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MEASURING, MATERIALS CHARACTERIZATION AND NUMERICAL SIMULATION IN PRESSURE VESSEL WITH CYLINDRICAL HULL AND TORISPHERICAL LID

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Abstract. *Pressure vessels are equipments that keep fluid in it into with a pressure end they are a lot of use in the industries, being that it failure may cause economic and human losses. Because this danger level high, the pressure vessels should get a heavy conservatism about the design and inspection. This paper drive studies about the performance of a pressure vessel made with ASTM A-36 steel when this is had submetided the intern pressure by measuring, materials characterization and numerical simulation by Finite Element Method (FEM). For this analysis, was need the realization of design according with the code American Society of Mechanical Engineers – ASM and, knowledge of manufacturing and welding process.*

Keywords: *pressure vessel, hydrostatic test, Finite Element Method, inspection, design.*

1. INTRODUCTION

Pressure vessels are one of the categories of equipments with big importance at oil industries, refineries, chemicals industries and general mechanical segment. In short, they are a part of a continuous chain, working under rigorous operational conditions, many times with no stop for inspection or maintenance.

Unscheduled stops result not only in big losses of production and profit, but failures could lead to accidents of untold proportions, including material and environmental damages and even loss of human lives (Martins, 2009).

In the research of de efficient bigger of industrial process, bigger pressure and temperatures operation are being have used, resulting in more strong conditions for the equipments, what already is possible because the advanced technological of materials used in the designs (Mendonça, 2011).

With this increase, as consequence, the internal stresses of pressure vessels require a more careful analysis. In Brazil, the standard regulating activities involving pressure vessels is the NR-13, that show minimum request about installations, inspections, operation and maintenance related aspects, to get security and the health of worker and it will be use with the basement in this paper.

Among other things, the geometry and kind of material used in the building of the vessels are the main factors that result in the capacity of stock flow under pressure, therefore, study these factors can get in increase of mechanical efficiency without lose the operational security.

There are many models buildings of pressure vessels, changing according with your applications or service, the more common are: vertical cylindrical vessels, horizontal and spherical, can have some changing, like: inclined vessels, conic vessels, etc. (Telles, 2013). One study of geometric design must be necessary, as like the determination of materials properties used.

With this, some of mainly motivations in the research is the determinations of parameters getting a big work field in the area mechanic.

2. OBJECTIVE

This paper had as objective:

a) Realize a characterization of material used to in the building, that this case was steel, through mechanics tests, getting the elasticity module e elasticity limit stress;

b) Define one geometry according the ASME Code, section VIII, Division I;
c) Make one numerical simulation with the geometry adopted and with one service pressure through Finites Elements Methods using Computer Aided Engineering.

3. MATERIALS AND METHODS

3.1 Characterization of material

The characterizations were made about a steel used in the manufacturing vessel, where got the results of Admissible Stress Material.

The flow stress limit corresponds is the point that start the plastic fase, where the deformations are permanents and off limits security. This stress is the Admissible Stress Material (S). It is a fundamental engineering parameter and applications in materials (Callister, 2007).

This test and a measuring and prepared of samples were made according a brazilian norm ABNT NBR ISO 6892-1:2013 corrected version: 2015 – Metallic Materials - Traction test, Part 1: Method of test in envelopment temperature, that specific the method for metallic materials and your mechanic propriety. The Figure 1 show the fits of samples in millimeters.

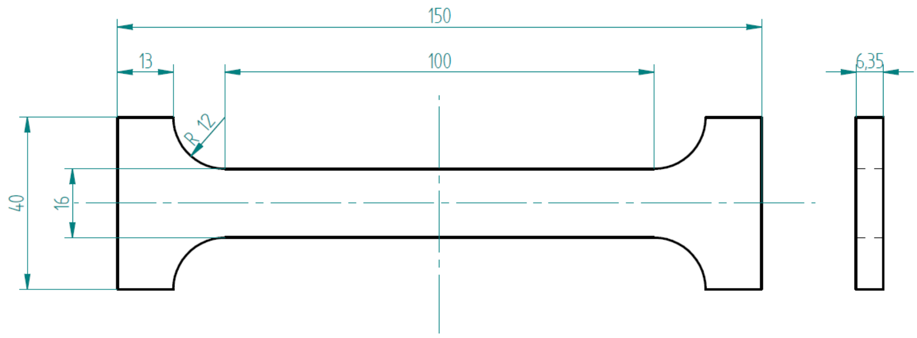

Figure 01 – Fits of samples (mm).

