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Одарка Прохоренко[1], к.т.н., доц.; Володимир Прохоренко[1], д.т.н., проф.; Чеслав Пулька[2], д.т.н. проф.; Віктор Сенчишин[2], к.т.н.
[1] Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Україна
[2] Тернопільський національний технічний університет імені Івана Пулюя, Україна

ЧИСЛОВЕ МОДЕЛЮВАННЯ ЗАЛИШКОВОГО НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ ОДНОБІЧНОГО І ДВОБІЧНОГО СТИКОВИХ З'ЄДНАНЬ ПРИ ЗВАРЮВАННІ ПІД ФЛЮСОМ

Анотація. Для моделі стикового з'єднання зі сталі DC04 розмірами 600х600х10 мм методом скінченних елементів розв’язана нестаціонарна задача термопружнопластичності з урахуванням фазових перетворень для двох варіантів зварювання стикового шва під флюсом: шов заварений за один прохід і шов заварений з обох боків з’єднання. Для вказаних варіантів зварювання представлені результати дослідження залишкового напруженого стану, які мають науково-практичну цінність для прогнозування безпечної роботи зварних конструкцій.
Ключові слова: напружено-деформований стан, скінченно-елементна модель, стикове зварне з’єднання, сталь DC04

Odarka Prokhorenko, Ph.D., Assoc. Prof.; Volodymyr Prokhorenko, Ph.D., Prof.; Cheslav Pulka, Ph.D., Prof.; Viktor Senchyshyn, Ph.D.

NUMERICAL MODELING OF THE RESIDUAL STRESS-STRAIN STATE OF A SINGLE AND DOUBLE-SIDED BUTT JOINTS DURING SUBMERGED ARC WELDING

Abstract. For a model of a butt joint made from DC04 steel with dimensions of 600x600x10 mm, a non-stationary thermoelastoplasticity problem which takes into account phase transformations during single and double-sided submerged arc welding, was solved by means of the finite element method. For both variants of welding, the results of the study of the residual stress-strain state are presented, which have important scientific and practical interest in terms of predicting the safe operation of the welded structures.
Key words: stress-strain state, finite element model, butt welded joint, DC04 steel

Single and double-sided butt welded joints made by arc welding are commonly used for the manufacture of leak-proof and durable structures in the oil and gas industries, shipbuilding, bridge construction, industrial and civil engineering: pipelines, bottom sections of welded tanks, side sections of ship hulls, etc. To ensure the stable weld quality and high productivity of welded joints, automatic submerged arc welding is used, which is characterized by high heat generation and allows, if necessary, to perform welds in a single pass.

However, high heat input causes structural changes during welding and cooling, as well as volumetric changes in the metal due to the development of significant plastic strains. All of this causes welding stresses to form.

The high-gradient effect of the welding arc on the peculiarities of thermo-deformation processes should also be taken into account, as this can lead to the formation of residual stresses of a critical level, that will be dangerous for the operation of the welded structure, since they will lead to an excess of the allowable load.

For a model of a symmetrical butt joint with dimensions of 600x600x10, made of low-carbon steel DC04, the paper presents the results of solving the coupled thermoelastoplasticity problem by the finite element method for single and double-sided submerged arc welding: variant 1 - the joint is welded from one side in a single pass; variant 2 - the welds on the front and back sides of the joint are welded with a time interval of 1200 s.

A comparison of the received parameters of the residual stress-strain state (SSS), which takes into account the distribution of phase composition in the weld in the residual state, is of scientific and practical value for optimizing welding technology and predicting the safe operation of welded structures.

For two variants of the butt joints welding, Figs. 1-6 show the distribution of residual shear, longitudinal, transverse and equivalent stresses, and equivalent plastic strain in the welded joint and the distribution of structural phases along the weld axis.

