STRUCTURAL AND THERMAL ANALYSIS ON COMPOSITE CYLINDER

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Abstract: Fiber reinforced composites due to their high stiffness to weight ratio and strength to weight ratio are being considered for liquid nitrogen cylinders. Tests have been shown that graphite/epoxy composites have tendency to micro crack at very low temperatures. In the case of cylinders these micro cracks can act as passages for the cryogenic liquid to penetrate which could ultimately lead to failure of the whole structure, hence it is very important to understand the fracture behavior of fibre composites at cryogenic temperatures before they are used in cryogenic storage systems.

Earlier research are focused on the effect of higher temperatures on the behavior of composites, very little research is made to determine the low temperatures response of composites. The goal of this project is to analyse the behavior of composite cylinders for preservation of cryogenic liquids. Thermal and structural analysis is to be done on the composite cylinders at cryo conditions as well with conventional alloys and compare the results to get the best suited material for the cylinders to store cryogenic fluids

1. Introduction

1.1 Cryogenics

In physics, cryogenics is the study of the production of very low temperature (below −150 °C, −238 °F or 123 K) and the behavior of materials at those temperatures. A person who studies elements that have been subjected to extremely cold temperatures is called a cryogenicist. Rather than the relative temperature scales of Celsius and Fahrenheit, cryogenicists use the absolute temperature scales. These are Kelvin (SI units) or Rankine scale (Imperial and US units). The term cryogenics is often mistakenly used in fiction and popular culture to refer to the very different cryonics.

1.2 Cryogenics

The branches of physics and engineering that involve the study of very low temperatures, how to produce them, and how materials behave at those temperatures.

1.3 Industrial applications

Liquefied gases, such as liquid nitrogen and liquid helium, are used in many cryogenic applications. Liquid nitrogen is the most commonly used element in cryogenics and is legally purchasable around the world. Liquid helium is also commonly used and allows for the lowest attainable temperatures to be reached.

These liquids may be stored in Dewar flasks, which are double-walled containers with a high vacuum between the walls to reduce heat transfer into the liquid. Typical laboratory Dewar flasks are spherical, made of glass and protected in a metal outer container. Dewar flasks for extremely cold liquids such as liquid helium have another double-walled container filled with liquid nitrogen. Dewar flasks are named after their inventor, James Dewar, the man who first liquefied hydrogen. "Thermos" ® bottles are smaller vacuum flasks fitted in a protective casing.

Cryogenic transfer pumps are the pumps used on LNG piers to transfer liquefied natural gas from LNG carriers to LNG storage tanks, as are cryogenic valves.

1.4 Cryogenic processing

The field of cryogenics advanced during World War II when scientists found that metals frozen to low temperatures showed more resistance to wear. Based on this theory of cryogenic hardening, the commercial cryogenic processing industry was founded in 1966 by Ed Busch. With a background in the heat treating industry, Busch founded a company in Detroit called

CryoTech in 1966 which merged with 300 Below in 1999 to become the world's largest and oldest commercial cryogenic processing company.[citation needed] Busch originally experimented with the possibility of increasing the life of metal tools to anywhere between 200%-400% of the original life expectancy using cryogenic tempering instead of heat treating. This evolved in the late 1990s into the treatment of other parts.

Cryogens, like liquid nitrogen, are further used for specialty chilling and freezing applications. Some chemical reactions, like those used to produce the active ingredients for the popular statin drugs, must occur at low temperatures of approximately −100°C (about -148°F). Special cryogenic chemical reactors are used to remove reaction heat and provide a low temperature environment. The freezing of foods and biotechnology products, like vaccines, requires nitrogen in blast freezing or immersion freezing systems. Certain soft or elastic materials become hard and brittle at very low temperatures, which makes cryogenic milling (cryomilling) an option for some materials that cannot easily be milled at higher temperatures.

