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Limit Analysis of A S235- Steel Bottle for Domestic Gas

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Abstract: *Within the framework of systems and pressure devices, conception and the manufacturing, for example, the domestic 12kg gas bottle , obtained by plastic strain shaping processes. Several questions can be asked, mainly, at the level of the mechanical reliability, materials choice, manufacturing process and the soldering mechanical failures which can, brutally appear and cause human and goods damage.*
The aim of this work is to determinate the maximum load in the bottle. Knowing that in the entire chain, we consider the elastic perfectly plastic material (EPPM), then we proceed to a numerical simulation using Patran and Nastran software. The paper shows experimental and numerical results obtained by a series of experimental trials using the CODAP Pressure Standard Design.
Keywords: *Plasticity, Element Finite Method, Limit Load, Limit Analysis.*

I. Introduction

12 kg Gas bottles, represented in fig.1. (a), are a pressure equipments. Now, this kind of bottles is frequently and intensely applied in daily domestic uses. This leads us to ask several questions, essentially, on the safety of user-people if this equipment has exploded, show fig.1. (b). This kind of accident can be due to a defect in the materials or in the welded joint [1]. The manufacturing of the bottle goes through various stages. The first one is the collision of its two upper and lower parts [2] in shaping process by plastic strain. The second one is soldering those parts, as well as with other used treatments. After manufacturing, bottle undergoes Quality Control for manufacturing validation [3]. The principal aim of this study is widen the domain of analysis for a real mechanical behaviors of the bottle under internal pressure, than, to determinate the optimal thickness of bottle's shall. For that purpose, we are going to make destructive attempts on a prototype to localize the mostly sought zones in the shell which can be cracked in the first attempt. Than we are going to elaborate a numerical simulation of the shell of various bottle models under pressure in aim to determine their plastic behavior.

(a) (b)

Figure 1- (a) Photo of a12kg gas bottle (b) Example of an exploded 12kg gas bottle

II. Geometrical And Mechanical Characteristics

A. Geometry:

The shape of the bottle is made up of an axisymmetric shell of relatively simple revolve as well, the elliptical form of the upper and lower funds. This shell is subjected to an internal pressure distributed uniformly and symmetrically. CODAP standard allows to determine the geometrical characteristics of the bottle of gas [1]. We sized all the bottle components.

B. Thickness

To apply the rules of thicknesses calculation of pressure device, according to the CODAP standard [1] the following condition should be respected:

$$D_m \geq 5e \qquad \textbf{Eq (1)}$$

With

$$D_m = \frac{D_i + D_e}{2} \qquad \textbf{Eq(2)}$$

C. Rule of calculation

The necessary minimal thickness of the cylindrical envelope is given by the one of the two equations.

$$e = \frac{P.D_m}{2.f.z} \qquad \textbf{Eq(3)}$$

De = Envelope External Diameter
Di = Envelope Internal Diameter
Dm = Envelope Average Diameter
e = Necessary minimal thickness of the envelope
f = Nominal Force of the envelope's material
P = Pressure
z = weld Coefficient

For making our bottle's shape, we apply the manufacturing procedures: shaping by plastic strain, collision from between upper and lower parts. Such as all structure components have the same thickness.

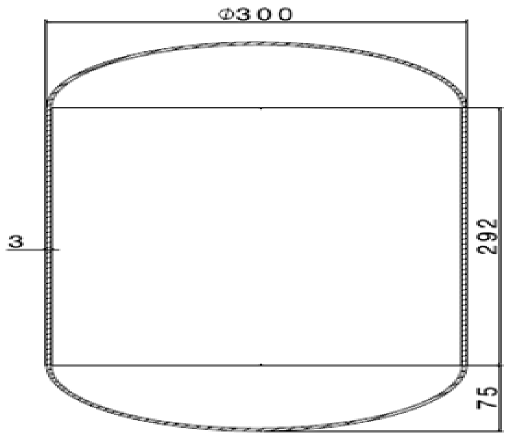

Figure 2- Geometrical model of the bottle the 12Kg.

