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Effect of Powder Surfacing on the Geometry of Run Surfaced on Flat and Cylindrical Elements

Abstract: Comparative tests of self-shielded arc surfacing of flat and cylindrical elements led to the conclusion that both of the above-named cases revealed the identical effect of surfacing conditions on the run width and the base material content in the layer subjected to surfacing. It was revealed that penetration depth and stirring degree were mostly affected by the value of surfacing current whereas the stability of welding process, the formation of the surfaced layer and its quality were influenced by arc voltage. Shallower penetration depth in the case of the cylindrical elements if compared with that of the flat elements, subjected to surfacing performed using the same surfacing parameters, was attributed to the shift of the electrode in relation to the perpendicular. The identified correlations enable the use of test results obtained in relation to the surfacing of flat surfaces when adjusting the optimum surfacing conditions in relation to cylindrical elements.

Keywords: arc surfacing, self-shielded flux-cored wire, welding parameters, stirring degree

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Introduction

One of the more important issues which must be properly addressed during surfacing is the limitation of melting or, more precisely, the stirring degree defined through the base material content in the surfaced layer. During surfacing performed using flux-cored wires, the stirring degree (SD) is primarily affected by surfacing parameters and, to a lesser degree, by shapes of elements subjected to surfacing, i.e. flat or cylindrical. The research-related tests involved the use of self-shielded flux-cored arc surfacing (process 114 according to EN ISO 4063:2010), characterised by easy operation and efficiency as well as enabling the visual monitoring of run formation and providing reliable weld pool protection, even in assembly/fixing conditions [1, 2].

When adjusting optimum conditions for surfacing performed using self-shielded flux-cored wires it is necessary to pay particular attention to the value of arc voltage as an increase in voltage and, consequently, an increase in the arc length are accompanied by the deterioration of the shielding of a surfaced metal against ambient atmosphere; metal gets enriched in

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nitrogen and develops gas pores [1, 3]. During surfacing performed using self-shielded wires it is necessary to distinguish between two arc voltage ranges: ΔU_T – the range ensuring proper formation, minimum spatters and acceptable stirring degree (SD) and ΔU_{OP} – the range preventing the formation of pores (Fig. 1) [3]. In cases of various types of weld deposits and flux-cored wire mixture compositions, ΔU_T and ΔU_{OP} may vary greatly. The range of parameters where ΔU_T and ΔU_{OP} coincide is the most favourable in terms of surfacing. For instance, Figure 1 presents the effect of arc voltage on the weld porosity during surfacing performed using self-shielded flux-cored wires having the same contents of metal ingredients of the core but different contents of gas-forming or slag-forming ingredients, i.e. 1 - rutile, marble, fluorite; 2 - rutile, fluorite, calcium fluorozirconate and mica.

Research Objective

The work aimed to compare the geometry of runs obtained during the surfacing (performed using self-shielded flux-cored wires) of flat elements with those obtained when surfacing cylindrical elements. The analysis of data should make it possible to identify the correlations related to the effect of surfacing performed using self-shielded wires on the formation and geometrical dimensions of surfaced runs as well as to evaluate the possibility of the wider use of results obtained during the surfacing of flat elements in the determination of optimum parameters related to the surfacing of cylindrical elements having various dimeters.

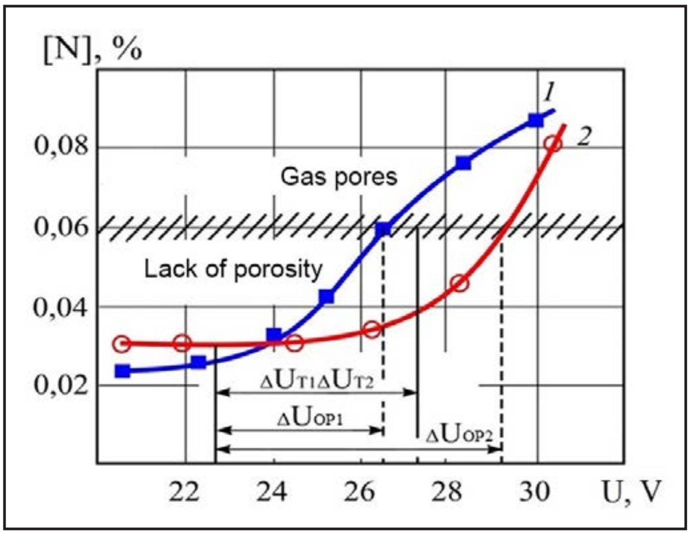

Fig. 1. Effect of arc voltage and of the composition of the core mixture of self-shielded flux-cored wires on the porosity of metal subjected to surfacing [3]; designations as in the text

