EVALUATION OF STRENGTH OF JOINTS PRODUCED USING WELDING WITH CONCURRENT BRAZING

V.I. SAVULYAK, S.A. ZABOLOTNY and **D.V. BAKALETS**
Vinnytsa National Technical University
95 Khmelnitskoe Shosse, 231021, Vinnytsa, Ukraine. E-mail: vsavulyak@mail.ru

Grounded was the rationality and the technology of producing permanent joints by combining the processes of welding and brazing using heat generated in the process of arc burning was described. The aim of the work is to establish the influence of formed brazed component on strength of the joint and structure as a whole. Developed were the methods for manufacture of pilot specimens, allowing establishing the necessary dependencies of strength of joints on type of braze material and its quantity. Namely the strength tests and processing of experimental data were performed in accordance with recommendations of GOST 28830–90. The use of programs of finite element analysis allowed determining the optimal welding conditions with concurrent brazing and the amount of braze material that can be melted. This technology can be used for repair of frames of transport machinery, damaged by cracking, by welding-on of strengthening cover plates. Also, it is rational to use the developed technology in production of frame structures. It was proved that the use of technology for producing permanent joints by combining the processes of welding and brazing using braze alloys based on copper can increase the strength of joint by one third as compared to conventional joint. 12 Ref., 3 Tables, 4 Figures.

Keywords: *frame structure, transport, crack, technology, repair, strengthening, welding, brazing, strength*

The perspective direction of increasing and improving the service properties of welded structures during repair and manufacture is the use of combination of several related processes [1–4]. The use of such technologies is rational to provide the increased requirements to reliability and long life. As an example, the repair of frames of transport means, in particular longerons, the areas of which are damaged with cracks, is given [2, 5]. For their repair and strengthening it was suggested to mount the additional elements by their welding-on using the concurrent brazing. The technology envisages the use of high-temperature braze alloys, allowing improving strength of the joints and corrosion resistance of the near-weld zone [6, 7]. The peculiarity of the technology is that braze alloy is mounted between the main elements, which are welded together and melted due to heat in the near-weld zone, released in the process of arcing [2].

The previous investigations established that the use of welding with concurrent brazing allows increasing the life of structure as compared to other known methods of repair [5]. However, to establish the influence of formed brazed component on strength of joint and structure as a whole the additional studies are necessary.

The generally-accepted technology of high-temperature brazing includes such additional operations [8] as cleaning and tinning of base material, preceding the assembly of structure into the required position with a necessary gap. Afterwards, the base is heated to the temperature higher than the melting point of braze alloy, the flux is applied and only then the braze alloy is introduced, previously coated with flux. Introduction of braze alloy is carried out by its touching the heated place in the area of joint, as a result of which it is melted and flows into the gap between the parts [9].

In the technology providing the combination of welding with concurrent brazing the performance of all the operations recommended above is almost impossible or complicated. The realization of welding with concurrent brazing is performed using another technology and, therefore, it becomes necessary to study the strength characteristics of brazed area of produced joint, which will allow predicting its general strength.

The brazed areas were investigated, produced using copper, copper-silver, copper-zinc and self-fluxing copper-phosphorus braze alloys. The previous micro- and macroanalysis of brazed area showed the possibility of producing the high-quality joints [2].

The test on strength and processing of experimental data were performed by recommendations of GOST 28830–90. Before carrying out welding with concurrent brazing of that parts *1* and *2* (Figure 1, *a*), at the places of location of braze alloy *3* additional elements *6* were welded-on, which is necessary for fixing in the machines for rupture test. For shear tests a specimen (Figure 1, *b*) was cut out from the welded-brazed

