2011 DOE Hydrogen & Fuel Cell Program

Alternate Fiber Evaluation and Optimization of Filament Winding

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Project ID # ST106

QUANTUM TECHNOLOGIES

Overview

Phase I Objective

- Alternate Fiber Evaluation
- Optimization of Filament Winding Processing

Timeline

- Project start date: 08/2011
- Project end date: 03/2012
- Percent complete: 99%

Budget

- Total Budget: $149,682

  DOE Share: $149,682
- Funding for FY11: $149,682

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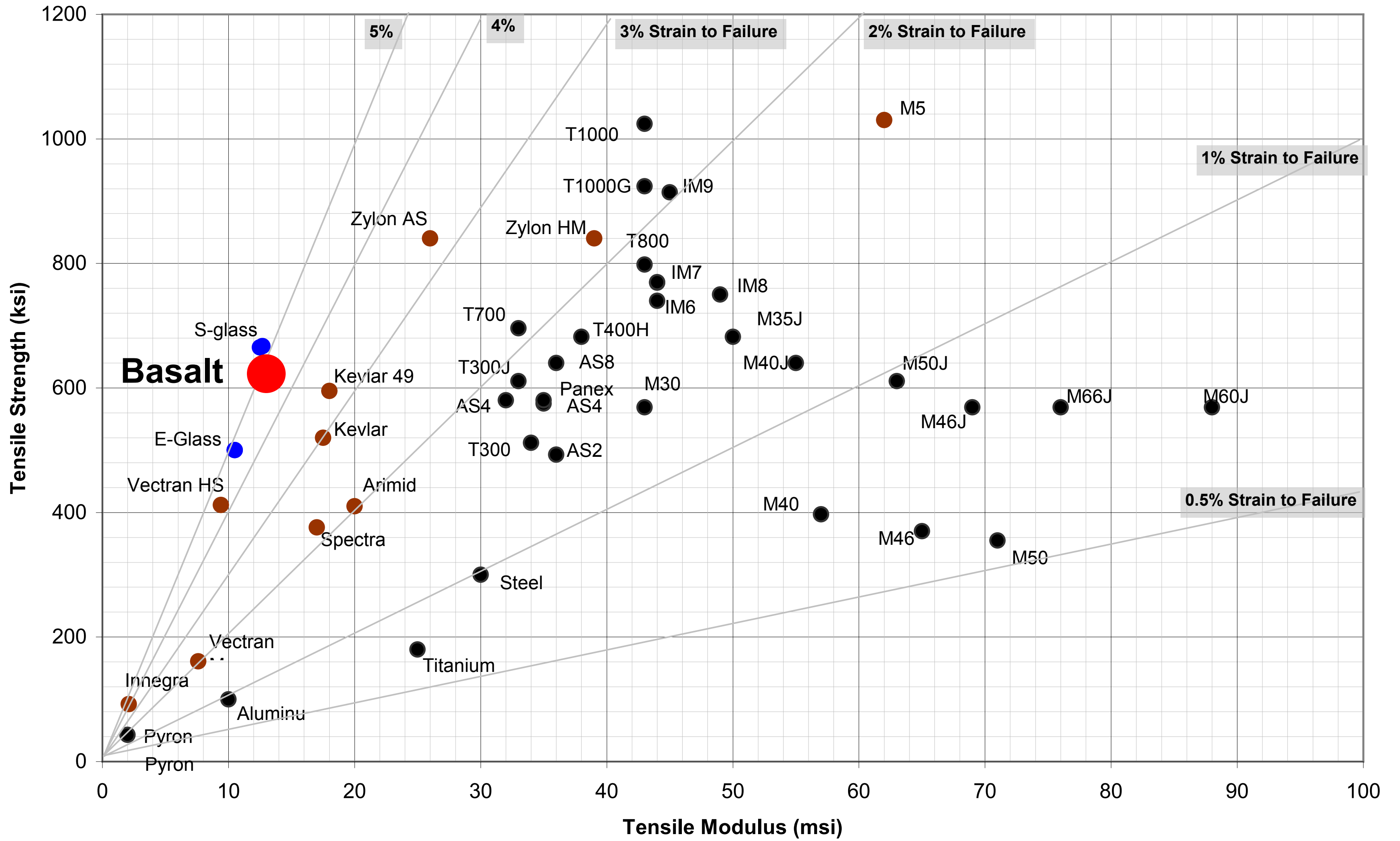
Alternate Fiber Evaluation

