PROPERTIES OF THE WELDED JOINTS OF TUBULAR BILLETS PRODUCED BY PRESSURE BRAZE-WELDING WITH A FORMING DEVICE

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The paper generalizes the results of assessment of the influence of a forming device on properties of a circumferential butt joint forming in solid-state pressure butt braze-welding of tubular billets. Chemical elements distribution and phase composition were studied in the weld metal and the adjacent zone.

Keywords: *welding, pressure butt welding, braze-welding, upsetting, deformation, formation, weld, chemical composition, distribution of elements*

Formation of the weld metal in a process of solid-state pressure welding with a high-frequency heating occurs non-uniformly along the entire length of the joint, which shows up in different thickness of the weld. This non-uniformity is caused mainly by a complex character of movement of heated edges in upsetting during their plastic deformation and, in particular, by a non-uniform heating of the edges across the billet section.

The resulting peripheral fillet areas of the weld have a larger width of solidified interlayer of the weld, compared with the internal weld areas, where only common intergrowth grains of the base metal are located instead of the weld metal.

Separate visible fragments of the solidified weld interlayer have size comparable with grain size of the base metal, as well as the weld exhibits the trend to increase in thickness with distance to the fillet area [1–5].

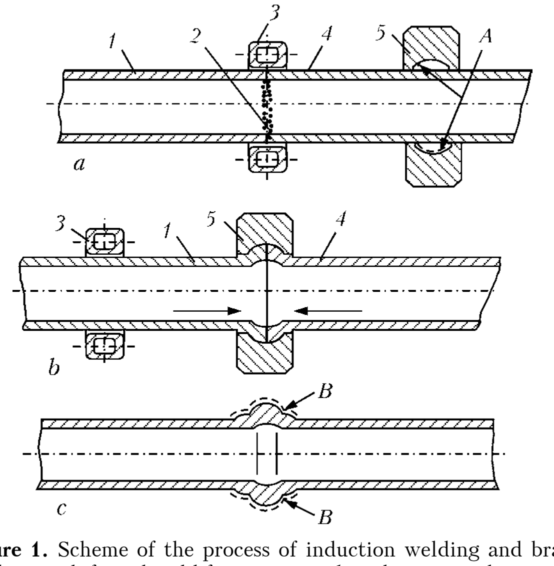

Figure 1. Scheme of the process of induction welding and braze-welding with forced weld formation: *a*, *b* — heating and upsetting process, respectively; *c* — resulting welded joint: *1*, *4* — tubular billets; *2* — mixture of brazing and welding consumables; *3* — circular inductor; *5* — forming device; *A* — forming surface of the device; *B* — weld bead surface

The E.O. Paton Electric Welding Institute suggested using a forming device in solid-phase pressure braze-welding of pipes to provide the weld with a uniform thickness.

This process of solid-phase butt braze-welding is performed in the following way. The edges of the parts being welded are covered with a mixture of brazing filler metal and activating substances, and the weld zone is shielded by flux. Heating is stopped after the billet edges reach the required temperature, at which melting of activating substances takes place. At the same moment the forming device is placed over the weld plane, and upsetting is performed. Formation of the weld bead occurs with the help of circumferential forming device (Figure 1, clamps and upsetting mechanism are not shown). The welds on tubular samples of diameter 26 × 2.5 mm from 08kp (rimming) steel (GOST 1050–74) were made by the braze-welding method according to the above-described scheme by using the P-137 UKhL 4 unit designed for pressure welding and brazing of 21.3–60.0 mm diameter pipes under a nominal upsetting force of 4.5 kN.

Heating of the joining zone was carried out with a high-frequency generator. The PVV-100/8000 converter with a speed of 8000 rpm, GVV-100/8000 generator with a frequency of 8000 Hz, and T33-800 UKhL 4 quenching transformer were used.

Chemical compositions of metal of the tubular billets, brazing filler metal and weld metal, which were used for the braze-welding process, are given in the Table. For that the nickel-based brazing filler metal (with ≈ 67.298 % Ni) applied prior to the braze-welding process by plasma spraying on edges of the billets and their outer surface near the joining zone was used [6].

