Analysis of Deformation of a Liquid Packaging Made with Board of the LPB Type.

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Abstract: The liquid food products packaging are now predominantly made with LPB type board (Liquid Packaging Board), derived from the pulping process, polyethylene and aluminum. In the storage process such packages deform plastically and elastic. Then, it aimed to analyze the deformation profile of a simplified packaging, made only with board without rolling of aluminum and polyethylene, and parametrically vary the elastic constants of the material. The results indication that the strain profile is function of the density of the liquid packaged in the packaging, the elastic constant of the board, mainly Poisson's ratio, and it was possible to establish the main equations governing the deformation profile.

Keywords: Deformation, Liquid Packaging, LPB, Paper.

1. Introduction

Currently, general packaging have wide scope in their use. Besides of the basics functions that include the physical and chemical protection, shipping and handling, were incorporated to packaging the information functions and visual communication. They can be produced from different materials such as wood, paper, board, metal, aluminum, glass, polymers and textile materials (NESPOLO, 2015).

The carton packaging are defined to as a six-layer composite comprising paper, low density polyethylene and aluminum, these containers known as Long Life represented by Figure 1.

A descriptive analysis reveals that aluminum, polyethylene and board sequentially represent 5%, 20% and 75% of the total pack weight (PERUZZO, 2005).

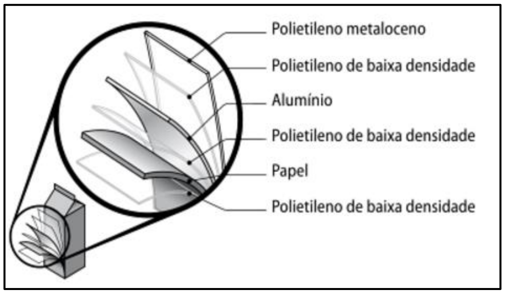


Figure 1. Constitution of carton packaging (NESPOLO, 2015).

The plastic in this case made from polyethylene polymers, provides enhanced resistance to water flow. The use of aluminum foil, can give the container different degrees of stiffness, depending on the thickness, shape and alloy. By itself, the aluminum foil does not provide high barrier against the flow of oxygen due to its high porosity, but when coated with polyethylene, its efficiency is improved because in this case the holes are covered. The use of paper, consisting of virgin fibers (primary) coming from the Kraft process and CTMP (chemithermomechanical pulp), provides packaging characteristics of strength and opacity, this component will be further detailed in the following sections.

1.2 Paper and Board

On the day, paper and board are words used as synonyms for each other. Are products obtained from the pulping process, a process which is the individualization of wood cells, called fibers. Such processes can be classified as mechanical, chemical or hybrid that mixes the use of chemical and mechanical process steps. The following Table 1 to statement of pulping process on the yield of the obtained pulp (single fiber):

Table 1- Classification of pulping processes based on pulp yield (IPT, 1988)

Pulping Process	Yield of wood (%)
Mechanic	95 - 98
Chemical Thermo Mechanical Pulping	85 - 95
Semi Chemical	65 - 85
High Performance Chemical	50 - 65
Chemical	40 - 50
Chemical to Soluble Pulp	30 - 40

The basic properties of any type of paper and paperboard include moisture content, weight, thickness, density and bulk; properties that describe the product (LEVLIN, 1999).

The moisture content of paper it described by ISO 287, is expressed as a percentage of the weight of the wet sample.

The weight of paper, called a weight, representing the quantity of mass in grams per square meter (g/m^2), as described by ISO 536.

The thickness measurement described by ISO 534, is given by a unit of two parallel plates which apply the paper a 100 kPa pressure, thereby obtaining normal expression of weight in microns (µm); this value may be representative of a single a sheet or the sheet set.

The apparent density is the mass per unit volume of paper, calculated as the ratio of the weight and thickness of the material, and is usually expressed in kg/m^3 or g/cm^3. From the apparent density is defined as the bulk, through its inverse:

$$Bulk = \frac{1}{density} = \left[\frac{cm^3}{g}\right] \qquad eq(1)$$

According to the process of formation, the paper is different board. The paper is formed from the drainage of a fibrous suspension of cellulose while the board is usually composed of several sheets of cellulose fibers bound by starch or adhesive. Also points to the fact that the term board is used for heavy paper (XIA, 2002).

