PANEVĖŽIO KOLEGIJA ISSN 2029-1280, eISSN 2669-0071. Taikomieji tyrimai studijose ir praktikoje – Applied Research in Studies and Practice, 2024, 20.

STUDY OF THE CONTACT PRESSURE ON FIT DEVIATION IN AN INTERFERENCE FIT JOINT

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Annotation. This work investigates the influence of dimensional deviations of pressed hollow two-layer coils on the contact pressure. Two possible calculation schemes are presented. Calculations were performed using the finite element method. It was determined how the contact pressure depends on the deviations, the outer diameter of the pressed joint, the thicknesses of the layers and the "arrangement" of the materials in the joint, i.e. whether the inner or outer layer is more rigid. It was found that when the bias is about 1 percent. of the outer diameter of the joint, or about 10 percent. of the total wall thickness of the joint, the contact pressure, when changing the deviations, can change by more than 10 percent.

Keywords: pressed connection, tension, radius deviations, wall thickness deviations, plane axisymmetric stress state, contact pressure

INTRODUCTION

Pressed joints are widely used in industry, especially in manufacturing processes where different materials need to be joined. These joints are used in various industries, such as automotive manufacturing, furniture manufacturing, etc. Even when pipes are joined without an initial stress (most multilayer pipes), under the influence of internal pressure, contact pressure occurs at the contact of the pipe or tube layers, i.e. a working stress occurs [1, 2].

A classic press joint is formed by joining two hollow rolls (pipes). The initial stress is obtained when the outer diameter of the inner roll is larger than the inner diameter of the outer roll. By changing the deviations of these diameters, it is possible to obtain stresses of different sizes. The stresses arising in such a press joint can be calculated using the Lame formulas. Pressed joints are studied taking into account various effects, e.g., the influence of vibrations on the formation of a pressed joint (pressing depth and force) [3], the influence of the size of the stress on the occurrence of microcracks in the connecting elements [4], the influence of the adhesion phenomenon on the size of the pressing force [5], etc. In work [6] it was established that knowing only the type of pressed joint (e.g., H8/z8) in advance, i.e. without performing calculations, it is impossible to say whether elastic or elastic-plastic deformations will occur in the contact of the connected parts. The contact pressure arising in the contact of two rolls, injected with stress, can be calculated, e.g., using the methodology of [7] (it is based on Lame formulas):

$$p_k = \frac{\dfrac{\Delta_{1;2}}{r_1} + \dfrac{2\left(1-v_1^2\right) r_0^2}{E_1\left(r_1^2 - r_0^2\right)} p_0 + \dfrac{2\left(1-v_2^2\right) r_2^2}{E_2\left(r_2^2 - r_1^2\right)} p_2}{\left(1+v_1\right)\left[\dfrac{\left(1-v_1\right)\left(r_1^2 + r_0^2\right)}{E_1\left(r_1^2 - r_0^2\right)} - \dfrac{v_1}{E_1}\right] + \left(1+v_2\right)\left[\dfrac{\left(1-v_2\right)\left(r_2^2 + r_1^2\right)}{E_2\left(r_2^2 - r_1^2\right)} + \dfrac{v_2}{E_2}\right]}; \quad (1)$$

where r0 – inner radius of the inner (1st) roll; r1 – nominal outer radius of the 1st roll and nominal inner radius of the outer (2nd) roll; r2 – outer radius of the 2nd roll; p0 – internal pressure; p2 – external pressure; Δ1; 2 – initial tension between the rolls; E1 and v1 – elastic modulus and Poisson's ratio of the material of the 1st roll; E2 and v2 – elastic modulus and Poisson's ratio of the material of the 2nd roll.

Applying formula (1) to the joints D_{-a} with d^{+v} and D_{-v} with d^{+a}, the contact pressure would be the same (here D = d; D – inner diameter of the outer roll; *d* – outer diameter of the inner roll; a and *v* – absolute value of the lower or upper deviation). It is obvious that in large-sized joints with a small bias, the influence of deviations will be negligible. However, in a small-sized pressed joint with a large bias (e.g., the wall thickness is only up to several times greater than the deviation value), the deviations can significantly affect the stress state in the pressed joint.

The aim of the study is to determine the dependence of the contact pressure of the pressed joint on the deviations of the surfaces being pressed, at the same initial bias.

