Wood Veneer Applications in Surfboard Construction: A Study of Impact Resistance

Dave Bissell

Wood 493
A Report Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Wood Products Processing
In
The Faculty of Forestry

April 16, 2013

Abstract

Surfboards are manufactured with a shaped polyurethane foam core that is wrapped in fiberglass cloth, and sealed with multiple applications of a curing resin product. A graduating project was conducted to find a suitable method to replace the fiberglass with a wood based material, and perform tests to determine the comparable impact resistance qualities of the wood material with the standard fiberglass build method.

The wood material selected was a woven veneer mat, made out of 10mm wide strips of Douglas fir veneer. Multiple versions of strip size and mat configurations were considered, with two final mats chosen: a densified, woven, 10mm strip mat, and a non-densified, woven, 10mm strip mat. Samples for testing consisted of a 6” x 6” x 1.25” 3lb/ft^3 foam block, a fiber substrate (either a woven veneer mat or fiberglass) and a curing resin (either Polyester or Epoxy), with the fiber substrate bonded to the foam block with the resin. Samples were constructed according to standard surfboard building methods. Samples were tested using an Impact Testing Apparatus, which consisted of a vertically mounted piece of PVC pipe with holes drilled in the side at specific heights, and a plate underneath the pipe on which samples were placed for testing. A 320g steel ball was pushed through the holes in the pipe and dropped onto the face of each sample. Failure was determined to occur when circular cracks appeared in the surface of the sample that could be seen with the naked eye and felt with a bare finger, through which water could access the foam core in a typical surfboard.

Samples made with Epoxy resin were approximately 150% stronger than those made with Polyester resin, when averaged across samples of all fiber substrates. Fiberglass samples were on average 115% stronger than woven veneer samples, ranging from a 50% difference between the strongest veneer sample and the weakest fiberglass sample, to 240% between the weakest veneer sample and the strongest fiberglass sample. The strongest sample used a 6oz – 4oz fiberglass combination with Epoxy resin, with the weakest sample using a Densified Woven Veneer mat and Polyester Resin.

Densification of wood veneer prior to weaving made construction of the samples easier, as the material was more flexible and easier to weave, but resulted in weaker samples than those made with non-densified veneer.

More veneer configurations should be designed and tested to further determine the viability of building a surfboard with wood veneer as opposed to fiberglass.

Table of Contents

Contents

List of Figures

List of Tables

1.0 Introduction

I have had an interest in surfboards and surfboard manufacturing since entering Wood Products Processing almost 4 years ago. One of the first papers I wrote was on the forces applied to the wood stringer in surfboards during the act of surfing for a course on the Mechanics of Wood Properties. Since that time I have developed more of an interest in surfing, and surfboard building in particular, and plan on undertaking numerous surfboard build projects after graduation.

During my time in Wood Products Processing, I have developed an appreciation for both the aesthetic and mechanical properties of wood, and became interested in the various manners in which I could combine those properties with my interest in surfboards. My starting point was looking for a way in which I could highlight the aesthetic properties, while taking advantage of the mechanical properties – an attractive surfboard that performed as good, if not better, than a board with a traditional build. Applying veneer to a standard foam core was the combination method that I chose.

After preliminary discussions with my project advisor – Professor Gregory Smith, I paired up with a PhD student – Shayesteh Haghdan, who was conducting material tests on different configurations of wood veneer-polymer composites. With direction from our advisor, we began looking at ways in which wood veneer strips could be woven, combined and compared with fiberglass and resin combinations, and various other versions.

This paper will discuss the steps taken to create surfboard-type samples with woven wood veneer, and tested and compared to samples built in a similar manner using standard surfboard building materials.

2.0 Objective

The objective of this project is to compare the material properties of fiberglass and woven wood veneer in a surfboard application. Samples containing a foam core, either woven fiberglass of various weights and types, or woven wood veneer, and resin will be built and tested. The property in question is impact strength, and whether or not the substitution of wood veneer for industry used fiberglass cloth has any effect on that property.

3.0 Background/Research

Information for the project has come from various supply sources and surfboard manufacturing resources. For proper and safe material usage, advice and information came from the material supplier, Fiber-Tek, located in Burnaby, BC. For information on surfboard manufacturing techniques, various online forums and material/equipment suppliers were used. Greenlight Surf Supply is an online resource for surfboard builders, and includes detailed information on manufacturing surfboards. Swaylock's is a surfboard design forum and has been used to confirm information and get ideas on different things various builders have attempted.

3.1 Surfboard Construction and Design

Standard construction methods for surfboards involve a foam core (referred to as a surfboard blank, or just a blank), often with a thin wood strip running down the centerline, and a hard outer shell consisting of one or more layers of fiberglass cloth and a hardening resin.

Foam blanks are either made from Polyurethane (PU) foam or Expanded Polystyrene (EPS) foam, with the majority made out of PU foam since the 1950s. These blanks were made almost exclusively by Clark Foam, a company based in California that supplied the majority of the world's surfboard blanks until they shut down operations and went out of business in December 2005. Since that point there have been other foams and other methods of construction developed, but the majority of boards are still made out of PU foam, supplied by other companies that took up where Clark Foam left off, including US Blanks, a company made up of ex-employees of Clark Foam. These blanks are then planed and sanded by shapers to a desired or requested shape, with multiple dimensions being taken into account and playing large roles in how the final board will perform.

Shaped blanks are then wrapped in fiberglass cloth of various weights and types depending on end use. Weight is designated in weight per square yard (Fiber-Tek) and range from 4oz/sq. yard up to 10oz, with multiple layers used in some applications. (Greenlight) The majority of cloth used in surfboards is referred to as E-Glass cloth, which is "woven from fine yarns of twist and ply construction, with the actual glass being a lime-alumina borosilicate glass of low alkali content" (Fiber-Tek). An alternate cloth, referred to as S-Glass is made with more chemical coating on the fibers for additional strength properties, but increased manufacturing costs results in this cloth coming to almost twice the price of E-Glass. (Fiber-Tek)

Short boards (high performance boards, typically 5 to 7 feet in length, designed for speed and maneuverability) are typically wrapped in 4oz cloth, with a single layer on the bottom and two layers on the top. Longboards (8 to 10 feet in length, longer in some applications, ridden in a smoother style than short boards and frequently by beginners given their increased buoyancy and ease with which they catch waves) are typically wrapped in multiple layers of 6oz cloth for extra strength. Short boards can go up to 10oz of layered cloth, and longboards up to 18oz. (Greenlight)

Boards are wrapped in the cloth one side at a time, with resin being applied after the cloth is laid onto the blank. Resin will be applied with a plastic squeegee or brush in either 2 or 3 layers, with sufficient drying time between each layer. The first layer of resin is referred to as the laminating layer, and is used to firmly bond the cloth to the foam blank. The second layer, referred to as a hot-coat, is used to fill all the gaps and bumps in the first layer, and ensures that the core is completely sealed with no open areas that water could get in. An optional third layer, the gloss coat, is done for those that desire a polished, high gloss finish, and are not worried about the additional weight that another layer of resin adds.

The resin used will either be Polyester or Epoxy based resin. Polyester resins have historically dominated the surfboard industry, with Epoxy resins becoming more popular in recent years due to the lack of toxic odours and improved strength properties (which may be confirmed or disproved during testing).

4.0 Materials

The materials used will fall into one of three categories: foam core, fiber substrate and Resin. The construction of the samples will be discussed in the following section.

