УДК 621.721.052.539.4.014

О.В. Прохоренко[1] к.т.н., доц., В. М. Прохоренко[1] д.т.н., проф.,
Ч.В. Пулька[2] д.т.н., проф., В. С. Сенчишин[2] к.т.н.
[1] КПІ ім. Ігоря Сікорського, Україна
[2] Тернопільський національний технічний університет імені Іваа Пулюя, Україна

ЧИСЛОВЕ МОДЕЛЮВАННЯ НАПРУЖЕНОГО СТАНУ З УРАХУВАННЯМ КІНЕТИКИ ФАЗОВИХ ПЕРЕТВОРЕНЬ У СТИКОВОМУ З'ЄДНАННІ ЗІ СТАЛІ DC04 ДЛЯ РІЗНИХ ТЕХНОЛОГІЧНИХ СХЕМ ЗВАРЮВАННЯ

Анотація. Для моделі стикового з'єднання зі сталі DC04 розмірами 600х600х10 мм методом скінченних елементів розв’язана нестаціонарна задача термопружнопластичності з урахуванням фазових перетворень при однопрохідному зварюванні під флюсом стикового шва. Для трьох технологічних схем зварювання представлені результати дослідження напруженого стану з урахуванням розподілу фазового складу у шві в залишковому стані, які мають науково-практичну цінність для прогнозування безпечної роботи зварних конструкцій.

Odarka Prokhorenko Ph.D, Assoc. Prof., Volodymyr Prokhorenko Dr., Prof.,
Cheslav Pulka Dr., Prof., Viktor Senchyshyn Ph.D
Igor Sikorsky Kyiv Polytechnic Institute, Ukraine
Ternopil Ivan Puluj National Technical University, Ukraine

NUMERICAL SIMULATION OF THE STRESS STATE TAKING INTO ACCOUNT THE KINETICS OF PHASE TRANSFORMATIONS IN A BUTT WELDED JOINT OF STEEL DC04 FOR DIFFERENT TECHNOLOGICAL WELDING SCHEMES

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

Butt-welded structural elements, joined by arc welding, are the most common elements for the manufacturing of various structures in shipbuilding, industrial and civil building: bottom sections of welded tanks, side sections of ship hulls, etc. High manufacturing productivity of welded flat structural elements is provided by the use of automatic submerged arc welding with a fusible electrode, which is characterized by high rate of heat generation, which allows elements to be welded together in a single pass. However, high heat input causes structural transformations during welding and cooling, which are accompanied by volume changes of the metal, which can cause the formation of welding deformations and stresses. From the works [1, 2] it is known that high-gradient thermal cycle during welding causes complex kinetics of thermo-deformation processes and the formation of temporary stresses and strains with their gradual irreversible transition into residual ones, the magnitude of which could be critical for safe operation of the welded structure, as they need to be taken into account together with normative loads during strength analysis.

