EFFECTS OF THE WEAVING PROCESS ON TENSILE STRENGTH DISTRIBUTION OF S2 GLASS FIBER TOWS EXTRACTED FROM DIFFERENT 3D-WOVEN FABRICS

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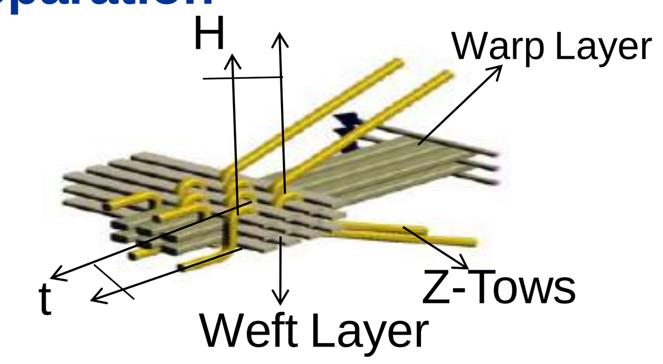
- **Motivations and Concerns**
  - 3D fabrics advantages over 2D fabrics, such as:
    - High interlaminar fracture toughness
    - Tailored 3-D properties (hybridization)
- Tow Damage can occur during weaving process (curvature and abrasion mechanisms)
- **Objectives**
  - Evaluate strength properties of S2-glass fiber tows extracted from different sub-layers of 3D fabrics
  - Identify the degradation mechanisms due to weaving process

Materials and Specimen Preparation

- **Control Samples**
  - S2-glass 1250 (6,104 den)
  - S2-glass 250 (18,040 den)
  - S2-glass 750 (3,614 den)
- **3D S2-Glass Fabrics**
  - 28oz/yd^2
  - 50 50oz/yd^2
  - 100oz/yd^2



Schematic for 3D WEAVE

- **Specimen Preparation**
  - Tows were carefully cut from the spool and carefully extracted from the 3D fabrics without inducing any damage

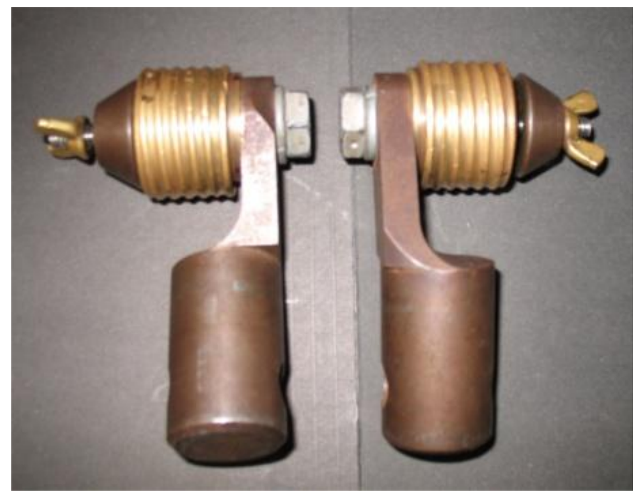
Cutting a strip (1" width) along the warp direction

Removing warp tows from both sides

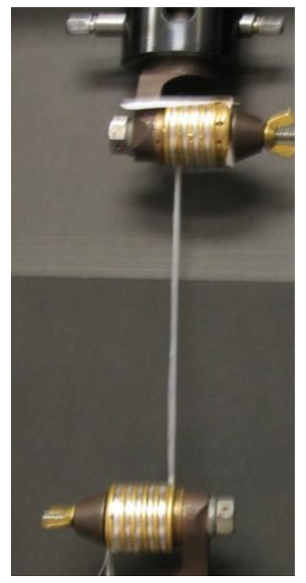
Gentle shaking the strip by hand to collect Z-tows

Experimental

- **Tensile Test**
  - Appling ASTM standard D 2256-02
    - 10-inch gauge length
    - Crosshead speed of 12 inches/minute (304.8 mm/min)
  - Specimens were wrapped around the cylindrical fixture
  - At least 30 samples were tested