4.1 Foam Core

As described in the background section, 3lb/ft^3 (referred to as 3lb from now on) density Polyurethane (PU) foam is used to form the core in the majority of surfboards. A 2lb/ft^3 (referred to as 2lb from now on) Expanded Polystyrene (EPS) core is starting to be used by some companies, but 3lb PU cores originally manufactured by Clark Foam have been historically dominant, and preferred by shapers. As a result, a 3lb PU core was chosen to be the base material for the samples, both for its historical prevalence, but also the fact that the material being tested is the hard outer shell of surfboards, with the foam core simply adding a base to which the top can be applied and tested.

With a moderate amount of research, the only supplier of potentially applicable foam blocks found was Fiber-Tek, with all other suppliers only stocking 2-part pour foam. The blocks available at Fiber-Tek were 2lb, with 3lb only being available in pour foam. As a result, the 3lb pour foam was chosen to mimic a typical surfboard core as closely as possible, and molds were designed to create a foam block of suitable dimensions.

Molds were built out of ¾" MDF (Figure 1), based on material availability and the plan to line molds with a release agent or covering before pouring the mixture in, making the material selection unimportant in the forming and release of the molds. The inner dimensions are 6" x 6" x 2.5", which will create a foam block with a surface area easy to cover with the woven veneer mat (discussed next) and a thickness similar to the top range of a surfboard. However, during the testing of the molds and manufacturing of the blocks, it was determined that the samples needed to be cut in half to expose a flat area on which to laminate, as the edges of the blocks were often curved and inconsistent when they came out of the molds. This kept the thickness still in an appropriate range, and provided a smooth and consistent surface for the fiberglass or woven veneer. The molds had three ¼" holes drilled into the top cover to allow for excess foam expansion to escape as recommended in the product directions. (Figure 2)

Figure 1: MDF Foam Block Mold

Figure 2: Foam Block Manufacture - Expansion Hole Use

Different methods were used for the first few foam blocks to determine the easiest and most consistent combination of release materials and liners. Plastic kitchen wrap, aluminum foil and no liner were all attempted, both with and without cooking oil applied. Both aluminum foil and no liner proved very difficult to release the foam during this testing, and one MDF mold was damaged and had to be discarded. The most effective combination involved the application of cooking oil to the mold before lining with plastic wrap (this made release easier, but the main benefit was that the plastic wrap did not stick to itself and was able to be properly pushed into place in the mold), and two layers of plastic wrap to ensure that the corners of the mold were properly covered.

The foam used was "Smooth-On Foam-It! 3", a 3lb, 2 part rigid polyurethane foam, (Figure 3) which was mixed in equal portions. The foam product predicted a 15 to 18 times expansion, and 45ml of each part was measured out for the first samples as a result (the mold containing room for approximately 1475ml, which would have required approximately 16 times expansion). However, this measurement combination did not completely fill the mold (Figure 4), and the volumes were increased to 65ml of each part. This increase satisfactorily filled the mold, and was maintained for the rest of the foam samples.

Figure 3: 3lb 2 Part Polyurethane Foam

Figure 4: Insufficient Foam Mix

4.2 Fiber Substrate

The component of the surfboard being experimented with and material tested is the woven cloth that is wrapped around the foam core before applying resin to the unit. 3 different types of fiberglass cloth combinations (referred to as glassing schedules (Greenlight)) were applied and tested, including two layers of 4oz “E” cloth, one layer of 4oz “E” cloth and one layer of 6oz “E” cloth (with the 6oz cloth placed beneath the 4oz cloth on samples), and one layer of 6oz “S” cloth (Figures 5 – 7). These combinations were chosen as both common and minimum glassing schedules, offering a chance for woven wood veneer to compare to typical surfboard examples that have not been designed for extra strength or durability.

Figure 5: 4oz - 4oz "E" Fiberglass Cloth

Figure 6: 6oz - 4oz "E" Fiberglass Cloth

Figure 7: 6oz "S" Fiberglass Cloth

These cloth samples were tested against mats made of two different types of woven veneer strips, each measuring 10mm wide. Weaving strips of veneer to create a mat and the resulting material properties is being tested in S. Haghdan’s research, with the woven design and technique developed in that research shared with the author of this paper. (Haghdan, S. 2013) One set of mats were made with regular Douglas fir veneer, and the other with densified Douglas fir veneer (Figures 8 and 9). Densified veneer was suggested as an additional material to test by S. Haghdan based on a literature review performed that indicated the method would improve the mechanical properties of veneer. Veneer sheets were piled in stacks of 10 with aluminum foil separating the layers, and pressed at 150°C and 200psi for approximately 9 minutes with steam injection to maintain moisture content and reduce cracking. Thickness decreased approximately 20%. (S. Haghdan, 2013).

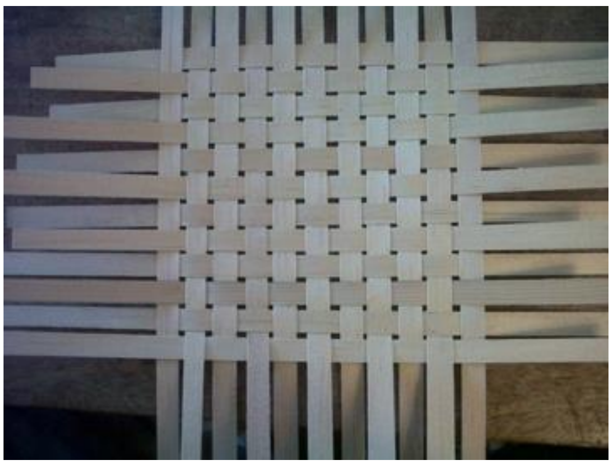


Figure 8: Non-Densified Woven Veneer Mat

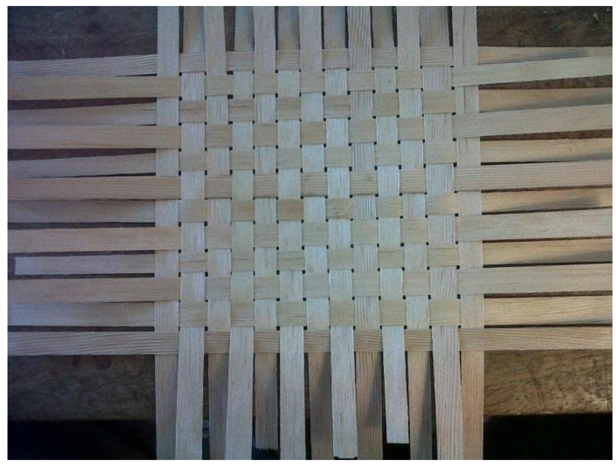


Figure 9: Densified Woven Veneer Mat

A number of different veneer weaving methods and structures were discussed and experimented with before deciding on this final structure, including:

> **2mm Veneer Strips – Woven Pattern** (Figure 10): Determined to be too thin during weaving. The strips could not be pushed close enough together to have an appropriate amount of fiber in the sample, and significant splitting and cracking occurred, making even the first sample very difficult to build, with a very weak structure when it was completed. Attempted with both densified and non-densified, with negative results for both materials.

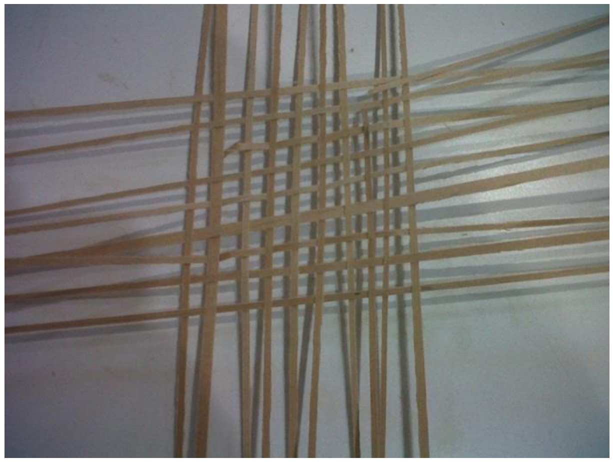


Figure 10: 2mm Woven Veneer Mat

5mm Veneer Strips – Woven Pattern (Figure 11): Acceptable for the easier to weave densified strips, but did not create an acceptable mat for non-densified veneers. Strips could not be pushed together easily, and split and cracked leaving the mat with gaps and weak points.