Results

The performance of related tests required the making of three lots of self-shielded flux-cored wires PP-Np-25H5FMS (gas-shielding system $CaO+TiO_2+MgO+CaF_2+Al_2O_3$) having diameters of 1.8 mm, 2.4 mm and 2.8 mm. The above-named wires were used to surface flat specimens (15 mm thick plates) and cylindrical specimens (tubes ϕ 125×20 mm) made of steel St3 (equivalent for S235) using a wide range of surfacing current and arc voltage. The tests were performed using a constant surfacing rate of 20 m/h. This was because of the fact that within the range of 20 to 40 m/h and with the remaining parameters being constant, the rate of surfacing nearly did not affect geometrical dimensions of surfaced runs [4, 5]. In all of the cases, the angle at which the electrode was inclined in relation to the surfaced layer amounted to 90°.

The surfacing tests were performed using a U-653 universal machine for mechanised arc surfacing. The machine was provided with a VDU-506 welding rectifier and a computer measurement system making it possible to record oscillograms of surfacing current and arc voltage [6]. The analysis of the recorded oscillograms enabled the obtainment of additional information concerning the transfer of electrode metal in arc and the stability of the surfacing process. The experiments also involved the assessment concerning the formation of surfaced runs as well as the presence of gas pores and other welding imperfections.

To determine the effect of electric parameters of the self-shielded flux-cored surfacing process on the geometrical parameters of runs (i.e. run width and height as well as penetration depth) and on the stirring degree, the tests plates and tubes were cut across to obtain appropriate macroscopic metallographic specimens. Measurements of geometrical parameters of the runs on the metallographic specimens of the flat elements were performed using a BMI-1 microscope and a magnification of 75 times. In terms of the surfacing of cylindrical elements (Fig. 2), the performance of tests using the above-presented manner was not possible as the cross-section of the specimens was skew (Fig. 2c) and the fixing of the specimen on the horizontal table was accompanied by the occurrence of a significant measurement error depending on the angle at which the metallographic specimen surface was inclined in relation to the level.

The determination of the inclination angle and the making of individual strips or the calculation of appropriate corrective coefficients for each of more than 100 specimens was deemed irrational, therefore it was necessary to develop an appropriate measurement methodology easily adaptable in relation to variously shaped specimens.

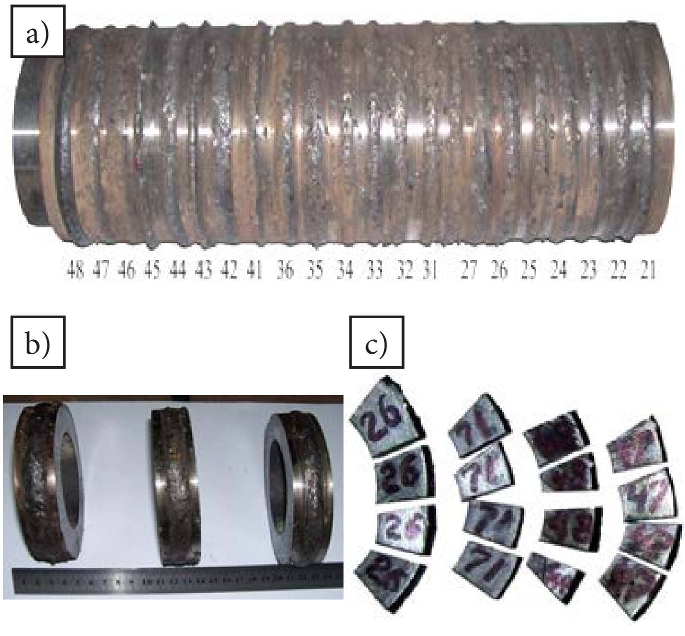

Fig. 2. Preparation (in stages) of specimens used in measurements of geometrical characteristics of surfaced runs: a: cylindrical element after surfacing with run numbers; b: single rings intended for further tests, c: specimen cut out of single rings

