MECHANICAL PROPERTIES OF BRAZED JOINTS ON DISPERSION-STRENGTHENED COPPER ALLOY

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The paper gives results of investigations of a set of properties of the brazed joints on a copper alloy strengthened by dispersed particles of Al_2O_3, produced by vacuum brazing using adhesion-active brazing filler metals. It is shown that application of heat treatment of the base metal in combination with filler metal of the Cu–Ti system ensures tensile strength of the brazed joints at a level of 81 % of that of the as-received base metal, and 92 % of that after preliminary heat treatment.

Keywords: *vacuum brazing, dispersion-strengthened copper alloy, butt brazed joint, adhesion-active brazing filler metals, tensile mechanical properties*

Joints produced by high-temperature brazing are heterogeneous systems consisting of different materials characterised by different physical-mechanical properties. Strength of the brazed joints greatly depends on a proper choice of composition of a brazing filler metal, its mechanical properties and compatibility with the base material. The technological process of brazing allows avoiding high residual stresses in the joints, melting of the base metal and cracking. Hence, the process makes it possible to preserve properties of the base metal with no disturbance of its structural state. The brazing process involves physical-chemical interaction of the base metal with a molten filler metal, this affecting composition the brazed seam. At the same time, mechanical properties of the brazed joints differ from properties of the filler metal in the initial state [1], and are in direct dependence on the structural state of the seam metal and its width [2].

This study gives results of investigations of mechanical properties of the brazed joints on a dispersion-strengthened copper alloy (Glidcop Al-25) produced by using adhesion-active filler metal based on the Cu–Ti, Cu–Mn–Ni–Fe–Si and other systems (Table 1). Microstructural peculiarities of the brazed joints on heat-resistant copper alloy Glidcop Al-25 strengthened with dispersed oxide particles of Al_2O_3 were studied earlier by using different filler metals and heating methods [3, 4].

Dispersion-strengthened copper alloy Glidcop Al-25 in the as-received state and after annealing at a temperature of 950 °C for 1 h was used to investigate mechanical properties of the base metal and brazed joints. Cylindrical billets about 70 mm long with prepared edge surfaces were utilised for making butt brazed joints. To ensure alignment of the brazed pieces, before brazing they were put in a special fixture, the filler metal was introduced into the gap, and then they were placed in a furnace. Brazing was performed in vacuum at a liquidus temperature of the filler metal by using radiation and resistance heating. In case of resistance heating, compressive pressure of 10 g/cm^2 was applied to the brazed pieces. The time of holding at a brazing temperature was 3 min in both cases. However, in radiation heating the total brazing time (till unloading from the furnace) was longer — about 130–140 min, and in resistance heating it was approximately 20 min. Cylindrical specimens for static tensile tests were made from the produced butt brazed billets about 140 mm long. Sizes of the gauge zone of the specimens were as follows: length $l_0 = 50$ mm, and diameter $d_0 = 10$ mm. Thread M16 was made in the grip regions of the specimens.

Tensile tests were carried out according to GOST 6996–66 and GOST 1497–84. Electromechanical testing machine UME-10tm fitted with the required electronic equipment, strain gauge with a gauge length of 25 mm and X–Y recorder N307/1 was used for the tests. Deviations of the measured load were not in excess of ±1 %. The test temperature was 20–24 °C.

Conditional values of tensile strength σ_t, yield strength $\sigma_{0.2}$ and elasticity limit $\sigma_{0.01}$, as well as elongation $\delta_{2.5}$, reduction in area ψ and elasticity modulus E were determined. Deformation diagram F (load) and Δl (elongation of a specimen) was recorded during the tests. To determine the $\sigma_{0.2}$, $\sigma_{0.01}$ and E values, the speed of a grip was $8 \cdot 10^{-3}$ mm/s, while further tests to complete fracture were conducted at a speed of $8 \cdot 10^{-2}$ mm/s. Upon achieving the residual elongation value of $\varepsilon \geq 0.2$ %, the load was decreased to $F = 0$. After readjustment of the grip movement mode and scale of recording of the diagram, the tests were continued to complete fracture.