Cryogenic processing is not a substitute for heat treatment, but rather an extension of the heating - quenching - tempering cycle. Normally, when an item is quenched, the final temperature is ambient. The only reason for this is that most heat treaters do not have cooling equipment. There is nothing metallurgically significant about ambient temperature. The cryogenic process continues this action from ambient temperature down to −320 °F (140 °R; 78 K; −196 °C). In most instances the cryogenic cycle is followed by a heat tempering procedure. As all alloys do not have the same chemical constituents, the tempering procedure varies according to the material's chemical composition, thermal history and/or a tool's particular service application.

The entire process takes 3–4 days.

1.5 Fuels

Another use of cryogenics is cryogenic fuels for rockets with liquid hydrogen as the most widely used example. Liquid oxygen (LOX) is even more widely used but as an oxidizer, not a fuel. NASA's workhorse space shuttle used cryogenic hydrogen/oxygen propellant as its primary means of getting into orbit. LOX is also widely used with RP-1 kerosene, a non-cryogenic hydrocarbon, such as in the rockets built for the Soviet space program by Sergei Korolev.

Russian aircraft manufacturer Tupolev developed a version of its popular design Tu-154 with a cryogenic fuel system, known as the Tu-155. The plane uses a fuel referred to as liquefied natural gas or LNG, and made its first flight in 1989.

1.6 Other applications

Some applications of cryogenics:

Nuclear Magnetic Resonance Spectroscopy (NMR)

NMR is one of the most common methods to determine the physical and chemical properties of atoms by detecting the radio frequency absorbed and subsequent relaxation of nuclei in a magnetic field. This is one of the most commonly used characterization techniques and has applications in numerous fields. Primarily, the strong magnetic fields are generated by supercooling electromagnets, although there are spectrometers that do not require cryogens. In traditional superconducting solenoids, liquid helium is used to cool the inner coils because it has a boiling point of around 4 K at ambient pressure. Cheap metallic superconductors can be used for the coil wiring. So-called high-temperature superconducting compounds can be made to super conduct with the use of liquid nitrogen which boils at around 77 K.

Magnetic resonance imaging (MRI)

MRI is a complex application of NMR where the geometry of the resonances is deconvoluted and used to image objects by detecting the relaxation of protons that have been perturbed by a radio-frequency pulse in the strong magnetic field. This is mostly commonly used in health applications.

Electric power transmission in big cities

It is difficult to transmit power by overhead cables in big cities, so underground cables are used. But underground cables get heated and the resistance of the wire increases leading to waste of power. Superconductors could be used to increase power throughput, although they would require cryogenic liquids such as nitrogen or helium to cool special alloy-containing cables to increase power transmission. Several feasibility studies have been performed and the field is the subject of an agreement within the International Energy Agency.

Frozen food

Cryogenic gases are used in transportation of large masses of frozen food. When very large quantities of food must be transported to regions like war zones, earthquake hit regions, etc., they must be stored for a long time, so cryogenic food freezing is used. Cryogenic food freezing is also helpful for large scale food processing industries.

Forward looking infrared (FLIR)

Many infra-red cameras require their detectors to be cryogenically cooled.

Blood banking

Certain rare blood groups are stored at low temperatures, such as −165 °C.

Special effects

Cryogenics technology using liquid nitrogen and CO2 has been built into nightclub effect systems by Kryogenifex to create a chilling effect and white fog that can be illuminated with colored lights.