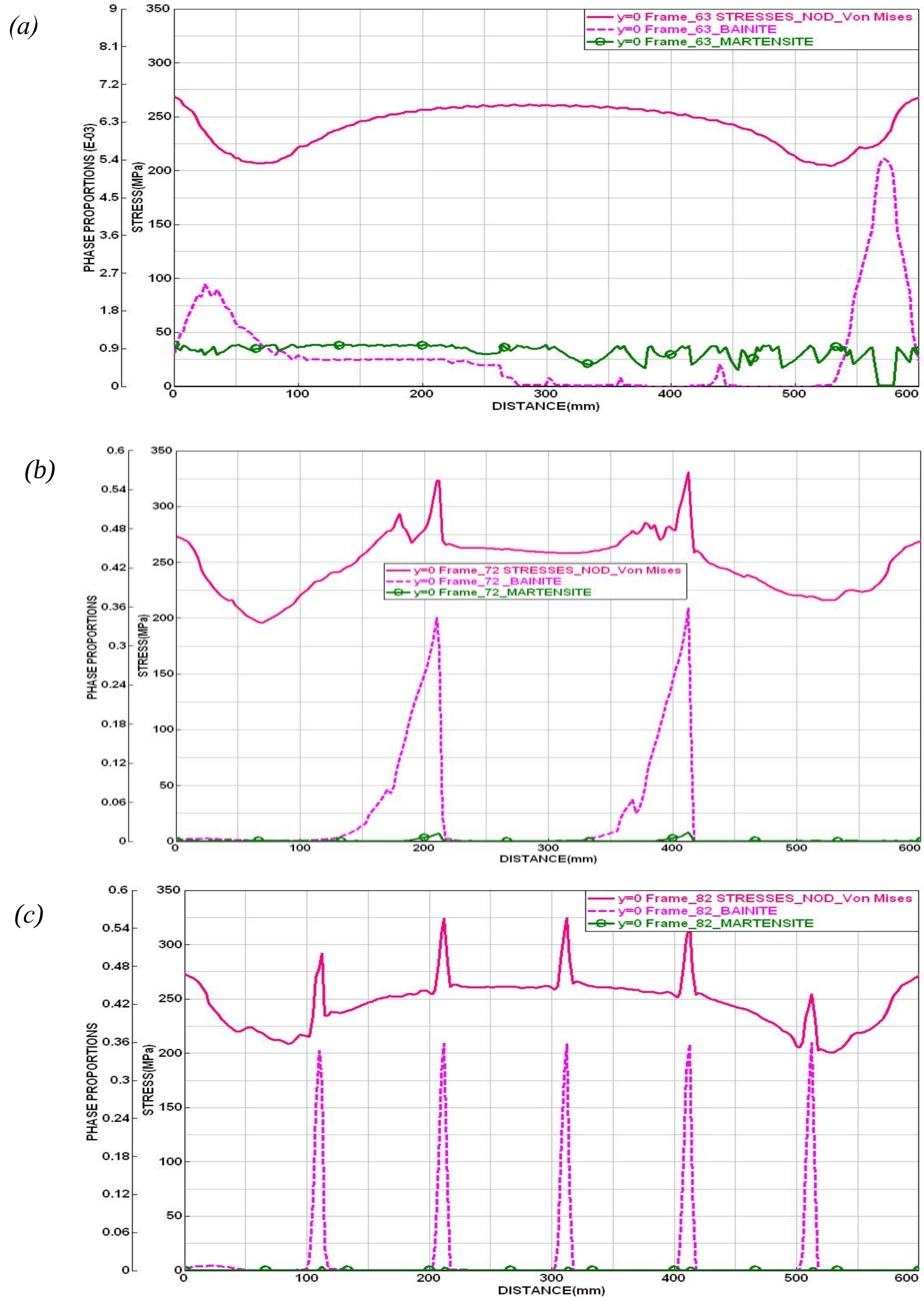

Fig. 1. Distribution of martensite, bainite and equivalent stresses
in the residual state along the weld axis at |y|=0 for various technological
welding schemes: *(a)* - Fr_63; *(b)* - Fr_72; *(c)* - Fr_82

In the work for three technological welding schemes a symmetrical butt joint with dimensions 600x600x10 mm and made from steel DC04 a compatible solution for the thermo-elastoplasticity problem was obtained using the finite element method using the SYSWELD software complex [3]. The distribution of martensite and bainite structural phases, and the equivalent stresses in the residual state along the weld axis is shown in Fig. 1.

The technological welding schemes, considered in the work, are denoted by the number of frames needed to achieve the required accuracy of the problem to be solved: single pass welding - "Fr_63", the back-step welding scheme with three 200 mm long sections - "Fr_72", the back-step welding scheme with six 100 mm long sections - "Fr_82". Welding time for each technological scheme is 120 s. The time of heating and cooling of the welded joint is 1200 s.

Based on the calculation results [4, 5] of the temperature in the nodes of the mesh model of the welded joint, as well as the kinetics of different phase proportions in the weld, it was established that: for "Fr_63" scheme, the weld and the heat-affected zone (HAZ) on (99.44...100)% consists of ferrite; for "Fr_72" scheme - in two places where adjacent sections of the back-step weld joining with each other, in the weld and HAZ, localized circular shape regions with a diameter of ~ (20...25) mm are formed with peak values of upper bainite ~ 36%, ferrite ~ 62%, martensite and austenite make up ~2% in total; for the "Fr_82" scheme - distribution and the quantitative values of the phase proportions are similar to the "Fr_72" welding scheme. Characteristic cone-shaped surfaces of the maximum values of the phase structure considered parameter are also formed here (upper bainite ~36%; ferrite ~63%, martensite and austenite make up a total of ~1%), above the back-step weld in the vicinity of the junction of the adjacent sections with each other. The analysis of the distribution of equivalent stresses for technological schemes showed that for the "Fr_63" scheme no peak values of stresses are observed (Fig. 1, *(a)*), since the amount of bainite along the weld does not exceed the average value of ~0.07%, and martensite ~0 .01%. The magnitude of stresses in the middle of the welded joint is ~260 MPa, in the near-end regions ~267 MPa. For the "Fr_72" and "Fr_82" schemes, as a result of metal volume changes that occur during the bainite transformation, localized areas of increased values of equivalent stresses are formed in the weld, which correspond to areas of increased values of bainite (Fig. 1, *(b), (c)*). In particular, the level of the peak stress on the weld axis for these schemes is the same (~ (325...331) MPa) and is ~20% higher than the stress level between the peak values and the stress level for the «Fr_63» scheme. Thus, the obtained results of the distribution of equivalent stresses show the necessity and importance of taking into account the number of sections for performing a butt joint in terms of the strength of the welded structure.

References

1. Makhnenko V.I. Raschetnyye issledovaniya kinetiki svarochnykh napryazheniy i deformatsiy. Kiyev: «Naukova dumka», 1976.
2. Prokhorenko V. M., Prokhorenko D. V., Zvorykin C. O., Hainutdinov S. F. (2019). Kinetics of strains during single-pass fusion welding of a symmetrical butt joint. Technological Systems, 3 (88), 87–98. https://doi.org/10.29010/88.11
3. SYSWELD. (2015) Reference manual version 2015. ESI Group
4. Prokhorenko, O., Hainutdinov, S., Prokhorenko, V., Pulka, Ch., Senchyshyn, V. 2022. Numerical simulation of the kinetics of temperature and phase composition in a butt joint made from steel DC04 during a single-pass submerged arc welding. Procedia Structural Integrity, 2022, 36, P. 290–297 https://doi.org/10.1016/j.prostr.2022.01.037
5. Prokhorenko, O., Hainutdinov, S., Prokhorenko, V., Pulka, Ch. 2022. Numerical simulation of the phase proportion distribution in a butt welded joint of steel DC04 for different back-step welding technological schemes. Procedia Structural Integrity, 2022, 36, P. 254–261 https://doi.org/10.1016/j.prostr.2022.01.032