

DESIGN OF COMPOSITE STRUCTURE :

LIQUID NITROGEN TANK

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INDEX

AIM OF THE PROJECT	5
1.1.INTRODUCTION	6
1.1.1 LIQUID NITROGEN	6
table 1:liquid properties.....	6
Source : http://encyclopedia.airliquide.com	6
1.1.2 COMPOSITE MATERIALS.	7
1.3 PROJECT PLANNING	8
2.1 CHARACTERISTICS OF LIQUID NITROGEN	9
Table 2	9
Source http://encyclopedia.airliquide.com/	9
2.1.1 TYPES OF MATERIALS	10
2.1.1.1 TYPES OF FIBERS	10
GLASS FIBER:	10
CARBON FIBER.....	11
BASED ON CARBON FIBER PROPERTIES, CARBON FIBERS CAN BE GROUPED INTO:	11
BASED ON PRECURSOR FIBER MATERIALS, CARBON FIBERS ARE CLASSIFIED INTO;	11
BASED ON FINAL HEAT TREATMENT TEMPERATURE, CARBON FIBERS ARE CLASSIFIED INTO.....	12
PROPERTIES OF CARBON FIBERS	12
Table 3	13
Source: http://web.utk.edu/~mse/Textiles/CARBON%20FIBERS.htm	13
ARAMID FIBER	13
PROPERTIES OF ARAMID FIBERS.....	14
STIFFNESS:	14
RESISTANCE:	14
THERMAL PROPERTIES	14
2.1.1.2 MATRIX PROPERTIES.....	14
POLYMERICAL MATRIX.....	14
THERMOSETTING EPOXY POLYESTER.....	14



THERMOPLASTIC.....	15
INORGANICAL MATRIX.....	15
METALIC MATRIX.....	15
Table 4.....	16
Source:Slights of “ Manufacture of Composite materials “ of Escuela Superior de ingenieros de SanSebastian , Spain.....	16
3.1 TANK DESIGN.....	17
3.1.1 STRESS ANALISYS	17
3.1.1.1 DETERMINING OF THE STRESSES	17
3.1.1.2 ANALISYS OF STRESS IN THIN WALL TANKS	18
Figure 1.....	18
Source: [2] “ Elasticity and Resistance of materials II“ and “ Composite materials “UC3M	18
Figure 2.....	19
Source: “ Elasticity and Resistance of materials II“ and “ Composite materials “UC3M	19
Figure 3.....	20
Source:Autocad.....	20
3.1.2 DESIGN OF THE LAMINATE	21
3.1.2.1 THEORY OF LAMINATES.....	21
3.1.1.2 PLANE STIFFNESS OF SIMETRIC LAMINATES.....	22
Figure 4.....	22
Source: “ Elasticity and Resistance of materials II“ and “ Composite materials “UC3M	22
Figure 5.....	23
Source:“ Elasticity and Resistance of materials II“ and “ Composite materials “UC3M	23
3.1.1.3 FLEXURAL STIFFNESS OF SIMETRIC LAMINATES	24
Figure 6.....	25
Figure 7.....	26
Source“ Elasticity and Resistance of materials II“ and “ Composite materials “UC3M	26
3.1.1.3 CALCULATION OF THE LAMINATE	27
PROPERTIES OF DIFERENTS COMBINATIONSOF COMPOSITES	28
3.2 MATHCAD	29



Table 5.....	37
3.3 MODELING USING ANSYS.....	39
Table 6.....	39
Figure 9.....	41
Figure 10.....	42
Figure 11.....	43
3.1.1.4.1 STRESSES PLOT	44
3.1.1.4.2 STRAIN PLOT	45
1.2 MODAL ANALYSIS	46
Table 2.....	46
NODAL SOLUTION.....	47
Figure 20.....	47
Figure 21.....	48
4.THERMAL ANALYSIS	49
4.1 MATERIAL	49
4.2 CALCULATION OF THE CRITICAL RADIUS OF INSULATION	51
Figure 23.....	51
Table 3	52
5. CONCLUSIONS	54
6.BIBLIOGRAPHY.....	56



AIM OF THE PROJECT

This project focuses on the study and analysis of a special kind of structure, nitrogen tank made of composite structures.

The main idea of this project is for being use in a hospital because is one of the best places for the application of this kind of material, but due to the properties of the tank it will be able for use everywhere.

I want to make this project using this materials because nowadays there is an important increasing of the investigation in this topic, and I think that it could improve the tanks that are manufacturing now by the companies making it too much resistant and light.

The aim of the project is evaluate the improvements that composites materials makes in this type of structures, using the properties which they are going to contribute and also evaluate the most important characteristic composites has it, which is designing for using the resistances in the exactly directions that we need to makes the tank completely resistant and also do it the most cheaper way, which will be the different against the competence.

The main objective of my project is showing the relationship between using some theoretical calculus and also use some programs such as mathcad or ANSYS to evaluate the final results and to be able for assuring that the tank will resist all the pressure combination that are going to appear due to the liquid and the extreme temperatures which it has in the internal surface.

For this project I have designed use the a cylindrical tank which the appearance it could be :





1.1.INTRODUCTION

1.1.1 LIQUID NITROGEN

Nitrogen is a colorless odorless gas it's inert in molecular state, except in some special conditions.

This gas doesn't burn and it doesn't maintain the combustion. It's slightly soluble in water and nitrogen is in the atmosphere in 78 percent.

this gas is obtained industrially by fractional distillation of liquid air. The most important uses of the liquid nitrogen are:

Inert atmosphere	Welding and cutting
Fluids purge	Analyse instruments
Degassing and agitation	Biologic and medical investigation
Refrigeration	Food industries

table 1:liquid properties

Source : <http://encyclopedia.airliquide.com>



1.1.2 COMPOSITE MATERIALS.

Composite materials are combination of metals ceramics and polymerical material. the properties that we obtained of this materials are upper than each material separately. So that it's the reason of the increased use of this kind of materials for example in parts that need mix of properties that one type of material can't get it.

The final properties are the result of the combination of reinforcements and matrix that are used, and it's highly important to be sure about the properties of the mix fibers –matrix.

In general the worst disadvantage of this materials is the price. the special characteristics of this materials and also the processes make this materials expensive

On the other side the advantages of this materials are high mechanical properties like very high stiffness, dimensional stability, and temperature tolerance, high strength at break, good behavior against corrosive situation, lightness, and a better behavior against fatigue than traditional material, so these aspects make that composite material compensate the price.

Besides the reinforcement and the matrix are other components such as fillers and additive materials which give compounds of features peculiar to each type of manufacture and application



1.3 PROJECT PLANNING

The Project is going to be divide in several chapters

Chapter 1:

In this chapter are going to be describe the general characteristics of materials that we'll use to design and the scopes of the Project. Finally at the end appears the planning of the project.

Chapter 2:

Its divide in subchapters:

Liquid nitrogen characteristics Technical parameters of composites Insulation characteristics

Normative

Manufacturing criteria

Chapter 3:

This section is calculated from the current regulations the design parameters required for deposit insurance. We are going to obtain the design with several types of laminates fo selecting the best of them to ensure that the tank will be able to resist all loads.

Chapter 4:

In this chapter we will use programs such as ANSYS or mathcad to evaluate if the previous theoretical calculations are able to resist all the loads and make the tank suitable to the design. Also we will evaluate other aspects like the support design and the thermal analisis that we need to select the best insulation for the tank

Chapter 5 :

Finally in this chapter are going to be all the budgets and conclusions of the project



CHAPTER II

2.1 CHARACTERISTICS OF LIQUID NITROGEN

The natural state of the nitrogen is gas. Nitrogen is a colorless chemical element which belongs no metal group. The atomic number of nitrogen is 7. The melting point of the nitrogen is 63,14 Kelvin. The boiling point is 77,35 Kelvin .

The most important propertis for this Project that we must know about de nitrogen are:

Melting point	63.14 K
Boiling point	77.35 K
Heat of fusion	0.3604 KJ/mol
Critical temperature	126.19 K
Crtycal pressure	3.39 MPa
Specific heat	1040 J/(K·KG)
Thermal conductivity	0.02598 W/(K·m)
density	0,808 Kg/l

Table 2

Source <http://encyclopedia.airliquide.com/>



2.1.1 TYPES OF MATERIALS

In this part of the project I will explain all the characteristics of the materials which we will use. After know all the properties, we will be able to select the best combination for our design.

Composites material have a more higher elasticity module so that means lower deflections and more security for our design .Also composite materials don't have problems of oxide and it makes that the maintenance is more less than with other materials. Finally if we talk about dynamics effects we must said that composites materials entering fatigue when the stresses are minimum the 90% of the resistant capacity of the tensile strength. Finally composites has a great behavior in extreme temperatures.

That are the reason why we will use composite to design nitrogen liquid deposit.

2.1.1.1 TYPES OF FIBERS

- 1.fibers are the responsible of resistance all the traction efforts that the piece could have.
- 2.fibers provide rigidity to avoid important deformations
- 3.the fibers are also used to endow the conductivity or the electrical insulation, it depends of the type of the fiber

GLASS FIBER:

Mineral fiber made from silica, lime, alumina and magnesite.

These materials are added various oxides are finely ground and obtaining a homogeneous mass, which is later introduced into a furnace at 1550 ° C. The molten glass is extruded and stretched, applying a sizing and thus achieving the filament.

Type E:

Its the most widely used type of fiber is characterized by its dielectric properties, representing 90% reinforcement for composites. Inorganic fiber which composition is 53-54% SiO₂, 14-15.5% Al₂O₃, 20-24% CaO, MgO y 6.5-9% B₂O₃



Type R:

60% SiO₂, 25% Al₂O₃, 9% CaO, and 6% MgO. It has good properties and is resistant to mechanical fatigue, temperature and humidity.

Type D:

This fiber has a great dielectric power so they are used in radars, electromagnetic application ...

Type AR:

This fiber has zirconium oxide so they are great for working with alkalis.

Type C:

The most important property is that this type of fiber has the most higher chemical resistance. The composition is 60-72% SiO₂, 9-17% CaO, MgO y 0.5-7% B₂O

Tipo S :

It is used for aeronautic applications. 65% SiO₂, 10% MgO y 25% Al₂O₃

CARBON FIBER

BASED ON CARBON FIBER PROPERTIES, CARBON FIBERS CAN BE GROUPED INTO:

Ultra-high-modulus, type UHM (modulus >450Gpa)

High-modulus, type HM (modulus between 350-450Gpa)

Intermediate-modulus, type IM (modulus between 200-350Gpa)

Low modulus and high-tensile, type HT (modulus < 100Gpa, tensile strength > 3.0Gpa)

Super high-tensile, type SHT (tensile strength > 4.5Gpa)

BASED ON PRECURSOR FIBER MATERIALS, CARBON FIBERS ARE CLASSIFIED INTO;

- PAN-based carbon fibers
- Pitch-based carbon fibers



- Mesophase pitch-based carbon fibers
- Isotropic pitch-based carbon fibers
- Rayon-based carbon fibers
- Gas-phase-grown carbon fibers

BASED ON FINAL HEAT TREATMENT TEMPERATURE, CARBON FIBERS ARE CLASSIFIED INTO

Type-I, high-heat-treatment carbon fibers (HTT), where final heat treatment temperature should be above 2000°C and can be associated with high-modulus type fiber.

Type-II, intermediate-heat-treatment carbon fibers (IHT), where final heat treatment temperature should be around or above 1500°C and can be associated with high-strength type fiber.

Type-III, low-heat-treatment carbon fibers, where final heat treatment temperatures not greater than 1000°C. These are low modulus and low strength material

PROPERTIES OF CARBON FIBERS



Physical strength, specific toughness, light weight

High dimensional stability, low coefficient of thermal expansion, and low abrasion

Good vibration damping, strength, and toughness

Electrical conductivity

Biological inertness and x-ray permeability

Fatigue resistance,

self-lubrication,

high damping

Chemical inertness,

high corrosion resistance

Electromagnetic properties

Table 3

Source: <http://web.utk.edu/~mse/Textiles/CARBON%20FIBERS.htm>

ARAMID FIBER

Several grades of Kevlar are available:

1. *Kevlar K-29* – in industrial applications, such as cables, [asbestos](#) replacement, brake linings, and body/vehicle armor.



