V. M. PROKHORENKO, A. O. PEREPICHAY, I. MAMUZIĆ, A. ČIKIĆ

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REDUCTION OF LONGITUDINAL AXIAL RESIDUAL STRESSES IN NEAR-ROOT REGION OF CIRCUMFERENTIAL JOINT OF STEAM PIPELINE IN TECHNOLOGICAL WAY

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The paper proposes a variant for solving the problem of reduction of longitudinal residual stresses in near-root region of a circumferential welded joint of section of steam pipeline by FEM simulation of the stress-strain state of repaired section of a circumferential weld in the zone of lack of root penetration on a thin-wall shell of 89 mm diameter and 6 mm wall thickness from steel 20. The result of solving the problem is total distribution of stresses and residual plastic deformations in the repaired zone.

Key words: steel, weld, stress, steam pipeline, static strength of welds

INTRODUCTION

Residual stresses and deformations in a near-root region of circumferential welds of steam pipelines with allowed by standard lack of root penetration are to be determined, first of all, for evaluation of static strength of the welds and prediction of propagation of natural sharp crack from a tip of lack of penetration in the weld.

Propagation of such cracks in the circumferential welds can result in weld failure and damage of the steam pipeline.

Considering mentioned-above, study of residual welded stresses in the circumferential joints of steam pipelines with circumferential crack-like defects and evaluation of their static strength is relevant and significant scientific-and-technical problem.

Steels 20 of 89, 159 and 219 mm diameters with 6 mm wall thickness are used, as a rule, for manufacture of the technological steam pipelines.

Chemical composition and mechanical properties of steel 20 are shown in Tables 1 and 2.

Table 1 **Chemical composition of steel 20 / %**

Content of elements / %							
C	Si	Mn	Ni	S	P	Cr	Cu
0,2	0,3	0,5	0,25	0,04	0,04	0,2	0,2

Table 2 **Mechanical properties of steel 20**

Ultimate strength / MPa	Yield strength / MPa	Specific elongation / %	Hardness / HB
420	234	25	130 - 160

The investigations showed an area of tensile residual welding stresses appearing over the lack of penetration in the near-root zone of circumferential weld. They open crack faces and promote its propagation deep into the wall thickness of steam pipeline [1].

Finite-element method (FEM) was used for solving of the stated problem. A thin-wall shell of necessary geometry was simulated and calculation for several variants of manual arc welding technology, namely one pass, two and three passes welding, was performed using this method [2].

PROBLEMS OF THE INVESTIGATION

The flowing problems were considered in the present work:

- FEM based solution of a joint temperature elastic-plastic problem on residual stress-strain state from two or three pass welding of circumferential weld;
- analysis of rules and peculiarities of distribution of residual stresses and deformations in the vicinity of section of the circumferential weld where the lack of penetration was simulated;
- selection experimental check of obtained calculation results regarding axial residual stresses in weld on internal and external surfaces;
- formulation of the conclusions on possibility of reduction of the stress-strain state in the vicinity of tip of the circumferential lack of penetration in technological way and, thus, increase of static strength of the circumferential welds of steam pipelines.

SIMULATION OF STEAM PIPELINE SECTION WITH ROOT DEFECT

Solving of problems of strained body mechanics for regions with cuts (cracks) is connected with significant

V. M. Prokhorenko, A. O. Perepichay, National Technical University of Ukraine “Kyiv Polytechnic Institute”, Kyiv, Ukraine
I. Mamuzić, Croatian Metallurgical Society, Zagreb, A. Čikić, Technical College in Bjelovar, Croatia

mathematical difficulties due to presence of specific (singular) points.

Most of these problems can be effectively solved only with computer help.

The finite-element method obtained the highest distribution among the computational approaches used for solving of fracture mechanics problems. This is, first of all, connected with its versatility, well-developed theory and presence of significant number of powerful computational complexes realizing FEM.

Different aspects of the FEM application can be considered in fracture mechanics problems. Firstly, these are the calculation of coefficients of stress intensity, loop J-integrals etc. for different shape areas [3,4]. Secondly, FEM can be used for simulation of fracture processes or behavior of bodies with stationary cracks under such conditions for which accurate mathematical models are absent. Such calculations are useful, in particular, in combination with the full-scale experiments. The third area of FEM application important for practice is the analysis of strength of the real structures from point of view of brittle fracture resistance.

