EXAMINATION OF THE SIZE EFFECT ON STRENGTH IN A HEMP FABRIC COMPOSITE

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ABSTRACT

The variation of strength in tension and flexural test specimens for composites containing glass or carbon fiber is well documented in the literature [1]. While holding the fraction of fiber content constant and scaling up the test specimen size, research has indicated a significant diminishing in tensile and flexural strength in unidirectional fibrous composites [2]. The size effect states that for fibrous composites there is distinct reduction of tensile strength as the net cross-section of a beam in 4-point bending is increasing. Size effects are important from a fundamental point of view in understanding failure. They are also important in a practical sense since tests to establish values of material strength are normally performed on relatively small specimens. As very little is known concerning the size effect for composites bearing the natural fibers this research will show a correlation in data to a discernible reduction in tensile strength for a given size in a structural member. The multifunctional attributes are show in the mechanical connection of the large samples where steel imbedded in the material does not increase its sensitivity to strain.

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1. INTRODUCTION

At the advent of World War II, Henry Ford working from the Ford Nutritional Laboratory in Dearborn Michigan, for the development of agriculturally derived products, brought to the automotive industry, with the assistance of George Washington Carver, a method to turn soybeans into plastics and combined with Biobased filaments such as hemp fibers, produced the first composite vehicle of north America. Working together, Ford and Carver in a shared commitment to the development of advanced materials for the use in building cars, while deriving the fuels to power them, with all the materials adapted from the agricultural domain.

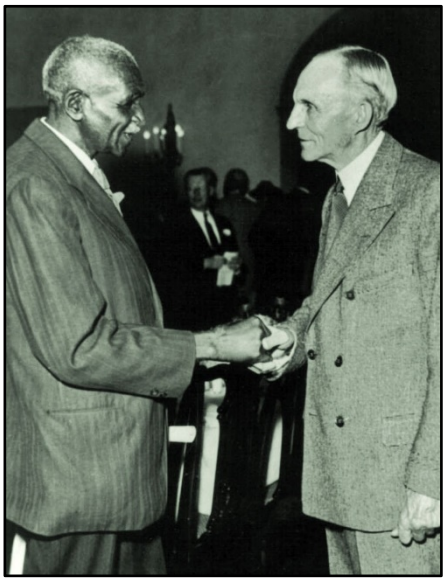


*Figure 1: Henry Ford & George Washington Carver Collaborating on Soybean Plastics**Invalid source specified.**.*

The experiments resulted in the creation of a soybean "plastic-bodied car." Ford eventually unveiled the "Soybean Car" on August 13, 1941 at Dearborn Days, an annual community festival.



Figure 2: Soy Bean Lab [2].

The outbreak of World War II and the suspension of automobile production forced Ford to abandon his efforts to mass-produce plastic car bodies. Until 1943, however, he maintained that he would build them as soon as the war was over, even though engineers had run into problems; the plastic ended up costing much more than steel because the panels took a long time to cure in their molds.

Ford died in 1946 and, according to the Ford Motor Company, the idea just seems to have gotten lost in the files (*Atlanta Journal and Constitution* 1973) [3].

The research reflected in this paper builds on the pioneering work of these dedicated men to the discovery of products made in sustainable materials. This effort will show that a composite derived from the combination of woven hemp fabric casted in a matrix of epoxy resin will show strength variation which is dependent on the size of the sample tested. The data collected during this experiment in tensile strength of sample composites will be evaluated using the Weibull distribution method.

2. EXPERIMENTATION

2.1 Materials & Testing Methods

The woven hemp fabric was supplied by the Rawganique Company as a product that was not produced in any sweatshop facility from USA, Canada and Europe. Furthermore there was no animal testing in connection of this material and it is free of GMO, PVC, dioxin, formaldehyde, acids, and other industrial chemicals commonly used in manufacturing. The fabric is referred to as HWC2, a canvas like consistence and weight.

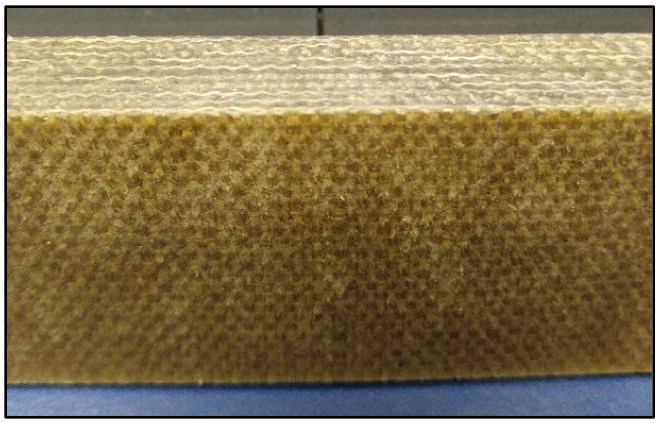


Figure 3: What is this?



Figure 4: Is the Ruler Backward?

The epoxy used in this assembly is the West system with 105 resin and the 205 hardener produced by the Gougeon Brother, Inc. of Bay City, Michigan.