To check their physical and structural properties, the paper has its oriented analysis in three orthogonal directions: **M**achine **D**irection (MD), **C**ross **D**irection (CD), and the **Z** **D**irection (ZD). The MD direction is the longitudinal direction of the paper corresponding to the direction of movement of the continuous sheet on the paper machine. The CD direction corresponding to the direction perpendicular to the movement of the web in the paper machine. Both CD and MD directions, are in the plain paper. The ZD orientation refers to the direction out of the paper plane or through their thickness (Andrioni, 2006).

For better representation, the following the Figure 2 that represents a formed paper roll and the Figures 3 and 4, that structurally represent the paper and board sequentially.

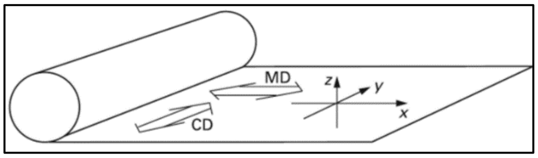


Figure 2. Orientation on a paper roll (NESPOLO, 2015).

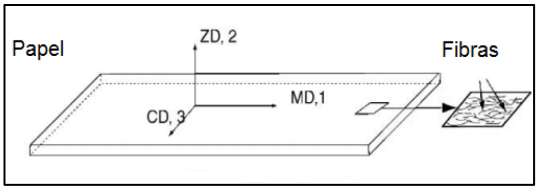


Figure 3. Design macro and micro structural of the paper (XIA, 2002).

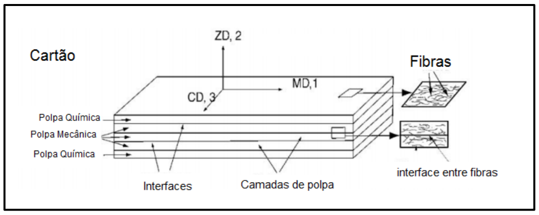


Figura 4. Design macro and micro structural of the paper roll (XIA, 2002).

1.3 Paper and Board Elastic Constants

The elastic constants give the paper the stress-strain relation in the elastic region. The main ones are the Modulus of Elasticity (E), Shear Modulus (G) , and Poisson's ratio (ν). For the analysis of elastic symmetry of materials, there is four classifications: homogeneous materials, isotropic materials, orthotropic and anisotropic (NASH, 2014):

- Homogeneous material, when the elastic property (E, G, ν) are the same in any point of the examined body;
- Isotropic materials having the same elastic properties (E, G, ν) in all directions of the body;
- The orthotropic material have three mutually perpendicular planes, and elastic symmetry between them;
- The anisotropic materials do not have any kind of elastic symmetry.

The behavior of materials during a charging process reveals itself in two ways: elastic and plastic. A material has elastic behavior after the process of loading and load removal, there are deformations in the body. If the specific strain (ε) does not return to zero, conceptualizes up their behavior as plastic or permanent plastic deformation. For better representation of such deformations, the following figures 5 and 6, these images illustrating the elastic and plastic deformations of a generic packaging liquid food products.

Figure 5- Representation of elastic deformation (front and side)

Figure 6- Representation of plastic deformation (front and side)

2. Methodologies

This article is a simplified study, which aims to evaluate the deformation of a package made only with board LPB type, without the presence of polyethylene and aluminum. It is also proposed the equation that governs the process as well as the analysis of the properties of the board and the liquid bottled in the packaging deformation profile. The effect of an external load corresponding to a second container, as well as the effect of temperature were not considered.