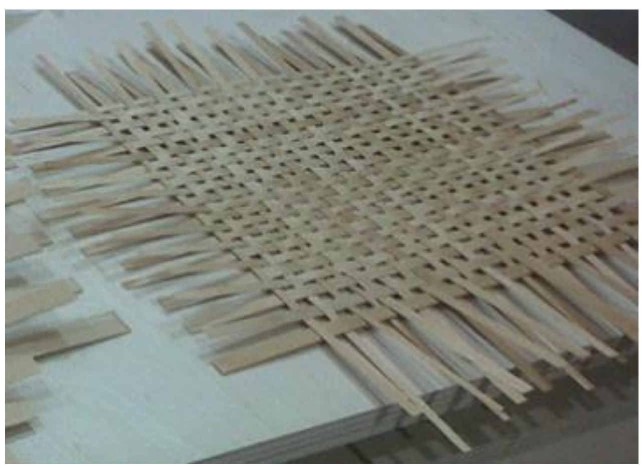


Figure 11: 5mm Woven Veneer Mat

10mm Veneer Strips – Unidirectional Pattern (Figure 12): A potentially testable alternative to the chosen material, but would require more design time than was able to be allocated to the project. The mats were held together with rice paper tape, and were significantly weaker structurally than the woven mats. To create a comparable product to the woven mats, they would also require two layers, as a single layer contained half the number of strips of a woven mat. It was determined that a woven mat would be more closely comparable to fiberglass, and if testing proved successful, different mat weaves and structures could be tested.

Figure 12: 10mm Unidirectional Veneer Mat

4.3 Resin

Resin was applied by standard surfboard construction methods - an initial laminating coat and a sealing hot coat using waxed Polyester (PE) resin or Epoxy resin. Unwaxed Polyester resin will cure with a slightly tacky finish, allowing for the addition of more coats without scuff sanding, with waxed resin curing smooth and hard. (Fiber-Tek) Waxed resin was the only available PE resin at the time the samples were made, so it was used for both coats.

4.3.1 Waxed Polyester Resin

The waxed polyester resin used was Fiber-Tek's FT 150 Waxed Fiberglassing Resin (Figure 13) and consisted of two parts – the resin itself and a curing catalyst. The quantity of catalyst to be added depended on the temperature of the environment where the samples would be curing and the desired curing time, and ranged from 10ml to 20ml per liter of resin. The room in which the samples would be curing was exposed to the outdoors, which at the time the samples were made had an average daytime temperature of between 10 and 15^{o}C. There was a heater placed in the room at night to prevent the temperature from dropping too low, but most samples were made in the morning and the room temperature should have held somewhere between 10 and 15^{o}C. Taking these factors into account, 1ml of catalyst was used per 50ml of resin, or 20ml per liter of resin. All polyester samples cured properly.

Figure 13: Waxed Polyester Resin

Resin was measured and placed in a disposable plastic cup. Catalyst was measured using a syringe and mixed with the resin when the appropriate amount had been drawn from the container. The two were mixed with a clean stir stick for approximately 1 minute. Working time was between 30 and 40 minutes. The resin started turning brown from its original blue colour as curing began, indicating that there were approximately 5 more minutes of working time. Curing happened quickly once it began and the resin became gummy and immovable. If there was leftover resin at this point it was discarded instead of attempting to use it.

The laminating coat was allowed to fully cure (more than 12 hours) and scuff sanded before a second coat was applied.

The Polyester resin had a very strong odour to it and a respirator was used during all application processes. The odour stayed in the room in which the samples were made for more than 24 hours after application. Cleanup of tools and measuring devices was accomplished with acetone.

The Polyester resin cured to a smooth, matte finish.

4.3.2 Epoxy Resin

The Epoxy resin used was System Three Cold Cure Epoxy Resin (Figure 14) and was also a two part mix. The ratio for this mixture was 2 parts resin, 1 part hardener, not dependent on temperature unlike the Polyester resin. Each part was measured in a plastic measuring container, and the two were mixed into a disposable plastic cup. The Epoxy resin was significantly thicker than the Polyester resin, and mixing was more difficult. The two components were mixed for approximately one minute, at which time the mixture became slightly less viscous. Working time was stated to be 1 hour on the product container, but all resin was used up within 40 minutes with each batch of samples. No curing issues appeared during the manufacture of samples.

Figure 14: Epoxy Resin

The laminating coat was allowed to cure between 12 and 24 hours, and a second coat was applied without scuff sanding at the advice of the supplier.

The Epoxy resin had minimal odours. A respirator was used for safety, but no smell stayed in the room for longer than 1 hour after application. Acetone was used for cleanup of tools and measuring devices.

The Epoxy resin cured to a hard, high gloss finish.

5.0 Procedure

Both the procedure for joining all the materials and building the samples, as well as the procedure used for testing, will be discussed in the following section.

5.1 Sample Building Procedure

All materials were prepared and organized prior to the final manufacture of the samples. Foam blocks were labelled on the side using duct tape and masking tape, with ID tags indicating the cloth and resin types, as well as the individual sample number in each grouping. Sheets of fiberglass cloth were all cut to approximately 7” x 7”, and sheets of woven wood veneer were measured to as close as possible to 6” x 6”, with a 1 strip adjustment made (either wider or narrower) if necessary. All measuring and application tools and safety equipment was prepared. A thorough check of all supplies and materials was done before mixing resin and catalyst/hardener. 5 samples of each type plus a test sample were manufactured.

5.1.1 Laminating Coat

As mentioned in the background section, the first coat applied is referred to as the laminating coat. The purpose of this coat is to bond the fiberglass or woven wood mat with the foam. A small amount was poured onto the open face of the foam block and spread around using a plastic squeegee quickly before it all soaked in. More was applied if there were parts on the foam face that did not receive any resin.

5.1.1.1 Fiberglass Cloth

For the fiberglass samples, the one or two layers of cloth were laid squarely onto the foam block and gently pressed into place until the resin began to soak through slightly. More resin was then poured from the mixing cup on top of the cloth and gently spread around with the squeegee. Once the cloth was saturated, the squeegee was used to press harder with the intent of pushing any air bubbles out the sides of the piece, as well as removing any excess resin. Excess resin was wiped onto the paper or cardboard on which the block sat. Once satisfied that the cloth was properly bonded to the block, an even amount of resin had been spread over the entire face, and any air bubbles were minimized, the block was set to the side for curing.

5.1.1.2 Woven Veneer Mat

Taking into account that the woven veneer mats are less permeable than the fiberglass cloth, one extra step was added when applying the veneer. After a thin layer of resin was applied to the foam block, resin was poured onto the back of the veneer mat and spread around with a squeegee. The mat was then laid onto the block, with the resin side down, and the rest of the laminating coat was applied as it was for the fiberglass. The non-densified mats were slightly thicker than the densified versions, and did not seem to bond as evenly as the densified mats. Once the resin was applied, the blocks were set aside for curing.