Figure 5: Epoxy Components.

Every sample was constructed so that the warp of the fabric will see the tensile load during testing and each layer will be parallel with the others. No pretreatment was done to the fabric prior to layup. All work in preparation of the samples was performed at Tulane Engineering consultants in Taylor, Michigan. The shape for each sample was hand shaped with the aid of a template that could be resized for each sample required. The cutting was with carbide tools only and no refinishing of cut surface was done.


Figure 6: Carbide cutting tool.

The volume for each layer count was measured by sandwiching the number of required layers together under the weight of an aluminum platen then this size was reproduced as a regulator frame during vacuum forming.


Figure 7: Regulator Frame with Escape channels.

The individual layers were saturated prior to lay-up than the excess amount of epoxy was drawn from the clamping fixture under a vacuum force of 10 inches of mercury.

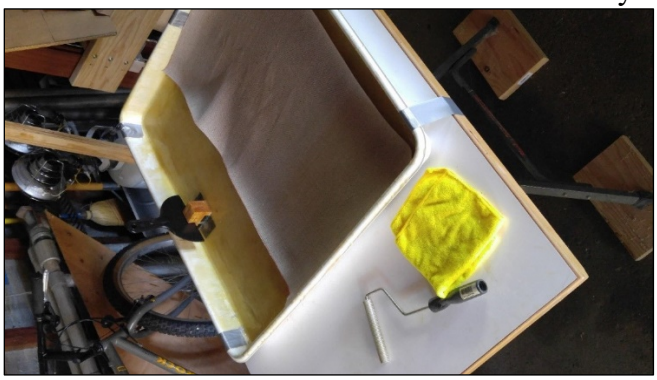


Figure 8: Layer Saturation.

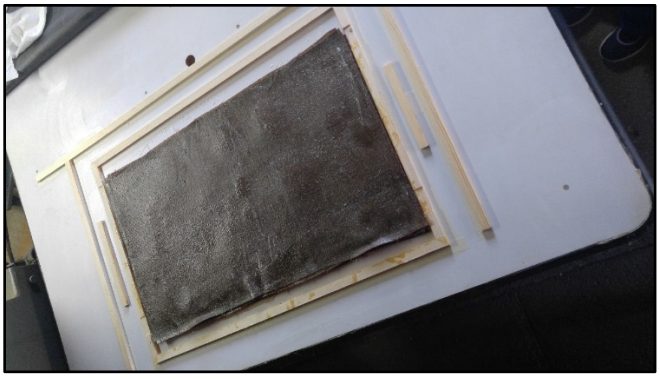


Figure 9: Stacked Layers of Saturated Fabric.

After stacking the required number of layers the aluminum plate was positioned over the pile then the rubber sheet drawn over all the included elements.

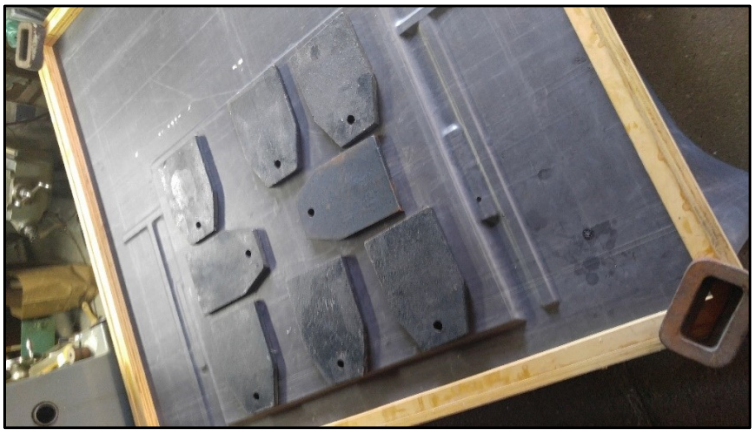


Figure 10: Aluminum Plate with distributed weight.

To aid the compression phase during evacuation, settling weights are added over the rubber sheet. The aluminum sheet must be thick enough to minimize deflection under these weight there by making an irregular thickness composite sheet.

A small amount of epoxy was poured out onto a flat surface to cure to be an indicator of the setting rate of this current sheet.



Figure 11: Curing Sample.

After the epoxy sample has become sufficiently ridged to resist bending, the vacuum is discontinued and left to normal air pressure for the remainder of 24 hours. After which the fixture can be stripped from the vacuum table and trimmed for sawing.