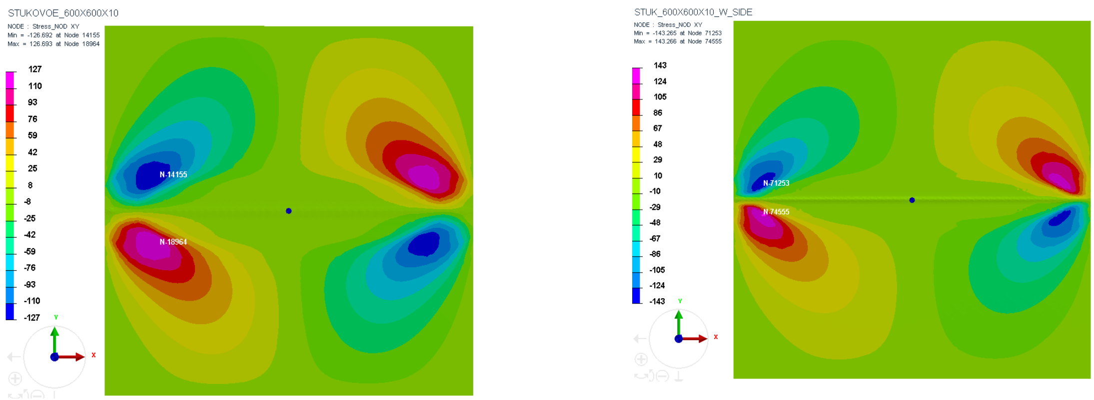


Fig. 1. Fields of residual shear stresses for different variants of welding of the butt joint: (a) - variant 1; (b) - variant 2

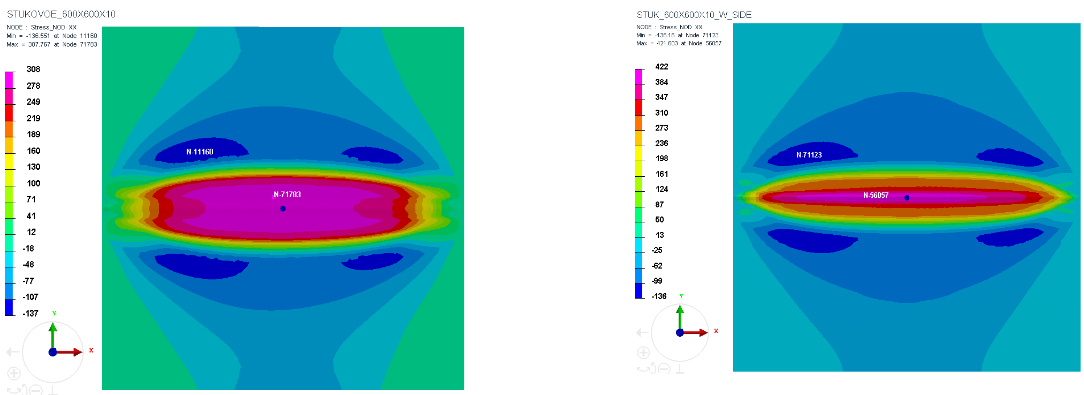


Fig. 2. Fields of residual longitudinal stresses for different variants of welding of the butt joint: (a) - variant 1; (b) - variant 2