Tow cylindrical fixture



Sample during tensile testing

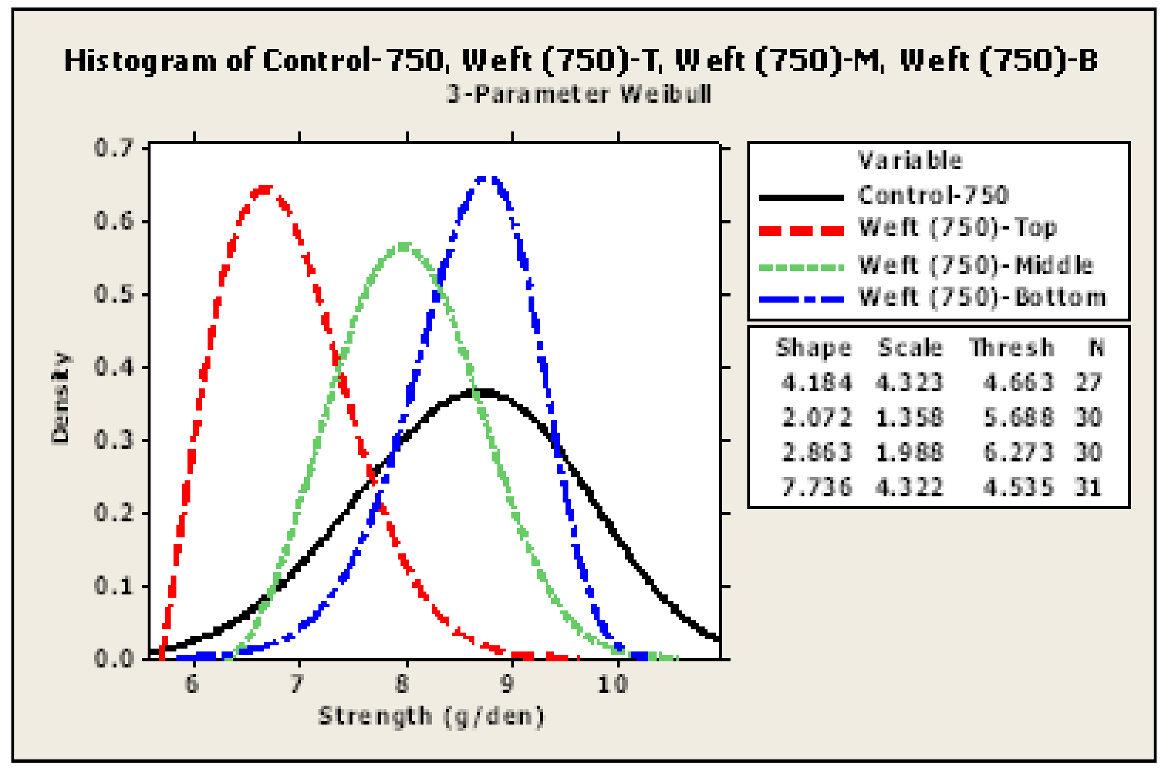
Data Reduction

- **Tensile Strength**
  - From load-displacement data obtained for each product, the strength was calculated as:

$$Strength = \frac{Failure\ Load\ (g)}{LD(den)}$$

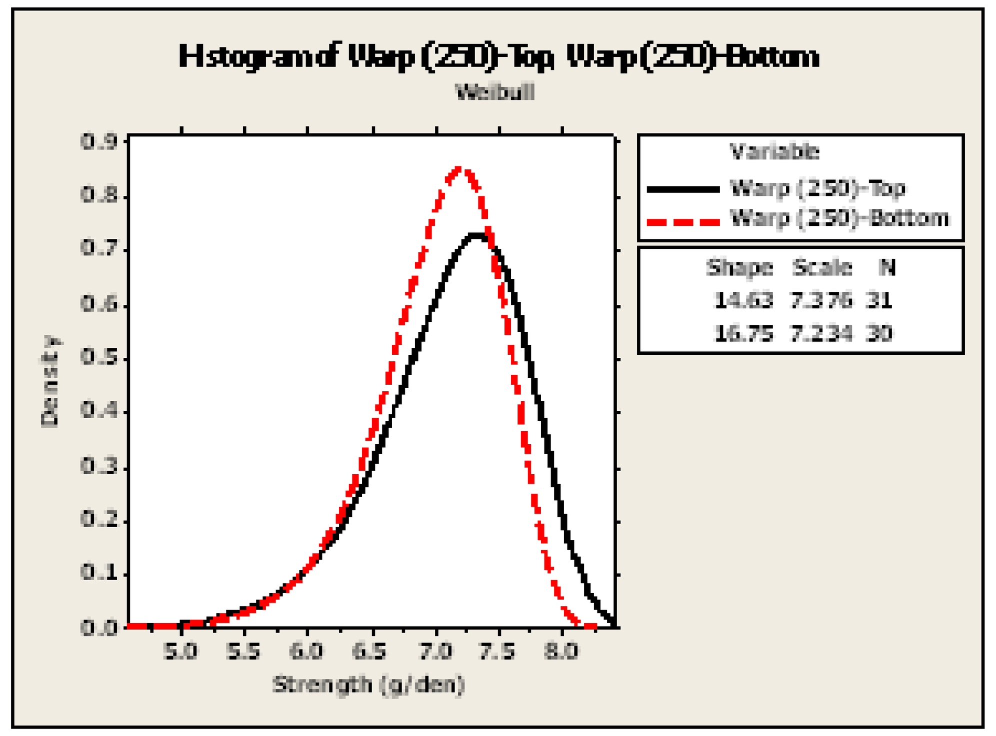
  - Where LD is the average linear density of the tow. Linear density was averaged over 15 specimens
- **Tensile Strength Distribution**
  - MINTAB software was used to reduced the data:
  - Strength distribution
  - Failure probability
  - Retention based on mean strength (Rm)
  - Retention value at 10% and 90% failure probability.

