Formation of a Seam Using Automatic Unsupported Argon Arc Welding with a Non-Consumable Electrode with Flux Pastes

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Abstract. It was demonstrated that applying the flux paste on the back side of the welded joint during welding low-alloyed steels provides control over the sizes of the root and its defect-free formation. It was found that the back bead width is vital to unsupported root formation of thin-walled articles for the considered welding modes.

1. Introduction
Modern production rates require high and consistent quality of the welded joints [1]. In terms of economy and performance for many constructions the most efficient and sometimes the only possible mode is series welding with unsupported formation of the root. Such joints are the least laborious.

The root of a welded joint is one of its most important areas. Efficiency of the whole welded joint depends on its quality [2]. Usually the root is welded manually, which requires high professional skills of the welder. Besides, for the purpose of the formation control the root is welded with a minimal amount of deposited metal, so the automatic welding cannot be used to fill the beads and the additional layers should be applied with manual arc welding. The welding efficiency is significantly decreased and the high-quality joint is not guaranteed [3].

The study of reasons for the defects of these joints reveals unacceptable deviations in the root dimensions as the main problem which results in poor penetration or a burn-through [4-10].

The form of the seam, performed with full penetration of edges according to the static equilibrium diagram [11-12], depends on the equilibrium condition of the concurrent forces on the weld pool (gravity, arc pressure and surface tension). Alteration of the weld pool volume, arc pressure, surface tension coefficient or melt surface curve radius, caused by various reasons should result in alteration in the main seam dimensions and, in particular, in its sagging both on the face and on the root [13].

2. Experimental part
This work studied how the main parameters of automatic argon arc welding with a non-consumable electrode influence the unsupported formation of the root weld. The studies were conducted on St3ps steel plates 3 mm thick. Welding variables: welding current 150-220 A, welding rate 5-25 m/h, arc length 2.0 mm. A tungsten electrode 4 mm in diameter with grind angle 45° was used. The circuit also included a digital multimeter OWON B35+, which recorded the arc voltage readings at different welding current.
3. Results and discussion

To find the calculated seam width in the work [14-15] the heat transfer diagram (figure 1) was used characterized with a linear heat source, moving with the rate over the unlimited plate. The area of heating up to temperature $T_{\text{max}}$ is a theoretically flat layer limited with the planes ±$y$, with parallel planes XOZ of movement of the linear source (figure 1).

The maximal temperature of the plate with no regard to the heat transfer:

$$T_{\text{max}}(y) = \frac{0.484q}{2\gamma V w c y d}$$

where 2y is the seam width, $T_{\text{max}}$ is the metal melting temperature, $c\gamma$ is volume specific heat.

The data obtained showed that the variation in the face width B1 (Figure 2, b, the dashed line) with respect to the welding current is fundamentally described with the equation (1).

During welding using the flux paste the seam width B1 is reduced (dashed line on Figure 2, b) compared to welding without it. This is, evidently, due to alteration in the arc energy characteristics (Table 1), in particular, in its length due to the weld pool sagging under action of gravity and weld pool weight.

**Table 1. The arc energy characteristics at welding with and without flux paste.**

| $I_{\text{arc}}$, A | $U_{\text{arc}}$, V | $q$, W |
|---------------------|-------------------|--------|
| without flux paste  | 150               | 180    | 200    | 150               | 180    | 200 |
| flux paste $Y_2O_3$ | 11.92             | 12.3   | 13.5   | 894               | 1107   | 1330 |

The inclination angle of the resulted dependences of the face width B1 on the welding current (figure 2, b, the blue line) is the same in all cases and demonstrates persistency (constancy) of its increase without regard to the environment parameters on the back side of the seam. Across the entire range of the current under study the width decreases at about 0.5 mm when $Y_2O_3$-based flux paste is used.

The situation is different on the back bead side. During welding without the flux paste the back bead width B2 (figure 2, b, the red line) is changing more intensively than the face width. This is evidenced by the inclination angle of the resulted dependence. The change pattern of B2 (figure 2, b) with the flux paste indicates that physical-chemical processes during the back bead formation has lower rate (are more consistent), which guarantees the formation quality.

