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Fiberglass Composite Repairs Presentation

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Fiberglass Composite Repairs

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Composite Overview

- A composite is a material with a matrix (resin) and reinforcement (fibers)
- Concrete/rebar, wood (cellulose fibers and lignin), carbon fiber/epoxy
- Used in a variety of fields:
  airplanes, boats, wind turbine blades, sports equipment

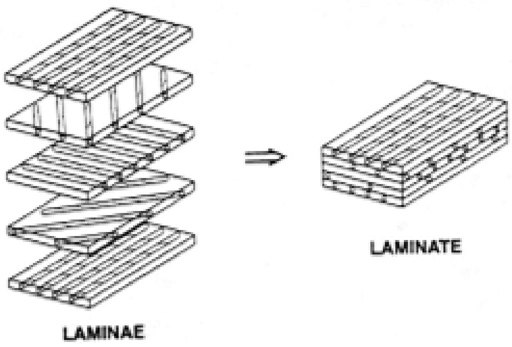

Figure 1. Laminate Composite [1]

Composite Repairs

- Repairs are a necessary part of composite life cycle

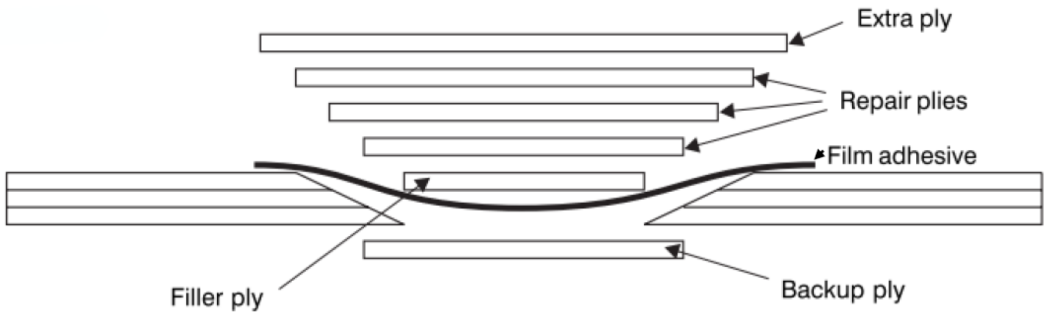

Figure 2. Taper sanded (scarf) repair [2]

Project Overview

Problem: Determination of fiberglass composite repair factors that affect crack propagation fracture toughness.

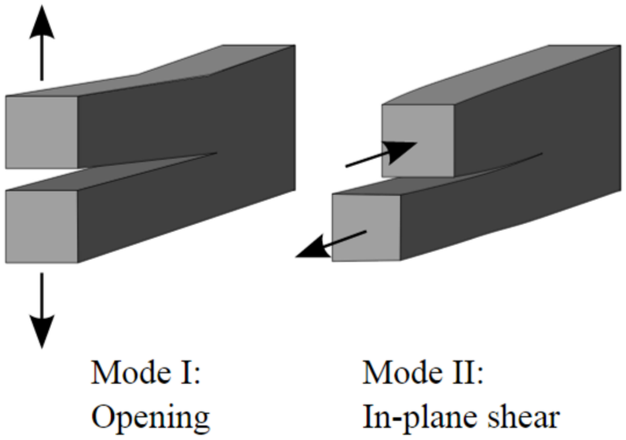

Figure 3. Crack Propagation Modes [3]

Project Objectives

- Factors must have an expected affect on crack propagation fracture toughness
- The testing and manufacturing procedure should be repeatable
- The testing apparatus and equipment must be able to effectively monitor crack growth
- The testing procedure should replicate conditions the repairs will experience in use
- The materials and equipment used will be those that are available from the PET lab
- The cost for materials and equipment required for the study should be minimized
- Wear on lab equipment should be minimized

Project Design

- Factors: resin, grinding depth, and chopped strand mat
- Testing under ASTM D6671 Mixed Mode Testing
- Three mode mixture ratios, 5 specimens each, total of 120 specimens
- Total mixed-mode fracture toughness (G_C) would be calculated

Table 1. 2^3 Factorial Design

Run #	Coded Factor Levels			Uncoded		
				Grind depth	Resin	Chopped Strand Mat
1	-	-	-	half	Polyester	No CSM
2	-	-	+	half	Polyester	CSM
3	-	+	-	half	Vinylester	No CSM
4	-	+	+	half	Vinylester	CSM
5	+	-	-	full	Polyester	No CSM
6	+	-	+	full	Polyester	CSM
7	+	+	-	full	Vinylester	No CSM
8	+	+	+	full	Vinylester	CSM

