FEASIBILITY STUDY OF INSULATOR, ADHESIVE, AND Y-JOINT STRUCTURE FOR THE CRYOGENIC PROPELLANT TANK OF REUSABLE LAUNCH VEHICLE

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SUMMARY: Single Stage to Orbit (SSTO) reusable vehicles are regarded as the most promising space recovery systems, which succeed the current Space Shuttle systems, to reduce space transportation cost drastically. The U.S.A started to develop the system and Japan is now starting. Super lightweight propellant tank is thought to be essential to realize SSTO and advanced materials to take the place of aluminum alloy should be developed. Our current research purpose is to assess the possible reduction of weight and to identify technical problems on the way of SSTO development. We will show the research status in this paper, including carbon fiber reinforced plastic (CFRP) material properties, basic properties of insulator and adhesive, and analysis of Y-joint structural element.

KEYWORDS: SSTO, Cryogenic propellant tank, Insulator, Adhesive, Y-joint structure

INTRODUCTION

SSTO reusable vehicle is regarded as a promising next generation of space transportation system which decrease the transportation cost drastically. One of the important problem to realize SSTO is to decrease the weight of the vehicle. In this stage super light weight cryogenic propellant tanks made of CFRP is considered as the most promising technology to reduce the weight of the vehicle because of the superiority in specific strength and stiffness over high strength aluminum alloys which are normally used for conventional expendable launch vehicle. In order to develop practical propellant tanks made of CFRP, adhesive joints for CFRP and insulators for very low temperature propellant are also important technology. In this paper we discuss about the basic material properties of CFRP and adhesives and insulators for cryogenic propellant tank, and Y-joint structure which could be one of the most difficult elements to design and fabricate.

MATERIAL PROPERTIES OF CFRP

We conducted basic experiments for obtaining material properties using several kinds of materials as promising candidates as below:

a. 180°C cured epoxy resin (3 kinds) : Aa, Ba, Ca
b. 120°C cured epoxy resin (2kinds) : Ab, Bb
c. Bismaleimide resin: Ad
d. PEEK: Ae

The Effect of Thermal Cycle to CFRP

The propellant tank of RLV experiences cryogenic temperature by fuel such as LOX or LH2 and high temperature by heat invasion of flux heating during reentry repeatedly. For evaluating the effect of thermal cycle to the material properties, thermal cycle of from +100°C to 160°C was given to the specimens mentioned above at maximum 500 cycle first. After the experience of thermal cycle, we conducted several tests as below.

a. Micro-crack creation

The specimens after thermal cycle of 100 times and 500 times are observed at cross-section. As the result that creation of micro-crack and other symptoms of damage were not found.

b. Tensile strength at LN2 temperature

Fig. 1 shows tensile test result at LN2 temperature using specimens after thermal cycle.
We can see that tensile strength of each material is different from another one largely, but the effect of thermal cycle to tensile strength is very small.