This work made these tests, by cuts in the steel plate, using the Universal Machine EMIC line DL 100 kN, weight cell Trd 28 and extensometer Trd 6. For test was using 03 (three) proof bodies, according with.

3.2 Measuring

The ASME Code, section VIII, Division I, was used as a reference for the measuring of pressure vessel, comprising the measuring of hull and lid.

To building of hull was one steel plate ASTM A-36, with fit 1500 x 1000 millimeters and espessure of 6,22 millimeters. The characterization him will be show forward.

To the lid, was used an industrial shape, gave by *Nacional Tampos*, with the fowling measuring:
e = 6,22 millimeters;
S = 250 MPa;
Elasticity Module = 200 GPa;
Torispherical kind 6%
Radius 477,47 and 28,65 millimeters;

According the ASME code, the Maximum Pressure of Admissible Work (MPAW) for hull has defined as, by Eq. 1:

$$MPAW = \frac{S.E\,(e - C)}{R + 0{,}6\,(e - C)} \quad (1)$$

And to the lid, by Eq. 2:

$$MPAW = \frac{S.E.e}{0{,}885.L + 0{,}1.e} \quad (2)$$

Where:
S = Admissible Stress Material;
E = weld security factor;
e = espessure according with the pressure intern (mm);

C = corrosion margin (mm);
R = intern radius of cylinder (mm);
L = central crown radius.

Considering that the espessure had been pre fixed, the work defined the Maximum Pressure of Admissible Work (MPAW). The MPAW must be small than Admissible Stress Material (S).

- **Weld security factor (E)**

It is determined considering the kind of weld and inspection degree adopted. This coefficient aims to compensate for the possible lower resistance in the region of the weld, in relation to the entire plate of the same thickness, due to the existence of flows into the weld.

To the hull, was adopted a factor 0,70: weld made in both sides and non-radiographed.

To the lids, was adopted a factor 0,60: weld made in one side and non-radiographed.

- **Corrosion margin (C)**

It is an over thickness of material due to external and environments factors, prone to equipment's corrosion. It is usual to adopt the following values for corrosion margin in carbon steel vessels or low alloy steels:

- C = 1,5 mm for environments few corrosives;
- C = 3,0 mm for environments half corrosives (common);
- C = 4 a 6 mm for environments strongly corrosives.

- **Hydrostatic Test Pressure (P_{HTP})**

According ASME Code the pressure used to test structural integrity of pressure vessel must came by Hydrostatic Test Pressure. This test consists filling of fluid (usually water) until that the intern pressure in the equipment will be 30% upper than MPAW.

With this, is possible get maybe failures by leaks that can happen, mainly in the welding areas and in the lids.

Therefore, the Hydrostatic Test Pressure has been used for the numerical simulation.

4. NUMERICAL SIMULATION

After the dates of measuring, a numerical simulation was performed to check the structural integrity of pressure vessel when submitted the operation pressure.

The MEF simulation using ANSYS software in its free academic version, which presents limitations on the number of available nodes, so only the pressure vessel top was chosen for analysis, as shown in Figure 2.

