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# Development of Composite Material Testing Facility for Cryogenic Fuel Tank Applications

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***Abstract: Composite materials are being used extensively in different realms of science for various applications. There use is prominent in the aerospace industry. The testing of these composite materials is of substantial importance, as they might be susceptible to failure due to the variation in the temperature ranges and the cryogenic temperatures which the materials have to endure. In the present work, the tensile strength of composite materials are observed using double walled vacuum chamber which is designed for the Universal Testing Machine (UTM).***

Keywords— **Composite material, Universal Testing Machine, Cryogenics, Load cell**.

## I. Introduction

Man has still not quenched his inquisitiveness about outer space which has led to constant advancement in the materials used in space-crafts. Composite materials exhibit properties which makes them suitable for uses at cryogenic temperatures. In the present world scenario, where space exploration and research are of great relevance to every nation, it is the need of the hour for science congregants to take the next big leap in design and manufacture of spacecraft and the materials used in the different parts[1-10].

In order to achieve this efficiently, there is a need to explore new materials which can cater to the specific requirements [11]. This is followed by the meticulous testing of these materials, as a failure at that altitude can be fatal [12]. The present work focuses on testing the composite materials in a cryogenic environment, which resemble outer space temperatures created using LN2, in a double walled vacuum chamber used as an attachment to the Universal Testing Machine (UTM).

The chamber with two walls, each separated by vacuum, is made of SS316.The chamber is designed in such a way that, so as to accommodate a moving shaft on the bottom part which applies tensile load on the specimen while the upper shaft connected to the chamber is fixed. One end of both shafts from the cryogenic chamber is fixed to the jaws of the UTM and has a chuck fitted on the other end to hold the specimen during the test. The chamber acts in such a way so as to provide a cryogenic environment for the testing of the materials. The cryogenic temperature in the chamber is obtained by the use of LN2 which is sprayed into the chamber. A vacuum pump of capacity $10^{-3}$ mille bar is used to create vacuum between the walls of the chamber, to create an isolated environment. Two digital thermocouples are fitted in the chamber to collect data pertaining to temperature. The high resolution camera planted inside the chamber gives an insight on how and when the fracture occurs. The design of the cryogenic chamber is done in the designing module CATIA.

Some technical challenges are:

- Constructing a chamber for the UTM in which the entire lower jaw moves
- Bellows were considered for making the chamber but would purge due to vacuum
- Type of vacuum to be used
- Maintaining the vacuum
- Maintaining the cryogenic environment in the chamber
- Visually being able to see the process of tensile strength test using a camera in the cryogenic environment
- Material used to make chamber
- Storage of Liquid Nitrogen

## II. Material and Methodology

Stainless steel grade 316LN is an austenitic type of steel that is a low carbon, nitrogen-enhanced version of grade 316 steel. The nitrogen content in this steel provides solid solution hardening, and raises its minimum specified yield strength. It also possesses good resistance to general corrosion and pitting/crevice corrosion. It is composed of (in weight percentage) 0.03% Carbon (C), 2.00% Manganese (Mn), 1.00% Silicon (Si), 16.0-18.0% Chromium (Cr), 10.0-14.0% Nickel (Ni), 0.045% Phosphorus (P), 0.03% Sulphur (S), 2.0-3.0% Molybdenum (Mo), 0.10-0.30% Nitrogen (N), and the base metal Iron (Fe).

Table 1: Physical properties for 316 stainless steel alloys (room temperature)

| **Property** | **Value** |
|---|---|
| Density | 7.99 g/cm$^3$ |
| Specific Heat (0-100$^o$C) | 485 J.kg$^-$1.K$^{-1}$ |
| Modulus of Elasticity | 200 GPa |
| Electrical Resistivity | 7.4 Ω/cm |
| Thermal Conductivity | 16.3 W.m$^{-1}$.K$^{-1}$ |
| Thermal Expansion | 16.5 mm/m/$^o$ C |

The chamber is constructed using a stainless steel of grade 316 with a wall thickness of 1 cm, which can withstand the cryogenic conditions. Vacuum is created between inner and outer chamber. The thermocouple is fitted on the sides of the mainframe. Spraying of $LN_2$ is done by a cylinder. Two ports on top and bottom of the chamber are provided for shafts. The upper shaft will remain fixed to the upper crosshead of the UTM and the lower shaft will be connected to the movable crosshead which will apply the load on composite material.