1. Evaluated basalt fiber mechanical properties
   - Prepared basalt fiber composite unidirectional coupon
   - Prepared basalt fiber composite NOL ring coupon
   - Performed unidirectional tensile test
   - Performed short shear beam test
   - Performed hydrogen compatibility test
2. Evaluated basalt fiber composite tank performance
   - Designed preliminary FEA basalt fiber composite 34L 18.6 MPa tank
   - Fabricated basalt fiber composite 34L 18.6 MPa tank
   - Performed burst test
   - Performed environmental stress cracking test
3. Phase II plan

Fiber Properties Comparison



Carbon fiber, Glass, Aramid

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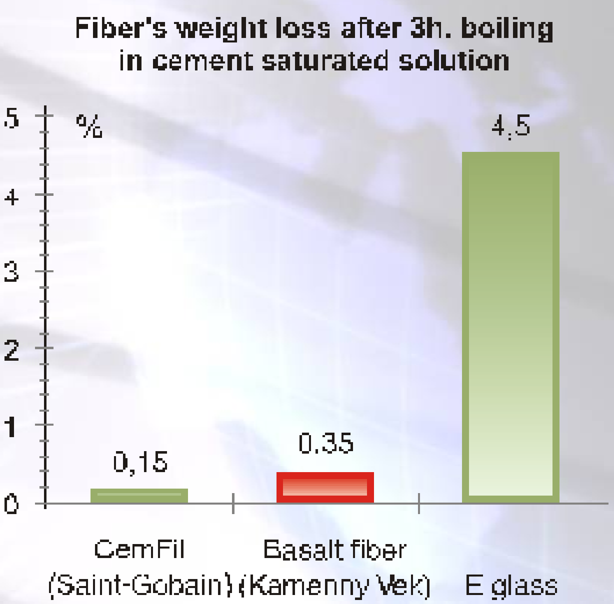
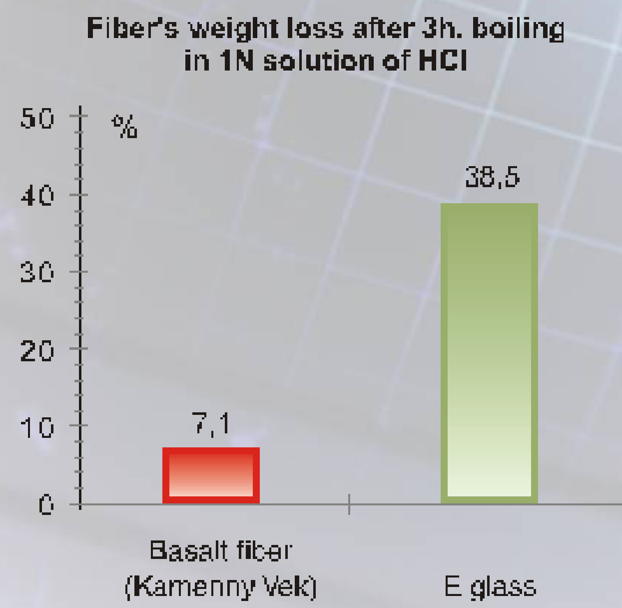
Basalt vs. E Glass

- Higher tensile strength (by 15-20%), higher tensile modulus (by 15-20%)
- Extended operation temperature range
- Better chemical resistance





