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# EFFECT OF CHEMICAL COMPOSITION AND STRUCTURE OF DEPOSITED METAL ON DEFORMATION OF THIN STEEL PLATES

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The paper gives a comparative experimental evaluation of effect of different factors on residual deformation in arc surfacing of thin steel plates. Effect of composition, structural state and method of part fixation in surfacing with Sv-08A, PP-Np-25Kh5FMS and Sv-Kh19N18G6M3V2 wires on plates of St.3 steel of 3x150x240 mm size were evaluated at different conditions of their fixation. It was experimentally found that differences in physical properties and structural state of base and deposited metal have the highest effect on the level of residual deformations. The results obtained in this work can be used in development of technology of wear-resistant surfacing of thin sheet structures. 9 Ref., 2 Tables, 4 Figures.

***Keywords:*** *arc surfacing, thin plate, residual deformations, structural changes, coefficient of thermal expansion, method of fixation, wear-resistant layer*

It is known that in surfacing of thin-sheet structures the residual stresses and deformations are observed, the cause of which are the non-uniform heating of metal in the surfacing zone, casting shrinkage of the deposited metal, difference in coefficient of temperature expansion (CTE) of deposited and base metals, structural transformations in the deposited metal during the cooling process, and also method of part fixation [1–3].

Depending on the type and level of residual deformations after surfacing, the service characteristics of manufactured parts can be greatly deteriorated [1-3]. It refers to the greatest degree to thin plates or sheets with large areas of deposited surfaces. Therefore, the problem of evaluation of effect of different factors on residual surfacing deformations is the most urgent one for the surfacing (welding) production.

The aim of the present work is the comparative experimental investigations of effect of chemical composition, structure of deposited metal, as well as method of fixation of the part surfaced on the level of residual deformations during surfacing of thin steel plates.

It is known that with the growth in temperature in the surfacing zone the tensile strength, elasticity and heat conductivity of steel are decreased, and thermal expansion and specific heat capacity are increased. Such change in physical-mechanical properties of metal has an effect on heat emission and homogeneity of heat distribution in the part. The higher the heating temperature, the higher is CTE, the lower is heat conductivity of steel and, thus, the level of stresses and deformations in the workpiece is higher [1, 2]. If the CTE of base and deposited metal differ greatly between themselves, this can cause the additional negative effect on the level of residual stresses and deformations.

Phase transformations during cooling of deposited metal also lead to the formation of stresses and deformations, which are accompanied by change in its volume [1–3]. In low-carbon steels it causes the change in about 1 % of volume, however, in steels, containing more than 0.35 % of carbon and most alloyed steels, tended to hardening, the large volume changes are observed due to martensite transformation.

The method of part fixation has also a definite effect on level of the residual deformations. In a general case, at rigid fixation of the deposited part up to the moment of its full cooling to a room temperature the stresses in the deposited metal will be observed, which will lead to the part deformation during clamps unfastening [1–3]. By using fixture with heat-removing surfaces, for example, copper backings, it is possible to provide some decrease in the level of residual deformations. Efficiency of heat removal in use of such backings depends on their sizes, difference in temperature of backing and part being deposited, thermal resistance in the zone of backing and part contact [4, 5].

**Materials and procedures of investigation.** In the present work for comparative experimental evaluation of effect of physical-mechanical properties of surfacing materials, their structure class, as well as the method of part fixation on the level of residual deformations in surfacing of thin plates of a rather large area the following materials and fixture were used.

**Table 1.** Chemical composition of base and deposited metals [6, 7]

| Grade of steel or wire | Weight share of elements, % | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | Cr | Ni | V | Mo | W |
| St.3 | 0.14–0.22 | ≤0.05 | 0.3–0.6 | ≤0.3 | ≤0.3 | – | – | – |
| Sv-08A (08rimmed) | 0.05–0.12 | ≤0.03 | 0.25–0.45 | ≤0.1 | ≤0.3 | – | – | – |
| PP-Np-25Kh5FMS | 0.2–0.3 | 0.8–1.3 | 0.5–1.0 | 4.6–5.8 | – | 0.2–0.6 | 0.9–1.5 | – |
| 4Kh5FMS* | 0.3–0.4 | 0.9–1.2 | 0.2–0.5 | 4.5…–.5 | – | 0.3–0.5 | 1.2–1.5 | – |
| Sv-Kh19N18G6M3V2 | 0.1–0.2 | 0.3–0.6 | 4.0–0 | 17.0–19.0 | 16.0–18.0 | – | 2.4–3.3 | 1.8–2.5 |
| 20Kh23N18* | ≤0.2 | ≤0.1 | ≤2.0 | 22.0–5.0 | 17.0–20.0 | – | – | – |

*Note*. There is no data in literature on CTE for used materials: Sv-08A, PP-Np-25Kh5FMS and Sv-Kh19N18G6M3V2. Therefore, data are given for the materials, most close to them by structural class and chemical composition of steels.

