EAN 2017
55th conference on experimental stress analysis

Comparison of Methods used for the residual Stress Analysis in a Pipe made from Polypropylene

František Fojtík[1, 2, a], Paška Zbyněk[2,b], Kolář Petr[2,c]

[1]IT4Innovations, VŠB – Technical University of Ostrava, 17. listopadu 15/2172 Ostrava-Poruba, Czech Republic

[2]Faculty of Mechanical Engineering, VŠB – Technical University of Ostrava, Department of Applied Mechanics, 17. listopadu, 2172/15 Ostrava, Czech Republic

[a]frantisek.fojtik@vsb.cz, [b]zbynek.paska@vsb.cz, [c]petr.kolar@vsb.cz

Keywords: Slitting method; hole drilling method; residual stresses.

Abstract. This contribution is focused on the problematics of measuring residual stresses in a pipe, which is made from polypropylene. The pipe is usually used for supply. Two experimental approaches were used to analyse the residual stresses. The slitting method was applied to find out the hoop residual stresses. The results were then confronted with those gained from the hole drilling methodology. The distribution of the residual stresses along the thickness of the tube was investigated by these two experimental methods. The FEM analysis was performed and the results were compared with the results from the measurements.

Introduction

It is well known that inside every fabricated part there is some level of the residual stresses. The producers are trying to reduce the amount of the residual stresses by applying many techniques. Lifespan of component is then usually decreased, which is caused by influence of the residual stresses. Therefore it is desirable to know their amount and distribution.

The residual stresses in materials are caused by external forces, deformation of the component, or by the temperature acting on the component (in the whole component or only its pieces), which must cause elasticity plasticity state inside the component. Two experimental approaches were used to analyse the residual stresses in the polypropylene pipe. The first method is the slitting method, which was in publication [1, 2, 3] applied for analysis of the pipe made from different material. In the above-mentioned literature, apart from the dependence of lifespan on residual stresses, changes of stresses and other mechanical parameters were also investigated in time with interval of several weeks. In this contribution, the changes of mechanical parameters in time are not observed, even if it takes place in polypropylene material. The results obtained by the slitting method and by the hole drilling method are also compared. If these experimental methodologies are applied to plastic materials, then some difficulties may occur [4, 5, 6]. The experimental results are then confronted with those obtained from the FEM analysis.

Characteristics of the pipe

The outer diameter of the pipe, which was used for residual stresses measurement, is 63mm. The thickness of the wall is 10.5mm. Pressure category is denoted PN 20. The pipe is made from polypropylene – PPR. This type of the pipe is used for cold water distribution to the maximum pressure of 1 MPa. Some parameters of the pipe are listed in Table 1. The parameters were adopted from the catalogue lists. The elastic modulus was determined by three point bend tests.

Property	Value	Unit
Density	905	$[kg \cdot m^{-3}]$
Elastic modulus	850	$[MPa]$
Poisson′s ratio	0.40	$[-]$
Yield strength	25	$[MPa]$
Ductility at yield point	10	[%]
Coefficient of thermal expansion	0.00012	$[K^{-1}]$
Coefficient of thermal conduction ($20°C$)	0.24	$[W \cdot m^{-1} \cdot K^{-1}]$
Specific thermal capacity ($20°C$)	2000	$[J \cdot kg^{-1} \cdot K^{-1}]$

Tab. 1. Physical and thermal parameters of the material.

Determination of the hoop stress by the slitting methodology

Procedure of the slitting method is based on the methodologies described in literature [1, 2, 3]. The wall of the pipe was imaginary divided into 10 layers and then sliced up into rings, which were 10mm wide. In total, 13 specimens were obtained. Specimen number one was without machining. Turning was used to remove first six layers from the inner side of the specimens denoted 2 to 6. In the same way, the first six layers were removed from the outer side of the specimens denoted 8 to 13 (Fig. 1). A CNC controlled turning machine was used for this task.