Source: Kamenny Vek http://www.basfiber.com/src/filament_winding.pdf

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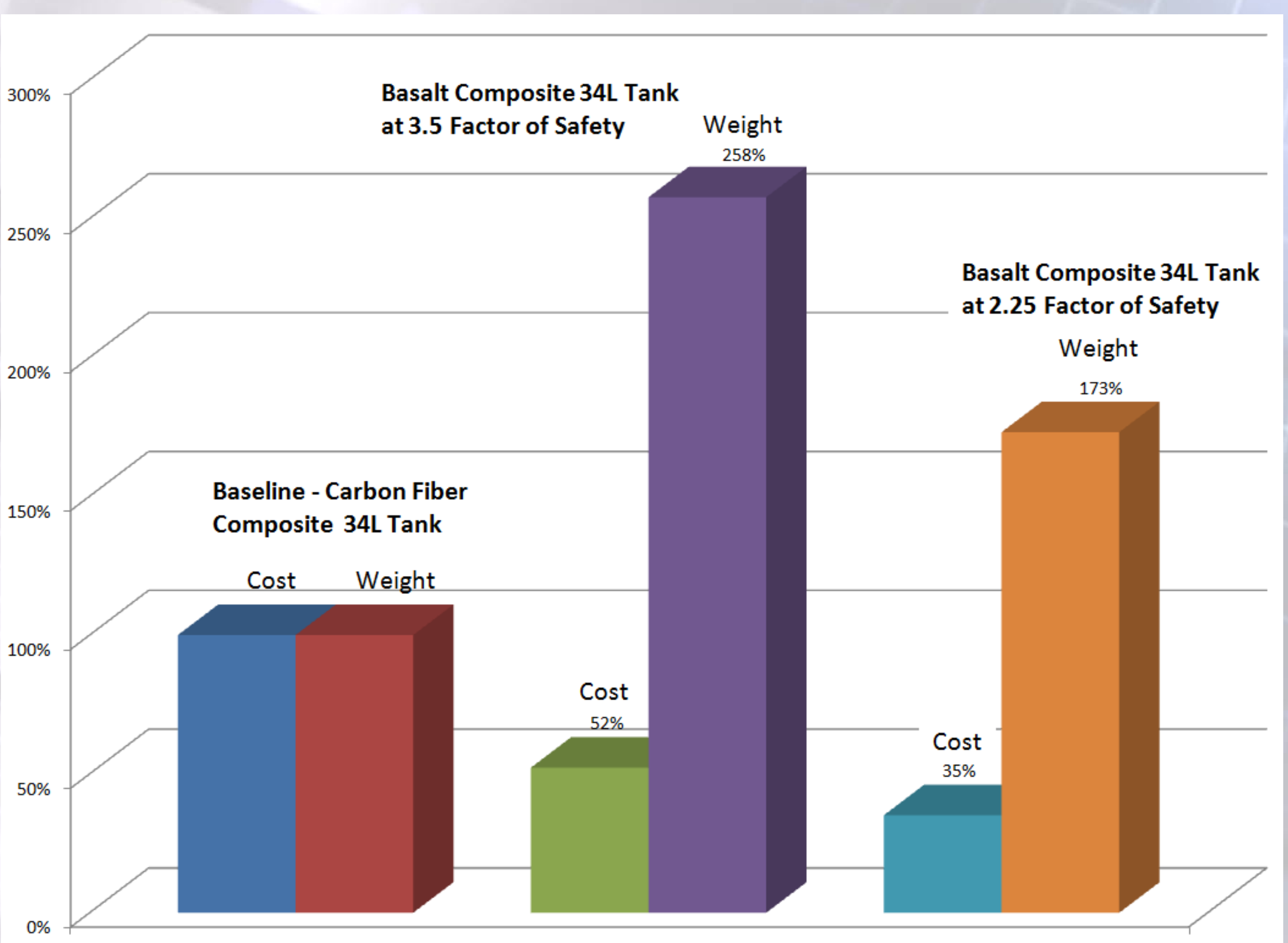
Basalt 34L Tank vs. Carbon 34L Tank



