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Modernization of the Joint of an Angle Bar with a Gusset Plate Based on General Principles of Design

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Abstract—The stress state of the joint of an angle bar with a gusset plate is studied using the SolidWorks Simulation software package. Designs are proposed that reduce the imbalance caused by the misalignment of the axes of the angle bar and gusset plate to decrease the stresses that arise in the joint.

Keywords: gusset plate, angle bar, joint, stress state, bending

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In the production of welded joints, rolled sections and, in particular, angle bars are used. In the traditional method of joining rolled sections, special elements made of sheet metal are used, gusset plates. The angle bar is installed on the surface of the gusset, and they are connected by welding [1], observing the general principles of design [2]: cost-effectiveness, manufacturability, minimization of operations, multithread processing, equal strength. However, in this design, a complex stress state and bending occur. Therefore, when exposed to a longitudinal tensile load, significant additional stresses arise due to bending.

Figure 1 shows a diagram of a traditional joint of a gusset and an angle bar, in which the longitudinal axes of gusset *2* and angle bar *1* do not coincide, which leads to an imbalance in the structure and the occurrence of additional stresses in the sections of the joint [3].

The imbalance caused by the misalignment of the axes in the plan can be eliminated by moving the angle bar along the gusset until the axes completely coincide. The imbalance caused by the misalignment of the axes in the lateral projection is determined by the distance between the axes of the gusset and the angle bar:

$$e_1 = 0.5\delta_2 + y_{\text{c.g.a}}, \tag{1}$$

where δ_2 is thickness of the gusset; $y_{\text{c.g.a}}$ is coordinate of the center of gravity in the section of the angle bar.

The bending moment in the joint is:

$$M_{\text{bend}} = Pe_1 = \sigma F_1 e_1, \tag{2}$$

where P is longitudinal force; σ is stress close to but not exceeding the permissible value for the given material; F_1 is cross-sectional area of the angle bar.

The stress caused by the bending of the angle bar [4] is found using the formula

$$\sigma_{\text{bend1}} = M_{\text{bend}}/W_1 = \sigma F_1 e_1 y_{\text{c.g.a}}/I_1, \tag{3}$$

where M_{bend} is bending moment determined by formula (2); $W_1 = I_1/y_{\text{c.g.a}}$ is moment of resistance of the angle bar section, depending on the characteristics of the section.

For an angle bar with dimensions 35 × 35 × 5 mm: $I_1 = 3.56$ cm^4; $F_1 = 3.28$ cm^2; $\delta_2 = 6$ mm, then according to formula (3) we get $\sigma_{\text{bend1}} = 1.76\,\sigma$.

The maximum stresses in the cross-section of the angle bar are determined by the formula

$$\sigma_{\max} = \sigma + \sigma_{\text{bend1}} = 2.76\sigma. \tag{4}$$

Thus, failure to comply with the general design principles requiring the exclusion of bending led to an

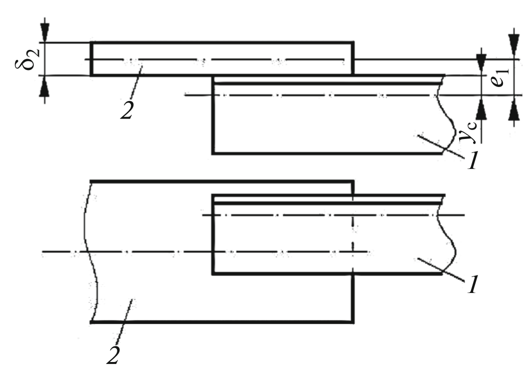

Fig. 1. Diagram of the traditional joint of angle bar (*1*) and gusset (*2*).

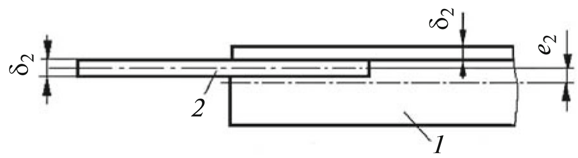

Fig. 2. Diagram of the proposed joint of the angle bar with the gusset.

Fig. 3. Scheme of fastening and loading joints of an angle bar with a gusset.

increase in the stresses in the sections of the structure by 2.76 times. When developing a new design, we will consider the iteration principle [2], which consists in a multistep approach to solving the problem.

The first step is to move the gusset from the outer surface of the angle bar to the inner surface, which requires making a longitudinal groove in the gusset or angle bar. The depth of the groove is equal to the overlap (the overlap of the angle bar and the mating gusset). The width of the groove in the angle bar should be equal to the thickness of the gusset, and the width of the groove in the gusset should be equal to the thickness of the angle bar flange. This ensures that the axes of the gusset and angle bar are closer together (Fig. 2) compared to the traditional joint.

The distance between the axes of the gusset and angle bar elements will be:

$$e_2 = y_c - 0.5\delta_2 - \delta_1 = 0.24 \text{ cm}, \quad (5)$$

where δ_1 is thickness of the angle bar flange.

The proposed design reduces the misalignment of the axes to 0.24 cm (5.6 times); therefore, the bending moment in the sections of the joint under consideration is reduced by 5.6 times, and the bending stress will be $\sigma_{bend2} = \sigma_{bend1}/5.6 = 0.31\sigma$; $\sigma_{max2} = \sigma + \sigma_{bend2} = 1.31\sigma$.