Table 1. Melting temperature of brazing filler metals, °C

No. of filler metal	Base system	T_S	T_L
1	Cu–Ti	950	990
2	Cu–Mn–Ni–Fe–Si	810	890
3	Ti–Zr–Ni–Cu–V–Be	748	857
4	Ti–Zr–Ni–Cu	830	955

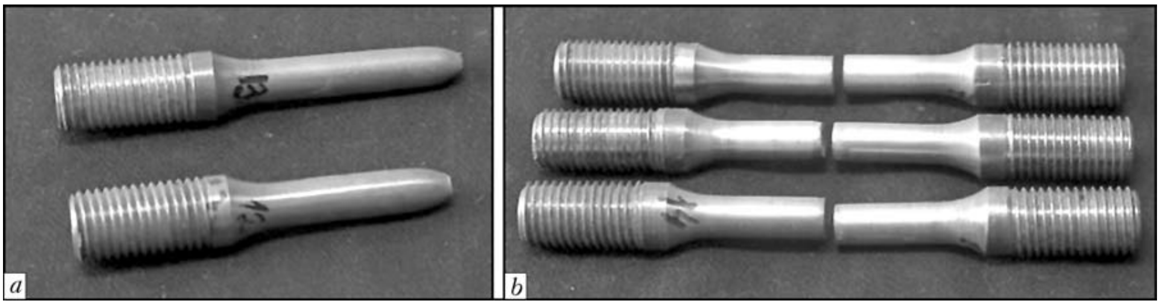

Figure 1. Appearance of specimens after mechanical tests: *a* — base metal; *b* — brazed joints

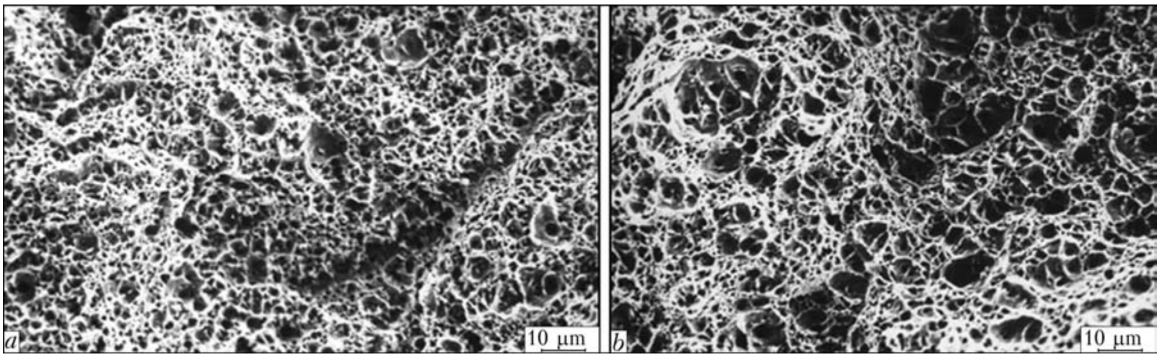

Figure 2. Fractographs of fracture surface of base metal in initial state (*a*) and after annealing (*b*)

Diameter of the gauge region of the specimens before the tests, d_0, and after the tests, d_t, was measured in three different sections and in two mutually perpendicular directions. Measurements of the brazed specimens were made in sections along the joining zone by using micrometer MKO-25 with a scale division value of 0.01 mm.

Elongation $\delta_{2.5}$ at fracture was determined from the deformation diagram for deformation meter gauge length OL = 25 mm, and by measuring residual elongation between the base marks on a specimen, $\Delta l = l_U - l_O$. For this, light transverse marks were made on the specimen surfaces on two sides from the seam centre for a gauge length of 25 mm. To reveal the character of non-uniform deformation, additional

Table 2. Results of tensile tests of base metal and butt brazed joints on copper alloy Glidcop Al-25