EC79: Carbon fiber safety factor (SF) = 2.25, glass fiber SF = 3.5
2.25 < Basalt SF < 3.5

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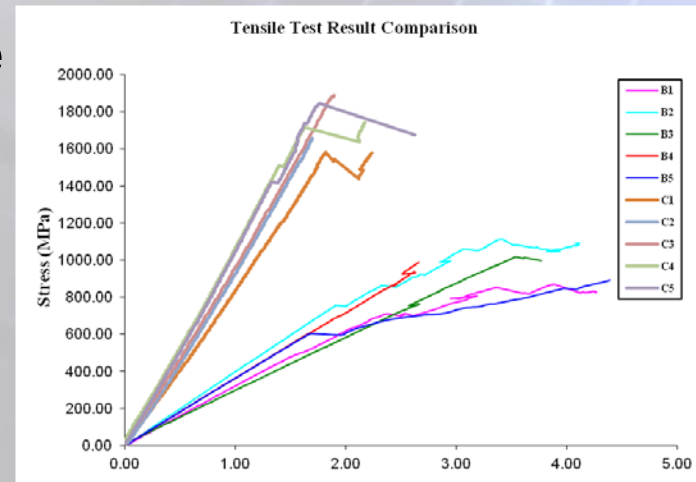
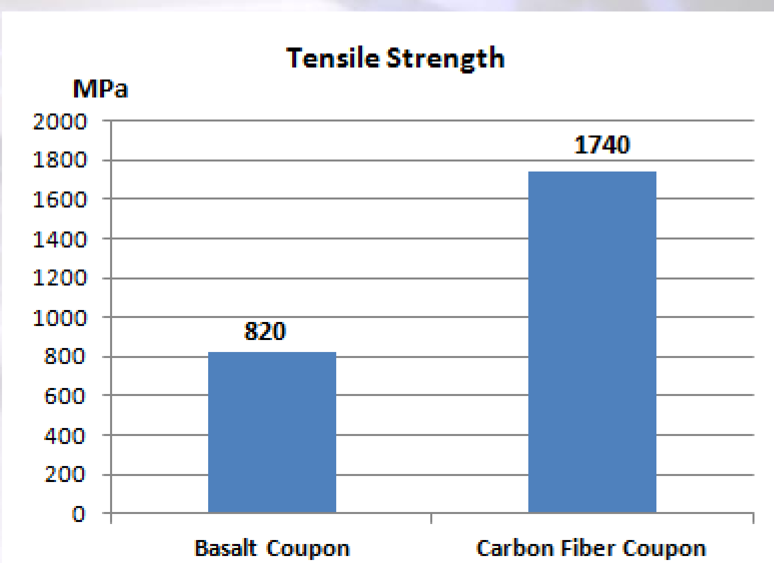
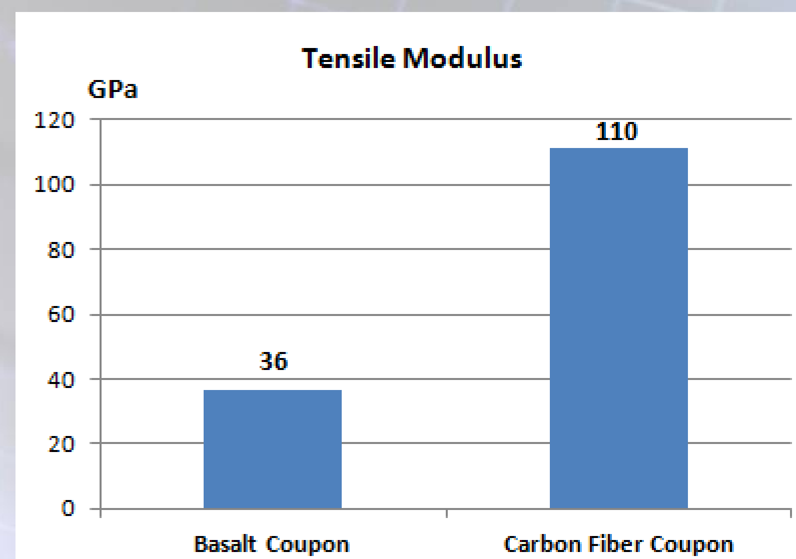
Basalt Composite Unidirectional Tensile Test