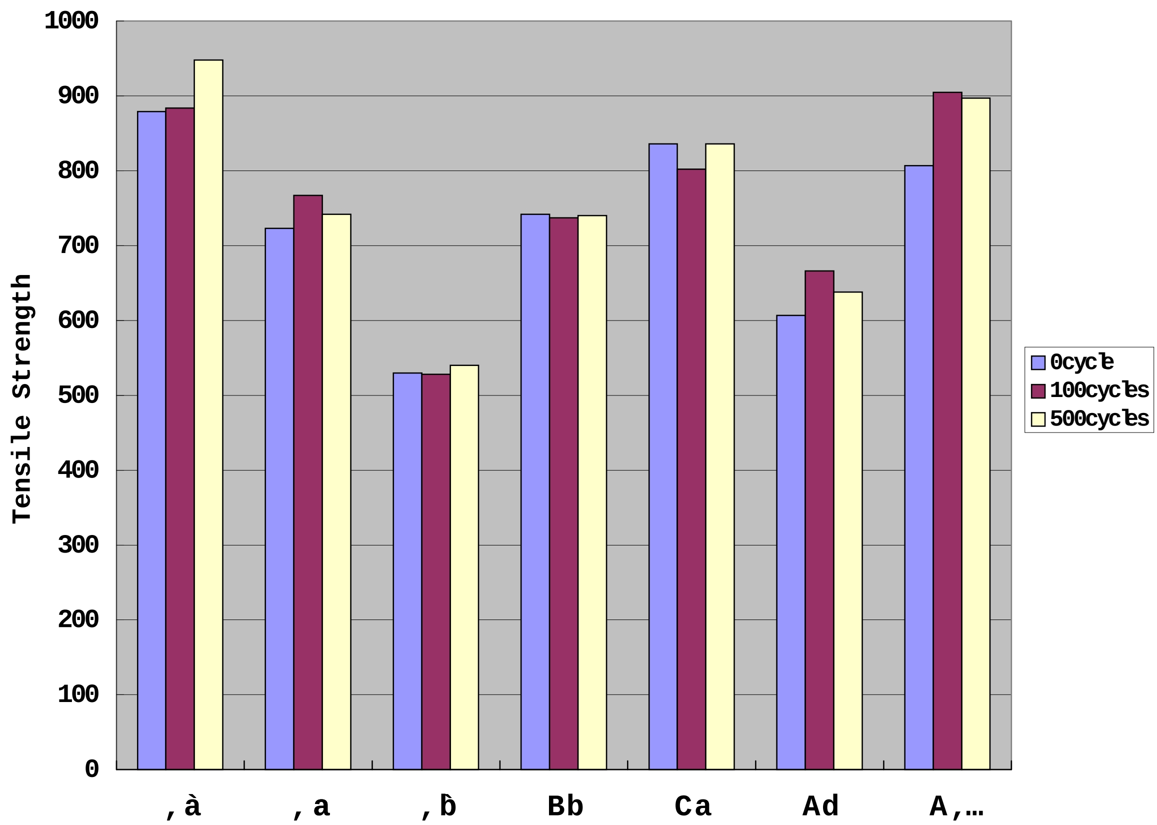

Fig.1 The Effect of Thermal Cycle to Tensile Strength

c. Permeability properties at LHe temperature

Permeability of CFRP disk was measured with helium leak detector. The specimens are sealed up in the device, which seals up CFRP disk and provide helium gas into the one side and make the another side vacuum by helium leak detector and detect helium gas. Fig. 2 shows the result of permeability test with regards to material Aa and Ba (180°C cured epoxy systems). Two kinds of specimens were tested after thermal cycle of 0 time, 100 times, and 500 times. Permeability test were conducted at room temperature, LN2 temperature, and LH2 temperature. The graph shows that the effect of thermal cycle to permeability is small and that the lower temperature is, the fewer the permeability is. As the result that the effect of this magnitude of thermal cycle is almost nothing to material properties of high tough epoxy resin.

