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To cite this article: R U Khaybrakhmanov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **681** 012023

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IOP Conf. Series: Materials Science and Engineering **681** (2019) 012023 doi:10.1088/1757-899X/681/1/012023

Reducing the distortion in thin-sheet structures made from high-strength steel based on CAE-welded joint analysis

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Abstract. High competition in the field of mechanical engineering requires the manufacture of lightweight thin-sheet structures made of high-strength steels ensuring the geometry of a certain accuracy. Supporting a given geometry is achievable by improving methods to reduce residual deformations. Therefore, the purpose of the investigation is to reduce the distortion based on the analysis of the influence of clamping rigidity on the stress-strain state of the assembly using computer simulation by the finite element method. The result of the study is a clamping model that allows to adjust the level of residual stresses and deformations, confirmed experimentally.

1. Introduction

Welding of thin-sheet parts from high-strength steel of martensitic-bainite class (panels, beams, shells) is accompanied by a change in the geometry of the assembly after welding. It is associated with the loss of structure stability due to the small thickness of the parts and the resulting stresses in the welded joints due to thermal loading of the parts by the welding arc and structural transformations accompanied by a change in the resulting structure volume. Common methods to reduce deformation are the use of welding devices which ensures maximum setup stiffness of structural elements [1].

This solution results in an increase in residual stresses in the welded joint. When reaching their critical value, cracks are formed. The aim of the work is to reduce the level of residual welding distortion without a significant increase in residual stresses. To achieve this goal, a scheme of adaptive clamps has been developed. The clamps change their rigidity depending on the stresses in the welded joint. To realize this scheme, a development estimate of the stress-strain state (SSS) over time was carried out by means of a finite-element analysis applied to the shell, which is a characteristic thin sheet part. Consider the effect of adaptive clamps on the shell SSS.

When modeling the welding process, an adaptive clamping force search was performed, in which after welding the level of part surface deformation in the considered section will be the smallest, while residual stress value will increase slightly so as not to increase the probability of cracking.

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IOP Conf. Series: Materials Science and Engineering **681** (2019) 012023 doi:10.1088/1757-899X/681/1/012023

2. Methods and materials

In this study, a shell of high-strength steel 30HGSA (analog 14331), in which the longitudinal weld is made by tungsten gas welding (TIG) according to Fig. 1, is investigated.

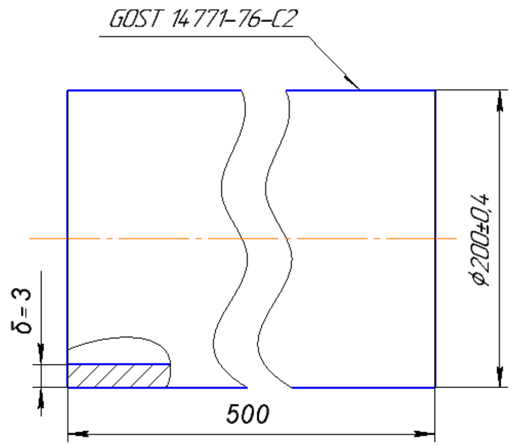

Figure 1. Shell scheme

The calculation was carried out in relation to the butt joint of plates with dimensions of 100x100x3 mm which gives results like a shell provided D / δ> 20 [2, 3], Fig. 2. The heating scheme is adopted to be a movable line heat source. The boundary conditions of the third kind are specified in the form of thermal interaction with the ambient air at a temperature of 20 ° C, in the absence of air movement.

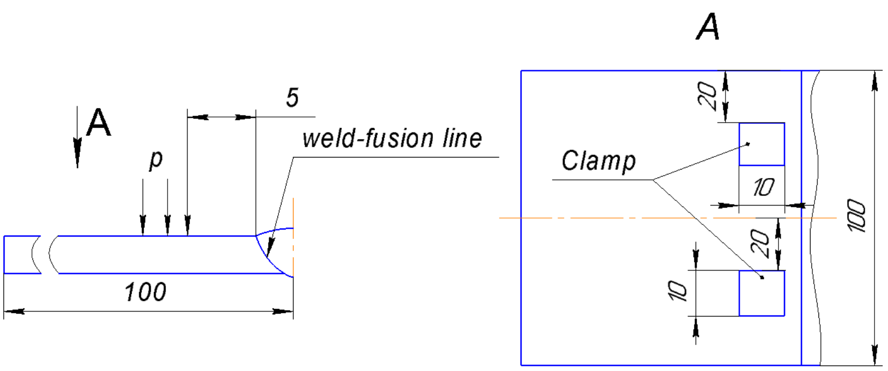

Figure 2. Scheme of the studied model

The calculations were performed using the SYSWELD software package. To solve the thermal and mechanical problem, volumetric elements of a prismatic shape were used, which together form the computational mesh according to Fig. 3. In the weld and heat affected zones (HAZ), the computational grid was thickened 10 times compared to the rest areas due to significant thermal and mechanical field gradients.