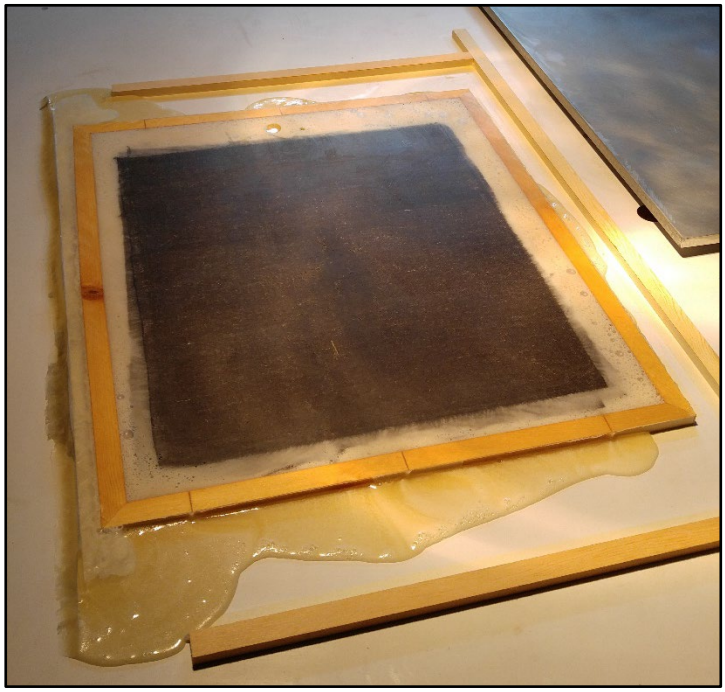


Figure 12: Sample Post Epoxy, excess Epoxy drawn out through escape ports.

An important consideration to casting with epoxy resins is not to let large amounts of mixture stand in the mixing pail, epoxy under goes an exothermic reaction and tremendous heat can be

generated within a deep volume of this material. To counteract this tendency each layer is saturated individually with enough mix then it is placed flat on a vinyl plastic sheet till needed for the final stack up. This way a single layer can have 45 minutes of open time.

The image of the cured sheet shows how the still fluid epoxy is drawn from the casting cavity through the corrals surrounding the layup. There are narrow vents milled into the regulator frame to allow the emergence of epoxy from around the curing stack. Also notice that large amounts of air are being drawn from the fabric and replaced by epoxy during this setting phase.



Figure 13: Epoxy with escaped air from fabric.

This is very important to the complete merging of epoxy to the fabric, without the outward bound motion of fluid epoxy with air entrainment vast regions of none bounding layers will occur.

The entire cured sheet can be pried from the flat table and made ready for sawing to the tab width required by first trimming the frame work away.

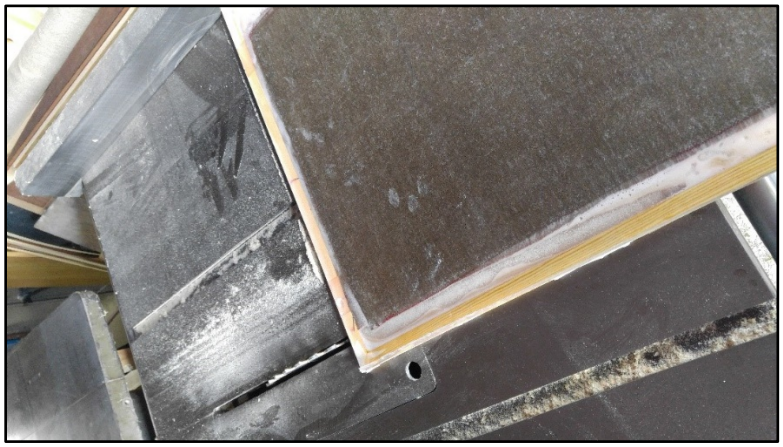


Figure 14: Table saw used to cut specimens.

The table saw is fitted with a 40 carbide tooth 12” blade and slowed to 40Hz with VFD unit. After squaring the sheet the actual sample blanks are sawn.



Figure 15: Blanks being cut to size.

These blanks are then prepared for mounting into the shaping template by drilling locator holes through the material at precise locations.



Figure 16: Drilled holes for specimen testing rig.

After adjustments to the convertible templet are made to conform to the require cross section width the shaping to size is performed.



Figure 17: Specimens are shaped using a template.

This procedure is repeated approximately 30 times for each of the four thickness used and of the two widths for each thickness. The first attempt to have the samples brake at a particular spot following ASTM periodical led to repeated failures.

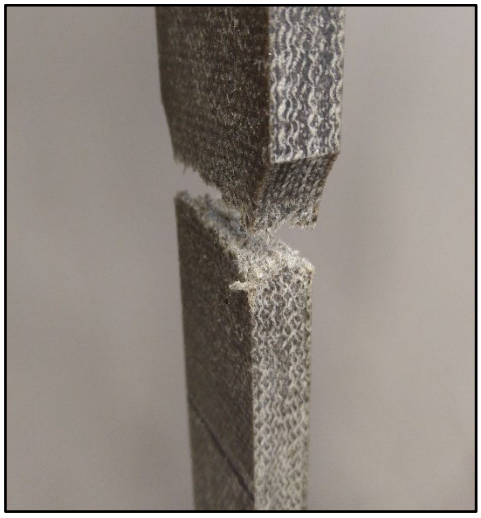


Figure 18: Parallel specimens continued to break in the incorrect location.



Figure 19: Series one of specimens.

The final sample shape took two years to discover both for the proper brake location and gripping the oversize tabs.