The material was considered as orthotropic, and the MD orientation of the board in the direction of the height of the packaging and the board CD orientation in the circumferential direction to it. Through the tool "*parametric sweep*", the elastic constants of the material were parametrically varied in a specified range around the I note the representative value on the theoretical reference as well represented by Table 2:

Table 2 - variation range of the board properties

Variable	Units	Minimum	Maximum
Liquid Density	kg/m^3	800	1200
Board Density	kg/m^3	600	1500
Young Modulus (MD)	MPa	5000	8000
Young Young Modulus (CD)	MPa	3000	4600
Poisson (MD)	-	0,2	0,45
Poisson (CD)	-	-2,5	0,4
Shear Modulus (MD)	MPa	1000	3500
Shear Modulus (CD)	MPa	8,8	15000

Through Solid Mechanics Module, was inserted the effect that the presence of liquid causes inside the package using pressing tools without the physical presence of the liquid.

After making the simulation of the deformation process, was evaluated the variation of lateral and upper volumes for equalization and better discussion of the results according to figure 7.

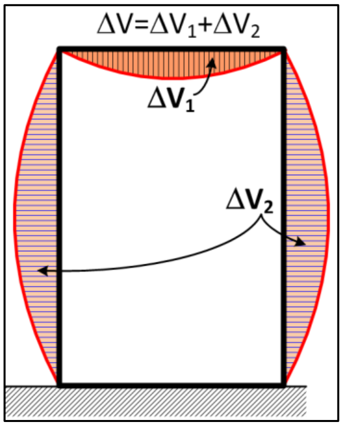


Figure 7- Analysis of the volume variation

For comparison of results was measured at a real deforming packaging through the use of hydraulic jack, and caliper slider, this scheme represented in Figure 8.

Figure 8- Project for measurements

3. Equations e Results

The structural model initially proposed, as presented deformation Figure 9. The values are shown three-dimensionally in millimeters on a scale of 2,42, i.e., 2.42 times larger than the actual deforming to better interpret the results visually. This simulation was made in order to verify the behavior if the package remained open in the environment without any restrictions.

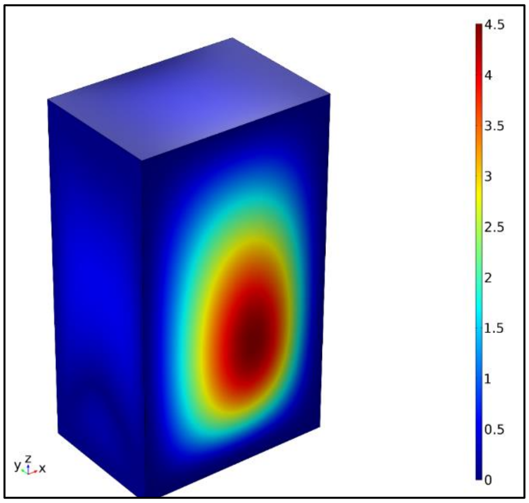


Figure 9- deformation profile analysis in millimeters with volumetric variation

At this early stage of the simulation, the parabolic profile deformation in the larger surfaces of the packaging, this profile that resembles this deformation in open containers was obtained.

It was observed that the smaller faces moving towards the inner region of the package, while the larger faces move to the outer region. Therefore it equated to volume constraint followed by Equation 2 and 3 so as to represent the initially closed package:

$$\Delta V = \Delta V_{expansion} + \Delta V_{compression} = 0 \qquad eq(2)$$

$$\Delta V_{compression} = \Delta V_{expansion} \qquad eq(3)$$

where $\Delta V_{compression}$ is the volumetric variation generated by the displacement of the smaller sides, and $\Delta V_{expansion}$ is the volume variation generated by the displacement of the larger sides.