Parent Plates

- Plates were manufactured using Vacuum Assisted Resin Transfer Method

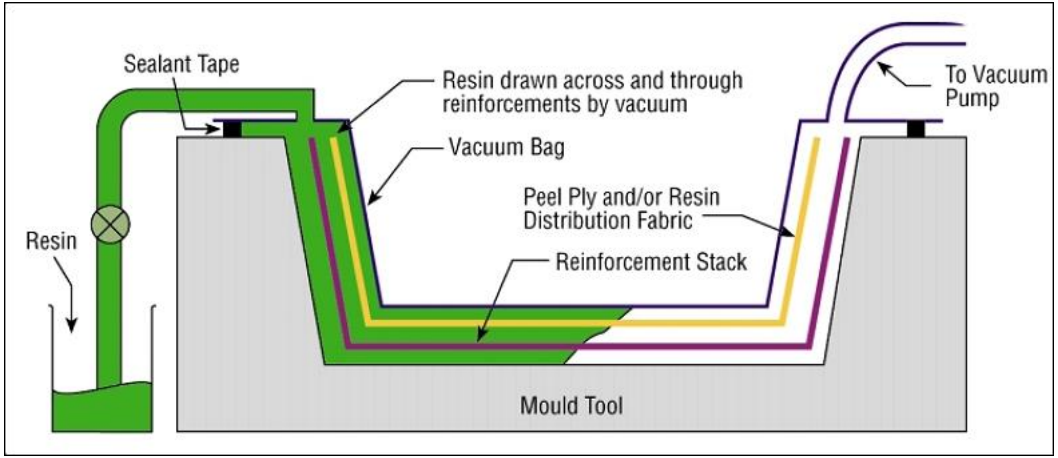

Figure 4. VARTM Diagram [4]

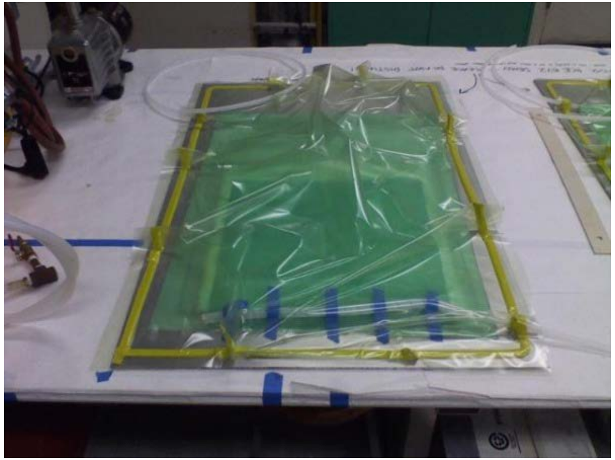

Figure 5. VARTM Setup

Grinding

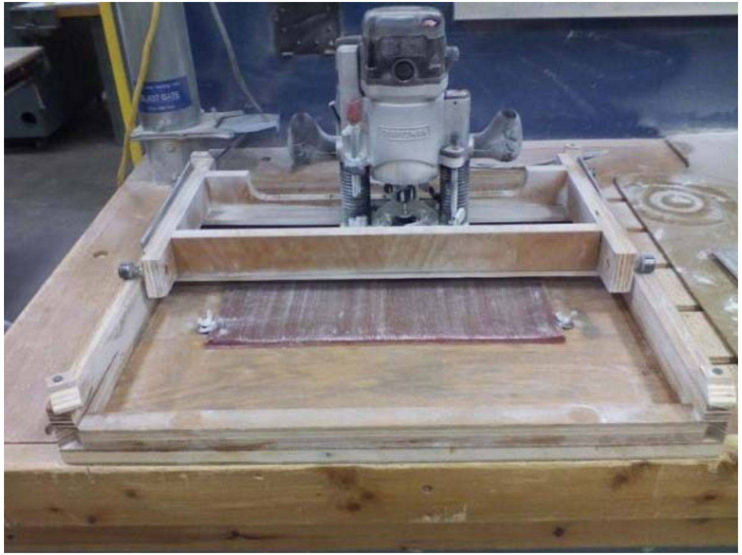

Figure 6. Grinding Setup

- Table frequently got stuck
- Grind depth would surpass router setting
- Table deflected in the middle
- Table accommodated 15.75” plates
- Relied on visual cues

Figure 7. Full (left) vs half grind (right) surfaces

Hand Lay up

- Clean surface of plate with stiff resin brush
- Place 7.5cm crack initiation insert 7.5cm from edge
- polyester - general purpose orthophthalic resin from jabberwocky composites llc (B and J fiberglass)
- vinyl ester - hydrex 100 from fiberglass supply

Figure 8. Cleaning plate surface

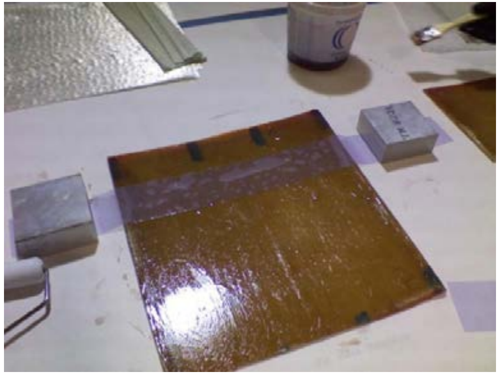

Figure 9. Crack Initiation Insert

Hand Lay up

- Place chopped strand mat
- Five 16x16” uni-directional fiberglass sheet
- One triaxial fiberglass on top
- Cure for 24 hours, post cure for 16 hours at 40 °C

Figure 10. Foam roller for resin

Figure 11. Metal roller for smoothing sheets

Specimen Preparation

Figure 12. Cutting out specimens

- Table saw did not cut straight, laser alignment was off
- Difficult to cut hinges straight

Figure 13. Cutting out hinges

Specimen Preparation

- Hinges were grinded, and teflon tape was added to allow consistent/even adhesive bonding surface
- Specimens were marked with white out and marked with fine tip ink pen marks to aid crack propagation/displacement measuring
- Hinges were adhered with methacrylate adhesive (Plexus MA300)

