DOI: http://dx.doi.org/10.15407/tpwj2019.07.05

PLASMA-ARC BRAZING OF STEEL 08kp (rimmed) BY USING BRAZING FILLER METALS OF Cu–Mn–Ni–Si SYSTEM

S.V. MAKSYMOVA and **I.V. ZVOLINSKYY**
E.O. Paton Electric Welding Institute of the NAS of Ukraine
11 Kazimir Malevich Str., 03150, Kyiv, Ukraine. E-mail: office@paton.kiev.ua

The paper presents the results of high-temperature differential thermal analysis of brazing filler metals based on Cu–Mn–Ni–Si system, metallographic examination of brazed joints of 08kp steel, made with application of plasma-arc heating. It is shown that at silicon alloying of Cu–Mn–Ni system the alloy melting temperature decreases and its wetting ability increases. X-Ray microanalysis revealed that brazed weld of 08kp steel joints consists of copper-based solid solution and dispersed precipitates of a silicon-enriched phase. An iron-based phase with higher concentration of silicon and manganese is formed on brazing filler metal–base metal interphase as a thin band (along the brazed weld), that is indicative of appearance of silicides of a complex composition. Brazed joint strength becomes higher with increase in nickel concentration in the alloy and is equal to 367 MPa (average value). 9 Ref., 2 Tables, 6 Figures.

Keywords: *plasma-arc brazing, brazing filler metal, microstructure, spreading, solidus and liquidus temperature, strength*

Brazing together with welding is one of the most widespread methods for producing permanent joints. The most important advantage of brazing is the formation of a brazed weld at a temperature below the point of autonomous melting of materials being joined. During brazing, different sources of heating are used, including concentrated ones like arc, plasma, etc. At present, the technological process of brazing by plasma-arc heating is used in the manufacture of different parts and components in the instrument-making industry, automotive industry, electrical engineering, aircraft industry, etc. [1–3].

This paper presents the results of high-temperature differential thermal analysis and the initial structure of brazing filler metals of the Cu–Mn–Ni–Si system. It shows the peculiar features of microstructure formation of brazed joints of structural carbon steel 08kp using plasma-arc heating.

Experimental alloys were produced by casting on a «cold» substrate using arc heating. The solidus and liquidus temperatures were determined using high-temperature differential analysis (HTDA) in helium environment. Plasma-arc brazing of butt joints of the sheet carbon steel 08kp was carried out at a special laboratory bench. As a heating source, the installation KEMPPI Master TIG MLS 2300 AC/DC, applied for argon-arc welding, and the unit for ignition of pilot arc were used. The spreading of brazing filler metals on the base metal substrate in a shielding medium of argon, as well as in a mixture of argon + 10 % hydrogen was carried out.

Specimens were cut out of the produced brazed joints for manufacture of microsections and carrying out metallographic and micro X-ray spectral analysis using a scanning electron microscope TescanMira 3 LMU, equipped with an energy-dispersed spectrometer Oxford Instruments X-max of 80 mm^2 under the control of software package INCA. The locality of measurements was up to 1 μm. The distribution of elements and filming of microstructures were carried out in back-scattered electrons (BSE), which allow examination of microsections without chemical etching.

As the basic brazing filler metal Cu–23.5Mn–9Ni [4] was used, which has a solidus temperature of 920 °C and a liquidus temperature of 955 °C. However, when studying spreading on carbon steel 08kp under the conditions of arc heating, it showed unsatisfactory result. In order to improve spreading of brazing filler metal, alloying with silicon was used (1–3 wt.%), which is a universal depressant for many brazing filler metals [5–8].

The analysis of the results of high-temperature differential thermal analysis of experimental brazing filler metals, containing a high concentration of nickel, showed that the introduction of 3 wt.% of silicon reduces the solidus temperature to 903 °C and the liquidus temperature to 949 °C. A further decrease in the liquidus temperature by about 56 °C (899 °C) became possible at the lower nickel content.