D. Calculation of the elliptic funds

The dimensions of funds have to be such as [1]:

$$1.7 \prec \frac{D_i}{2.h_i} \leq 2.2 \qquad \textbf{Eq(4)}$$

E. Material:

Upper and lower parts of the bottle were made up of an ordinary steel E24, assembled by a welded joint formed by other metal. To simplify the calculations it is assumed that the E24 steel is elastic perfectly plastic and whose behaviors are given in the following table:

Table 1- Steel's behaviors

Material behaviors	Values
Young's modulus	210000MPa
Poisson coefficient	0.3
Yeld limit	235MPa
Breaking load	40DaN/mm²

III. Experimental Studies

To make the behavioral research of material of the gas bottle, based on the experimental trial, to achieve this bench test we are going to use the following means:

- A hydraulic thermal group

- A system of data acquisition connected with computer
- data analysis software (DasyLab)
- A new 12 kg cylinder of gas filled with oil, and connected to the hydraulic group by one flexible which allows the subject of pressure created by the thermal group towards the bottle.
- Displacement Sensors
- Pressure Sensor
- Strain Gauges (two bows in 90 °)

A bow of capacity of strain is stuck on point A and another one to point B to raise the strain in these points. Two sensors of displacement are placed in the both points, A and B, in aim to size the radial displacements. The set is connected to the system of data acquisition. The bottle, filled with oil, is connected to the hydraulic thermal group by a flexible which allows subject of the pressure of the group towards the bottle fig.3. And we fix the bottle in a simple position to experiment, we increase the internal pressure until bottle failure., and we track the evolution of the pressure according to movement in point A.

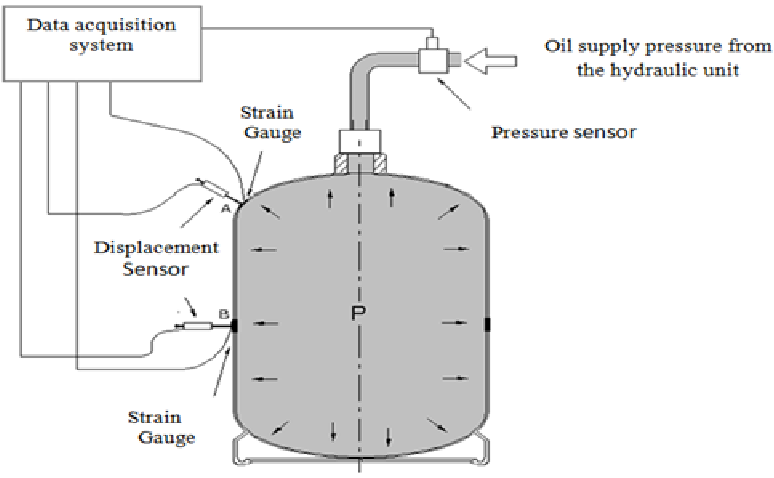

Figure 3 Test bench

F. Experimental results

During the trial the software of acquisition of data analysis DasyLab allows to draw in terms of level of the loading the curve load-displacement [1] which illustrates the elastoplastic bottle behavior at A.

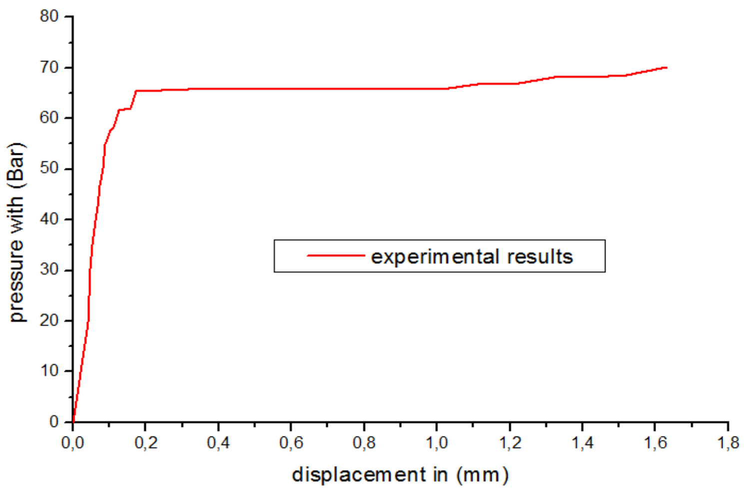

Figure 4- experimental trial of a bottle of 12Kg

G. Modeling by finished elements

The aim of this article is to study the limit analysis behavior of a butane gas cylinder of 12kg for the domestic used, in the case of static load. Firstly, the numerical work was led for the use of bottles in the plastic zone without explosion risk. All simulation works are achieved by the calculation code by finite elements