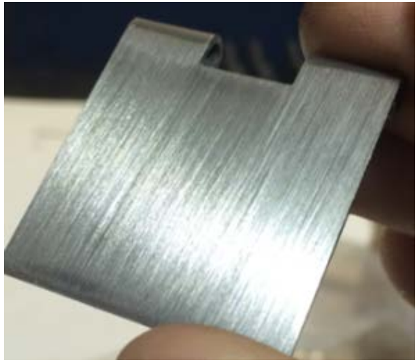

Figure 14. Roughed hinge surface

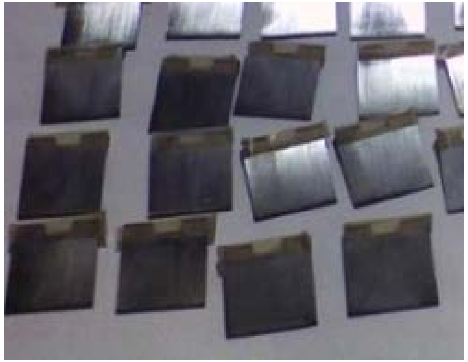

Figure 15. Teflon tape on hinges

Figure 16. Hinge held by clamp

Testing

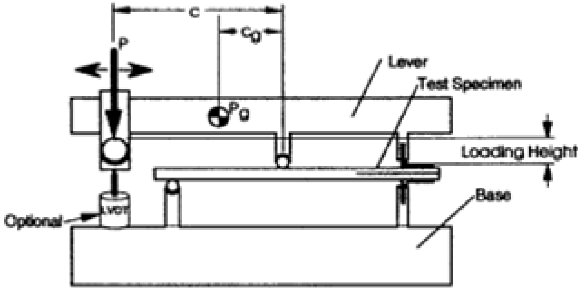

Figure 17. MMB testing apparatus [5]

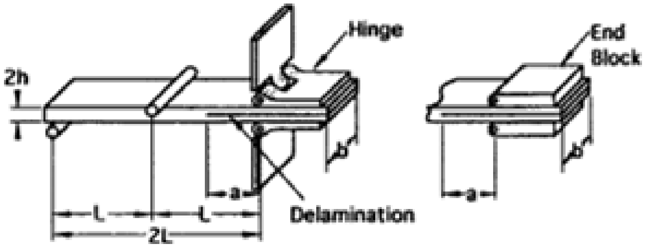

Figure 18. Specimen variables [5]

$$c = \frac{12\beta^2+3\alpha+8\beta\sqrt{3\alpha}}{36\beta^2-3\alpha}L \qquad \alpha = \frac{1-\frac{G_{II}}{G}}{\frac{G_{II}}{G}} \qquad \beta = \frac{a+\chi h}{a+0.42\chi h}$$

$$\chi \equiv \sqrt{\frac{E_{11}}{11G_{13}}\left\{3-2\left(\frac{\Gamma}{1+\Gamma}\right)^2\right\}} \qquad \Gamma = 1.18\frac{\sqrt{E_{11}E_{22}}}{G_{13}}$$

$$E_{1f} = \frac{8(a_0+\chi h)^3(3c-L)^2+\left[6(a_0+0.42\chi h)^3+4L^3\right](c+L)^2}{16L^2bh^3\left(\frac{1}{m}-C_{sys}\right)}$$

$$G_I = \frac{12P^2(3c-L)^2}{16b^2h^3L^2E_{1f}}(a+\chi h)^2 \qquad G_{II} = \frac{9P^2(c+L)^2}{16b^2h^3L^2E_{1f}}(a+0.42\chi h)^2$$

$$G = G_I + G_{II} \qquad \frac{G_{II}}{G} = \frac{G_{II}}{G_I+G_{II}}$$

Figure 18. Calculation equations [5]

Testing

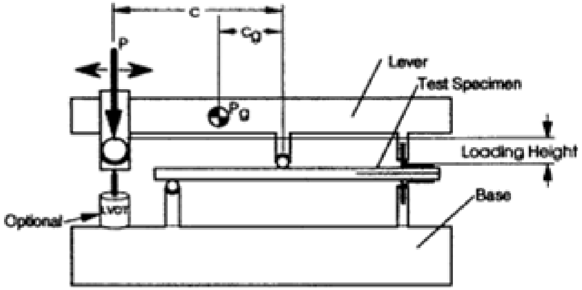

Figure 17. MMB testing apparatus [5]

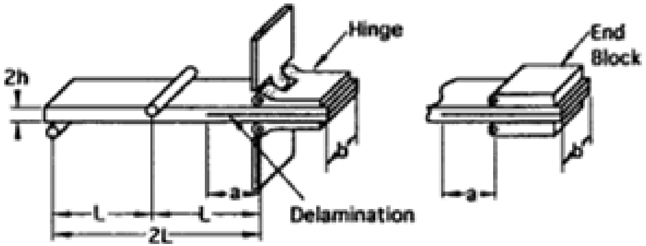

Figure 18. Specimen variables [5]

Variables recorded during testing:

a (mm): delamination length
P (Newtons): applied load
d (mm): opening displacement

Other variables:
b (mm): specimen width
h (mm): specimen half thickness
d (mm): opening displacement
m (N/mm): slope of load displacement curve
L (mm): half span length
C (mm): lever length

Testing

- Dinocapture 2.0 software with Dino-Lite Edge Digital usb microscope to capture crack propagation
- Vicsnap/Vic2d software with digital camera used to capture opening displacement
- Applied load measured with MTS Sintech 5/GL Testworks 4 software