To this proposed equation, we used the tool "Global Constraint", made this way the deformation profile shown in Figure 10:

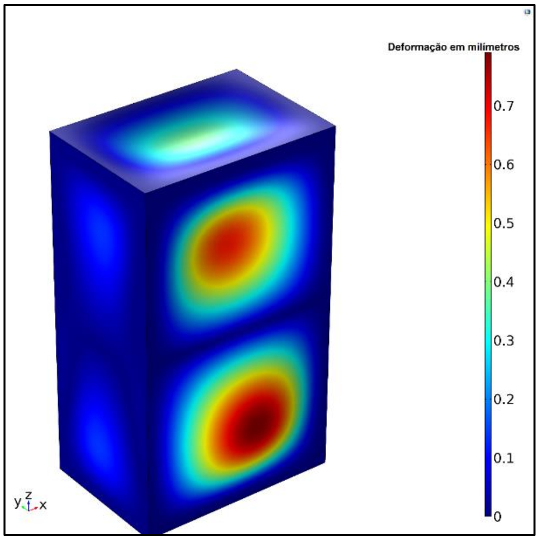
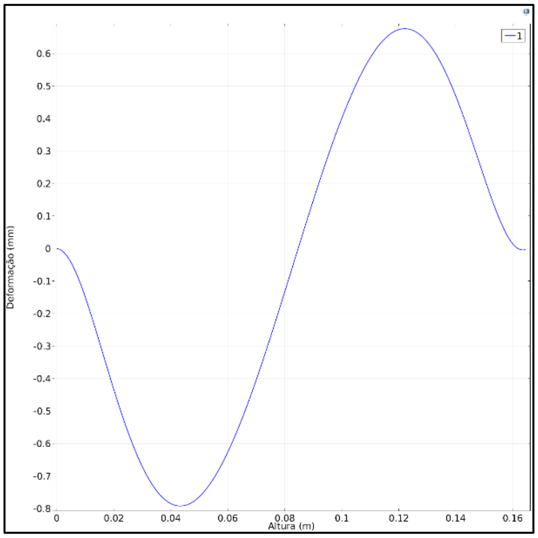


Figure 10- deformation profile analysis in millimeters with volume restriction.

For a two-dimensional graphical analysis with the aid of the "*Cut line 3D*" tool was analyzed deformation of the largest side according to the graph 1, where the abscissa represents the height of the package in centimeters, and the ordinate the value of the deformation in *mm* . The obtained deforming was named Profile Profile "S".

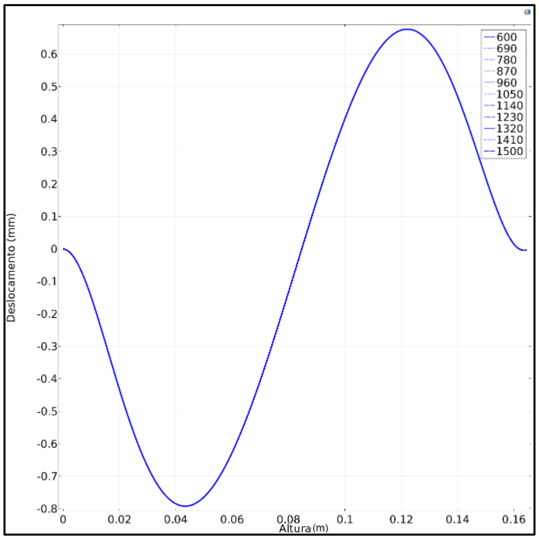


Graphic 1- Profile "S" of deforming.

Later, comparison of the deformation obtained through COMSOL Multiphysics software with the deformation of a real packaging was performed, thereby generating the graph 2 annexed in this article.

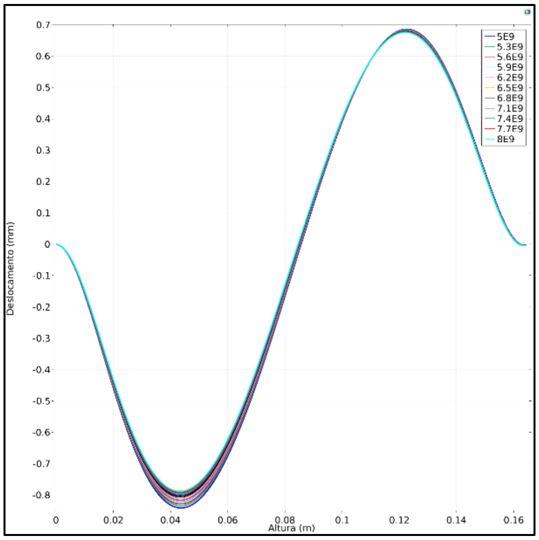
There are variations in the deformation obtained through software and experimental measurements. Factors such as the process of measuring the real packaging, presence of folds, absence of polyethylene and aluminum rolling can justify such deviation. To enhance the discussion between the results obtained from the COMSOL software and experimental, they were varied the elastic constants of the board according to Table 2.