X-ray spectral microanalysis was performed with the Comebax device (model SX-50) to examine distribution of main chemical elements across the welded joint. The examinations were carried out with move-

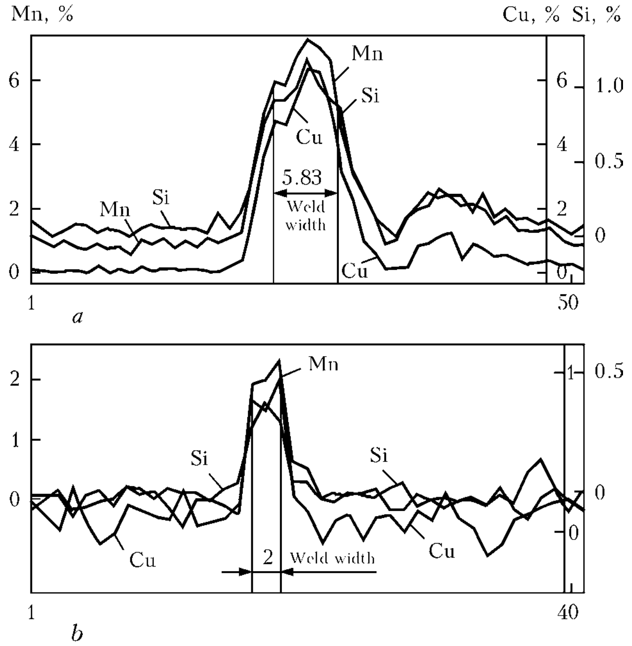

Figure 2. Distribution of Mn, Cr and Si determined in the first (*a*) and second (*b*) point in cross section of the joint with the optically revealed area of the weld metal

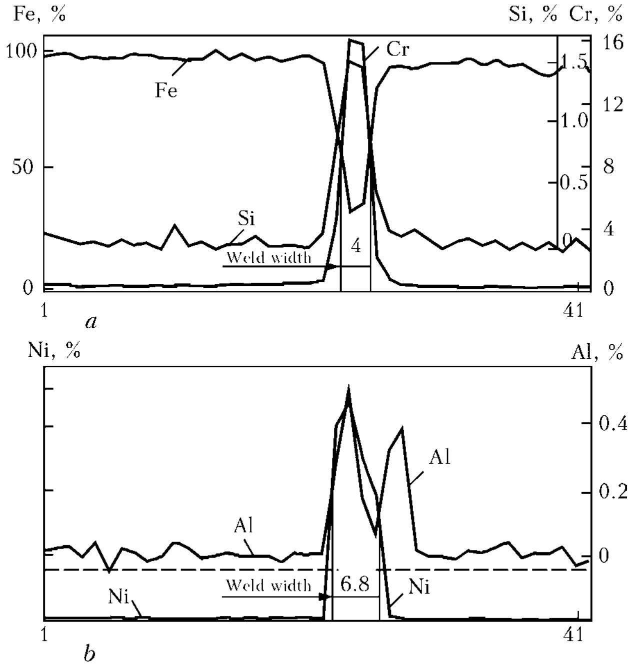

Figure 3. Distribution of Fe, Si, Cr (*a*), Ni and Al (*b*) in cross section of the joint with the optically revealed area of the weld metal

ment of the microprobe to a distance of 50 μm (1.02 μm step).

The X-ray spectral microphotographs of distribution of chemical elements in a cross-section of the joint with the optically identified area of the weld 2–7 μm wide are presented in Figures 2 and 3.

The examinations of microstructure were performed in several points on fragments of the weld, where a non-displaced interlayer of the crystallized solid-state phase can be visualized.

The analysis was carried out in four points for seven main chemical elements. Microhardness of the resulting welds and base metal in the near-weld zone was also measured with the help of the LECO microhardness gage M-400 under 25 g loading. Immediately before the welding process the edges of the tubular billets were covered with powdered flux — borax $Na_2B_4O_7$ on a binder.

It can be seen that base of the weld metal in the solidified areas is iron, the content of which due to its diffusion from metal of the billets into the weld exceeded 45 %. The content of iron in a sprayed layer of the brazing filler metal was only 3.7 %.

At the moment of heating shutdown, the formed liquid phase contains primarily components of the sprayed layer of the brazing filler metal. The content of nickel as a component of the brazing filler metal reduced from 67.298 to 32.172 % in wetting the base metal edges with the liquid phase. However, its content in the base metal of the billet was only 0.25 %.

Thus, an interdiffusion of nickel from the liquid phase into the base metal and vice versa took place.

It is known that the depth of penetration of diffusion fluxes into the base metal in iron to nickel welded joints made in $3\cdot10^{-4}$ mm Hg vacuum at a temperature of 1300 ± 10 °C and pressure of 15 MPa is about 20 μm for a period of welding of 10 min [7].

Application of plastic deformation and a high speed of the braze-welding process (deformation rate $\dot{\varepsilon} \geq$ ≥ 100–$120\ s^{-1}$) [8] lead to reduction of both thickness of the weld up to 2–7 μm (see Figures 2, 3) and diffusion zone in the base metal. The content of chromium in the weld metal also increased to 16.772 % (however, originally its content in the deposited brazing filler metal was 14.012 %, and in the base metal — 0.1 %). It is known that chromium, in particular, forms high-resistant alloys and Cr–Ni systems, which are located in the weld zone in a solid-liquid state during welding.