The structure of brazing filler metals of the system Cu–Mn–Ni–3Si is two-phase: solid solution dendrites, along the boundaries of which the phase,

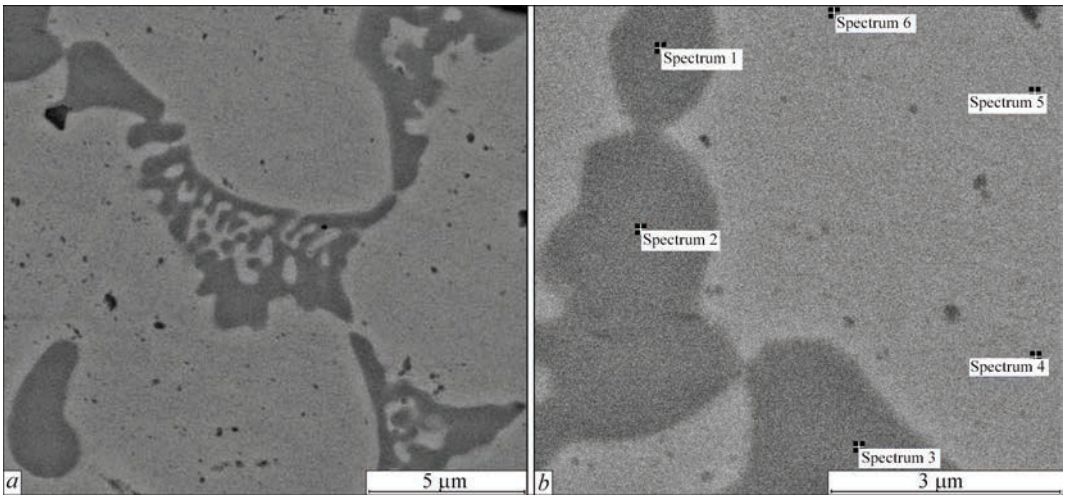

Figure 1. Microstructure (*a*) and investigated areas (*b*) of brazing filler metal of Cu–Mn–Ni–3Si system in the initial cast state

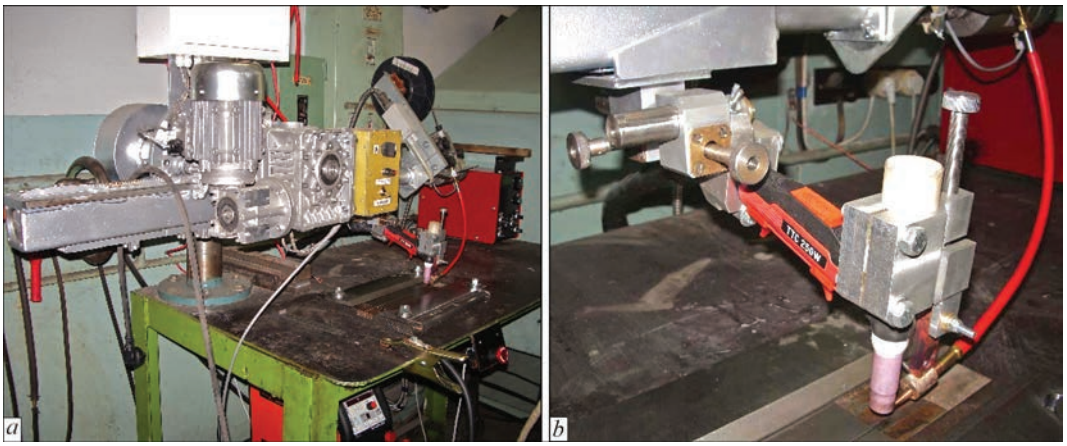

Figure 2. Special bench for plasma-arc brazing (*a*) and unit for torch displacement (*b*)

enriched with silicon, crystallizes (Figure 1, *a*, *b*, Table 1).

The local X-ray spectral microanalysis determined the discrete concentration of silicon in the solid solution and showed that it does not exceed 1.95 wt.%, while in the phase that precipitates along the grain boundaries, its concentration rises to 7.9 wt.% (Figure 1, *b*, Table 1).

In study of the brazing filler metals spreading, a special laboratory bench was used (Figure 2, *a*), which allows moving and fixing the torch, as well as the base metal substrate (Figure 2, *b*).

