases and the lithium content decreases, the ultimate tensile strength of the joints at test temperatures of 20 and 77 K rises by 20 and 10 %, respectively. Such a change in the chemical composition of the weld metal in practice can be carried out by using 1201 alloy as filler material. Impact toughness of the weld metal increases by 3–10 times, and sensitivity to stress concentrators decreases.

2. It is rational to introduce filler material into the welding pool during EBW of 1460 alloy with the use of a molten insert from 1201 alloy. Satisfactory welded joint formation during EBW with an insert is achieved by such a distribution of beam power density, at which about 80 % of the beam power is accounted for welded edges of 1460 alloy and the rest 20 % is accounted on the tail part of the pool.

3. Mechanical properties of welded joints of dissimilar 1460 + 1201 alloys at test temperatures of 20, 77 and 293 K are at a level not lower than the properties of the joints of 1460 alloy, welded using 1201 filler material.

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