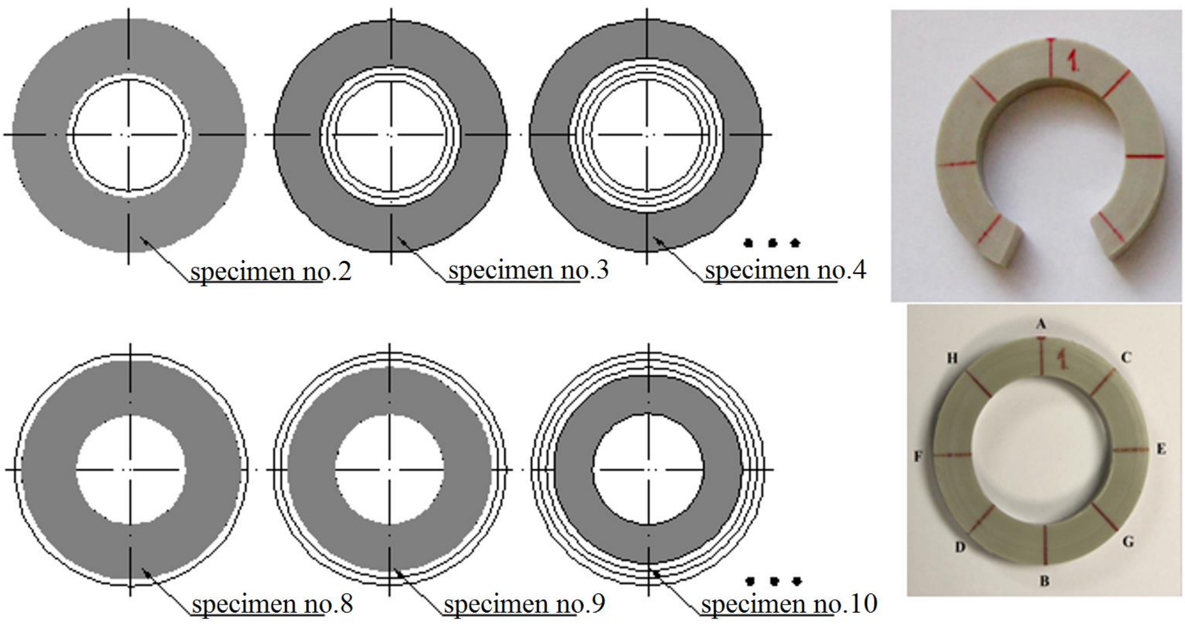

Fig. 1 Scheme of the turning operation on the left side. On the right side, specimen number one before and after the cutting can be seen. The points of measurement are marked.

Outer and inner diameter of the specimens were measured in several places and several cuts. (Figure 1). The measurements were performed by applying Wenzel LH65 X3M with the touch probe SP25M with modulus SM25-1. For each ring, the arithmetic mean value was determined from the measured values in different places. The change of the outer diameter was, after the segment was cut, measured in the same way and is shown in Figure 2.

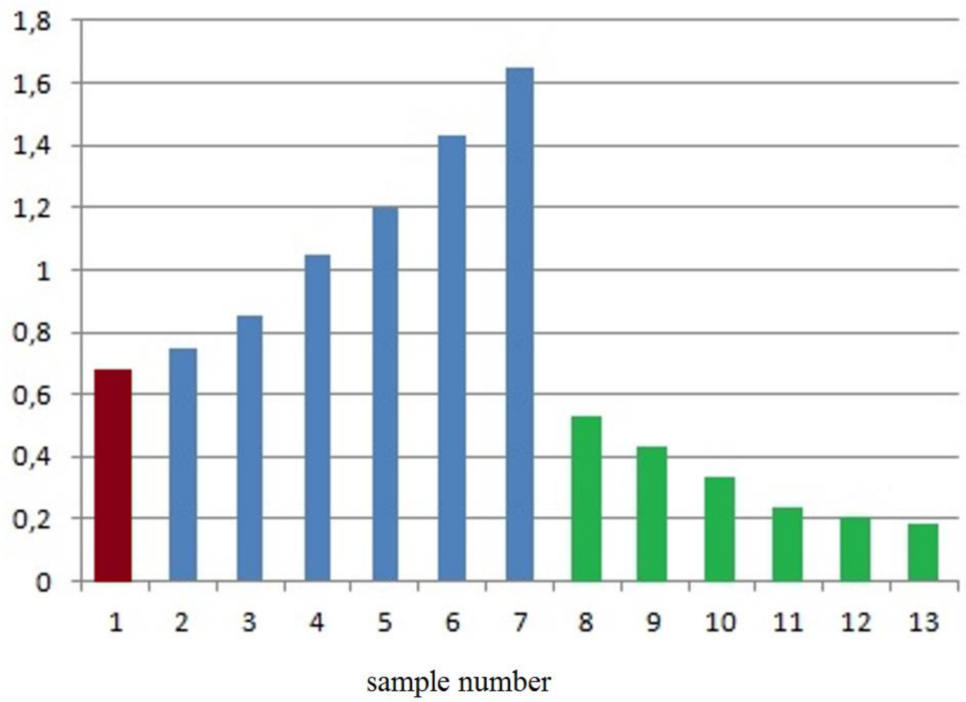

Fig. 2. Change of the outer radius.