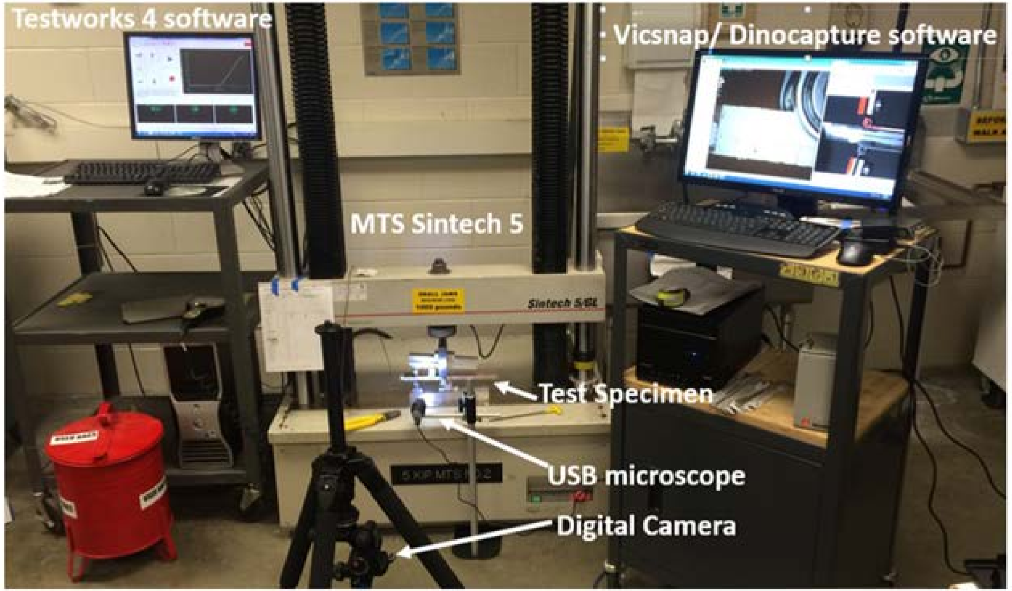

Figure 19. Testing setup

Testing

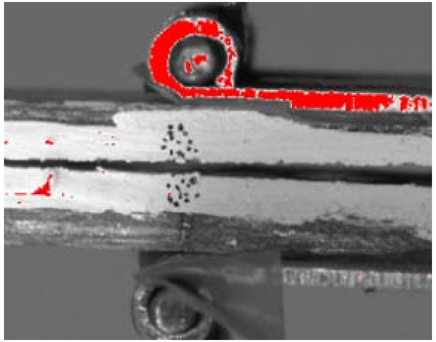

Figure 20. Load point deflection

Figure 21. Crack length

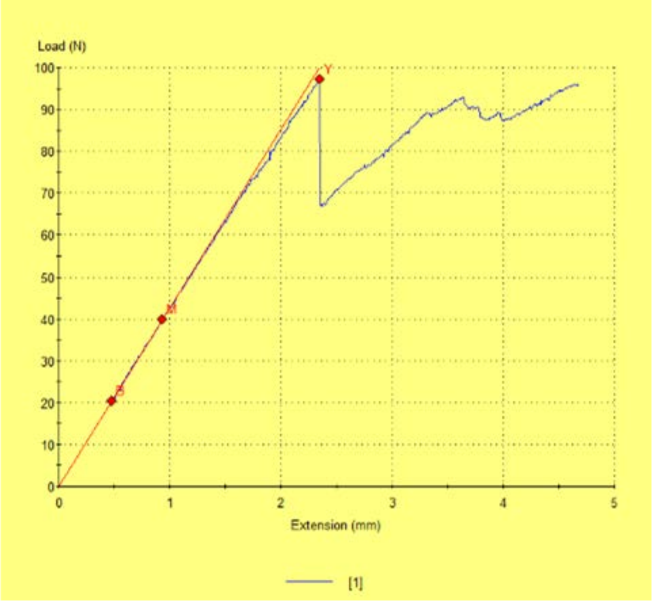

Figure 22. Applied load

Calculating variable m

- Digital camera was set to record one image every .5 seconds
- MTS measured applied load every half second