The proposed methodology enabling the determination of the geometrical parameters of surfaced runs was based on a simple proportion method. Initially, each macroscopic metallographic specimen was photographed with an end gauge (a standard having a known length) located in one frame. Afterwards, obtained photographs were imported to the AutoCAD software programme, where the option of "Segment" was used to prepare appropriate segments determining the length of the standard (x) as well as the width (e) and the height of the excess weld metal (g) and penetration depth (h) (Fig. 3).

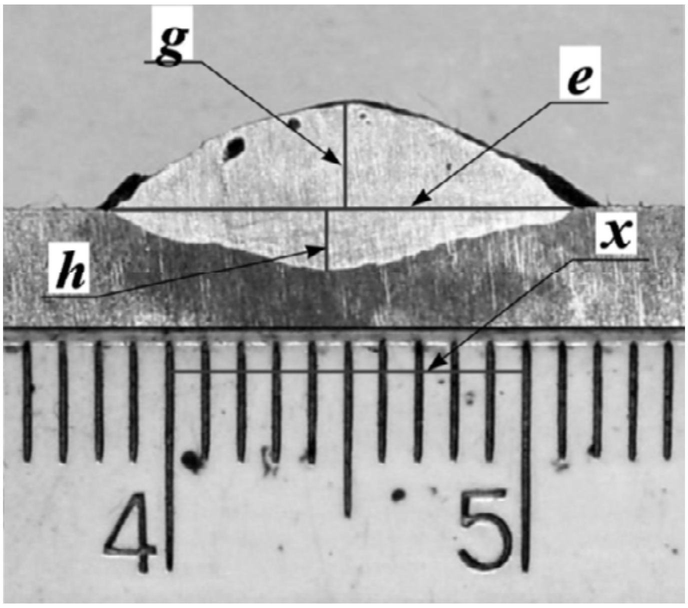

Fig. 3. Exemplary identification of geometrical dimensions of the overlay weld according to a photograph of a macroscopic metallographic specimen provided with the end gauge

Afterwards, the menu "Properties" was used to save the length of each segment and, on the basis of a known standard size and using the method of a simple proportion, geometrical dimensions of the runs were calculated. In the aforesaid case, the measurement error for obtained high-resolution photographs (300 dpi) did not exceed 1 px or 0.09 mm.

The base material content in the overlay weld (g_o) was determined using the "spline" option successively encircling the outline of the surfaced metal and molten metal. Next, the menu "Properties" was used to determine the area occupied by the obtained figures. The obtained values were substituted to a well-known formula in order to determine g_o [4]:

$$g_O = \frac{F_O}{F_O + F_N} \cdot 100\%$$

where F_O – cross-sectional area of molten base material, F_N – cross-sectional area of surfaced metal.

Because of the considerable number of measurements (as for each run the mean value of a related geometrical parameter, based on measurements of six to eight macroscopic metallographic specimens, was calculated), it was necessary to develop an algorithm for calculating measured values using the MathCAD software programme.

All of the collected data were entered into a related table. The data were used to identify correlations concerning the effect of geometrical dimensions of the surfaced runs on surfacing parameters. Afterwards the identified correlations were subjected to analysis. The tests also involved the performance of experiments aimed to compare results obtained when surfacing flat and cylindrical elements. Related correlations concerning both of the above-named cases are presented in the following diagrams (Fig. 4 ÷ 6).