Strength Distribution Results for Weft Sub-layer Tows from 100 oz Fabric



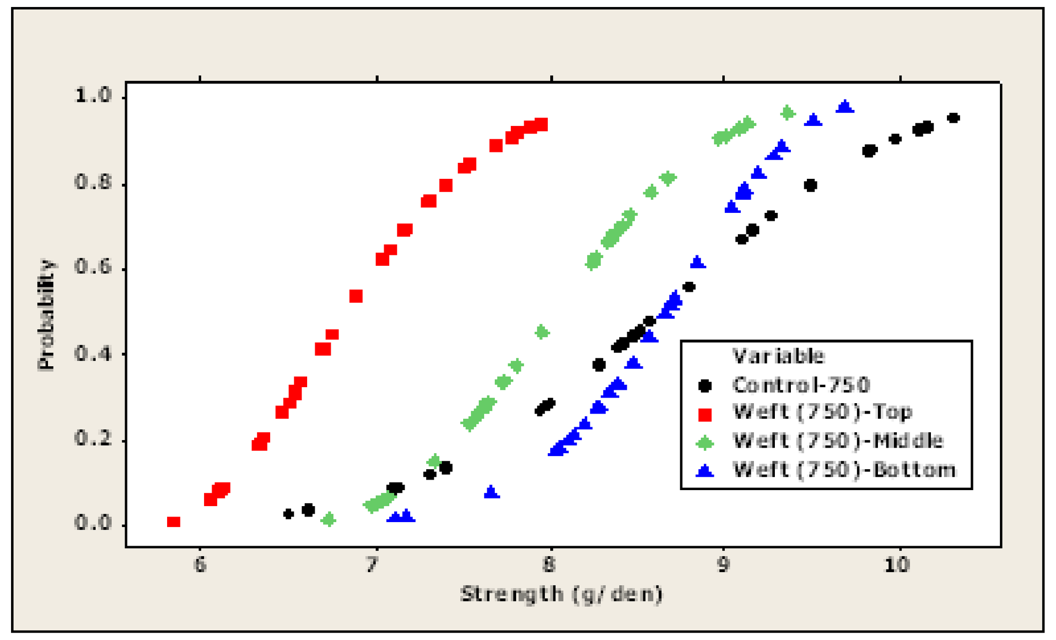
- With respect to control samples, the peak of the distribution in weft tows from 100 oz fabric show shift to lower strength by 24% (for middle sub-layer) and 9% (for top sub-layer)

Strength Distribution Results for Warp Sub-layer Tows from 100 oz Fabric fabric



- With respect to control samples, the peak of the distribution in warp tows from 100 oz fabric decreased to lower strength levels by 14%

Failure Probability Curves for Weft Sub-layer Tows from 100 oz Fabric



- Weft-top tows exhibit the highest failure probabilities for a given strength among all sub-layers
- For tows from weft sub-layers (middle and bottom), the effect of weaving is to narrow the distribution and rotate the probability curve counter clockwise