**Table 2.** Coefficient of thermal expansion of base and deposited metals in the range of 20–900°C [6]

| Grade of steel | Coefficient of thermal expansion α, $10^{-6}$ 1/°C | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 20–100 | 20–200 | 20–300 | 20–400 | 20–500 | 20–600 | 20–700 | 20–800 | 20–900 |
| 08rimmed* | 12.5 | 13.4 | 14.0 | 14.5 | 14.9 | 15.1 | 15.3 | 14.7 | 14.7 |
| 4Kh5FMS* | 12.6 | 13.1 | 13.7 | 14.0 | 14.3 | 14.6 | 14.7 | 14.6 | 14.1 |
| 20Kh23N19* | 14.9 | 15.7 | 16.6 | 17.1 | 17.5 | 17.8 | 18.2 | – | – |

*There is no data in literature on CTE for used materials: Sv-08A, PP-Np-25Kh5FMS and Sv-Kh19N18G6M3V2. Therefore, data are given for the materials, most close to them by structural class and chemical composition of steels.

The surfacing was performed on 240×150 mm plate of steel St.3 of 3 mm thickness using three wires: low-carbon solid wire Sv-08A of 1.2 mm diameter, providing the ferrite-pearlite deposited metal, close to base metal by chemical composition and properties; medium-alloyed flux-cored wire PP-Np-25Kh5FMS of 1.4 mm diameter, providing martensite-bainite deposited metal with a small amount of residual austenite; and high-alloyed solid wire Sv-Kh19N18G6M3V2 of 1.2 mm diameter, providing deposited metal with austenite structure. Chemical composition and properties of materials are given in Tables 1 and 2 [6, 7].

The selection of namely these surfacing materials is explained by difference in their physical-mechanical properties and structural state as compared with the base metal and, respectively, their assumed different effect on the level of residual deformations of plates being surfaced.

Thus, in surfacing with wire Sv-08A the level of deformation of plates of steel St.3 will depend only on the effect of a local heating, as there is almost no difference in CTE and structural state. For the wire PP-Np-25Kh5FMS it will depend on the effect of a local heating and martensite transformation, which is accompanied by increase in volume of deposited metal, as the difference in CTE in this case is minimum. In surfacing with wire Sv-Kh19N18G6M3V2 it will depend on the effect of a local heating and large difference in CTE of base and deposited metal.

The sizes of surfacing zone were 200×100 mm. Surfacing with all the wires was performed by single beads with overlapping of neighboring beads by 40–50 %, at similar mode: 150–160 A current; 22–23 V voltage; 30 m/h surfacing speed. This mode of surfacing was realized in one or two layers for each type of wire.

Surfacing modes were selected coming from recommendations, available in technical literature about the feasibility of producing the quality deposited (welded) thin-sheet joints, which have no burn-outs, pores and other defects, as well as from positive results of own preliminary experiments [8, 9].

Plates for surfacing were fixed on a welding table with a copper surface and clamped to it by means of two metallic straps, located along the long sides of plates. One of the straps clamped the plate edge to the table, preventing completely its movement (rigid fixation), and another one prevented the plate edge from deforming in vertical direction, but gave the possibility to its displacement in horizontal plane (movable fixation) (Figure 1). The selection of this scheme of fixation was made on the base of positive results, obtained in preliminary experiments on surfacing of thin sheets [9].

Also, for evaluation of degree of effect of thermal contact between the part surfaced and welding table on residual surfacing deformations, the surfacing of plates was performed with similar fixation, but in gravity conditions. For this, the narrow steel straps were arranged under plate clamping edges so, that the surfacing could be realized with a gap of 10 mm from the welding table surface.