5.1.2 Hot Coat

The second coat of resin, referred to in surfboard manufacturing as a hot coat (Greenlight), was applied after an amount of curing described in sections 4.3.1 and 4.3.2. Excess fiber substrate was first trimmed from the sides using a razor. Resin was mixed and a small amount was poured onto the top of the blocks. It was gently spread with a bristle painting brush with the intent of having a smooth, even application across the surface of the block. Once satisfied that the block was thoroughly coated with no dry spots showing through (approximately 1/8" of resin), the block was again set aside to cure. This time all blocks were allowed to fully cure for more than 24 hours before touching or moving.

5.1.3 Build Comments

The veneer mats required significantly more resin to ensure a smooth surface than the fiberglass samples due to the variation in height created by the weave pattern and the thickness of the strips. This seemed to create issues that will be discussed in the Discussion section.

Different amounts of resin were used between the different types of samples as the goal was to create equivalent products. Extra resin in the woven veneer samples may affect results, but without sufficient resin to completely seal the sample, its full scale version would not behave as a surfboard would, making an irrelevant product whose properties would not be comparable to a surfboard.

5.2 Sample Testing Procedure

As discussed previously in this paper, the goal of the study is to determine differences in impact resistance between the various fiberglass, veneer mat, and resin combinations. This was accomplished with the use of an Impact Testing Apparatus. (Figure 15) The apparatus consists of a piece of PVC pipe, with holes drilled into the side at set heights. The pipe was clamped vertically with a steel plate at the bottom on which to place samples. (Figures 16 and 17) Heights of holes were measured and started at 55mm from the top of a sample block, increasing by approximately 50mm up to 1060mm, at which point there were three additional holes, located at 1310mm, 1565mm and 1815mm. A 320g stainless steel ball was pushed through a hole and allowed to fall through the pipe and land on the piece being tested at the bottom.

Figure 15: Impact Testing Apparatus

Figure 16: Testing Plate

Figure 17: Testing Plate with Sample

Samples were tested with their respective batches, 5 samples of each type, with the test T pieces being used first. For these pieces, drop heights started at 55mm (the lowest hole) and increased the entire way up until the approximate break point was found. For the remaining pieces within each group, drop heights started closer to the expected break point to increase the efficiency of the testing process, and to decrease the number of impacts each piece had to sustain. While no breaks occurred at the lowest heights, it was assumed that there was some non-visible damage to the piece, which could alter results if a piece would otherwise be able to sustain drops from much higher.

A piece was considered to have failed when circular cracks that could be seen with the naked eye and felt with a bare finger appeared on the surface of the piece after testing. Some deformation of the foam was visible through the clear fiberglass after some drops, but was not considered a break. (Figure 18) The height at which a piece failed was recorded and the next piece tested. In a surfboard, damage is detrimental and needs to be addressed when water is able to get through the hard shell to the foam core. The appearance of circular cracks was considered to be damage that required addressing. (Figure 19)

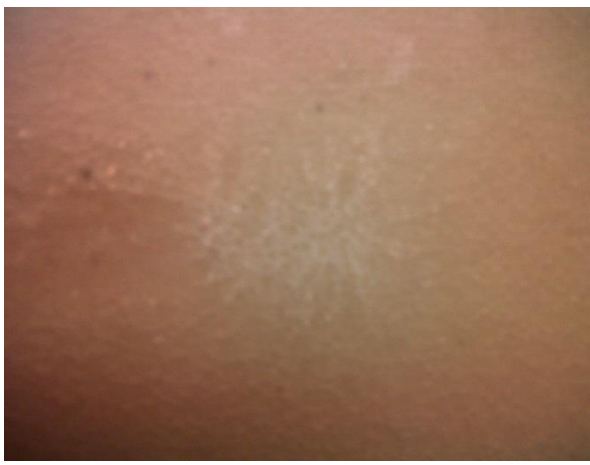


Figure 18: Non-Failure "Spider" Crack

Figure 19: Failure "Circular" Crack

6.0 Results

The height at which the ball was dropped and caused failure in each piece was recorded and input into an Excel spreadsheet. Using the formula for potential energy (PE = mgh) in which m is the mass of the ball dropped (320 grams, converted to kilograms for the formula), g is the acceleration due to gravity ($9.81 m/s^2$), and h is the height at which the drop occurred (in millimeters, converted to meters for the formula) and taking into account that all potential energy is converted to kinetic energy at the moment of impact, the energy (in Joules) required to break each piece was calculated. The type averages of this data can be seen in Table 2, along with the average mass of each sample type in Table 1. The tables are broken down into sections comparing Resin type across all Fiber substrates, Fiber substrate type across all resin types, and individual sample type. Within each grouping, all entries are compared to the lowest value in that group, showing by percentage how much heavier or how much more energy was required compared to the lowest performer in the group. Two complete tables (Tables 8 and 9) comparing all factors to all other factors are located in the Appendix. These two tables were used for the analysis, and the information in the following section was derived from those tables, as well as additional averages calculated in the Excel file.

Table 1: Mass Comparison - Summary

Material	Mass (g)	% Increase on Lowest in Group
Resin Comparison		
PE Resin Samples	92.00	**0.0%**
Epoxy Resin Samples	97.00	5.4%
Fiber Substrate Comparison		
44	87.73	3.6%
64	89.18	5.4%
6S	84.65	**0.0%**
Densified Veneer	100.18	18.3%
Non-Densified Veneer	110.47	30.5%
Individual Type Comparison		
44(PE)	87.90	7.5%
64(PE)	88.62	8.4%
6S(PE)	81.78	**0.0%**
D(PE)	94.03	15.0%
ND(PE)	107.32	31.2%
44(E)	87.55	7.1%
64(E)	89.86	9.9%
6S(E)	87.10	6.5%
D(E)	107.35	31.3%
ND(E)	113.62	38.9%

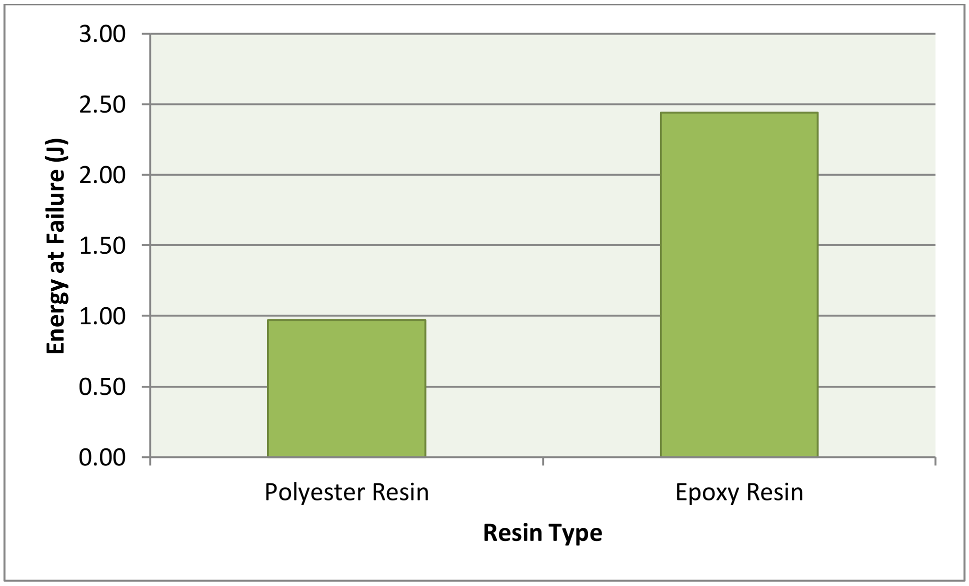
Table 2: Energy at Failure Comparison - Summary

Material	Energy at Failure (J)	% Increase on Lowest in Group
Resin Comparison		
PE Resin Samples	0.9721	**0.0%**
Epoxy Resin Samples	2.4413	151.1%
Fiber Substrate Comparison		
44	2.0419	143.0%
64	2.8552	239.8%
6S	1.8220	116.8%
Densified Veneer	0.8403	**0.0%**
Non-Densified Veneer	1.2308	46.5%
Individual Type Comparison		
44(PE)	0.9606	44.2%
64(PE)	1.1432	71.7%
6S(PE)	1.2808	92.3%
D(PE)	0.6660	**0.0%**
ND(PE)	0.9104	36.7%
44(E)	2.9430	341.9%
64(E)	4.9097	637.2%
6S(E)	2.2087	231.6%
D(E)	1.0438	56.7%
ND(E)	1.5513	132.9%

6.1 Resin Comparison

Samples made with Epoxy resin were 5.4% heavier on average than those made with Polyester resin. Compared across all fiber substrates they were 151.1% stronger. Epoxy resin samples showed less deformation of foam after non-failure drops than Polyester resin did.