The analysis density of board showed no influence on the packaging deforming profile, as represented by Graph 3, where both graphics overlap.



Graph 3- Deformation depending on the density of board.

Later it was varied other elastic constants of the board, both in the direction MD and in CD direction. Both results demonstrate that generated the largest amplitude variation is a function of changes in direction contained in the CD, as shown by the graphs 4 and 5, in which was varied the modulus of elasticity of the material. This effect can be explained by the concept of pressure vessels, where the highest pressure occurs in the circumferential direction of the package.



Graph 4- Deformation due to the variation of the MD Elasticity Module (5GPa <E <8GPa).

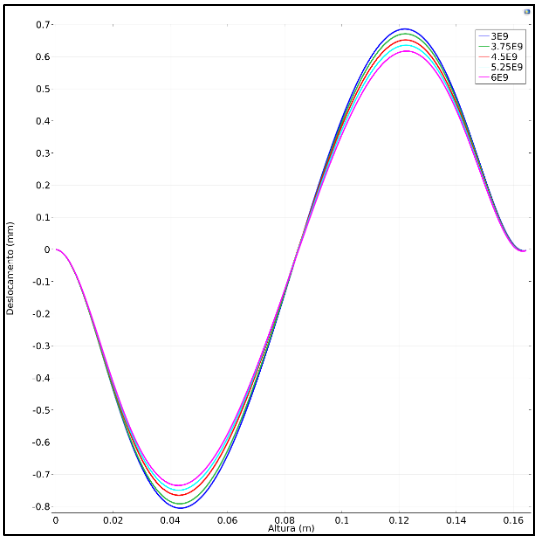
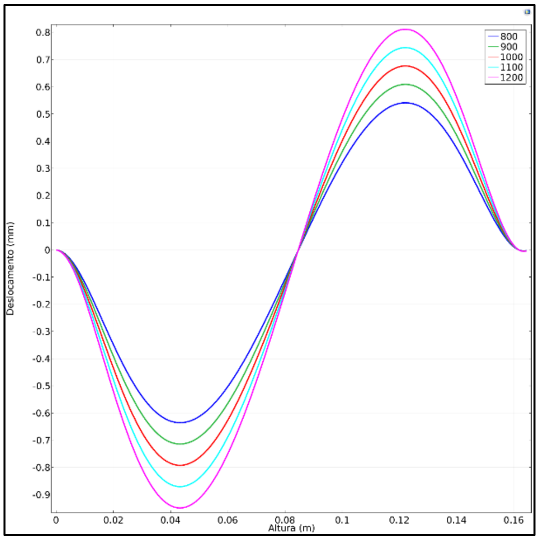


Gráfico 5- Deformation as a function of variation of CD elasticity module (3 GPa <E <6 GPa).

Finally, to check the influence of the change in the density of the liquid the bottled in the package on the deformation, the liquid density was varied in a range comprising 800 kg.m^{-3} to 1200 kg.m^{-3}. Results obtained by the following Graph 6 which shows significant influence on the deformation profile on the basis of the variation of the density of the liquid bottled in the packaging.



Graph 6- Deformation due to the variation of the density of the packaged fluid (800 $\frac{kg}{m^3}$ to 1200 $\frac{kg}{m^3}$) .

4. Conclusion

It was possible to evaluate the profile of the deformation of a packaging made of board type of LPB, the influence of variations of the elastic constants of the board and the density of the liquid the bottled in the package on the deformation. Equating proposed for the closed container, with restriction internal volume, was the potential equation that governed the deformation profile. The results indicate the study considering the composite board with polyethylene and aluminum, as well as the optimization of physical measurement method of the actual package.