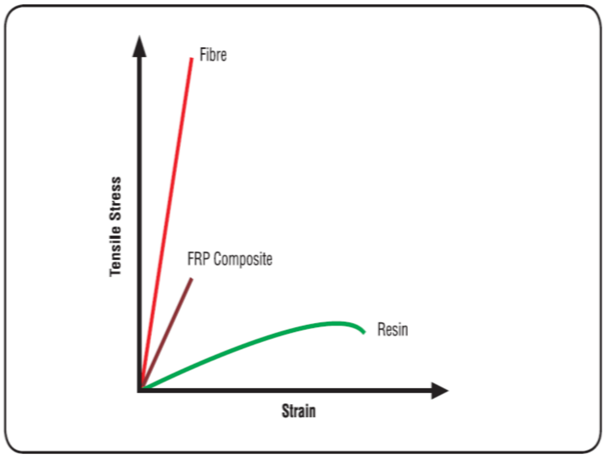
1.7 Basic composite theory

In its most basic form a composite material is one, which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the 'matrix'), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. This reinforcement is usually in fibre form. Today, the most common man-made composites can be divided into three main groups: Polymer Matrix Composites (PMC's) – These are the most common and will be discussed here. Also known as FRP - Fibre Reinforced Polymers (or Plastics) – these materials use a polymer-based resin as the matrix, and a variety of fibres such as glass, carbon and aramid as the reinforcement. Metal Matrix Composites (MMC's) - Increasingly found in the automotive industry, these materials use a metal such as aluminium as the matrix, and reinforce it with fibres, or particles, such as silicon carbide. Ceramic Matrix Composites (CMC's) - Used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibres, or whiskers such as those made from silicon carbide and boron nitride.

1.8 Polymer matrix composites

Resin systems such as epoxies and polyesters have limited use for the manufacture of structures on their own, since their mechanical properties are not very high when compared to, for example, most metals. However, they have desirable properties, most notably their ability to be easily formed into complex shapes. Materials such as glass, aramid and boron have extremely high tensile and compressive strength but in 'solid form' these properties are not readily apparent. This is due to the fact that when stressed, random surface flaws will cause each material to crack and fail well below its theoretical 'breaking point'. To overcome this problem, the material is produced in fibre form, so that, although the same number of random flaws will occur, they will be restricted to a small number of fibres with the remainder exhibiting the material's theoretical strength. Therefore a bundle of fibres will reflect more accurately the optimum performance of the material. However, fibres alone can only exhibit tensile properties along the fibre's length, in the same way as fibres in a rope. It is when the resin systems are combined with reinforcing fibres such as glass, carbon and aramid, that exceptional properties can be obtained. The resin matrix spreads the load applied to the composite between each of the individual fibres and also protects the fibres from damage caused by abrasion and impact. High strengths and stiffnesses, ease of moulding complex shapes, high environmental resistance all coupled with low densities, make the resultant composite superior to metals for many applications. Since PMC's combine a resin system and reinforcing fibres, the properties of the resulting composite material will combine something of the properties of the resin on its own with that of the fibres on their own.

Graph: Strain vs Tensile stress



Overall, the properties of the composite are determined by: i) The properties of the fibre ii) The properties of the resin iii) The ratio of fibre to resin in the composite (Fibre Volume Fraction) iv) The geometry and orientation of the fibres in the composite The first two will be dealt with in more detail later. The ratio of the fibre to resin derives largely from the manufacturing process used to combine resin with fibre, as will be described in the section on manufacturing processes. However, it is also influenced by the type of resin system used, and the form in which the fibres are incorporated. In general, since the mechanical properties of fibres are much higher than those of resins, the higher the fibre volume fraction the higher will be the mechanical properties of the resultant composite. In practice there are limits to this, since the fibres need to be fully coated in resin to be effective, and there will be an optimum packing of the generally circular cross-section fibres. In addition, the manufacturing process used to combine fibre with resin leads to varying amounts of imperfections and air inclusions. Typically, with a common hand lay-up process as widely used in the boat-building industry, a limit for FVF is approximately 30-40%. With the higher quality, more sophisticated and precise processes used in the aerospace industry, FVF's approaching 70% can be successfully obtained. The geometry of the fibres in a composite is also important since fibres have their highest mechanical properties along their lengths, rather than across their widths. This leads to the highly anisotropic properties of composites, where, unlike metals, the mechanical properties of the composite are likely to be very different when tested in different directions. This means that it is very important when considering the use of composites to understand at the design stage, both the magnitude and the direction of the applied loads. When correctly accounted for, these anisotropic properties can be very advantageous since it is only necessary to put material where loads will be applied, and thus redundant material is avoided. It is also important to note that with metals the properties of the materials are largely determined by the material supplier, and the person who fabricates the materials into a finished structure can do almost nothing to change those 'in-built' properties. However, a composite material is formed at the same time as the structure is itself being fabricated. This is a FUNDAMENTAL distinction of composite materials and MUST always be considered during design and manufacturing stages.