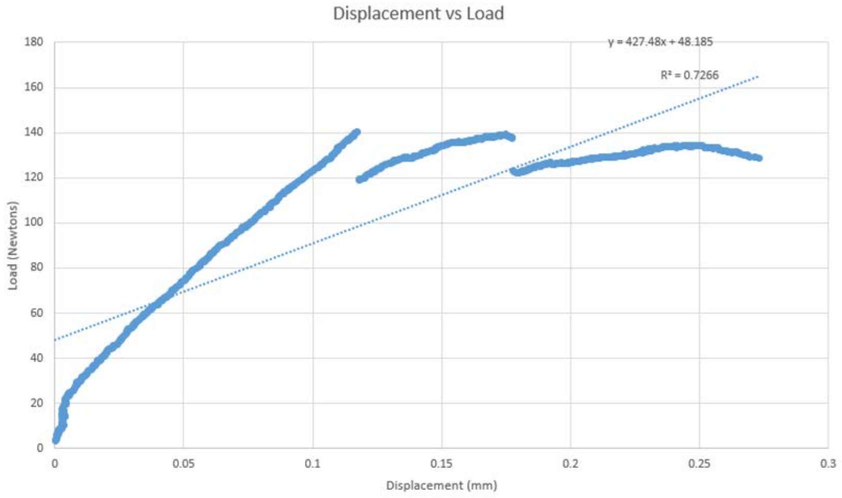

Figure 23. Raw load vs displacement data

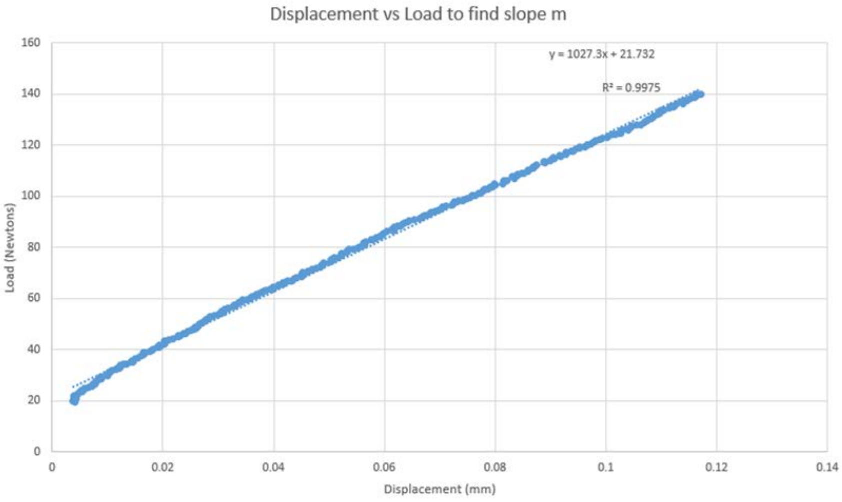

Figure 24. Refocused graph to determine slope of linear region (N/mm)

Calculating Crack Propagation & Loads

- Import MTS Data
- Sync Video & Load
- Record loads & corresponding crack propagations

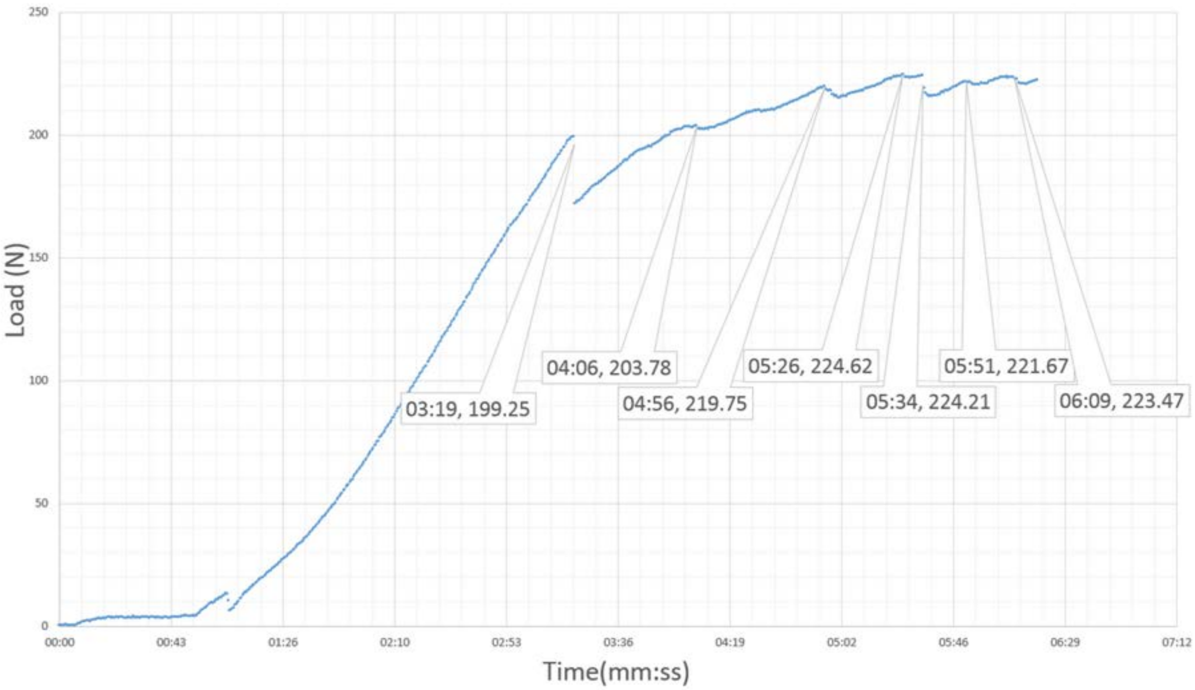

Figure 25. Load vs time graph

Results

- Only significant results were obtained with .2 Mode Mixture (High mode 1 - Tensile Load)
- Specimens at .5 and .8 either broke the hinges before the crack propagated, or propagated too quickly