Specimen No.	Filler metal alloying system	σ_t, MPa	$\sigma_{0.2}$, MPa	$\sigma_{0.01}$, MPa	E, MPa	$\delta_{2.5}$, %	ψ, %
PM-1	–	491.5	440.6	245.1	108,606	10.40	68.80
PM-2*	–	430.1	351.9	243.6	101,365	7.20	75.80
1	Cu–Ti	353.2	337.4	230.8	94,594	0.561	2.70
2	Cu–Ti	353.4	333.1	219.5	99,925	0.79	2.31
3*	Cu–Ti	397.2	322.7	217.2	96,970	1.42	5.99
4*	Cu–Ti	382.4	320.3	218.6	94,365	3.89	5.41
5	Cu–Mn–Ni–Fe–Si	111.9	>111.9	111.9	93,898	0.05	0.10
6	Cu–Mn–Ni–Fe–Si	253.9	>253.9	191.2	98,727	0.07	0.50
7*	Cu–Mn–Ni–Fe–Si	305.3	304.1	202.5	97,388	0.27	1.69
8*	Cu–Mn–Ni–Fe–Si	282.6	>282.6	215.2	95,785	0.09	1.00
9	Ti–Zr–Ni–Cu–V–Be	310.3	>310.3	245.1	91,539	0.07	0.99
10	Ti–Zr–Ni–Cu–V–Be	234.3	>234.4	234.3	99,917	0.01	0.20
11	Ti–Zr–Ni–Cu	136.8	>136.8	>136.8	108,823	0	0.60
13***	Cu–Ti	387.1	322.1	223.0	92,300	4.20	16.40
14***	Cu–Ti	376.6	322.2	197.1	99,160	2.50	8.40
15**	Cu–Mn–Ni–Fe–Si	357.9	334.0	214.7	99,914	0.60	2.04
16**	Cu–Mn–Ni–Fe–Si	305.0	>305.0	214.9	100,833	0.12	0.56

*Preliminary annealing. **Brazing with resistance heating.

transverse marks were made within the gauge length on the specimen surfaces (PM-1, PM-2, Nos. 3, 4, 7, 8, 13 and 14) with the roughness removed by grinding: with an interval of 1 mm within the seam zone, and with an interval of 2 mm outside the seam. Toolmaker's microscope BIM-1 having micrometric screws and a scale division value of 0.005 mm was employed to make the transverse marks and measure the elongation value. The measurement data were used to determine residual local elongations between the neighbouring marks $\delta_{l_i = 1} = \frac{l_{U,\,i} - l_{O,\,i}}{l_{O,\,i}} \cdot 100$ %, where $l_{U,\,i}$ and $l_{O,\,i}$ are the distances between the marks before and after the tests, respectively.

Base metal specimens PM-1 and PM-2 subjected to tension fractured with a substantial plastic deformation within the gauge (proportional) part of a specimen to form a neck in the fracture zone (Figure 1, *a*). Structure of the fracture surface in the initial state was homogeneous, characterised by a pit-like tough relief (Figure 2, *a*).

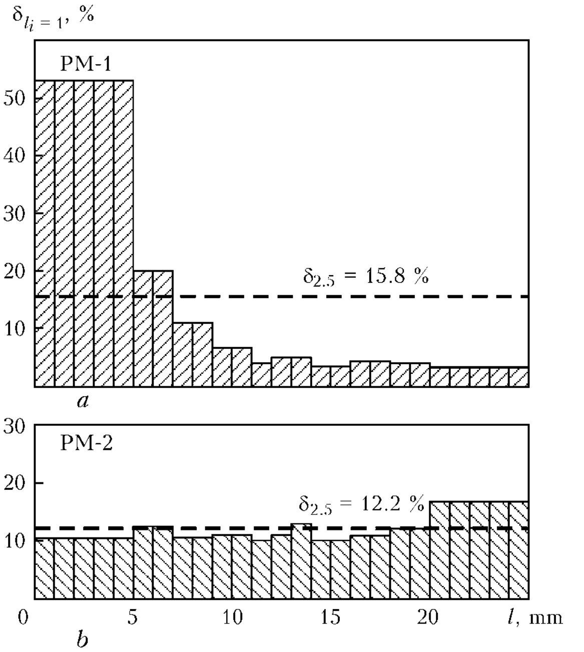

Figure 3. Character of distribution of residual elongation in tensile tests of cylindrical specimens of alloy Glidcop Al-25 in initial state (*a*) and after annealing (*b*)