Patran-Nastran. The structure of model is constituted by two big Parts:

- simplified model define
- kind of calculation define

The model includes various modules allowing to write:

- Shapes,
- Material,
- Limit and load conditions.
- Meshing

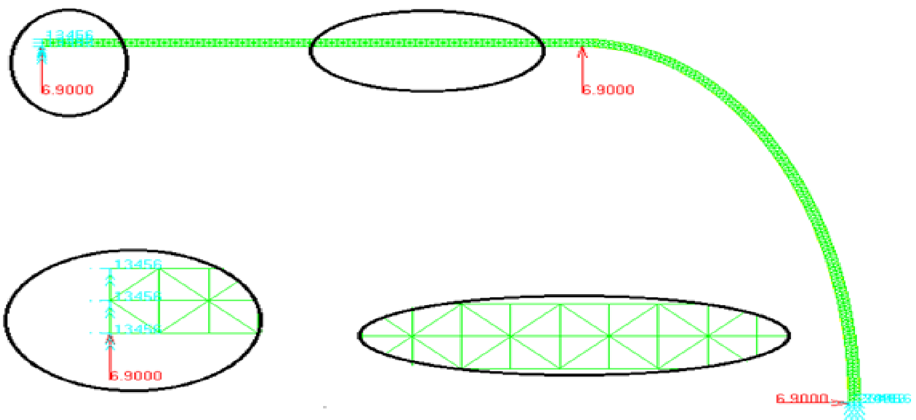

Figure 5- Simplified model with loads, mesh and the limits conditions.

H. Meshing

We use the linear triangular mesh for all structure. Details of this kind of meshing are presented in the following table:

Table 2- meshing

Kind of elements	Number of elements	Number of nodes	Element sizes
linear triangular	872	660	1

I. Numerical results

The numerical simulation of the bottle came true by means of the software Patran-Nastran . The results of this study is shown us the variation of the pressure in point A, according to the displacements, knowing that the zone round a further damage as we increase the load (fig.6)

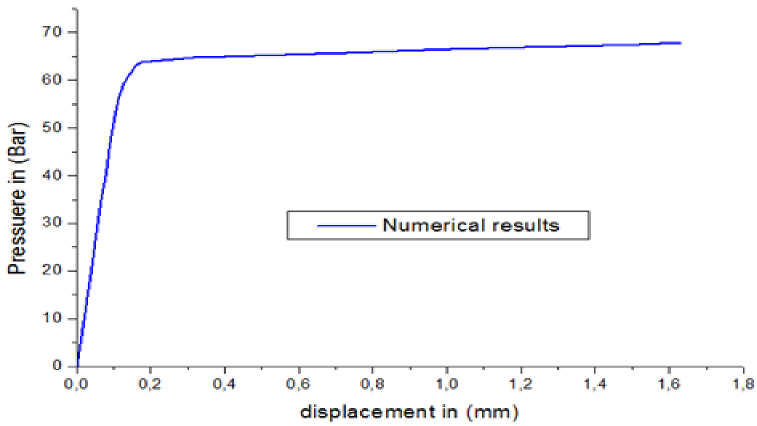

Figure 6- Numerical simulation of a bottle 12Kg

IV. Comparison Between Numerical And Experimental Studies

To validate all these kinds of numerical models, a current method is used to proof that the numerical results obtained, reproduce well the possible experimental scenarios under the same conditions. To reach this aim, we tried to build a model which takes into account the maximum of details we can observe at the level of our tested specimens and of our limits conditions.

