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Study the Effect of the Stress generated for an internally Pressurized Thick-walled Cylinders containing an Internal Radial Hole Using FEM

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Abstract: *This paper Study the Effect of the stresses generated incrementally in Finite Element Method under internal pressure. The holes, which can be considered as a stress raiser, are established in internal surface. The effect of the hole depth, which varied between 0.5 to 4.5 mm, and the hole diameter, which varied between 1 to 2.5 mm, on the generated stresses are presented and also, the effect of the stress concentration factor. It was found that, the hoop stress increases due to increase of the hole parameter, diameter and depth. Moreover, the characterizations of notch may be used to determine the maximum stress limit.*

Keywords: FE analysis, Thick-walled cylinder, ABAQUS

1. INTRODUCTION

Many efforts have carried out on analytical and experimental aspects of thick-walled tubes under internal pressure, external pressure, torsion, temperature gradient, and combinations of these loads. However, the internal pressure is often the fundamental mode. Internal pressure carried by the hollow cylinders develops both radial and tangential stresses with values, which dependent on the radius of the cylinders, [1]. Determination of radial stress σr and tangential stress σt, which can be carried out under the assumption the longitudinal elongation is constant around the circumference of the cylinder.

Analysis of pressure vessel and hydraulic cylinder may have a variety of phases, [2]. Mechanical loads, elastic and deformation analysis, are the most common phase may be applied. An analytical solution for the stress, strain and displacement fields in an internally pressurized thick-walled cylinder of an elastic strain-hardening plastic material in the plane strain state were presented, [3]. The classical plasticity-based solution of the internally pressurized thick-walled spherical shell of an elastic–plastic material was recovered, [4]. It was found that the gradient solution could capture the size effect, where the classical solution does not have the same capability.

In case of, the internally pressurized thick-walled was studied using no small micro length scale, [5].The numerical data was demonstrated that the classical plasticity-based solution and the gradient plasticity-based solution predict almost identical results. Fracture mechanics analysis of cylindrical pressure vessels was carried out. The study was included examples of cracks growth in pressure vessels and cannons, [6]. Furthermore, the study was described fracture mechanics test method, which were developed specially for testing of cylindrical geometrics. The study was included, also, the effect of tension residual stress and crack shape beside the life calculation methods for cylindrical pressure vessels.

A three-dimensional finite element modeling was considered to analysis the generated stresses due to a longitudinal crack in wall cylinder, [7]. The stress intensity factor for external cracks has a major effect compared to internal cracks. It was found that, the maximum stress intensity factor was located at the corner points of the crack.

Semi-elliptical cracks, also, was considered. Three-dimensional cracks were analyzed using three-dimensional finite element modeling, [8]. The results were showed that, fatigue crack grow of a semi-elliptical shape grows independent of the initial shape of the crack. A three-dimensional finite element technique was used to simulate crack shape developments from elliptical arc cracks, [9]. The study was carried out at different aspect radius for round bar under axial tension. The aspect ratio changes for the elliptical cracks were predicated and compared with some published experimental results.

The stress concentration factor for an internally pressurized cylinder containing a radial U-notch along length studied, [10]. The external to internal radius ratio has considered being equal to 1.26, 1.52, 2.00, and 3.00 and the notch radius to internal radius ratio had a constant value of 0.026. The U-notch depth was varied from 0.1 to 0.6 of the wall thickness. It was found that, even relatively small notches were introduced large stress concentrations and

