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Special features of technologies of arc welding thin-sheet components of Kh23Yu5 Chromal alloy

I E LAPIN, S N VLASOV and V I LYSAK
Volgograd State Technical University

Precision alloys of the iron–chromium–aluminium system (chromal) are used in the fabrication of resistance elements of rheostats and different heating devices. At the present time, the reconditioning of elements of this type, taken out of operation, by means of welding, is the important task in transport, engineering and other branches of industry. The characteristic special feature of the weldability of these alloys is their high susceptibility to overheating, caused by the presence of the single phase structure of the ternary α_3-solid solution, which does not undergo polymorphous transformations during heating and cooling, resulting in a large decrease in the mechanical properties of the weld it joins. In addition to this, the dense surface oxide film, consisting of more than 98 % of the Al_2O_3 aluminium oxide, prevents the melting of the welded edges and is also the reason for the formation of lack of fusion defects and nonmetallic inclusions in the weld metal.[1,2] The chromal resistance elements are produced in most cases in the form of strip with a thickness of 0.2–3.2 mm, and this also requires taking into account the technological special features of welding thin-sheet materials.

At the present time, welding of thin-sheet structures is carried out in many cases using argon-shielded TIG welding. In comparison with other methods, this welding method has a number of advantages which include universal nature, high technological properties, relatively simple procedure and easy availability of liquid iron.

In this work, investigations were carried out into the possibility of using this welding method for welding thin-sheet resistance elements of Kh23Yu5 alloy with a thickness of 0.8 mm. Welding was conducted using EVL electrodes with a diameter of 2 mm, with the working section sharpened to a cone with a tip angle of 20–25°, root face 0.3 mm. The design of assembling-loading equipment ensured the alignment and securing of the welded edges and also gas shielding of the reverse side of the welded joint. The flow rate of the shielding gas through the torch was 5 l/minute, and 2.5 l/minute on the reverse side of the welded joint. No filler materials were used. The quality of the welded joints was evaluated on the basis of metallographic examination at a magnification of 10 and also by examination of macro- and microsections. The mechanical properties of the welded joints were determined by the bend and tensile tests in accordance with GOST 6996, 11701 and 14019.

The experimental results show that the presence of the lack of fusion defects is associated with the relatively low concentration of energy in the heating spot, which does not make it possible to utilise completely the mechanism of thermal cleaning of the metal surface. The removal of the oxide film from the weld edges in this case is possible as a result of the flow and mixing of the metal of the weld pool which is possible only if the weld pool is very large. For example, in butt welding sheets without edge preparation, with a welding speed of 6 m/h, complete penetration is obtained at a welding current of 45 A. At a welding speed of 18 m/h, the required current increases to 60–65 A. Welding in these conditions results in the formation of a very large welded joint, characterised by low ductility properties: the bend angle of the specimens does not exceed 25–30°, and σ_B = 580–590 MPa (for the parent metal these values are 180° and 830 MPa, respectively).

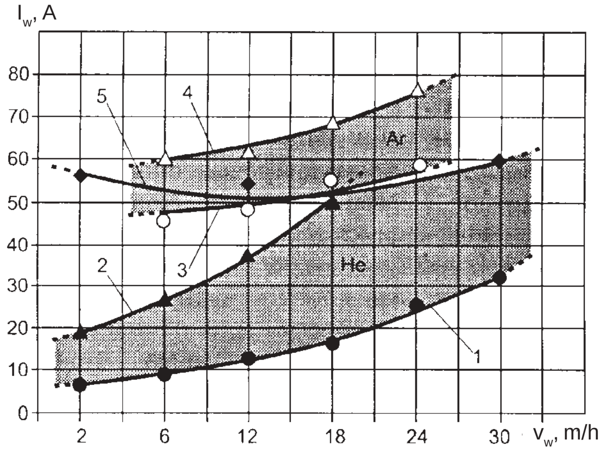
The directional flow of metal in the case of smaller weld pools can be assured by the preparation of the welded edges. However, if melting is incomplete, the welded joint is characterised by the formation of an internal stress concentrator decreasing the mechanical properties. To ensure the complete melting of the prepared welded edges, the welding current must be increased to 70–75 A. The presence of the convex region in this case leads to the failure of the specimens in the weld zone and results in a slightly higher bend angle (37–49°).