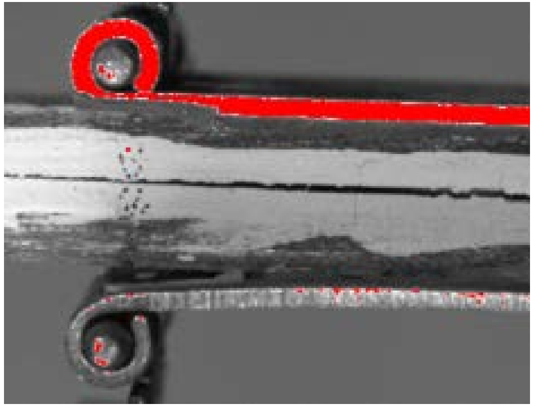

Figure 26. Hinge right before breaking

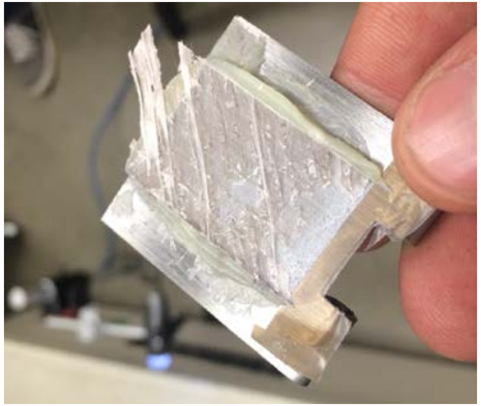

Figure 27. Broken Hinge

Results Overview

Table 2. Specimen Average Gc (Fracture Toughness) Value at .2 Mode Mixture*

Factor	Gc	%Increase
Full Grind	7.728	31%
Half Grind	10.126	
Polyester	7.604	35%
Vinyl Ester	10.253	
No CSM	6.515	74%
CSM	11.344	

*Values have been normalized.

Analysis - Grinding

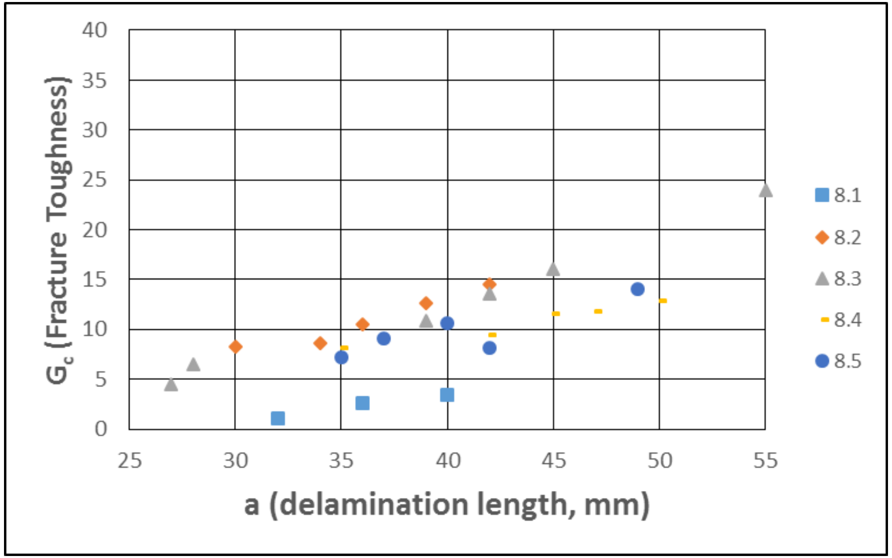

Figure 28. Plate 8 (**full grind**, csm, vinyl ester)*

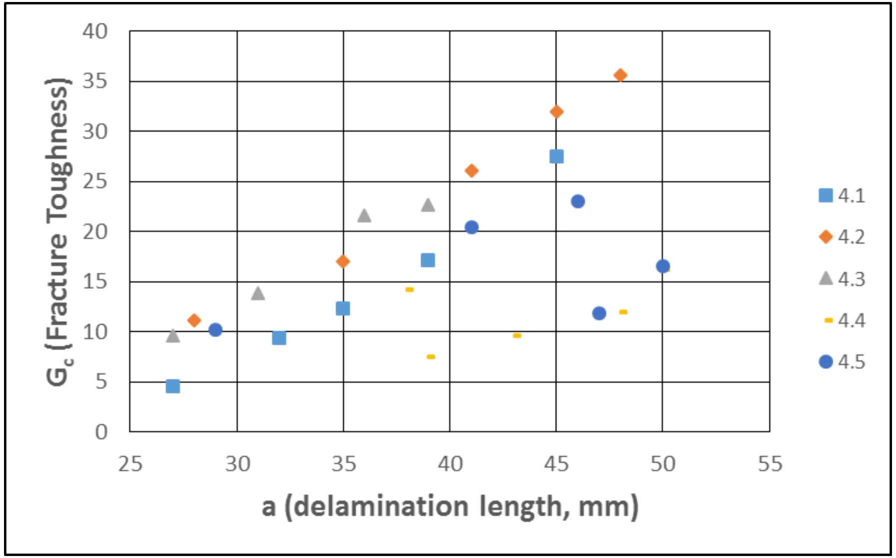

Figure 29. Plate 4 (½ **grind**, csm, vinyl ester)*

*Values have been normalized.