The change in the curvature of the curved beam neutral surface in Figure. 2 plays the key role for the stress distribution determination in the wall of the pipe:

$$\frac{1}{R^I} - \frac{1}{R} = \frac{M}{E * A_s * e * R}, \quad (1)$$

where R is the radius of neutral surface in original state, R^I is the radius of the neutral surface in the deformed state, M is the bending force, E is elastic modulus, A_s denotes cross section area, and e is the eccentricity.

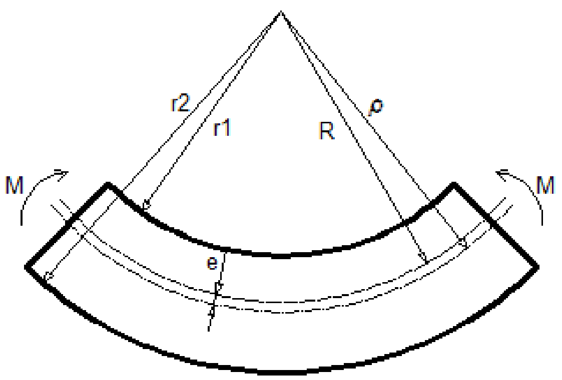

Fig. 3. Scheme of curved beam element.

If the wall of the pipe is divided into n layers with the same width, then each layer i has radius r_i, stress components σ_i and moment M_i. The bending force depends on the position R of the neutral surface and can be determined by equation:

$$M_i = F_i(R - r_i) = \sigma_i \cdot \Delta r \cdot W * (R - r_i)\,, \tag{2}$$

where $\Delta ri = r_{i+1} - r_i$ a W is axial dimension of the ring. Overall bending force corresponds to the change of the curvature of the non machined ring:

$$M = \sum_{i=1}^{n} Mi\ . \tag{3}$$

The condition of equilibrium must be satisfied:

$$\sum_{i=1}^{n} \sigma i = 0\ . \tag{4}$$

The distribution of the residual stress along the wall of the tube is plotted in Fig. 6 in the manner from the inner to outer diameter. On the inner diameter, there is the tensile stress, but on the outer diameter, there is the compressive stress. The stress in the absolute value is bigger on the outer diameter. This is due to manufacturing process, when cooling is only on the outer surface. The fluctuations in the upper half of the graph may be the consequence of the inaccurate measurements.

Determination of the residual stress by the hole drilling methodology

The procedure of measuring residual stresses by the hole drilling method can be found in literature [5]. The procedure according to standard ASTM E 837 – 13a [7] is also widely used. The integral methodology or the methodology of power series are suitable for determination of the stress gradient under the surface [5]. The strain gauge rosette RY 1.5/120M was glued on the pipe. Another rosette was added to eliminate influence of temperature. A special milling-cutter for plastic materials was used to drilling hole 1.8mm of diameter to the depth of 2mm.

The procedure was performed in accordance with the ASTM standard. The calibration constants were determined from the experimental setup on beam with equivalent strength, and these constants are valid for this material, strain gauge rosette, and chosen procedure. The measurement was carried out on inner and outer surface of the pipe. The results of the residual stress gradient in the circumferential direction, obtained by the hole drilling method, across the depth of the hole can be also seen in Figure 6. On the outer surface (0.05 mm under the original surface), the hoop stress value of -5.15 MPa was determined by the numerical approach. On the inner surface, the value of 1.41 MPa was established. The main advantage of this method is determination of the principal stresses and their direction, so stresses in any direction can be calculated. Furthermore, we obtain idea about the residual stress in the axial direction of the pipe.

Residual stresses from the FEM analysis

Analysis was performed in the MSC Patran software with the MSC Marc solver [8]. Simulation was, due to symmetry, carried out on one quarter of the model. Material parameters are listed in Table 1. Isoparametric quadratic elements QUAD 4 were used for representation of the finite element model.

The inverse approach was used with regard to the manufacturing process - heating up of the model. The initial temperature condition of 283 K (the temperature of cooling bath) was applied on the cooled surfaces of the model. In the next step, another temperature condition of 403 K (the temperature of the pipe when it is coming to the cooling bath) is applied on the outer surface of the pipe. The pipe is cooled only on the side of the outer diameter. The time of the simulation was 144 s, which is exactly the cooling time in the manufacturing process.

The boundary conditions are illustrated in Figure 4. The values of the normal stress in the circumferential directions are shown in Figure 5. The calculated residual hoop stress on the outer surface takes the value of -6.12 MPa and on the inner surface 4.07 MPa.