MODEL USED IN THE RESEARCH

The flat deformation state will be studied, i.e. it is assumed that there are no axial deformations. Friction and surface roughness between the injected rolls are neglected. It is assumed that the joint can be affected only by the internal pressure p_0 . In this work, the stress N, when changing the deviation of the outer diameter of the inner (1st) roll n_1 and the deviation of the inner diameter of the outer (2nd) roll n_2 , remains the same, i.e. the deviation n_1 will be changed in the range from 0 to N, and the deviation n_2 – from - N to 0, so that

$$N = \text{const.} = n_1 - n_2 .$$

Two flat, axisymmetric models were created. The geometry of these models is presented in Fig. 1:

- In model 1, the pipe wall thicknesses remain unchanged when changing the deviations;
- In model 2, the inner and outer diameters of the pipe remain unchanged when changing the deviations.

In the contact area of the two-layer roll, the finite element mesh in the computational model is about 10 times denser than at the inner or outer radius of the roll (see Fig. 2). Two types of connections M-H and H-M were studied in the work. Here, the first letter indicates the material of the inner layer, and the second - the material of the outer layer. "M" (soft) indicates that the layer material is high-temperature polyethylene (PE-RT), with an elastic modulus E_P = 0.65 GPa, Poisson's ratio ν_P = 0.42. Accordingly, the letter "H" (hard) indicates that the layer material is an aluminium alloy with an elastic modulus E_A = 69 GPa, Poisson's ratio ν_A = 0.33.

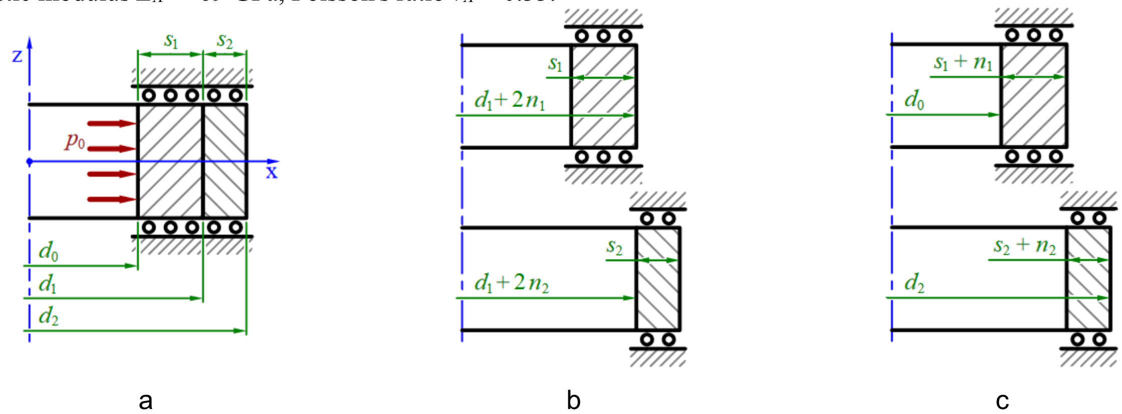


Fig. 1. **Flat, axisymmetric model of a two-layer roll: a – calculation scheme; b – model I; c – model II. Here n1 and n2 – deviation of the geometry of the inner and outer layers of the roll from the nominal value, respectively**

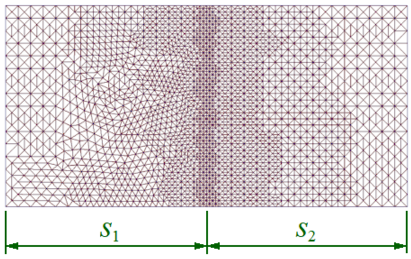


Figure 2. **Mesh of a two-layer roll finite element model (flat, axisymmetric model)**

ANALYSIS OF RESEARCH RESULTS

The influence of deviations on the contact pressure, and at the same time on the stress state, at different sizes of the interference is presented in Fig. 3. Model 2 was "more sensitive" to the change in the interference size. At a small interference, when the interference is about 0.36 or less percent. of the outer diameter of the connection (or about 5 percent. of the total wall thickness of the connection), changing the dimensional deviations almost does not change the contact pressure (changed by only about 1.04 carats). When the interference is not less than 1.43 percent. of the outer diameter (or about 20 percent. of the total wall thickness), then when the deviations change from the smallest possible to the largest possible value, the contact pressure changes by up to 1.21 times. If we consider that a significant change in contact pressure is 10 percent or more, then dimensional deviations should be evaluated when the interference is about 0.7 percent. or more of the outer diameter of the joint (this would correspond to approximately 10 percent of the total wall thickness of the joint).