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were disrupted the hoop stress distribution all over the cross section. The stresses generated incrementally in Finite Element Method under internal pressure. The holes, which can consider as a stress raiser, established in external surface. The effect of the hole depth, which varied between 0.5 to 4.5 mm, and the hole diameter, which varied between 1 to 2.5 mm, on the generated stresses are presented, [11]. It was found that, the hoop stress increases due to increase of the hole parameter, diameter and depth. The inner surface texture of the cylinder was simulated with sinusoidal, squared and saw-tooth waves, where Finite Element Method "FEM" package is used to evaluate its effects, [12]. Based on detailed three-dimensional elastic finite element analysis, the elastic stress concentration factor for a pipe with local wall thinning was considered, [13]. The Results of stress concentration factors were tabulated for practical use, and the effects of relevant parameters such as pipe and defect geometries on stress concentration factors were discussed. Local deformation field and fracture characterization of V-notch were studied experimentally using coherent gradient sensing, [12]. The local deformation field and fracture characterization of V-notch tip with different V-notch angles were experimentally investigated using three-point-bending specimen via coherent gradient sensing method. The stress factor obtained from coherent gradient sensing measurements shows a good agreement with finite element results. A three notch sizes of the same stress concentration factor were considered, [13]. The high cycle fatigue limit stress can be corresponding to a life of 106 cycles was experimentally determined at a stress ratio of 0.1 and a frequency of 25 Hz at room temperature. The stresses were calculated using finite element analysis and the specimens were analyzed using scanning electron microscopy. It was found that, the notch was affected by a combination of the stress and plastic strain fields at the notch tip. The aim of this work presents simulations of internal holes in the wall of cylinder. The stresses were generated incrementally in Finite Element Method under internal pressure. The holes, which can be considered as a stress. The effect of the hole depth, which varied between 0.5 to 4.5 mm, and the hole diameter, which varied between 1 to 2.5 mm, on the generated stresses are presented and also, the effect of the stress concentration factor.

2. FINITE ELEMENT MODEL CREATION

A Finite Element package is used to predict the effect of surface texture parameters on the generated stresses in the thick-walled cylinder under the action of internal pressure. The investigated object is an extruded thick-walled cylinder of stainless steel grade 630. The details of the cylinder dimensions and the mechanical properties are shown in the following table, [16]:

Cylinder internal diameter	84 mm
Cylinder external diameter	114 mm
Cylinder height	335 mm
Internal pressure	12 MPa
Modulus of elasticity "E"	196 GPa
Poisson's ratio "µ"	0.3

The stresses were generated incrementally in Finite Element Method under internal pressure. The holes, which can be considered as a stress raiser, are established in internal surface. The effect of the hole depth, which varied between 0.5 to 4.5 mm, and the hole diameter, which varied between 1 to 2.5 mm, on the generated stresses are presented and also, the effect of the stress concentration factor. In addition, the effect of excess internal pressure has been studied, where an increase of 5%, 10%, 20%, 30% and 40% of the nominal acting pressure is considered.

For this study several methods were tested. Finite element analysis offers many ways to analyze structures; it requires an understanding of the program and subject being modeled. If the operator does not use the correct model, time is wasted and more importantly the data is useless. Element types included shell and solid elements. In the case of shell elements, linear and quadratic elements were compared. Models tested included two-dimensional models "Model I". Contact elements were then tested to determine how best to employ them to determine contact points between nodes.

3. COMPARISON BETWEEN ANALYTICAL AND FE SOLUTIONS

The results of FEM are compared with of analytical model. The analytical solution can be obtained from Lame's equations, which are used to determine both of radial and hoop stress.

Therefore, the radial stress can be expressed as follows:

$$\sigma_r = P_i R_i / (R_e^2 - R_i^2) [1 - (R_e^2/R^2)] \qquad 1$$

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Therefore, the hoop stress can be determined from the following relation:

$$\sigma_t = P_i R_i / (R_e^2 - R_i^2) [1+ (R_e^2/R^2)] \qquad 2$$

Where;

P_i: The internal pressure and has the value of 12MPa,

R_e: The external radius and has the value of 57mm,

R_i: The internal radius and has the value of 42mm,

R: The radius for the point at which the stresses is calculated, Where $R_i < R < R_e$.

According to the analytical calculations of the radial and hoop stresses generated in thick cylinders, the radial stress introduced in the cylinder due to internal pressure of 12 MPa, varies between zero at the outer surface and -12 MPa at the inner surface of the cylinder, i.e., σ_{ri} = -12MPa and σ_{ro} = 0 MPa. Also, the hoop stress introduced in the cylinder due to internal pressure, varies between 40.5 MPa at the inner surface and 28.5 MPa on the outer surface of the cylinder, i.e., σ_{ti} = 40.5 MPa and σ_{to} = 28.5 MPa. Fig. 1 shows the variation of the radial and hoop stresses across the cylinder thickness.

