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MATERIALS FOR THE GENERAL AVIATION INDUSTRY: Effect of Environment On Mechanical Properties of Glass Fabric / Rubber Toughened Vinyl Ester Laminates

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Abstract

A screening evaluation is being conducted to determine the performance of several glass fabric/vinyl ester composite material systems for use in primary General Aviation aircraft structures. In efforts to revitalize the GA industry, the Integrated Design and Manufacturing Work Package for General Aviation Airframe and Propeller Structures is seeking to develop novel composite materials and low-cost manufacturing methods for lighter, safer and more affordable small aircraft. In support of this Work Package, this study is generating material properties for several glass fabric/rubber toughened vinyl ester composite systems and investigates the effect of environment on property retention. All laminates are made using the Seemann Composites Resin Infusion Molding Process (SCRIMP), a potential manufacturing method for the General Aviation industry.

I. Background

Lighter, safer and more affordable aircraft structural concepts are needed to revitalize the American General Aviation (GA) industry. Such goals are the focus of the Integrated Design and Manufacturing Work Package for General Aviation Airframe and Propeller Structures at NASA Langley Research Center (LaRC). As part of this Work Package, NASA LaRC researchers are currently developing novel composite materials and low-cost manufacturing methods to meet the specific needs of the GA industry.

In an effort to ultimately determine design guidelines for GA aircraft manufacturers, extensive testing is underway to generate material properties for the glass fabric/vinyl ester (VE) composites and to investigate the effect of humidity and temperature on these properties [1]. The primary glass fabric chosen for evaluation was an 8-harness satin composed of E-glass fibers (Style 7781). This fabric is known to have superior drape, a critical measure of manufacturability, but is more expensive than other glass fabrics and with a thickness of only 10 mils per ply, requires extensive layup time to build up to the designed laminate thickness. The primary vinyl ester chosen for evaluation was the Novolac based Dow Derakane 470-36. This resin has the highest glass transition temperature (Tg) of all available vinyl esters, and therefore, will have the highest operating temperature capabilities, but its low failure strain has generated concerns of possible reductions in fatigue life and adhesive properties, both key to successful aircraft composites.

To address these concerns, a 10-week material property screening evaluation of alternative glass fabric/vinyl ester composites was conducted. The study was sponsored by the Langley Aerospace Research Summer Scholars (LARSS) Program.

II. Material Selection

Because the GA industry is primarily driven by cost, reductions in part lay-up time is crucial. The high lay-up time associated with small ply thickness fabrics, like the woven yarns, is avoided when using knit rovings. These fabrics contain multiple layers of fiber, oriented at various angles and all knit together to form one ply. This feature allows for far more cost efficient part lay-up. For this reason, it was thought that a comparison of the mechanical properties of knit roving laminates with the existing data on woven yarns would be beneficial to the GA aircraft manufacturers. Table 1 summarizes some of the characteristics of the glass fabrics considered.

Further, because the questions surrounding the performance of the Novolac based VE chosen as the primary matrix resin were mainly raised due to its low failure strain, it was thought that a comparison of the mechanical properties of rubber toughened VE laminates with the existing Novolac based data would also be beneficial. Table 2 summarizes properties of the Novolac based and rubber toughened vinyl esters available as laminating resins.

Woven Yarns	Knit Rovings
°~10 oz./sq. yd.	°12-72 oz./sq. yd.
°good drape characteristics	°low fiber waviness
°expensive	°multiple layers per ply
°small ply thickness	°low lay up time

Table 1: Comparison of Candidate Glass Fabrics

Vinyl Ester Type	Tg (°F)	Failure Strain (%)	Viscosity (cps)	E (KSI)	Example
Rubber Toughened	200	10	400	440	Derakane 8084
Novolac Based	280	2~3	350	500	Derakane 470

Table 2: Comparison of Candidate Matrix Resins

In considering alternative materials to supplement the current data for the woven glass yarn/Novolac based VE, it was decided that 5 different panels would be constructed using the Seemann Composites Resin Infusion Molding Process (SCRIMP). This process has been the focus of several studies of low-cost resin transfer forming [2,3,5,6]. Components of the five panels are as follows (glass fabric/resin):

1) 8-Harness Satin (Style 7781)/Dow Derakane 8084
2) 16 oz. Biaxial Knit (Style C16)/Dow Derakane 8084
3) 18 oz. Biaxial Knit (Style C18)/Dow Derakane 8084
4) 24 oz. Biaxial Knit (Style C24)/Dow Derakane 8084
5) 32 oz. Biaxial Knit (Style C32)/Dow Derakane 8084

III. Test Plan

The core questions to be answered in testing the five laminates follow:

- Are rubber toughened vinyl esters suitable laminating resins for General Aviation aircraft?
- What is the effect of biaxial knit fabric weight on laminate properties?
- How do glass biaxial knit/vinyl ester laminates compare to glass weave/vinyl ester laminates?
- Is the reduction in hot/wet data due to property degradation of resin? of fiber? and/or of interface?