Figure 20: Custom adjustable gripping rig to maintain consistent hold on specimens.

This image shows how the griping solution was solved by using steel inserts within the tab region and a through pin to give the needed holding power to rupture these large samples. The steel was 16 gage 4130a sheet metal casted into the sheets during layup. The sawing of these samples was accomplished using a 200 tooth HSS hollow ground cold saw blade mounted in the table saw and run at 9 Hz as adjusted with the VFD unit. A word of caution: do not run a cold saw blade above the recommended RPM's as defined by the manufacture. This was a one of a kind sawing technique that gave remarkable results to size and finish without having to alter the sample material in the process.

2.2 Tensile Testing the Samples

Tensile test were conducted for each size family of samples using the MTS Q100 test machine without measuring the absolute strain only the force and specimen cross section were recorded.

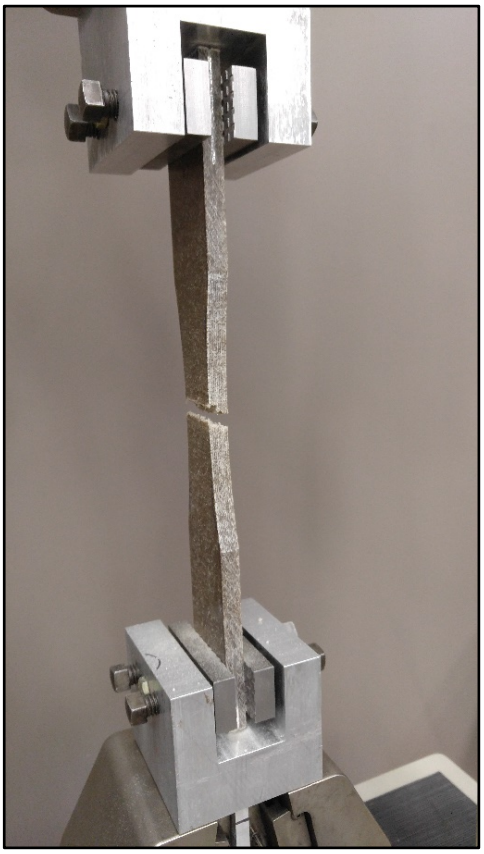


Figure 21: Specimen shape and gripping rig allows the breaks to occur where intended.



Figure 22: Discoloration of Specimen at breaking point.

Typically as the sample was being subjected to tensile force a characteristic color change would occur in the narrow of the sample at half the rupture strength then closer to rupture force multiple snapping noises were audible and finally a load discharge upon rupturing. The rupture face was consolidated without loose particles ejected from the surface.

Full size specimen with modified grip and pin arrangement. The gradated strain field is shown here surrounding the rupture face. With these large samples a grip tightening routine had to be developed to ensure consistent holding results. The square head bolts seen here were cross tightened to full allowable torque for these harden ½-13 set screw bolts. The bolts bare onto the grip blocks which have serrated texture scribed into their surfaces.

3. RESULTS

The fracture of the tension specimens occurred throughout the population within the middle third of the test region and no failures occurred within the clamping section. Two typical views of broken specimens are shown in Figs. 22 and 21. For all tests the maximum load was recorded and the strength was calculated on the bases of the individually measured minimal cross-sections.

GROUP	1	2	3	4	5	6	7	8
Average Area (mm^2)	564	389	191	136	39	87	276	94
Average Stress (MPa)	79	83	88	90	62	71	81	69
Deviation Area ± (mm^2)	33	16	13	13	4	8	5	7
Deviation Stress ± (MPa)	4	5	7	4	7	7	4	8
LAYERS	10		5		1	3	7	3

Table 1: Each layer construction group and corresponding physical statistics.

The cumulative frequency for those groups that had two cross-section areas constructed for a given thickness are shown here.