2. *Kevlar K49* – high modulus used in cable and rope products.
3. *Kevlar K100* – colored version of Kevlar
4. *Kevlar K119* – higher-elongation, flexible and more fatigue resistant.
5. *Kevlar K129* – higher tenacity for ballistic applications.
6. *Kevlar AP* – has 15% higher tensile strength than K-29.^[10]
7. *Kevlar XP* – lighter weight resin and KM2 plus fiber combination.^[11]
8. *Kevlar KM2* – enhanced ballistic resistance for armor applications^[12]

PROPERTIES OF ARAMID FIBERS

STIFFNESS:

Kevlar possesses exceptional rigidity to be a polymeric fiber. The value of the modulus of elasticity at room temperature is around 80 GPa (Kevlar29) and 120 (Kevlar49) GPa. The value of a typical steel is 200 GPa

RESISTANCE:

The Kevlar has exceptional tensile strength, at 3.5 environment GPa. Steel, by contrast has a strength of 1.5 GPa. The exceptional resistance of Kevlar (and other similar polyarylamides) is due to the orientation of molecular chains in the direction of the fiber axis and to the large number of bonds by hydrogen bonds between the chains, between amide groups (see structure).

THERMAL PROPERTIES

Kevlar maintains its strength and resilience down to cryogenic temperatures (-196°C); in fact, it is slightly stronger at low temperatures. At higher temperatures the tensile strength is immediately reduced by about 10–20%, and after some hours the strength progressively reduces further. For example at 160°C (320°F) about 10% reduction in strength occurs after 500 hours.

2.1.1.2 MATRIX PROPERTIES

POLYMERIC MATRIX

THERMOSETTING EPOXY POLYESTER

Solidifying the liquid resin by intermolecular bonds. The properties vary according to the initial molecule. The curing process is done at room temperature.



They are fragile epoxy being the most tenacious of them all.

THERMOPLASTIC

They have intermolecular bonds

They can be amorphous or crystalline

Are ductile with good thermal stability and corrosion resistant

INORGANICAL MATRIX

METALIC MATRIX

Fundamentally Al and Mg are properties depend greatly on the thermal treatment

They tend to be ductile and isotropic

It seeks to increase rigidity and low abrasion alpha

CERAMIC MATRIX

vitreous complex oxides with some crystalline phase produced by thermal treatment

Softening relatively low manufacturing facility

Conventional-Ceramics: SiC, Al₂O₃, Si₃N₄, ZrO₂

-

Matrix Study

	Density (Mg/m^3)	Young's modulus (GPa)	Strength ^a (MPa)	Ductility (%)	Toughness K_{IC} ($MPa\ m^{1/2}$)	Specific modulus [(GPa)/ (Mg/m^3)]	Specific strength [(MPa)/ (Mg/m^3)]
CERAMICS							
Alumina Al_2O_3	3.87	382	332	0	4.9	99	86
Magnesia MgO	3.60	207	230	0	1.2	58	64
Silicon Nitride Si_3N_4		166	210	0	4.0		
Zirconia ZrO_2	5.92	170	900	0	8.6	29	152
β -Sialon	3.25	300	945	0	7.7	92	291
Glass-ceramic Silicram	2.90	121	174	0	2.1	42	60
METALS							
Aluminium	2.70	69	77	47		26	29
Aluminium-3%Zn-0.7%Zr	2.83	72	325	18		25	115
Brass Cu-30%Zn	8.50	100	550	70		12	65
Nickel-20%Cr-15%Co	8.18	204	1200	26		25	147
Steel mild	7.86	210	460	35		27	59
Titanium-2.5% Sn	4.56	112	792	20		24	174
POLYMERS							
Epoxy	1.12	4	50	4	1.5	4	36
Melamine formaldehyde	1.50	9	70			6	47
Nylon 6.6	1.14	2	70	60		18	61
Polyetheretherketone	1.30	4	70			3	54
Polymethylmethacrylate	1.19	3	50	3	1.5	3	42
Polystyrene	1.05	3	50	2	1.0	3	48
Polyvinylchloride rigid	1.70	3	60	15	4.0	2	35

Table 4:properties of matrix

Source:Slights of “ Manufacture of Composite materials “ of Escuela Superior de ingenieros de SanSebastian , Spain.



CHAPTER III

3.1 TANK DESIGN

Overall the design of pressure tanks in accordance with ASME Code, Sección VIII, Division 1, are designed by rules and do not require a detailed assessment of all efforts. It is recognized that high flexural high secondary stresses may exist but are supported by the use of a high safety factor and details. Without design rules, however, require that all the loads are considered.

3.1.1 STRESS ANALYSIS

The stress analysis is the determination of the relationship between external forces applied to the vessel and the corresponding stresses. The stress analysis is necessary to determine the material thickness and sizes of the parts of the container.

The first point to perform a stress analysis is to determine all design conditions for a particular project and then determine all relations with external forces. It should relate these external forces to the parts of the container which must resist efforts to get involved. Separating the causes (loads), effects (efforts) may be more need to be identified.

3.1.1.1 DETERMINING OF THE STRESSES

According to the relation with the thickness of tank walls and the diameter the tanks could be classified like, heavy wall tanks or thin walled tanks. The ASME CODE says that we can consider thin wall tanks when the relation between wall thickness and the internal diameter are equal or less than 0.1.

For thin wall tanks, we can suppose walls won't oppose flexion, so it means that internal forces are tangent to the surface of the tank, that is to say that they behave like membranes under stresses.

3.1.1.2 ANALYSIS OF STRESS IN THIN WALL TANKS

In this case the tank is cylindrical, that means that to calculate the pressure that will appear in the tank are only normal stresses, and these are the main stresses.

We can obtain the value of this pressure using the following figure and we must be careful because it is only valid for thin wall tank situation.

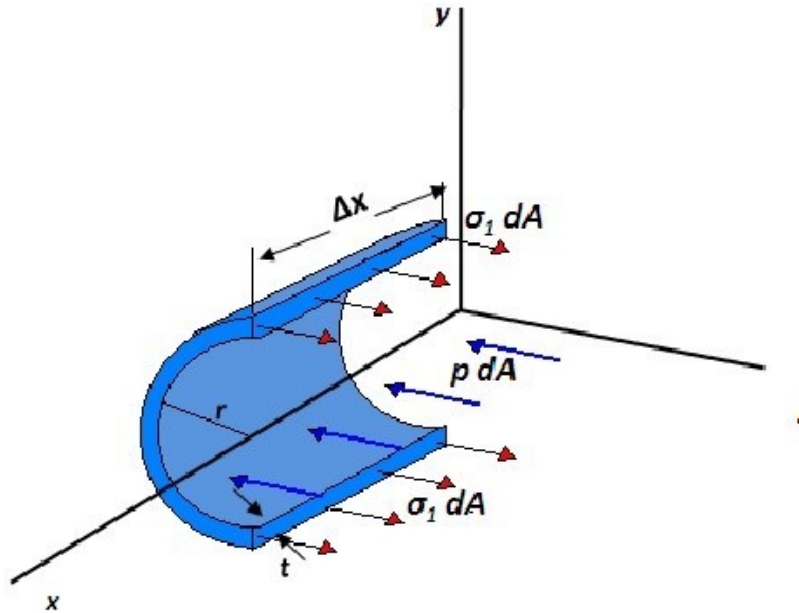


Figure 1

Source: [2] "Elasticity and Resistance of materials II" and "Composite materials" UC3M

To obtain the internal pressure, in this case we only have to present the following equation, which shows the force balance of the infinitesimal part that we have:

$$F_{int} = F_{tank}$$

$$P \cdot \Delta x \cdot 2 \cdot r = \sigma_{\theta} \cdot \Delta x \cdot e \cdot 2$$

$$\sigma_{\theta} = \frac{P \cdot r}{t}$$

Analogously we can find the stress in the longitudinal direction for a close tank:

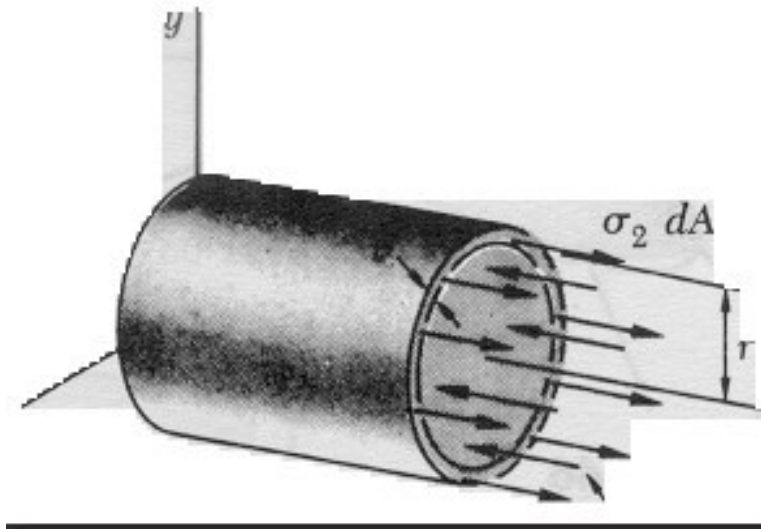


Figure 2

Source: "Elasticity and Resistance of materials II" and "Composite materials" UC3M

$$F_{int} = F_{tank}$$

$$\pi \cdot r^2 \cdot P = 2 \cdot \pi \cdot r \cdot t \cdot \theta$$

$$\theta_z = \frac{P \cdot r}{2 \cdot t}$$

Finally we must calculate , using the mohr circle, which are the tangential stresses that appears due to the main stresses.

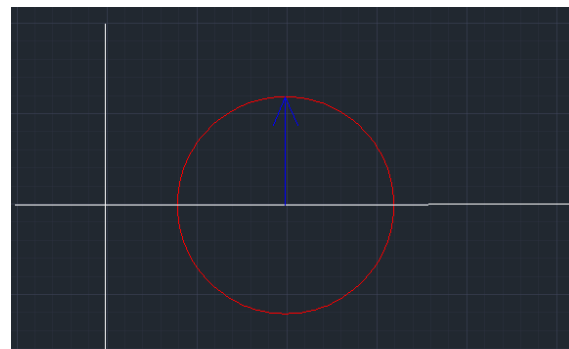




Figure 3

Source:Autocad



From the morh we obtain that the radius of the circle it's the value of the maximum tangencial stresses, so for calculate:

$$\theta_{center} = \frac{\theta_{\theta} + \theta_z}{2}$$

$$R = \text{tang max} = \theta_{center} - \theta_z$$

Finally the stress state that will appear in the tank is:

$$[T] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \theta_{\theta} & \tau \\ 0 & \tau & \theta_z \end{bmatrix}$$

The value of the stresses depends of the value of the internal pressure, and pressure will be the main parameter to determine the thicknes of the tank.(this equations are only valid for thin wall tank)

3.1.2 DESIGN OF THE LAMINATE

At now, we know which pressure must resist our tank but we have to calculate how to do it using composite materials.

3.1.2.1 THEORY OF LAMINATES

To work with laminates we will introduce some hypothesis:

Composite laminates show elastic behavior till break.

Laminates has an small thickness

Deformation of any ply is the same that all the laminate

3.1.1.2 PLANE STIFFNESS OF SIMETRIC LAMINATES

Such as we can observe at the figure deformation of all the plys is the same ϵ_0

While the stresses of each ply are diferentes however the stress distribution is simetric in both part respect midplane.