The finite-element method is based on the assumption that a body can be represented in a form of set of elements connected between each other only in the nodes. Connection of node forces with node displacements is set with the help of element stiffness matrix. Conditions of body equilibrium can be obtained joining the stiffness matrix of separate elements in a global body stiffness matrix. Solution of system of algebraic equilibrium equations at set active stresses or displacements and known global stiffness matrix allows finding all the node forces and then stresses and displacements within the framework of each element. Thus, stress-strain state of the body is determined [5].

Algorithm of FEM calculation for section of steam pipelines of 89, 159 and 219 mm diameter and 6 mm wall thickness with lack of root penetration of circumferential weld is given below.

Stage of pre-process preparation of the model includes creation of date base necessary for calculation, setting of coordinate system, development of geometrical model of cylindrical shell with circumferential weld for two variants of welding (with full penetration and with predetermined lack of root penetration of circumferential weld, Figure 1), setting of material properties, type and time of analysis, mode of welding and boundary conditions according to Tables (1,2), creation of net of finite elements and setting of element type.

Further, a joint thermo-mechanical analysis involving large displacements (Nonlinear Geometry) and automatic stabilization of dissipation of energy is performed. Time of the analysis, i.e. 3 600 seconds up to complete cooling, is set.

Loading is a volume heat source according to J. Goldak model [6]:

Temperature on the edges of shell (20 °) and absence of structure fastening are the boundary conditions of the

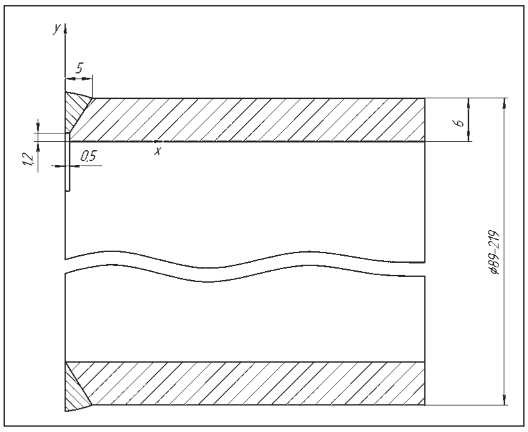

Figure 1 Geometrical model of section of pipeline with lack of root penetration in circumferential weld

structure. Displacement of the nodes in any directions is allowed.

Simulation of the structure for the purpose of solving of joint thermoplasticity problem was performed by volume eight-node elements. Elastic-plastic model with strengthening was taken for the material of welded shell.

Distribution of stresses and residual plastic strains in the vicinity of circumferential weld with allowed by standard lack of root penetration is a result of problem solution.

The problems were solved for different number of passes (from one to three) in welding of circumferential welds. A diagram of distribution of stresses on line of continuation of lack of penetration (1,2 mm depth) from its tip in direction to shell external surface (Figure 2) was built. Also the diagram of dependence of axial stresses σ_x on depth of lack of penetration at different technological schemes of welding (Figure 3) was made for one the most close to the tip of lack of penetration point on the weld axis.

Besides, simulation of pipe section with the circumferential weld made in three passes with complete cooling after each next pass as well as without cooling (continuous welding) was performed.

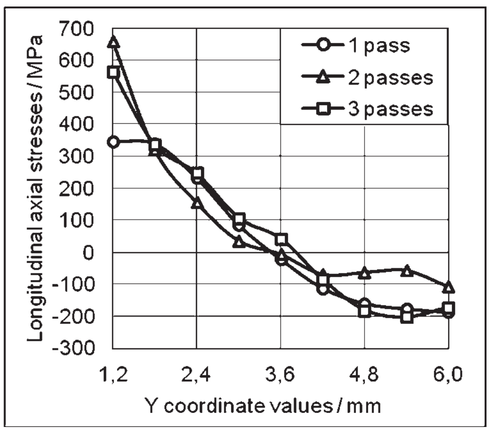

Figure 2 Distribution of longitudinal residual welding stresses on line of continuation of lack of penetration (depth 1,2 mm) from its tip in direction to external surface of thin-wall shell from steel 20 of 89 x 6 mm diameter at different number of passes of circumferential weld