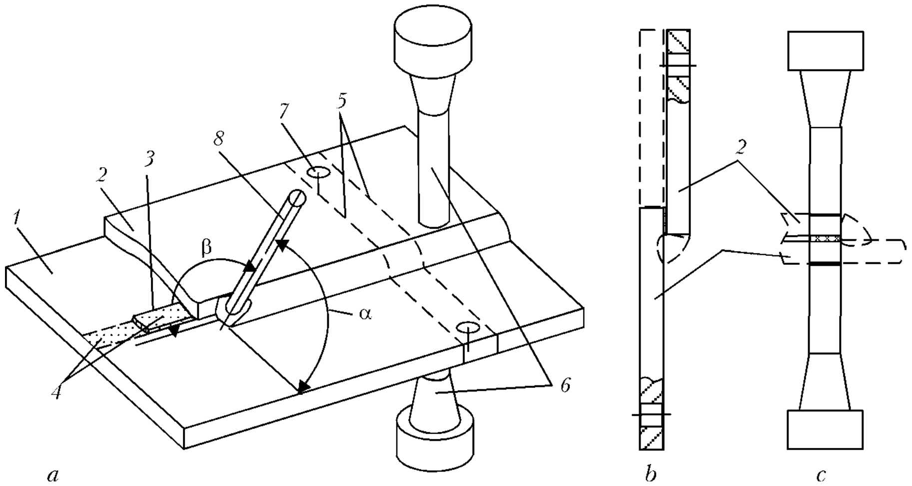

Figure 1. Scheme of preparation of specimens for rupture and shear testing of the brazed area: *a* — welding with concurrent brazing; *b* — specimen of V-type; *c* — specimen of II-type (for designations see the text)

structure (Figure, 1, *a*) along the dotted line *5*, and two holes *7* were drilled.

After welding with concurrent brazing the specimens for rupture test (type II) and shear test (type V) were machined till the sizes in accordance with GOST 28830–90. At the same time the weld was completely removed and only the brazed joint remained (Figure 1, *b*, *c*).

While producing the brazed joints on test specimens the researchers tried as much as possible to approach the real technological process of welding-on of cover plates for strengthening, i.e. the surface of base and braze material was cleaned mechanically and then assembled (see Figure 1, *a*) and welding process was carried out. In a number of experiments a thin layer of flux *4*, based on boric acid and borax, was placed between the braze material and semi-product [10]. It was established that the increase of its amount results in excessive pore formation, and its absence significantly reduces the ability of braze alloy to wet the steel surfaces.

In the course of experimental studies it was not always managed to reach the complete melting of braze material by the heat, which was spread from the weld pool. It was established that the maximum width of strip, which can be melted in the process of welding, depends essentially on power of the arc, temperature of melting of braze material, geometry of the parts (walls thickness of frame structure, strengthening elements, etc.), as well as spatial position of electrode relatively to the parts during welding process (see Figure 1, *a*, angles α and β).

Investigation of influence of the abovementioned parameters was performed using the package of applied programs of finite element analysis. One of the most informative methods of output of simulation results is temperature fields, the value and nature of distribution of which allows judging about the maximum amount of braze material which can be melted under the preset conditions.

For example, let us consider the model of welding-on of cover plate of 5 mm thickness to 7 mm thick base. The thickness of strip of braze alloy (in the specified model) here is 1 mm, welding power is 37 W/mm^2. The welding was carried out using electrode of 4 mm diameter at direct current of straight polarity at angle $\alpha = 45°$. The section across the weld pool indicates the character of propagation of temperature field from welding zone (Figure 2, *a*) perpendicular to the weld. This section of temperature field does not completely determine the allowable width of the strip of braze alloy as its propagation speed is not equal to welding speed. The correct one is the use of additionally plotted isotherms of quasi-stationary temperature field on the horizontal section *A*–*A* passing along the axis of plate of braze material (Figure 2, *b*).

The rational width of the strip of braze alloy can be determined using its main heat and physical characteristics (melting point, thermal conductivity, specific heat) [6]. In this study braze material is used with melting points of 800 and 600 °C. The tangents plotted towards the isotherms of melting points (see Figure 2, *b*) should be parallel to the axis of the plate of braze material. The width of braze strip should be placed within the limits from the border of weld till the corresponding tangent. Considering the scale of plates let us determine the width of braze alloy plates. For braze alloy with melting point of 800 °C the width should be 4.2 mm, and for 600 °C it should be 7.6 mm under the conditions of abovementioned parameters. To melt the braze material, except of the required temperature, it requires time, at which the necessary amount of heat will be supplied to it. For its determination the thermograms of heating of braze plate in the process of welding with respect to the most dis-