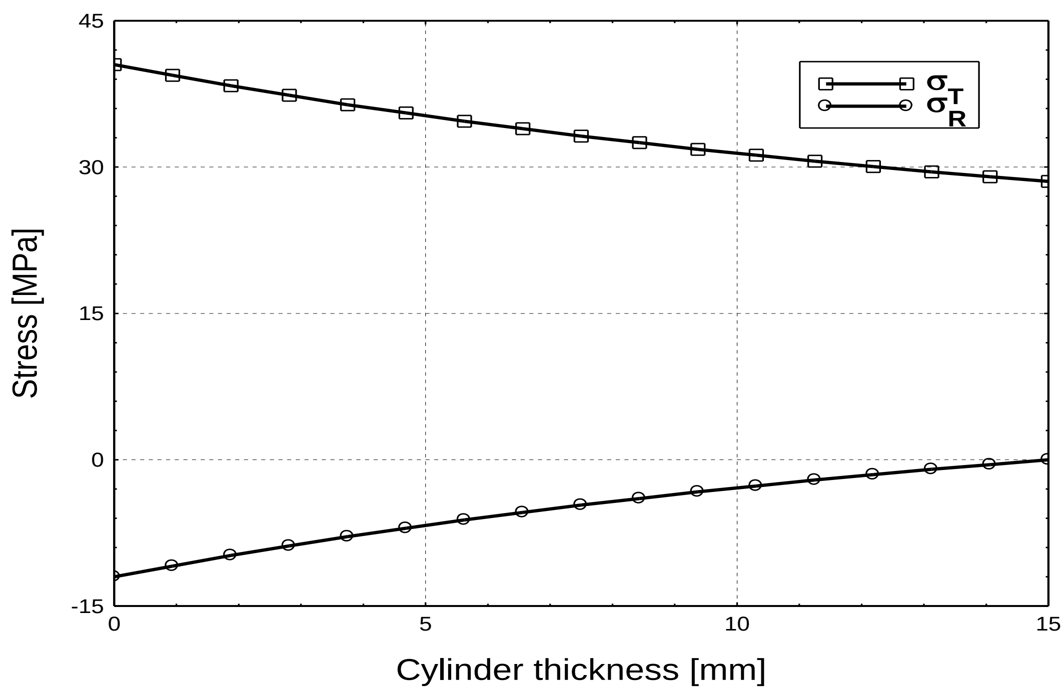

Fig. 1 Radial and hoop stresses generated on the cylinder due to internal pressure of 12MPa

According to the simulation of non-notched thick-wall cylinder using finite element method (FEM), a good agreement has been detected between the results and that obtained from analytical solution. The radial stress introduced in the cylinder due to internal pressure of 12 MPa, varies between zero at the outer surface and -11.95 MPa at the inner surface of the cylinder with an error of 0.25%. The hoop stress introduced in the cylinder due to internal pressure, varies between 40.48 MPa at the inner surface with an error of 0.05% and 28.48 MPa on the outer surface of the cylinder with an error of 0.07%.

The results of FEM show the stresses at any point in two perpendicular directions, it is found that the values of the calculated stress at the horizontal direction (i.e. at Y=0) have a good agreement with the analytical values that introduced from the equations. Here, the radial stress is equivalent to the obtained values in the x-direction while the tangential stress is represented by the results in the y-direction. Moreover, it is important to notice that, the values in x- and y-directions at the horizontal section ($\Theta=0^o$, Y=0) is similar to the values of the stress in y- and x-directions at the vertical section ($\Theta=90^o$, X=0) receptively. Fig. 2 shows the stresses and the mesh of a quarter of the cylinder under internal pressure of 12 MPa.

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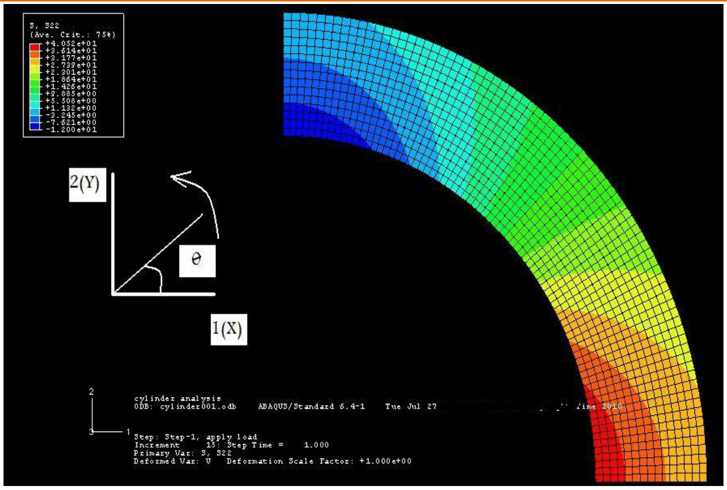