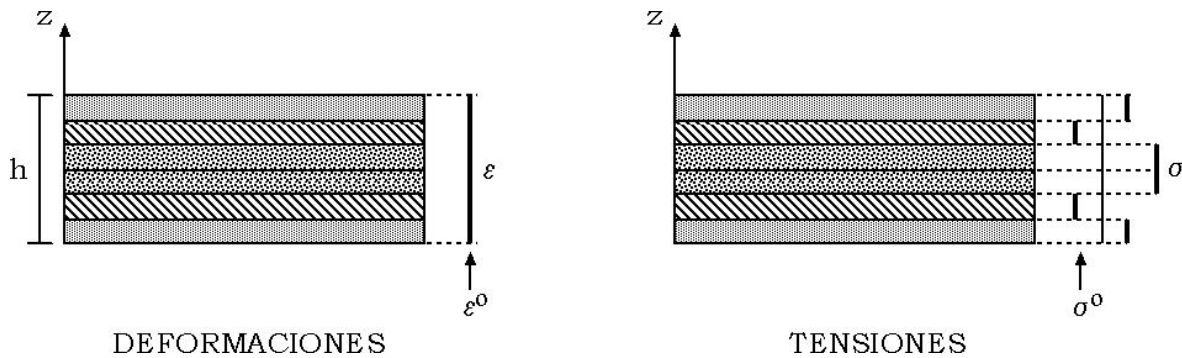


Figure 4

Source: " Elasticity and Resistance of materials II" and " Composite materials "UC3M

We can obtain the relation between the efforts and the deformation that will appear in the laminate using:

$$\{\theta\} = \begin{Bmatrix} \theta_x \\ \theta_y \\ \theta_{xy} \end{Bmatrix} (Pa)$$

$$\{\epsilon\} = \begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{Bmatrix}$$

$$\{N\} = \begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} (N/m)$$

To define the positive ways of the efforts that appears in the laminate we must use

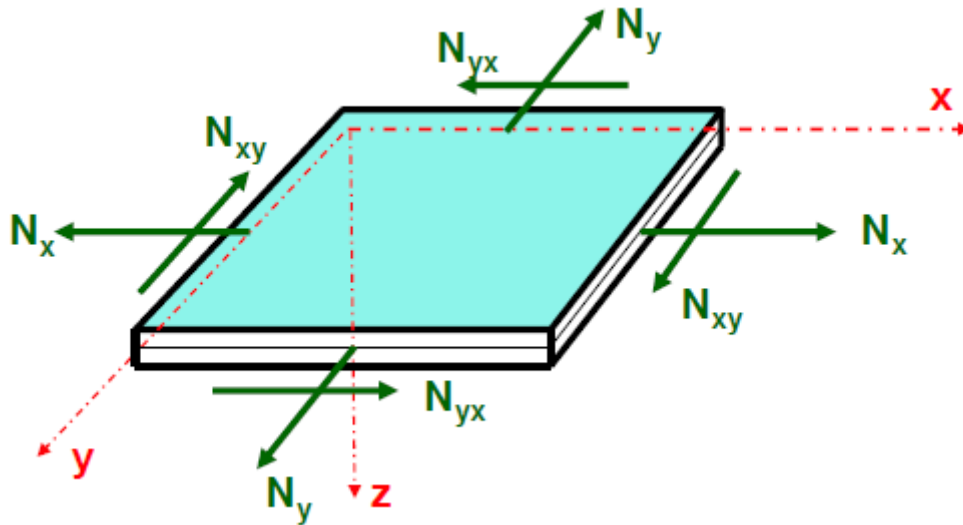


Figure 5:axial components in the plies

Source: " Elasticity and Resistance of materials II" and " Composite materials "UC3M

Finally the relation between the efforts that we apply in the laminate and the deformation that appears can be obtained integrating along the thickness

$$\{N\} = \int_{-\frac{h}{2}}^{\frac{h}{2}} \{\sigma\} dz = \int_{-\frac{h}{2}}^{\frac{h}{2}} [Q] \{\varepsilon\} dz$$

Q: it's the stiffness matrix of each ply

But it is necessary to use the relation of all the laminate not only for one ply, so we have to use A matrix which will represent the stiffness for all the laminate

$$[A] = \int_{-\frac{h}{2}}^{\frac{h}{2}} [Q] dz, \text{ that means we have to do this to obtain the stiffness matrix of all the laminate}$$

$$[A] = \sum_{i=1}^m [Q]_i \cdot h_i$$

3.1.1.3 FLEXURAL STIFFNESS OF SIMETRIC LAMINATES

Calling u, v, w movements anywhere in the laminate according to the axes x, y and z to point B of can be raised, under the above assumptions, the following:

$$\alpha = \frac{\partial w_a}{\partial x}$$

$$U_B = U_a - Z_b \cdot \alpha = U_a - Z_b \cdot \frac{\partial w_a}{\partial x}$$

In a similar way we could also express the displacement of point B in the y direction as:

$$\beta = \frac{\partial w_a}{\partial y}$$

$$V_B = V_a - Z_b \cdot \beta = V_a - Z_b \cdot \frac{\partial w_a}{\partial y}$$

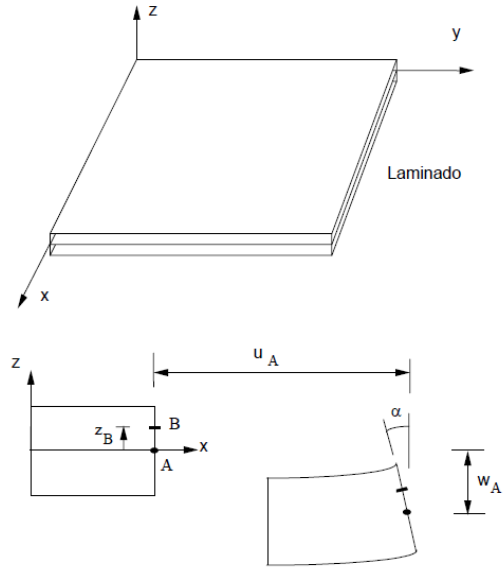
The deformations can be calculated from displacement as indicated above

$$\varepsilon_x = \frac{\partial U_B}{\partial X} = \frac{\partial U_a}{\partial X} - z \frac{\partial^2 W_a}{\partial X^2}$$

$$\varepsilon_y = \frac{\partial V_B}{\partial Y} = \frac{\partial V_a}{\partial Y} - z \frac{\partial^2 W_a}{\partial Y^2}$$

$$\gamma_{XY} = \frac{\partial u_B}{\partial Y} + \frac{\partial v_B}{\partial X} = \frac{\partial u_a}{\partial Y} + \frac{\partial v_a}{\partial X} - 2z \frac{\partial^2 W_a}{\partial X \partial Y}$$

$$\varepsilon_z = \gamma_{xz} = \gamma_{yz} = 0$$



The above equations can be generalized to any point of the laminate at a distance z from the median plane and written in matrix form:

$$\begin{Bmatrix} \varepsilon_X \\ \varepsilon_Y \\ \varepsilon_{XY} \end{Bmatrix} = \begin{Bmatrix} \varepsilon_X^0 \\ \varepsilon_Y^0 \\ \varepsilon_{XY}^0 \end{Bmatrix} + Z \cdot \begin{Bmatrix} K_x \\ K_y \\ K_{xy} \end{Bmatrix}$$

$$\begin{Bmatrix} \varepsilon^0_X \\ \varepsilon^0_Y \\ \varepsilon^0_{XY} \end{Bmatrix} = \begin{Bmatrix} \frac{\partial U_A}{\partial X} \\ \frac{\partial v_a}{\partial y} \\ \frac{\partial U_a}{\partial y} + \frac{\partial V_a}{\partial x} \end{Bmatrix}$$

$$\begin{Bmatrix} k_X \\ k_Y \\ k_{XY} \end{Bmatrix} = - \begin{Bmatrix} \frac{\partial^2 W_a}{\partial X^2} \\ \frac{\partial^2 W_a}{\partial y^2} \\ 2 \frac{\partial^2 W_a}{\partial X \partial y} \end{Bmatrix}$$

Figure 2 shows the deformation and stress state of the laminate being able to appreciate that the strain height varies linearly with respect to the median plane while the variation of the voltages in each sheet, it corresponds to a predetermined law

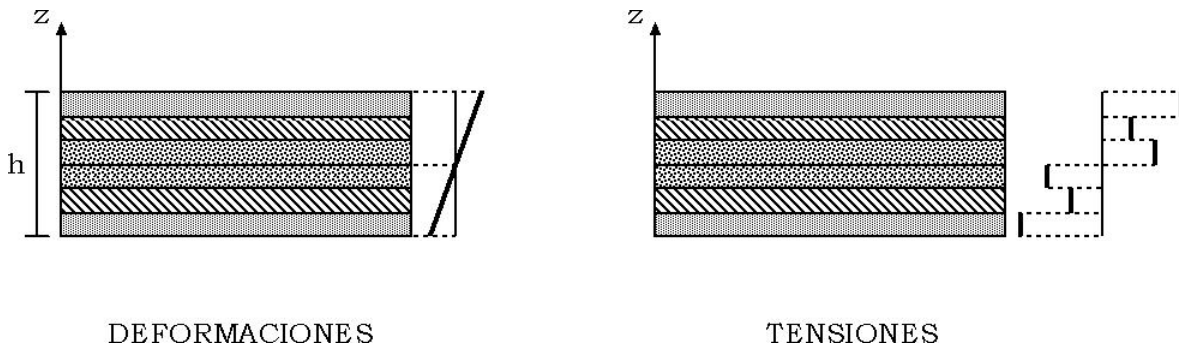


Figure 6: diagrams of stress and deformation variability

Source “Elasticity and Resistance of materials II” and “Composite materials” UC3M

Assuming, on the laminate acting moments per unit length represented in Figure 3.

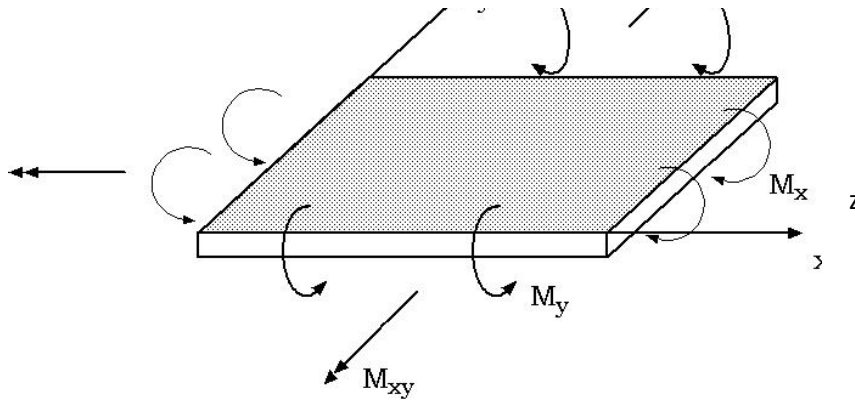


Figure 7: bending moments in the ply

Source" Elasticity and Resistance of materials II" and " Composite materials "UC3M

{M} Denoting the vector of moments applied:

$$\{M\} = \int_{-\frac{h}{2}}^{\frac{h}{2}} \{\sigma\} \cdot z \cdot dz = \int_{-\frac{h}{2}}^{\frac{h}{2}} [Q] \{\varepsilon\} \cdot z \cdot dz$$

$$\{N\} = \int_{-\frac{h}{2}}^{\frac{h}{2}} [Q] z^2 dz \{k\} = [D] \{k\}$$

$$[D] = \int_{-\frac{h}{2}}^{\frac{h}{2}} [Q] z^2 dz \quad [\text{N.m}]$$



Finally the D matrix is:

$$[D] = \frac{1}{3} \sum_{i=1}^m [Q] [(z^3) - (z^{i-1})^3]$$

Once time that we have this equations we are able to calculate all stresses and deformation that will appear in our laminate and then we can use all the failure methods to know if the laminate going to be prepare to resist all the request.

3.1.1.3 CALCULATION OF THE LAMINATE

To starting calculation of the laminate the first thing that we should know are the material properties.

The following table shows the summary of some properties of several combinations of materials using 60% of fiber volume.

This table is valid only for a 60 % of fiber. If we want to use another percent its possible obtain the properties of the material using lamintate micromechanic.

Once time that we have the properties of the material, using a MATHCAD program we can obtain the theoycal laminate.

For this proyect I will use twu types of laminate to compare.

The first one ,we will use a simetric laminate to avoid problems during the cure, because if the laminate isn't simetric are going to appear residual stresses between plis which can broke the tank.



