Fabrication of cryogenic chamber for the UTM testing of composite material used for space applications

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Abstract

In space applications, the space vehicles encounters cryogenic environment. In this present research, liquid nitrogen (LN2) is used for the purpose of testing of the composite material used in aircraft application at the cryogenic temperature. A double walled rectangular chamber using 2mm thick stainless steel sheet (SS316LN) is used for the purpose of testing of composite materials physical properties under cryogenic. The gap between the two walls of the chamber is 7mm and it is uniform throughout its surface. The vacuum pressure of 10^{-3} mbar is maintained inside the gap between two walls so as to keep the composite material inside the chamber free from the external environment and also reduces the heat transfer rate. For maintaining vacuum, a vacuum pump which is attached to the outer wall of the chamber. In addition, a Dewar containing liquid nitrogen is attached, to supply LN2 to the cryogenic chamber. Thermocouples are attached to the chamber to measure the temperature inside the chamber and a camera to keep watching the activities or process happening inside the chamber during the test. After the assembly of all the components such as chamber, pump, Dewar, camera and thermocouple, the setup is attached to the universal testing machine (UTM). Later, the strength of the composite material used for preparing the chamber is analyzed using tensile testing on that material by spraying liquid nitrogen on it.

Keywords: Space applications, cryogenic chamber, liquid nitrogen, universal testing machine (UTM), thermocouples, data acquisition system (DAQ)

1 Introduction

In the present engineering world fabrication are extensively used for various applications under different environmental condition. In shape and size fabricated product lines from very small parts that are used in daily commercial purpose that is utensils and containers to a huge one which is represented nationally or globally that is bridges, metal body structures etc. From the literature it is observed that fabrication process or fabrication method is different for the different components and materials used for different applications. Major hindrance in the fabrication work is to choose the fabrication process and techniques which is being used for the fabrication of given product and for choosing this one must consider the material that are using for our fabrication purpose. The fabrication work needs a proper place and environment which contains all the equipments and machines.

The fabricated SS316LN chamber is used to keep the composite material separate from the outer environment and also reduces the heat transfer rate to and from the chamber. The temperature inside the chamber is not affected by the outer environment. In present work, the composite material used in space application and check the behavior of material under cryogenic temperature (below -150°C) and the strength of material is evaluated by applying the tensile and compressive stress on it.

To improve the quality of testing and result with minimum error the chamber need to be fabricated in a proper way according to a proper design in which the welding must be done properly so that the air cannot rush inside the chamber and appropriate vacuum is created between two walls of the chamber. It is also necessary to understand the mechanism that causes the testing process failure or causes error. So as to find alternative solution according to the requirements like SS316LN are preferred for the testing of composite material under cryogenic temperature.

In the past, woven fabric-reinforced glass fiber is made into composite using Epoxy, to evaluate the tensile strength at cryogenic temperatures [1]. Later, The glass fiber with epoxy resin is used for testing the impact properties in the cryogenic environment [2]. In the past different resins are used to study the tensile strength of the carbon fibers at cryogenic temperatures [3]. A comprehensive review on the polymer composites is done to predict the cryogenic properties [4]. The mechanical stresses of the FRP composite is analyzed at cryogenic environment [5].

2 DESIGN AND FABRICATION OF CRYOGENIC CHAMBER

2.1 Chamber design

The design of a cryogenic chamber is done as an attachment to the Universal Testing Machine (UTM) in which composite materials used for space applications are investigated based on their mechanical characterization. The material used to create the chamber isSS316LN and has its two walls separated by vacuum. The chamber is designed such that, it accommodates two shafts on the upper and the lower part of the cryogenic chamber. One end of the shaft is fitted to the jaws of the UTM, while to the other end; a chuck is fitted using an L-key mechanism so as to hold the specimen. Tensile load is applied on the specimen by the lower jaw of UTM to which the movable lower shaft from the cryogenic chamber is attached. However, the upper shaft of the chamber is fixed and does not move. LN2 is purged into the chamber to create the cryogenic temperature. A camera is installed in the chamber to observe the fracture when it takes place. Two thermocouples are also installed to ensure that the chamber remains at cryogenic temperatures. Figure 1 shows the cryogenic chamber to be designed for experimental investigation in the UTM.