Table 3 summarizes the testing planned to deliver answers to the above questions.

Test	Condition	7781/8084	c16/8084	c18/8084	c24/8084	c32/8084
Tension	RTD	5	5	5	5	5
Tension	ETD	5	5	5	5	5
Tension	RTW	5	5	5	5	5
Tension	ETW	5	5	5	5	5
Compress.	RTD	5	5	5	5	5
Compress.	ETD	5	5	5	5	5
Compress.	RTW	5	5	5	5	5
Compress.	ETW	5	5	5	5	5
Condition Key:	RTD	No Conditioning/Tested @70°F				
	ETD	No Conditioning/Tested @165°F				
	RTW	Conditioned @ 120°F, 85%RH, 3 months/Tested @ 70°F				
	ETW	Conditioned @ 120°F, 85%RH, 3 months/Tested @ 165°F				
Test Key:	Tension			ASTM D638		
	Compression			ASTM D695		
	Volume Fraction			ASTM D2584		
	Transition Temp.			DSC		

Table 3: Test Matrix

IV. Results to Date and Discussion

Due to time constraints, the samples (100 in all) that require 3 months of pre-test conditioning have not been tested at this point. All testing should be concluded in the near future at Boston University. The data for the 100 unconditioned test samples follows.

A) Effect of Fabric:

i) Tension Modulus

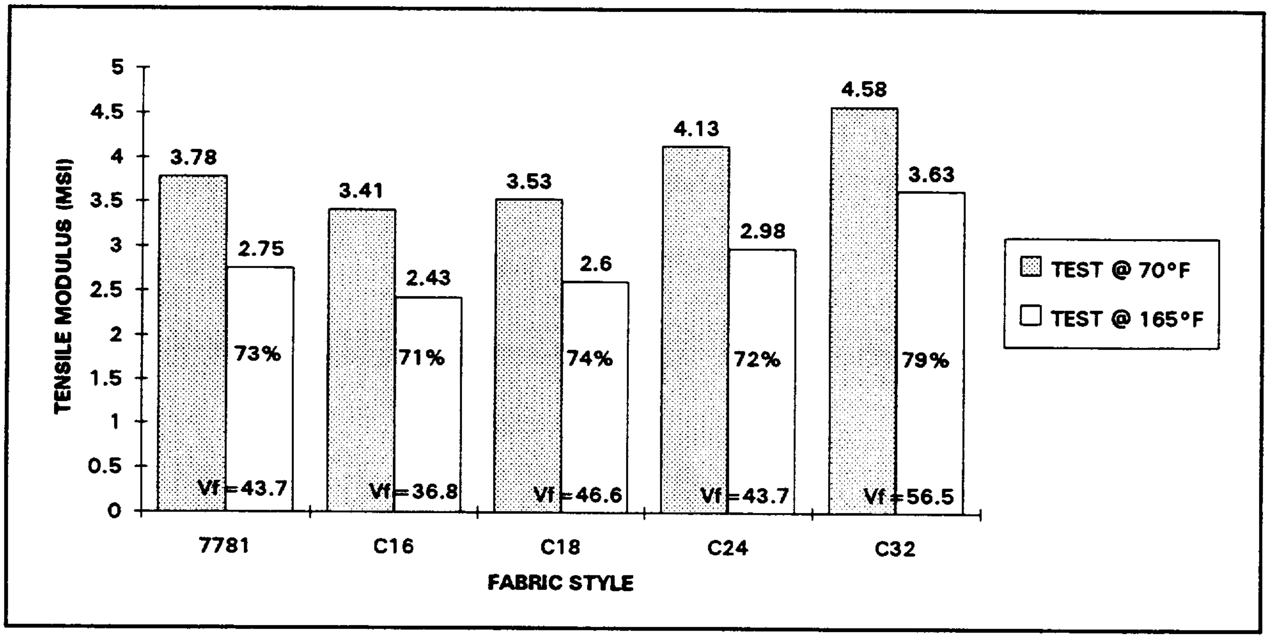

Figure 1: RTD and ETD Tension Modulus

As seen in Figure 1, with regard to the knit laminates, tension modulus increased as the fabric weight increased, not necessarily as fiber volume fraction increased as one typically expects of composites. This anomaly to the common trend is evident in the 17% higher tension modulus of the 24 oz. fabric than of the 18 oz. fabric despite a slightly lower fiber volume fraction. In general for the knit laminates and especially for the heavier ones, tension moduli were higher than for the weave. This is consistent with the idea that uncrimped (straight) fibers result in higher composite tension moduli. Moduli retention at 165°F was similar for all laminates (71-79%).