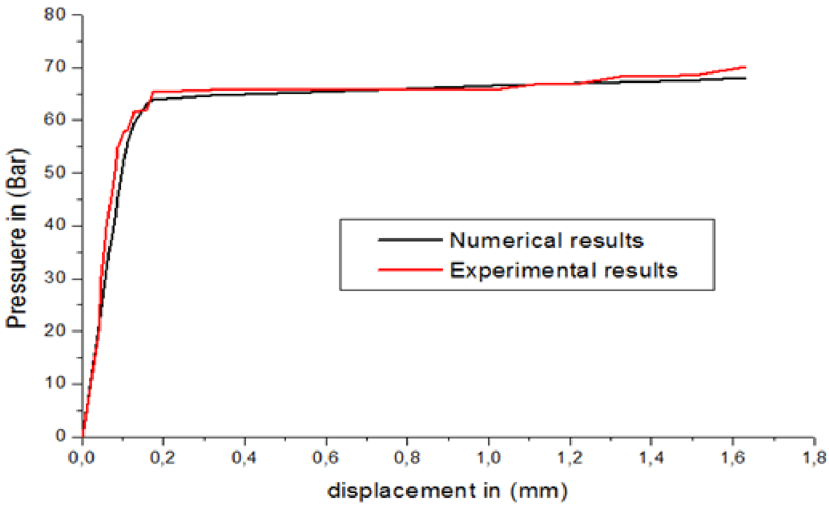

Figure 7- Comparison between numerical and experimental results.

J. Applied loads

We summarize the results stemming from the experimental study and those of the numerical simulation in the table below. We note that the numerical and experimental values of the maximum load, the maximal displacement and the equivalent constraints of Von Mises coincide.

Table 3- Comparison between numerical and experimental results

	Maximum Charging in (MPa)	Displacement maximal In (mm)	Equivalent Von Mises stress in (MPa)
Numerical	6.9	1.63	235
Experimental	7	1.62	235

V. Modeling By Elements Finished By A Gas Bottle Of 35kg

K. Geometrical and mechanical Characteristics

1) Geometry:

The shape of this bottle is constituted by an axi-symmetric shell of relatively simple revolve as well as two funds, upper and lower of elliptic shape is a ferrule between both funds. This shell is subjected to an internal pressure distributed uniformly and symmetrically on the internal wall. The standards CODAP and ASME allow to determinate the geometrical behaviors of the gas cylinder [1-2]. We sized all components of the specimen from these standards.

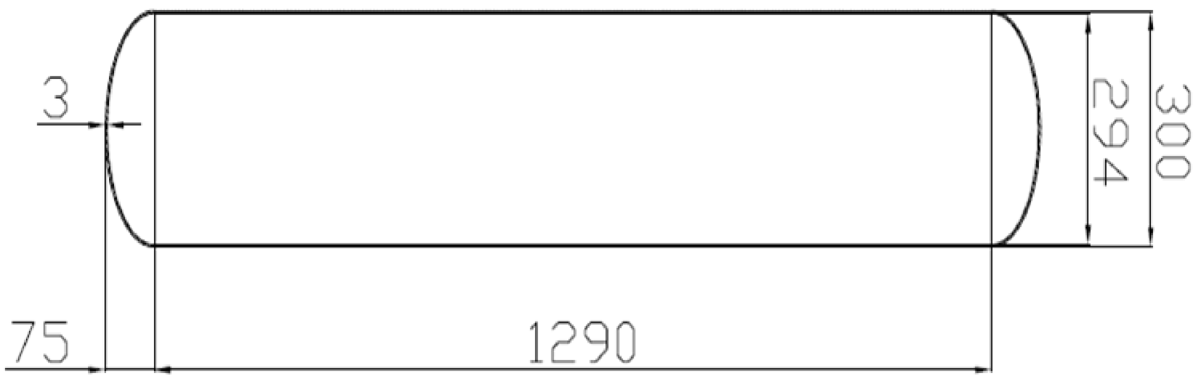

Figure 8- Geometrical model of the bottle the 35K

2) Simplified model by a gas cylinder of 35Kg

From the previous study of a gas bottle of 12Kg, we drew the variation of pressure in terms of displacement by numerical simulation; this evolution is very brooch with regard to the experimental trial. Thus we can make the same study of the behavior of limit analysis of a gas bottle of 35kg for Butane for domestic use, in the static load case. The aim of this numerical study is to generate the studies of the other models of pressure devices, to gain the trial time. All the simulations are realized by the code of calculation by finite elements Patran-Nastran. The structure of model is constituted by two big Parts:

- Definition of simplified model by a gas cylinder of 35Kg.
- Kind of calculation define.

