ARC BRAZING OF LOW-CARBON STEELS

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The article is dedicated to investigation of the process of arc brazing on thin-sheet steel 08kp (rimmed) by using brazing filler alloy BrKMts 3-1. Peculiarities of spreading of the filler alloy under conditions of tungsten-electrode arc heating using different shielding atmospheres are considered. It is shown that the best spreading is achieved in a mixture of argon with 10 wt.% of hydrogen. Heat input in arc welding and brazing was compared by the calculation method: the values of heat input (for a specific case) were 1200 and 516.7 J/cm, respectively. The possibility of decreasing the heat input by using the pulsed process is shown. Peculiarities of formation of butt and overlap joints are revealed. In brazing of the butt joints the gap can be adjusted over wide ranges (0.2–0.8 mm), and in brazing of the overlap joints this parameter is within the narrower ranges. However, in general the use of the overlap joints seems more promising. As seen from the data of optical microscopy and X-ray spectrum microanalysis, a silicide interlayer forms at the interface of the joint, where the content of silicon may exceed 10 wt.%. Structure of the seam is a solid solution with discrete precipitates of the phase with the increased silicon content along the grain boundaries. It is shown that in brazing under optimal conditions the strength value of the butt joints on low-carbon steel brazed by using filler alloy BrKMts 3-1 is 330–390 MPa. In the overlap joints the full strength value is achieved at an overlap equal to thickness of the materials joined. 11 Ref., 8 Figures.

Keywords: *welding, arc brazing, low-carbon steels, brazing filler alloy, shielding atmosphere, spreading of brazing filler alloy, coating, strength of joints*

Brazing is one of the most important technological processes of modern production. Rapid development of different industries resulted in its wide application first of all in motor car construction and in other sectors where it is necessary to join structures of thin-sheet materials, including those having protective coatings (zinc, aluminium, etc.). This can be explained by the fact that brazing as a process of formation of joints on materials is performed at a temperature below the melting point of a material being brazed.

Brazing, along with welding, is now one of the most common methods for production of permanent joints. A wide variety of the technological tasks makes it necessary to use different heating methods for brazing, the arc being among the most promising heat sources for production of the brazed joints. At present the methods of brazing using arc heating are applied for joining assemblies of thin-sheet billets, including the galvanised ones, e.g. car bodies [1–11]. However, some methods of high-temperature arc brazing, and gas-shielded tungsten-electrode arc and plasma brazing in particular, are little studied as yet.

The purpose of this study was to investigate the capabilities of arc brazing of low-carbon steels by using standard Cu-base alloy BrKMts 3-1 as a brazing filler alloy.

The special bench was prepared to conduct experiments. The bench comprised Kemppi argon-arc welding device Master TIG MLS 2300, 0.8–1.6 mm diameter wire feeder with gradual adjustment of the feed speed in a range of 0–130 mm/s (468 m/h), and device for moving the torch at a speed of 0.5–25.0 mm/s (90 m/h). Filler wire was fed to under the arc, i.e. it was not alive, which widened the ranges of adjustment of the arc brazing parameters.

To conduct the experiments, the above filler alloy was used in the form of the 1.2 mm diameter wire. Liquidus temperature of the alloy was 1020 °C. Specimens of steel 08kp (rimmed) measuring 150 × 60 × 1 mm in the horizontal position were used as substrates. The effect of heat input, gap, pulse duration and filler alloy feed speed on the weld parameters was investigated.

Naturally, it was interesting to determine how the heat input changed in transition from welding to arc brazing. As a starting point, it should be noted that parameters of welding of such a specimen in the shielding atmosphere of argon by using 1.2 mm diameter wire Sv-08G2S were as follows: $I = 100$ A, $U = 10.8$ V, $v_w = 22.7$ m/h, and $v_f = 10$ mm/s.