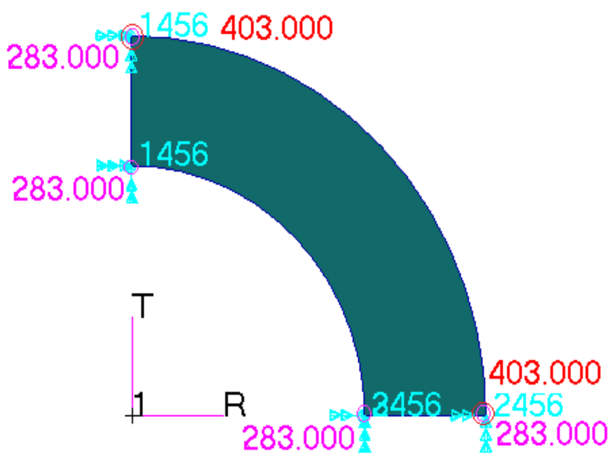

Fig. 4. Boundary conditions and thermal load.

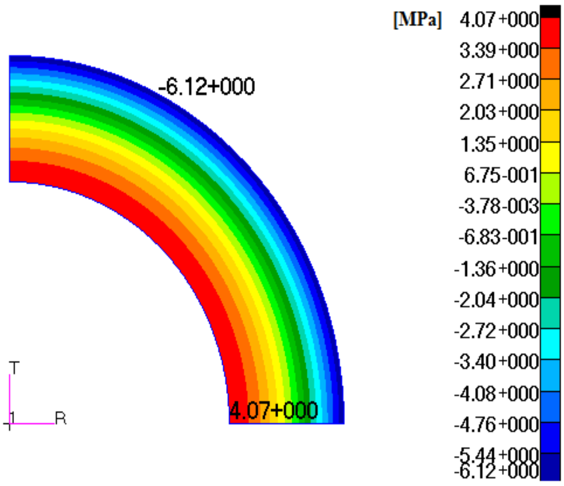

Fig. 5. Normal stress distribution in circumferential direction.

Comparison of results

The results obtained by the experimental measurements and FEM analysis are shown in Figure 6. It also shows the circumferential stresses calculated according to the slitting method. On the outer surface, the hoop stress has the value of -6.84 MPa. On the inner surface, which corresponds to the first removed layer, the hoop stress has the value of 3.37 MPa.

The residual stresses were also investigated by the hole drilling method. This methodology enables principal stresses and their direction to be determined, and thus the stresses in any direction can be calculated. Furthermore, we obtain idea about the residual stress in the axial direction of the pipe in one measurement. The results of the residual stress gradient in the circumferential direction, obtained by the hole drilling method, across the depth of the hole can also be seen in Figure 6. On the outer surface (0.05 mm under the original surface), the hoop stress value of -5.15 MPa was determined by the numerical approach. On the inner surface, the value of 1.41 MPa was established. From the measurement, it is apparent that on the outer surface the residual stresses correspond with the results obtained by the slitting method. On the side of the inner diameter, some difference can be seen. The difference may be caused by the manufacturing process, when the pipe is extruded over the mandrel. This process caused deformation in the surface layer and new distribution of the residual stresses so the slitting method cannot catch them. The results gained from the slitting method are shown in Figure 6, when the thick curved beam theory was implemented. More information can be found in literature [1].

The distribution of the residual stresses across the thickness of the pipe, which was determined by the FEM approach, is shown in Figure 6. The values of the normal stresses in the circumferential direction are shown in Figure 5. The calculated residual hoop stress on the outer surface takes the value of -6.12 MPa and on the inner surface 4.07 MPa.