Table 3: Comparison of Resin Performance



6.2 Fiber Substrate Comparison

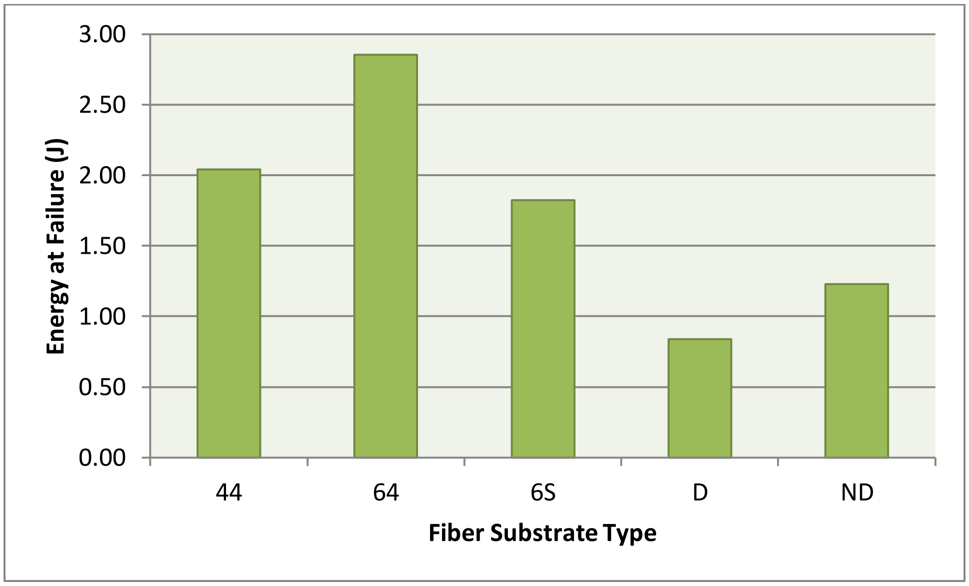
Due to the small size of each sample, there were minimal differences in the mass between the fiberglass samples. The densified veneer samples were approximately 15% heavier than the fiberglass samples, and the non-densified samples were approximately 25% heavier. Less than 5% of this difference is due to the additional weight of the wood veneer (each woven veneer mat was approximately 5 grams heavier than the fiberglass mats), indicating that approximately 20% more resin was required to create an equivalent sample with non-densified woven veneer, and 10% more resin for densified woven veneer.

The combination of a piece of 6oz “E” cloth and 4oz “E” cloth was the strongest of the three fiberglass samples, approximately 40% stronger than the two pieces of 4oz cloth, and 50% stronger than the one piece of 6oz “S” cloth.

The non-densified woven veneer was 45% stronger than the densified veneer.

The fiberglass samples were on average 115% stronger than the woven veneer samples. The biggest difference was between the 6oz-4oz combination and densified woven veneer, with the fiberglass being 240% stronger. The smallest difference was between the 4oz-4oz combination and non-densified veneer, with the fiberglass being 50% stronger.

Table 4: Comparison of Fiber Substrate Performance



6.3 All Samples Comparison

The heaviest samples were the non-densified woven veneer samples with Epoxy resin, being approximately 20% to 40% heavier than all fiberglass samples, and 5% to 20% heavier than all woven veneer samples. Most fiberglass samples were within 5% of the weight of other fiberglass samples, with a couple 6oz-4oz combinations reaching almost 10% heavier.

The strongest samples were the 6oz-4oz combination with Epoxy resin, at 70% to 120% stronger than other fiberglass Epoxy combinations, and 280% to 410% stronger than all fiberglass Polyester combinations. They were 215% to 370% stronger than woven veneer samples with Epoxy resin, and 440% to 640% stronger then woven veneer samples with Polyester resin.

The strongest wood sample was the non-densified woven veneer with Epoxy resin, which was 50% stronger than the densified sample with Epoxy resin, and 70% to 130% stronger than the wood samples with Polyester resin. Both wood samples constructed with Epoxy resin performed 10% to 60% better than the 4oz-4oz PE combination, and the non-densified Epoxy sample performed 20% to 60% better than all fiberglass Polyester resin combinations.