- Determine basalt/epoxy composite tensile properties
- Compare with carbon fiber
- Data for basalt tank design







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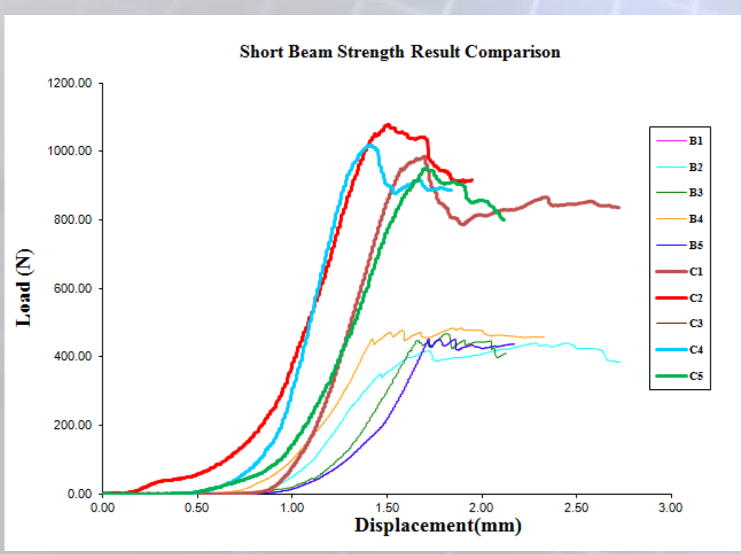
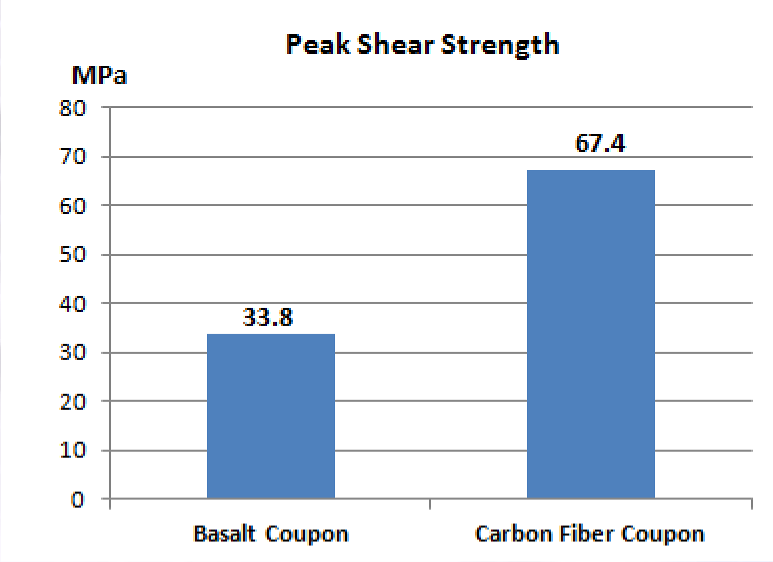
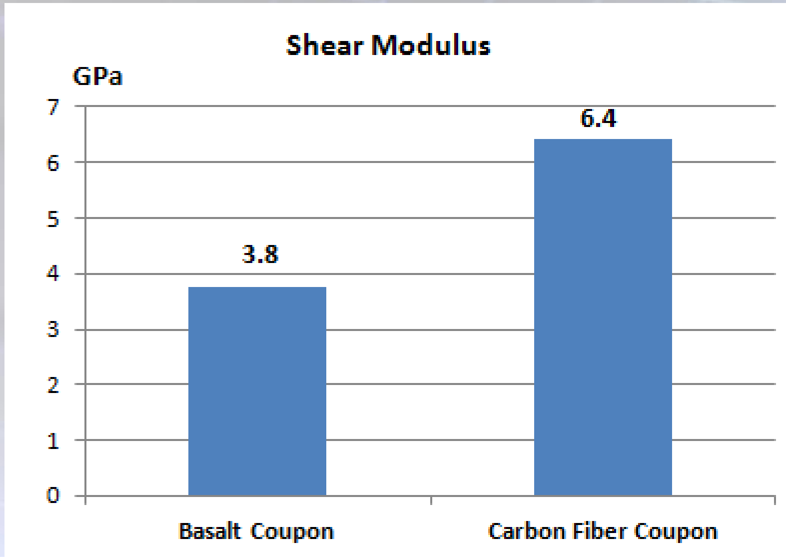
Basalt Composite Short Beam Shear Test