Fig. 2 The mesh and stress for one quarter of the cylinder

The effect of an internal hole, which can be considered as a stress raiser, is studied. Fig. 3 shows a quarter of the cylinder with the established hole. The mesh and generated stresses due to a hole with a diameter of 1mm and depth of 0.5 - 4.5 mm are shown in Fig. 4. It is found that, the maximum hoop stress takes place at the root of the hole and its value varies with the hole depth. The hoop stress at depth of 0.5 mm is found to be σ_t= 111.334 MPa and that at depth of 4.5mm is σ_t= 362.273 MPa for internal pressure of 12 MPa. Therefore, the hoop stress increases with the increase significantly of the hole depth.

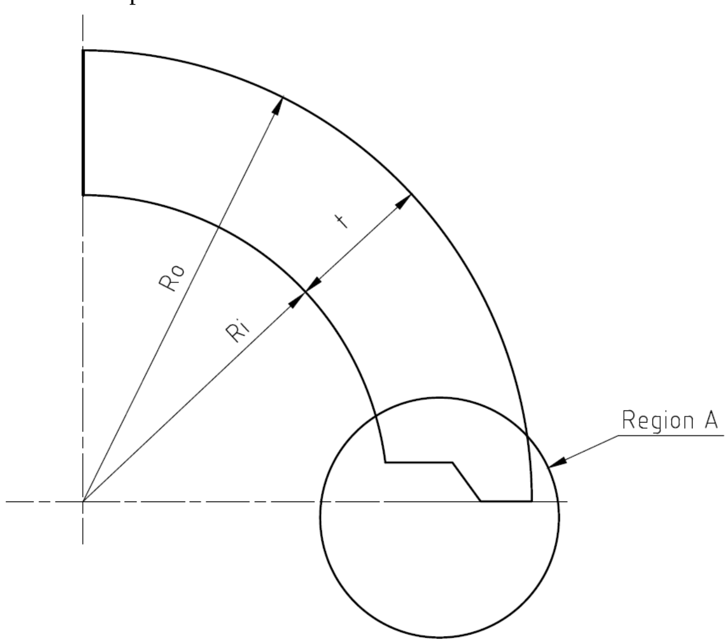

Fig. 3 Cylindrical internal stress raiser

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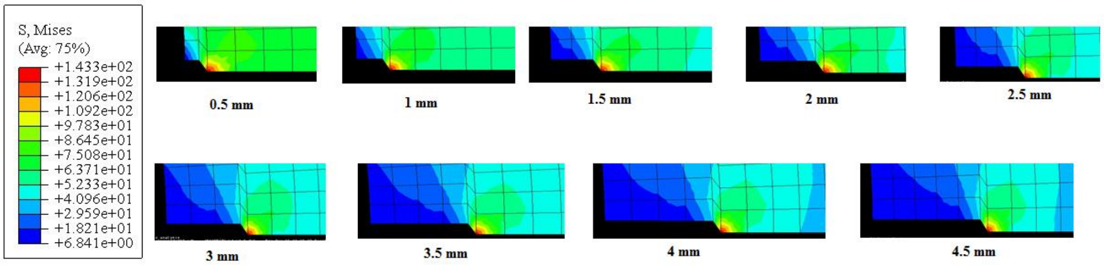

Fig. 4 Hoop stress generated for cylindrical stress raiser of 1mm diameter

The variation of the maximum hoop stress versus the internal pressure for holes with 1, 1.5, 2 and 2.5 mm diameter are shown in Fig. 5 to Fig. 8. It can be seen that, the increase of the both the internal pressure and the hole depth increase the hoop stress. Moreover, the stress values under the yield stress indicates the working safety region for the cylinder under the corresponding working pressure, while the stress values above the yield stress line indicates the critical working condition.

This means that, at working pressure of 15 MPa a hole with diameter 1 mm and depth of 2.5 mm insures safety operating conditions at this pressure. Also, the same case can be obtained for hole diameter of 1.5, 2 and 2.5mm with depth of 2, 2.5 and 2 mm receptively. However, Fig. 9 shows the stress concentration factors K_t versus hole depth for different hole diameter.