The effective power of the arc was around 750 J/s, and heat input was approximately 1250 J/cm. It might be expected that in a case of using metal with a considerably lower melting point less energy would be required for formation

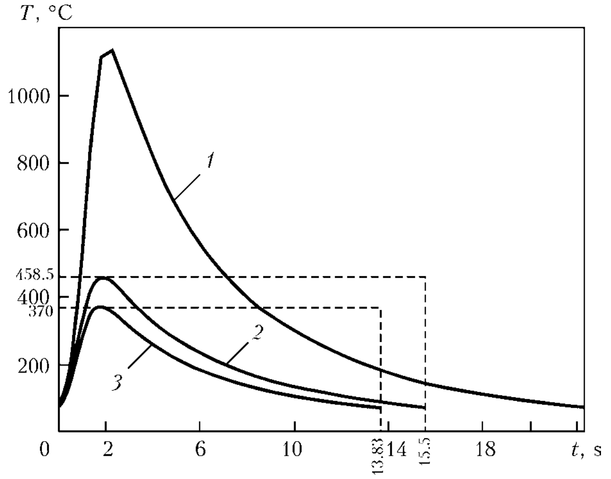


Figure 1. Thermal cycle of arc welding and brazing of steel 08kp at different process parameters: *1* — welding at $I = 100$ A, $U = 10.8$ V, $v_w = 22.7$ m/h, $v_f = 10$ mm/s; *2* — brazing at $I = 60$ A, $U = 9.5$ V, $v_b = 22.7$ m/h, $v_f = 15$ mm/s, $\delta = 0.4$ mm; *3* — brazing in pulsed mode at $I_{pulse} = 100$ A, $I_{pause} = 10$ A, $U = 10.2$ V, $v_b = 22.7$ m/h, $v_f = 6$ mm/s, $\nu = 5$ Hz, $\tau_{pulse} = 30$ %, $\delta = 0.04$ mm

of the joint. Indeed, in arc brazing the heat input was approximately 625 J/cm ($I = 60$ A, $U = 9.5$ V, $v_b = 22.7$ m/h, $v_f = 15$ mm/s). The value of the heat input can be decreased due to using the pulsed mode. For instance, when brazing was performed in mode 3 (Figure 1), the heat input was about 416.7 J/cm.

Calculations were made by using the known formulae to evaluate changes in heat input in transition from welding to arc brazing. The ratio of thermal cycles at a point located at a distance of 0.6 mm from the seam centre is shown in Figure 1.

It follows from the given data that transition from welding to arc brazing allows a substantial decrease in heat input and, hence, reduction of the probability of burns-through and distortions in the process of formation of the joints.

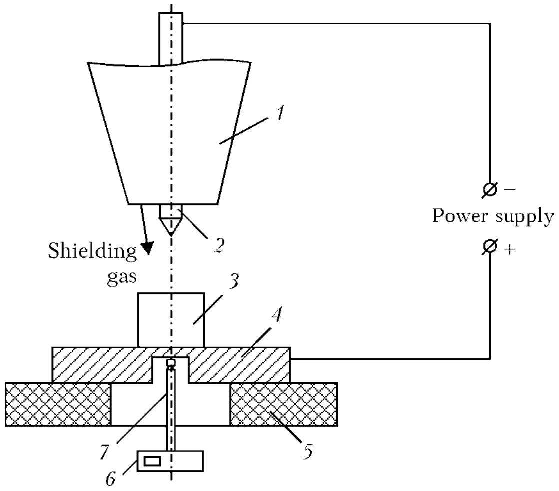


Figure 2. Schematic of the experiment on spreading of filler alloy under the arc heating conditions: *1* — nozzle; *2* — tungsten electrode; *3* — filler alloy charge; *4* — substrate; *5* — insulator; *6* — temperature recorder; *7* — thermocouple

Obviously, the data on behaviour of filler alloys under the arc heating conditions are lacking. In particular, no generally accepted procedure for investigation of the spreading process under the considered conditions is available. Therefore, we used the known recommendations, which were adapted to arc heating (Figure 2).