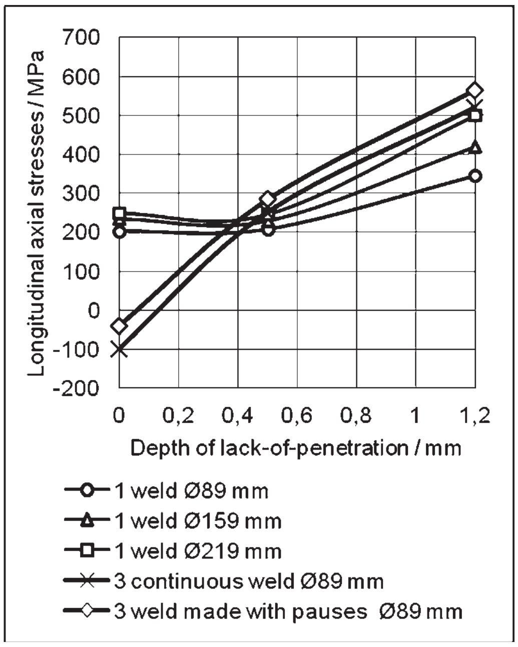

Figure 3 Distribution of longitudinal residual welding stresses depending on depth of lack of penetration on line of its continuation from the tip for thin-wall shell from steel 20 of 98, 159 and 219 mm diameter considering different technological schemes of welding

Obtained results provides the possibility for evaluation of value of longitudinal axial stresses over the lack of penetration in the whole range of change of lack of penetration depth 0 - 1,2 mm.

Curves from Figure 3 can also be used for comparison of the stresses in one-pass welds and welds made per three passes without pauses and with cooling during 3600 s after each pass.

Three following peculiarities of stress-strain state (Figure 3) can be outlined based on calculation results.

Firstly, more or less uniform increase of the longitudinal axial stresses for all pipe diameters in a point over the raiser is observed with the increase of depth of lack of penetration.

Secondly, the axial stresses in zone over the tip of lack of penetration at small lack of penetration (up to 0,5 mm) in multi-pass welds are compressive ones in the level up to " - " (50 - 100) MPa with their further transfer in tensile ones at increase of depth of lack of penetration.

Thirdly, an effect of equally spaced displacement with stable difference in 50 MPa of the curve for axial stresses in the weld with three passes provided cooling after each pass can be explained by insignificant increase of the stresses due to their summing at each cooling step (Figure 3).

SELECTION EXPERIMENTAL CHECK OF CALCULATION RESULTS

Deformations were measured and residual longitudinal stresses from welding of circumferential weld on 219 × 6 mm diameter pipe were calculated for external and internal sides in the vicinity of lack of penetration (Figures 4, 5) and in zone with full penetration (Figures 6, 7) in order to perform comparative analysis of experimental data with calculation results.

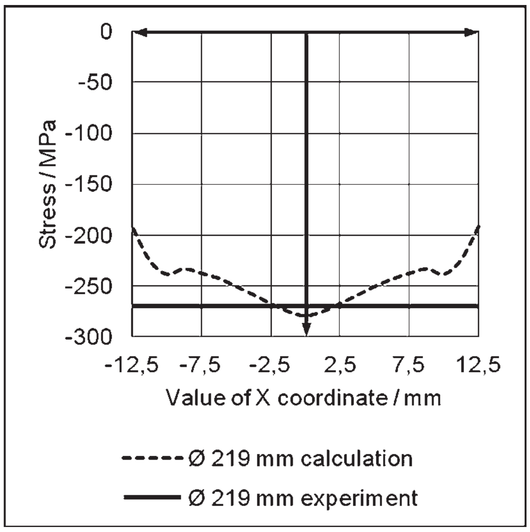

Figure 4 Distribution of longitudinal stresses over the lack of penetration on external surface of pipe

Stresses on external surface of 219 × 6 mm diameter pipe along its generatrix in the middle of zone of weld with lack of penetration (Figure 4) are negative (compressive).

Average experimental value of stresses on 25 mm basis makes 270 MPa and average calculation value equals 244 MPa. The difference is around 9,6 %.

Presence of the stress raiser in a form of lack of penetration (Figure 5) promotes non-uniform distribution of the longitudinal residual stresses on external surface of the pipe.