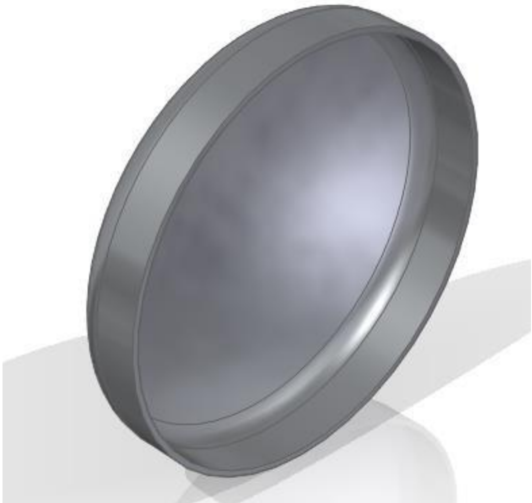

Figure 2 – Geometry of lid f pressure vessel.

This consideration will not compromise the studies, since this one presented itself as the main component when it comes to criticality. .

5. RESULTS

After made the analysis, got fowling results:

5.1 Characterization of material

The traction tests results stress x deformation curves showed in the squares of Figure 3, where the letters are the three proof bodies.

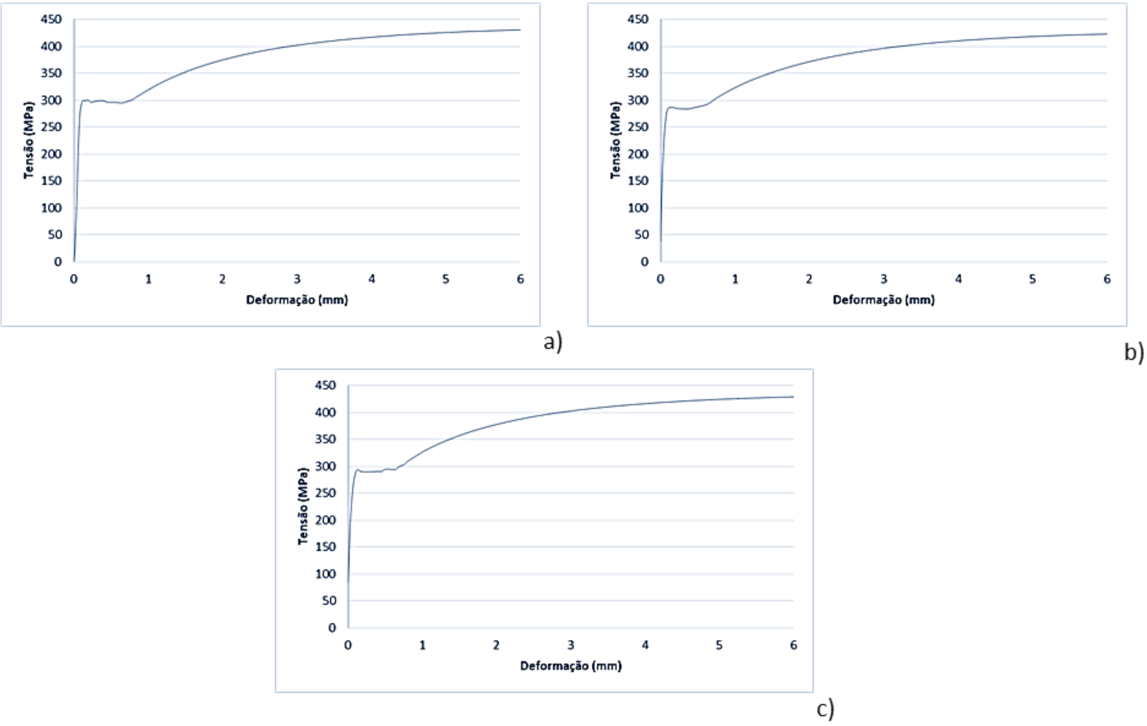

Figure 03: Stress x deformation curves.

The values of Admissible Stress Material (S) is in the Table 01.

Table 01: Results Admissible Stress Material (S).

Samples	Admissible Stress Material (MPa)
01	300
02	283
03	289
Medium Value	291

To about measuring, used the medium value for Admissible Stress Material, that is, 291 MPa for the steel used.