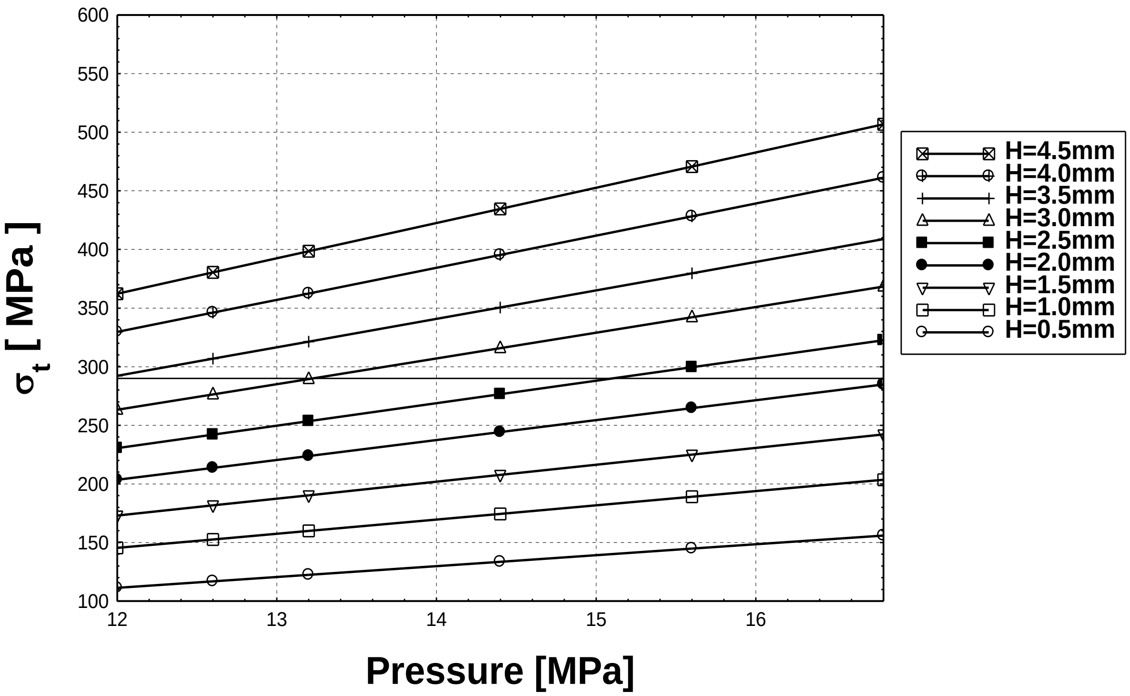

Fig. 5 Variation of tangential stress versus acting pressure for internal cylindrical raiser (internal hole) with 1 mm of different hole depth

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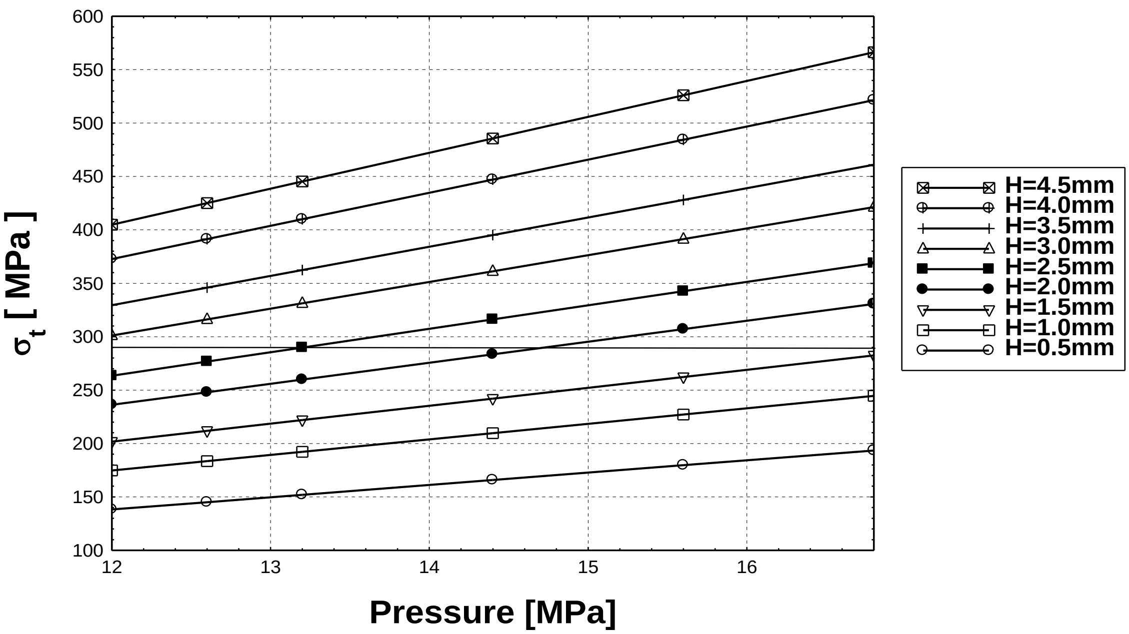

