# INFLUENCE OF RESIDUAL STRESSES IN WELDED JOINTS OF TWO-LAYER STEELS ON SERVICE RELIABILITY OF METAL STRUCTURES

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The main purpose of the present investigations is determination of influence of residual stresses in the near-weld zone of cladding layer of two-layer steel VSt3 + 10Kh13 on its operation properties. The task put before the authors was to compare theoretical and experimental values of residual stresses in welded specimens of two-layer steels VSt3 + 08Kh13, VSt3 + 10Kh13, VSt3 + 10Kh17N13M2T and to determine the material which is the most suitable for the further service. To define the level of residual stresses of cladding layer the low-cycle uniaxial loading of specimens and mathematical calculations were used. The results of measurements of residual stresses carried out using strain gauges and comparison of their values with theoretical ones allow making the confirmation that preset values of residual stresses in the near-weld zone of the joint VSt3 + 08Kh13 equal to 100 MPa evidences of the presence of reserve of operation reliability of the joints. On this reason the bimetal steels, described in the given work, are suitable for manufacture of large metallurgical units. 6 Ref., 1 Table, 5 Figures.

**Keywords:** *arc welding of bimetals, residual stresses, cladding layer, near-weld zone, elasticity modulus, strain gauge, layer deformation, service properties*

The continuous growth of requirements to the quality of manufacture of metallurgical units, performance of their repair applying the technology of welding of two-layer steel predetermine the appearance of new methods for calculation and determination of service properties. The prediction of life of metal structures plays here the special role. In this connection the developments in the mentioned direction are very challenging.

Two-layer steels VSt3 + 10Kh13 are widely applied both as corrosion- and heat-resistant materials during manufacture of parts operating in water, salt solutions, aggressive thermal environments, petroleum industry [1]. Thus, the values of rate of general corrosion on the side of cladding layer amount to 0.1–0.3 mm/year.

The investigations directed to determination of working efficiency of welded joints of two-layer steels have a significant importance, as far as these materials are applied both during manufacture as well as during repair of industrial units.

According to the data of work [2] due to increase in the level of residual stresses and formation of heterogeneities in the structure of joints during welding of two-layer steels the values of impact toughness are decreased by 20–25 % as compared to the initial state. Moreover, near the welded joints the defects can arise caused by plastic shortening deformation [3]. The tendency of welded joints to formation of such defects is higher the lower is the deformation capacity.

The purpose of this work is determination of residual stresses of near-weld zone of two-layer steel VSt3sp (killed) + 10Kh13, study and analysis of regularities of distribution of stresses in the welded joint.

To carry out the investigations the plates of 20 × 100 × 600 mm size of two-layer steel VSt3sp + 10Kh13, supplied according to the standard TU 14-1-1670–86, were used.

Welding of plates, intended for tests, was carried out according to the technology developed by the contractor company «Promtekhmontazh Ltd» using welding machine ADF-1002 of the type 2TS-17S. The welding was performed in two passes: the first pass — the main layer (steel VSt3sp) at $I_w$ = 520–570 A, $U_a$ = 38–40 V, $v_w$ = = 22 m/h, with flux AN-348A and wire Sv-08A. The preparation of edges of plates both for the main layer as well as for secondary one was V-shape.

The welding of separating (transition) layer was performed in one pass, after welding of the main layer under the following conditions: $I_w$ = = 280–300 A; $U_a$ = 23–25 V; $v_w$ = 18–20 m/h, with flux AN-45 and wire Sv-10Kh16N25M6.

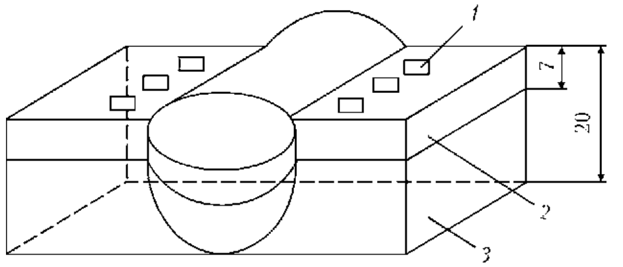


**Figure 1.** Section of welded specimen of two-layer steel for investigations: *1* — strain gauge; *2* — cladding layer; *3* — base metal

For welding of cladding layer 10Kh13 the following conditions were applied: $I_w$ = 330–350 A; $U_a$ = 24–28 V; $v_w$ = 18–20 m/h, flux AN-18, wire Sv-10Kh16N25M6.