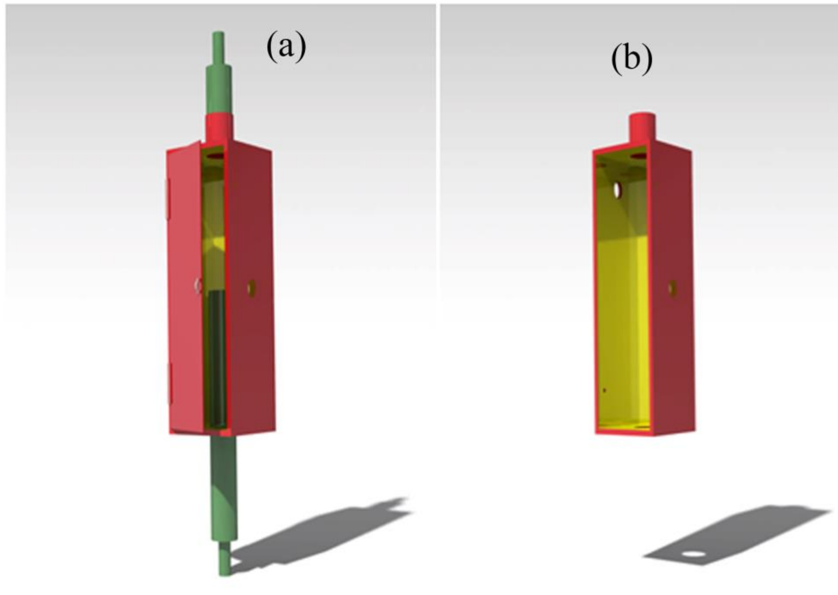

Figure 1 Design of the cryogenic chamber used for the analysis

2.2 Fabrication

The designed model is fabricated using SS316LN sheet of 1mm thickness and shaft of the same material whose diameter is 50mm. Later, the sheet is joined to create the chamber by using TIG Welding, after joining, the sheet grinding process is used to finishing the sheet of welded zone. The hole is created in the sheet by using punching method.

There are two layer of chamber with 7.5mm gap. The upper and lower hole is for inserting the shaft. The desired dimension of shaft is achieved by using turning and hole inside the shaft is created by using drilling operation. The front side of chamber is opened to insert the composite material for testing and other side of chamber is closed. Front side of camber is look like door and gasket is attached to the door because the air cannot pass inside the chamber. The shaft is fixed to upper portion of the chamber by welding and the shaft attached is movable to lower portion of chamber. The shaft is attached to the drill chuck by using L-key mechanism. The drill chuck is used to hold the material while tensile test is performing. Figure 2 shows the fabricated model of cryogenic chamber for the analysis.

