Determination of shrinkage of weld

Nikolay Velikanov¹*, Sergey Koryagin¹, and Oleg Sharkov¹
¹Immanuel Kant Baltic Federal University, 236041 Kaliningrad, Russia

Abstract. A calculation-experimental technique of determination of weld shrinkage is described in that work. Experimentally, with the help of strain gauges, residual stresses are determined at two points, which are at known distances from the weld. Shrinkages are found out from the theoretical solution of the plane elasticity theory about the insertion of bodies with interference. Calculations have been carried out for experimental studies of a weld 400 mm long for different thicknesses of metal. It is found that when the thickness of the metal increases, the shrinkage values also increase. This is due to the fact that as the thickness of the metal increases, the heat input required to penetrate it also increases.

1 Introduction

Determining the shrinkage of welds is an urgent task. It is solved theoretically and experimentally in a number of papers [1–16].

The aim of the paper [1] was to study the influence of various arc welding processes on the development of microstructure, mechanical properties, residual stresses and deformations in welded joints of sheets of austenitic stainless steel 9 mm thick. Welded joints were made in 3 different modes of arc welding, which are used in the nuclear industry. All the welds underwent X-ray examination. The microstructural characteristic was determined using an optical and scanning electron microscope.

As shown in [2], welding deformations not only worsen the accuracy of the production of hull blocks, but also reduce productivity due to correctional work. An accurate prediction of the deformation caused by welding will help to control the accuracy of the structure dimensions.

The work [3] shows that linear shrinkage of two-component specimens was greater than the shrinkage of one-component specimens because the incompatibility of shrinkage of both materials causes biaxial stresses and enhances bonding processes.

In [4], the process of joining of steel plates 25 mm thick with a narrow gap between them. The joint was made using gas arc welding with the preservation of vertical building up. The assembly of thick plates was also performed by the widely used multistage multipass building up procedure. Shrinkages in welded joints were determined, and the influence of the heat parameters of welding on shrinkage and bending was studied.

In some cases, the welded elements undergo stresses even before welding begins. The initial stress state of structure, which can be caused by previous technological operations

* Corresponding author: nvelikanov@kantiana.ru

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(including previous welding) or external loads, influence on the kinetics of deformations and stresses and consequently on the shrinkage value. However, as experimental and theoretical studies have shown [5–16], this influence can be neglected when calculating stress fields in full-scale structures.

2 Calculation-experimental procedure

2.1 Accepted hypotheses and assumptions

Thus, the problem of determining residual stress fields in full-scale structure can be solved by a superposition of the problem of determining the stresses from individual components. These components include: external loads acting on the structure; prestresses before welding; welding stresses; temperature difference of the structure individual parts, etc.

2.2 Theoretical model

The weld (Figure 1) is modeled by a rectangular insert in a plate with longitudinal and transverse interferences equal to, respectively $2\Delta_1$ and $2\Delta_2$(Figures 2, 3). Residual stresses after welding are determined using the Kolosov-Muskheilishvili potentials [4]:

\[
\begin{align*}
\varphi(z) &= \frac{G}{\pi i(\chi + 1)} \left[ \frac{g(t)}{L} \right]_{t - z} \, dt, \\
\psi(z) &= -\frac{G}{\pi i(\chi + 1)} \left[ \frac{g(t) + i\gamma(t)}{L} \right]_{t - z} \, dt.
\end{align*}
\]

where $z$ – is the complex coordinate of the point of the plate, $z = x + iy$; $G$ – is the shear modulus of elasticity; $\chi = (3 - \mu)/(1 + \mu)$ – is the coefficient expressed through the Poisson constant $\mu$; $t$ – is the point coordinate at the edge of the rectangular insert; $g(t)$ – displacements at the edge of the insertion $L$.

Expressions for displacements at the edge of insert $g(t)$ depend on the longitudinal and transverse shrinkage of the insert: for the upper edge $g(t) = \Delta_1 x/L + i\Delta_2$, for the bottom edge $g(t) = \Delta_1 x/L - i\Delta_2$.
For the accepted displacements at the insert edge, we obtain the following values of the potentials from (1):

\[
\begin{align*}
\varphi(z) &= \frac{2G(\Delta_1 h - \Delta_2 l)}{\pi i (\chi + 1)} \ln \frac{l - z}{l + z}, \\
\psi(z) &= -\frac{2G}{\pi i (\chi + 1)} \left[ (3\Delta_1 h + \Delta_2 l) \ln \frac{l - z}{l + z} + \frac{2lz(\Delta_1 h - \Delta_2 l)}{z^2 - l^2} \right].
\end{align*}
\]

(2)

Residual stresses are expressed through the potentials (2) by the Kolosov-Muskhelishvili formulas.

2.3 The calculation algorithm

Weld shrinkage \( \Delta_1 \) and \( \Delta_2 \) are determined by the calculation-experimental method. After weld deposit on the plate and its cooling, the strain gauges are attached to the plate surface (Figure 1), their readings are taken. Then, the sections of the plate are cut out together with the strain gauges and their readings are taken again. By the difference in readings before and after the cutting, the residual welding stresses are determined. According to these stresses, the weld shrinkages are evaluated from the Kolosov-Muskhelishvili equations.

3 Results of calculations and discussion

From the data of the experiments, received by different authors, the values of normal stresses \( G_X \) at points with different coordinates and weld length \( 2l = 400 \) mm for different thicknesses of metal \( s \) were taken.
Then these values were used to calculate the values of the longitudinal $\Delta_1$ and transverse $\Delta_2$ shrinkages during the weld deposit and the welding of the stiffening rib.

In the calculations we took the value of the coefficient of transverse deformation (Poisson's ratio) $\mu=0.3$, the modulus of elasticity (the Young's modulus) $E=2.1 \times 10^5$ MPa.

The shrinkage values obtained this way, depending on the metal thickness, are shown in Figures 4, 5.

As follows from the figures, as the thickness of the metal increases, the shrinkage values also increase. This is due to the fact that as the thickness of the metal increases, the heat input required to penetrate it also increases, i.e. the electric current value in arc welding and the gas rate in gas welding increase. The same factors explain the increase in shrinkage, compared with manual welding, in case of semi-automatic and automatic welding.

**Fig. 4.** The shrinkage values during the welding of the seam: 1 – $\Delta_2$; 2 – $\Delta_1$.

We also note that when the length of the weld increases, the transverse shrinkage remains practically unchanged, and the longitudinal shrinkage increases in linear dependence with the weld length.

**Fig. 5.** The shrinkage values during the welding of the rib: 1 – $\Delta_1$; 2 – $\Delta_2$. 
The obtained graphical dependences of weld shrinkages on the metal thickness (Figures 4, 5) can be used to develop techniques aimed at preventing the destruction of hull structures.

4 Conclusion

The above method of determination of residual welding stresses can be used in structure individual parts while the thermal heating, warming up with a laser beam, etc.

The proposed methodology can be used not only to calculate the stress field in the current construction, but also to create residual stresses fields of specified type in the structure. This fact can be used to reduce stress concentrations in structure individual parts to reduce post-repair stresses and in particular cases, for example, to remove camber, embossing.

References