Surfacing of each plate started from the side of a rigid fixation and continued to the another edge without

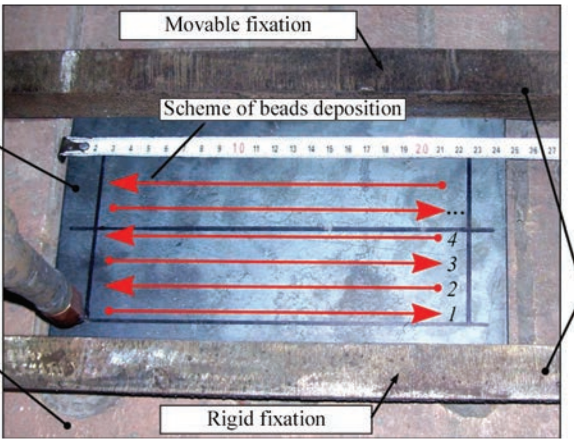


**Figure 1.** Appearance of plate being surfaced (*1*), fixed on welding table (*2*) by clamping straps (*3*) with indication of scheme of beads deposition

interruptions for cooling in accordance with a scheme shown in Figure 1. After surfacing of a layer the clamping straps were not removed up to a complete plate cooling, and then the visual inspection was made.

The measurement of deformations was carried out with a help of a rigid rule, mounted on the rear side of deposited plate, and an indicator head, moved along the rule, with a record of separate points by the scheme shown in Figure 2. As a large number of experiments was planned, then to facilitate the subsequent analysis the complete profilograms were taken only in a perpendicular direction to the deposited welds in plate centre, and value of maximum deformation in free edges of plates was also recorded as additional parameters.

**Discussion of obtained results.** It was found that during surfacing of plates in one and two layers, fully pressed to the welding table surface, the deposited metal has no defects of such types as burn-outs, pores, cracks, etc. Due to surfacing, all the plates had deformation in the form of upward deflection, however, the value of these deformations in each case was different.

For the given type of fixation the largest deformations were recorded for plates, deposited by the austenite wire Sv-Kh19N18G6M3V2, maximum values of deformations for plates, deposited in two layers, were 2.7 mm in plate centre and 6.7 mm at their free edges. The intermediate value of deformation was in plates deposited by wire PP-Np-25Kh5FMS: their maximum deformation was 2.4 and 6.5 mm, respectively. And the lowest value of deformations was noted in plates, deposited by wire Sv-08A: 0.8 mm in plate centre and 4.5 mm at the free edges.

Such difference in residual deformations of plates during surfacing with wires, different in chemical composition and structural class, is explained by the appearance of residual stresses, caused by a large difference between the values of CTE of base and deposited metals in case of surfacing with wire Sv-Kh19N18G6M3V2, as well as by martensite transformations with increase in volume in case of surfacing with wire PP-Np-25Kh5FMS.

In case of fixation of plates in gravity conditions with 10 mm gap to the welding table surface, it was managed to produce the deposited layer without burn-outs only at increase in surfacing speed from 30 up to 40 m/h. The rest surfacing modes remained unchanged. It was also noted in this case that the largest deformations are typical for plates, deposited by an austenite wire Sv-Kh19N18G6M3V2, however, the

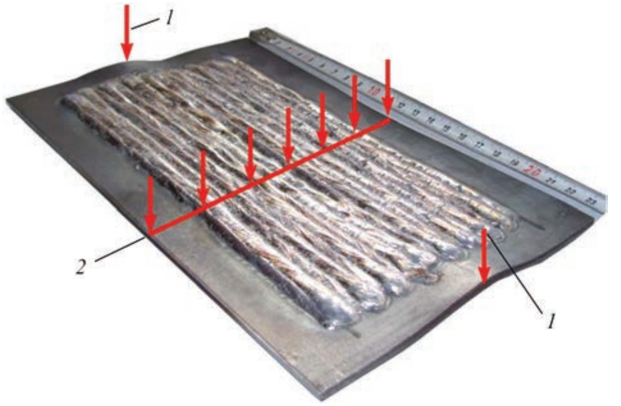


**Figure 2.** Scheme of measuring the value of plates deformation after surfacing: measurement of maximum value of deformation at free edges of plates; *2* — measurement of value of deformation in transverse direction in plate centre at different distance *l* from its edge