5.2 Measuring

The measuring of vessel according with ASME Code, Section VIII – Division I, got the fowling results:

- **Hydrostatic Test Pressure for hull**

The Hydrostatic Test Pressure P_{HTP} for hull use the Equation 3:

$$P_{HTP} = 1{,}3.MPAW \quad (3)$$

A MPAW for hull has been calculated through of Equation 4.

$$e = \frac{MPAW.R}{S.E - 0{,}6MPAW} + C \Rightarrow MPAW = \frac{SE.(e - C)}{R + 0{,}6.(e - C)} \tag{4}$$

The work adopted a security factor (SF) equal the three, SF = 3, the Admissible Stress Material ($\sigma_{adm} = S$) can be solve by Equation 5:

$$S = \frac{\sigma_e}{S.F} = \frac{291}{3} \therefore S = 97\ MPa \tag{5}$$

The diameter (D) of pressure vessel was determined considering the width (w) of plate 1500 mm, by Equation 6:

$$W = \pi D \Rightarrow D = \frac{w}{\pi} = \frac{1500[mm]}{\pi} = 477{,}47[mm] \Rightarrow R = 238{,}735[mm] \tag{6}$$

Considering environments few corrosives, corrosion margin (C) is: C = 1,5 mm.

The MPAW for the hull is, by Equation 7:

$$MPAW = \frac{97[MPa].0{,}70.(6{,}22[mm] - 1{,}5[mm])}{238{,}735[mm] + 0{,}6.(6{,}22[mm] - 1{,}5[mm])} \therefore \boldsymbol{MPAW = 1{,}33\ MPa} \tag{7}$$

Where was considered Weld security factor (E) equal the 0,70. Therefore, The Hydrostatic Test Pressure for hull (P_{HTP}) is, by Equation 8:

$$P_{HTP} = 1{,}3.(1{,}33[MPa]) \therefore \boldsymbol{P_{HTH} = 1{,}72\ MPa} \tag{8}$$

- **Hydrostatic Test Pressure for the lid**

The MPAW for lids is, by Equation 9:

$$MPAW = \frac{S.E.e}{0{,}885.L + 0{,}1.e} = \frac{97[MPa].0{,}60.(6{,}22[mm] - 1{,}5[mm])}{0{,}885.477{,}47[mm] + 0{,}1.(6{,}22[mm] - 1{,}5[mm])} \tag{9}$$

$$\boldsymbol{MPAW = 0{,}65\ MPa}$$

Where was considered Weld security factor (E) equal the 0,60. Therefore, The Hydrostatic Test Pressure for lid (P_{HTP}) is, by Equation 10:

$$P_{HTP} = 1{,}3.(0{,}65[MPa]) \therefore \boldsymbol{P_{HTP} = 0{,}84\ MPa} \tag{10}$$

By security questions, between the two values, the MPAW and the Hydrostatic Test Pressure for the equipment (P_{HTP}) was, respectively, 0,65 MPa and 0,84 MPa.

5.3 Numerical Simulation

A pressure is applied throughout the inner wall of the top, in the amount of 0,65 MPa, and also the force weight of 144.286 N. As a boundary condition, the joining face of the hull was considered fixed, that is, with displacements equal to zero.

- **Informations of net**

The used mesh of the study was of the tetrahedral type and its information can be seen in Table 02.

Table 02 – Informations of net *ANSYS*.

Kind of net	**Tetrahedral**
Total number bodies with net	01

Total number of elements	39.204
Total number of nodes	65.767
Size of subjective net (1-10)	03

- **Displacements**

The results for the nodal displacements can be visualized in Figure 4, in which it presents a deformed, that is, exaggerated image, for easier visualization.