When using $Y_2O_3$-based flux paste the decrease of the back bead width B2 at the current 150 A is amounted to 1.0 mm, and at the current 200A – 3.0 mm.
According to GOST 14771-76 during welding without preparation the back bead height $g$ is one of the regulated variables and it should vary within a rather narrow range from 0 to 1.0 mm (figure 2, a, the red line). During welding without the flux paste the back bead height $g$ does not exceed the limit value at maximal current $160$ A, whereas during welding with $Y_2O_3$ -based flux paste – at $210$-$220$ A. Thus, the application of the flux paste on the back side of the joint before welding increases the range of welding current providing high and consistent quality of the back bead by a factor of 1.3-1.4.

**Figure 2.** Influence of the welding current ($I_{arc}$) on the back bead geometry with and without the flux paste: $S=3$ mm, preparation C2 acc. GOST 14771-76, $L_{arc} = 2$ mm; $V_w = 16$ m/hr; $d_e = 4.0$ mm; shielding gas Ar.
The study of influence of the welding rate at constant current on the back bead formation also demonstrates the face width $B_1$ decrease (figure 3, b, blue line) when using $Y_2O_3$-based flux paste at about 0.5 mm. This is related to the arc length decrease due to the change of the face camber, which results in the arc voltage and power decrease.

![Graph showing influence of welding rate on back bead formation](image)

**Figure 3.** Influence of the welding rate ($V_w$) on the back bead geometry with and without the flux paste, shielding gas is Ar: $S=3$ mm, preparation C2 acc. GOST 14771-76, $L_{arc} = 2$ mm; $I_w = 180$ A; $d_e = 4.0$ mm.

The situation is different on the back bead side. During welding without the flux paste the back bead width $B_2$ (figure 3, b, the red line) is changing more intensively than the face width. This is evidenced by the inclination angle of the resulted dependence. The change pattern of $B_2$ with the flux...
paste indicates that physical-chemical processes during the back bead formation has lower rate (are more consistent), which guarantees the formation quality within a wide range of welding rate.

![Figure 4. Dependence of the root sagging on its width with and without the flux paste.](image)

When using Y₂O₃-based flux paste the decrease of the back bead width B₂ at the welding rate 20 m/h is amounted to 1.5 mm, and at the rate 12 m/h – 4.0 mm.

During welding without the flux paste the rate decrease at constant current results in the dramatic increase of the back bead height exceeding the specific range defined by GOST 14771-76 (Figure 3, a, the red line). At \( V_w = 20 \) m/h g amounts to 0.8 mm, and at the rate 10 m/h the height is amounted to 2.5 mm. When using the flux paste the back bead height is changing less intensively (characterized by the inclination angle of the curve figure 3, a). Thus, at welding rate 20 m/h the back bead height g is amounted to 0.4 mm, and at 10 m/h – 0.9 mm (0.5 mm increase), whereas at welding without the flux paste g increased at 1.7 mm. This demonstrates the decrease of the back bead formation rate by a factor of 3.4 at changing conditions, such as 2 times increase of heat input. The diagram (figure 3, a) shows that application of the flux paste increases the welding rate control range, at constant welding current from 18 – 24 m/h to 8–24 m/h, with the back bead height not exceeding the limits defined by GOST 14771-76.

Figure 4 shows that the curves of dependence of the root sagging on the weld pool width (for the wide range of welding current) lie within a rather narrow area both at welding with the flux paste and without it. Increase of the welding current at constant seam width results in marginal increase of sagging, which is attributable to increase in the arc pressure and the weld pool length and, as a result, in the molten metal volume.
4. Conclusion
During automatic argon arc welding with the tungsten electrode without filler material with full penetration the alteration of the welding characteristics (welding current increase, welding rate decrease) resulted in the increase of the weld pool width and the face and root sagging, and at welding with the flux paste the height and width of the root camber is at 30 – 70 % less (within the specified ranges) compared to the welding in similar modes without it. In the considered mode range at overhead welding the arc pressure influences insignificantly on the seam sagging value. The weld pool width has major impact in this process.

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