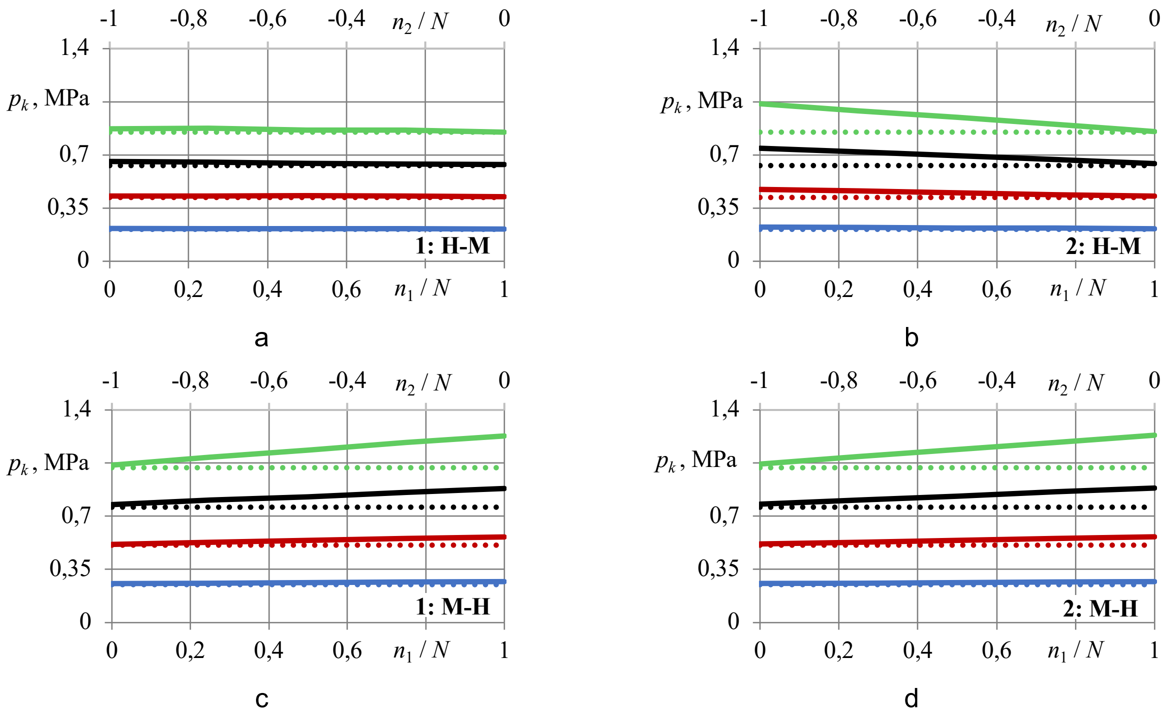


Fig. 3**. Dependence of contact pressure pk on deviations *n1* and *n2* and stress N, when: $p_0 = 0$; $d_2 = 14$ mm, $s_1 = s_2 = 0.50$ mm; ■ – $N = 0{,}025$ mm; ■ – $N = 0{,}050$ mm; ■ – $N = 0{,}075$ mm; ■ $N = 0{,}100$ mm; a – 1st model H-M type; b – 2nd model H-M type; c – 1st model M-H type; d – 2nd model M-H type; (———) – calculated using BEM; (· · · ·) – calculated according to formula (1)**