The structure of the metal of the produced welded joint is characterised by the presence of large columnar crystals, the structure of the weld zone by rapid grain growth. However, the grain growth resulting from the absence of phase transformations is not a direct explanation of the low quality of the welded joints. According to the data published in Ref. 1, the welded joints in thin-sheet high-chromium ferritic steels with a single-phase structure are characterised on the whole by a high level of the mechanical properties; the effect of superheating the metal in contrast to thick-plate welded joints is less marked. The main reason for the low mechanical properties of the welded joints in Kh3Yu5 alloy is the presence of the oxide film on the surface of metal and, consequently, it is necessary to produce a larger weld pool in order to ensure stable and complete penetration.

Thus, argon-shielded welding using a DC arc does not make it possible to ensure the required quality of welded joints when welding thin-sheet elements reduced from the Chromal type alloys. The commercial method of removal of the oxide film in TIG welding, i.e. the application of alternating current, also does not ensure the formation of the welded joints of the required quality because of the low special stability of the arc (as a result of rapid wandering of the cathode spot) leading to the formation of a very wide welded joint. Because of these reasons, the Chromal alloys should be welded by the methods ensuring the maximum concentration of the thermal energy supplied into the weld metal, and also by a decrease in the degree of superheating and efficient thermal cleaning of the welded metal.

One of the methods of increasing the concentration of energy in the heating spot in TIG welding is the variation of the composition of the shielding gas. For example, the application of helium results in compression of the arc column as a result of the rapid removal of energy caused by the high heat conductivity of the gas. This is accompanied by a decrease in the effective diameter of the current-conducting channel of the arc column leading to an increase in the current density in the anode spot and, consequently, an increase in the concentration of the energy supplied to the anode.[3]

Experiments with helium-arc welding of resistance elements were carried out in the conditions identical with argon-shielded welding. The consumption of argon was 10–12 l/minute. The reverse side of the welded joint was shielded with argon. The ranges of the permissible conditions of welding of resistance elements of Kh23Yu5 alloy with a thickness of 0.8 mm in shielding gases are presented in Fig. 1. It may be seen that the range of the permissible conditions of helium-arc welding is well below the identical region determined for welding in argon. The criterion for the determination of the lower boundary of the weldability range was the complete penetration of the weld edges and the absence of lack of fusion defects and also oxide films in the weld root. In welding in helium, the lower boundary (Fig. 1, curve 1) corresponds to the range of variation of welding current from 8 to 32 A with an increase in the welding speed from 2 to 30 m/h. The



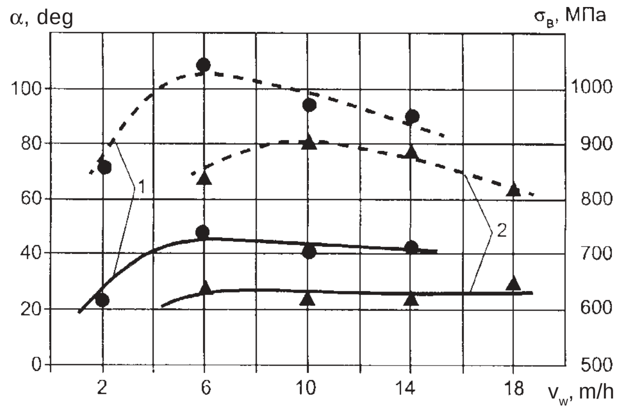
1 *The range of permissible conditions of TIG welding in a shielding gas of resistance elements made of Kh23Yu5 alloy with a thickness of 0 .8 mm.*

corresponding boundary for welding in argon (Fig. 1, curve 3) is determined by the welding current of I = 45–60 A.