PROPERTIES OF DIFERENTS COMBINATIONSOF COMPOSITES

MATERIAL	GLASS	KEVLAR	CARBON
Density	2080	1350	1530
Tensile Stress at break in the 1 direction	1250	1410	1270
compressive Stress at break in the 1 direction	600	280	1130
Tensile Stress at break in the 2 direction	35	28	42
compressive Stress at break in the 2 direction	141	141	141
Shear Stress at break in the 1-2 plane	63	45	63
Shear Stress at break interlaminar	80	60	90
Young modulus in the direction 1 E1	45000	85000	134000
Young modulus in the direction 2 E2	12000	5600	7000
Shear modulus G12	4500	2100	4200
Poisson	0.3	0.34	0.25

Table 5: composite combination properties

Source“ Elasticity and Resistance of materials II” and “ Composite materials “UC3M



3.2 MATHCAD

The first point will be obtain the properties of the composite material

For this tank the best combination its kevlar with epoxy , due to the great behavior of the kevlar when is working at low temperatures.

We will use for design 60% of kevlar fibers with a epoxy matrix and the propierties are the followig

Values of the tank

$$P := 11 \text{ MPa}$$

In a perfectly sealed container this is the pressure of the liquid nitrogen

$$R := 1 \text{ m}$$

$$H := 4 \text{ m}$$

this are the values to have in a cilicrical tank 12000 liters which is the suppose amount for hospital working.

MATERIAL PROPERTIES

KEVLAR
EPOXY

$$\text{density} := 1350 \frac{\text{kg}}{\text{m}^3}$$

break stress traction in the longitudinal direction

$$\text{MPa} = 1 \times 10^6 \text{ Pa}$$

$$X_T := 1410 \times 10^6 \text{ Pa}$$

$$\text{ME1} := 85000 \times 10^6 \text{ Pa}$$

break stress compression in the longitudinal direction

$$\text{ME2} := 5600 \times 10^6 \text{ Pa}$$

$$G_{12} := 2100 \times 10^6 \text{ Pa}$$

$$X_C := 280 \times 10^6 \text{ Pa}$$

$$V_{\text{poi}} := 0.3$$

$$\text{vol}_{\text{fib}} := 60\%$$

break stress in the transversal direction

$$Y_C := 28 \times 10^6 \text{ Pa}$$

break stress in the transversal direction

$$Y_T := 141 \times 10^6 \text{ Pa}$$



break stress tangencial direction

(we dont need it because in our design the special stacking makes that the tangencial stresses are 0)

$$S_{xx} := 45 \times 10^6 \text{ Pa}$$

1. CALCULATE THE STIFFNESS PROPERTIES MATRIX

$$\nu_{12} := \frac{(ME2 \cdot V_{poi})}{ME1}$$

$$\nu_{12} = 0.022$$

$$Q := \begin{bmatrix} \frac{ME1}{1 - \nu_{12} \cdot V_{poi}} & \frac{(V_{poi} ME2)}{1 - \nu_{12} \cdot V_{poi}} & 0 \\ \frac{(\nu_{12} ME1)}{1 - \nu_{12} \cdot V_{poi}} & \frac{(ME2)}{1 - \nu_{12} \cdot V_{poi}} & 0 \\ 0 & 0 & G12 \end{bmatrix}$$

X

$$Q = \begin{pmatrix} 8.565 \times 10^{10} & 1.919 \times 10^9 & 0 \\ 1.919 \times 10^9 & 5.643 \times 10^9 & 0 \\ 0 & 0 & 2.1 \times 10^9 \end{pmatrix} \text{ Pa}$$

Now we have the properties for one ply of kevlar/epoxy, but we need to calculate the properties of the laminate to evaluate the failure test.



2. STIFFNESS MATRIX

To calculate the rigidity matrix we should use the stresses in the general coordinates.

this is the rigidity matrix in general axis for 0

$$w := 0$$

$$c_{xx} := \cos(w) = 1$$

$$s_{xx} := \sin(w) = 0$$

$$T0 := \begin{bmatrix} c^2 & s^2 & 2sc \\ s^2 & c^2 & -2sc \\ -sc & sc & (c^2 - s^2) \end{bmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$Q0 := T^{-1} \cdot Q \cdot T = \begin{pmatrix} 8.565 \times 10^{10} & 1.919 \times 10^9 & 0 \\ 1.919 \times 10^9 & 5.643 \times 10^9 & 0 \\ 0 & 0 & 2.1 \times 10^9 \end{pmatrix} \text{ Pa}$$

This is the rigidity matrix in general axis for 45

$$w2 := \frac{\pi}{4}$$

$$c2 := \cos(w2) = 0.707$$

$$s2 := \sin(w2) = 0.707$$

$$T45 := \begin{bmatrix} c2^2 & s2^2 & 2s2c2 \\ s2^2 & c2^2 & -2s2c2 \\ -s2c2 & s2c2 & (c2^2 - s2^2) \end{bmatrix} = \begin{pmatrix} 0.5 & 0.5 & 1 \\ 0.5 & 0.5 & -1 \\ -0.5 & 0.5 & 0 \end{pmatrix}$$



$$T_{45}^{-1} = \begin{pmatrix} 0.5 & 0.5 & -1 \\ 0.5 & 0.5 & 1 \\ 0.5 & -0.5 & 0 \end{pmatrix}$$

$$Q_{45} := T_{45}^{-1} \cdot Q \cdot T_{45} = \begin{pmatrix} 2.483 \times 10^{10} & 2.273 \times 10^{10} & 4 \times 10^{10} \\ 2.273 \times 10^{10} & 2.483 \times 10^{10} & 4 \times 10^{10} \\ 2 \times 10^{10} & 2 \times 10^{10} & 4.373 \times 10^{10} \end{pmatrix} \text{ Pa}$$

This is the rigidity matrix in general axis for 90

$$w1 := \frac{\pi}{2}$$

$$c1 := \cos(w1) = 0$$

$$s1 := \sin(w1) = 1$$

$$T_{90} := \begin{bmatrix} c1^2 & s1^2 & 2s1 c1 \\ s1^2 & c1^2 & -2s1 c1 \\ -s1 c1 & s1 c1 & (c1^2 - s1^2) \end{bmatrix}$$

$$Q_{90} := (T_{90}^{-1}) \cdot Q \cdot T_{90} = \begin{pmatrix} 5.643 \times 10^9 & 1.919 \times 10^9 & -1.989 \times 10^{-7} \\ 1.919 \times 10^9 & 8.565 \times 10^{10} & 9.997 \times 10^{-6} \\ -9.946 \times 10^{-8} & 4.998 \times 10^{-6} & 2.1 \times 10^9 \end{pmatrix} \text{ Pa}$$



This is the rigidity matrix in general axis for -45

$$w3 := \frac{-\pi}{4}$$

$$c3 := \cos(w3) = 0.707$$

$$s3 := \sin(w3) = -0.707$$

$$T_{\text{minus45}} := \begin{bmatrix} (c3)^2 & (s3)^2 & 2(s3 c3) \\ s3^2 & c3^2 & -2(s3 c3) \\ -s3 c3 & s3 c3 & (c3)^2 - (s3)^2 \end{bmatrix} = \begin{pmatrix} 0.5 & 0.5 & -1 \\ 0.5 & 0.5 & 1 \\ 0.5 & -0.5 & 0 \end{pmatrix}$$

$$(T_{\text{minus45}})^{-1} = \begin{pmatrix} 0.5 & 0.5 & 1 \\ 0.5 & 0.5 & -1 \\ -0.5 & 0.5 & 0 \end{pmatrix}$$

$$Q_{\text{minus45}} := T_{\text{minus45}}^{-1} \cdot Q \cdot T_{\text{minus45}} = \begin{pmatrix} 2.483 \times 10^{10} & 2.273 \times 10^{10} & -4 \times 10^{10} \\ 2.273 \times 10^{10} & 2.483 \times 10^{10} & -4 \times 10^{10} \\ -2 \times 10^{10} & -2 \times 10^{10} & 4.373 \times 10^{10} \end{pmatrix} \text{ Pa}$$

Now its time to determine how many plies of each orientation tanks needs.
To determine it we will use a safety value of 2 for the tank.

number of plies of each
degrees

thickness of plies

$$n0 := 10$$

$$h := 0.125 \text{ mm}$$

$$n90 := 5$$

$$n45 := 1$$

$$n_{\text{minus45}} := 1$$



$$\underline{A} := (Q_0 \cdot n_0 \cdot h) + (Q_{90} \cdot n_{90} \cdot h) + (Q_{\text{minus}45} \cdot n_{\text{minus}45} \cdot h) + (Q_{45} \cdot n_{45} \cdot h)$$

$$\underline{A} = \begin{pmatrix} 1.168 \times 10^9 & 9.281 \times 10^7 & 0 \\ 9.281 \times 10^7 & 6.679 \times 10^8 & 5.96 \times 10^{-8} \\ 0 & 2.98 \times 10^{-8} & 1.487 \times 10^8 \end{pmatrix} \frac{\text{kg}}{\text{s}^2}$$

$$t := (n_0 + n_{90} + n_{45} + n_{\text{minus}45}) \cdot h = 0.02 \text{ lm}$$

$$\text{sigc} := \frac{P \cdot R}{t} = 5.176 \times 10^8 \text{ Pa}$$

$$\text{siglo} := \frac{P \cdot R}{2 \cdot t} = 2.588 \times 10^8 \text{ Pa}$$

$$\underline{N} := \begin{pmatrix} \text{sigc} \cdot t \\ \text{siglo} \cdot t \\ 0 \end{pmatrix} = \begin{pmatrix} 1.1 \times 10^7 \\ 5.5 \times 10^6 \\ 0 \end{pmatrix} \frac{\text{kg}}{\text{s}^2}$$

$$\text{eps} := \underline{A}^{-1} \cdot \underline{N}$$

this is the elongation in general axis but we need in material axis to evaluate the failure methods

$$\text{eps} = \begin{pmatrix} 8.861 \times 10^{-3} \\ 7.003 \times 10^{-3} \\ 0 \end{pmatrix}$$

$$\text{eps}_0 := T_0 \text{eps} = \begin{pmatrix} 8.861 \times 10^{-3} \\ 7.003 \times 10^{-3} \\ 0 \end{pmatrix}$$

$$\text{eps}_{45} := T_{45} \text{eps} = \begin{pmatrix} 7.932 \times 10^{-3} \\ 7.932 \times 10^{-3} \\ -9.292 \times 10^{-4} \end{pmatrix}$$



$$\epsilon_{90} := T_{90} \epsilon = \begin{pmatrix} 7.003 \times 10^{-3} \\ 8.861 \times 10^{-3} \\ 0 \end{pmatrix} \quad \epsilon_{\text{minus}45} := T_{\text{minus}45} \epsilon = \begin{pmatrix} 7.932 \times 10^{-3} \\ 7.932 \times 10^{-3} \\ 9.292 \times 10^{-4} \end{pmatrix}$$

$$\sigma_0 := Q \cdot \epsilon_0 = \begin{pmatrix} 7.724 \times 10^8 \\ 5.652 \times 10^7 \\ -2.947 \times 10^{-9} \end{pmatrix} \text{ Pa} \quad \sigma_{45} := Q \cdot \epsilon_{45} = \begin{pmatrix} 6.946 \times 10^8 \\ 5.998 \times 10^7 \\ -1.951 \times 10^6 \end{pmatrix} \text{ Pa}$$

$$\sigma_{90} := Q \cdot \epsilon_{90} = \begin{pmatrix} 6.168 \times 10^8 \\ 6.344 \times 10^7 \\ 2.709 \times 10^{-9} \end{pmatrix} \text{ Pa} \quad \sigma_{\text{minus}45} := Q \cdot \epsilon_{\text{minus}45} = \begin{pmatrix} 6.946 \times 10^8 \\ 5.998 \times 10^7 \\ 1.951 \times 10^6 \end{pmatrix} \text{ Pa}$$