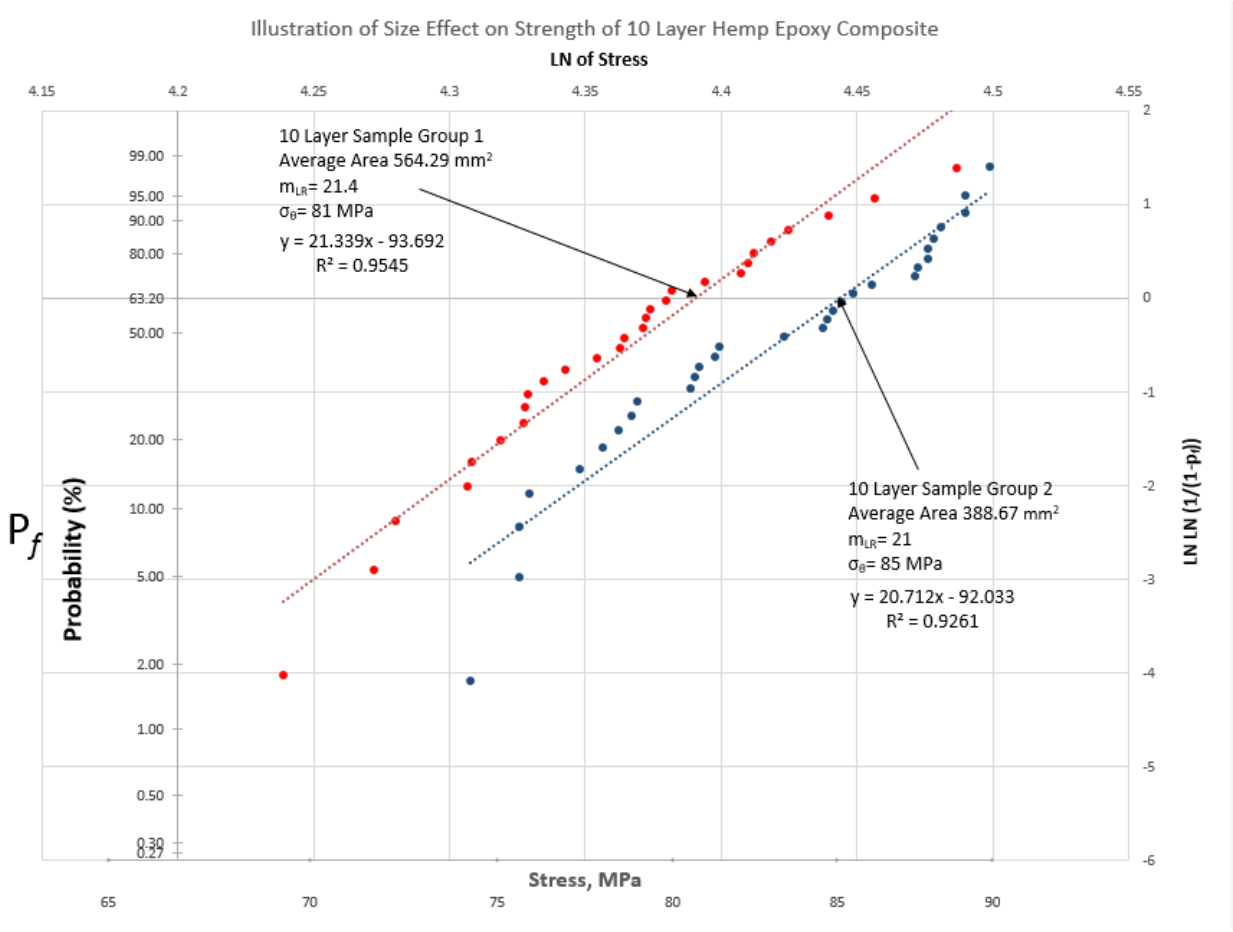


Figure 23: 10 Layer Hemp Epoxy Composite.