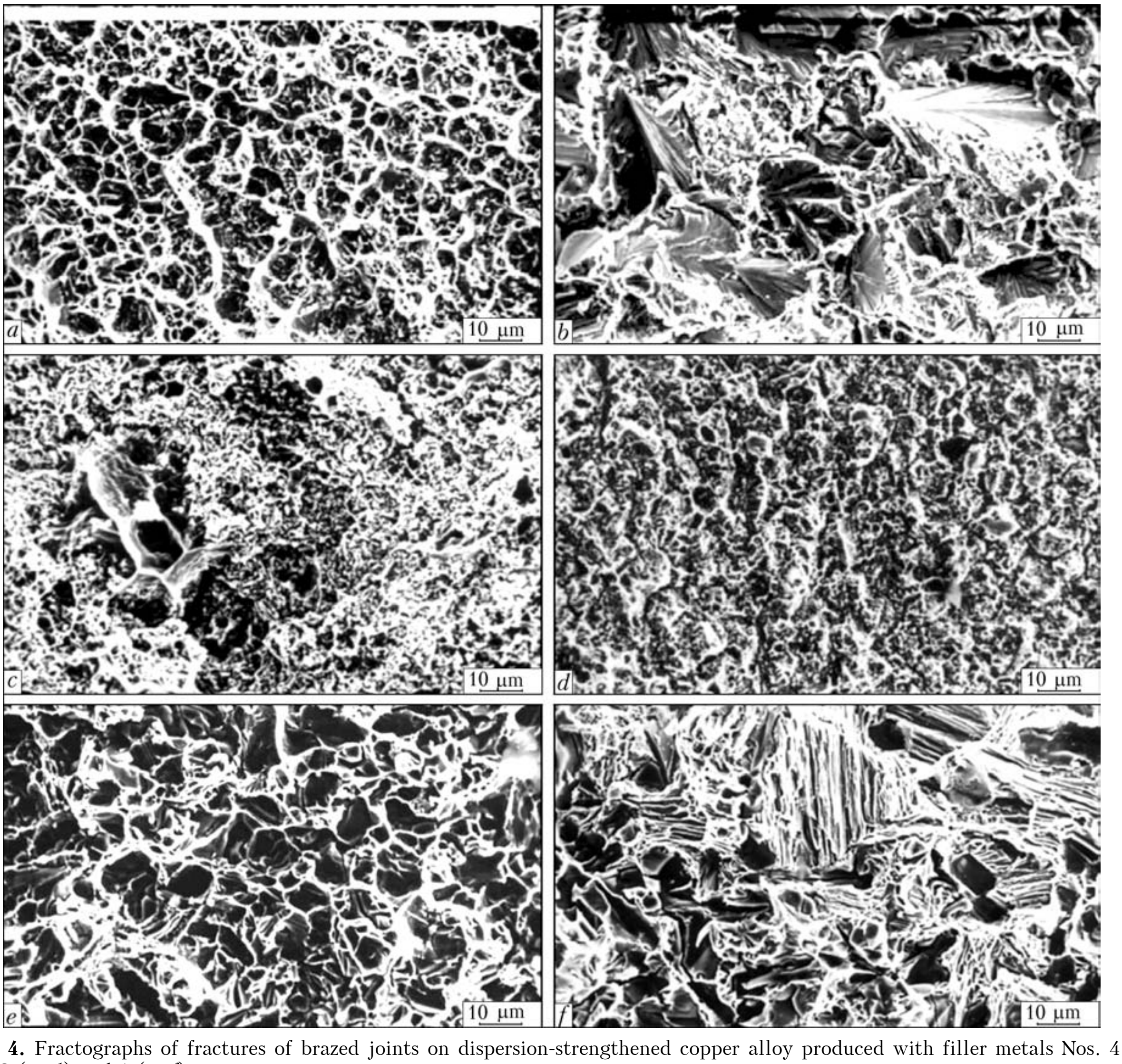

Figure 4. Fractographs of fractures of brazed joints on dispersion-strengthened copper alloy produced with filler metals Nos. 4 (*a*), 3 (*b*), 2 (*c*, *d*) and 1 (*e*, *f*)

