COLD STRETCHING TEST OF A CRYOGENIC PRESSURE TANK

Marian STAICU[1], Dan BIRSAN[1]

[1] *"Dunarea de Jos" University of Galati, dbirsan@ugal.ro.*

Abstract: *Cold stretching increases the yield limit of a stainless steel material by work hardening it after all forming and welded steps are complete. The tank has been stretched by over pressurizing it 1.6 times design pressure under careful control of the deformation vs. pressure. The permanent plastic deformation increases the diameter from 1330 to 1382mm, approximately 4%. The mechanical properties of the material from which the tank was made, following the cold stretching test, were improved by hardening it. The thickness of the material after performing the test shows a modification of this at 9.5mm, 0.5mm less than the thickness measured before the test.*

Therefore, following the analysis we performed on the inner tank, through the finite element analysis, it is observed that the value of the effective stresses up to 401N/mm^2, upper than yield stress value, led the material to the area of plastic deformation, the resulting residual deformations being plastic.

Keywords: *pressure tank, stretching test, finite element*

1. Introduction

Investigation on mechanical behaviors of cold stretched and cryogenic stretched austenitic stainless steel pressure vessels has been studied by Lu and Hui, Ref. [2].

Finite element simulations of residual stresses have been analyzed by Shariffudin, Hashim, Nigrelli, Refs. [1,6,7].

The present cryogenic tank is the prototype of an entire production line of cryogenic tanks of different sizes. After the realization of this first cryogenic vessel and implicitly after its certification by the Classification Society, the preparation of its series production will be carried out, but also of other cryogenic tanks of 1500L and 5000L.

Cryogenic tanks are tanks that are used to store material at very low temperatures. This tank on which the entire study is performed is designed for oxygen storage.

The present cryogenic reservoir is subject to risk category IV, according to PED Directive 2014/68/EU.

The main constructive elements of the cryogenic tank are: the inner tank, the outer tank and the vaporizer.

The inner tank is also called the pressure vessel, because the pressure at which it will operate in operation is 37bar, but during the cold stretch test the pressure will reach the value of 57bar. The inner tank is made of 10 mm stainless steel, and the outer tank is made of a material with the same properties as the inner tank, but with a thickness of 6 mm.

The connection between the inner tank and the outer tank is made after mounting all the connecting elements, but especially after degreasing the two cryogenic tanks. After the degreasing has been carried out, the next step is to install the insulation, and then the vacuum between the two cryogenic tanks is made.

2. Finite element analysis of the cryogenic tank

The 3D finite element model was made by discretizing with finite elements the 3D CAD model, which was made according to the execution drawing of the tank.

The material used in this simulation is austenitic stainless steel x5CrNi18-10, with yield strength of 240MPa with the following characteristics:

- Youngs modulus $E=2.9\cdot10^5$N/mm^2;
- Poisson's ratio $\upsilon = 0.28$.

Discretization of the continuous structure into finite elements represents the pre-processing of the real structure and obtaining the model with equivalent finite elements.

The model contains 3320 quad elements and 3322 nodes.

According to the material specification from which the tank is made, we chose the material yield point as $R_{p0.2}$ = 240MPa and for the plasticity area of the material law, we used the value of $R_{p1.0}$ = 280MPa. Thus, the material law used is of the bitangent type.

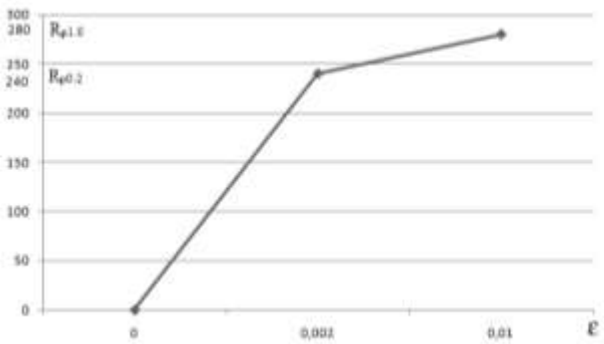

Figure 2: *Graph of the bitangent nonlinearity law*

The cold stretching test consists in introducing the pressure loads inside the inner tank. The variation in time of the pressure can be seen in Fig.4 and the pressure loads in Fig.3.