This design of the joint makes it possible to reduce the total maximum stresses by 2.1 times and provides automatic basing during assembly for welding since basing is carried out not only on the inner surface of the angle bar but also on the surface of the groove.

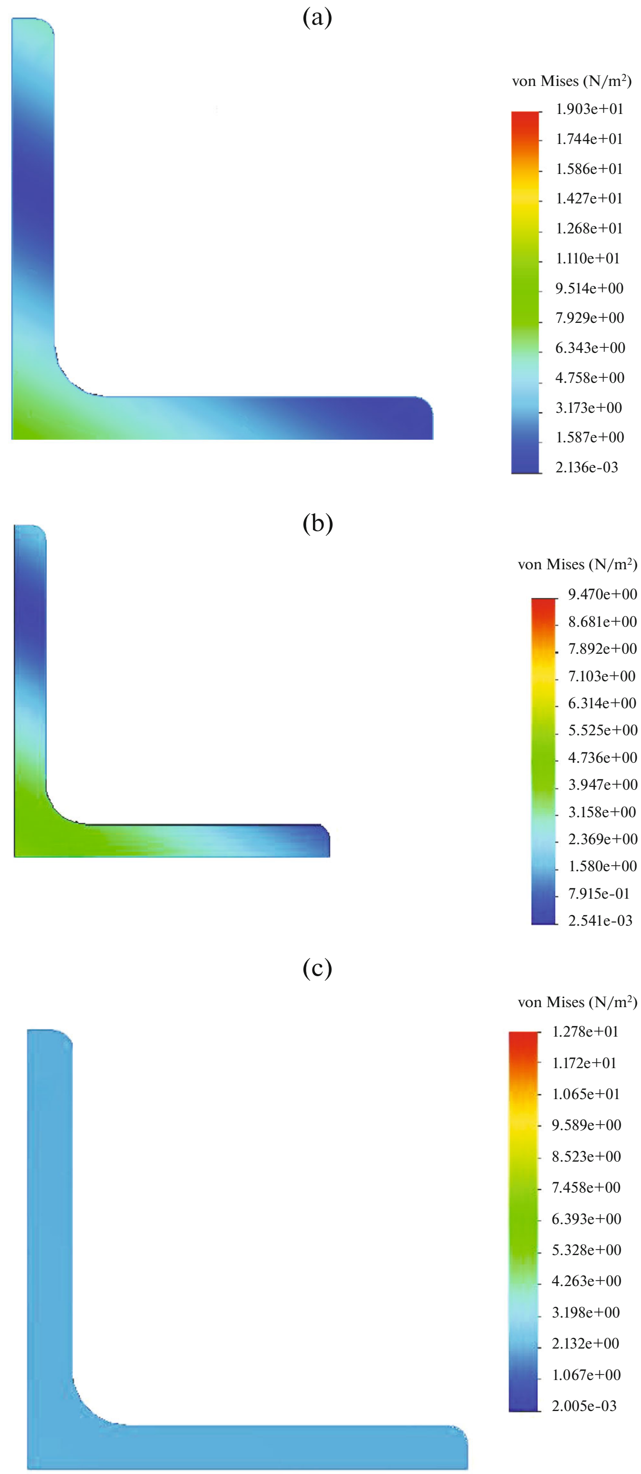

Fig. 4. Distribution of stresses σ across the angle bar section for the traditional joint scheme with $e_1 = 1.34$ cm (a), for the proposed design of the gusset with $e_2 = 0.24$ cm (b), and when eliminating the imbalance ($e_3 = 0$) (c).

The next step in improving the design is to move the grooved gusset away from the inner surface of the angle bar and install it with the clearance e_2, which completely eliminates the misalignment of the axes. This ensures the following conditions: $e_3 = 0$; $M_{bend3} = 0$; $\sigma_{bend3} = 0$.

To ensure automatic basing during assembly, a gasket is used, the thickness of which δ_{gask} is equal to the clearance e_2 between the inner surface of the angle bar and the gusset.

Apart from additional bending stresses, the joint may also contain stresses caused by changes in the geometry of the transition from the angle bar to the gusset. In this case, the width of the structure changes since the gusset is wider than the angle bar.

To fully understand the features of the proposed design solution, a finite element analysis was performed in the SolidWorks Simulation program. As a loaded model, we studied an angle bar with a length of $l = 500$ mm with a section size of 35 × 35 × 5 mm with two symmetrically installed identical gussets at the edges. This design is used in lattice structures, such as trusses. One gusset is used to secure the joint, the other is loaded in the longitudinal direction along the end surface of the gusset (Fig. 3).

The calculation results are presented in Figs. 4a–4c, which confirm the presence of significant additional stresses in the traditional design in comparison with the applied load; the maximum stress was 7.33 Pa (see Fig. 4a).

The finite element calculation for the proposed option of basing the gusset on the inner surface of the angle bar with a similar system of fastening and loading showed a reduction in stress to 4.85 Pa, i.e., 1.51 times (see Fig. 4b).

In this work, a finite element calculation of the joint was also performed. In the design with complete elimination of imbalance and coincidence of the axes of the gusset and angle bar on the lateral projection ($e_3 = 0$), the maximum reduction in stresses to 2.28 Pa was achieved (see Fig. 4c), i.e. 3.22 times compared to the traditional version.

The results obtained confirm the effectiveness of the application of design principles.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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