Brazing filler metals were applied in a cast state, the amount of brazing filler metal, distance from the electrode end to brazing filler metal and temperature were controlled. The thermocouple was fixed on the back side of the substrate. The brazing filler metal was heated at a direct current in a shielding argon medium and in a mixture of argon with hydrogen. The

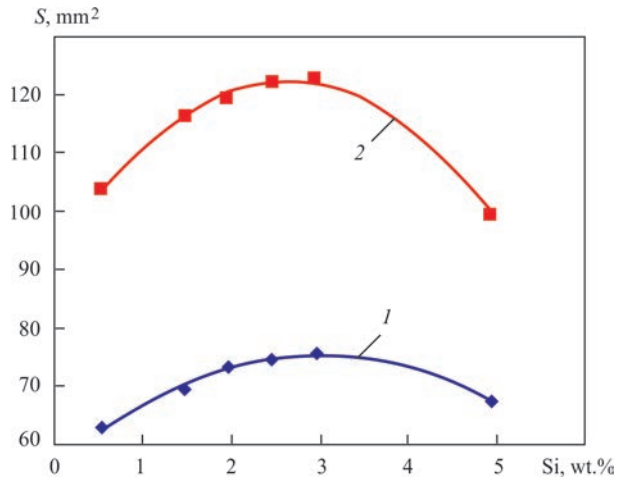

Figure 3. Dependence of area of brazing filler metal spreading on the content of Si at arc heating in argon (*1*) and a mixture of argon with hydrogen (*2*)

Table 1. Distribution of chemical elements in separate phases in brazing filler metal Cu–Mn–Ni–3Si

Spectrum number	Chemical elements, wt.%			
	Si	Mn	Ni	Cu
1	7.40	28.68	3.52	60.40
2	7.90	30.30	3.36	58.44
3	7.55	29.83	4.06	58.56
4	1.95	12.61	0.38	85.06
5	1.72	12.22	0.46	85.61
6	1.91	12.28	0.59	85.22

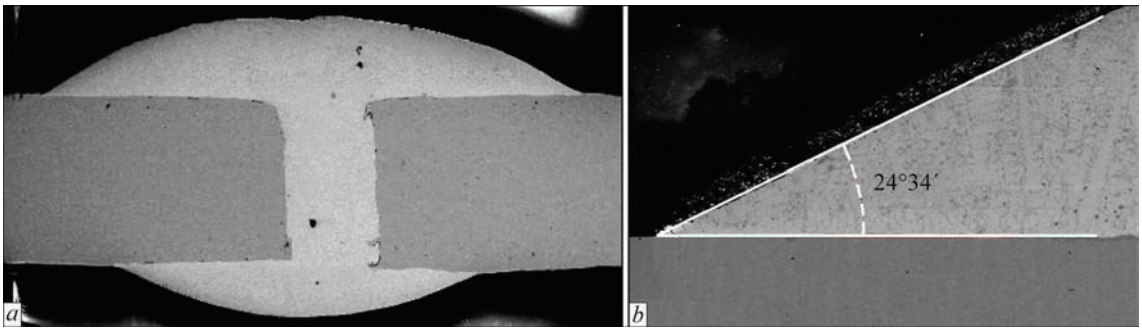

Figure 4. General view of brazed joint (*a*), wetting angle (*b*) of carbon steel 08kp produced by brazing filler metal Cu–Mn–Ni–3Si in the conditions of plasma-arc heating

experiments on spreading of brazing filler metal under arc heating (TIG) in argon showed that the adding of silicon into the alloy of the Cu–Mn–Ni system significantly increases the area of brazing filler metal spreading. Its most intensive effect is observed when the content of silicon is 2–3 wt.% (Figure 3). The further increase in the silicon content to 5 wt.% leads to a decrease in spreading area.

A similar dependence is observed during the study of brazing filler metal spreading in the shielding mixture of argon with 10 % hydrogen, but spreading area increases significantly (Figure 3, curve *2*). This dependence can be explained by the fact that hydrogen is an active reducing agent.