The model includes various modules allowing writing:

- Shape [1-2].
- Material.
- Boundary and load conditions.
- Meshing.

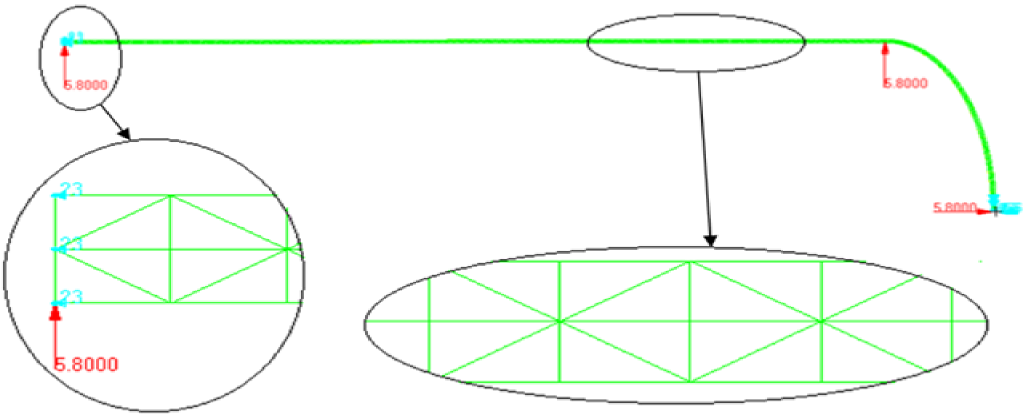

Figure 9- Simplified model with loads, meshing and the boundary conditions of a gas bottle of 35Kg.

3) Meshing

We adopted a linear triangular meshing for all specimen. The details of this type of meshing are presented in the following table:

Table 4- Meshing

Kind of elements	Number of the elements	Numbers of knots	Size of elements
Linear Triangular	1164	878	1.5

4) Numerical results

The numerical simulation of the bottle came true by means of the software Patran-Nastran. The results (profits) of this study show us the variation of the pressure in the point A in terms of displacement such us the zone in the tour of A plasticizes of advantage as we increase the load (fig.10).

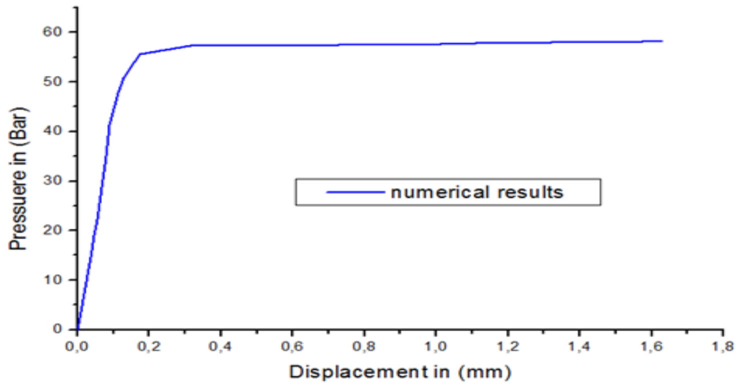

Figure 10- Numerical simulation of a bottle 35Kg

VI. Conclusion

Both approaches of analysis were used to find the load of collapse of the 12 kg gas bottles. The first one is to apply the finite elements method [6-7-8], based on elastoplastic theory in axisymmetric state. The second approach was realized by proceeding to a trial of internal pressure of the bottle until the appearance of a

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zone strongly plasticized in the shell and which has allowed the determination of the second limit value. We note that the difference between these two limit states can be decreased on one hand by summarize the numerical simulation by using elements hoops and by taking into account the weld. On the other hand by summarize again the determination of the experimental limit load through controlling loading velocity.

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