- Determine basalt/epoxy composite shear properties
- Compare with carbon fiber
- Data for basalt tank design







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Basalt 34L 18.6 MPa Tank Burst Test

- Designed Burst Pressure: 43.7 MPa
- Burst at 60.61 MPa

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Basalt 34L 18.6 MPa Tank Environmental Stress Cracking Test

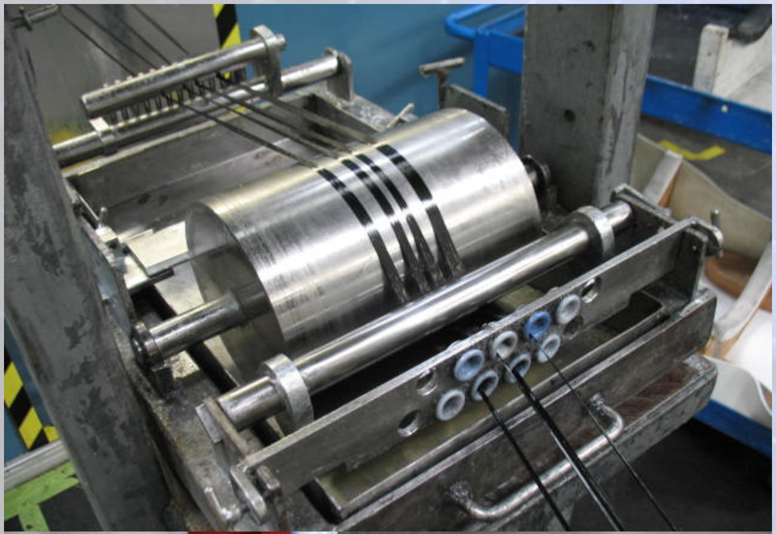
- Pendulum impact (30J) followed by chemical exposure
  - Sulphuric acid – 19% solution by volume in water
  - Sodium hydroxide – 25% solution by volume in water
  - Methanol/Gasoline – 5/95% concentration
  - Ammonium nitrate – 28% solution by volume in water
  - Windshield washer fluid
- Failed at 2714th cycles
- Failed at cylinder section near aft end away from 5 chemical exposure locations
- Chemical nearest failure location
  - Windshield washer fluid
- Possible failure reasons:
  - Improper design safety factor
  - Damage at AFT End during pendulum impact

Phase II Plan

- Determine Proper Design Safety Factor (2.25 to 3.5)
- Develop FEA model
- Optimize winding parameters
- Build 35 MPa (5000 psi) basalt tanks
- Perform standard tests
  - H2 Gas Cycle Test
  - Burst Test
  - Cycle Test
  - Accelerated Stress Rupture
  - Extreme Temperature Cycle Test
  - Composite Flaw Tolerance Test
  - Drop Test
  - Penetration Test
  - Bonfire Test
  - Chemical Exposure Test

Background: Automatic Resin Mixing and Impregnation System - Why It is Important

- Errors may be inadvertently introduced by operators misreading the scales or using the wrong weight values.
- The current impregnation system retains a large amount of resin which is subject to large viscosity changes.
- The rotating drum used in the current impregnation system may introduce micro-bubbles at high filament velocities.
- The uncontrolled ambient temperature of the production area has a great effect on the mixed resin and its viscosity.
- The tension applied to the fiber is also effected by both the fiber velocity and resin viscosity.