Analysis - Resin

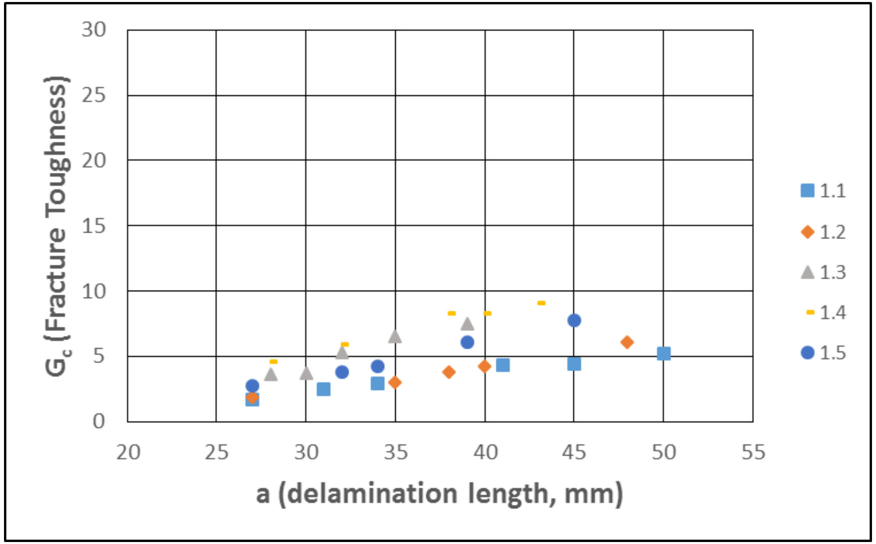

Figure 30. Plate 1 (½ grind, **polyester,** no csm)*

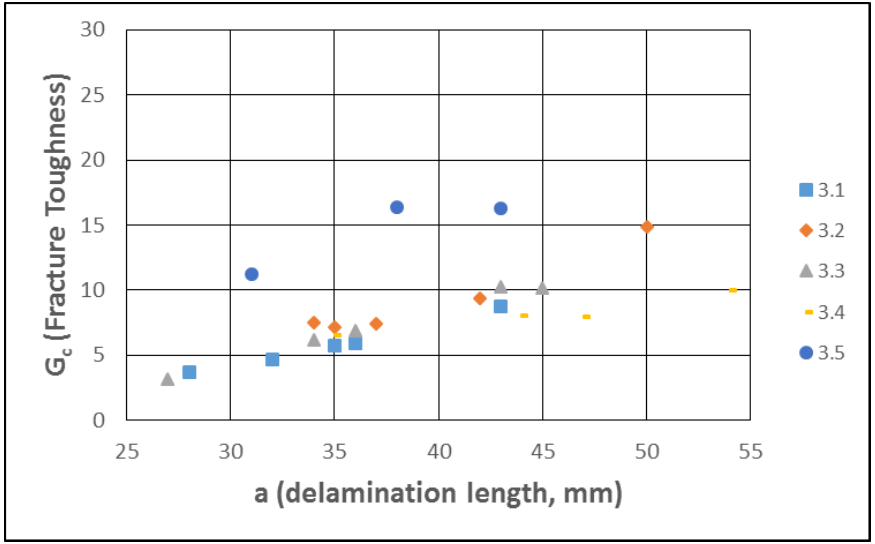

Figure 31. Plate 3 (½ grind, **vinylester**, no csm)*

*Values have been normalized.

Analysis - Chopped Strand Mat

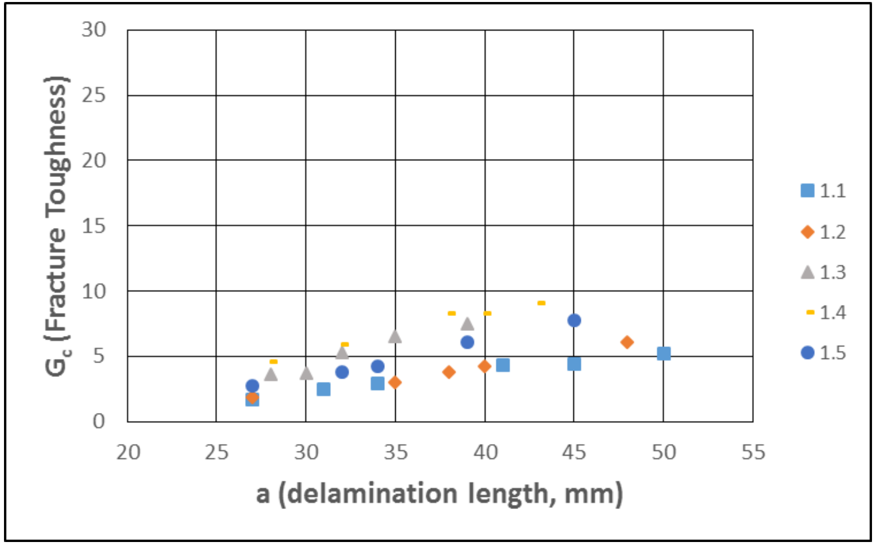

Figure 32. Plate 1 (½ grind, polyester, **no csm**)*

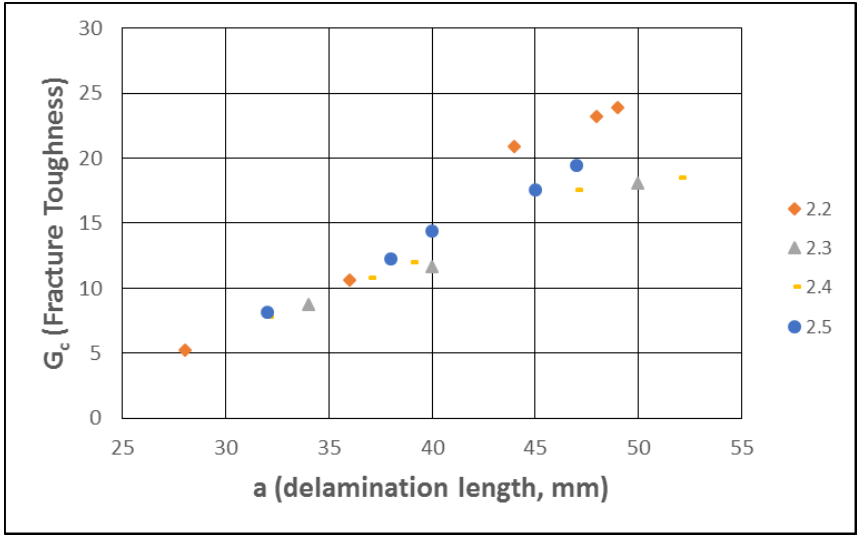

Figure 33. Plate 2 (½ grind, polyester, **csm**)*

*Values have been normalized.