Table 5: Comparison of Fiber Substrate Type with Polyester Resin

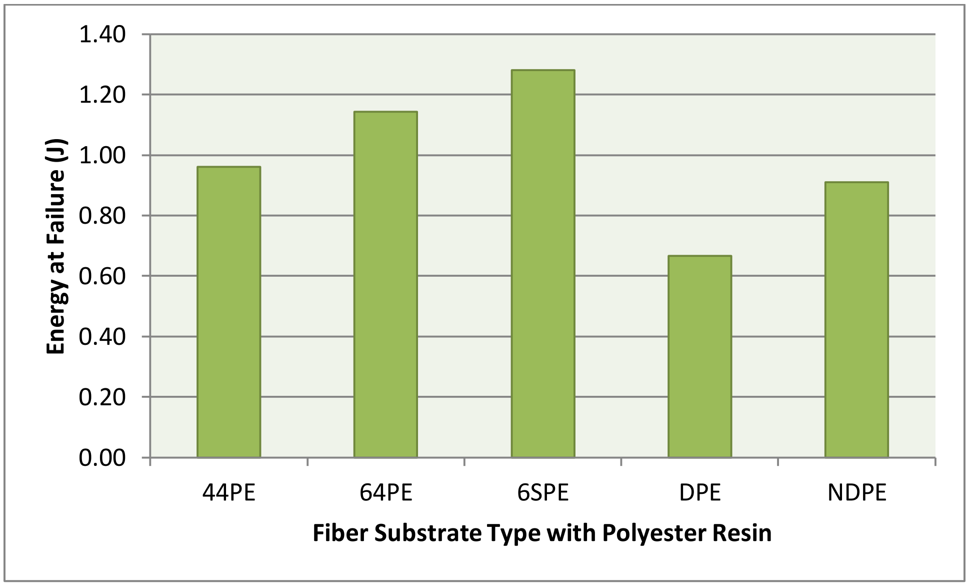


Table 6: Comparison of Fiber Substrate Type with Epoxy Resin

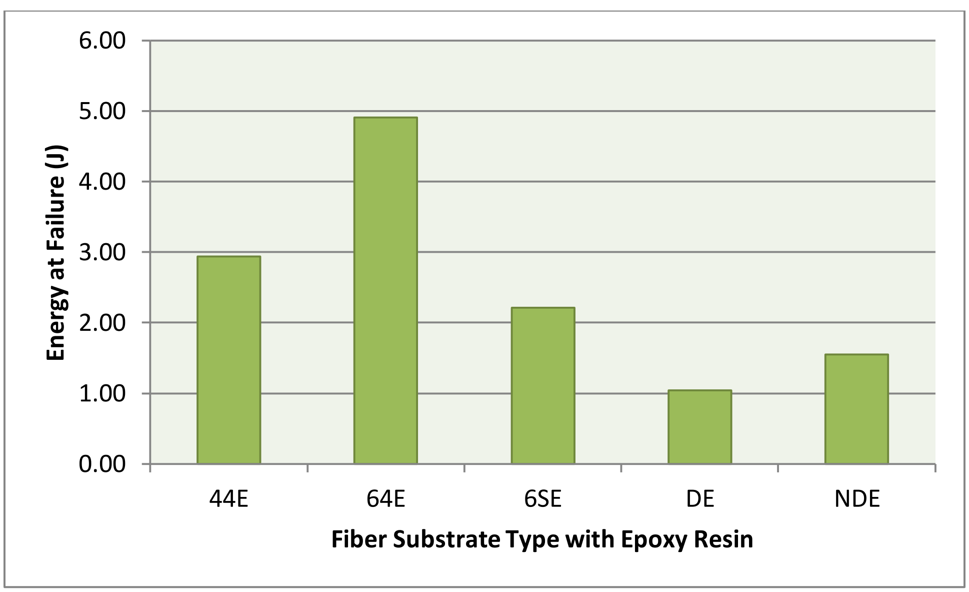
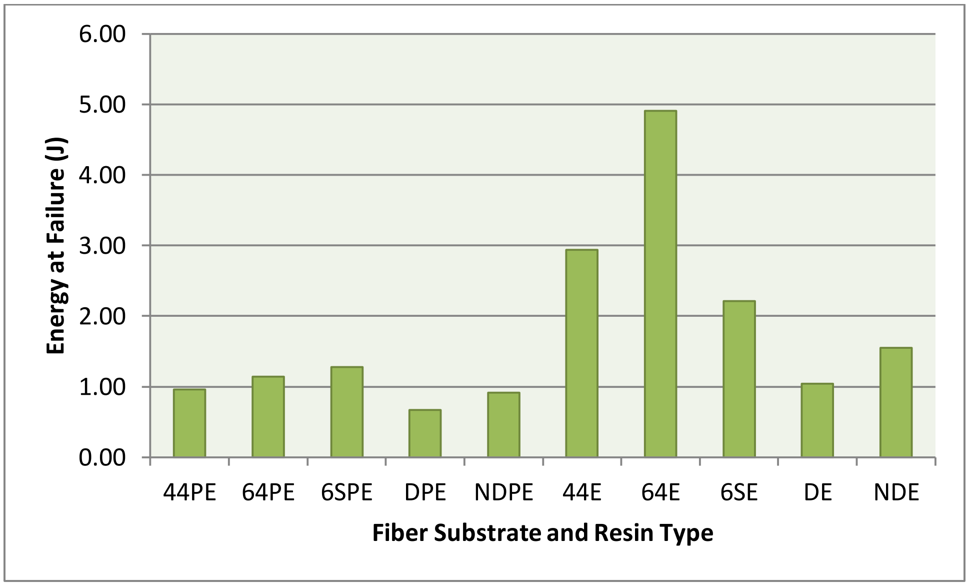


Table 7: Comparison of All Samples



7.0 Discussion

As shown in the results, the woven veneer samples were able to withstand far less impact in comparison with all other fiberglass samples. The non-densified woven veneer samples performed better than the densified samples, and almost all Epoxy resin samples performed better than the samples made with Polyester resin.

7.1 Discussion of Failure Results

The type of failure seen in the fiberglass and woven veneer samples consistently differs, and may be an indication of why the veneer samples failed to perform as well as the fiberglass samples. When the steel ball was dropped on fiberglass samples, a series of small deformations in the foam or internal cracks appeared, radiating out from a single point, referred to from this point on as “spider” cracks. (Figure 20) As mentioned in the testing procedure section, these deformations were not considered failure, as there did not appear to be any breaks in the outer surface of the resin, nor could any cracks be felt when touched with a bare finger. At the point of failure, these spider cracks appeared, but also circular cracks, (Figure 21) seen at varying distances from the center of impact, with the furthest out being the most distant indicator of impact from the center. As mentioned, these circular cracks could be felt with a bare finger and were considered failure.

Figure 20: Non-Failure "Spider" Crack

Figure 21: Failure "Circular" Crack

In comparison, the cracks that appeared in the woven veneer samples did not show any spider cracking, nor did they show consistent circular cracking. In some cases there were clear circular or curved cracks that appeared similar to the circular cracks in the fiberglass samples, but in the best cases there were less than 3 of these cracks in the veneer, (Figure 22) compared to fiberglass which showed multiple cracks at varying distances from the center of impact. In other cases in veneer samples, there were straight cracks, or straight cracks with small crack branches off the side of the main crack. (Figure 23) These results indicate that the fiber substrate did not interact with the steel ball during impact, and therefore did not disperse the energy in the same manner that the fiberglass was able to. This is likely due to the inconsistent amount of resin that had to be applied to the woven veneer samples in order to create a product with an equivalent function – sealing out water from the foam core. In areas where resin was thick and pooled, these straight cracks seemed to be more prevalent. Developing a different method of construction (weighting the top of the sample after laminating coat application) or a different veneer configuration (unidirectional layered) could potentially overcome this problem.

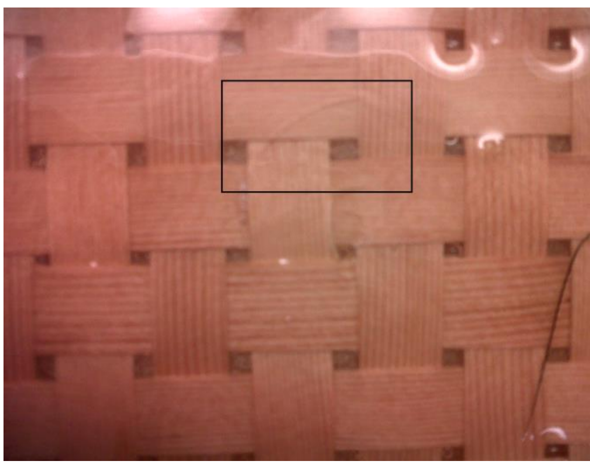


Figure 22: Single Circular Crack

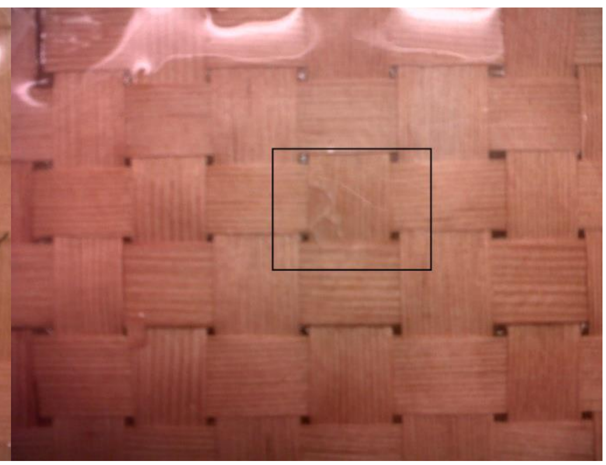


Figure 23: Straight Branching Crack

7.2 Discussion of Densification

The densification of the veneer prior to weaving had both positive and negative effects on the samples. As discussed in the materials section, the densified veneer strips were significantly easier to weave than the non-densified strips. They were more flexible and less susceptible to cracking, making it not only easier to weave the mats, but also to get the strips much closer together. (Figures 24 and 25) In the personal opinion of the author, the densified mats also had an added aesthetic appeal over the non-densified mats.