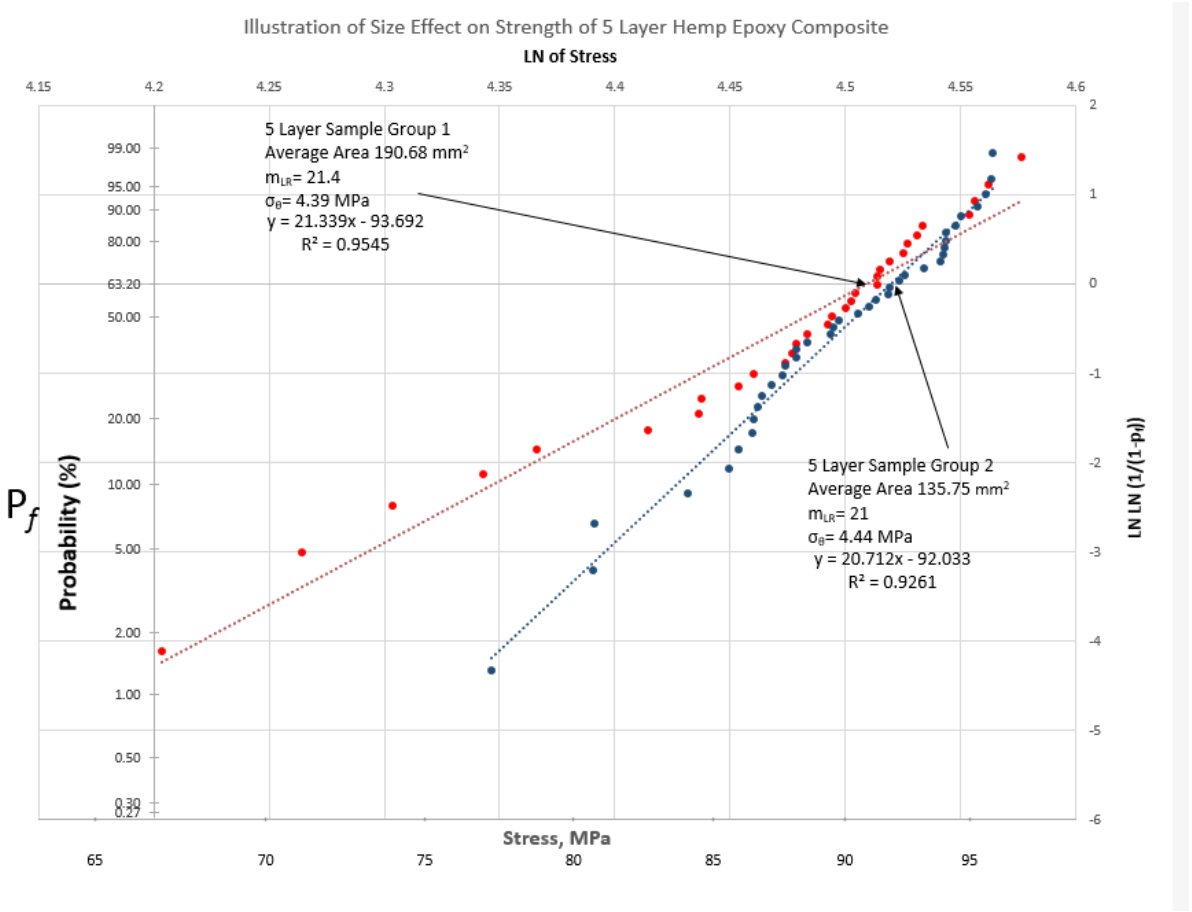


Figure 24: 5 Layer Hemp Composite.

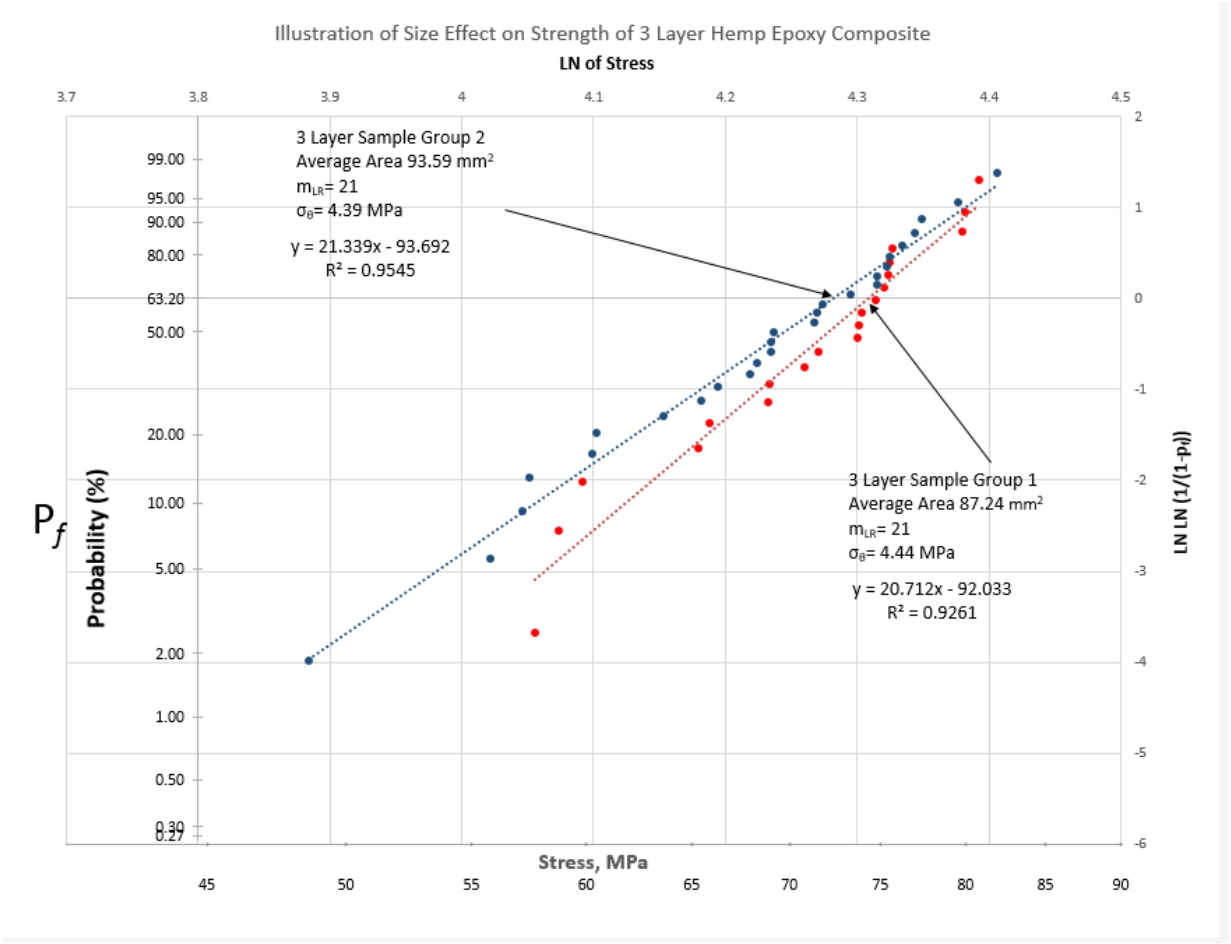


Figure 25: 3 Layer Hemp Composite.

