THE CRYOGENIC TENSILE EVALUATION OF AN ALUMINUM-COMPOSITE BOND

Eric A. Clark, Dr. Thomas H. Fronk, Michael D. Lambert

Mechanical Engineering Department, Utah State University, 4130 Old Main Hill, Logan, UT 84321

Introduction

Due to their high strength to weight and stiffness to weight ratios, composite materials have developed into the primary candidates for many aerospace applications. One main area in which the benefits of composite materials would be paramount is in the use of pressure vessels for storing liquid hydrogen and liquid oxygen for spacecraft propellant [1].

One concern associated with a thin walled composite overwrapped pressured vessel (COPV) is that during depressurization, the resulting compressive stress associated with the elastic recovery of the composite overwrap will cause the thin-walled liner to delaminate from the composite overwrap and buckle. However, it is theorized that if the bond at the composite-aluminum interface is strong enough, it will be possible to maintain the structural integrity of the vessel even if the critical buckling load is exceeded. Hence, the need for a superior bond that can maintain its integrity in a cryogenic environment between the composite and the liner is vital.

Experimentation

Materials

Four different resin systems were evaluated during the investigation: HEI 535, Epon 862, West 105, and an experimental urethane. HEI 535 is an epoxy resin system formulated by HyPerComp Engineering Inc. (HEI) specifically for low temperature applications. The experimental urethane was also designed for use in a cryogenic environment. The other two resin systems are typical commercial resin systems designed for use at ambient temperatures, however they were included to see how they would behave when subjected to a low temperature environment.

Various surface preparation techniques including sanding, grit blasting and use of the AC 130 surface etchant were also evaluated. Additionally, several different bondline thicknesses were also included in the investigation.

Apparatus and Procedure

ASTM D952-02, Standard Test Method for Bond or Cohesive Strength of Sheet Plastics and Electrical Insulating Materials, was used as a guideline in conducting the tensile tests, however the test fixture was modified in order to allow the test specimen to be tested while submerged in Liquid Nitrogen (LN_2) [2].

The cryogen bath used to contain the LN_2 during testing was fitted with two 19.05mm (0.75 in) steel rods under which a cylindrical collar was fitted over the test sample. As the tensile load was applied to the aluminum test sample, the rods caused the cylindrical collar to apply a uniform pressure on the composite material eliminating any bowing of the composite or peeling of the test piece.

All of the tensile tests were performed using a Tinius Olson H50 KS, 10000 lb test machine.

Results

The bond of many of the Epon 862 and West 105 test samples failed when submerged in the LN2 without even being stressed.

Due to their poor performance, they were dismissed at an early stage from further evaluation.

A prebond, or thin layer of resin, applied and cured to the aluminum test piece prior to the bonding procedure resulted in a substantial increase in the cryogenic tensile strength as illustrated in Figure 1.

Figure 1. Result of Prebond.

One of the most interesting findings from these tests was the importance of sanding *the prebond* prior to applying the test piece to the composite layup for bonding as seen in Figure 2.

Figure 2. Effect of sanding the Prebond.

Figure 3 illustrates how the different surface preparation techniques performed in conjunction with the urethane and HEI 535 resin systems.

Figure 3. Comparison of different surface preparation techniques.

Conclusions

The tests involving the Epon 862 and West 105 resin systems clearly demonstrate that in order to maintain the bond integrity for cryogenic applications, a flexible, low modulus resin system must be used.
Also, the samples prepared with a prebond performed significantly better than those without. One reason the prebond proved to be so successful is that the thin layer of resin helped to offset the large dissimilarity between the coefficient of thermal expansion (CTE) between the aluminum and the composite. Furthermore, it was found that the prebond must be sufficiently roughed up prior to the bonding application.
Based on the limited number of tests conducted, neither the surface preparation nor the prebond thickness had a significant effect on the cryogenic tensile strength of the samples prepared with the HEI 535 prebond.
Alternatively, the urethane samples prepared with a thin prebond and the AC 130 surface etchant resulted in a dramatically greater tensile strength.
It is believed that the stiffer HEI 535 resin system behaves in a more brittle nature at such an extreme temperature, thus making it more susceptible to brittle fracture.

References

[1] Tudela, M. and Kim, R. "Impact Damage Response of Composite Materials at LOX/Cryogenic Temperatures," *AIAA* 2157 (2005): 4356-4367.

[2] ASTM D952-02. *Standard Test Method for Bond or Cohesive Strength of Sheet Plastics and Electrical Insulating Materials.* 2002.