Influence of Design Factors of Butt-welded Sheet Joints on Elastic Stress Concentration Level in Joints

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Abstract. The aim of this study is to determine the influence of design factors of butt-welded sheet joints on the level of elastic stress concentration in joints. The finite element method was used to model the stress-strain state in the zones of constructive concentration of butt sheet joints with double-sided seams. The design model simulated the form of the joint in all the elements since the distribution of stresses and strains in the cross section depends on the joint configuration. The following parameters for butt sheet joints such as sheet thickness, the width of the joint, the bead width and bead height in butt welding joints were varied in the study. A nonlinear model was used to approximate the values of the elastic stress concentration factors obtained for different values of the geometric parameters for butt-welded sheet joints. This model is in good agreement with the values of the elastic stress concentration factors in the transition zone between the weld seam and base metal obtained by the stress-strain state modelling in joints with the help of FEM (the coefficient of determination $R^2 \geq 0.856$).

1. Introduction
A number of butt-welded joints in sheets in constructions are widely used in various industries. Without taking into account the characteristics of steel deformation and destruction in stress concentration zones the design of butt-welded sheet joints in constructions, which are dependent on cyclic influences of different nature and intensity, could result in increased both fatigue and quasi-brittle fracture.

Stress concentration of butt-welded sheet joints depends on joint geometric parameters. The dependencies connecting the design parameters for the butt-welded sheet joints with elastic stress concentration value $\alpha_\sigma$ are given in [1,2]. The regularities of stress concentration factor $K_i$ and deformations $K_i$ in the stage of elastoplastic deformation are shown in [3,4].

The analysis of the dependence of elastic stress concentration value $\sigma_\alpha$ on the design parameters of the butt-welded joints of the sheets, which are given in [1,2], showed the following:
- the radius in the zone of transition of weld bead to base metal (Figure 1) is included into the dependence; in practice, this radius is difficult to measure and in some cases the absence of the such radius can be observed;
- the values of the elastic stress concentration factor of the butt-welded sheet joint, which were calculated from the dependencies given in [1,2], differ in 1.45 times.
2. Methodology of research
Currently, there are many methods for studying the deformed state of the material in the zones of constructive stress concentration: brittle-lacquer technique [5], etching of the deformed surface [6], the method of optically active coatings [7,8], the moire method [9,10], the interferometric method [11], the tensometric method [12], the method of precision dividing grids [13-16], the finite element method [17-20] and other methods.

We used the finite element method (FEM) to determine the stress fields in the stress concentration zone. This method is versatile and allows one to analyse joints of a more complex geometry.

Since the distribution of stresses and strains in the cross section depends on the joint configuration, the design model simulated the joint form in all elements (Figure 1). The size of the final element was 1 mm, except for the region at the transition zones, in which the element was 0.1 mm in size.

![Figure 1. The design model of the joint.](image)

The weld seam geometry, the value of penetration were modelled like welded butt joints with double-sided seams of C18, C21, C23, C24, C39, C40 types according to GOST 5264-50; C4, C18 types according to GOST 8713-79.

The following parameters for joints were varied in this study:
- the thickness of sheets: from 4 to 60 mm;
- the width of the joint: from 100 to 300 mm;
- bead width in butt welding joints: "e" from 8 to 68 mm, "e1" - from 3 to 8 mm;
- bead height in butt welding joints: "g" from 0.5 to 2 mm, "g1": from 0.5 to 2 mm.

We used the ANSYS software to perform the calculations.

3. Results and discussion
It can be seen in the images shown in Figure 2 that stress concentration in the butt-welded joint with double-sided seams is maximum on the side of the seam with the smaller width.

In order to reduce the proportion of unexplained dispersion in $\alpha_\sigma$ dispersion we used a nonlinear model to approximate the values obtained of the elastic stress concentration factors at different values of geometrical parameters for welded joints:

$$\alpha_\sigma = \beta s^\beta b^\beta e^\beta g^\beta g_1^\beta$$  \hspace{1cm} (1)
where $\beta, \gamma, \mu, \theta, \varphi, \delta, \alpha$ are the parameters; $s$ is the welding sheet thickness ($s=s_1$); $b$ is the width in butt joint; $e$, $e_1$ are the width of the beads in a double-sided butt weld; $g$, $g_1$ are the height of the beads in a double-sided butt weld.

Taking the logarithm of equation (1) allowed the model to be transformed into a linear one:

$$\ln \alpha = \ln \beta + \gamma \ln s + \mu \ln b + \theta \ln e + \varphi \ln e_1 + \delta \ln g + \alpha \ln g_1$$  \hspace{1cm} (2)

Figure 2. Distribution of isofields of stress intensity in a butt-welded joint: $\sigma_n=95.19$ MPa, $s=10$ mm, $b=200$ mm, $e=20$ mm, $e_1=4$ mm, $g=2$ mm, $g_1=1$ mm.

The results of regression analysis, which was performed in the Microsoft Excel software suite with the application of the method of least squares, are given in table 1; the results showed that they are significant. Therefore, we used a six-factor nonlinear model to approximate the data obtained in the Microsoft Excel software suite (1).

The dependence (1) represented in Figure 3 is in good agreement with the elastic stress concentration factors in the zone of transition between the weld seam and base metal; these factors were obtained when modelling the stress-strain state of the FEM joints (coefficient of determination $R^2 \geq 0.856$).

| Model $\alpha = \beta S^{1/\mu} e^\varphi e_1^{\delta} g^{\gamma} / g_1^{\alpha}$ |
| --- |
| $\alpha$ | $\delta$ | $\varphi$ | $\theta$ | $\mu$ | $\gamma$ | $\ln \rho$ |
| Parameter | -0.1796 | 0.0732 | -0.0149 | 0.6208 | -0.0557 | -0.5010 | 0.3228 |
| $\Delta b$ | 0.0186 | 0.0135 | 0.352 | 0.0547 | 0.0080 | 0.0408 | 0.0396 |
| $t_{\text{observ}}$ | -9.657 | 5.429 | 4.253 | 11.339 | -6.854 | -12.277 | 8.153 |
| $t_{\text{crit}}$ | 1.9876 | | | | | | 0.856 |

Table 1. The results of the regression analysis.
Figure 3. The dependence of elastic stress concentration factor $\alpha_\sigma$ for the butt-welded sheet joint on $s$, $b$, $t$, $e$, $g$, $x$.

4. Conclusion

1. Elastic stress concentration in the butt-welded sheet joint with double-sided seams is maximum on the side of the seam with the smaller width.

2. The elastic stress concentration factor value in the butt-welded sheet joint with a double-sided seam is determined by the thickness of welded sheets, the width of the joint, and bead height in butt welding joints.

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