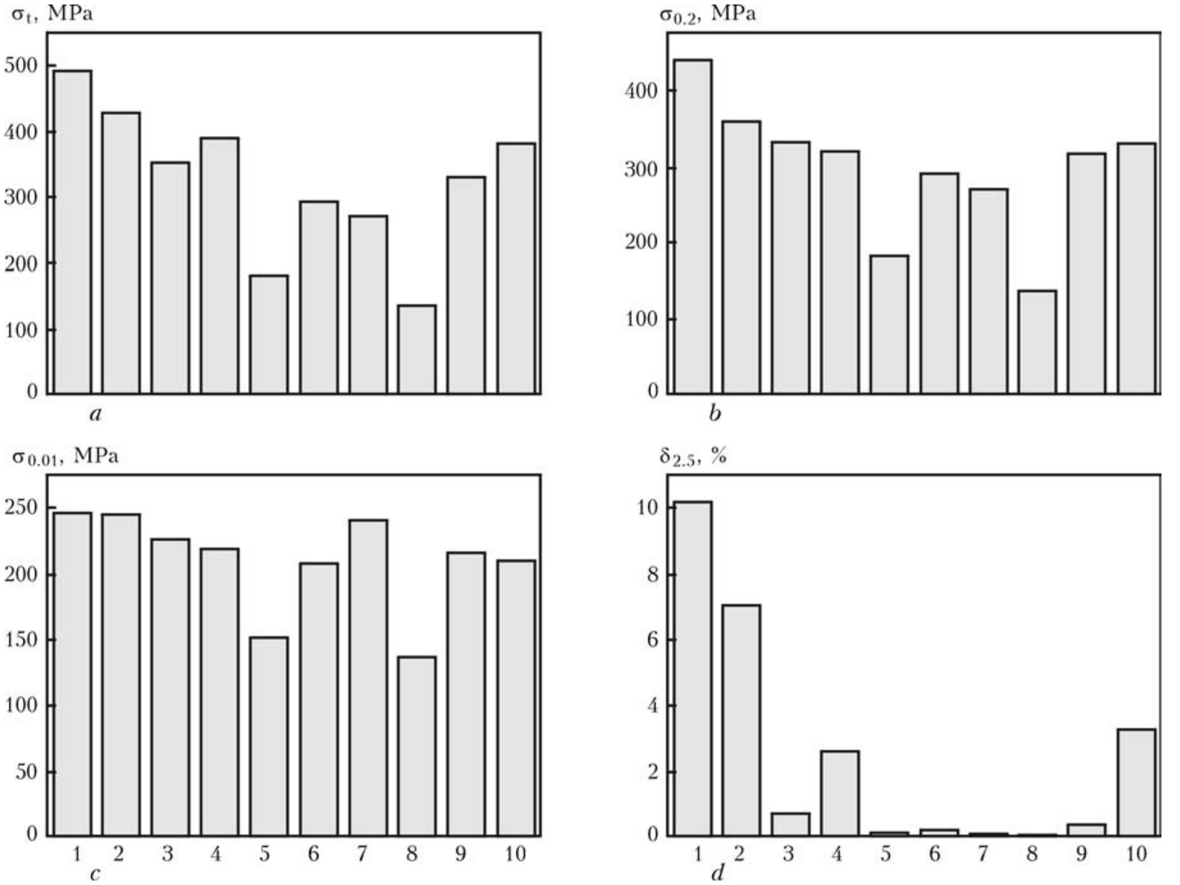

Figure 5. Diagrams of average values of mechanical properties of alloy Glidcop Al-25 in the initial (1) and annealed state (2), and of the brazed joints (3–10) produced with filler metals based on the Cu–Ti (3), Cu–Ti[1] (4), Cu–Mn–Ni–Fe–Si (5), Cu–Mn–Ni–Fe–Si[1] (6), Ti–Zr–Ni–Cu–V–Be (7), Ti–Zr–Ni–Cu (8), Cu–Mn–Ni–Fe–Si[2] (9) and Cu–Ti[1, 2] (10): [1] — preliminary heat treatment of base metal at 950 °C for 1 h; [2] — brazing by using flowing current

Annealing led to increase (two times) in the local value of residual elongation, compared with the non-annealed specimen (Table 2, Figure 3). However, because of fracture of the specimen in the annealed state outside the measurement part, it had a lower value of residual elongation $\delta_{2.5}$.