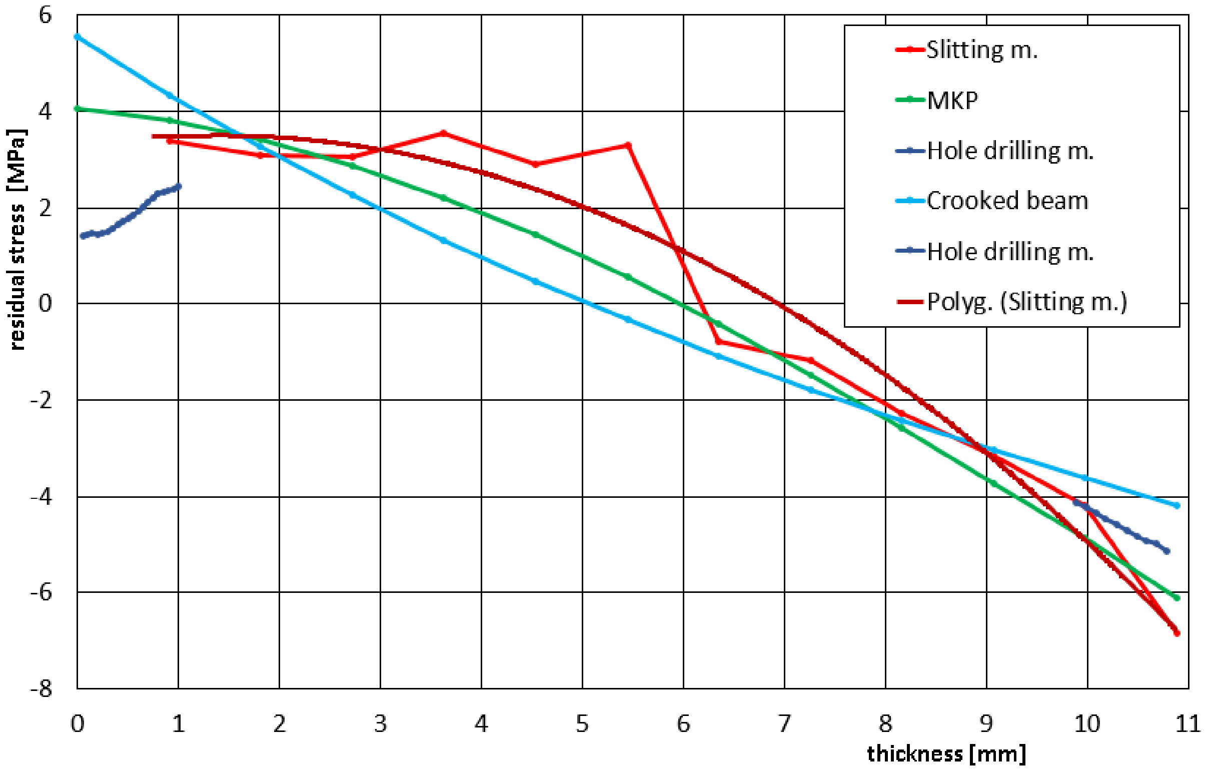

Fig. 6. The distribution of the residual stresses across the thickness of the pipe and approximation by the polynomial function.

Conclusion

This contribution is focused, in detail manner, on the comparison of the two experimental methodologies, the slitting method and the hole drilling method, carried out on the pipe, which is made from polypropylene. The experimental results have been verified with the results of the residual stresses obtained by the FEM approach. The distribution of the residual stresses across the thickness of the pipe can be seen in Figure 6. Quite good correspondence between the experimental methodologies and the FEM approach is observed on the outer surface. On the inner surface the situation is different. The evaluation of the residual stresses by the slitting method is carried out after the first layer is removed, then the results obtained from the slitting method agree quite well with the results from the FEM analysis. The results from the hole drilling method are different from those obtained from the FEM analysis. This is probably caused by manufacturing, when the pipe is extruded through the thorn. This processing caused the deformation of the outer surface due to cooling of the pipe. The residual stresses are then redistributed and cannot be caught by the slitting method.

Acknowledgement

This work was supported by The Ministry of Education, Youth and Sports from the National Programme of Sustainability (NPU II) project "IT4Innovations excellence in science - LQ1602", by the Czech Science Foundation (GA15-18274S) and partially supported by the Specific Research (SP2017/136). The support is gratefully acknowledged.

References

[1] P. Kolar, Measurement of Residual Stresses in Plastics Separation Methods, Thesis, VŠB – TU Ostrava, 2014.

[2] J. Kucera, J. Krivanek, Morphology and internal stress distribution in the PP pipe wall. Deformation und Bruchverhalten von Kunstoffen. 2007, Merseburg.

[3] J. Z.W. Guan, J.C. Boot, A method to predict triaxial residual stresses in plastic pipes, Polymer Engineering and Science, October 1, 2004

[4] N. S. Rossini, M. Dassisti, K. Y. Benyounis, A. G. Olabi, Methods of measuring residual stresses in components. 2012, vol. 35, s. 572- 588

[5] G. S. Schajer, Practical Residual Stress Measurement Methods, Wiley, 2013.

[6] ASTM E 837 – 13a: Determining Residual Stresses by the Hole – Drilling Strain-Gage Method.

[7] K. Kolarik, Z. Pala, N. Ganev, F. Fojtik, Combining xrd with hole-drilling method in residual stress gradient analysis of laser hardened c45 steel. Adv Mater Res 996:277–282, 2014. doi:10.4028/www.scientific.net/AMR.996.277.

[8] Patran Element Library. http://web.mscsoftware.com/patran/current/html_patran/wwhelp/wwhimpl/js/html/wwhelp.htm#href=Marc/marc05_ examples 2.7.6.html