2. Modeling and Analysis

2.1 Material and load conditions

Steel:

Density = 7.85 g/cc

Tensile Strength, Ultimate = 690 - 825 MPa

Tensile Strength, Yield = 515 MPa

Modulus of Elasticity = 200 GPa

Poissons Ratio = 0.29

Specific Heat Capacity = 0.470 J/g-°C

Thermal Conductivity = 52.0 W/m-K

2.2 Component Elements Properties

Carbon, C 0.13 %

Iron, Fe 89.62 %

Manganese, Mn 0.90 %

Nickel, Ni 8.5 - 9.5 %

Phosphorous, P 0.035 %

Silicon, Si 0.15 - 0.40 %

Sulfur, S 0.040 %

2.3 S-glass:

Table 1: Youngs modulus at each node

	Young's Modulus	Peak Stress	Average Modulus
	GPa	MPa	GPa
X-1	17.47	368	**18.8**
X-2	18.89	368	
X-3	19.97	360	
Y-1	19.90	302	**18.9**
Y-2	18.33	294	
Y-3	18.39	303	
Z-1	7.32	437	**7.83**
Z-2	7.33	436	
Z-3	8.83	448	

Density 2.46 g/cc

Poissons Ratio 0.23

Specific Heat Capacity 0.737 J/g-°C

Thermal Conductivity 1.45 W/m-K

2.4 Loads:

Pressure: 18.202159219200002 N/mm^2

3. Result Analysis

3.1 Static structural analysis of cylinder with steel

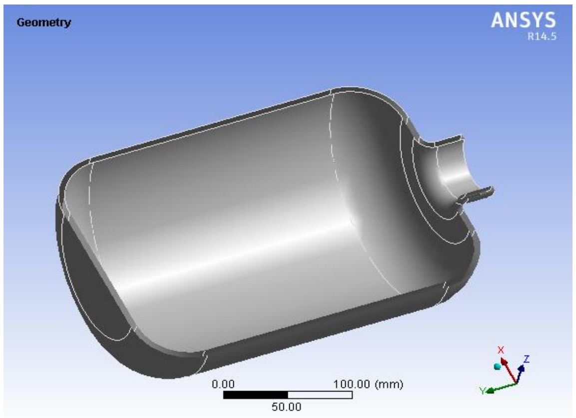


Figure 1: The sectional view of component model was generated in ansys workbench

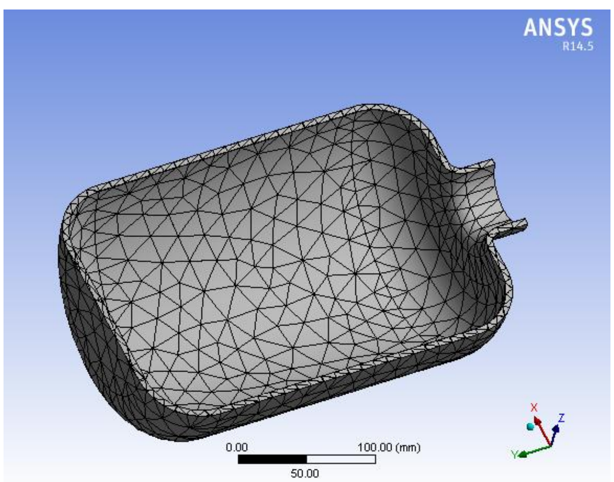


Figure 2: Mesh model of the component

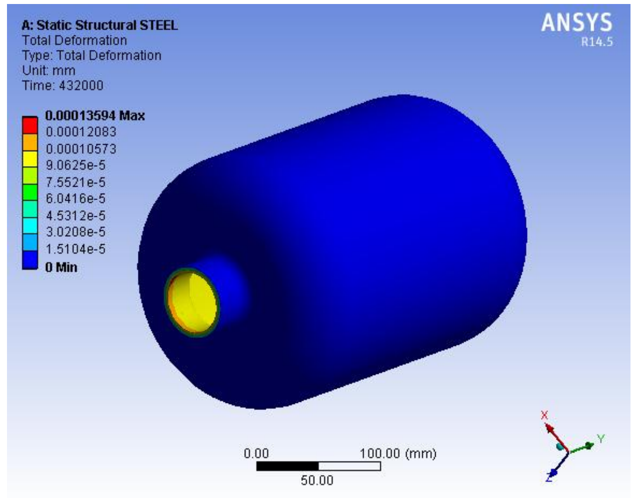


Figure 3: Deformation range with the help of colour bar.

3.2 Tables

Table 2: Static structural

	steel@-160°C	steel@-200°C	S2@-160°C	S2@-200°C
Total deformation	0.00012083	0.00013594	0.00050347	0.00050347
Strain	2.5105e-5	2.5105e-5	9.2981e-5	9.2981e-5
stress	5.0164	5.0164	5.0164	5.0164

Table 3: Steady state thermal

	steel@-160°C	steel@-200°C	S2@-160°C	S2@-200°C
Total heat flux	2.8132	3.4384	6.696	8.1839
Thermal error	1.8466e5	2.7585e5	4.3952e5	6.5656e5

Table 4: Transient structural

	steel@-160°C	steel@-200°C	S2@-160°C	S2@-200°C
Total deformation	5.4375e-5	5.437e-5	0.00020139	0.00020139
Strain	1.0042e-5	1.0042e-5	3.7192e-5	3.7192e-5
stress	2.0066	2.0066	2.0066	2.0066

Table 5: Transient thermal

	steel@-160°C	steel@-200°C	S2@-160°C	S2@-200°C
Total heat flux	2.8132	3.4384	6.6959	8.1839
Thermal error	1.8466e5	2.7585e5	4.3952e5	6.5656e5

Table 6: Couple field

	steel@-160°C	steel@-200°C	S2@-160°C	S2@-200°C
Total deformation	0.016562	0.016562	0.16574	0.20199