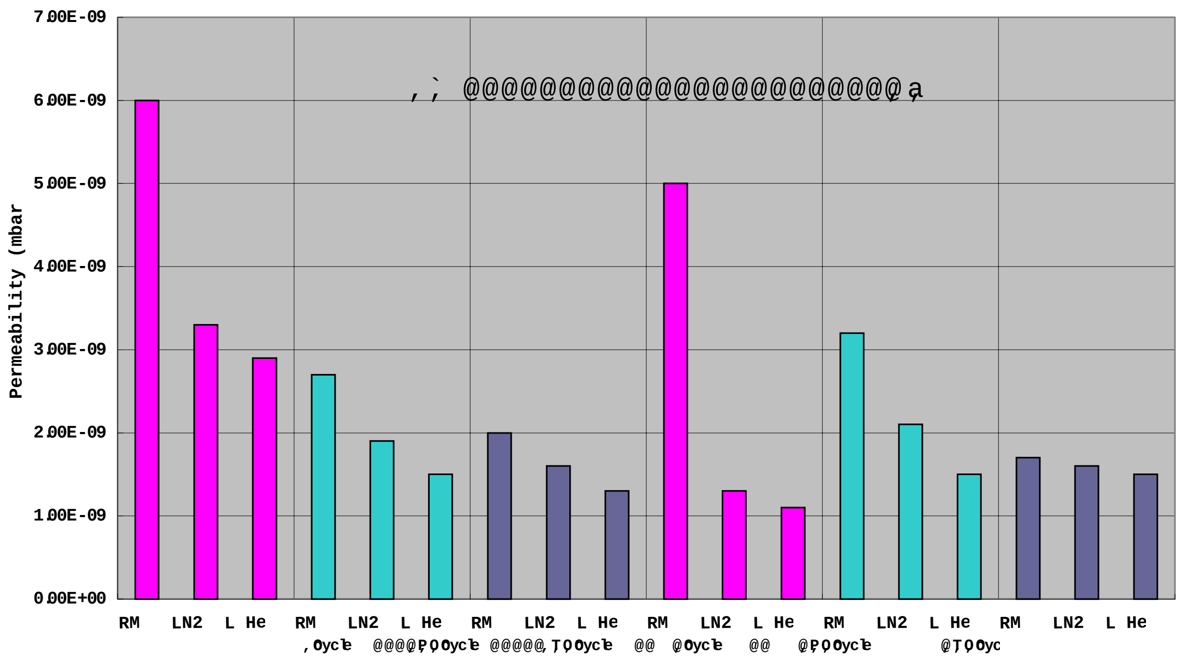

Fig.2 The Effect of Thermal Cycle to Permeability

d. Interlaminar Shear Strength

Fig.3 shows the result of interlaminar shear strength test at room temperature at each number of thermal cycles. We can see shear strength do not decrease with 500 times thermal cycle.

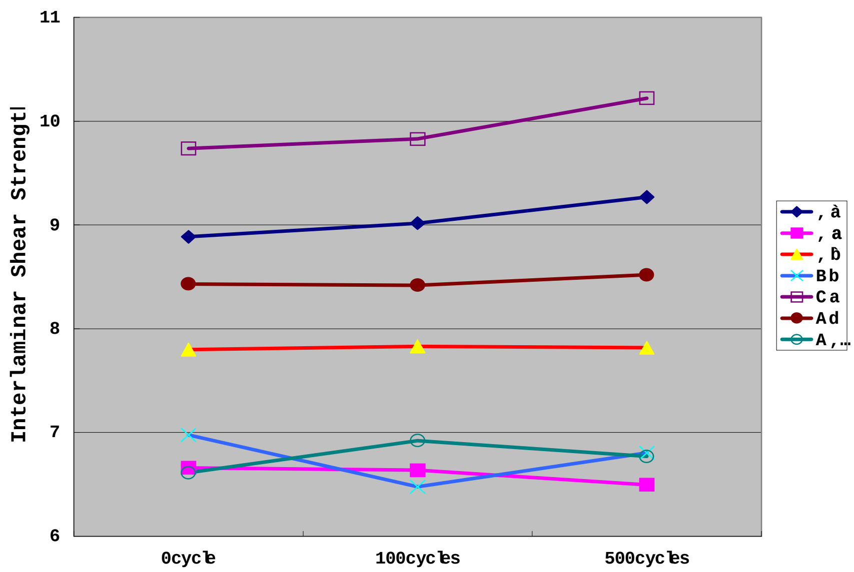

Fig.3 The Effect of Thermal Cycle to Interlaminar Shear Strength

Thermal contraction properties

Thermal strain between fibers and matrix is one of the most important factors to determine micro cracking properties and possibly delamination properties. In order to estimate this internal strain it is necessary to obtain thermal contraction properties of fibers and resins. Therefore, thermal contraction of uni-directional materials was measured in both of fiber direction and laminate direction. The results are shown in Fig. 4 with regards to material Aa and Ba (180°C cured epoxy systems). The difference between two materials is very small. While very small contraction in laminate direction reached about 0.6 %. This discrepancy is considered as the source of internal thermal stress. This data was obtained by use of a special facility at the Institute of Science and Industrial Research, Osaka University, through the courtesy of Prof. Nishijima.