On the basis of experimental alloys the brazing filler metals in the form of flux-cored wires of 2.9 and 3 mm diameter, respectively, were manufactured, which were used to carry out plasma-arc brazing of specimens of steel 08kp (in argon). The feeding of brazing filler metal in the form of a wire was carried out manually.

During optimizing the technological process of plasma-arc brazing, the optimal modes (I = 50 A, U = = 14 V) were established, which provide a good formation of bead of a brazing filler metal, wetting of base metal and the value of a contact angle of 24°34′ (Figure 4, *a*, *b*).

The formation of direct and reverse fillets is observed. Examinations of the weld microstructure in brazed joints, produced using two brazing filler metals, did not reveal any significant differences. Most of the section is occupied by the grains of a solid solution based on copper, containing a small amount of silicon (1.38 wt.%). Along the grain boundaries of the solid solution, the copper-based phase, enriched in silicon (up to 7.93–8.45 wt.%) is precipitated, which confirms the presence of silicides (Figure 5, Table 2).

In both cases, on the boundary interface brazing filler metal–base metal, a diffusion layer based on iron enriched with silicon (up to 10.23–13.08 wt.%) and manganese (13.58–15.92 %) solidifies, which indicates the formation of iron silicides of a complex composition (Figure 4, Table 2) and well correlated with the state diagrams of metallic systems. Thus, in accordance with the binary diagrams of state of the iron-silicon system state, the limiting solubility of silicon in γ-iron at 1150 °C is 3.84 at.%. With the temperature drop, it decreases, which leads to the formation of silicide phases [9]. The solubility of copper in iron is limited and also decreases with the drop in temperature. Such structural features of the diagrams of state of iron-silicon and copper-silicon metallic systems contribute to the fact, that during brazing the iron silicides are formed at the interface.

Table 2. Chemical composition of the structural components of the brazed weld

Spectrum	Chemical composition, wt.%				
	Si	Mn	Fe	Ni	Cu
1	1.38	13.05	0.64	0.62	84.31
2	7.93	31.16	1.02	2.11	57.77
3	8.45	31.44	1.73	4.76	53.61
4	12.68	15.70	66.73	2.20	2.69
5	12.20	15.35	62.80	2.08	7.57
6	10.32	13.58	54.98	1.95	19.16
7	13.08	15.92	67.06	2.15	1.80

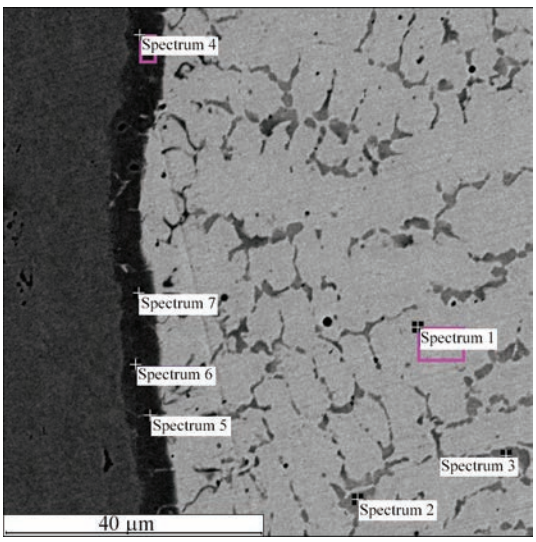

Figure 5. Boundary interface of the joint made by brazing filler metal of the Cu–Mn–Ni–3Si system using plasma-arc heating