The measurements of residual stresses were carried out on welded specimens after one loading cycle of $20\cdot10^3$ oscillations [3]. The welded joints of the following compositions were investigated: VSt3sp + 08Kh13, VSt3sp + 10Kh13, VSt3sp + 10Kh17N13M2T. The working pressure at the loading of specimen amounted to 1210 MPa, and the value of deformation at the surface of the specimen was $\varepsilon_{av}$ = 0.0031. The main purpose of these tests was the measurement of real values of residual stresses of welded specimens (Figure 1).

As one of the criteria for evaluation of the service reliability of welded joint of two-layer steel the level of residual stresses was determined. The state of specimens and averaging of value of yield strength of base and cladding layers are given in the Table.

The stress $\sigma_a$ in the specimen at the distance $Q$ from the surface was determined according to the following formula:

$$\sigma_a = \frac{1}{2} E\,(h - a)\,\frac{d\varepsilon}{d\varepsilon}\,(a) - 3E(h - a) \int\limits_0^a \frac{\varepsilon(\delta)}{(h - a)^2}\, d\delta, \quad (1)$$

where $a$ is the thickness of all removed layers; $h$ is the total thickness of specimen; $E$ is the elasticity modulus; $\delta$ is the thickness of removed layer; $\varepsilon(a)$, $\varepsilon(\delta)$ is the deformation at the lower surface of the specimen during removal of layer of thickness $a$ and $\delta$.

In the carried out investigations the thickness of removed layer $\Delta i$ (mm), total thickness of all the removed layers $\alpha_i$ (mm), deformation $\varepsilon(\alpha_i)$ = $= \varepsilon_i$, measured using gauge of resistance, were considered. To calculate the derivatives the parabolic approximation was used:

$$\frac{d\varepsilon}{d\alpha}\,(0) = \varepsilon_1 \left(\frac{\Delta_1 + \Delta_2}{\Delta_1\Delta_2}\right) + \varepsilon_2 \left[\frac{-\Delta_1}{\Delta_2(\Delta_1 + \Delta_2)}\right] = \varepsilon_1 K_0^{(2)} + \varepsilon_2 K_0^{(3)},$$

$$\frac{d\varepsilon}{d\alpha}\,(\alpha_1) = \varepsilon_{i-1} \left[\frac{-\Delta_{i+1}}{\Delta_1(\Delta_i + \Delta_{i+1})}\right] + \varepsilon_i \left(\frac{\Delta_{i+1} - \Delta_i}{\Delta_i\Delta_{i+1}}\right) + \varepsilon_{i+1} \left[\frac{\Delta_i}{\Delta_{i+1}(\Delta_i + \Delta_{i+1})}\right] = \varepsilon_{i-1}K_i^{(1)} + \varepsilon_i K_i^{(2)} + \varepsilon_{i+1}K_i^{(3)}. \quad (2)$$

The values of coefficients $K^{(1)}$, $K^{(2)}$, $K^{(3)}$ are given in Table 3.7 of work [4]. A half of the sum and integral values in the under-integral position are also indicated there. The value of residual stress $\sigma(\alpha_i)$ (the sum of values in the last three columns) is also given in work [4]. According to the calculation results the diagrams of distribution of residual stresses across the section of cladding layer were plotted (Figure 2).

In the presented material the emphasis is made on the fact that residual stresses arising at different stages of technological process of manufacture of structure metallurgical assemblies and elements have often a great influence on static and fatigue strength of structures. Therefore, the accurate calculation and analysis of real distribution of residual stresses can open the new possibilities of safe operation of metallurgical assemblies and units.

As is seen from Figure 2 of the diagrams of distribution of residual stresses of the specimens, not subjected to loading, in all the investigated compositions there are tensile residual stresses in the cladding layer. The nature of distribution of stresses across the section of cladding layer is approximately the same [2] for all the specimens: gradual increase from the fusion line of layers up to the maximum value at the depth of 0.2–0.8 mm from the free surface of cladding layer. While approaching the surface of cladding layer the value of stresses is decreased.