The experiments on wetting of steel 08kp were conducted in compliance with GOST 23904–79 «Determination of the Surface Area of Spreading of Brazing Filler Alloy». The specimens measuring 40 × 40 × 1 mm and the charges of filler alloy BrKMts 3-1 with a diameter of 4 mm (0.42 g in weight) were made for these experiments. A chromel-alumel thermocouple was used to monitor the temperature. The thermocouple was welded to a specimen to form a hot end. The temperature was controlled by using the TRM-202 instrument. Argon, helium and a mixture of Ar + 10 % H_2 were used as shielding gases. A filler alloy charge was placed strictly at the substrate centre to provide its uniform heating. The distance from the electrode tip to the charge was 2 mm.

The temperature of the wetting process was limited, it being 30 °C higher than the liquidus temperature of brazing filler alloys, i.e. for filler alloy BrKMts 3-1 it was 1050 °C. The wetting experiments were carried out at the direct and alternating currents with different pulse shapes. The resulting deposited beads were photographed, and the photos were processed on the computer by using the AutoCard 2002 software.

As seen from Figure 3, the spreading area strongly depends on the composition of a shielding atmosphere. The best results were achieved

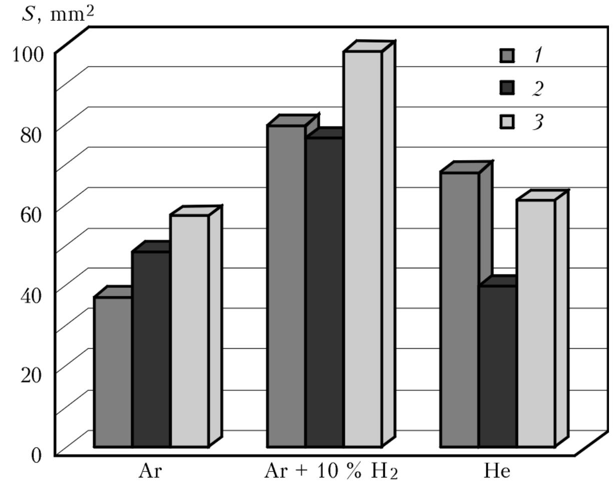


Figure 3. Diagrams of the area of spreading of filler alloy BrKMts 3-1 on steel 08kp depending on the shielding atmosphere and kind of the current: *1* — DC; *2* — AC (sinusoidal); *3* — AC with rectangular pulse shape