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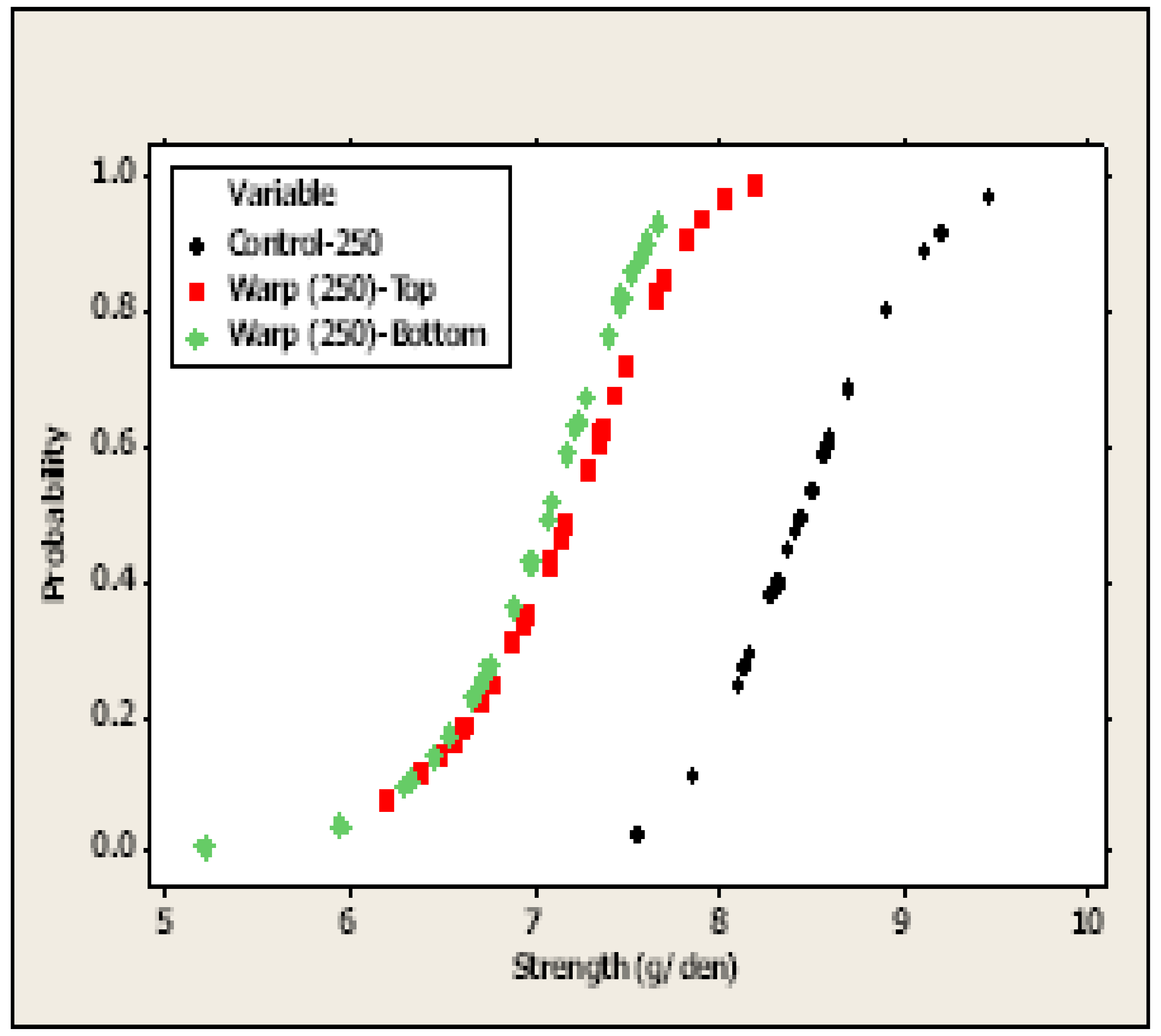
(Continued)