The boundary conditions of the model consist of locking a node at the top of the model with the release of translation in the z direction and a node at the bottom of the model. The nodes at the bottom of the model were also blocked to consider placed the tank on a support. In Fig. 3 and Table 1 the boundary conditions can be seen.

Table 1: *The applied constraints*

Boundary conditions	Degrees of freedom blocked					
	T_x	T_y	T_z	R_x	R_y	R_z
Upper node	1	1	0	1	1	1
Lower node	1	1	1	1	1	1

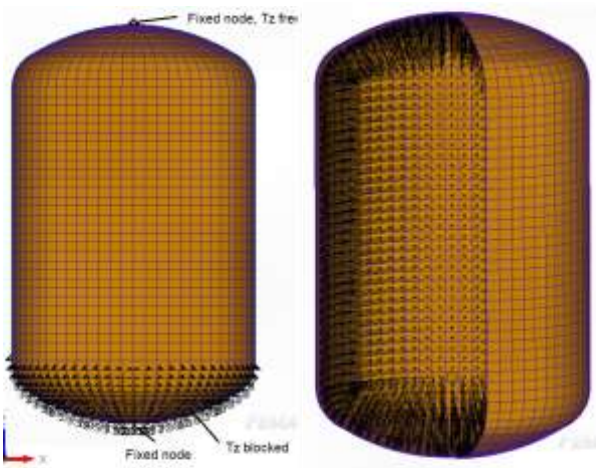

Figure 3: *Boundary conditions and pressure loads applied to the model*

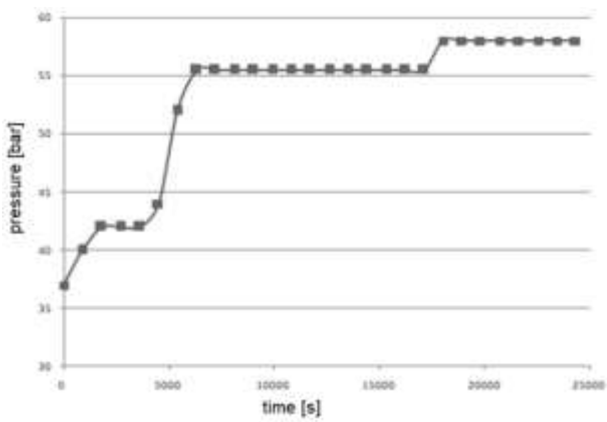

Figure 4: *Variation in time of the applied pressure during stretching test*

3. Results. Displacements and stresses due to FE analysis

This finite elements analysis has been performed to determine the new value of the tank diameter as well as the value and location of the VM stresses in the tank.

Fig. 5 shows the radial displacement of a node on the surface of the tank, this reaches the value of 26.5mm. The initial diameter of the tank of 1330mm, reached 1383mm following the deformation process. The new value of the tank diameter will have to be compared with the one resulting from the cold stretch test.

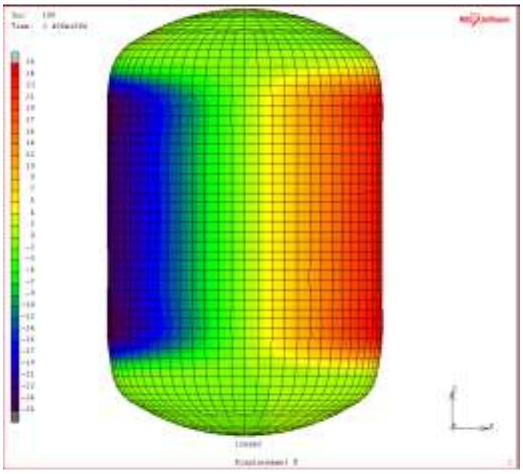

Figure 5: *Displacement X*

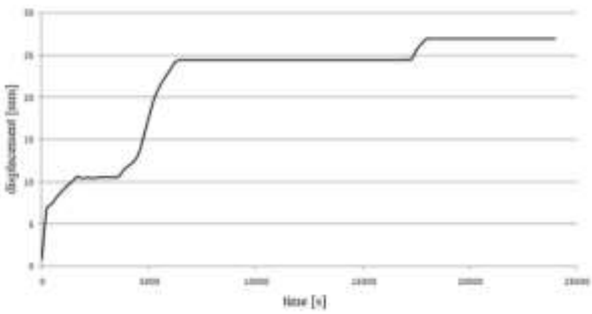

Figure 6: *The variation in time of the displacement of a node located of the tank cylindrical surface*