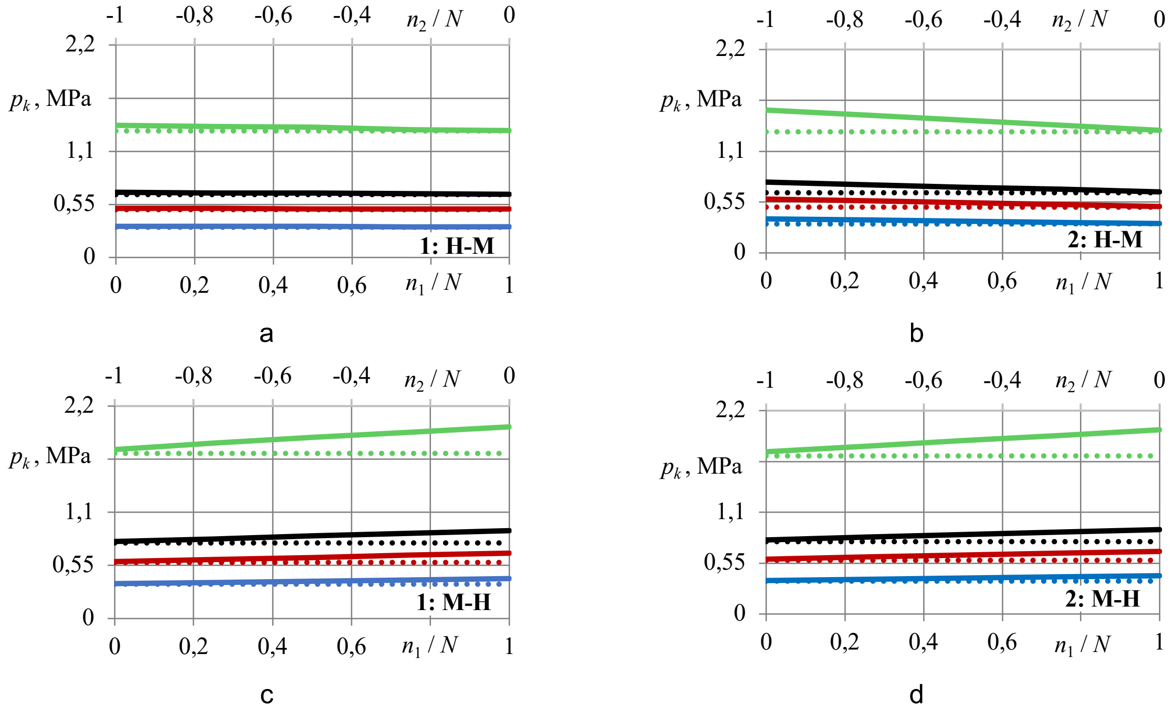


Fig. 4. **Dependence of contact pressure p_k on deviations n_1 and n_2 and outer diameter d_2, when: $p_0 = 0$; $N = 0{,}077$ mm; $s_1 = s_2 = 0{,}5$ mm; ■ – $d_2 = 20$ mm;■ – $d_2 = 16$ mm; ■ – $d_2 = 14$ mm; ■ –$d_2 = 10$ mm; a – 1st model H-M type; b – 2nd model H-M type; c – 1st model M-H type; d – 2nd model M-H type; (———) – calculated using BEM; (· · · ·) – calculated according to formula (1)**

The influence of deviations and the outer diameter of the double-layer roll on the contact pressure is presented in Fig. 4. The contact pressure increases with decreasing diameter. The least "sensitive" to the change in deviations was the H-M type of model 1. Calculations showed that when changing the outer diameter, the "sensitivity" of the contact pressure to deviations, i.e., the ratio pk / pk (1), changes very slightly (here pk – contact pressure calculated using the finite element method; pk (1) – contact pressure calculated according to formula (1)). When the outer diameter is increased

ISSN 2029-1280, eISSN 2669-0071. Taikomieji tyrimai studijose ir praktikoje – Applied Research in Studies and Practice, 2024, 20.

by 2 times, when the resistance is constant and the deviations are changed, the maximum change in pk / pk (1) from 16.3 percent. decreased to 16.1 percent.