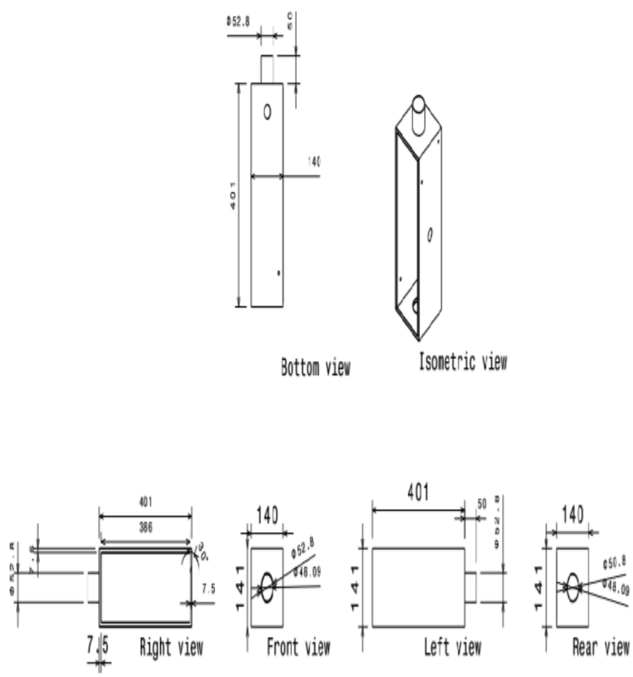


Figure 1: Dimensions of chamber (mm).

The overall efficiency of a cryogenic thermal insulation system can be summarized by the following four factors:

1) Thermal conductivity,
2) Vacuum level,
3) Density or weight, and
4) Cost of labour and materials.

Materials typically come in three basic forms: bulk fill, foam, or multilayer. The vacuum level, or cold vacuum pressure (CVP), is the major cost driver for the design, fabrication, and maintenance of most systems. After the actual operating conditions are considered, an analysis of the total heat leak of the mechanical system is needed to determine the insulation requirements. Often only a common-sense thermal review of the system is needed to ascertain which level of insulation material should be selected. The performance level will dictate the insulation materials and mechanical support structures or joining devices to be used.

An insulation material's performance under a large temperature difference is given in terms of mill watt per meter-Kelvin (mW/m-K) and is referred to as the apparent thermal conductivity or k-value. To compare k-values for different materials one must understand the warm and cold boundary temperatures, the vacuum level, the residual gas composition, and the installed thickness.

The designer has a very wide range of k-values with which to work: as low as 0.03 mW/m-K for perforated MLI blanket up to approximately 40 mW/m-K for cellular glass. As in all good designs, the performance must justify the cost. The performance of the total thermal insulation system as it is actually put to use is defined as the overall k-value for actual field installation.

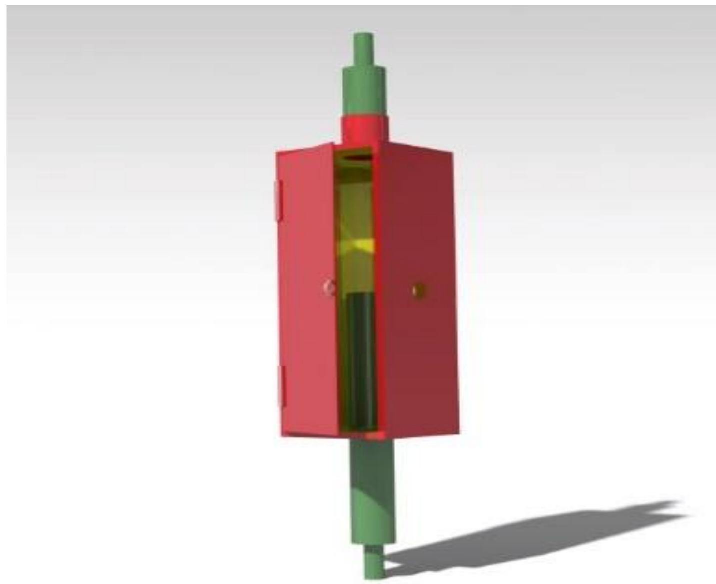

Figure 2: The Shafts are attached to the Cryogenic Chamber

## III. Results and Tables

Testing

Several test methods are usually needed to adequately test and evaluate the overall performance of an insulation system. Standardized material test methods can be employed for basic thermal, mechanical, and compatibility properties. Cryostat test methods provide the apparent thermal conductivity values for the insulation systems. Prototype testing is then needed to determine the actual performance for a specific mechanical system. The use of MLI systems illustrates the need for this three step testing process. The k-value for an MLI system under ideal laboratory conditions may be around 0.05 mW/m-K while the koafi can easily be 10 times worse

1) Temperature analysis

Here the temperature distribution of the double walled chamber is shown in figure 3. The analysis is done in the ANSYS APDL 14.5. Here the nodal temperature, thermal gradient and thermal flux are shown.

***2) Nodal temperature***

The nodal temperature is temperature is shown at various nodes as shown in figure 4. In the diagram we can see the temperature distribution in the inner and outer surface were the inside temperature is 77K and outside temperature is 300K. Where the radiation is taking place.