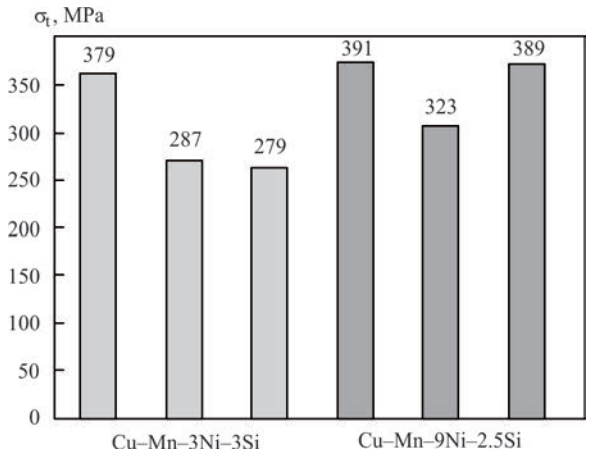

Figure 6. Rupture strength of brazed butt specimens of carbon steel 08kp

As is evidenced by the results of mechanical rupture tests of butt flat brazed specimens, produced using plasma-arc brazing and the brazing filler metal Cu–Mn–Ni–3Si, the fracture occurs along the weld. A large scattering in strength values from 279 to 379 MPa is observed (Figure 6), the average values of strength are approximately 93 % of the base metal strength (315 MPa). The increase in nickel content in brazing filler metal to 9 wt.% provides higher and more stable strength values (Figure 6). Specimens are fractured in base metal in the heat-affected zone, the average values of rupture strength increase to 367 MPa.

Based on the obtained results, a choice can be made in favor of the second brazing filler metal, which provides higher strength values and a degree of data stability.

Conclusions

Alloys of the system Cu–Mn–Ni–Si with different content of nickel and silicon were studied, melting intervals were determined, and it was shown that decrease in the liquidus temperature by about 56 °C (899 °C) provides a reduction in the nickel concentration to 3 %.

It was found that when alloying the brazing filler metals of the Cu–Mn–Ni system with silicon, the area of spreading increases. The optimum concentration of silicon does not exceed 3 wt.% In the structure of a brazed weld the dendrites of a solid solution based on copper and manganese are predominated, at the boundaries of which a phase with a higher mass fraction of manganese (31 %) and silicon (about 8 %) is located. An iron-based silicide containing manganese and silicon is formed along the brazing filler metal–base metal interface, with the content of the latter being 10.32–13.08 wt.%

It was established that an increase in the nickel content in brazing filler metal (up to 9 %) contributes to increase in strength values and their stability. Moreover, the fracture occurs in the base metal in the heat-affected zone, the average values of the rupture strength of brazed joints are 367 MPa, which is at the level of the base metal strength.

1. Knopp, N., Killing R. (2003) Hartlöten verzinkter Feinbleche mit dem Lichtbogen — sicher und wirtschaftlich (Teil 1). Solingen. *Der Praktiker*, **12**, 366–371 [in German].
2. Füssel, U., Schetzsche, V., Sziesb, U., Husner, J. (2002) Plasmalöten mit stromführendem Zusatzwerkstoff. *Ibid.*, **10**, 336–340 [in German].
3. Kallabis, M., Schwankhart, G. (2002) Plazmatron-technologie im Karosseriebau. *Blech Rohre Profile*, **4**, 42–45 [in German].
4. Pugh, C. (1970) *Die Verwendung von Ni–Mn–Lotes fur Plattierlotungen sowie das Verfahren zum Herstellen eines solchen Lotes*. FRG, Pat. 1284262 [in German].
5. Zhang, Q.K., Pei Yinyin, Weimin Long (2013) Investigations on formation mechanisms of brazing cracks at the austenitic stainless steel/filler metal brazing joint interfaces. *Acta Metallurgica Sinica — Chinese Edition*, 49(**10**), 1177–1184, October 2013, DOI: 10.3724/SP.J.1037.2013.00219
6. Davis, J.R. (Ed.) *ASM Specialty Handbook. Copper and Copper Alloys*, 276–302, DOI: 10.1361/caca P276.
7. Sejč, P., Kubíček, R. (2015) *MIG brazing of 304L type stainless steel using CuSi3 and CuSi3MnAl brazing wire*. Kovove Mater., **53**, 365–375, DOI: 10.4149/km 2015 5 365.
8. Jyrki Miettinen. (2003) *Thermodynamic description of the Cu–Mn–Ni system at the Cu–Ni side.* Calphad 27(**2**), 147–152, June 2003, DOI: 10.1016/j.calphad.2003.08.003.
9. (1997) *State diagrams of binary metallic systems*. Ed. by N.P. Lyakishev. In: Refer. Book, 3 Vol., Vol. 2. Moscow, Mashinostroenie [in Russian].

Received 22.04.2019