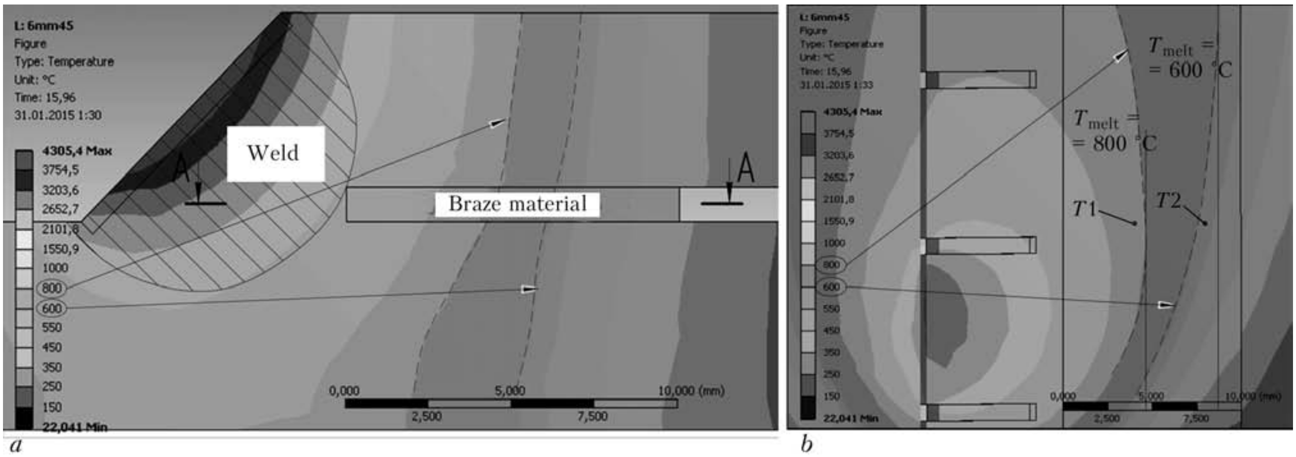

Figure 2. Temperature field of welding process with plotted isotherms: *a* — cross-section; *b* — horizontal section *A–A*

tant weld points $T1$, $T2$ are plotted (Figure 3). According to the plotted thermograms, except of maximum temperature, the time of staying the braze material in a certain temperature range can be determined. For braze alloy with melting point of 800 °C it is determined from the gap between lines *I* and *II*, and lasts 10 s.

Investigation of the influence of spatial position of electrode regarding the parts on configuration of the temperature fields and position of isotherms in the process of welding was performed using computer simulation and checked up experimentally. For the scheme of overlap welding the position of electrode regarding the parts is determined by the angle β to weld axis and angle α in the plane perpendicular to axis of the weld (see Figure 1, *a*). The change in the latter in overlap welding is controlled by GOST 5264–80 and may range within 30–60°. It partially determines the cross-section shape of weld, amount of weld metal, and accordingly affects the speed of welding. Therefore, the inclination angle of electrode changes the amount and distribution of heat energy over the volume of parts and partially determines the amount of braze material, which can be melted by welding heat.

In Tables 1 and 2 the data are given on choice of strip width of braze alloy of 1 mm thickness depending on inclination angle of electrode α in the process of welding for different wall thicknesses of the longeron of frame structure. The thickness of cover plate in this case was 5 mm, and welding power — 37 W/mm^2.

For the large thicknesses of the frame longeron the calculations were not performed, since the width of braze alloy strip, which can be melted, almost does not change with further increase in thickness of its wall.

Using the developed recommendations the quality welded and brazed joints were produced, and their mechanical tensile and shear tests were carried out, and tensile and shear strength values of the brazed seam area were calculated (Table 3).

The tests established that the use of Cu–P braze alloys for strengthening the welded joints is inappropriate, since the increase in strength due to brazed area is insignificant.

For calculations of strength of welded-brazed joint and prediction of strength of structure as a whole, the direction and value of loads affecting it must be taken into account (Figure 4).

The widespread variant of fracturing the overlap joints, loaded with forces F, occurs along the line of the smallest section of weld and brazed area *I–II*, and the strength depends on grade of materials, and working areas of section of weld and braze material [11, 12]. Furthermore, in the project calculations it is proposed to consider the service factor of theld (0.85–1) and the strength factor of

Table 1. Width of strip of braze alloy with T_{melt} = 800 ° C

Angle α, deg	Wall thickness of longeron frame, mm						
	5	6	7	8	9	10	12
	Width of braze alloy strip						
30	5.2	4.5	3.8	3.5	3.2	3	3
35	5.3	4.6	3.9	3.5	3.2	3	3
40	5.4	4.7	4.1	3.6	3.2	3	3
45	5.6	4.8	4.2	3.6	3.2	3	3
50	6	4.9	4.5	3.7	3.2	3	3
55	6.6	5.1	4.8	3.8	3.3	3.1	3
60	8.2	6.5	5.3	4	3.4	3.1	3