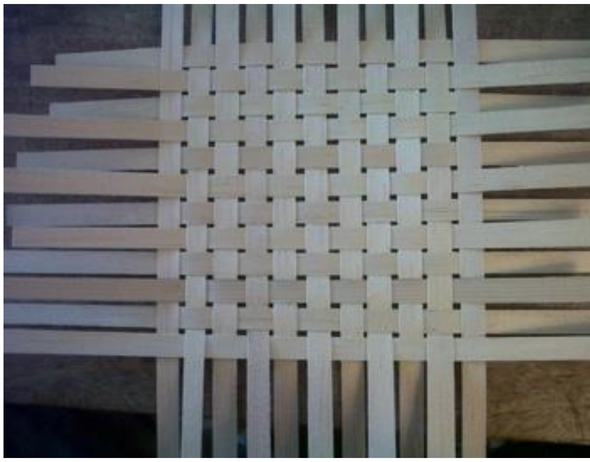


Figure 24: Non-Densified Woven Veneer Mat

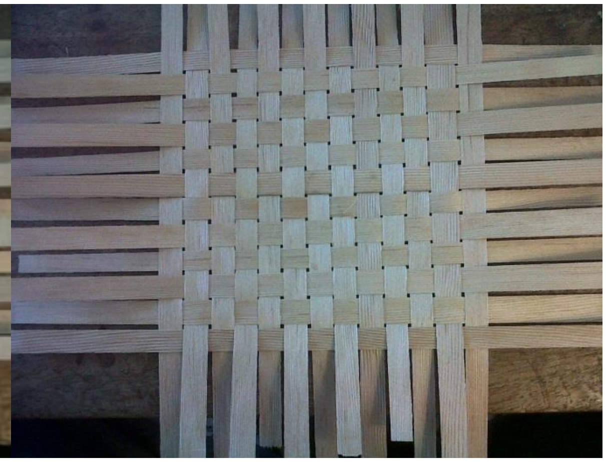


Figure 25: Densified Woven Veneer Mat

The densified mats were also easier to work with in terms of building the samples. There was less depth variation than in the non-densified samples, making it easier to apply the mat to the foam block, and requiring less resin to create a smooth top surface.

However, in all cases the densified samples were out-performed by the non-densified samples. In combination with Polyester resin, the non-densified samples were 35% stronger than densified samples, and with Epoxy resin, the non-densified samples were 50% stronger. This could be due to the structural damage that occurs during the densification process.

7.3 Application in Surfboards

The intended purpose of the project – to determine the material's qualities in terms of surfboard applications – can be discussed in terms of the testing results. Results of impact testing offers the best picture for whether or not wood veneer can or should be pursued as a material with which to laminate surfboards. When averaged across all resin types, both types of woven veneer were outperformed by their fiberglass equivalents. The densified samples with Epoxy resin were slightly better than the 4oz-4oz Polyester resin combination, and the non-densified Epoxy resin samples were better than all fiberglass samples with Polyester resin. Within all samples using Epoxy resin, the fiberglass samples outperformed the woven veneer samples by 40% to 370%, at an average of 170% better.

While in most scenarios the veneer samples were outperformed by their fiberglass counterparts, non-densified woven veneer with Epoxy resin can be considered an alternative to standard fiberglass Polyester resin construction, if the change to Epoxy is not viewed as a negative by the intended consumer. This could offer the opportunity to take advantage of the aesthetic appeal and marketing opportunities for a veneered surfboard.

7.4 Further Testing Scenarios

A number of changes to the sample design and construction and testing methods can be made to improve the product and the results of testing, and have been briefly mentioned or commented on previously in this paper.

Pressure or weights should be applied to the woven veneer samples during the laminating coat. This will ensure a good seal between the fiber substrate and foam block, as well as decrease the depth variations in the surface that require additional resin to fill. This has the potential to solve the issues found in testing where there was too much resin for the woven veneer to interact with the steel ball upon impact.

Samples combining woven veneer and fiberglass could be designed and tested. This could create a slightly stronger material that performs comparably or better under impact than the woven veneer itself, but still takes advantage of the aesthetic qualities of wood.

Woven samples could be densified after weaving. While the densified samples did not perform as well as the non-densified ones, they did have better properties in terms of workability and decreased depth variations, as well as having improved aesthetic qualities. Densifying after weaving could create a very flat mat, enabling the woven veneer to more closely mimic the construction qualities of fiberglass.

The definition of failure could be better defined in future testing, perhaps requiring testing itself to determine what the appearance of a crack would be that would be detrimental to a surfboard. Testing would involve determining at what point water is able to be absorbed through the hard outer shell. The spider cracks that were not considered failure in this set of testing may prove to be actual failures, which would alter the results, potentially making wood veneer a more viable alternative.

Different veneer configurations would probably be the area in which changes would have the biggest impact on results. A non-woven style may overcome the resin application issues, as well as allow the wood fiber itself to have more of an impact in the strength of the samples. One method suggested by the project advisor, Professor Smith, would be to have alternating layers of unidirectional strips, loosely aligned to allow resin to penetrate the entire structure. This could either be accomplished by applying resin one layer at a time and allowing curing before the next layer, or doing all layers at once and allowing one set of curing to occur.

8.0 Conclusion

This project studied the materials used in a surfboard built by industry standard construction methods, specifically the fiber substrate – typically woven fiberglass cloth – wrapped around the foam core and the curing resin used to create a hard outer shell. The goal was to determine if a suitable wood based material could be used in place of fiberglass cloth and have similar properties – specifically the resistance to impact. Two different woven wood veneer mat types were tested against three different fiberglass cloth weight combinations, with all fiber substrate materials being tested with both Polyester resin and Epoxy resin. Construction methods used were described and documented, and followed typical methods used by both home surfboard builders and industry professionals.

Samples were tested using an Impact Testing Apparatus, which consisted of a vertically mounted piece of PVC pipe with holes drilled in the sides, through which a stainless steel ball could be dropped from specific heights onto a sample. Failure was determined to occur when circular cracks appeared on the surface of a sample and could be seen with the naked eye and felt with a bare finger.

Wood based samples were outperformed by their comparable fiberglass samples in all groupings, with the exception of comparing wood veneer samples made with Epoxy resin with fiberglass samples made with Polyester resin. However, when compared across all fiber substrates, Epoxy resin samples averaged 150% stronger than Polyester samples, showing that the resin was mainly responsible for this difference. While the wood itself did not add to the strength of the product in this example, it offers a manner in which woven wood veneer could replace fiberglass and create a comparable product, taking advantage of the aesthetic and marketing properties of a wood product.

While the woven veneer samples did not perform as well as the fiberglass samples, different veneer configurations should be studied which may overcome the reasons for their lack of performance suggested in this paper. Specifically, the additional resin required by the extra depth caused by the weaving pattern in the veneer may be overcome by compressing the mats after weaving, or by experimenting with unidirectional, and possibly layered configurations.

References

Shayesteh Haghdan and Gregory D. Smith, "Effects of Wood Reinforcement Configuration and Densification on the Fracture Behavior of Polyester Composites", In Proceedings of 67th FPS and 56th SWST Joint International Convention: New Technology and Marketing Practices in Natural Fiber-based Products, June 9-11, 2013, Austin, Texas.