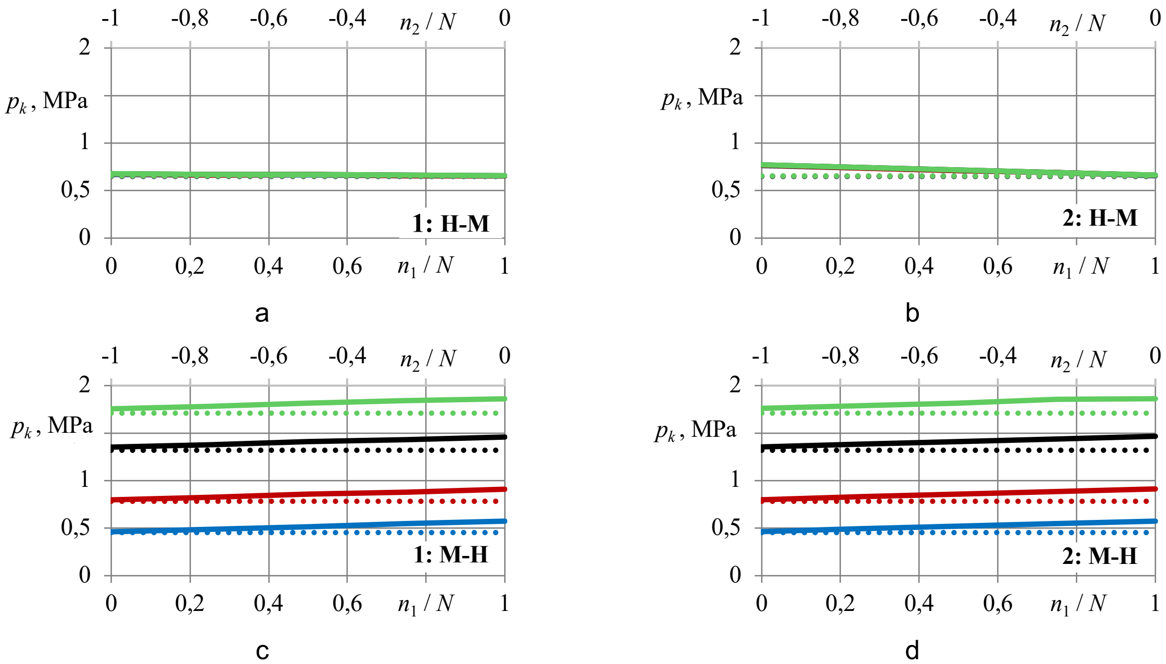
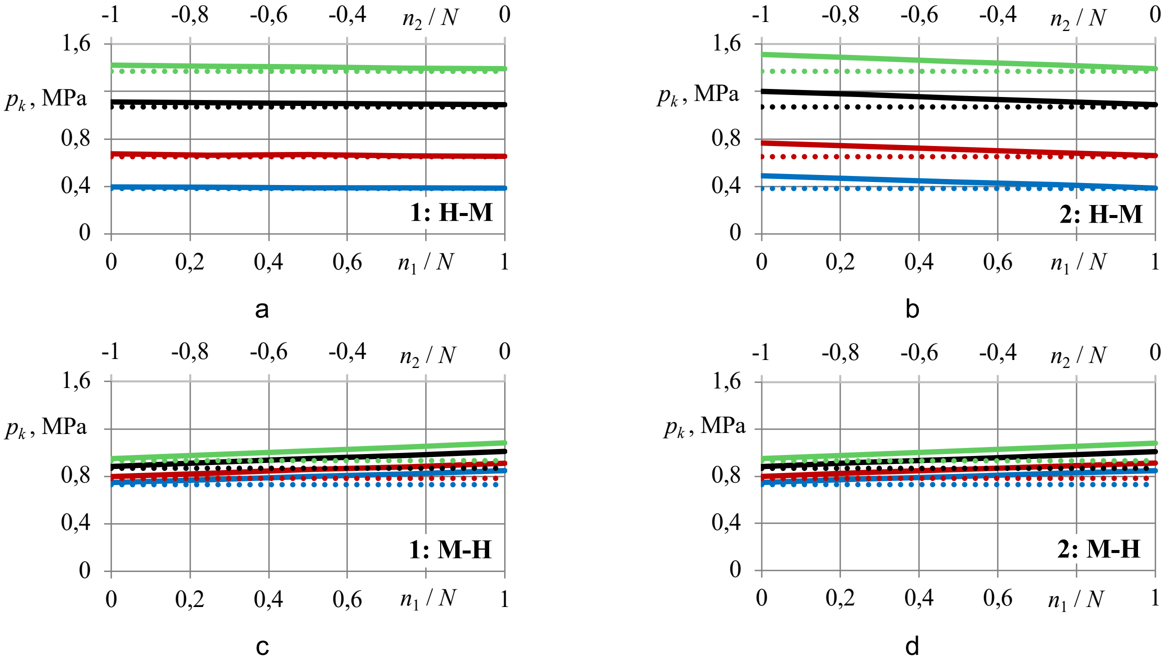


Fig. 5. **Dependence of contact pressure p_k k on deviations n_1 and n_2 and inner layer thickness s_1 , when: p_0 = 0; N = 0.077 mm; d_2 = 14 mm; s_2 = 0.5 mm; ■ – s_1 = 0.3 mm; ■ – s_1 = 0.5 mm; ■ – s_1 = 0.8 mm; ■ – s_1 = 1.0 mm; a – 1st model H-M type; b – 2nd model H-M type; c – 1st model M-H type; d – 2nd model M-H type; (——) – calculated using BEM; (· · · ·) – calculated according to formula (1)**