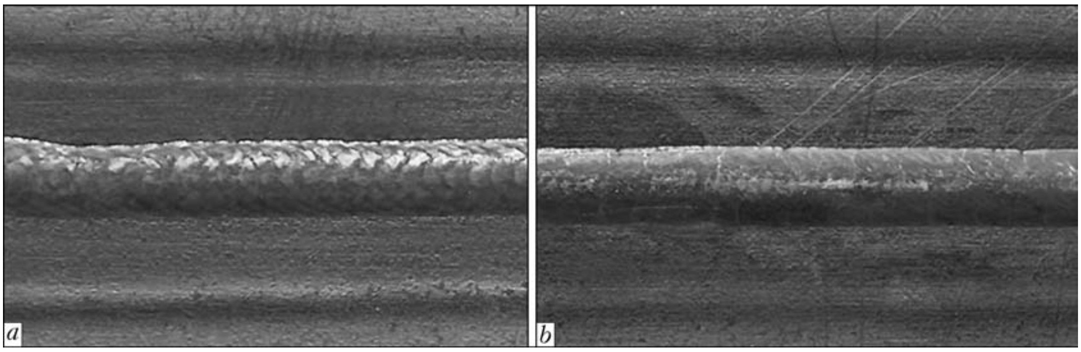


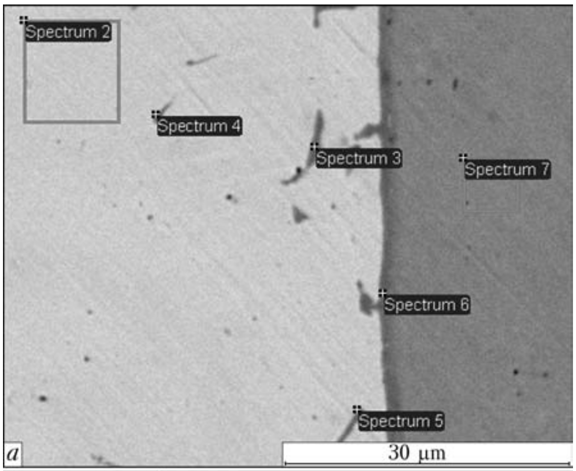
Figure 4. Appearance of the seams on butt joints brazed with filler alloy BrKMts 3-1 at different process parameters: *a* — I_{pulse} = 100 A, I_{pause} = 10 A, U = 10.1 V, ν = 5 Hz, τ_{pulse} = 30 %, v_{b} = 22.7 m/h, v_{f} = 6 mm/s, Q = 416.7 J/cm; *b* — I_{pulse} = 100 A, I_{pause} = 10 A, U = 10.3 V, ν = 10 Hz, τ_{pulse} = 30 %, v_{b} = 22.7 m/h, v_{f} = 10 mm/s, Q = 525 J/cm

in a mixture of argon with hydrogen. Moreover, the spreading area grew with increase in the electrode diameter.

From the practical standpoint, the use of helium is hardly expedient in view of its high cost, whereas it is worthwhile to pay attention to the mixture of argon with hydrogen as a promising shielding atmosphere.

Good formation of the butt and overlap joints was achieved by using the above brazing filler alloy. No spattering at all was observed in brazing of the butt joints under optimal conditions, and the seams had a smooth surface. Good formation of the brazed seams can be provided at different combinations of the arc brazing parameters, including in the pulsed mode (Figure 4). However, the integral criterion of quality of the seams is heat input. Variations of the gap within 0.2–0.6 mm in brazing of the butt joints had just a negligible effect on quality of the seams.

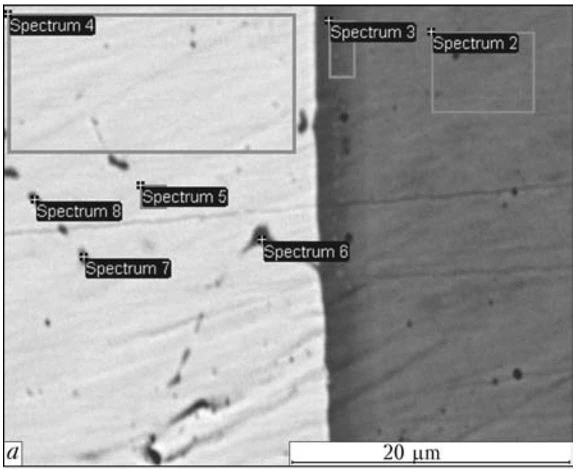
Examinations of microstructure of the joints brazed at different process parameters showed that in all the cases in brazing using filler alloy BrKMts 3-1 a clearly etchable interlayer formed at the interface of the joints, this interlayer looking light on a non-etched section, i.e. it had increased hardness. As the filler alloy contains



Spectrum No.	Chemical composition, wt.%			
	Si	Mn	Fe	Cu
2	3.87	1.13	0.89	94.12
3	12.93	2.74	40.30	44.02
4	14.74	10.15	32.33	42.78
5	10.29	1.47	47.66	40.58
6	12.04	0.83	78.91	8.21
7	0.16	0.24	99.47	0.13

b

Figure 5. Microstructure of interface of the joint on steel 08kp brazed with filler alloy BrKMts 3-1 at the following process parameters: I = 19 A, U = 8.9 V, v_{b} = 7.2 m/h, v_{f} = 2 mm/s, base metal thickness — 1 mm, filler wire diameter — 1.2 mm (*a*), and chemical composition of metal at the sampling locations (*b*)