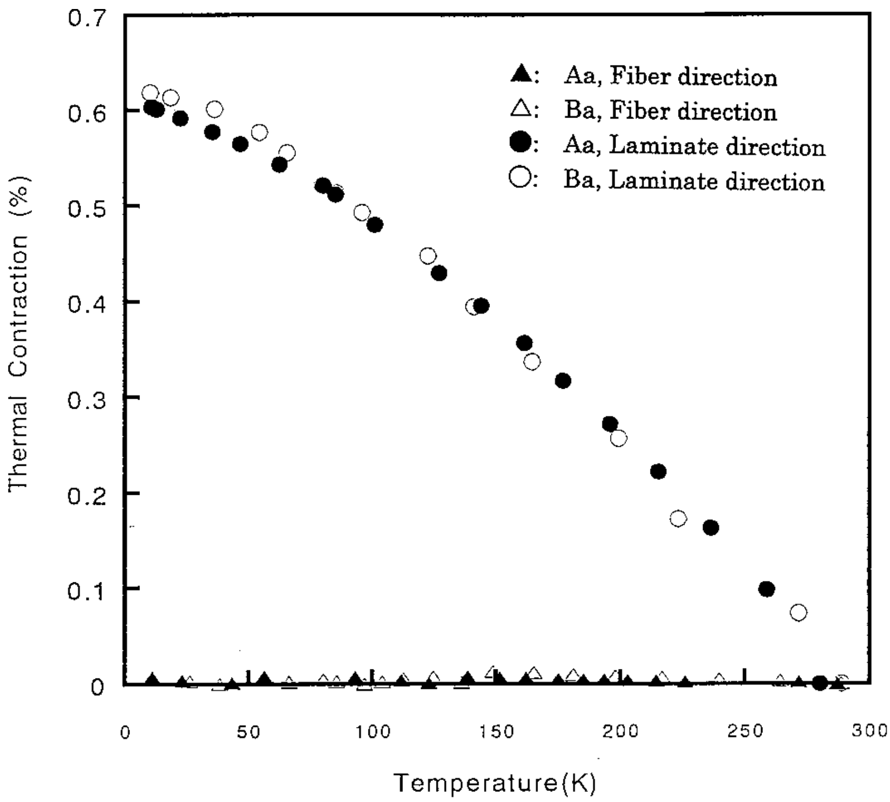

Fig.4 Thermal Contraction of CFRP

Permeability Properties of CFRP cylinder

This test was conducted as preliminary test for scaled tank test. Three kinds of cylinder specimen are used, each has 100 mm diameter and about 1.1 mm thickness. The specimen is sealed up in a devise and helium gas is provided into inside the specimen. Permeability was measured by vacuum evacuation of helium leak detector from external of specimen. Fig.5 shows the outline of this test. The measurement of helium permeability was kept for 24 hours. Each specimen was tested after thermal shock of one time into LN2 and ten times and no shock. Three kinds of specimen consist of two kinds of squai-isotropic CFRP and one made of cloth material lay-up.

Fig.5 Setting of CFRP Cylinder Permeability Test

The result is that permeability of the specimen after one time thermal shock increased by 30% compared to the virgin specimen. Furthermore permeability of the specimen after ten times thermal shock is five times of that of virgin specimen.
Fig.6 shows one of the permeability test results. These data is owing to permeability properties of the material itself, not the result of damage such as micro-cracking or delamination. We are still planing to measure the permeability properties after thermal shock of LHe.