Strain	0.0039731	0.0039731	0.039686	0.048404
stress	784.81	784.81	2116.5	2581.4

Table 7: Fatigue

	steel@-160°C	steel@-200°C	S2@-160°C	S2@-200°C
Life	5e10	5e10	5e10	5e10
damage	44.769	44.769	514.85	811.83

Table 8: Layers method results

Layers method	THERMAL GRADIENT	HEAT FLUX	Displacement	STRESS	STRAIN
3 LAYERS	.127E-11	.156E-13	.010506	6.99737	.939E-04
5 LAYERS	.131E-11	.162E-13	.010461	6.97259	.936E-04

4. CONCLUSION

this project work deals with the "structural and thermal analysis of axisymmetric composite cylinders (dewars) at cryo temperatures".

this project work is done on negative temparchers and effect of combinational load conditions (static& thermal), and also determines the effect on layers composite cylinders.

presents the life and damage percentage for the combinational load conditions (static& thermal) at 5000*1e005 cycles each cycle with 3600 sec time.

to achieve the aim of the project work following steps played the key role:

- collection of data about composites and its usage.
- literature survey given a over view of methodology and followed methods of previous study.
- static structural and thermal analysis was conducted using regular material steel and composite material s-glass epoxy at -1060c and -200^{0}c.
- transient structural and thermal analysis was conducted using regular material steel and composite material s-glass epoxy at -1060c and -2000c.
- coupled field analysis was conducted using regular material steel and composite material s-glass epoxy to determine values at combinational load conditions (static& thermal)
- fatigue analysis conducted to determine life and damage percentage.
- layer method is done to increase cylinder quality layer reinforced method gives tremendous variation due to its lode distributing property.
- tables and graphs are presented for the results obtained in ansys.

as per the obtained results reinforce composite cylinders with increased layers are the best option due to its structural and thermal behavior. without reinforcement composite cylinder will fail due to higher

stresses. using reinforcement composite cylinder weight is reduced by 4 times.

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