The level of VM stresses occurring in the tank sheet shows if the material has reached the plastic deformation zone in which case the deformation would be permanent and the tank would reach the new dimensions.

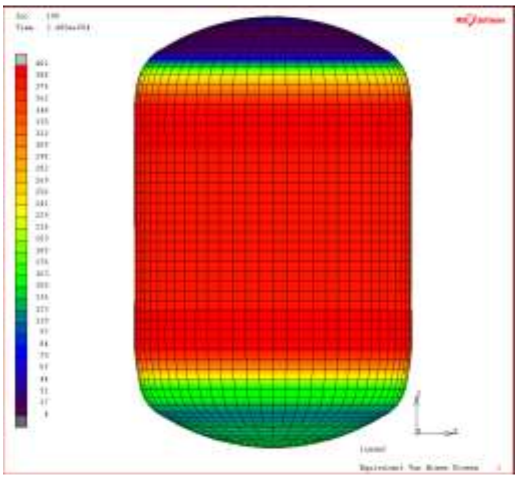

Figure 7: *Max. VM stresses in tank plate elements*

The maximum value of the VM stresses is 400MPa (see Fig. 7), a value higher than the yield stress value which is 240MPa.

4. Cold stretching test

4.1. Tank preparation for the cold stretching process

This process represents the procedure to be followed to tension the inner pressure tank of the cryogenic tank, built according to the technique of "cold stretching".

In order to perform the cold stretching process, a number of operations prior to the conduct of this test are required, including:

- visual inspection of the inner tank by a representative of the Classification Society;
- placing the tank on the device specially designed for performing the test;
- verification of the calibration certificates of the gauges used during the cold stretching test;
- mounting gauges at the highest point of the tank;
- the test liquid is water. Before introducing water into the inner tank, the basic condition is that it has the same temperature as that of the inner tank.

The home sample is the sample that is performed before the cold stretching test. This consists in introducing a pressure of 20bar, pressure that will remain constant for 24 hours.

It is intended that following the test we have confirmation that the inner tank is perfectly airtight and the cold stretching test can safely begin.

4.2. Operational procedure for performing the cold stretching test

The operational procedure for performing the cold stretching test is applied for carrying out the hydraulic reinforcement test of the internal tank, accordance to the following standards:

- 2014/68/EU Pressure Equipment Directive;
- EN 13458-2:2004 Cryogenic vessel. Part 2: design, manufacture, inspection and testing.

Figure 8: *The cold stretching installation and the tank*

All the data obtained from the cold stretch test have been centralized in the Table 2.

This test was carried out over a period of more than seven hours and the conditions mentioned in the procedure for carrying out the test were met.