The maximum values of residual stresses for the composition VSt3sp + 12Kh13 amount to about 200 MPa, whereas those for the composition VSt3sp + 10Kh13 are about 140 MPa. One should pay attention to the fact that the presence of residual tensile stresses in the cladding layer

Averaged values of properties of investigated steels

| Number of specimen | Composition | $G_{0.2}^{BM}$, MPa | $G_{0.2}^{CL}$, MPa |
|---|---|---|---|
| 12-9 | VSt3sp + 08Kh13 | 260 | 450 |
| 16-9 | VSt3sp + 10Kh17N13M2T | 260 | 490 |
| 2C-3 | VSt3sp + 10Kh13 | 260 | 460 |

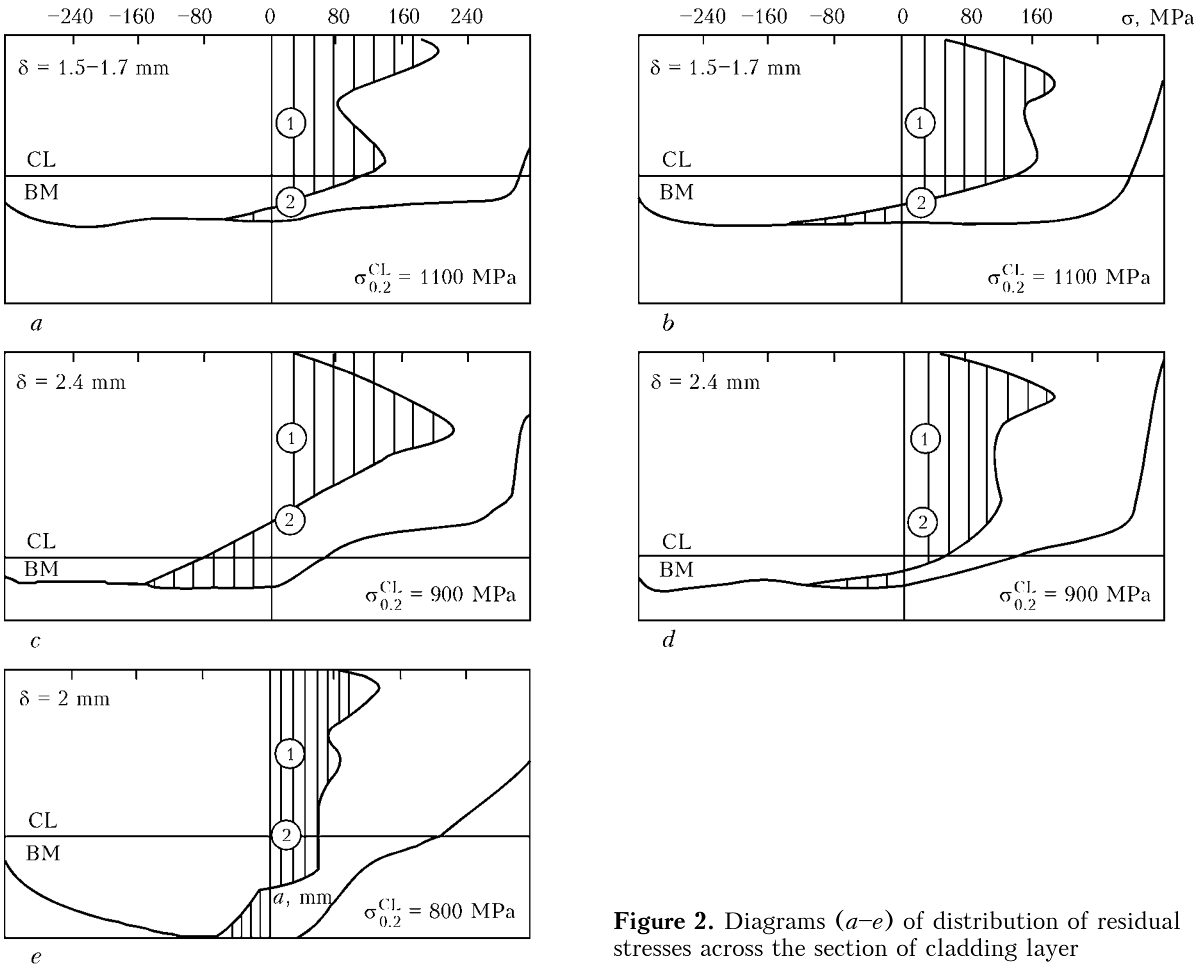


**Figure 2.** Diagrams (*a*–*e*) of distribution of residual stresses across the section of cladding layer

can influence the life period of specimen and future metal structure as a whole, especially, when both layers of composition are subjected to loading within the limits of elastic area. These arguments are decisive during selection of material of cladding layer (Figure 3).

Experimental and calculative data of residual stresses in the cladding layer after loading of the specimen, when $\varepsilon_{0.2}^{CL} < \varepsilon_{av} < 2\varepsilon_0^{BM}$, prove the presence