Arc voltage only slightly affected penetration depth, yet it had a significant influence on the width and quality of surfaced runs as well as on the appearance of a surfaced run. Overly low voltage led to the obtainment of a narrow and

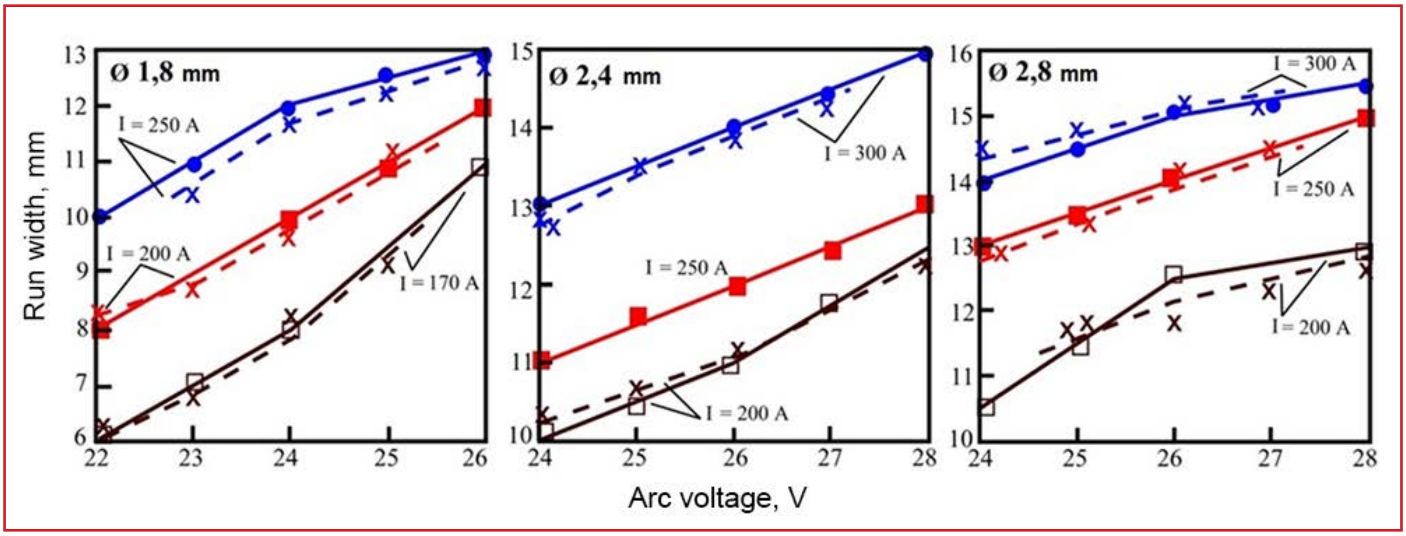

Fig. 4. Effect of surfacing parameters on the run width; full lines refer to the surfacing of the flat elements, whereas the dashed lines are related to the surfacing of cylindrical elements