The software implementation of the clamp is shown in Fig. 4. Parts will tend to angular deformation during welding, this movement limits clamping. To simplify the model, the physical clamp is eliminated by increasing the rigidity of the parts in the fixing areas and introducing the conventional friction force along the surface of the parts. When expanding (heating part), it acts in the weld direction, while compressing (cooling part) does in the opposite direction.

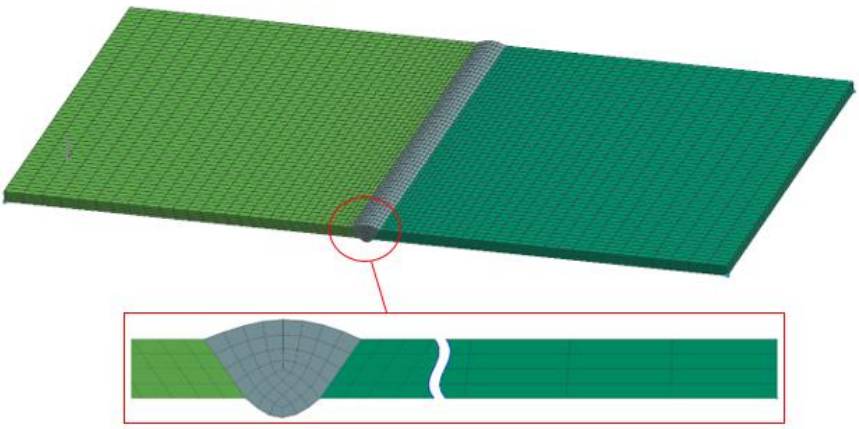

Figure 3. Mesh for solving thermal and mechanical problems

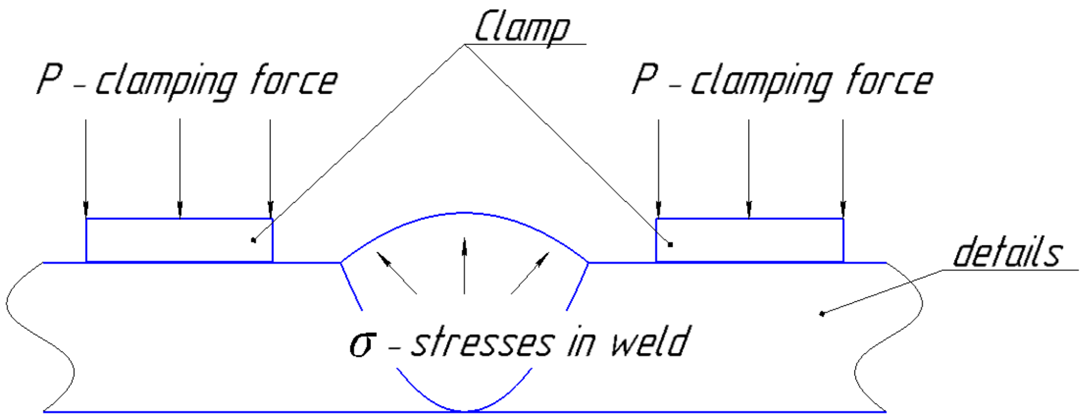

Figure 4. Adaptive clamp

The loading scheme includes the heat load forces arising due to uneven heating over the cross section of weld and the fixing point are replaced by four flat sections of the clamping action P = 0 - 5000 N, in which rigidity is increased according to the clamping force. A force of 0 N corresponds to free movement, and 5000 N corresponds to the absence of movement in the presence of force from thermal expansion. In the areas of the clamp action on the front and back sides of the plate, a friction force acts, which depends on the support reaction force (G) and the friction coefficient (μ). Friction force is determined by the formula [4]

$F_{fr} = \mu \cdot G$ (1)

It is customary to $\mu = 0{,}2$ [4].

Since the structure weight is negligible compared to the compression force, it can be disregarded, G=P. The input values for P and F_{fr} are given in Table 1.

30HGSA steel is a typical representative of the martensitic-bainitic class. A martensitic transformation occurs in it during welding, which is accompanied by an increase in the metal volume by about 3%, which significantly changes the deformation and stress kinetics [5, 6]. Structural changes were formalized in the model by changing the volume of the weld metal. Based on the thermokinetic diagram of 30HGSA steel, corresponding to the welding thermal cycle for different heat-input welding energies, the number of structural components (austenite, bainite, martensite) for different temperatures during cooling of the welded joint were taken. These data were entered into the calculation module in the SYSWELD software package in the analysis of SSS.

Based on the work done, an experimental check was made of the influence of the clamping rigidity on the stress-strain state of the plates, when the welding heat input is 500 J / mm, which corresponds to the welding parameters I = 120 A, U = 11.9 V, V = 2 mm / s. Welding was performed in automatic mode on a welding column of the MBL 2.0x2.0 series with a Lorch V40 AC / DC power source with an accuracy of 5%. Welding is produced for three samples. Three cases were tested: welding in a free state, with varying clamping rigidity, and in welding equipment, ensuring rigid fixing of the plates during welding. To ensure equal conditions for cooling all samples during the experiment, asbestos cloth was laid under the plates and clamps.

Loads of 20 kg mounted on each plate imitated the clamps providing constant pressure on the part. To estimate the residual stress level tests were selected for static bending and tension according to GOST 6996-66.