of residual compression stresses, their maximum value is different and depends on the level of load and yield strength of material of cladding layer. Thus, in the specimen 14-10 (VSt3sp + 08Kh13), preliminary loaded up to $\sigma_{av}$ = = 900 MPa, the maximum value of residual compression stresses is 100 MPa, and in the specimen 12-19 (VSt3sp + 08Kh13), loaded at $\sigma_{av}$ = 1050–200 MPa. Study of diagram of the specimen 13-1 (VSt3sp + 10Kh17N13M2T), having yield strength of material of cladding layer of 270 MPa, is of particular interest. As is seen, the stresses are distributed with a uniform decrease from the maximum on the surface to the fusion line, after the intersection of which their sign is changed. The attention should be paid to the fact that in this specimen the maximum value of residual stresses is highest as compared to the simi-

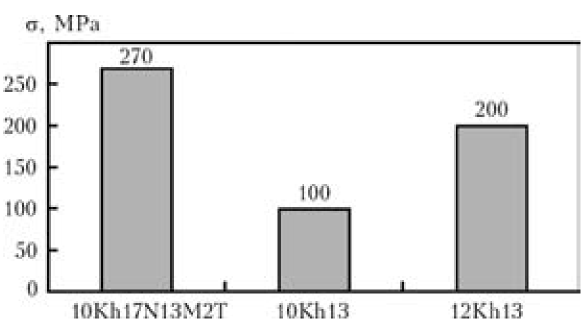


**Figure 3.** Dependence of residual stresses in the near-weld zone on material of cladding layer

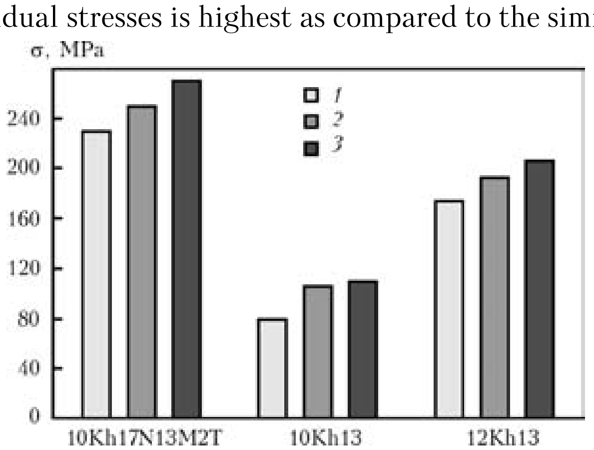


**Figure 4.** Influence of thickness of cladding layer on residual stresses in the near-weld zone: *1* — δ = 5; *2* — 7; *3* — 10 mm