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Optimization of Filament Winding Processing

1. Evaluate the selected hardware elements

2. Define the required software concepts and methods

3. Fabricate initial machined components for evaluation

4. Control software development

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Task 1: Evaluate the Selected Hardware Elements

- Brushless three phase servo motors were selected to drive the various pumps and mixers

- A four quadrant motor operation was specified in the original design

- The amplifier and motor combinations were successfully placed into service and tested using their respective RS485 link

- A test was conducted to demonstrate the ability of the scales accuracy and stability, via serial interface

Task 2: Define Required Software Concepts and Methods

- Demonstrated the ability to simultaneously drive and provide real time feedback of a typical mixer using the selected motor amplifier

- Demonstrated the ability to proportionately drive a peristaltic pump using a four quadrant servo control with the real time process variables obtained above

- Demonstrated the ability to incorporate real time operator interface graphics relating the system states and status

- Demonstrated the ability to utilize configuration files which alter the system's mixing and impregnation parameters

- Demonstrated the ability to simultaneously communicate with each of the two balance scales via RS232 serial links

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Task 3: Fabricate Initial Machined Components for Evaluation

- To date, six pump and two mixer assemblies have been fabricated. Illustrated are assembled resin pump and an assembled resin mixer.

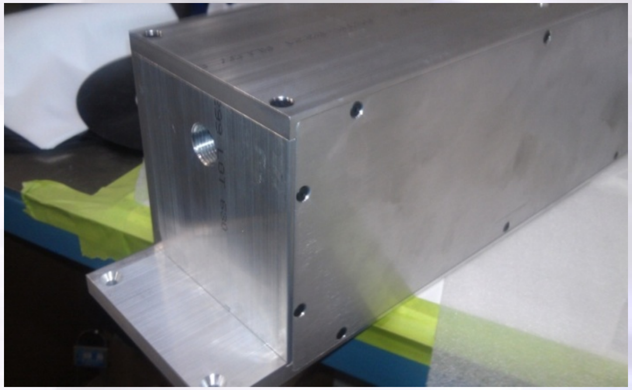

Figure 1: Aft end of an assembled resin pump. The initial assembly provided fit and print check.

Figure 2: Side view of an assembled resin mixer during fit and print check.

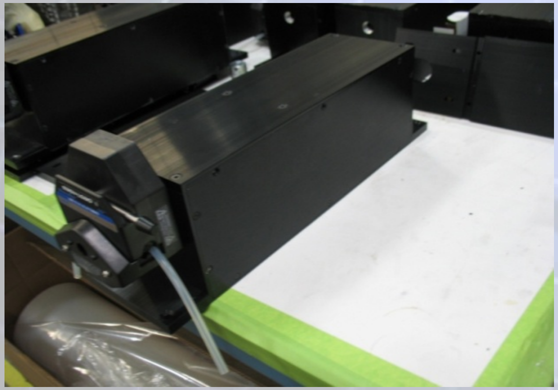

Figure 3: A completed resin pump assembly. The pump assemblies accommodate up to four pump heads which allows up to eight individual pumping tubes.

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Task 4: Control Software Development

- A control program utilizing all the functions and methods mentioned above has been completed
- Both resin mixing and impregnation process will be controlled using one graphics interface screen
- Provisions have been incorporated to allow the inclusion of several CSV data acquisition files of real time process data

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Task 4: Control Software Development