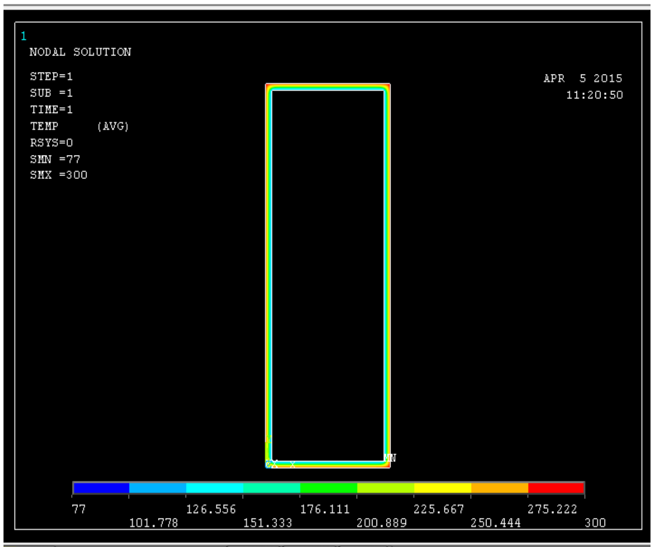


Figure 3: Nodal temperature

### *3) Thermal flux*

The rate of heat energy transfer through a given surface per unit area is defined as the heat flux. Here in the figure it's clear that the minimum value of thermal flux is 0.408E-5W/mm2 which is at the internal corners of outer surface, And the maximum value of thermal flux is 1527W/mm2 is near to inner surface. The value is increasing towards inner surface from outer surface.

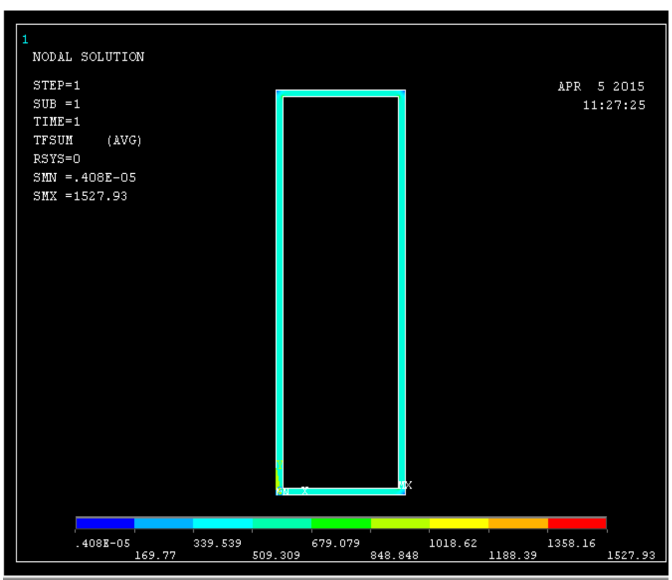


Figure 4 Thermal Flux

### *4) Thermal gradient*

It describes the direction and the rate of temperature changes around a particular location. In the figure, it shows that the minimum thermal gradient is near to the outer surface of 0.252E-06K/mm and the maximum value of 94.316K/mm is near to inner surface, which is of 77K.

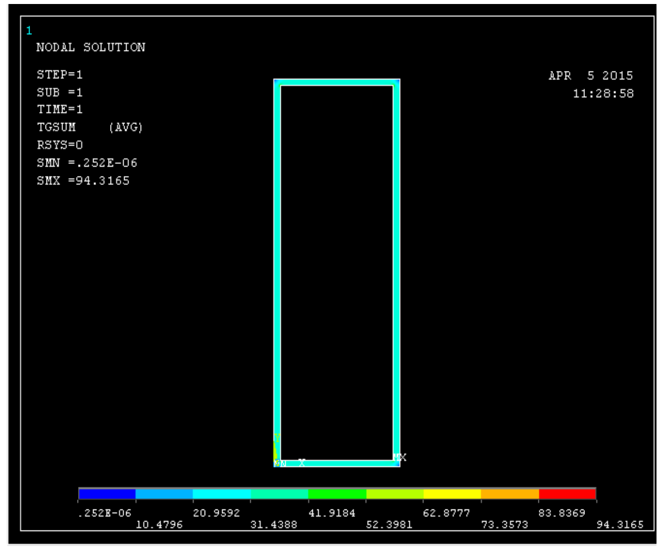


Figure 5 Thermal Gradient

## IV. Conclusion

It can be concluded from the present analysis that the composite material used for cryogenic fuel tank must be kept at 77K with vacuum being maintained between two chambers. Further, the test setup developed from the present work would be useful in characterizing the composite material for various mechanical loads also. Moreover, the permeability tests are planned to be done in the future.

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