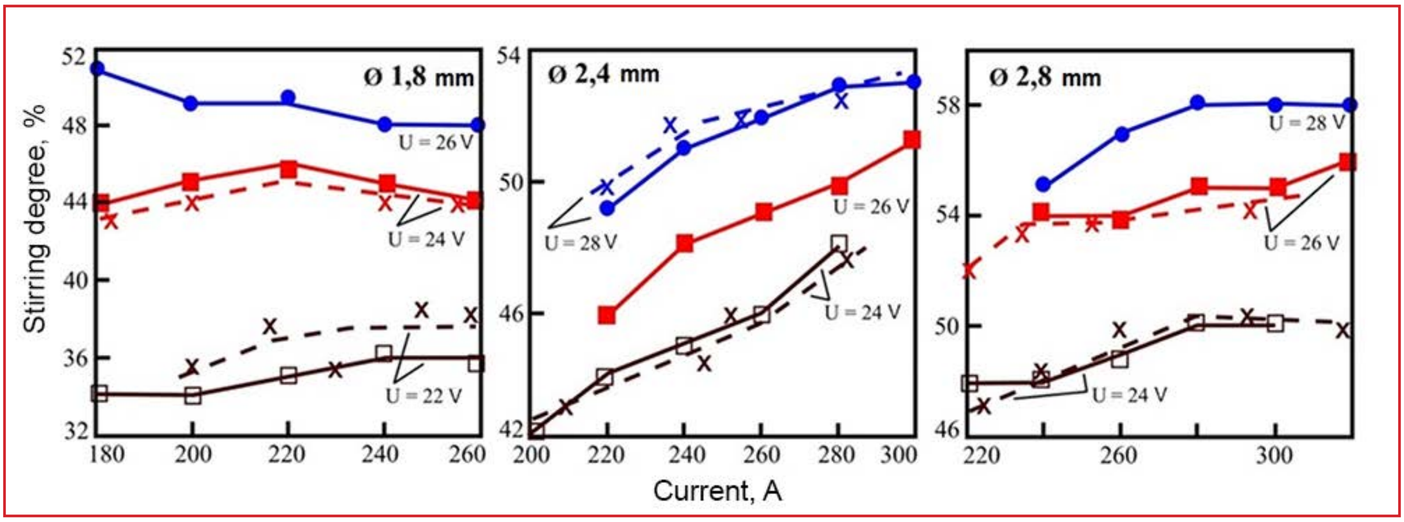

Fig. 5. Effect of surfacing parameters on the stirring degree; full lines refer to the surfacing of the flat elements, whereas the dashed lines are related to the surfacing of cylindrical elements

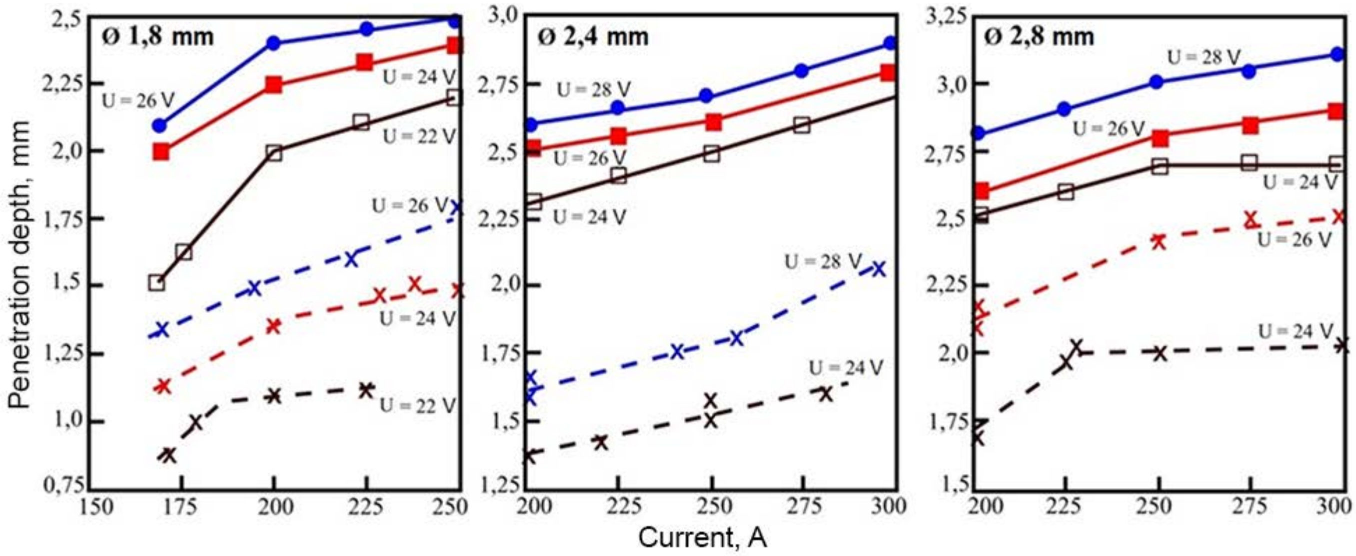

Fig. 6. Effect of surfacing parameters on penetration depth; full lines refer to the surfacing of the flat elements, whereas the dashed lines are related to the surfacing of cylindrical elements

high run. Higher voltage increased the width and decreased the height of the run. Excessively high arc voltage worsened the formation of the run, which became very wide. An increase in surfacing current significantly increased penetration depth and led to the formation of high and narrow runs. This was related to the more intense displacement of liquid metal from under the electrode (as a result of an increase in arc pressure and that in linear energy).

The effect of surfacing parameters on the stirring degree was of more complex nature (Fig. 5). In general, an increase in the above-named parameters increased the content of the base material in the overlay weld. However, within certain ranges, an increase in surfacing current was accompanied by the nearly unchanged content of the base material or even by its reduced content. This fact could be ascribed to the proportion of surfacing current to arc voltage, affecting the thermal power of arc and, consequently, an increase in the surfacing area and the area of molten base material, determining the stirring degree.