Spectrum No.	Chemical composition, wt.%			
	Si	Mn	Fe	Cu
2	0.15	0.26	99.11	0.48
3	10.19	0.67	84.91	4.24
4	2.41	0.92	2.53	94.13
5	3.01	0.93	1.63	94.44
6	4.93	1.26	17.32	76.50
7	3.90	1.13	4.23	90.74
8	3.43	1	2.38	93.19

b

Figure 6. Microstructure of interface of the joint on steel 08kp brazed with filler alloy BrKMts 3-1 at the following process parameters: I = 30 A (DC), U = 10.8 V, v_{b} = = 2 mm/s, v_{f} = 2 mm/s, base metal thickness — 1 mm, filler wire diameter — 1.2 mm, gap — 0 (*a*), and chemical composition of metal at the sampling locations (*b*)

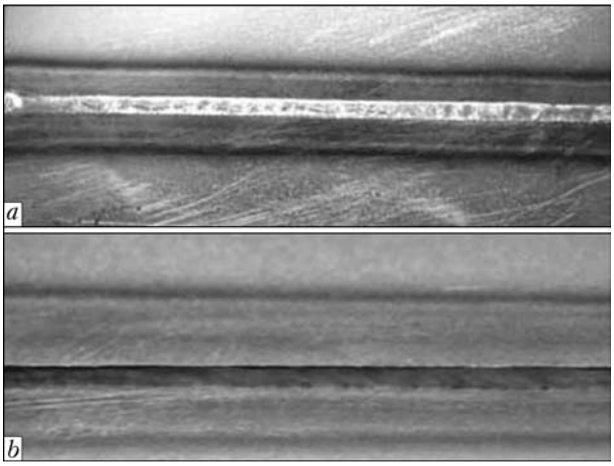


Figure 7. Appearance of the overlap joints made by arc brazing at the following process parameters: I_{pulse} = 100 A, I_{pause} = 10 A, U = 10.2 V, ν = 5 Hz, v_b = 22.7 m/h, v_f = = 6 mm/s, τ_{pulse} = 60 %: *a* — straightforward seam; *b* — reverse seam

3 wt.% Si, we assumed that it was silicide. Examinations using scanning electron microscope CamScan equipped with energy-dispersive spectrometer Energy-200 were carried out to generate data on a specific chemical composition of this interlayer.

Microstructure and results of X-ray spectrum microanalysis of the seam brazed at heat input of 591.7 J/cm are shown in Figure 5. The base metal and filler alloy preserved their initial composition practically without any change. However, the phase containing an increased amount of silicon — up to 12 wt.% solidified along the seam (at the joint interface), and this really was silicide (see Figure 5, spectrum 6). Moreover, the phase containing approximately 10–15 wt.% Si precipitated in the seam along the grain boundaries of the base metal (see Figure 5, spectra 3–5).

As heat input was increased approximately to 1125 J/cm, the width of the silicide interlayer grew (Figure 6), although the phase composition hardly changed.

The experiments on brazing of the overlap joints were carried out with allowance for the data obtained in brazing of the butt joints on low-carbon steel 08kp. As noted above, to produce the quality butt joints it was necessary to provide heat input within 416.7–583.3 J/cm. For the overlap joints this level of heat input turned out to be insufficient. The good straightforward (Figure 7, *a*) and reverse fillets (Figure 7, *b*) formed with a rise in heat input due to increase in the pulse duration approximately by 70 %.

It should be noted that the overlap joints are most characteristic of brazing, and it is reasonable to suppose that they will continue to be the key type of the joints used in industry.