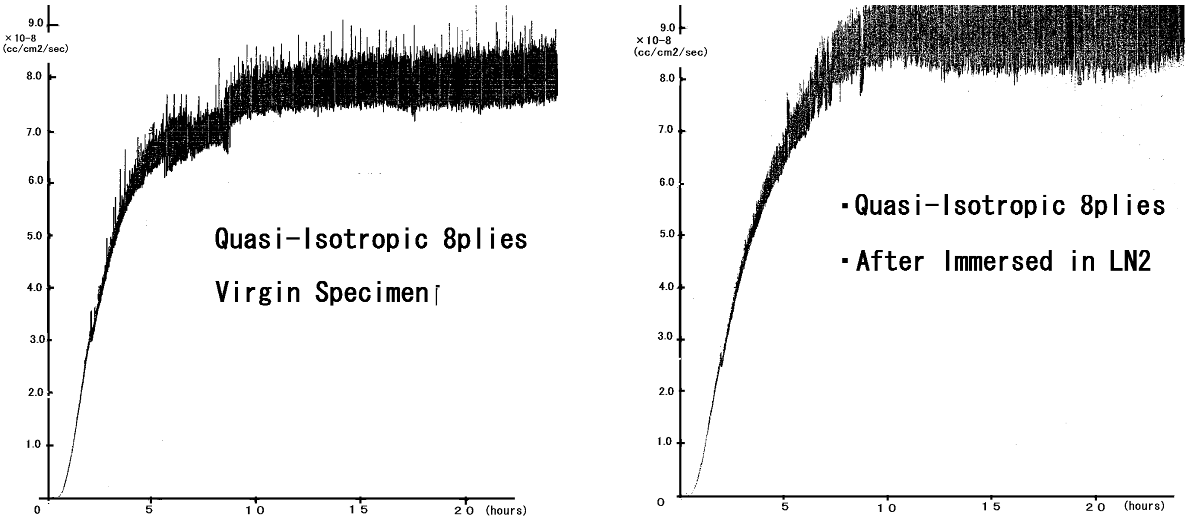

Fig.6 The Effect of Thermal shock to Permeability

BASIC PROPERTIES OF INSULATORS

Propellant tank of space transportation vehicle is exposed to cryogenic temperature of fuel inside and high temperature by heat flux during reentry outside. So protection of CFRP by insulator is inevitable for cryogenic propellant tank. We are now conducting a basic research of insulator for propellant tank. In this stage, several kinds of Rohacel insulator have been tested for obtaining basic properties. Fig.7 shows a setup of Insulator Tensile Test.

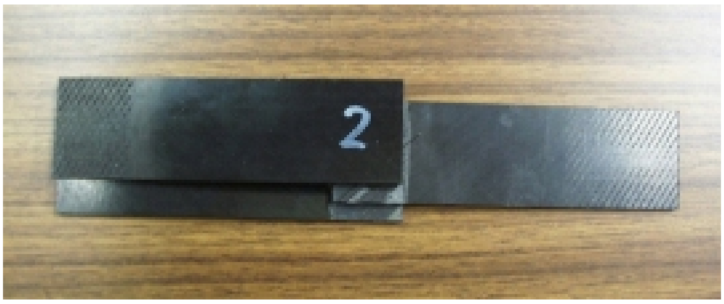

Fig.7 Insulator Tensile Test Fig.8 Specimen for Adhesive Shear Strength Test

BASIC PROPERTIES OF ADHESIVES

Bonding CFRP and CFRP or CFRP and insulator is also considered to be important for practical cryogenic propellant tank. We are also conducting a preliminary test for obtaining the basic properties of candidate adhesives for CFRP. EA9394 is considered to be a promising candidate for CFRP and we are now testing this adhesive. Fig.8 shows a specimen for adhesive shear strength test.

Y-JOINT STRUCTUAL ELEMENT

Rocket type of space vehicle like SSTO has “ Y “ shaped structural element at the connection of tank dome and external skin of rocket. This structure is complicated but for lightweight it is desired to manufacture as a unified element. In order to verify technical problem of this “ Y-joint “ structural element, we conducted strength test with 2-Dimensional specimen and calculated stress distribution by FEM in parallel. Fig.9 shows a setup of Y-Joint Strength Test.