3 calculate the first ply to broke with the failure test

MAXIMUM STRESS FAILURE TEST

Ply of 0

plies at 45

$$\frac{X_T}{\sigma_0} = 1.825$$

$$\frac{Y_T}{\sigma_1} = 2.495$$

$$\frac{S}{\sigma_2} = -1.527 \times 10^{16}$$

this value dont have sense because the value of τ is 0

$$\frac{X_T}{\sigma_{45_0}} = 2.03$$

$$\frac{Y_T}{\sigma_{45_1}} = 2.351$$

$$\frac{S}{\sigma_{45_2}} = -23.062$$



plies at minus45

plies of 90

$$\frac{X_T}{\sigma_{\text{minus45}_0}} = 2.03$$

$$\frac{X_T}{\sigma_{90_0}} = 2.286$$

$$\frac{Y_T}{\sigma_{\text{minus45}_1}} = 2.351$$

$$\frac{Y_T}{\sigma_{90_1}} = 2.223$$

$$\frac{-S}{\sigma_{\text{minus45}_2}} = -23.062$$

$$\frac{S}{\sigma_{90_2}} = 1.661 \times 10^{16}$$

this value doesn't
have sense because the value of τ is 0

To be sure that the deposit is safety design I am going to use another failure criteria

FAILURE TEST TSAY-HILL

$$\frac{(\sigma_{0_0})^2}{X_T^2} + \frac{(\sigma_{0_1})^2}{Y_T^2} + \frac{(\sigma_{0_2})^2}{S^2} - \frac{\sigma_{0_0} \cdot \sigma_{0_1}}{X_T^2} = 0.439 \quad \text{sa1}$$

$$\frac{(\sigma_{90_0})^2}{X_T^2} + \frac{(\sigma_{90_1})^2}{Y_T^2} + \frac{(\sigma_{90_2})^2}{S^2} - \frac{\sigma_{90_0} \cdot \sigma_{90_1}}{X_T^2} = 0.374 \quad \text{sa2}$$

$$\frac{(\sigma_{45_0})^2}{X_T^2} + \frac{(\sigma_{45_1})^2}{Y_T^2} + \frac{(\sigma_{45_2})^2}{S^2} - \frac{\sigma_{45_0} \cdot \sigma_{45_1}}{X_T^2} = 0.405 \quad \text{sa3}$$

$$\frac{(\sigma_{\text{minus45}_0})^2}{X_T^2} + \frac{(\sigma_{\text{minus45}_1})^2}{Y_T^2} + \frac{(\sigma_{\text{minus45}_2})^2}{S^2} - \frac{\sigma_{\text{minus45}_0} \cdot \sigma_{\text{minus45}_1}}{X_T^2} = 0.405$$



To obtain the value of se safety value we have to divide 1/final value

$$sa1 := \frac{1}{\frac{(\sigma_{0_0})^2}{X T^2} + \frac{(\sigma_{0_1})^2}{Y T^2} + \frac{(\sigma_{0_2})^2}{S^2} - \frac{\sigma_{0_0} \cdot \sigma_{0_1}}{X T^2}} \quad sa1 = 2.279$$

$$sa2 := \frac{1}{\left[\frac{(\sigma_{90_0})^2}{X T^2} + \frac{(\sigma_{90_1})^2}{Y T^2} + \frac{(\sigma_{90_2})^2}{S^2} - \frac{\sigma_{90_0} \cdot \sigma_{90_1}}{X T^2} \right]} \quad sa2 = 2.673$$

$$sa3 := \frac{1}{\left[\frac{(\sigma_{45_0})^2}{X T^2} + \frac{(\sigma_{45_1})^2}{Y T^2} + \frac{(\sigma_{45_2})^2}{S^2} - \frac{\sigma_{45_0} \cdot \sigma_{45_1}}{X T^2} \right]} \quad sa3 = 2.472$$

Finally the value of SAFETY VALUE is upper 2 so we have obtained the initial supposing for the design.

Finally the laminate is:

MATERIAL		KEVLAR / EPOXY		
PLIES	0	90	45	-45
NUMBER	100	50	10	10

Table 5

Source:MATHCAD



3.3 MODELING USING ANSYS

The discretization of the problem in the case of a continuous medium is performed using a modeling process to convert it into a finite number of elements assembled together at points called nodes, the approach movement of the equations for these nodes and impose appropriate boundary conditions in terms of nodal displacement compatibility.

According to the order, you will get the displacement field for each of the nodes, and from it the stress field

For working with the ANSYS the most important thing is the correct selection of the type of element which we will use to calculate the mesh of the total volume.

In our case , the tank has a slim thickness and it means that we'll have traction and compression stresses in our element, so the element that I select is SHELL 63 and the properties of the material are:

Properties of element	
Type of element	SHELL 63
Thickness of element	2
Thickness of the tank	2.1 cm
Height of the tank	4 m
Material properties	STRUCTURAL LINEAL ANISOTROPIC
$A = \begin{pmatrix} 1.168 \times 10^9 & 9.281 \times 10^7 & 0 \\ 9.281 \times 10^7 & 6.679 \times 10^8 & 5.96 \times 10^{-8} \\ 0 & 2.98 \times 10^{-8} & 1.487 \times 10^8 \end{pmatrix} \frac{\text{kg}}{\text{s}^2}$	

Table 6 :values of the different parameters of the ANSYS development

After introduce the values in tha ANSYS program we have to mesh the tank for be able to calculate the values abouts stresses and strains.

The parameters that we use to meshing are

And finally the mesh of the model is

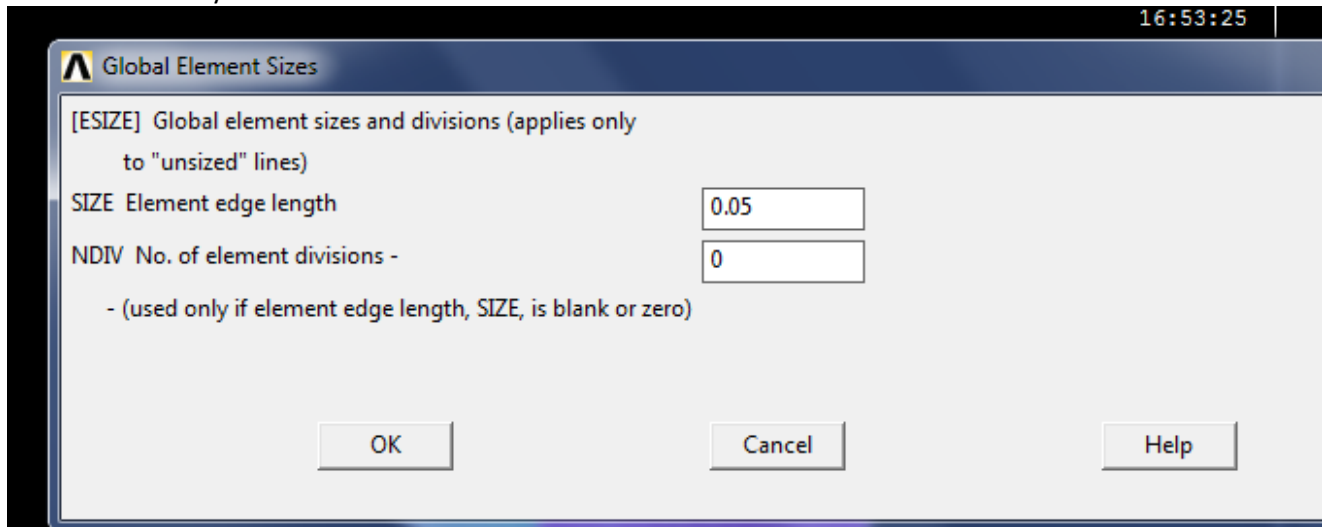


Figure 8: Shows the size of the elements of the mesh for ANSYS

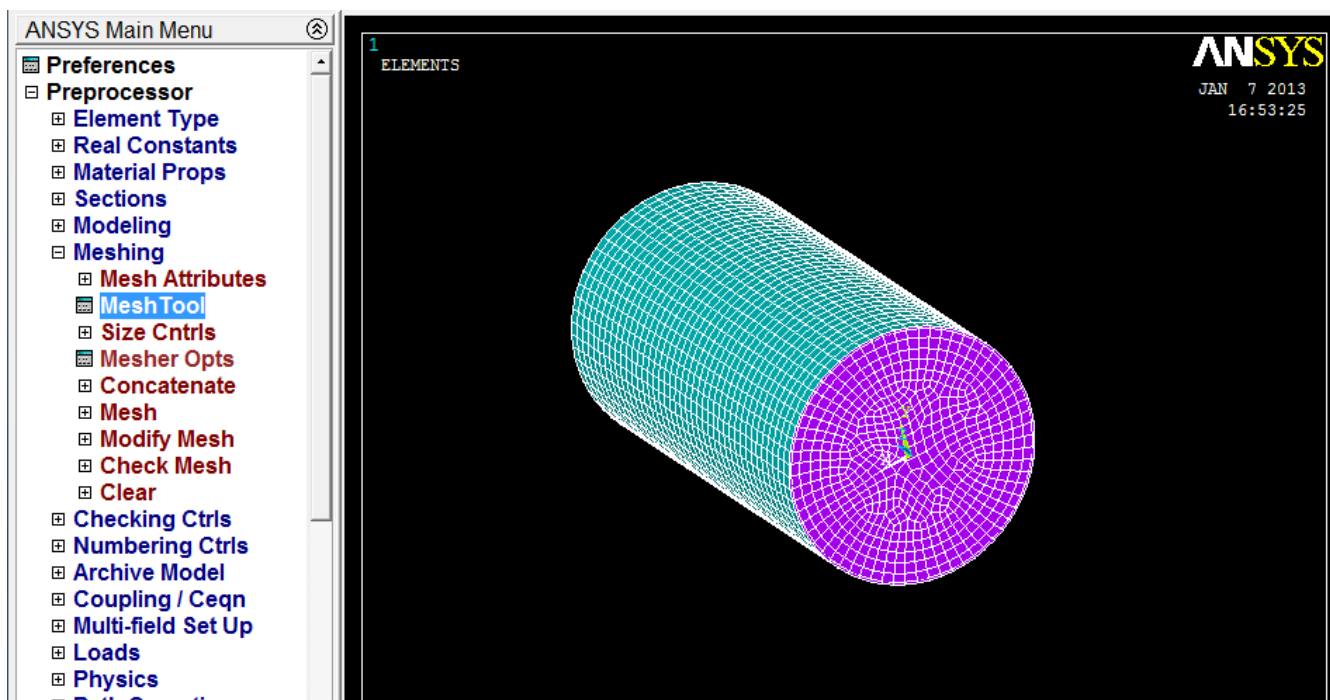


Figure 9: complete mesh for the tank

Now to calculate the parameters we have to impose some restrictions of movements and also we have to impose the value of the loads that the tank must be able to resist.

Our tank will be constructed in vertical orientation, it means that the constraints are going to be in the lower cap.

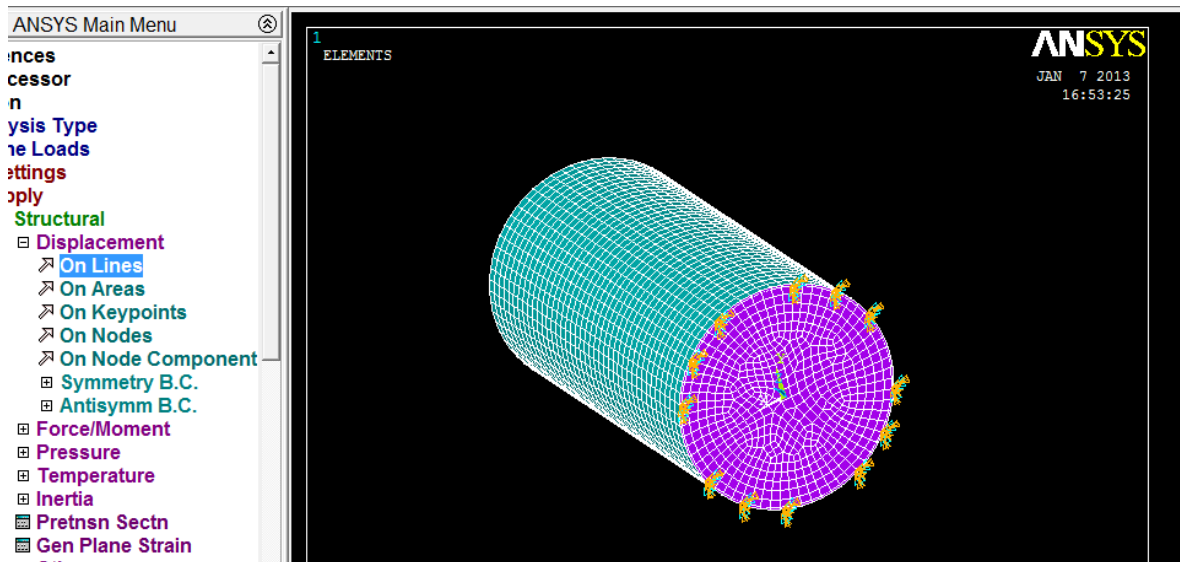


Figure 9:ANSYS displacement for calculation

To calculate the loads we must take into account that we are working with fluids so the distribution of the pressure will be the hydrostatic pressure.