Strength of the butt joints on low-carbon steel brazed with filler alloy BrKMts 3-1 was (with the removed reinforcement) 330–390 MPa. In the as-brazed state the rupture occurred in the base metal. The full strength value in the overlap joints was achieved at an overlap equal to thickness of the materials being joined.

As note above, the given experimental results on arc brazing of low-carbon steel were obtained by using the up-to-date equipment possessing wide capabilities in terms of control of the arc process. Therefore, transition to application of microplasma heating using the MPU-4 unit turned out to be ineffective, and the attempts to achieve the same results at the same heat input failed. With increase in heat input to 1275 J/cm the good formation of the seam on the arc side was achieved at a gap of 0.2, 0.4 and 0.6 mm. However, the reverse fillet formed only at a gap of 0.6 mm. Moreover, the gap was hardly filled in some places (Figure 8).

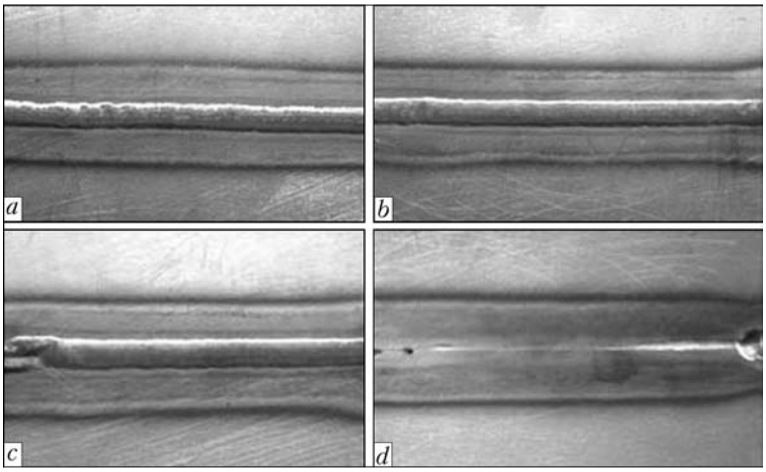


Figure 8. Appearance of the seams brazed at the following process parameters: I = 28 A, U = 15.2 V, v_b = 7.2 m/h, v_f = 4 mm/s, gap — 0.2 (*a*), 0.4 (*b*), 0.6 (*c*) and 0.6 (*d*) mm (reverse fillet)

By analysing the data obtained, it should be noted that increase in heat input within the investigated ranges did not give the expected effect in brazing of the butt joints at low currents: the amount of metal in the seam on the arc side increased gradually, whereas the reverse seam formed only at a sufficiently big gap (0.6–0.8 mm), i.e. the lower edge of the joint remained non-heated, and the filler alloy could not fill up the gap. In brazing of the overlap joints the conditions for formation of the joints were more favourable, the range of the favourable conditions being widened. For example, an attachment was made to the above Master TIG MLS 2300 unit, which allowed this process to be controlled over a wide power range. As a result, it made it possible to obtain the results close to those typical of using arc heating.

Conclusions

1. Filler alloy BrKMts 3-1 investigated in this study spreads well on steel 08kp and forms sound butt and overlap joints without a marked dilution of the base metal in the liquid filler alloy.

2. The most favourable shielding atmosphere for arc brazing using the investigated filler alloy is a mixture of argon with 10 wt.% of hydrogen.

3. The use of alloys with a melting point that is much lower than that of steel allows the level of heat input to be radically changed in production of permanent joints. For instance, in brazing of 1 mm thick plates the level of heat input is approximately 416–625 J/cm. The heat input required for welding of the similar specimens is 1166–1250 J/cm.

4. Strength of the butt joints on low-carbon steel brazed with filler alloy BrKMts 3-1 (with the removed reinforcement) is 330–390 MPa. In the as-brazed state the rupture occurs in the base metal. In the overlap joints the full strength value is achieved at an overlap equal to thickness of the materials being joined.

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