As can be seen in Figures 4 and 5, the process of surfacing of the flat elements and that involving cylindrical elements (performed using the same parameters) were characterised by nearly identical correlations between surfacing parameters and the run width as well as the degree of stirring. An error observed in the above-named Figures was restricted within the range of 3 to 5%, i.e. not exceeding a statistical error, and was caused by adding related measurement errors connected with surfacing parameters, cutting the specimens into single metallographic specimens and calculating mean values related to the aforesaid metallographic specimens.

It should be noted that the depth of penetration into the base material of the cylindrical elements was shallower than that obtained when surfacing the flat elements (Fig. 6). The foregoing could be ascribed to the fact that the formation of the surfaced layer on the cylindrical element was significantly affected by the shift of the welding head in relation to the perpendicular, i.e. the distance between the vertical axis of the surface subjected to surfacing and the electrode axis (Fig. 7).

The cross-sectional shape of the surfaced run depended on the balance between the pressure of surfacing arc and the hydrostatic pressure of the liquid weld pool. If a fragment subjected to surfacing was inclined in the same direction as that of moving arc, the level of liquid metal in the crater rose and the molten metal “pushed out” arc, leading to a decrease in penetration depth and allowing the run to adopt a more favourable shape (Fig. 7b).

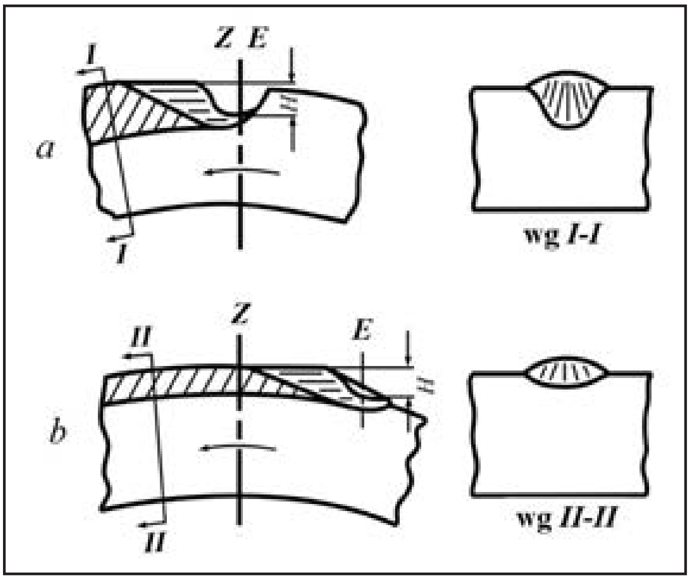

Fig. 7. Effect of the shift in relation to the perpendicular on penetration depth and the cross-sectional shape of the surfaced run: a – axis of electrode E overlaps with vertical axis Z of the element subjected to surfacing, b – axis of electrode E moved away from vertical axis Z in the direction opposite in relation to the direction of rotation; H – depth of the liquid metal level in the weld pool crater [4]

Conclusions

1. When surfacing performed using the self-shielded flux-cored wire, the penetration and stirring degree were primarily affected by surfacing (welding) current. In turn, the surfacing process stability and the quality of the surfaced layer (e.g. absence of imperfections) were mainly influenced arc voltage.

2. The surfacing processes involving flat and cylindrical elements (using the self-shielded flux-cored wire) were characterised by nearly identical correlations between surfacing parameters and the run width as well as the base material content. The shallower penetration depth when surfacing the cylindrical elements than that obtained when surfacing the flat elements (using the same parameters) could be ascribed to the effect resulting from the shift of the electrode in relation to the vertical axis. The ascertained correlations enable the use of results concerning the surfacing of flat specimen when adjusting optimum surfacing regimes related to cylindrical elements.

3. The tests made it possible to identify optimum ranges of parameters for surfacing performed using self-shielded flux-cored wires having diameters of 1.8; 2.4 and 2.8 mm enabling the obtainment of quality surfaced layer type 25H5FMS with the minimum penetration of the base material.

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