ii) Tension Strength

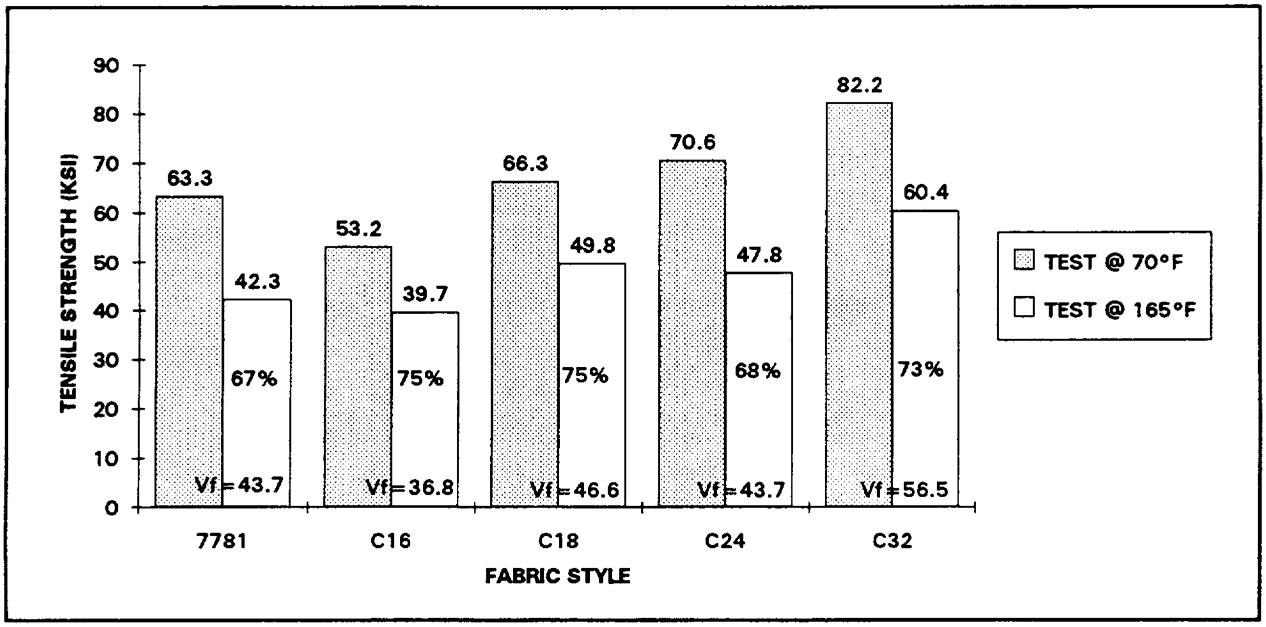

Figure 2: RTD and ETD Tension Strength

The trends of measured tension strength were similar to those of tension modulus as seen in Figure 2. With regard to the knit laminates, tension strength increased as fabric weight increased, not necessarily as fiber volume fraction increased. Similar findings for glass fabric/rubber toughened vinyl ester laminates have been reported elsewhere [2]. The knits were in general stronger than the weave. Again, this is attributed to the low crimp typically associated with knit fabrics. Tension strength retention at 165°F was similar for all laminates (67-75%). Because tension tests are fiber dominated, reduced matrix performance at the higher test temperature has minimal effect on tension properties. As will be seen following, this is certainly not the case for matrix dominated performance such as compression.