The temperature of the solid-state welding process carrying out (800–950 °C) also promotes formation of compounds of chromium with carbon, silicon and other impurities, in particular, with aluminum.

Distribution of main chemical elements in base metal, deposited brazing filler metal and optically revealed areas of weld metal in welded joints

Investigated area	Al	Si	Cr	Mn	Ni	Fe	Cu	Balance
Base metal	–	0.03	0.1	0.4	0.25	98.735	0.25	0.235
Sprayed brazing filler metal	2.673	2.359	14.012	0.26	67.298	3.736	0.374	9.287
Weld metal	0.381	1.691	16.772	0.339	32.172	45.688	0.439	2.516

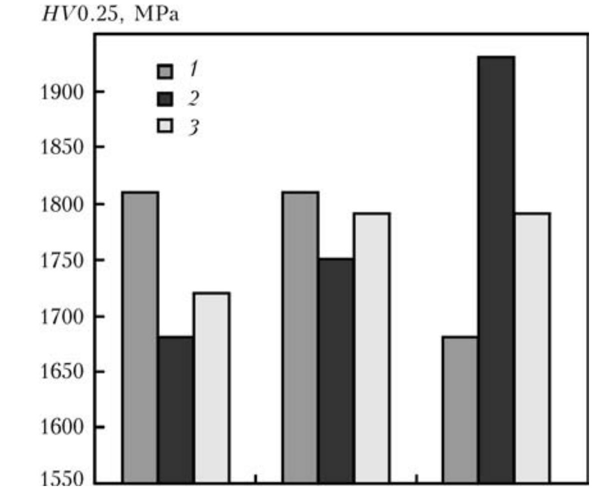

Figure 4. Diagram of distribution of microhardness in welded joint: *1* — weld metal; *2* — base metal; *3* — fusion line

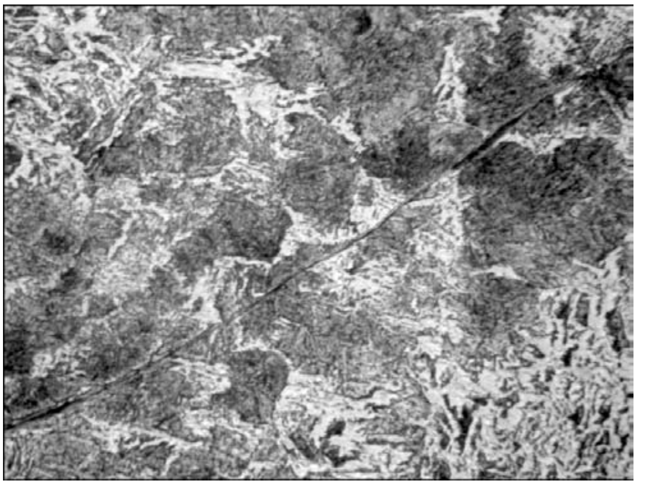

Figure 5. Microstructure (×320) of the weld region up to 3.5 μm thick

The content of manganese in the weld metal is 0.339 %, which is lower of than in the base metal (0.4 %). The content of manganese in sprayed brazing filler metal is even lower, and equals 0.26 %.

Manganese actively interacts with non-metals, i.e. impurities, such as carbon, nitrogen and phosphorus, in heating and formation of the liquid phase.

The data given in the Table indicate to a reduction of the content of impurities in the weld metal, compared with the deposited brazing filler metal. Thus, there was a reduction of the content of silicon from 2.359 % in the deposited brazing filler metal to 1.691 % in the weld metal, and of the content of aluminum from 2.673 to 0.381 %, respectively. The content of other elements, including impurities, decreased from 9.287 % in deposited brazing filler metal to 2.516 % in the weld metal.

Initially, with increase in temperature during heating, the non-metallic impurities dissociate from the compounds containing them. Then they diffuse into the liquid phase, where they form new compounds, including with components of the brazing filler metal, which is accompanied by increase in their content in the liquid phase, with which they are displaced from the weld zone during the upsetting process. The copper content of the weld metal grows. For example, the copper content of the billet base metal is 0.25 %, of the deposited coating is 0.374 %, and of the weld metal is 0.439 %. It is likely that copper diffuses from both base metal edges and deposited coating into the liquid phase, the fragments of which form a fusion line.