Strength of alloy Glidcop Al-25 decreased by 60 MPa after heat treatment (see Table 2), i.e. its strength corresponded to 430 MPa. Fracture was of a tough character, but pits had a larger size (about 10 μm) than in the previous specimen (see Figure 2, *b*), which may result from partial coarsening of the strengthening phase.

In tensile tests of the brazed specimens, fracture occurred in the seam with a minimal plastic deformation of the base metal in the near-seam zone (see Figure 1, *b*). It was determined that the lowest strength of the brazed joints, 137 and 234–310 MPa, was obtained with the brazing filler metals based on the Ti–Zr–Ni–Cu (see Table 2) and Ti–Zr–Ni–Cu–V–Be systems, respectively. The fracture surface contained a large number of regions with a brittle fracture (Figure 4, *a*, *b*).

The higher strength values were obtained with a filler metal of the Cu–Mn–Ni–Fe–Si system, although the spread of values was significant (of an order of 140 MPa). Preliminary heat treatment of the base metal in case of radiation heating allowed increasing the tensile strength value from 112–254 to 283–305 MPa. Further increase in strength (σ_t = 305–358 MPa) can be achieved by using resistance heating (Table 2, specimens Nos. 15 and 16), which provides rapid heating and cooling, and a minimal brazing time. Moreover, application of a compressive force led to pressing out of part of a molten filler metal from the gap, which also had a positive effect on mechanical properties of the brazed joints. Analysis of the data obtained shows that the use of resistance heating allows reducing the brazing time (approximately 6–7 times) compared to radiation heating and, at the same time, increasing strength of the brazed joints by about 50 MPa in brazing with the filler metal based on the Cu–Mn–Ni–Fe–Si system.

As shown by fractography results on the character of fracture of the brazed joints, topography of the fracture surfaces is affected by composition of the brazed seam, i.e. microstructural components of the seam. For example, the fracture surface of specimen No.6 (σ_t = 254 MPa, radiation heating) features a mixed character of fracture with a large number of tear ridges (Figure 4, *c*). Isolated particles containing up to 20 wt.% Al can be seen on the fracture surface.

The character of fracture of the specimens produced by brazing with the same filler metal (Cu–Mn–Ni–