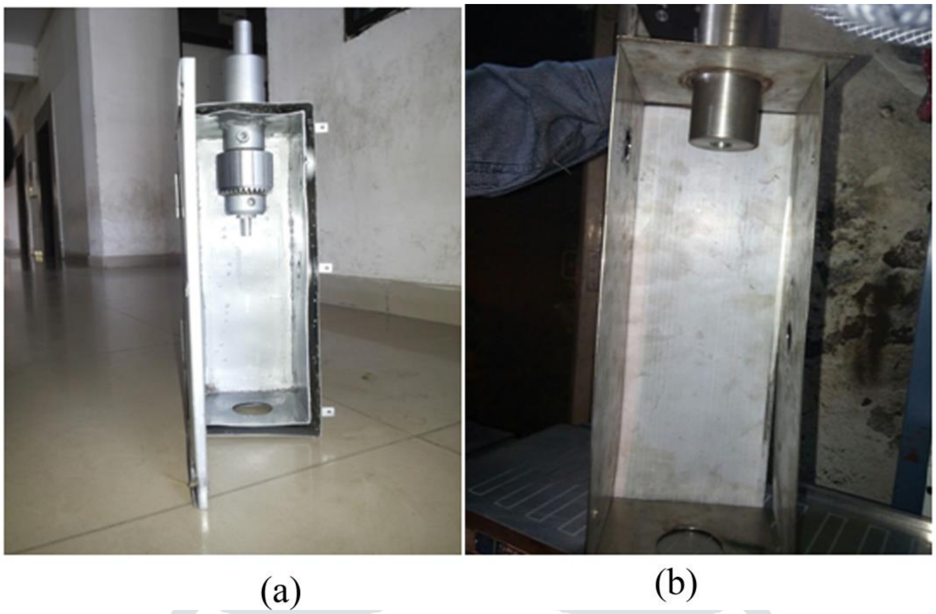

Figure 2 Cryogenic chamber fabricated for the analysis

Specimen of composite material is completely kept inside the cryogenic chamber and the chamber is completely packed after inserting the composite material and then the material is exposed to the liquid nitrogen (LN2) for some time and its effect is studied after performing the tensile test. The result is affected by the diffusion of air inside the chamber which is caused because of the different reasons first is the clearance at the hole made at the chamber faces for inserting different components with the cryogenic chamber. Second is the improper welding at the edges of the chamber. Third is the improper fixing of the chamber door or the clearance at the door edges. Fourth is the improper space between two walls of the cryogenic chamber and vacuum between these two walls is not created up to desired limit. Fifth is the material used for the fabrication of cryogenic chamber must sustain the cryogenic temperature for long time and so on. Thus all the factors should be varied so as to improve the final test result done on the UTM (universal testing machine). During fabrication no compromise with air leakage, material and vacuum space should be made. These factors are considered in the analysis. Then identification of various factors that contribute to the testing result failure for the different composite material should be done which is the major concern in the application of cryogenics.

3 EXPERIMENTAL PROCEDURE

For fixing the cryogenic chamber in the UTM, all the components of the cryogenic chamber are and the supporting equipments are examined properly. Figure 3 shows the tensile test of the cryogenic chamber carried in the UTM.

Figure 3 Testing of cryogenic chamber in the UTM

For testing of behavior of composite material used for the space application under cryogenic temperature an automated universal testing machine (UTM) which is having two jaws for holding the material and basically it is used for the purpose of tensile and compressive testing of the material. Initially, the fabricated cryogenic chamber is attached to the universal testing machine. The cryogenic chamber is having two shaft on is one the upper face and other is on the lower face and the upper face shaft is fixed to the upper jaw (fixed jaw) and lower face shaft is fixed to the lower jaw (movable jaw) of the universal testing machine. Later, the chamber is attached with universal testing machine we can insert other necessary things such as camera, thermocouple, LN2 pipe, suction pump pipe with the chamber at the appropriate holes provided for each of them at the chamber face. Then connect the other end of the LN2 pipe with the LN2 container (DEWAR) and other end of suction pipe with the pump. Now, attach load cell, data acquisition circuit (DAC), computer display etc.

Switch on the rotary suction pump and allow it to run for sometime so that the pressure between two walls of the chamber becomes 10-3 psi. If the desired pressure is reached so now turn on the LN2 (liquid nitrogen) valve and start purging liquid nitrogen on the composite material present within the cryogenic chamber. Then as we purge the liquid nitrogen on the composite material it starts to cool down and we will continue our purging process so as to cool the composite material up to the cryogenic temperature. Once the composite material attains the cryogenic temperature then start the tensile test of the composite material by slowly moving down the lower jaw of the universal testing machine and side by side start observing its mechanical properties on the universal testing machine display and apply the tensile load continuously so that necking occurs and ultimately the composite material break down.

Then sum up the whole physical and chemical properties together that we have observed through the tensile testing of composite material on the universal testing machine. Then study the result and check whether the material is compatible to use in the space application or not. If not so search the new ideas and techniques by which we can improve the strength of the composite material.

4 Conclusion

Study and fabrication of cryogenic chamber used for the UTM testing of composite material used in space application is carried out in this research and for 1mm thick SS316LN sheets which are having different physical and chemical properties than that of the normal stainless steel sheets. The SS316LN is a austenitic steel and cannot be welded by the normal welding process that are used for the welding of cast iron that is metal inert gas welding, oxy-acetylene welding, gas metal arc welding etc. In this research work we have used GTAW (Gas Tungsten Arc Welding) for the purpose of welding of the chamber plates and for making the chamber leakage proof.

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