iii) Compression Strength

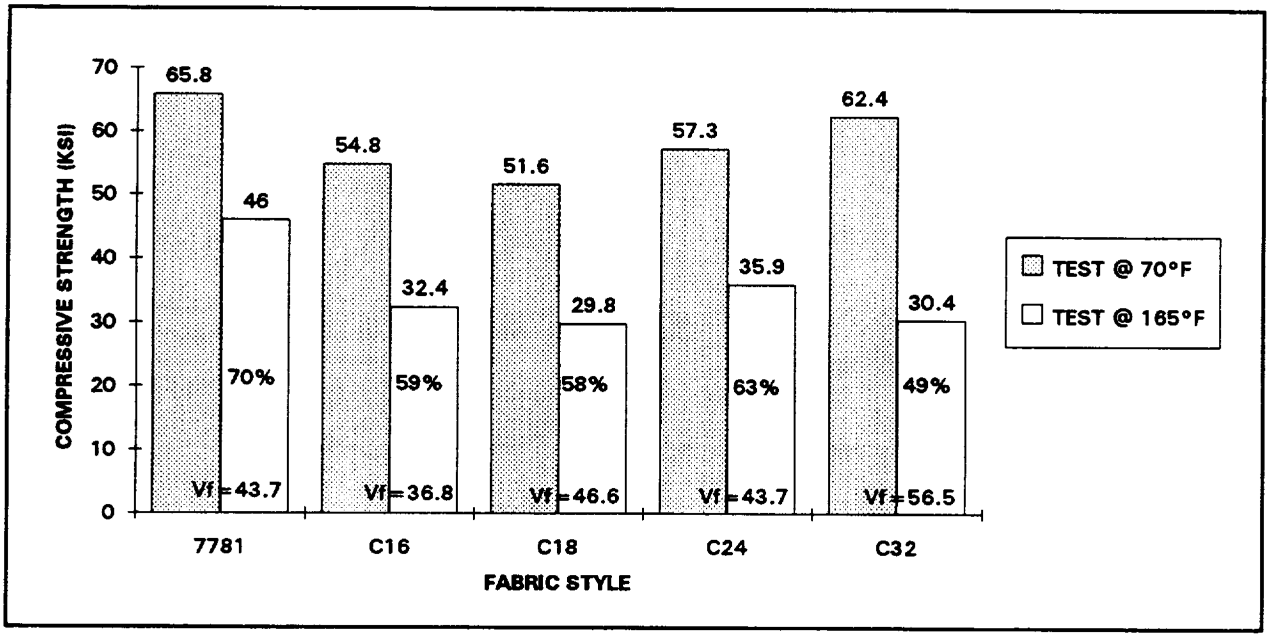

Figure 3: RTD and ETD Compression Strength

From Figure 3, it is seen that compression strength was 6% lower for the 18 oz. fabric than for the 16 oz. fabric despite a measured 26% increase in fiber volume fraction. Compression strength then increased for the two heavier knits. The lower than expected compression strength of the 18 oz. fabric may be attributed to the higher than expected crimp of that particular laminate. Initial visual observation of photomicrographs revealed more fiber waviness for the 18 oz. fabric than for the other knits.

The compression strength retention at 165°F of the knit laminates is alarmingly low, as up to 51% of compression strength was lost at the higher test temperature. Since compression tests are matrix dominated, this reduction of composite property is likely due to a reduction in the bearing ability of the resin. The large reduction of strength at 165°F indicates that additional matrix dominated testing (such as testing for bearing loads) should take place. Apparently, the lower Tg (200°F) of the rubber toughened VE used in this study is hindering the laminate's bearing ability at the higher test temperature when used in conjunction with the knit fabrics. It is anticipated that the knit laminate retention would be higher for the Novolac based VE chosen as the primary resin because of its high Tg.

The woven fabric laminate had a higher compression strength than all of the knit laminates. This was unexpected as higher crimp is typically associated with woven fabrics than with knit fabrics. Visual inspection of photomicrographs however, revealed lower than expected fiber waviness for the 8-harness satin being studied. Still, the measured difference between the weave and the knits is puzzling. It is obvious that parameters describing the form of the reinforcing fiber (fiber diameter, tow diameter, tow weight, etc) significantly affect compressive properties.