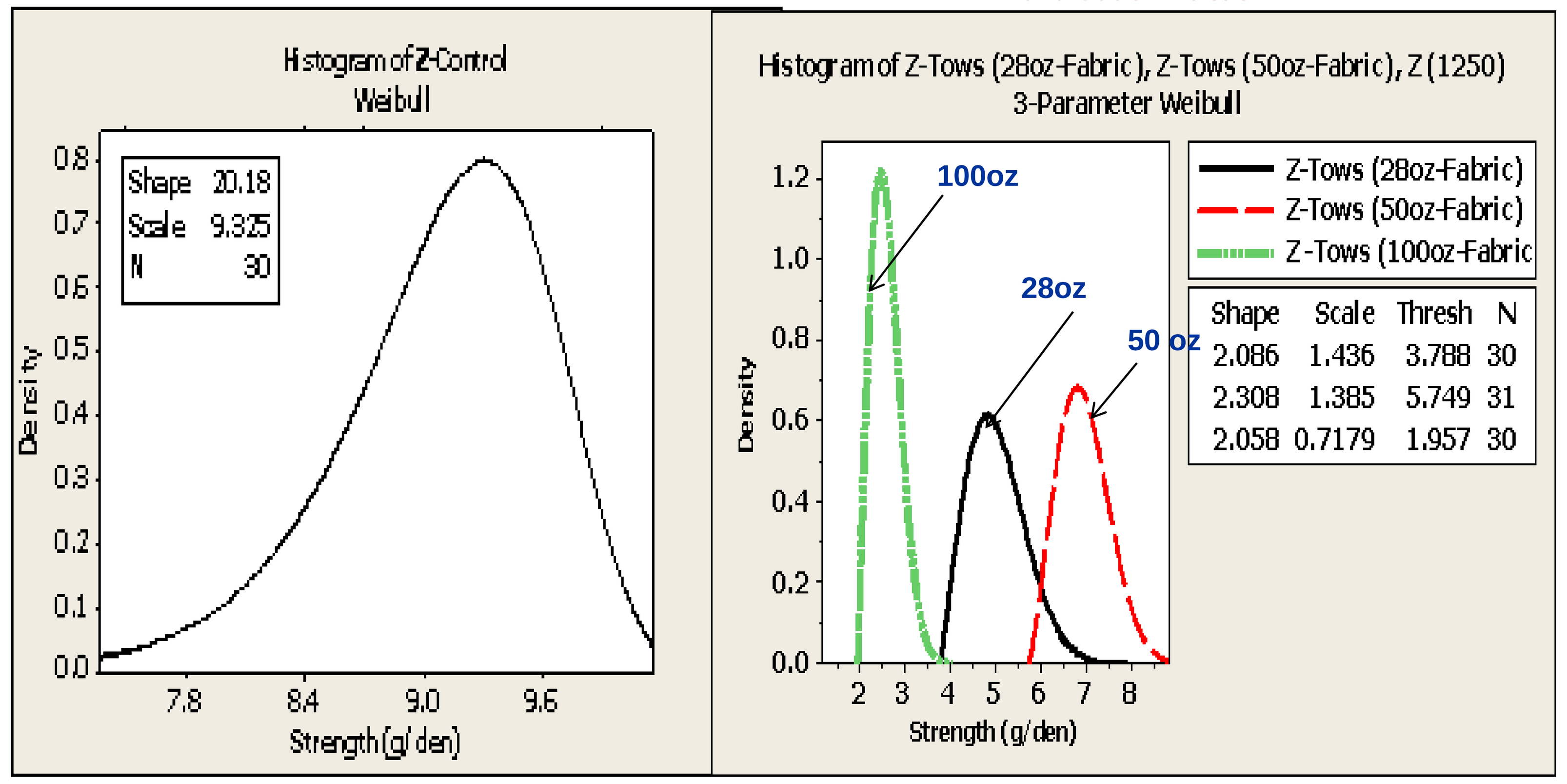
Failure Probability Curves for Warp Tows from 100 oz Fabric



- Warp tows exhibit shifts to lower strength levels, with respect to control
- Insignificant differences between top and bottom tows

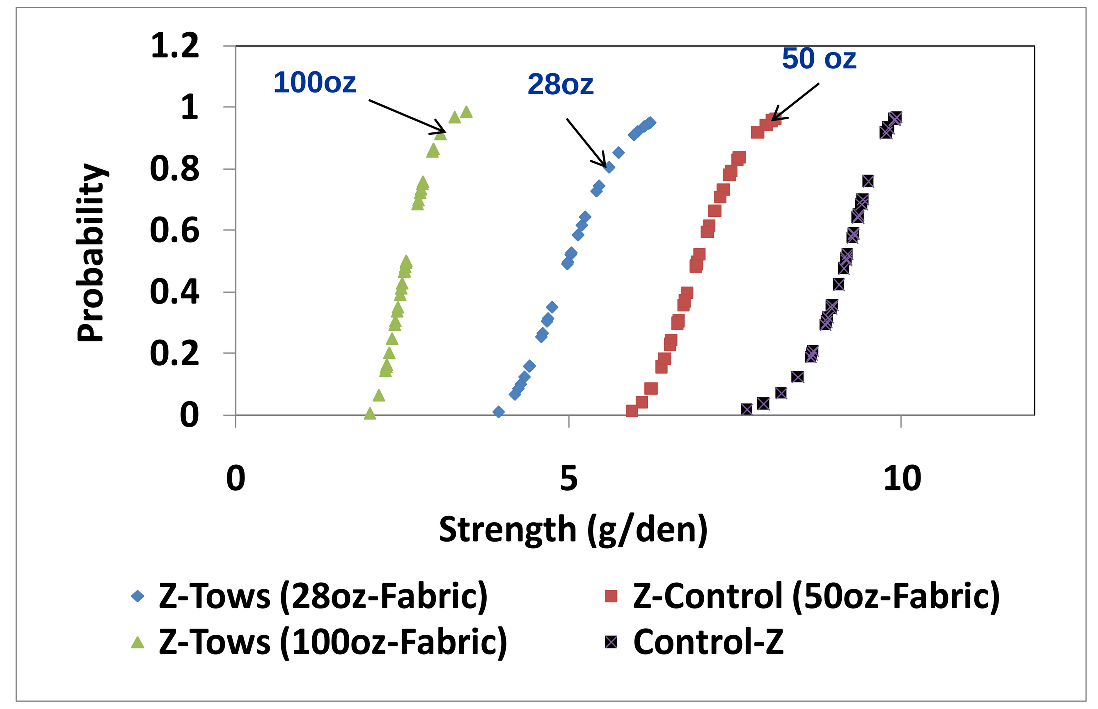
Strength Distribution Results for Z-tows Extracted from Different 3D-Woven Fabrics