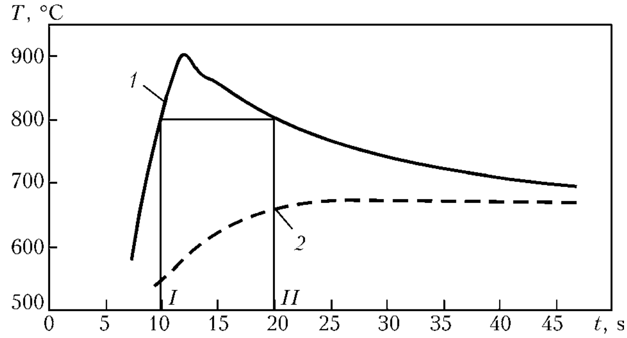

Figure 3. Thermograms: *1* — point $T1$ (800 °C); *2* — $T2$ (600 °C); *I–II* — brazed area

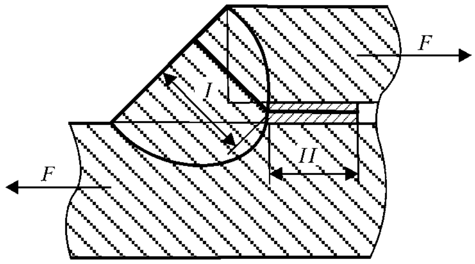

Figure 4. Scheme of design section of welded-brazed overlap joint

braze alloys (0.50–0.65). Thus, the maximum allowable forces on welded-brazed joints F_{WBJ} will be calculated according to formula:

$$F_{WBJ} = S_w R_{w.y} \gamma_s + S_{b.a} \tau k_{b.s}, \quad (1)$$

where S_w is the smallest sectional area of weld; $R_{w.y}$ is the calculated resistance of weld (we shall take it according to tensile strength of base metal); γ_s is the service factor (we shall take the maximum possible 0.85); $S_{b.a}$ is the brazed area working for shear; τ is the shear strength of brazed area; $k_{b.s}$ is the strength factor of braze alloys (we shall accept 0.5).

The brazed area is defined as the product of length by width of braze material. The area of smallest section of weld is located at angle of 45° to the legs, and calculated according to formula

$$S_w = \cos 45 kl \approx 0.7kl, \quad (2)$$

where k is the leg of weld (we shall take it in accordance with thickness of cover plate); l is the estimated length of weld equal to the actual one minus 10 mm.

The efficiency of using welding technology with concurrent brazing was considered for the case of welding-on of cover plate 5 mm thick to wall of longeron of frame of steel 09G2S ($R_{w.y}$ = = 500 MPa) with 7 mm thickness and braze material with T_{melt} = 800 °C. In the case of welding-on of cover plate using electrode with inclination angle α = 30° (width of plate of Cu–Zn braze alloy was 3.8 mm) the strength of joint is increased by 22 %, while at the same conditions with inclination angle α = 60° (width of braze plate was 5.3 mm) it is increased by 30 %. In the case of using the copper braze alloy for welding with concurrent brazing the strength of overlap joint can be increased by 36 % as compared to welding without brazing.

Table 2. Width of strip of braze alloy with T_{melt} = 600 °C

Angle α, deg	Wall thickness of longeron frame, mm						
	5	6	7	8	9	10	12
	Width of braze alloy strip						
30	9.2	7.1	6.7	6.2	5.7	5.2	5.1
35	9.5	7.6	6.9	6.3	5.8	5.2	5.1
40	10	8.4	7.2	6.4	6	5.3	5.1
45	10.5	9	7.6	6.8	6.3	5.4	5.1
50	11	9.7	8	7.3	6.6	5.5	5.2
55	12	10.3	8.9	7.9	6	5.7	5.2
60	13	12	10	8.5	7.6	6	5.2

Table 3. Mechanical properties of brazed joint

Mechanical properties	Type of braze alloy			
	Cu	Cu–Ag	Cu–Zn	Cu–P
σ_t, MPa	293	89	230	–
τ, MPa	205	73	172	–

Conclusions

A number of practical recommendations was developed regarding the use of welding with concurrent brazing for repair of frames of transport machinery by welding-on the strengthening overlays.

The methods given in the article, based on use of the programs of finite element analysis, allows determining the optimal parameters of welding mode with accompanying brazing and the amount of braze material, which can be melted.

For welding with concurrent brazing it is rational to use the high-temperature braze alloys based on copper, which allow increasing the strength of overlap joint by up to 36 % as compared to welding without brazing.

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