Reason for Results

- Factors increased the amount of fiber bridging

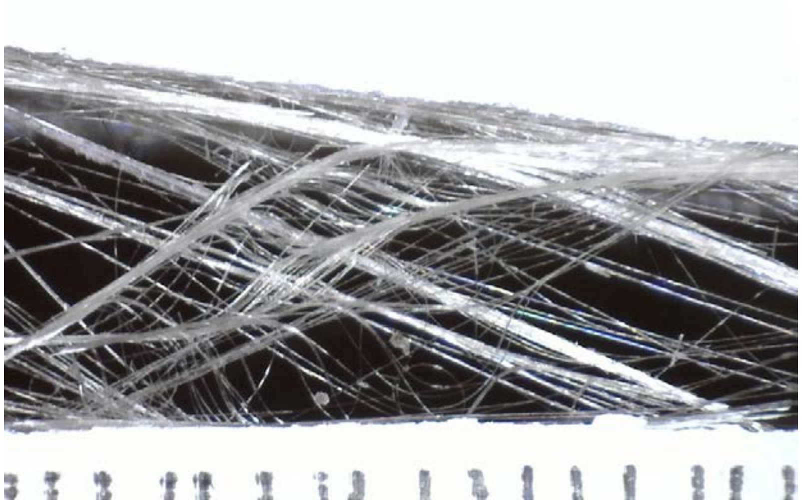
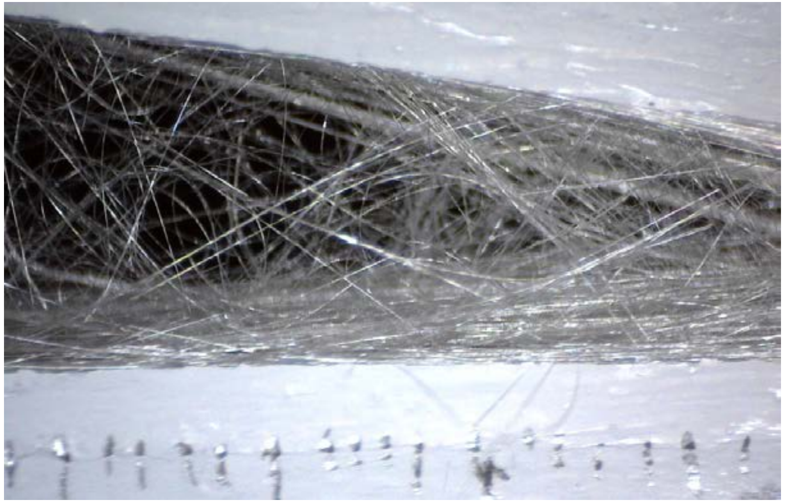

Figure 34. Fiber bridging in Plate 5 (full grind, polyester) vs Plate 3 (½ grind, vinyl ester)

Future Recommendations

Plate manufacturing

- Less thick specimens, in order to test modes .5 and .8 without breaking specimen hinge

Grinding

- More consistent process, change apparatus so it doesn't deflect

Hinges

- Less teflon tape, although allowed smoother adhesion, didn't provide bond strength in critical area at load point, where hinges failed
- Stronger hinge adhesion, either resin or surface preparation of specimens

Specimen Prep

- Straighter cutting device, such as the water jet
- Wider specimens, help improve bonding surface area between hinges and specimens
- Less white out, make sure it does not flake
- More speckles at load point to allow for easier Vic 2d analysis

Future Recommendations

Testing

- Use calibration with mts to measure displacement, more consistent strategy and a lot less time consuming than vic 2d analysis
- Better way to sync different measurements systems
- Take pictures rather than video of crack propagation

Analysis

- Use a better video playback software

Conclusion

Shortfallings

- Used more materials than expected - exceeded budget estimate
- Were not able to collect significant data on Mode Mixtures .5 and .8

Successes

- Equipment used was able to effectively monitor crack growth
- All factors chosen had significant results in Mode Mixture .2, with the use of a chopped strand mat being the most prominent
- No damaged tools/lab equipment

Acknowledgements

I would like to thank Michael Airoldi and David Frye for their consistent help while working in the plastics labs.

This project could not have been completed without the guidance of my sponsor Tanveer Chawla.

References

[1] FAO. "Composites." Application of Natural Fibre Composites in the Development of Rural Societies. N.p., 2015. Web. 12 May 2015. <http://www.fao.org/docrep/007/ad416e/ad416e05.htm>.
[2] Hexcel Composites, Composite Repair. Publication No. UTC 102, April 1999
[3] "Fracture Modes." Wikimedia Commons. N.p., 21 Jan. 2008. Web. 12 May 2015. <http://commons.wikimedia.org/wiki/File:Fracture_modes_v2.svg>.
[4] "Complete Guide to Composites, Part 6." AutoSpeed Articles RSS. N.p., n.d. Web. 19 May 2015. <http://www.autospeed.com/cms/article.html?&title=Complete-Guide-to-Composites-Part-6&A=108698>.
[5] ASTM D6671 / D6671M-13, Standard Test Method for Mixed Mode I-Mode II Interlaminar Fracture Toughness of Unidirectional Fiber Reinforced Polymer Matrix Composites, ASTM International, West Conshohocken, PA, 2013

Questions?