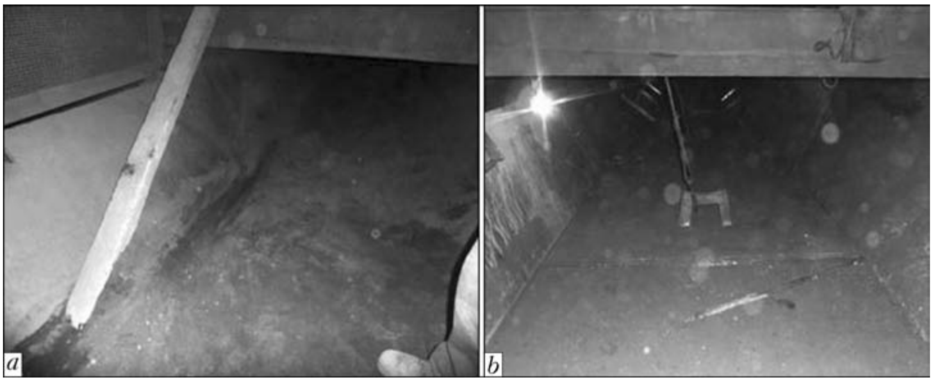

**Figure 5.** Chute of scrapper mechanism before (*a*) and after (*b*) restoration

lar values for other specimens and corresponds to the stress values of yield strength of material of cladding layer [5].

It is obviously connected with the fact that working deformations of the specimen considerably exceed the deformations of yield strength of material of cladding layer, i.e. the condition is observed, when $\varepsilon_{av} > \varepsilon_{0.2}^{CL}$. In this case residual compression stresses can be equal to the stresses of yield strength of material of cladding layer, as far as the last one is subjected to elastic-plastic deformation both during loading as well as during reset of working loading.

In the course of carried out investigations the value of longitudinal residual stresses, as a rule tensile ones, was considered, which is the result of selection of thickness of cladding layer (Figure 4). It should be also noted that the dependence given in this Figure is influenced by different levels of plastic deformation in welding, heating and cooling [6]. Basing on the analysis of diagrams of residual stresses $\sigma_{av}$ in specimens during welding using automatic machine ADF-1002 of type 2TS-17S the following peculiarities can be pointed out: the zone of compressive stresses predetermines the nature and properties of metal so that the thickness of cladding layer is directly proportional to the value of residual stresses in the cladding layer of all the investigated specimens.

As a result of introduction of developed technology of welding the chute of scrapper mechanism of traveling-grate sintering machine, designed by the contractor organization, the design of the metallurgical unit was produced capable to withstand the high preset loads and long operation period, as well as to prove the rationality of application of bimetal VSt3sp + 10Kh13 as a base material.

Thus, the results of carried out works evidence of the fact that to provide the guaranteed quality joint of the considered bimetals the application of the technology described above is possible. In this case the operation period can be increased to 80 %.

**Conclusions**

1. The established value of residual stresses in the near-weld zone of the joint VSt3sp + 08Kh13, equal to 100 MPa, is the best value among the investigated steels with the presence of residual compressive stresses, their maximum value is different and depends on the level of load and yield strength of material of cladding layer.

2. As a result of application of bimetal VSt3sp + 08Kh13 as the base material during manufacture of a chute of scrapper mechanism instead of the metal VSt3sp, the increase of operation period up to 80 % is guaranteed.


1. Medovar, B.I. (1958) *Welding of chrome-nickel austenitic steels*. Moscow: Mashgiz.
2. Glikman, L.A., Babaev, A.N., Kostrov, E.N. (1962) Fatigue strength and intensity of welded samples with deposited layer 10Kh13. In: *Properties of materials applied in turbine construction and methods of their tests*. Moscow-Leningrad: Mashgiz.
3. Nedoseka, A.Ya. (1988) *Principles of design of welded structures*. Kiev: Vyshcha Shkola.
4. Kovalenko, I.V. (2013) *Improvement of technology of arc welding of two-layer steels in manufacturing of industrial metal structures*: Syn. of Thesis for Cand. of Techn. Sci. Degree. Mariupol.
5. Nikolaev, G.A., Kurkin, S.A., Vinokurov, V.A. (1982) *Welded structures. Strength of welded joints and deformations of structures*. Moscow: Vysshaya Shkola.
6. Stafakov, Yu.P., Pobal, I.L., Knyazeva, A.G. (2002) Growth of cracks near interface of dissimilar materials under conditions of compression. *Fizich. Mezomekhanika*, **1**, 81–88.


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