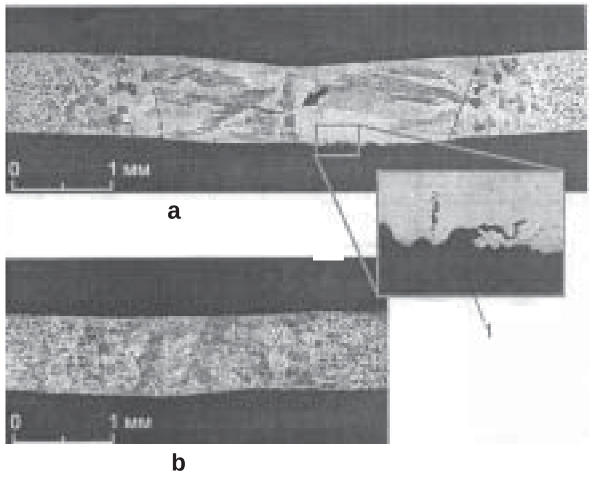
To determine the upper boundary of the range of permissible conditions, experiments were carried out using two criteria: the absence of burn-through and the correspondence of the width of the weld to the value determined in accordance with GOST 14771. For the welded joint of the type C2, at a thickness of the welded elements of 0.8 mm, the maximum permissible width of the welded joint was 6 mm. In welding in helium, the permissible range of the welding conditions was 2–12 m/h as regards welding speed, and 18–40 A as regards the maximum value of current (Fig. 1, curve 2). At a welding speed of 18 m/h or higher, burns form in the welded joint prior to the moment when the dimensions of the welded joint exceed the maximum permissible value. The welded joints produced by argon-shielded welding have the required dimensions at a current of 60–78 A in the range of variation of the welding speed of 6–24 m/h (Fig. 1, curve 4). Curve 5 in Fig. 1, which determines the boundary of formation of burns in the welded joint in welding in helium, is characterised by the presence of a minimum at a welding speed of 60–20 m/h. The small decrease in the maximum permissible welding current, detected in this case (not higher than 8–10 A), is evidently caused by the combined effect of various factors, such as the variation of heat input, the shape and geometrical diameters of the weld pool in relation to the welding speed.

In the experiments, it was not possible to produce high-quality welded joints in the elements at a welding speed exceeding 30 m/h. This was caused by the formation of burn-through even at reduced values of welding current. It should be mentioned that this fact does not contradict the literature data on the stability of the metal pool when welding thin-sheet materials. For example, it was shown in Ref. 4 that the condition for stability of the weld pool in thin metal is the small length of the pool which in turn is the function of the welding speed. Therefore, the welding of thin-sheet materials is possible only at a limited welding speed. In addition to this, the welding of resistance elements in the 'hard' conditions is not efficient because of the limited width of the strip (6–80 mm according to GOST 12766.2), complicating the control of the welding conditions at a short welding time and impairing the reproducibility of the welding results.

The characteristic dependences of the mechanical properties of the welded joints on the conditions of helium-arc welding of resistance elements are presented in Fig. 2. It may be seen that the mechanical properties are determined by the effect of welding current. The effect of welding speed on the ultimate tensile strength and yield limit is less marked. At the same time, the curve of variation of the bend angle has a distinctive maximum which is displaced to higher welding speeds with increasing welding current. After analysing the experimental data, it was possible to determine the optimum conditions of helium-arc welding resistance elements of the investigated alloy: the welding current 12–14 A, welding speed 5–7 m/h. The welding in these conditions results in a tensile strength of the welded



2 *The dependence of the ultimate tensile strength (solid line) and the dent angle (broken line) of the welded joints on the conditions of helium-arc welding: 1,2) I of 14 and 22 A, respectively.*



4 *Structure (×25) of a welded joint reduced by argon- and helium-shielded arc welding.*

joints not lower than 700 MPa at a bend angle of 95–110° (84 and 60 % of the properties of the parent metal, respectively).