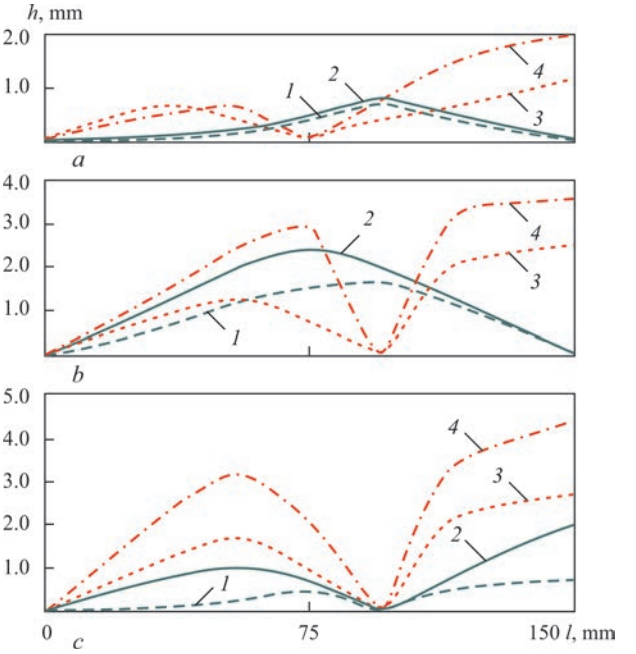


**Figure 3.** Value of deformation in centre of plates, fixed without a gap and with a gap, and deposited in one and two layers with the wires: Sv-08A (*a*), PP-Np-25Kh5FMS (*b*) and Sv-Kh19N18G6M3V2 (*c*): *1* — surfacing without a gap, 1st layer; *2* — surfacing without a gap, 2nd layer; *3* — surfacing with a gap, 1st layer; *4* — surfacing with a gap, 2nd layer

value and nature of deformation of plates, deposited in gravity conditions, differed from deformation of plates, deposited without a gap.

In spite of the fact that in surfacing with a gap the maximum deformation of plates at the free edges was somewhat lower, than without it: 5.8 mm for plates, deposited by wire Sv-Kh19N18G6M3V2; 5.5 mm during surfacing with wire PP-Np-25Kh5FMS and 3.6 mm in case of surfacing with wire Sv-08A, the value of deformation in plate centre was much higher than that in surfacing without a gap (Figure 3).

It should also be noted that as a result of deterioration of heat emission conditions of semi-products being deposited, and also rigidity of their fixation, the plates, deposited with a gap, obtained an unfavorable transverse profile from the point of view of subsequent possible straightening (Figure 4).

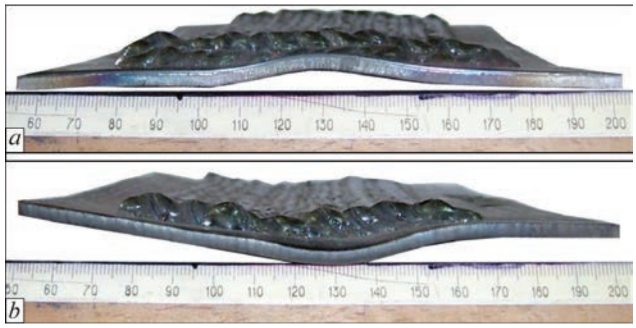

**Figure 4.** Appearance of deformed transverse edge of plate after surfacing of two layers with wire PP-Np-25Kh5FMS at fixation without a gap (*a*) and with a gap (*b*)

Thus, it was found experimentally that the difference in physical-mechanical properties and structural state of base and deposited metal, as well as the method of fixation of plates on the welding table have the greatest effect on residual deformations during electric arc surfacing of plates.

The application of electrode materials with CTE, close to that of base metal, but in which the significant structural transformations take place during cooling the deposited metal, is comparable by the level of effect on residual deformations with surfacing of materials without such transformations, but with a large difference in CTE of base and deposited metals.

It is planned in next works to give the more detailed description of established regularities with carrying out of comparative investigations of stressed and structural states of deposited plates.

## Conclusions

1. In arc surfacing of thin steel plates the following main factors have an effect on the level of their deformation:

● difference in CTE of base and deposited metals;

● structural transformations, preceding in deposited metal during cooling;

● method of plate fixation on welding table.

2. Among the above-mentioned factors the chemical composition and structure of metal being deposited have the greatest effect on value of residual deformations, which is pronounced in differences in CTE and structural transformations during cooling of base and deposited metals.

3. Application of clamping devices with heat removing surfaces in surfacing of thin plates can provide the decrease in residual deformations at keeping a good thermal contact between plate being deposited and heat removing surface.


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