To evaluate the value of the p_i we must use the steam pressure vs temperature diagram. Using this diagram we will obtain the value of the pressure for designing the tank. This value is too much increased with the temperature so it means that the isolation will be much important in this case to avoid dangerous pressures in the tank.

We will take a safety coefficient enough to avoid these problems and also in the construction of the deposit there will be a safety valve to limit the pressure into the tank.

DIAGRAM TEMPERATURE-VAPOR PRESSURE

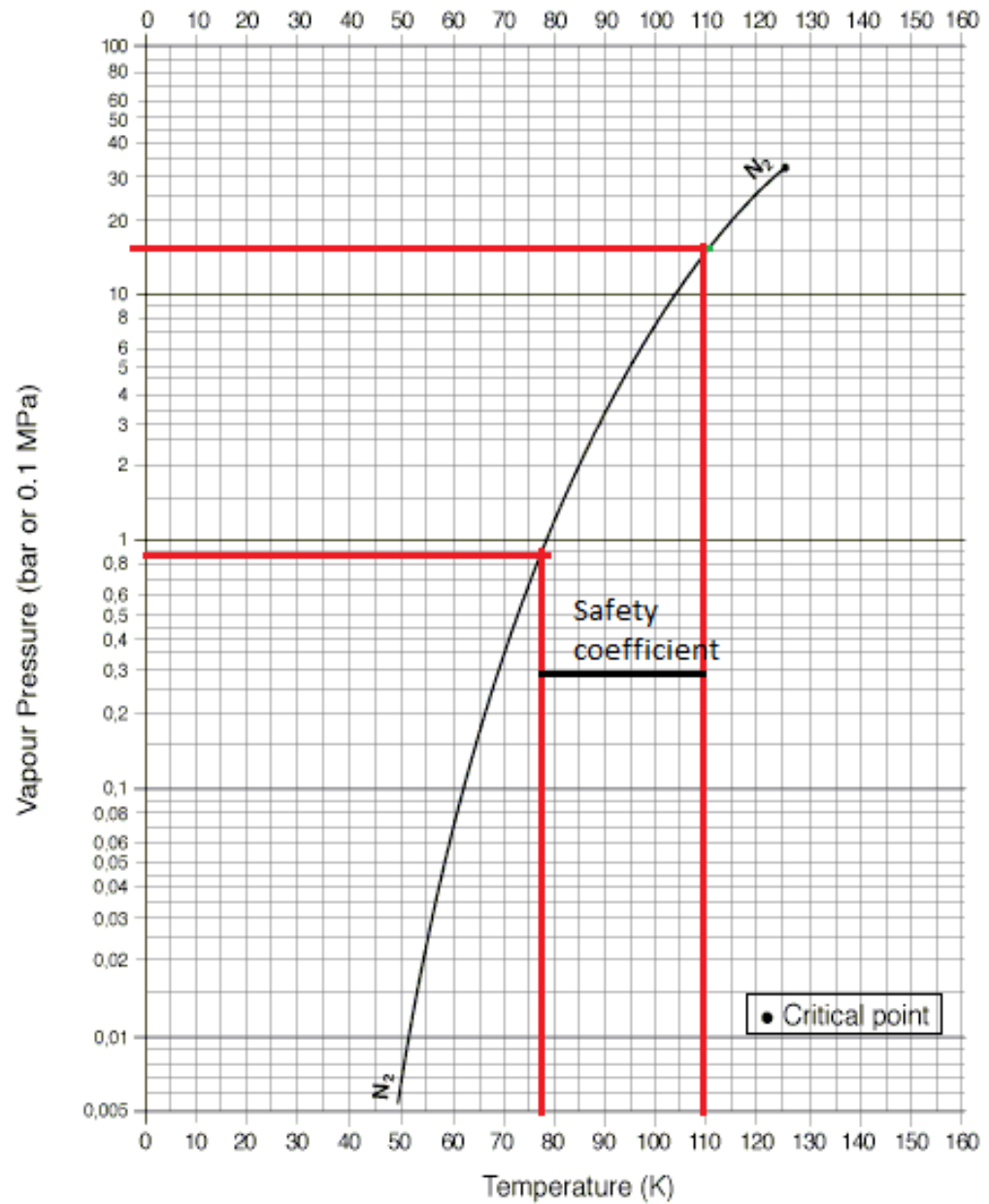
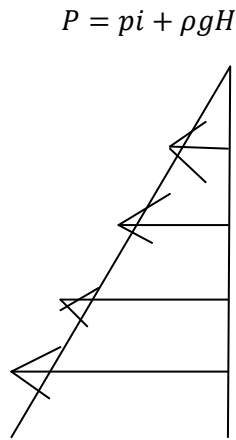


Figure 10

Source: <http://encyclopedia.airliquide.com>

This diagram shows the increasing of the pressure into the tank when the temperature changes when the temperature is lower than -196, due to amount of gas that we have in gas state.

Finally the value of the loads that we have in our tank are:

INTERNAL PRESSURE

$$P_i = 15 \text{ bar}$$

$$P_{max} = P_i + \rho * g * H = 1.5 \text{ MPa} + (808 * 9.8 * 4) = 15.31 \text{ e5 Pa} = 15.31 \text{ bar}$$

And to impose the loads:

Using The menu of ANSYS we distribute the value of the internal pressure in all internal areas and then we add the pressure cause by the action of gravity in the liquid.

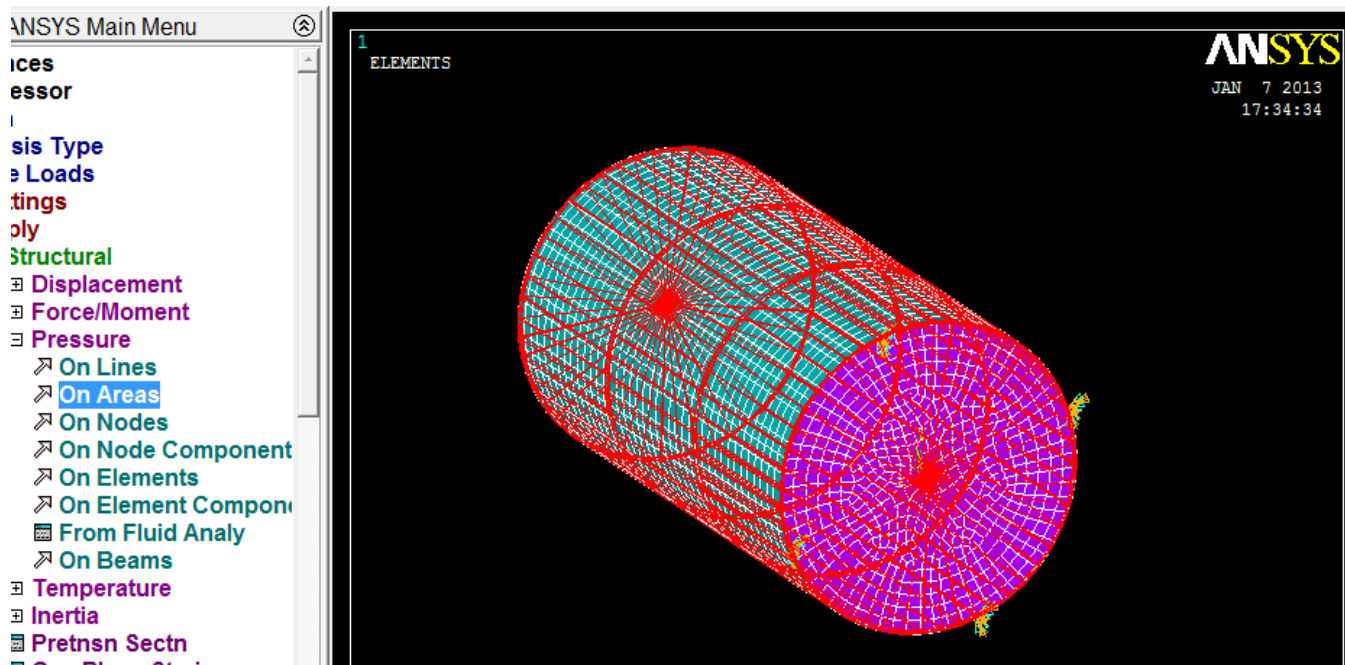


Figure 11: Loads that appears in the tank

Source :ANSYS

3.1.1.4.1 STRESSES PLOT

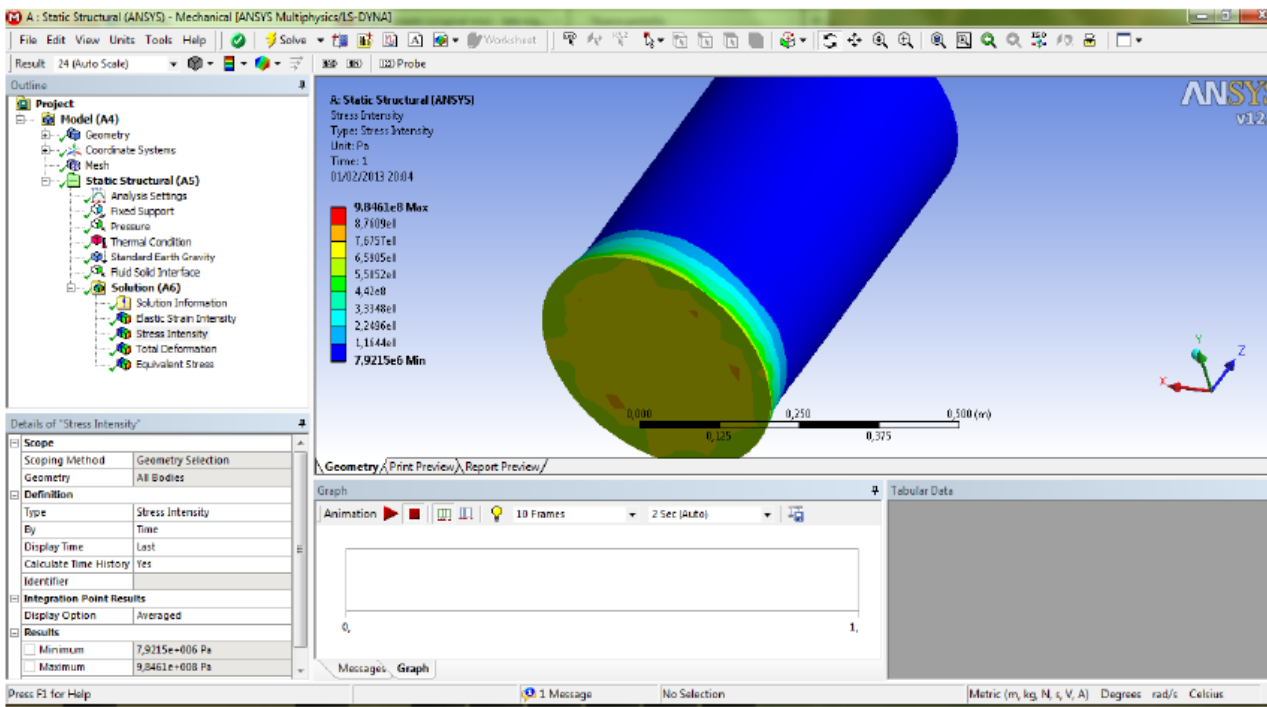


Figure 12: distribution of stresses ANSYS

When we have defined the properties of the material and the different loads that we have in the tank the program shows that the most dangerous part of the tank is the bottom.