Fig. 6 Variation of tangential stress versus acting pressure for internal cylindrical raiser (internal hole) with 1.5 mm of different hole depth

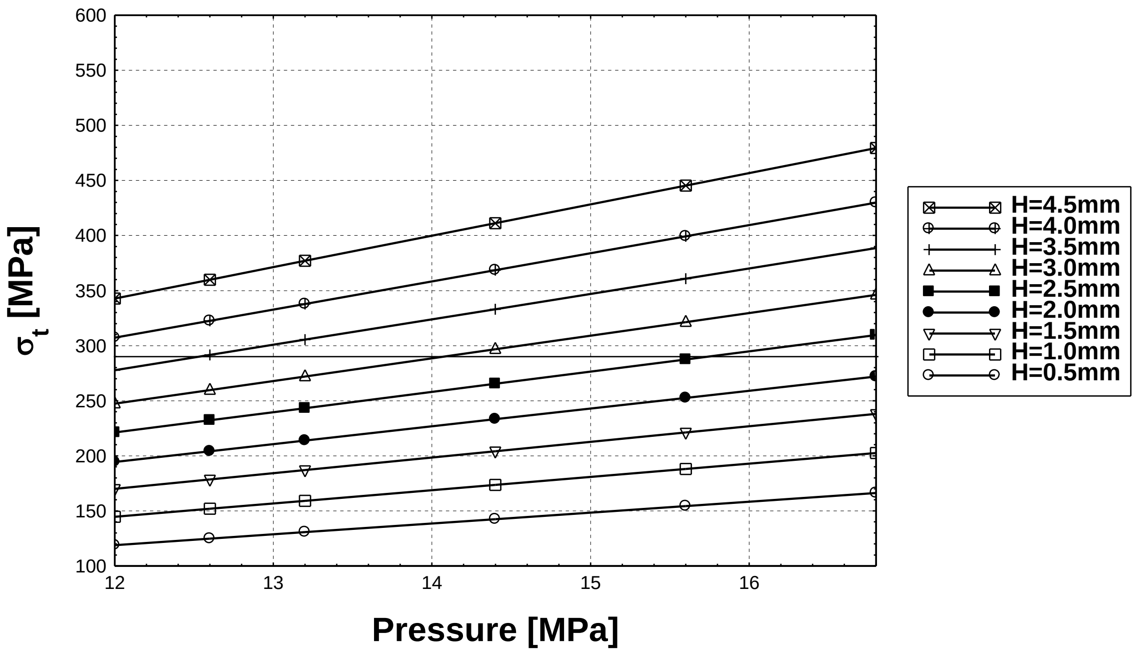

Fig. 7 Variation of tangential stress versus acting pressure for internal cylindrical raiser (internal hole) with 2 mm of different hole depth