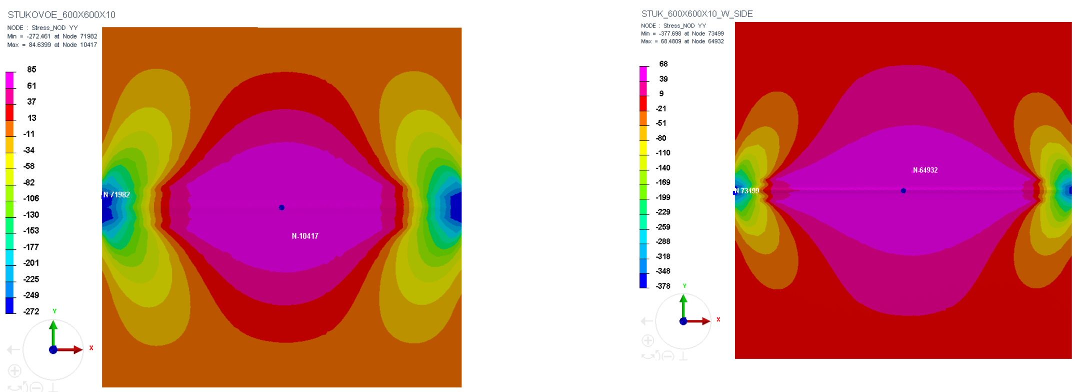
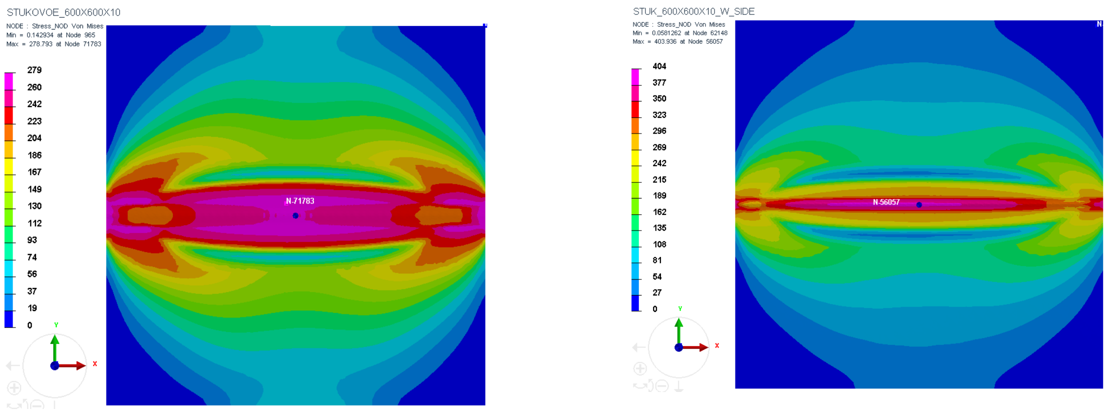
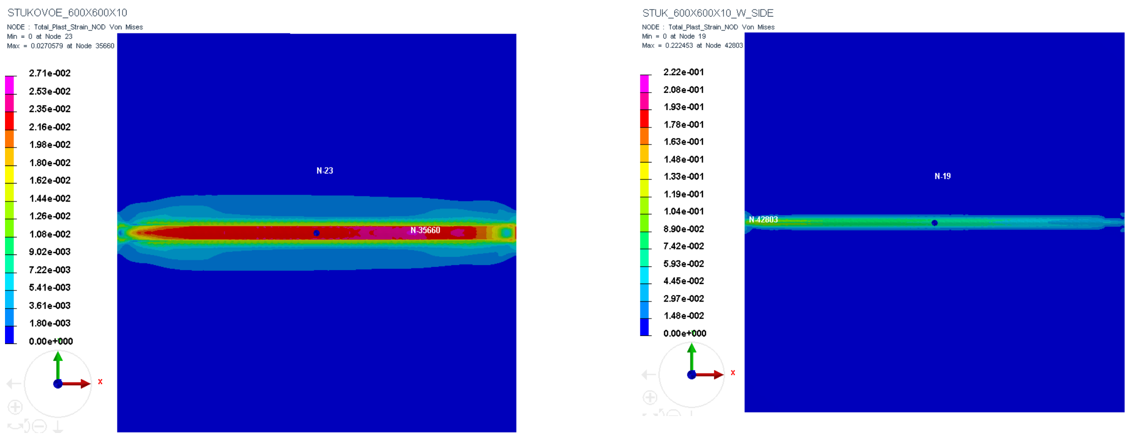


Fig. 3. Fields of residual transverse stresses for different variants of welding of the butt joint: (a) - variant 1; (b) - variant 2



(a) (б)

Fig. 4. Fields of residual equivalent stresses for different variants of welding of the butt joint: (a) - variant 1; (b) - variant 2



(a) (б)

Fig. 5. Fields of residual equivalent plastic strains for different variants of welding of the butt joint: (a) - variant 1; (b) - variant 2