Greenlight Surf Supply. http://greenlightsurfsupply.com/

Fiber-Tek. http://Fiber-Tek.ca/

Swaylock's Surfboard Design Forum. http://www.swaylocks.com/

Appendices

Figure 26: 4oz - 4oz “E” Polyester Resin Sample

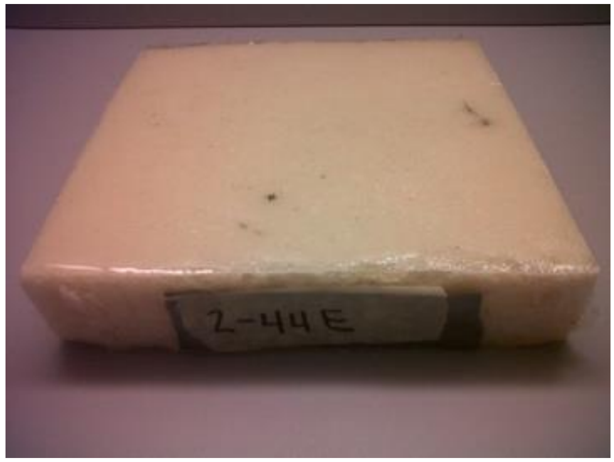


Figure 27: 4oz - 4oz “E” Epoxy Resin Sample

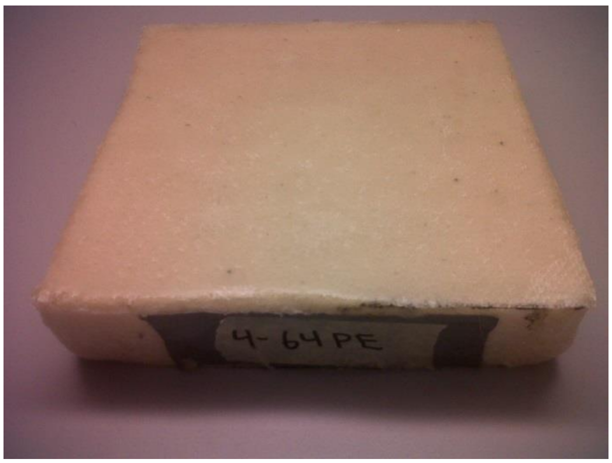


Figure 28: 6oz - 4oz “E” Polyester Resin Sample

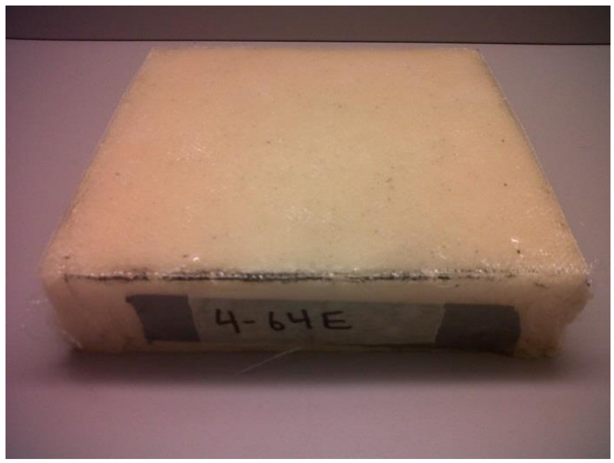


Figure 29: 6oz - 4oz “E” Epoxy Resin Sample

Figure 30: 6oz "S" Polyester Resin Sample

Figure 31: 6oz "S" Epoxy Resin Sample

Figure 32: Non-Densified Veneer Polyester Resin Sample

Figure 33: Non-Densified Veneer Epoxy Resin Sample

Figure 34: Densified Veneer Polyester Resin Sample

Figure 35: Densified Veneer Epoxy Resin Sample

Table 8: Mass Comparison

	Mass Comparison - Compared To:																
Factor	**PE Resin**	**Epoxy Resin**	**44**	**64**	**6S**	**D**	**ND**	**44PE**	**64PE**	**6SPE**	**DPE**	**NDPE**	**44E**	**64E**	**6SE**	**DE**	**NDE**
PE Resin	100.0%	94.8%															
Epoxy Resin	105.4%	100.0%															
44			100.0%	98.4%	103.6%	87.6%	79.4%										
64			101.7%	100.0%	105.4%	89.0%	80.7%										
6S			96.5%	94.9%	100.0%	84.5%	76.6%										
D			114.2%	112.3%	118.3%	100.0%	90.7%										
ND			125.9%	123.9%	130.5%	110.3%	100.0%										
44PE								100.0%	99.2%	107.5%	93.5%	81.9%	100.4%	97.8%	100.9%	81.9%	77.4%
64PE								100.8%	100.0%	108.4%	94.2%	82.6%	101.2%	98.6%	101.7%	82.5%	78.0%
6SPE								93.0%	92.3%	100.0%	87.0%	76.2%	93.4%	91.0%	93.9%	76.2%	72.0%
DPE								107.0%	106.1%	115.0%	100.0%	87.6%	107.4%	104.6%	108.0%	87.6%	82.8%
NDPE								122.1%	121.1%	131.2%	114.1%	100.0%	122.6%	119.4%	123.2%	100.0%	94.5%
44E								99.6%	98.8%	107.1%	93.1%	81.6%	100.0%	97.4%	100.5%	81.6%	77.1%
64E								102.2%	101.4%	109.9%	95.6%	83.7%	102.6%	100.0%	103.2%	83.7%	79.1%
6SE								99.1%	98.3%	106.5%	92.6%	81.2%	99.5%	96.9%	100.0%	81.1%	76.7%
DE								122.1%	121.1%	131.3%	114.2%	100.0%	122.6%	119.5%	123.2%	100.0%	94.5%
NDE								129.3%	128.2%	138.9%	120.8%	105.9%	129.8%	126.4%	130.4%	105.8%	100.0%

Table 9: Energy at Failure Comparison

	Energy at Failure Comparison - Compared To:																
Factor	**PE Resin**	**Epoxy Resin**	**44**	**64**	**6S**	**D**	**ND**	**44PE**	**64PE**	**6SPE**	**DPE**	**NDPE**	**44E**	**64E**	**6SE**	**DE**	**NDE**
PE Resin	100.0%	39.8%															
Epoxy Resin	251.1%	100.0%															
44			100.0%	71.5%	112.1%	243.0%	165.9%										
64			139.8%	100.0%	156.7%	339.8%	232.0%										
6S			89.2%	63.8%	100.0%	216.8%	148.0%										
D			41.2%	29.4%	46.1%	100.0%	68.3%										
ND			60.3%	43.1%	67.6%	146.5%	100.0%										
44PE								100.0%	84.0%	75.0%	144.2%	105.5%	32.6%	19.6%	43.5%	92.0%	61.9%
64PE								119.0%	100.0%	89.3%	171.7%	125.6%	38.8%	23.3%	51.8%	109.5%	73.7%
6SPE								133.3%	112.0%	100.0%	192.3%	140.7%	43.5%	26.1%	58.0%	122.7%	82.6%
DPE								69.3%	58.3%	52.0%	100.0%	73.2%	22.6%	13.6%	30.2%	63.8%	42.9%
NDPE								94.8%	79.6%	71.1%	136.7%	100.0%	30.9%	18.5%	41.2%	87.2%	58.7%
44E								306.4%	257.4%	229.8%	441.9%	323.3%	100.0%	59.9%	133.2%	282.0%	189.7%
64E								511.1%	429.5%	383.3%	737.2%	539.3%	166.8%	100.0%	222.3%	470.4%	316.5%
6SE								229.9%	193.2%	172.4%	331.6%	242.6%	75.0%	45.0%	100.0%	211.6%	142.4%
DE								108.7%	91.3%	81.5%	156.7%	114.7%	35.5%	21.3%	47.3%	100.0%	67.3%
NDE								161.5%	135.7%	121.1%	232.9%	170.4%	52.7%	31.6%	70.2%	148.6%	100.0%