Fig.9 Setup of Y-Joint Strength Test

The comparison between the test and analysis by FEM is being conducted for the purpose of establishing stress analysis method and strength evaluation method. There are three kinds of specimens of Y-joint structure – two of these are made by quasi-isotropic lay-up and one of these is made by cloth material lay-up. We have obtained strength data at room temperature and LN2 temperature. This is shown in Fig. 10. A4, B3, and C3 were tested at LN2 temperature. From this test result, We can see that temperature does not effect the strength so much and that the difference of lay-up method effected the strength. We are now conducting FEM analysis by ANSYS and the number of lay-up is less than the practical specimen for simplicity. We did not get good result of FEM analysis so far owing to these. The improvement of modeling is a problem hereafter.

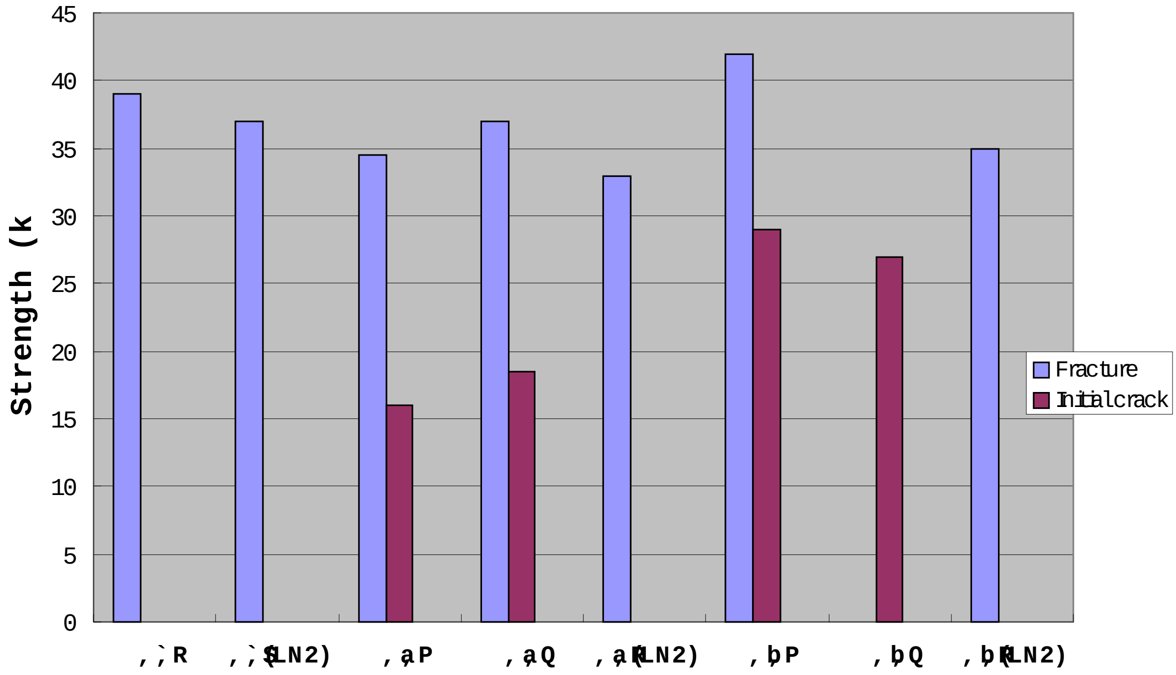

Fig.10 Strength of Y-Joint 2-D specimen

CONCLUSIONS

Recently research of applicability of CFRP materials to practical cryogenic tank structures is conducted lively especially in U.S.A. Japan started the research and is obtaining data such as material properties at cryogenic. We can say the basic technology to determine the way of research and development in this field is ready in Japan. We are obtaining an affirmative data for applicability of CFRP materials to practical cryogenic tank structures and should proceed to the next step of research for practical CFRP propellant tank.

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