Average value of stresses in this zone on the basis of 25 mm equals + 142 MPa (tensile) according to experimental results and their average value makes 217 MPa according to calculation data.

34 % difference appears due to an effect of high local stress concentration induced by presence of the lack

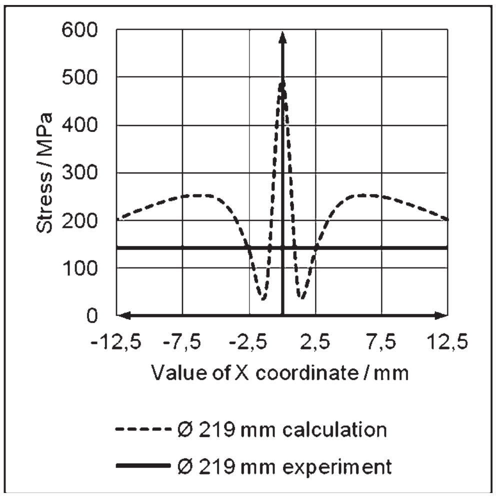

Figure 5 Distribution of longitudinal welding stresses in the vicinity of lack of penetration on internal surface of pipe

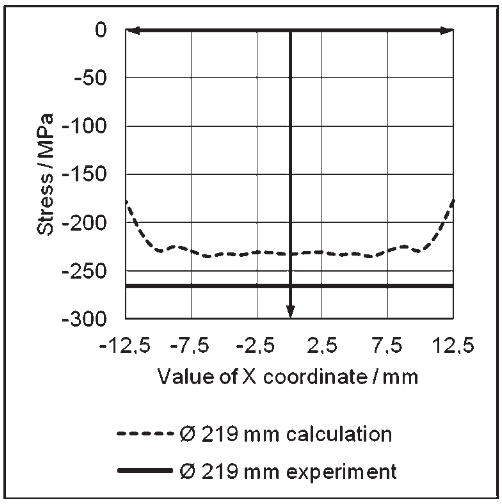

Figure 6 Distribution of longitudinal stresses on external surface of pipe with full penetration

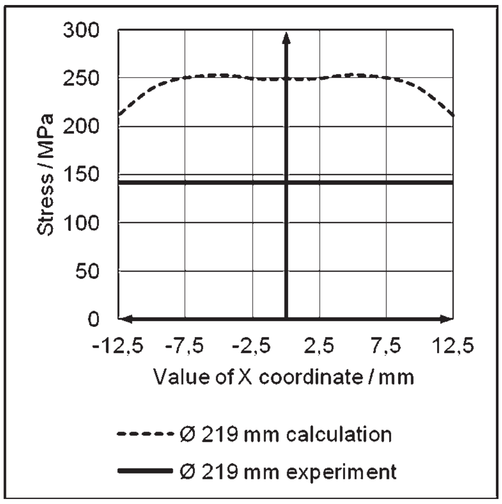

Figure 7 Distribution of longitudinal stresses on internal surface of pipe with full penetration

of root penetration of circumferential weld from internal side of the pipe.

Calculation stresses on pipe section with full penetration have good correlation with experimental data on external as well as internal surfaces of the pipe. This fact is explained by absence of the stress raisers on this section of the pipe.

Difference between the calculation and experimental data for this section does not exceed 9 %.

Therefore, FEM calculations can be considered as such providing sufficiently accurate determination of distribution of components of the residual stresses from welding of circumferential weld in the vicinity of stress raiser in a form of lack of penetration as well as in the points distant from it. Difference of FEM calculations with experimental data lies in 9 - 10 % range.

CONCLUSIONS

Application of the Finite Element Method provided the solution and analysis of the results of joint temperature elastic-plastic problem in multi-pass welding of circumferential weld of technological steam pipeline.

Analysis of calculations of the stress-strain state for different technological schemes of welding determined that increase of static strength of the circumferential welds can be achieved due to rise of number of passes from one to three. The latter promotes reduction of the lack of penetration up to 0,5 mm, axial stresses over the lack of penetration and the coefficients of stress intensity at the initial stage of crack propagation, respectively.

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Note: The responsible translator for English language is PEWI, Kiev, Ukraine