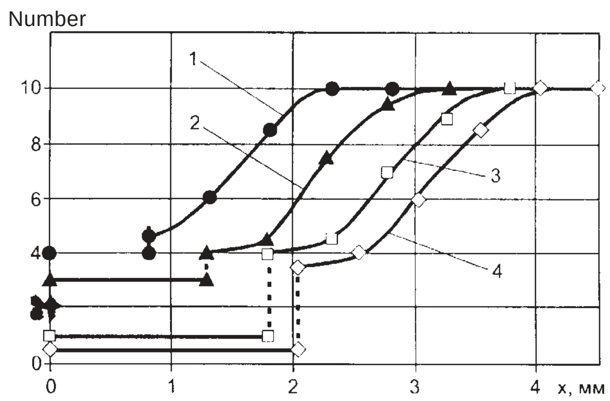
These large differences in the mechanical properties of the welded joints produced in argon and helium may be explained on the basis of analysis of the results of metallographic examination. The dependence of the grain size on the distance from the longitudinal axis of the welded joints and the welding conditions is presented in Fig. 3. The structure of the metal of the weld zone of the welded joints in welding in argon and helium is characterised by a rapid grain growth (the grain size number in the vicinity of the fusion boundary is 3–4, with the grain size number of the parent metal being 9–10). However, the structure of the weld zone in both cases is identical. The differences in the grain size number in the weld metal do not exceed 2 units, and the width of the weld zone changes only slightly, in the range 1.5–2 mm.

The largest differences in the structure are found directly in the metal of the welded joints. The structure of the weld metals, produced by argon-shielded welding, is characterised by the presence of large columnar crystals (Fig. 4 **a**). In addition to this, the welded joints contain a distinctive boundary of transcrystallisation, formed during collision of the growing dendrites (indicated by the arrow in Fig. 4). It should be noted that the failure of the specimens in mechanical tests takes place in the majority of cases in this zone. The welded joints also contain defects associated with incomplete removal of the oxide film (Fig. 4 **a**, position 1). The complete removal of the film is possible by increasing welding current. However, this results in even larger grain growth of the structure and the width of the weld increases to 4.2–7.8 mm.

The welded joints produced in helium have a finer and equiaxed structure (Fig. 4 **b**). The width of the welded joints changes in the range from 1.6 mm at a current of 9 to 5.4 mm at 22 A. The sagging of the welded joint is small and does not exceed 0.05–0.08 mm.

One of the requirements on the welded resistance elements is that the specific electrical resistance of the elements should correspond to the nominal resistance. Measurements of the specific electrical resistance were taken in accordance with GOST 7229 and 12 766.2 in both the normal conditions and when heating the specimens to a temperature of 800 °C bypassing electric current. Current density was 10 A/mm^2. The deviation of the specific electrical resistance of the specimens with the welded joints from the nominal value in all cases did not exceed the value recommended by GOST 127 66.2 (± 7 %) and did not exceed 2.5 %.

The results were used in the development of a technology of repair welding resistance elements of tramway accelerators produced from Kh23Yu5 alloy. At present, an experimental batch of the reconditioned elements has passed successfully the full-size tests at the Volgogradelektrotrans Company



3 *The dependence of the grain size on the distance from the weld axis: 1,2) Welding in helium, I_w of 9 and 14 A, respectively; 3,4) Welding in argon, I_w of 40 and 50 A, respectively.*

Conclusions

1 The welding of precision alloys of the Chromal type requires the application of methods and showing the maximum concentration of the thermal energy supplied into the weld metal in combination with the minimum holding time of metal and high temperatures.

2 When TIG welding these alloys, the acquired energy concentration is ensured as a result of the application of helium as a shielding gas so that it is possible to produce welded joints with the level of the mechanical properties greatly exceeding the identical parameter in welding in argon.

References

1 Kakhovskii N I: 'Welding stainless steels'. Publ Tekhnika Kiev 1968.

2 Marmorshtein L V: 'Iron–chromium–aluminium alloys'. Publ Metallurgizdat Moscow 1950.

3 Ivanova O N *et al*: 'The effect of the composition of the gas shielding medium on the current density in the anode spot of the welding arc'. *Avt Svarka* 1977 (1) 70.

4 Lebedev V K: 'The stability of the metal pool in welding thin metal'. *Avt Svarka* 1975 (6) 71.