Table 2: *The values obtained from the test*

Time	Pressure	Circumference	Elongation	Speed Deformation 1h	% Deformation
09:00	37,0	4.257,0	1,0037		
09:15	40,0	4.257,0	1,0037		0,0000%
09:30	42,0	4.260,0	1,0044		0,0705%
09:45	39,0	4.260,0	1,0044	0,070%	0,0000%
10:00	42,0	4.277,0	1,0085	0,470%	0,3991%
10:15	44,0	4.278,0	1,0087	0,423%	0,0234%
10:30	52,0	4.304,0	1,0148	1,033%	0,6078%
10:45	55,5	4.305,0	1,0151	0,655%	0,0232%
11:00	55,5	4.332,0	1,0214	1,262%	0,6272%
11:15	55,5	4.339,0	1,0231	0,813%	0,1616%
11:30	55,5	4.348,0	1,0252	0,999%	0,2074%
11:45	55,5	4.353,0	1,0264	0,485%	0,1150%
12:00	55,5	4.355,0	1,0268	0,369%	0,0459%
12:15	55,5	4.357,0	1,0273	0,207%	0,0459%
12:30	55,5	4.357,0	1,0273	0,092%	0,0000%
12:45	55,5	4.360,0	1,0280	0,115%	0,0689%
13:00	55,5	4.361,0	1,0283	0,092%	0,0229%
13:15	55,5	4.361,5	1,0284	0,103%	0,0115%
13:30	55,5	4.363,0	1,0287	0,069%	0,0344%
13:45	55,5	4.365,0	1,0292	0,092%	0,0458%
14:00	58,0	4.376,0	1,0318	0,332%	0,2520%
14:15	58,0	4.401,0	1,0377	0,871%	0,5713%
14:30	58,0	4.409,0	1,0396	1,008%	0,1818%
14:45	58,0	4.413,0	1,0405	0,846%	0,0907%
15:00	58,0	4.414,0	1,0408	0,295%	0,0227%
15:15	58,0	4.414,0	1,0408	0,113%	0,0000%
15:30	58,0	4.414,5	1,0409	0,034%	0,0113%
15:45	58,0	4.414,5	1,0409	0,011%	0,0000%
16:00	58,0	4.414,5	1,0409	0,011%	0,0000%
16:15	58,0	4.414,5	1,0409	0,000%	0,0000%

5. Conclusions

The finite element analysis method is approximate. Because the analysis is not done on a real structure but on a model generated in the virtual environment, the results obtained represent an approximation of the problem that is analyzed compared to the real testing.

The realization of the 3D FEM model, and later of the cold stretch test, showed the capacity of the material, from which the inner tank is built, to acquire new properties, both mechanical and sizing.

After performing the test, has been obtained new mechanical qualities, through its hardening. Following the analysis we performed on the inner tank, through the finite element analysis, it is observed that the value of stresses up to 401N/mm^2 led the material to the area of plastic deformation, the resulting residual deformations being plastic. It is observed that the values of the deformations that we obtained after the finite element analysis are close to those resulting from the actual performance of the cold tensile test.

Confirmation of the success of the cold test by the classification society ensures that the manufacturer is able to make this product, so that steps can be taken to equip the company with the equipment needed for series production of cryogenic tanks.

References

1. [Shariffudin, 2017], Shariffudin K. A., Karuppanan S., Patil S., *Finite element analysis of residual stress in cold expanded plate with different thickness and expansion ratio*, Conference Series Materials Science and Engineering 257(1):012019, 2017.
2. [Lu, 2015], Lu Y.Q., Hui H., *Investigation on Mechanical Behaviors of Cold Streched and Cryogenic Streched Austenitic Stainless Steel Pressure Vessels*, Journal of Procedia Engineering, pp. 628-637, 2015.
3. [Xu, 2016], Xu C., Shan-Tung T., *An Empirical Life Prediction Method of Cold-Stretched Austenitic Stainless Steel*, Journal of Applied Mechanics and Materials (Volume 853), pp. 67-71, 2016.

4. [Zheng, 2011], Zheng J., Guo A., Miao C., Xu P., Yang J., Ye J., Ma L., Wu L. and Yang G., *Cold Stretching of Cryogenic Pressure Vessels From Austenitic Stainless Steels*, ASME 2011 Pressure Vessels and Piping Conference, PVP2011-57331, pp. 693-698, 2011.
5. [Fu, 2015], Fu Y. C., Ende Ge., Honghua Su., Jiuhua Xu., *Cold expansion technology of connection holes in aircraft structures: A review and prospect*, Chinese Journal of Aeronautics 43(4), 2015.
6. [Hashim, 2013], Hashim M. H., Wahab A. A., *Finite Element Simulation of Residual Stresses in Cold-expanded Plate*, Asian Journal of Scientific Research 6(3):518-527, 2013.
7. [Nigrelli, 2008], Nigrelli V., Pasta S., *Finite-Element Simulation of Residual Stress Induced by Split-Sleeve Cold-Expansion Process of Holes*, Journal of Materials Processing Technology 205(1):290-296, 2008.