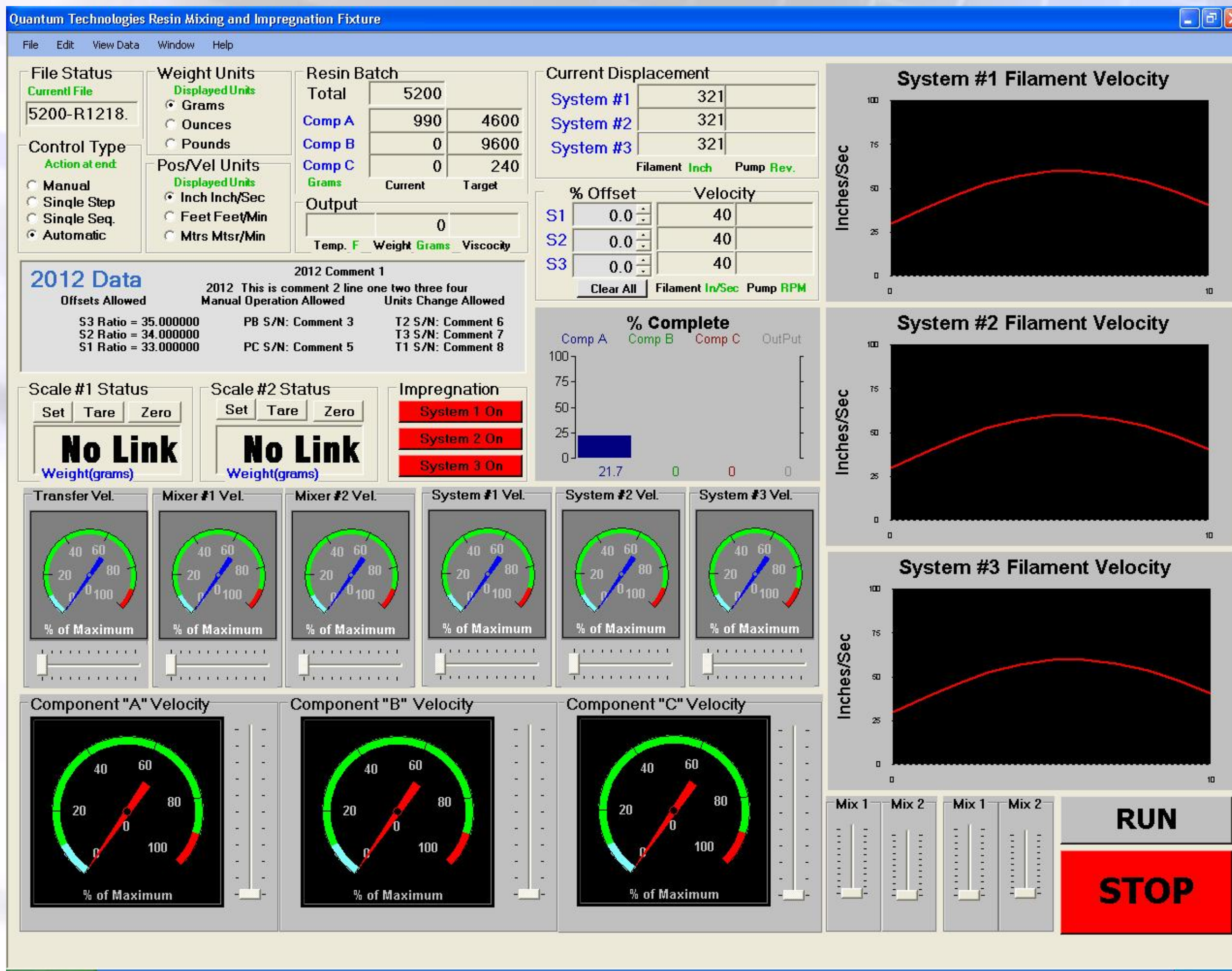

Figure 4: The main graphics screen used for operator interface

Recommendations for Completion of the Overall System

Listed below are items and milestones that are currently planned for future project.

1. Fabricate an impregnation assembly capable of impregnating up to eight tows of fiber simultaneously.

2. Using the newly fabricated resin mixing and impregnation system test and debug the control software.

3. Evaluation of the effects of the variance of the individual components as they relate to the overall accuracy of the system.

4. Evaluate the use of a static mixer in lieu of the batch measurement approach.

5. Evaluate composite structure with new mix and impregnation system

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