Analysis of microhardness of the weld metal and near-weld zone was carried out on samples in order to determine their comparative characteristics by using the known methods [9–14]. Microhardness $HV0.25$ of the weld metal was 1680–1810 MPa, that of the base metal was 1680–1930 MPa, and of the fusion line was 1720–1790 MPa, respectively.

Figure 4 shows the diagram of distribution of microhardness in a welded joint, based on the obtained data. The spread of the microhardness values from a mean measured microhardness of the weld equal to HV 1805 MPa amounts to 7 %. These data are indicative of the closeness of strength properties of the weld metal to properties of the base metal [15].

No elements of an activating substance, participating in the diffusion processes in the form of individual quenching structures and brittle phases, were revealed in the weld metal and near-weld zone.

The diffusion processes are activated along the phase contact boundaries in a short period of time upon reaching the melting temperature of the brazing filler metal and shutdown of heating before upsetting.

In upsetting, the internal, least heated deep layers of the base metal, which are situated between the middle and internal diameter of a tubular billet, take part in the weld formation.

The forming device protects the weld face from its exposure to the environment, while the weld formation proper occurs with a thermo-mechanical impact in the form of plastic deformation, followed by solidification under a pressure that is close to the uniform volumetric stressed state, which provides a more homogeneous composition of the weld metal along its entire length.

Sometimes, fragments of the weld interlayer solidified under a pressure can be seen along the length of the formed weld. These are the remainders of metal that was in the solid-liquid state, which were not completely pressed out, were plastically deformed and transformed into a thin weld interlayer (Figure 5).

CONCLUSIONS

1. Application of the forming device leads to a 2–7 μm decrease in the weld thickness and reduction of width of the diffusion zone, compared with the weld formation in a free state.

2. No quenching structures and brittle phases were revealed in the weld metal and near-weld zone.

3. Application of the forming device results in homogenization and formation of uniform phase composition of the weld metal and near-weld zone.

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EVALUATION OF STRESS-STRAIN STATE OF DISSIMILAR WELDED JOINTS FROM 10KH13G18D + 09G2S STEELS

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The features of determination of residual welding stresses on full-scale samples from 10Kh13G18D + 09G2S dissimilar steels are considered. A dependence is established between the size of the zone of plastic strains and longitudinal residual welding stresses on the applied technologies of gas-shielded welding, modes and heat inputs. Positive influence of the technology of cold metal transfer on residual stresses and dimensions of plastic strain zones in dissimilar steel joints is conformed.

Keywords: *residual stresses, welding modes, heat input, welds, near-weld zone, plastic strain zone, magnetic properties*

The cars of diesel-driven and electric trains being used at present time in Ukraine and CIS countries have two doors, car length up to 21.5 m and maximum capacity up to 240 persons. Car bodies are manufactured from low-carbon and low-alloy steels in a form of sheet, bar and plates (including cold bent sections) as well as steel castings separate elements of which, according to statistics, require a repair or change already after 5–6 years of running [1] due to high corrosion.

The main trend of development of a design of the electric and diesel-driven trains of this type is the maximum reduction of structure weight at retention or increase of the amount of seats with simultaneous providing of the necessary technical characteristics [2]. The elements and units of cars are subjected to corrosion, abrasive wear and temperature fluctuations in running along with multiple mechanical and alternating dynamic loads.

Steels having the following mechanical properties: σ_t = 500–550 MPa, σ_y = 400 MPa, δ = 21 % are recommended to use for cars engineering based on experience of running and experimental and theoretic investigations of R&D institutes VNIIZhT and VNIIV. Low-carbon and low-alloy steels used at present time do not fulfill the requirements mentioned above.

There is a world practice experience of application of stainless chromium-nickel steels of austenite class for skin of cars in transport industry with the aim of reaching more long-term resource of their running.

Stainless nickel-free 10Kh13G18D grade steel [3] was developed and recommended for manufacture of cars by the I.P. Bardin TsNII Chermet (Moscow, Russia) instead of 12Kh18N10T and 08Kh18N10 steels in order to provide the necessary requirements and economy of expensive nickel. This steel is characterized by high ductility in pressing and cavitation resistance, therefore it is good in application for body skin, and more cheap low-alloy higher strength 09G2S steels for framework elements of the body structures of cars. Application of 09G2S steel for framework elements of the body allows reducing the thickness of parts from 3.0–8.0 to 2.5–7.0 mm, and usage of 10Kh13G18D stainless steel in cold-worked state — skin thickness from 2.5 to 1.5 mm. As a result, it is expected that at significant increase of the car dimensions the weight will not change and its life time will increase.

It is well-known that a working capacity of welded structures significantly depends on thermo-mechanical properties occurring in area of the weld, values of