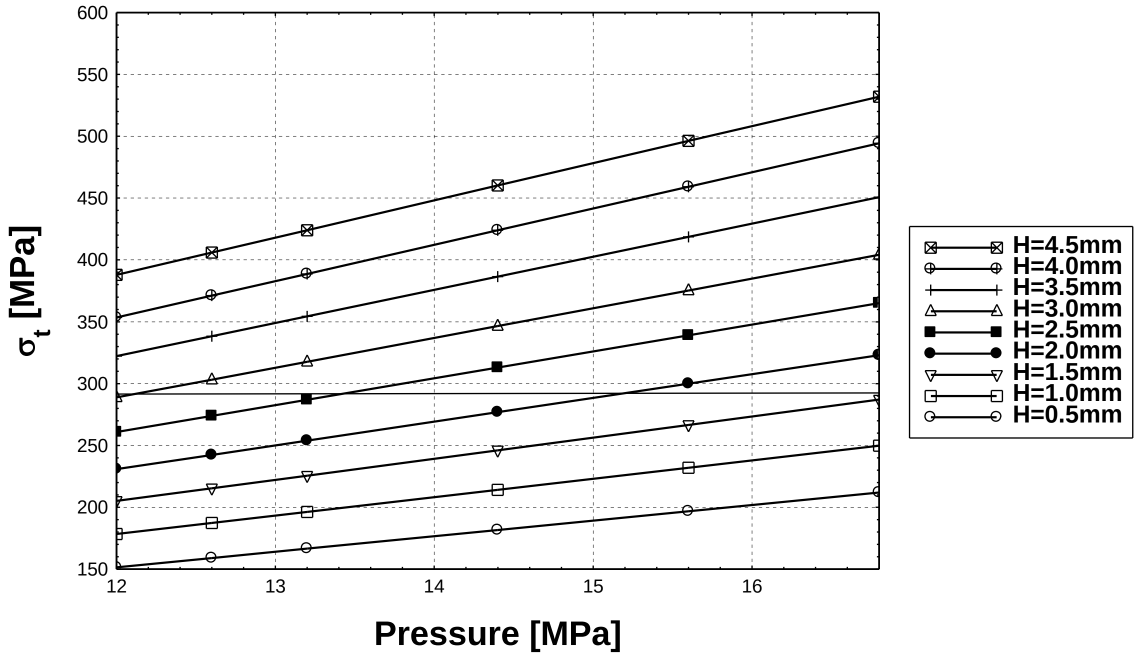

Fig. 8 Variation of tangential stress versus acting pressure for internal cylindrical raiser (internal hole) with 2.5 mm of different hole depth

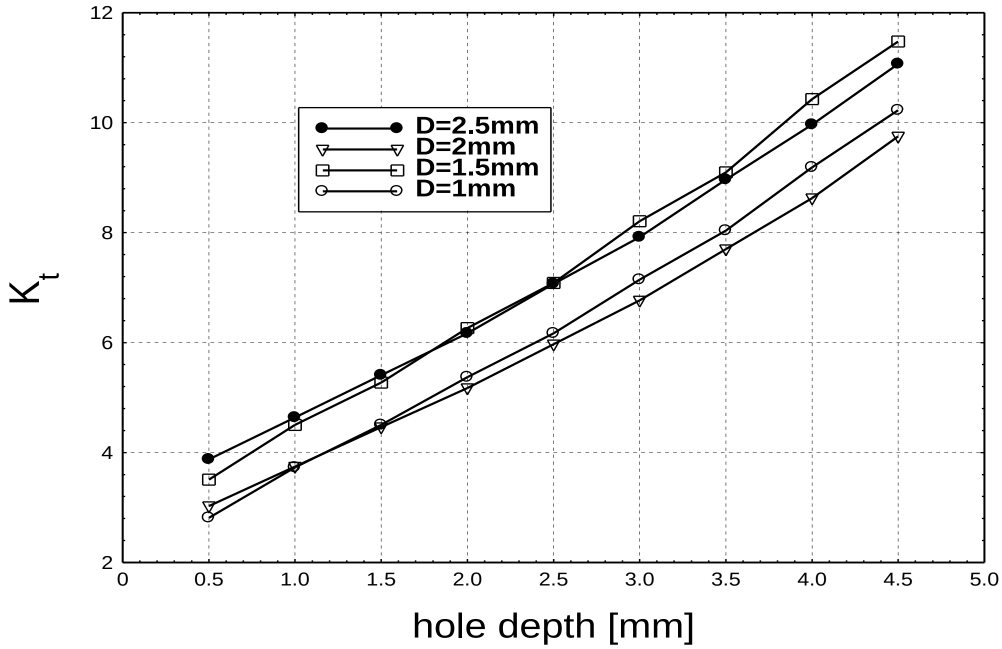

Fig. 9 Stress concentration factors versus hole depth for different hole diameter

4. Conclusions

According to the theoretical results, which obtained from the theoretical treatment of hydraulic cylinders, the following conclusions were drawn:

1. Presence of holes on the cylinder surfaces tends to increase the hoop stress. Furthermore, the hoop stress increase with increase of the hole diameter and depth.
2. The characterizations of holes affect significantly the maximum stress limit.
3. The concentration of stresses occurred at the hole root due to the sharp edge of the notch end.

4. The presence of the stress concentrations at the hole affects, as expected, the stress distributions not only locally but all over the section.
5. The larger is the thickness of the wall the higher was the K_t found.

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