It is logic because the weight and the hydrostatic pressure makes the maximum pressure in this zones. The problems that could appear will make the tank break in the bottom so probably we have to reinforce it.

The loads that we have taken into account are the thermal stresses, we are supposing all the material at -196°C , the hydrostatic pressure that the fluid makes into the structure due to its own weight along the proof of the tank.

After meshing we obtained that the most important stresses are lower than the mechanical resistance of our laminate so it means that we are not going to have problems of stability, so the stress design of the model are completely correct.

3.1.1.4.2 STRAIN PLOT

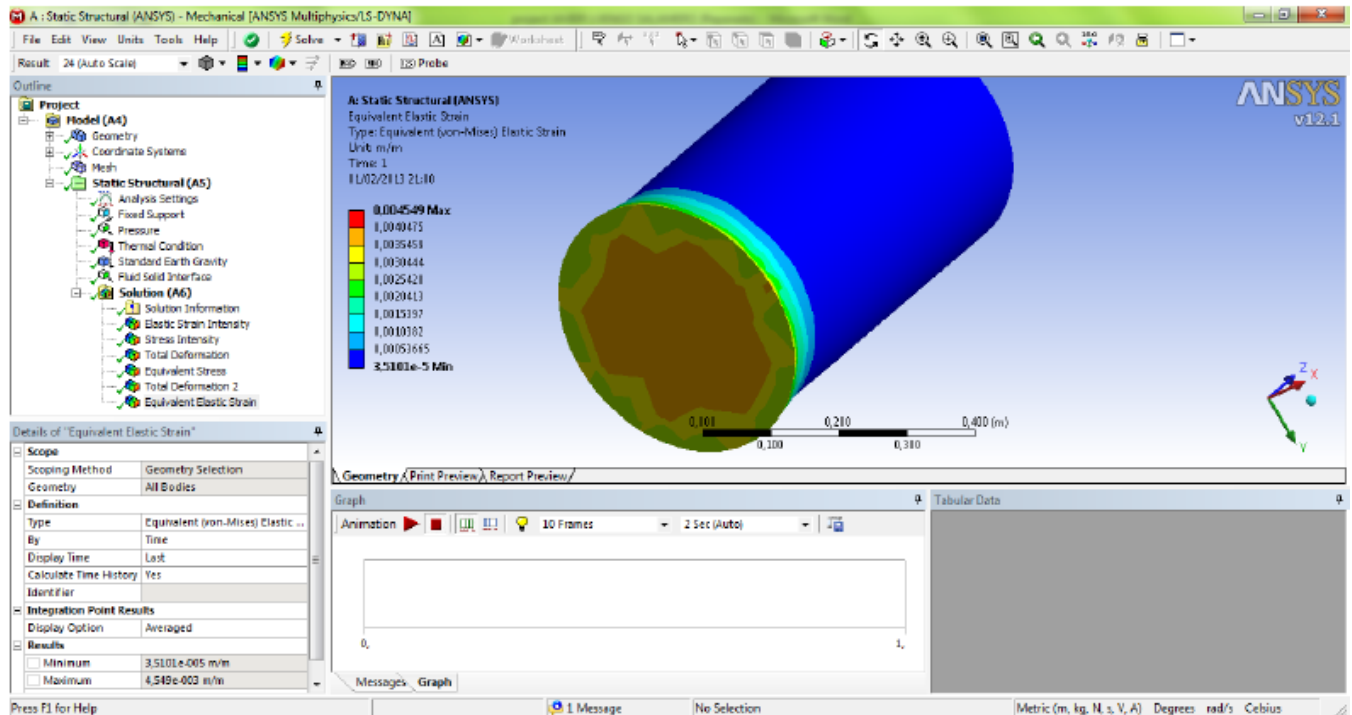


Figure 13: Strain distribution plot of ANSYS

For evaluating the deformation that we have associated too the design form the ANSYS WORKBENCH we obtained using a von mises criteria that the bottom is the most dangerous zone.

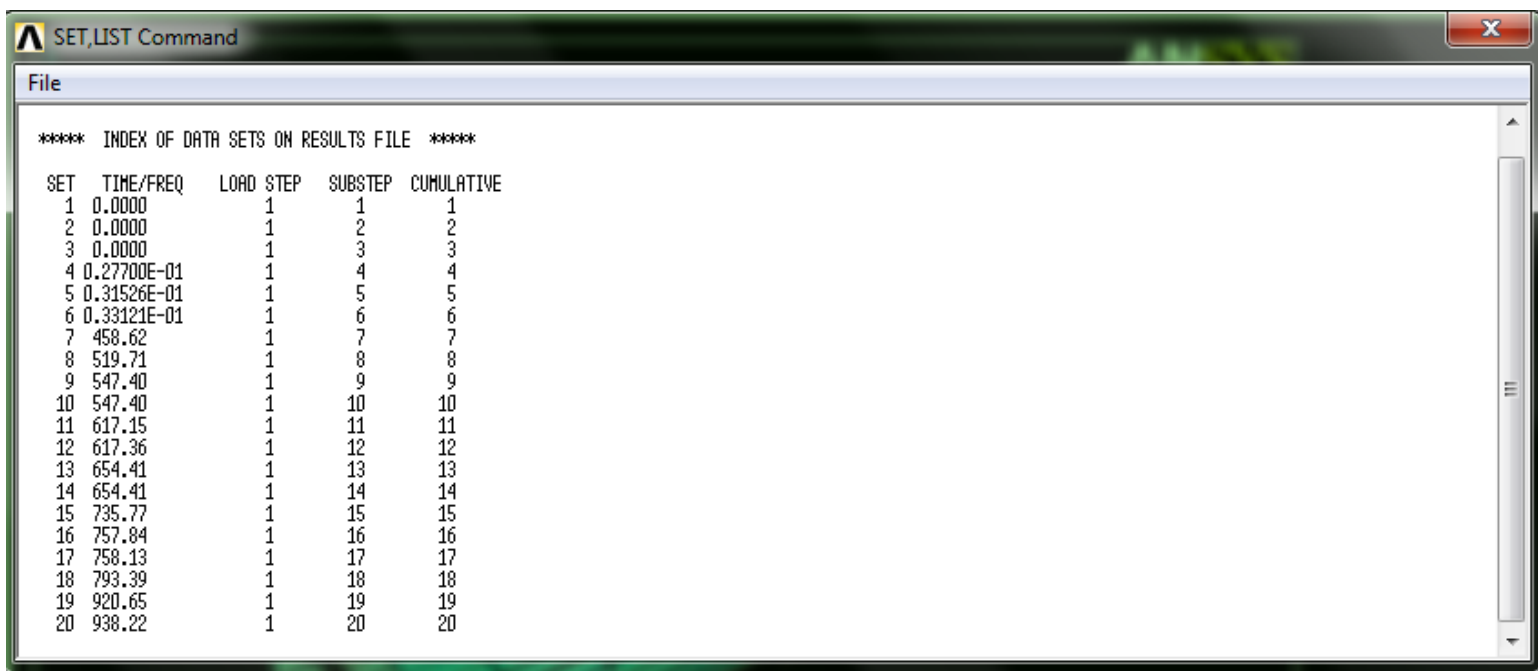
Its logic because there is the place we are the most important stresses. The analisys shows an important deformation but its not enough to plastify the material which it could be a important problem if we are using composite material, which has a completely different behavior compare with another material like steel, and probably we don't have too much modeling method to control the processes.

So it means that after evaluate with the FEM programs the design of the tank is completed and safety in order to the resist the imposing conditions.

1.2 MODAL ANALYSIS

In this paragraph we are going to calculate the behavior of the tank at several frequencies, for avoiding the resonance phenomena.

The way to calculate will be the ANSYS program. We are supposing only the behavior of the structure taking into account the internal pressure as result of the liquid and the load caused by the air pressure.



SET,LIST Command

File

**** INDEX OF DATA SETS ON RESULTS FILE ****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	0.0000	1	1	1
2	0.0000	1	2	2
3	0.0000	1	3	3
4	0.27700E-01	1	4	4
5	0.31526E-01	1	5	5
6	0.33121E-01	1	6	6
7	458.62	1	7	7
8	519.71	1	8	8
9	547.40	1	9	9
10	547.40	1	10	10
11	617.15	1	11	11
12	617.36	1	12	12
13	654.41	1	13	13
14	654.41	1	14	14
15	735.77	1	15	15
16	757.84	1	16	16
17	758.13	1	17	17
18	793.39	1	18	18
19	920.65	1	19	19
20	938.22	1	20	20

Table 6: list of vibration modes for the tank

Through the ANSYS we can obtain all effects that these frequencies make in the tank. For example for the number 17th, if there is some wind load that blows at 793.39 Hz the tank's behavior will be:

NODAL SOLUTION

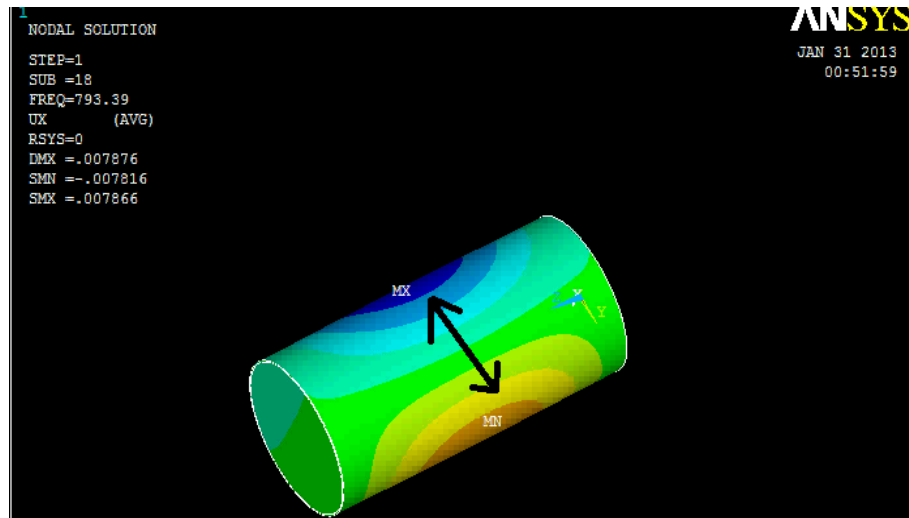


Figure 20:Stresses vibration at 793 HZ

Source : ANSYS

The arrow in the picture shows the stresses variability at this frequency , taking into account that we have a fluid in the internal part which is moving at the same order that the tank.

Also we can obtain the value of the deformation and the theoretical model that the tank will experiment at this frequency is:

DISPLACEMENT

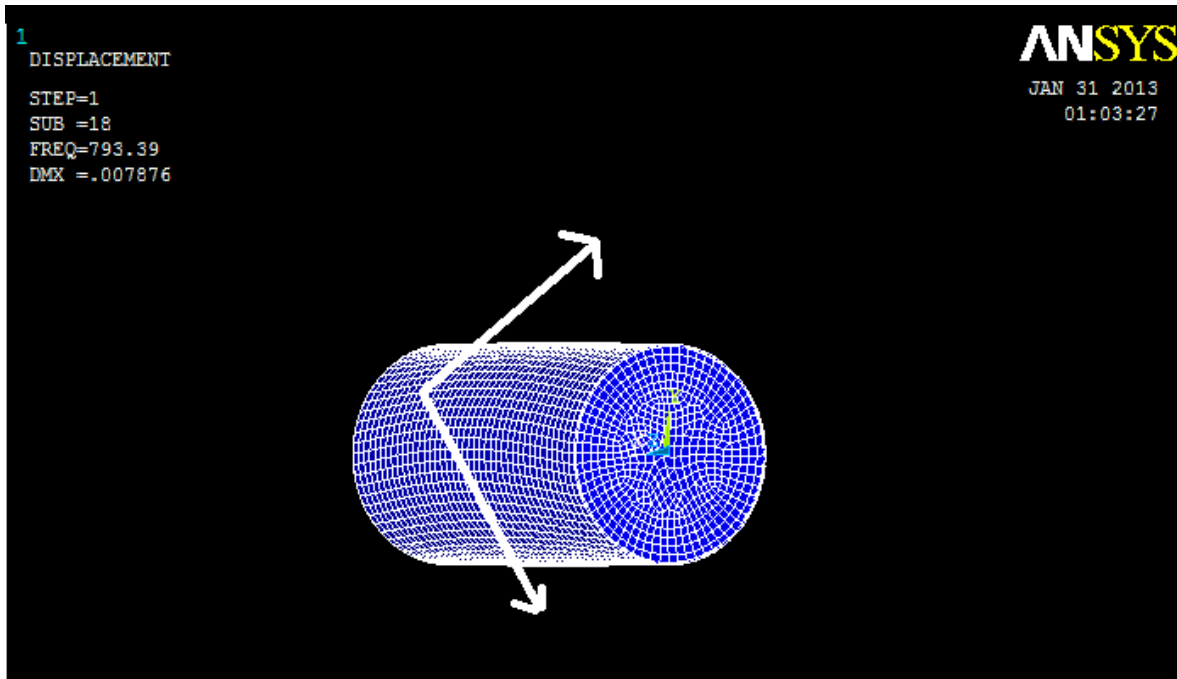


Figure 21: Deformation at 793 Hz of vibration

Source:ANSYS

We can observe that the modal analysis shows an important turn according to the symmetrical axis. Which is amplified by the liquid that is in the internal part.