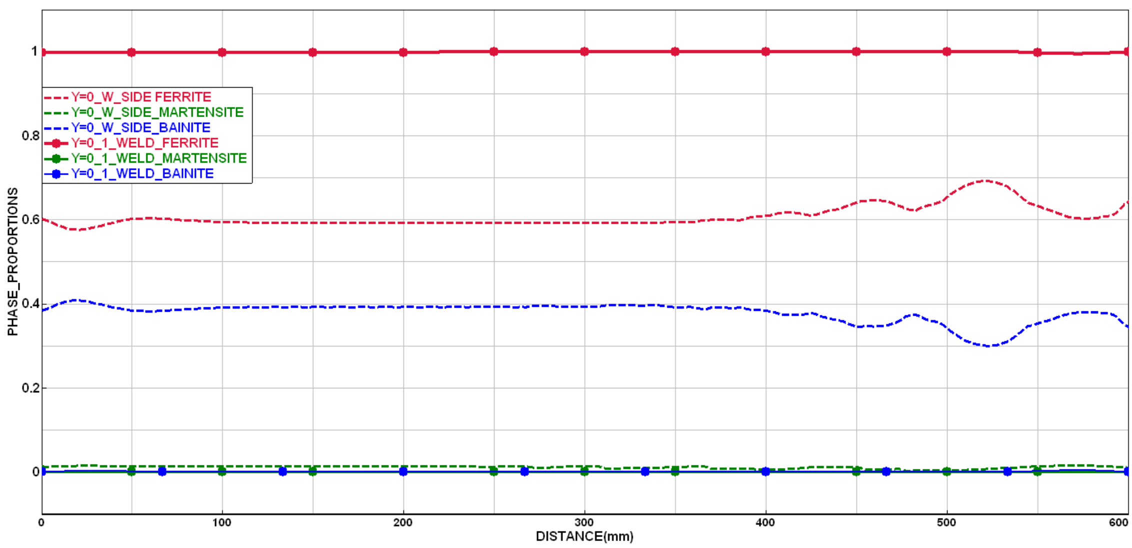


Fig. 6. Distribution of ferrite, martensite and bainite structural phases on the weld axis for different variants of butt joint welding

Table 1 represents the maximum calculated values of the parameters of the residual SSS in the butt joint and the phase proportion on the weld axis.

Table 1 - Parameters of the residual SSS and phase proportions on the weld axis for a symmetrical butt welded joint after welding by different variants

Parameter	Variant1 «single-pass»	Variant2 «double-side»
Width of plastic zone 2bn	~174 mm	~139 mm
Equivalent plastic strain at weld axis	$\sim 22{,}9\cdot 10^{-3}$	$\sim 69{,}3\cdot 10^{-3}$
Longitudinal stresses at weld axis	~308 MPa	~422 MPa
Transverse stresses along weld axis	~85 MPa	~68 MPa
Shear stresses	127 MPa	143 MPa
Equivalent stresses	~279 MPa	~404 MPa
Average phase proportion at weld axis: Ferrite	~99,8%	~60,8%
Average phase proportion at weld axis: Martensite	~0,08%	~1,2%
Average phase proportion at weld axis: Bainite	~0,08%	~38%

A comparison analysis of the residual stress-strain state parameters has showed that for butt joints welded per variant 1, the equivalent stresses on the weld axis are ~31% lower than for that welded per variant 2, which is due to a wider (~20%) zone of plastic strains of contraction; the proportion of bainite on the weld axis for variant 1 is ~38% lower than for variant 2, which indicates greater plasticity of the weld metal and its ability to resist fracture; the maximum values of residual longitudinal stresses on the weld axis for variant 1 are ~27% lower than for variant 2, which contributes to the durability of the welded joint; shear residual stresses on the weld axis for variant 1 are ~11% lower than for variant 2, which reduces the probability of development of deformations and cracking.

Thus, welding of the butt joint per variant 1 is optimal in terms of reducing residual stresses, improving ductility and fracture resistance, which is important for ensuring the durability of welded structures.