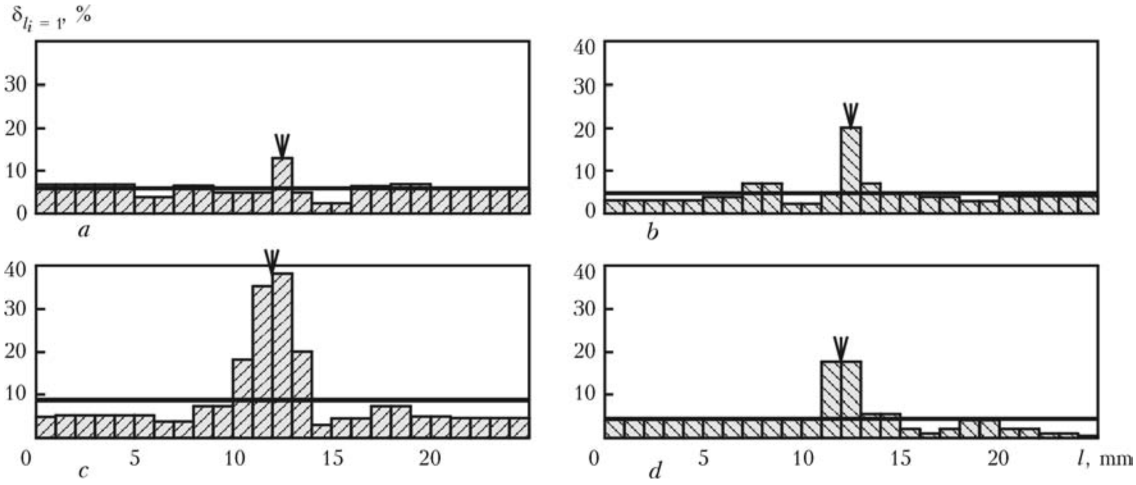

Figure 6. Character of distribution of residual elongation in tensile tests of butt joints brazed with the Cu–Ti system filler metal in vacuum furnace by using radiation heating (*a* — specimen No.3; *b* — No.4), and by the flowing current (*c* — No.13; *d* — No.14): $\delta_{2.5}$ = 5.90 (*a*), 4.76 (*b*), 8.86 (*c*) and 4.35 (*d*) %

Fe–Si) by using resistance heating (σ_t = 305 MPa) featured a structure with finer grains. The content of aluminium decreased and equalled about 10 wt.% in some particles. Specimen No.15 exhibiting the highest strength for the given filler metal (σ_t = 358 MPa) had a more fine-grained structure of the fracture surface (Figure 4, *d*). The content of aluminium in white particles continued decreasing, and was no more than 6 wt.%. Therefore, tensile strength of the brazed joints increased with decrease in the weight content of aluminium in the seam.

The best strength characteristics of the brazed joints (with good consistency) were obtained in brazing with the Cu–Ti filler metal by using both radiation heating (σ_t = 353 MPa, Table 2) and flowing current (σ_t = 377–387 MPa). The fracture had a fine-grained pit-like structure, the size of facets being relatively small and not in excess of 10 μm. The content of aluminium in the seam was no more than 1 wt.%.

Preliminary heat treatment of the base metal in case of radiation heating made it possible to increase tensile strength of the joints from 353 to 397 MPa, this being 81 % of strength of the base metal in the as-received state, and 92 % — after preliminary heat treatment. At the same time, brittle fracture of the transcrystalline type occurred at a maximal strength (Figure 4, *e*, *f*).

Advantages of this filler metal can be more clearly demonstrated by the diagrams that show the average results of tensile mechanical tests of the base metal, as well as of the brazed joints produced with different filler metals (Figure 5, *a*–*c*).

It should be noted that preliminary heat treatment in brazing (with radiation heating) leads to increase of elongation (Figure 5, *d*) in case of using the Cu–Ti filler metal. Short-time tensile strength σ_t of the brazed joints is no more than proof yield stress $\sigma_{0.2}$ of the non-annealed base metal, and the values of elongation $\sigma_{0.2}$ are more than two times lower than the corresponding value for the base metal (Figure 5, *d*). The value of conditional elasticity limit decreases but insignificantly.

Heat in brazing with the flowing current is released mostly within the zone of the mating surfaces, this being proved by comparison of the character of distribution of residual elongation $\delta_{2.5}$ in the annealed butt joints produced with the Cu–Ti filler metal (Figure 6, *c*, *d*).

Tensile strength of the brazed joints produced with the Cu–Ti filler metal in case of resistance heating is sufficiently stable (3.76.6–387.1 MPa), but lower than in brazing using radiation heating by about 10 MPa. Radiation heating, which has a favourable effect on structuring of the brazed seams [3] and, hence, mechanical properties of the brazed joints, is more preferable for this filler metal.

CONCLUSIONS

1. Strength of the brazed joints produced on dispersion-strengthened copper alloy Glidcop Al-25 by vacuum brazing with filler metals of the Ti–Zr–Ni–Cu–V–Be and Ti–Zr–Ni–Cu systems is at a low level, and does not exceed 310 and 137 MPa, respectively.

2. The use of the Cu–Ti filler metal (with radiation heating) combined with preliminary heat treatment of the base metal provides high tensile strength of the brazed joints, constituting 81–92 % of strength of the base metal. Resistance heating allows a considerable reduction of the brazing time (6–7 times) compared to radiation heating. However, in this case the brazed joints have a lower strength, which is 78–89 % of that of the base metal.

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