3. Result

Based on solving the thermomechanical problem, the maximum stresses and deformations were determined depending on the given effort, shown in Fig. 5. When analyzing the data, it was educed that there is such a critical value of the force Pcr, at which the maximum deformation region changes its localization. The graphs in Fig. 5 show that the smallest deformations are observed with a force of 600 N, residual deformations decreased by 45%, compared with the case of welding in a free state, and stresses increased only by 3%.

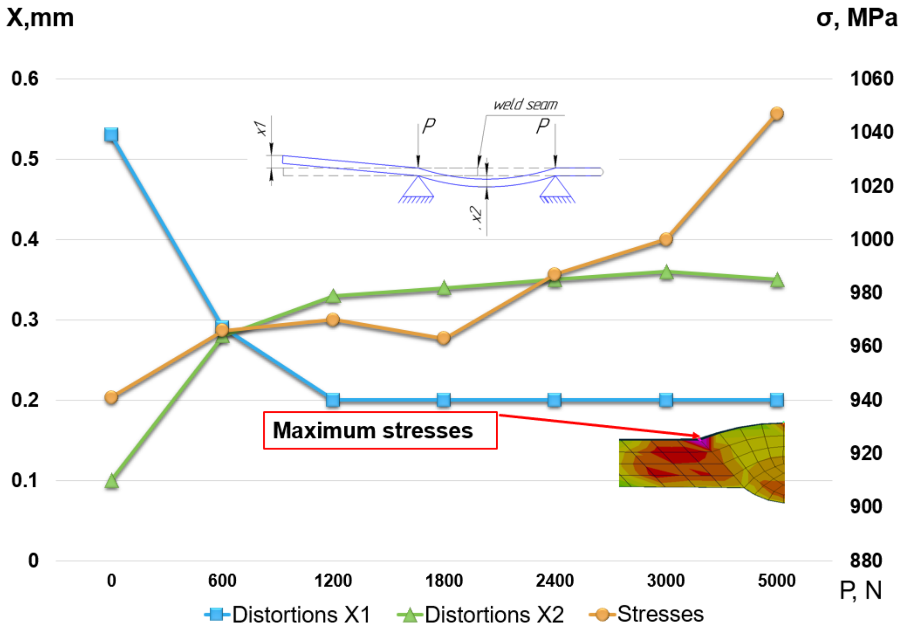

Figure 5. Change in maximum residual stresses and distortion depending on P

Mechanical tests have shown that when welding in a free state, the strength and ductility of the welded joint are increased in comparison with rigid fixing. Presumably, this is due to the favorable condition for the crystallization of the weld metal. The tensile strength of the welded joint with the use of a clamp has been increased by 67%, the bending angle by 20%, in comparison with rigid fixing.

X-ray inspection showed no cracks in the welded joints, i.e. the stress level did not achieve the ultimate strength in any of the cases. Deformations when welding in a free state amounted to 0.55 mm, using a clamp - 0.45 mm, with rigid fixing - 0.4 mm. The discrepancy between the calculated and experimental data did not exceed 11%.

4. Discussion
Based on the work done, it was proposed to equip the clamps of welding accessory with variable stiffness according to Fig. 4.

Clamps with variable stiffness in the welding accessory provide for ensure the feedback of the clamp elasticity and the level of stresses in the welded joint in the range of values close to the tensile strength. This allows to reduce the impact on the welded part during welding, which effectively reduces the deformation level and the likelihood of hot cracking. If the part due to thermal expansion begins to antagonize the clamp with a force greater than the determinate, the clamp provides some movement for the product deformation. This will allow to relax the stresses in the welded joints and heat-affected zone, as well as to limit the part deformations during welding. For example, feedbacks can be implemented in a pneumatic clamp by installing a check valve. This reduces the air pressure in the barrel diminishing the force on the part during welding. The part is deformed and those residual stresses are relaxed. And with the elastic deformation disappearance in the pneumatic cylinder barrel the pressure is increased the pressure leveling with the feed system. This scheme provides an impact on the part with a certain force that does not change over time.

The obtained results can be applied both for calculating the SSS of two plates when performing a butt weld and when welding a longitudinal joint of the shell.

5. Conclusion
The thin-sheet deformation construction model of high-strength steel during welding by computer calculations in SYSWELD has been developed.

Discrepancies between calculations and experimental data did not exceed 11%.

Experimental verification of the adaptive clamp effect on the SSS plates showed a similar strain value, and the absence of cracks in X-rays indicates that the residual stresses in the plates are below the tensile strength.

According to the calculation results, a decrease in the plate deformation by 45% was revealed when applying a clamp with variable stiffness, and the residual stresses did not significantly increase by 3%. It is assumed that the probability of cracking will remain at the same level.

According to the data obtained, it is possible to judge the residual stress and deformation level both during welding of the plate butt weld and during welding of the shell longitudinal weld. Adaptive clamping can be implemented in pneumatic, hydraulic, as well as in mechanical welding accessory.

Acknowledgments
The present study was supported by FASIE Grant №11995GU/2017. This work was done within the state order of IMP UB RAS on the subject “Laser”.

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