Control Tows | Extracted Tows



- With respect to control samples, extracted tows exhibit shift in the peak locations to lower strength levels by 48% , 26% and 73% for the tows extracted from 28, 50 and 100 oz fabric
- Z-tows from 100oz-fabric show significantly narrower distribution than others

Failure Probability Curves for Z-Tows Extracted from 100 oz Fabric



- Z-tows from 100oz fabric show the greatest shifts to lower strengths, with respect to control
- Z-tows from 50oz fabric show the smallest shifts to lower strength levels , with respect to control
- A significant increase in the slope can be obtained for Z-tows from 100 oz fabric

Strength Distribution Results for Z-tows Extracted from Different 3D-Woven Fabrics

	28 oz/yd^2 3D-Fabric	50 oz/yd^2 3D-Fabric	100 oz/yd^2 3D-Fabric
Type	Rm	Rm	Rm
Warp-Top	94%	78%	84%
Warp-Bottom			83%
Weft-Top	92%	95%	80%
Weft-Middle			94%
Weft-Bottom	98%	93%	100%
Z-Tows	56%	77%	29%

- Overall, the retention of strength values for Z-tows are significantly lower than those measured for in sub-layers

Mechanisms of Strength Degradation in Z-Tows

- Measured Strength Degradation Due to the Effects:
  - Curvature
  - Broken fibers
  - Abrasion
  - Other mechanisms and interactions
- D(Total)= D(broken fibers due to curvature & abrasion)+ D(abrasion & other mechanisms)
  - Degradation due to broken fibers was evaluated from elastic modulus measurements on extracted Z-tows
  - Fiber breakage is due to curvature and abrasion
    - Degradation due to curvature of control tows was quantified
  - D: Degradation in Strength=1-Retention

Strength Degradation in Z-Tows Due to Different Mechanisms

S2-Glass Z-Tows	Total Degradation	Curvature-Control	Broken fibers-Insitu (Due to Curvature & Abrasion)	Abrasion/Other Interactions-Insitu (Reduced Strength)
28oz	44%	6%	5%	39%
50oz	32%	10%	12%	20%
100oz	71%	15%	38%	33%

- Overall strength degradation can be ranked as: 100 oz >28 oz > 50 oz
- 28 oz fabric tows show similar level of broken fibers to curvature and the highest percent of abrasion that reduces fiber strength
- 100 oz fabric tows show the highest percent of broken fibers, which is also greater than control and comparable to abrasion levels. Abrasion reduces strength resulting in much higher degree of broken filaments
- 50 oz fabric tows exhibit an intermediate level of abrasion and smilar level of broken fibers to control

Conclusions

- Weaving can degrade dry tow strength (3-D fabrics). Highest degradation in strength was observed in the S2-glass Z tows. Z-tows extracted from 28, 50 and 100oz fabric strength loss of 44%, 31% and 71%, respectively
- Abrasion and fiber breakage mechanisms are the major factors for strength degradation for Z-tows
- The strength retention for impregnated Z tows (66-75%) is significantly higher compared to that measured for dry tows (29-35%).
- Hybridization of 3-D weaves offers opportunity to reduce Z-tow strength reduction

Acknowledgements

The financial support, provided by 3TEX® company this work possible.