In each case the right shift towards higher strength is associated with a decrease in cross-section area.

As pointed out by Quinn et al, that it can be seen from the charts that the slopes (Weibull moduli) indicate the strength widths. The similar slopes suggest that the same flaw types were active in similarly constructed samples and this verified by fractography analysis. See photos of SEM. The wiggles in the curves are not unusual and are common in small size sample sets. A high modulus, or steep slope, is associated with a narrow strength distribution. The characteristic strength, or Weibull scale parameter sigma sub theta, indicates the distribution location along the abscissa (x) axis, and is expected to move according to test specimen size or the amount of material that is highly stressed [4].

$$P_f = 1 - \exp\left(-(\sigma/\sigma_\theta)^m\right)$$
$$\ln\left(1 - P_f\right) = -(\sigma/\sigma_\theta)^m$$
$$ln\left[\ln\left(1/(1 - P_f)\right)\right] = m\ln\sigma - m\ln\sigma_\theta$$

1: The two-parameter Weibull distribution used for the test data analysis.

3.1 Fractography Analysis of Specimens

Samples were withdrawn from the specimen population two from each of the 8 groups which represent the highest and lowest braking stress from the tensile test. Each of these had a cut-away part of 1 cm square by the thickness of that group prepared for examination in the Quanta FEG 450 scanning electron microscope. The objective of this investigation is to find evidence of rupture initiation and how the fracture progressed. Pictured in the Figure is a representative finding of each sample.



Figure 26: Specimen 128, Low Breaking Stress.

The ‘fish eye’ object in the cross section of fracture zone which measures approximately 100 micrometers across, has emanating from its boarders the characteristic heckles of rupture which point to the start of fracture. The object is an air bubble frozen into the epoxy while setting. Surrounding the hemisphere are the strands of hemp fabric which were pulled from the opposite half of the broke specimen. Finally are the broken fibers themselves which nearly square across the brake. The fiber appears to have greater ductility when subjected to tensile forces then the bonding epoxy matrix.

The sequence of events within the fracture event are as follows(1) the load is accommodated equally across the narrow width of the sample, (2)as load increases the bubbles are first to brake as evidenced by auditable cracking and a visible color change in the epoxy, (3)The epoxy face ruptures and the entire load transfer to the fibers directed parallel to the load direction, (4) there is pull out of some fibers with subsequent separation of the fibers from each other which accounts for the long fiber bundles near the ‘fish eye’, (5) when enough of the fracture has taken place so as to diminish the effective cross section supporting the load, a final rupture occurs at the matrix and the still bonded fiber brakes across the remaining final section.

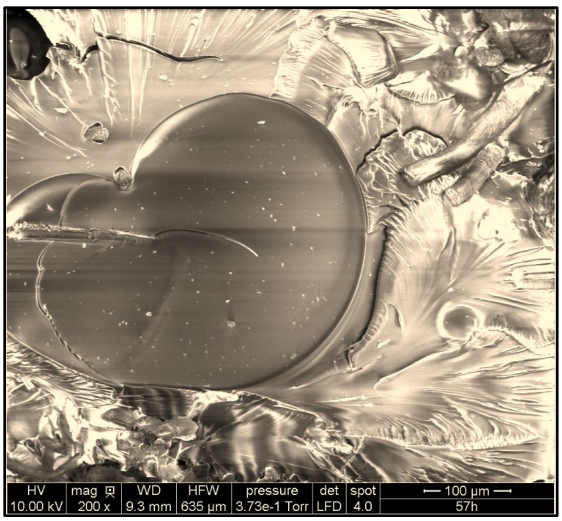


Figure 27: Specimen 57, High Breaking Stress.

The fiber bundle theory holds that load shifts from broke fibers to the local surrounding fibers until enough weak fibers are broke to cause a final rupture of the section. This disrobes well the action of a fiber bundle such as rope or braid but with a matrix present engulfing the fibers a multi-layer process is occurring during failure.

This graph shows the rise in strength with the increase number of layers of fabric until a maximum is reached then additional layers decrease the strength.