6 Fig. **Kontaktinio slėgio p_k priklausomybė nuo nuokrypių n_1 ir n_2 bei išorinio sluoksnio storio s_2 , kai: p_0 = 0; N = 0,077 mm; d_2 = 14 mm; s_1 = 0,5 mm; ■ – s_2 = 0,3 mm; ■ – s_2 = 0,5 mm; ■ – s_2 = 0,8 mm; ■ – s_2 = 1,0 mm; a – 1-o modelio H-M tipas; b – 2-o modelio H-M tipas; c – 1-o modelio M-H tipas ; d – 2-o modelio M-H tipas; (——) – apskaičiuota taikant BEM; (· · · · ·) – apskaičiuota pagal (1) formulę**

The influence of deviations and the thickness of the inner layer of the two-layer roll on the contact pressure is presented in Fig. 5. By increasing the thickness of the inner layer in both models 1 and 2, the contact pressure increases in the H-M type joints, while in the H-M type joints it practically does not change. By increasing the inner wall thickness by about 3 times, when the stress is constant and the deviations are changed, the maximum change in $p_k / p_{k\,(1)}$ (1) obtained in the M-H type joint from 27.6 percent. decreases to 8.8 percent., while in the H-M type joint the change in $p_k / p_{k\,(1)}$ increases slightly - in the 1st model from 2.6 to 4.3 percent., and in the 2nd model from 17.2 to 18.6 percent.

The influence of deviations and the thickness of the outer layer of the two-layer roll on the contact pressure is presented in Fig. 6. By increasing the thickness of the outer layer in both models 1 and 2, the contact pressure increases faster in H-M type joints than in M-H type joints. By increasing the outer wall thickness by about 3 times, when the stress is constant and the deviations are changed, the maximum change in $p_k / p_{k(1)}$ obtained in the M-H type joint practically does not change, while in the H-M type joint the change in $p_k / p_{k(1)}$decreases - in model 1 from 4.2 to 3.8 percent, and in model 2 from 28.9 to 10.4 percent.

The influence of deviations and internal pressure on the contact pressure is presented in Fig. 7. When increasing the internal pressure in both models 1 and 2, the contact pressure increases in the M-H type joints, while it practically does not change in the H-M type joints. When increasing the internal pressure from 0 to 1 MPa, when the stress is constant and the deviations are changed, the maximum change in $p_k / p_{k(1)}$ obtained in the M-H type joint decreases from 16.6 percent to 7.9 percent, and in the H-M type joint the maximum change in $p_k / p_{k(1)}$ decreases slightly - in model 1 from 3.6 to 5.1 percent, and in model 2 from 17.7 to 17.1 percent.

Regardless of the model used or the type of joint, the contact pressure calculated using the finite element method is always higher than the theoretical one, i.e. calculated using formula (1) (see Fig. 3-7).

Regardless of the model used, the contact pressure in M-H type joints obtained by applying the finite element method best agrees with the contact pressure obtained using formula (1) when the deviation of the inner layer is equal to 0, and the deviation of the outer layer is the largest possible (in absolute value), i.e. equal to the magnitude of the stress. The opposite trend was obtained in H-M type joints: the contact pressure obtained by the finite element method best agrees with the theoretical contact pressure when the deviation of the inner layer is the largest possible, and the deviation of the outer layer is equal to 0 (see Fig. 3-7).