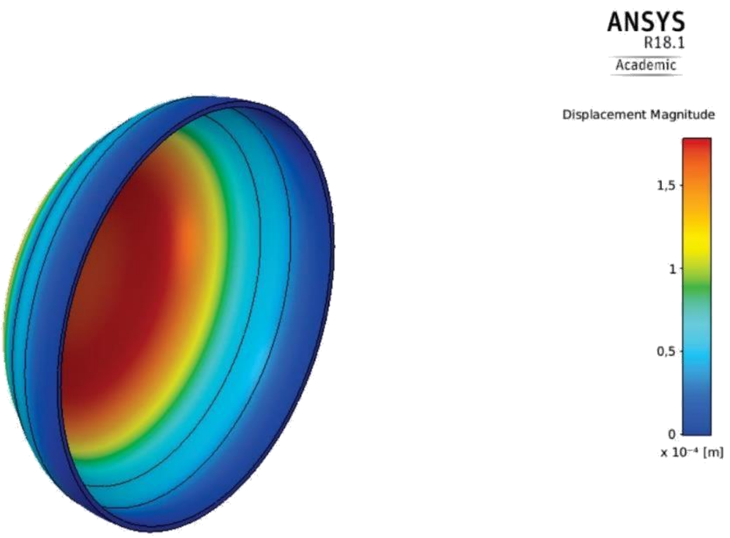

Figure 4 – Simulation *ANSYS* by FEM for displacements

Can be noted that the region in which the biggest nodal displacements are found in the cap of the torispherical lid. The maximum displacement value obtained was 0,1773 mm and the minimum displacement was 0 mm (zero millimeters).

- **Stress**

The results for stresses can be seen in Figure 5 below:

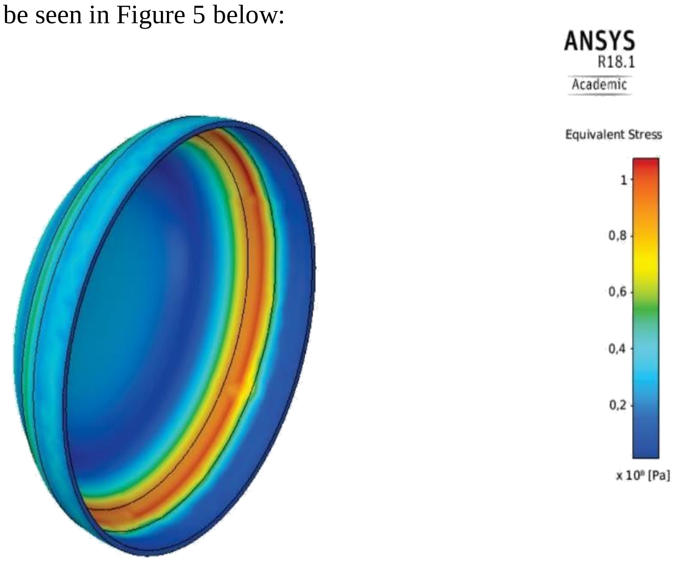

Figure 5 – Simulation *ANSYS* by FEM for stress.

Note that the highest stresses are located in the concordance radius of the torispherical lid. The maximum stress was 107,34 MPa and minimum stress was 1,48 MPa.

- **Security Factor (SF)**

The result of simulation drove a minimum security factor as, by Equation 11:

$$SF = \frac{S}{107{,}34} = \frac{291}{107{,}34} \therefore \boldsymbol{SF = 2,71} \tag{11}$$

6. CONCLUSION

The characterization of material brought a value of 291 MPa for structures steels, show a material with good performance and normally used in design and building pressure vessels.

The measuring followed the national and international norms, got The Hydrostatic Test Pressure for the equipment P_{HTP} = 0,84 MPa.

The numerical simulation with FEM and ANSYS, brought great results when subjected the pressure vessel to the Maximum Pressure of Admissible Work (MPAW) of 0,65 MPa, showing points in structure with down SF and more stress, like agreement radium of torispherical cap lid, because the geometric change. This analysis also revealed a point of biggest displacement in the cap lid.

Although the values of stress got for simulations FEM had few exceeded the Admissible Stress Material, the value is acceptable because of the big security factor.

The FEM show thus, be a great tool in the creating of designs together the joint engineer analysis.

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8. RESPONSIBILITY NOTICE

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