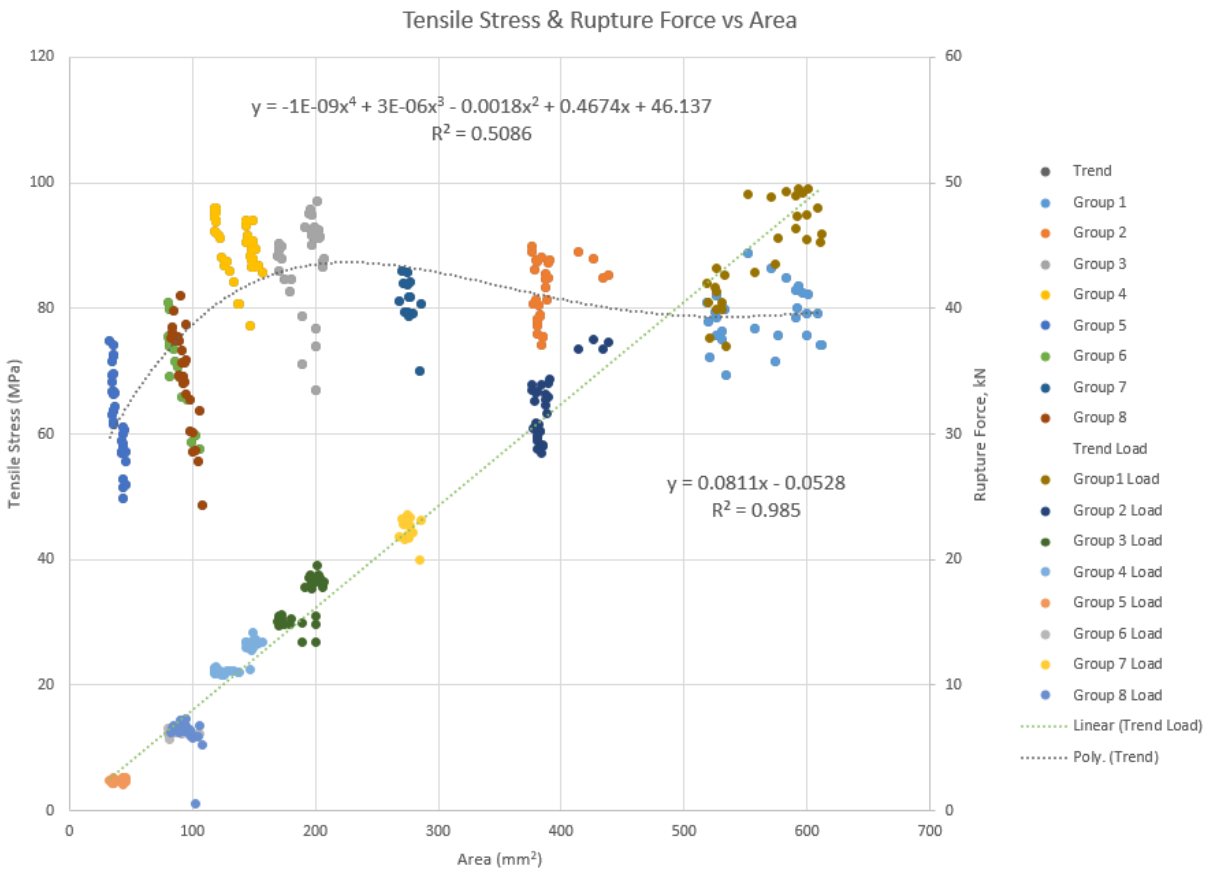


Figure 28: The straight line plot is the terminal load vs. the increase in cross section area. The load carrying capacity is increasing with size whereas the ultimate stress in decreasing.

4. CONCLUSIONS

We have shown the complete assembly process of hemp composites with the material selection and casting form design through to the sample cutting and sizing of each specimen to demonstrate the size effect on the tensile strength of woven fabric hemp composites. A method of specimen preparation was developed after preliminary trial runs so a consistent casted sheet resulted leading to uniform samples. The specimens grips were developed by responding to the holding dynamics afforded the composite samples, slipping out of the standard grips proved unsatisfactory to this experiment. The sample size and profile as a result of the adjustable templet for shaping each specimen was a project unto itself but the consistence of sample size was proof to the extra effort. A technique to manage the flow of epoxy into and out of the regulator frame used during casting of each sample sheet was brought about by observations and alteration to subsequent preparation sections. At the time of this testing there were no provisions to measure the strain associated with each tensile test and cross head motion in the test machine was not a reliable measurement as some slippage in the grips was present and the gage length would be too large for precise strain capture.

The data collected was subjected to plotting in a bar chart to reveal if a normal distribution was present. Our results shown that a shift left was present but this was within agreeable range to use

the Weibull plotting methods for data characteristic demonstration. The graphics illustrate the presence of a size effect on the tensile strength for the three layer count groups produced in this experiment. A secondary graph was devised to show a correspondence between the number of layers of fabric and the relative cross section size of the sample. This graph with all data shown and the best fit polynomial line, helps in the understanding the influence of layer count as being greater than the cross section size in each sample.

Fractography evidence suggest that during extension of the specimens a complete picture of the rupture zone in each sample is a collection of events coupled at first in parallel, the fabric and matrices, than a transition to failures in series prior to a rapid cascading and final separation of the test sample. A crack initiation region is clearly seen commencing from an air bubble and progressing into nearby fabric. This causing a loosening of the bond that surrounds the fibers and the subsequent pullout of those fiber bundles. The witnessing of audible cracking noise prior to sample fracture with discoloration on the sample surface lends credence the actual sequence of events leading to rupture in each specimen. The epoxy matrix is primarily susceptible to tensile loading as first seen at the bubble flaw. The loss of bonding to the fibers is hastened through a detachment of matrix from the fiber by the mechanical enlargement of the matrix surrounding the fiber. Each sample investigated by electron microscope shows a similar sequence to rupture regardless of how many layers are used in its construction.

5. REFERENCES

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