B) Effect of Resin

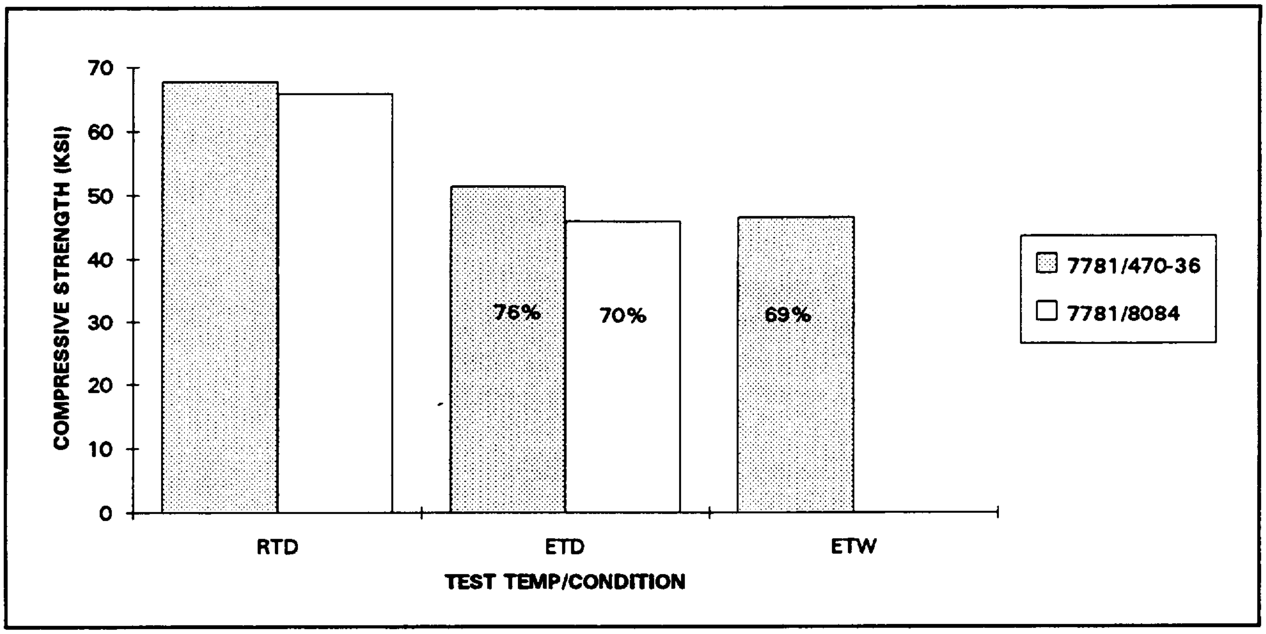

Figure 4: Compression Strength Retention, Rubber Toughened vs. Novolac Based VE

As can be seen in Figure 4 from the ETD and RTD data, the rubber toughened VE laminate had compression strength and retention similar to the Novolac based VE. Both laminates contained Style 7781 woven yarn. The conditioned samples are yet to be tested, but the ETW data point is anticipated to be the critical metric in determining the applicability of rubber toughened vinyl esters for certified use in the GA industry.

V. Concluding Remarks

From testing completed to date, the rubber toughened vinyl ester, Dow Derakane 8084 compares favorably to the higher temperature Novolac based vinyl ester Dow Derakane 470. The one exception to this statement occurs when the rubber toughened vinyl ester is reinforced with a knit glass fabric, as the compressive strength retention at 165°F was much lower than desired (only≈50%).

It is apparent at this point in the screening evaluation that the rubber toughened VE may provide sufficient mechanical properties for GA aircraft when reinforced with 8-harness satin weave. Eventually, testing of fatigue life and adhesive properties should take place to validate the idea that this performance will be improved with the rubber toughened VE versus the Novolac based VE. Until the conditioned samples are tested later this year, no conclusion can be made about the ultimate use of rubber toughened vinyl esters in the General Aviation industry.

VI. NASA LaRC Facilities Utilized

Mechanics of Materials Laboratory, Building 1205

- ▪Instron Series 8500 Mechanical Test Machine
- ▪56.2 kip Load Cell
- ▪Linear Variable Displacement Transducer
- ▪386 PC w/ Instron Flaps Software Controller
- ▪Measurement Group System 4000 Data Acquisition Tower
- ▪Machine Shop
- ▪Tennyson Temperature/Humidity Chamber

Polymer Physics Laboratory, Building 1293

- ▪Sintech Mechanical Test Machine
- ▪Test Oven, Thermocouple and Temperature Controller
- ▪486 PC w/ Test Works Software Controller and Data Acquisition

Light Alloy Metallography Laboratory, Building 1205

- ▪Photomicrograph Camera

Polymer Characterization Laboratory, Building 1293

- ▪DuPont 9900 Digital Scanning Calorimeter

Model Shop, Building 1238B

- ▪Seemann Composites Resin Infusion Molding Process (SCRIMP) [3]

NASA Technical Library

VII. References

[1] Dexter, H.B. and Hasko, G., personal communication

[2] Juska, T., Mayes, J.S. and Seemann III, W.H., "Mechanical Properties and Impact Damage Resistance of Composites Fabricated by Low Cost, Vacuum Assisted, Resin Transfer Molding," Naval Surface Warfare Center, Carderock Division, Survivability, Structures and Materials Directorate, Research and Development Report SSM-64-93/04, August 1993

[3] Seemann III, W. H., US Patent # 4,902,215

[4] Dow Chemical, Derakane Epoxy Vinyl Ester Resins Technical Product Information

[5] Research Release, "Low Cost, High Quality Composite Ship Structures Technology Demonstrated," Naval Surface Warfare Center, Carderock Division, May 1993.

[6] Nguyen, L.B. et al, "Design and Fabrication of a High-Quality GRP Advanced Materiel Transporter," unpublished