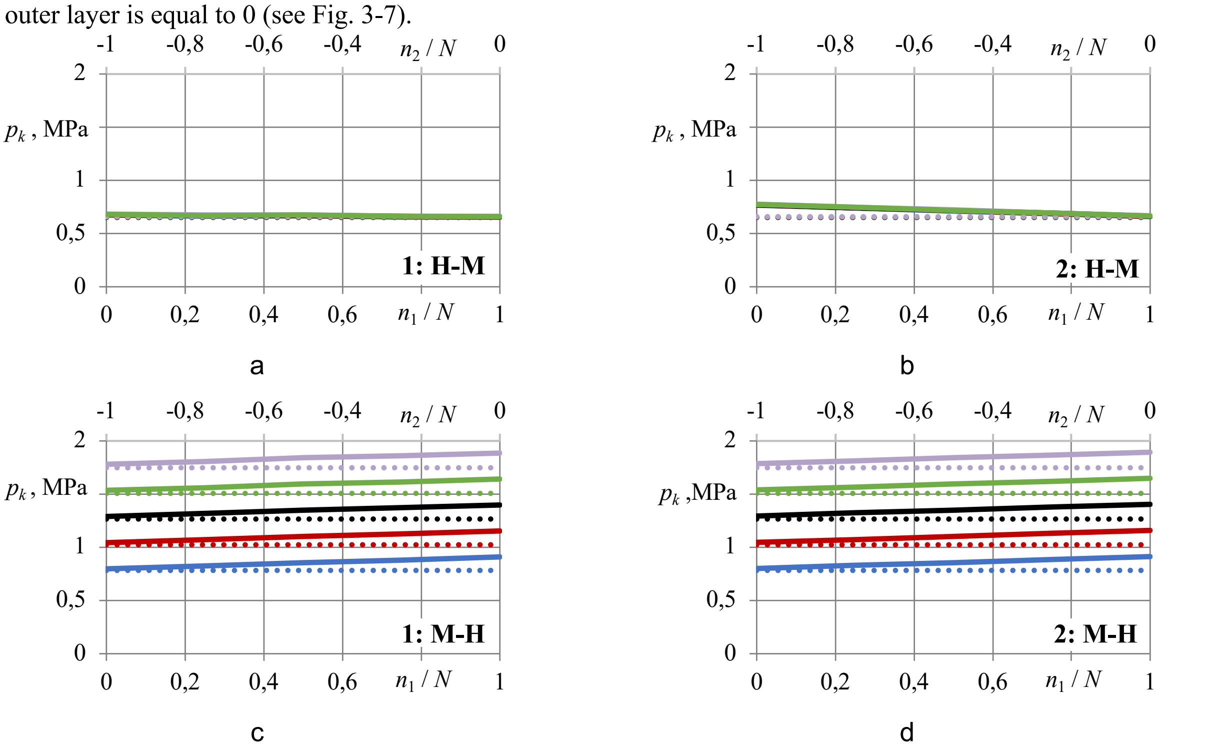


Fig. 7. **Dependence of contact pressure p_k on deviations n_1 anf n_2 and internal pressure p_0, when: N = 0.077 mm; d_2 = 14 mm; $s_1 = s_2$ = 0,5 mm; ■ – p_0 = 0; ■ – p_0 = 0,25 MPa; ■ – p_0 = 0,5 MPa; ■ – p_0 = 0,75 MPa; ■ – p_0 = 1 MPa; a – 1st model H-M type; b – 2nd model H-M type; c – 1st model M-H type ; d – 2nd model M-H type; (———) – calculated using BEM; (· · · ·) – calculated according to formula**

CONCLUSIONS

1. The geometric model, in which the stress is obtained by changing the wall thicknesses so that the inner and outer diameters of the double-layer roll remain unchanged, is from 0 to 25 percent more "sensitive" to deviations than the geometric model, in which the stress is obtained by changing the diameters so that the wall thicknesses of the roll remain unchanged.

2. In M-H type joints (the inner layer is less rigid), the contact pressure obtained by applying the finite element method best coincides with the theoretical contact pressure when the deviation of the inner layer is equal to 0, and the deviation of the outer layer is the largest possible (in absolute value), i.e. equal to the stress value. And in H-M type joints (the outer layer is less rigid), the contact pressure obtained by the finite element method best agrees with the theoretical contact pressure, when the deviation of the inner layer is the largest possible, and the deviation of the outer layer is equal to 0.

3. By changing the geometry of the joint (outer diameter from 10 mm to 20 mm, inner and outer layer thicknesses from 0.3 mm to 1 mm) and the deviation values from the smallest possible to the largest, at a stress of 0.077 mm, the calculated (using the finite element method) contact pressure differed from the theoretical one by approximately 2 to 18 percent.

4. In a pressed joint, where the stress is about 1 percent. of the outer diameter of the joint, or about 10 percent. of the total wall thickness of the joint, the contact pressure calculated by the finite element method can be more than 10 percent higher than the theoretical contact pressure. higher if the sizes of the deviations of the injected parts are evaluated.

5. Regardless of the model used or the type of connection, the contact pressure calculated using the finite element method is always higher than the theoretical one.

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