5. References

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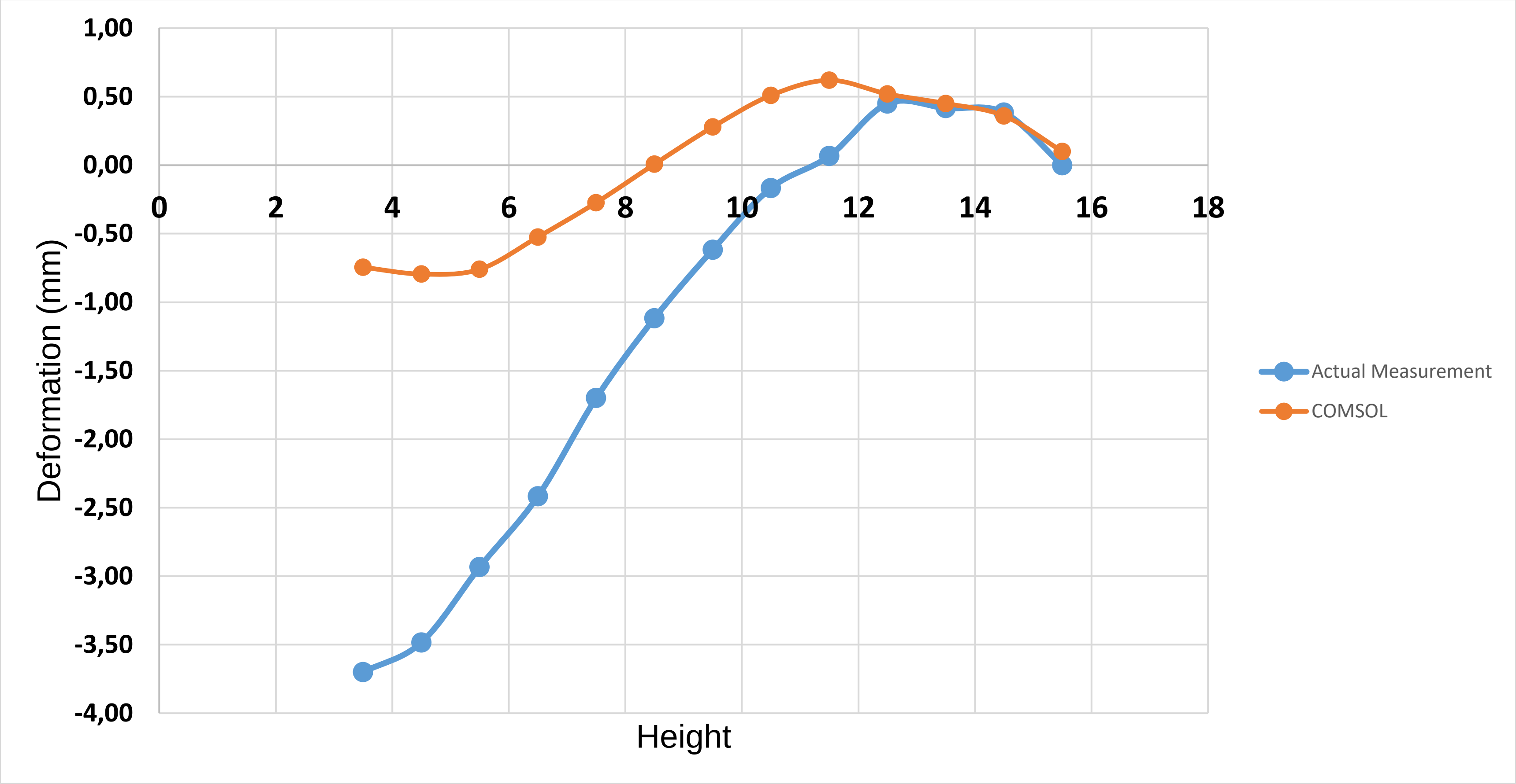
Annex 01.

Graph 2- Comparison of Deformation Measurement and Simulated



Orange points represent the deformation obtained by the software, and blue points deformation measured experimentally.