If this deposit resonates probably the movement will make deformations in the deposit that are going to be bigger than the deformation at breaks, and that means that we will have the failure of the material.

This is an study theoretical of modal modes, but probably it doesn't have problems at this aspect because the wind normally doesn't blow at so lower frequencies but still the wind never blow enough time at this small range of frequencies so for being sure that we are not going to have problems (for assure the safe mode) we can install inside of some small protection such as plastic stand.



4.THERMAL ANALYSIS

This paragraph is too much important because an small variation in the temperature of the liquid nitrogen means a very important pressure because there will be more amount of steam

That means thtat probably we will be out of the ultimate pressure state and probably the tank will explote with the dangers that it entails.

For the analysis we will suppose that we are working in a stationary situation and we are supposing an small thikness of the wall of the tank.

4.1 MATERIAL

For the isolation we are going to use PERLITA wool because it has excellent thermal properties so means that the wool doesn't lose properties in extremely temperatures simulation like in tanks of nitrogen liquid

Also it shows the lower value of thermal conductivity trough an big range of densitys. In this case the tank isn't too big so we can use a density of 72 Kg/m³.

Due to the structure of perlita it doesn't modify the shape of the tank. Also is incombustible so it doesn't threating the safety against the fire and is perfect for avoid problems with the design rules.¹

The next diagram shows the values of isolation for the different insulation.

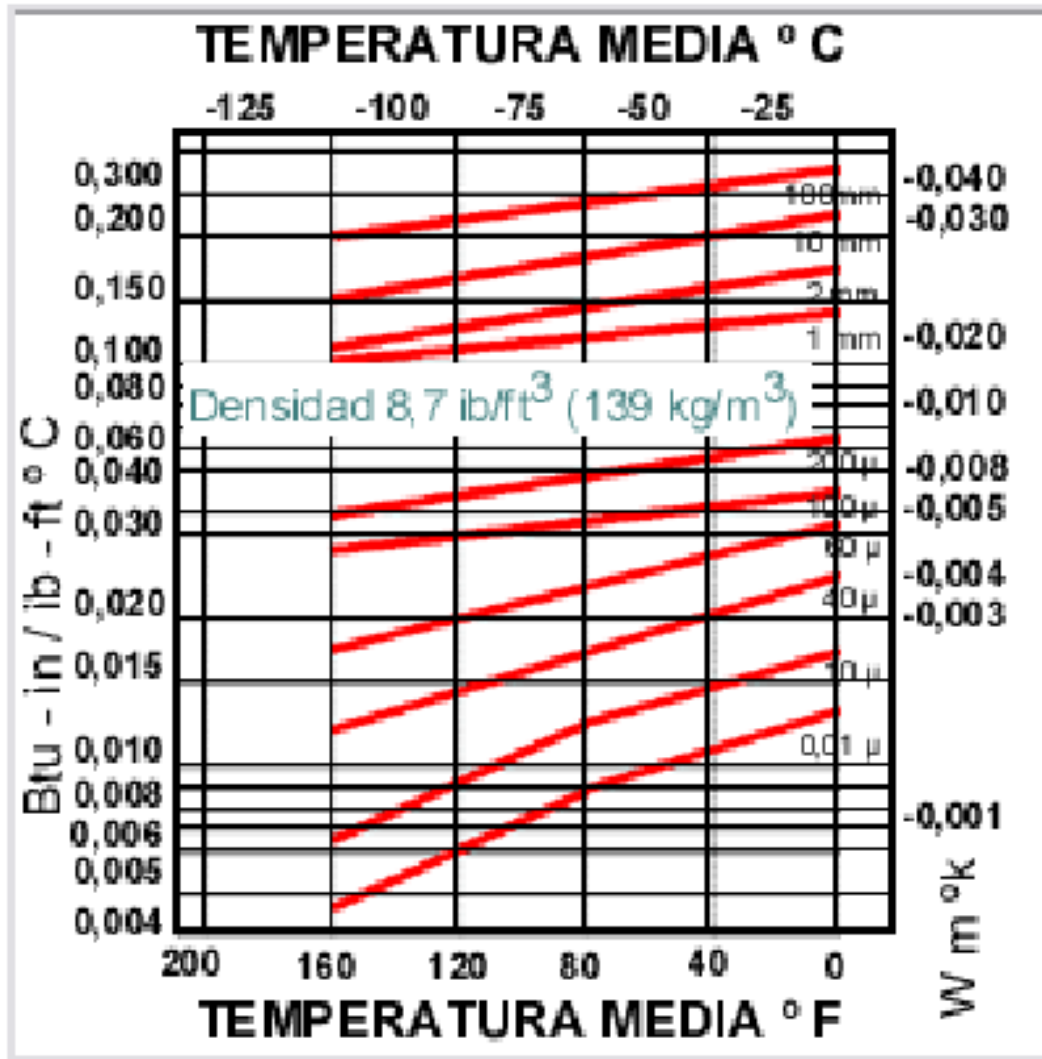


Table 8:thermal conduction variability

Source: REFERENCE [9]

This diagrams shows the variability of the material conduction when we change the diferents values of the thicknes of the insuolation .

4.2 CALCULATION OF THE CRITICAL RADIUS OF INSULATION

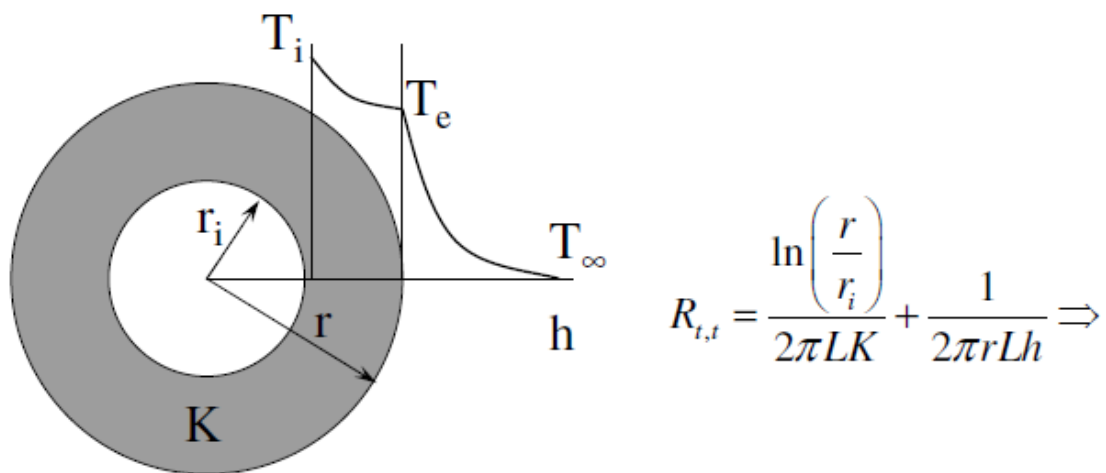


Figure 23: calculation the critical radius of insulation

Source REFERENCEN [10]

We have to obtained the lower variability of heat thropught the tank:

$$\frac{dR_{t,t}}{dr} = 0 \Rightarrow \frac{1}{2\pi LK} \left\{ \frac{1/r_i}{r_{crit}/r_i} - \frac{K}{h} \cdot \frac{1}{r_{crit}^2} \right\} = 0 \Rightarrow$$

$$r_{crit} = \frac{K}{h}$$

For calculating the radius of insulation we are going to use the general properties of the air ,but in another situation probably we must calculate by interpolation the values of the exactly h (convection coefficient).

The general properties of the air are:

Material	Convection coefficient (W/m ² *K)
Air(natural convection)	5-25
Air /Water steam(Forced convection)	20-300
Petroleum(forced convection)	60-1800
Water(forced convection)	300-6000
Water(boiled)	3000-60000
Water (condensation)	6000-120000

Table 7 Values of convection for air

Source: reference [9]

For the insulation we are going to use the medium one:

$$K=0.040 \text{ W/m}^2\cdot\text{K}$$



Calculating the critical values of the radius which we need we have:

$$R_{min} = \frac{K}{h} = \frac{0.040}{10} = 4 \text{ mm}$$



5. CONCLUSIONS

This point it for shows the finally decisions that we are able to make due to the values that we have obtained in the several paragraphs along this tank designing.

Firstly we have to talk about the dimension of the tank. We are designed a typical tank for a normal use of liquid nitrogen. To be sure of the correctly size of the designing we must do an study of all the needs of the hospital, the industry or whatever the place that we are going to use it.

We must evaluate the number of litres that we are going to need along the year and also the maximum volume flow of nitrogen that probably we are going to have at the same time for defining the exactly the capacity and for optimizing the number of replenishment that we have to do in order to reduce the cost, inasmuch as lower times we need nitrogen, It means less costs but we have to evaluate also the cost of oversize the tank, cause it could be counterproductive.

The second important conclusion that we have obtained is that manufacturing this tank using composite materials means the minimum amount of material and assure the stability of the deposit with a enough safe security coefficient which let the equilibrium between the quality of the design and the costs that the production of it carries

From the uses of the MATHCAD we have obtained that the thickness of the tank will be be 2 cm for a 1,2 m of diameter and then using ANSYS we obtained the most similar real values from the FEM method

It means that we have an resistant and safety tank with the minimum weight, perfect for transporting moving and using whatever it is necessary

Some chapters before have been commented the properties of this composites materials so it is usual that in the plot that we obtained form the Ansys we never reach the brake status of the material due to the exceptional properties that composite has it.

In order to the stresses we have an important volume of liquid so the hydrostatic pressure that is going to appear will cause a linear distribution of the stresses along the deposit. Probably it will be necessary to reinforce the lower part between the lateral part and the low top using some kind of welding which previously we have to check carefully because in the composite material welding is not like in metals where we have more range of temperatures, here if we overcomes some values of temperature we can produce delamination INTRAplies causing lose of mechanical properties which collapsing the structure.

For supporting the structure we can use an lattice structure to avoid problems with the buckling due to the weight of the liquid into the tank. Its not a big tank so using all types of section we are able to assure the estabily of the tank.

Due to the extremely characteristics of the liquid that we are containing we have done a modal analysis to evaluate in which frequencies we are going to have problems of resonance.



In this aspects we have to take into account also machines like pumps or another machines that are mounted near the tank that can produce problems in the structural. This kind of problem are not usefull but they must be considered in the designing.

For the last paragraph the insulation it must be detailed studied because we have one of the most cooled liquid and if it increase the temperature could appears several problems.

The most important which one we have to avoid is the increasing of the vapor pressure according to the increasing of the nitrogen GAS that appear when we are upper the boiling point of this gas. This increment could cause the break at the bottom of the tank which is the most committed zone in the structure

Other problem which appears with the increasing of temperature is that for some application the conditions are not going to be valid because the real temperature which we are working is wrong. For example for reduce to the minimum the electric resistance or evaluate impacts at lower temperatures simulating the space



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