DESIGN AND MANUFACTURING OF NATURAL COMPOSITE CANOE

by

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Abstract

This report looks into the application and feasibility of manufacturing natural composite canoes. The main fabrics that were analyzed are flax, hemp, and jute. These were then compared to carbon fiber and fiberglass to see the difference in mechanical properties. It was found that the natural fibers have lower mechanical properties but that this could be overcome by designing a balsa wood core with ribs running up the walls. After manufacturing a hemp canoe, many lesson were learned and areas of interest were further explored. With the use of different natural fibers, these canoes can greatly reduce the carbon footprint. They are cheaper, easier to harvest, and much friendlier to the environment.

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Introduction

Canoes are a popular choice amongst outdoor environmentalist types, but sadly, most canoes are made from non-biodegradable materials, and manufactured in ways that generate a large carbon footprint including toxic pollution. Many canoe builders have been looking for better material to build with but have yet to find an adequate solution. In this thesis the possibility of using natural fibers and more environmentally friendly materials, such as epoxies and bamboo, as well as their feasibility in the manufacturing processes, will be examined.

The goal of this project is to reduce the carbon footprint of manufacturing processes by making a canoe, which has at least 50% natural materials by weight. If a canoe can be made from natural composites and still perform like synthetic canoes, the atmosphere will be much cleaner and safer. Companies have just started looking into natural composite canoes, which makes this an ideal problem to solve.

This project originated after talking with a couple of students who were trying to find ways to produce natural composite I-beams which were just as strong as carbon fiber I-beams. The scope was then shifted into creating rigid flat panels for a canoe instead of I-beams and trying to maximize strength and stability while minimizing cost and weight.

An explanation of how canoe manufacturers currently make canoes and what kinds of materials are used will be described. This report will also look into the different kinds of natural composites that can be used and compared to the current materials being used. This will show that synthetic materials are not always the best choice for a canoe.

The main deliverable will be a natural composite canoe, but with this canoe come many different methods and materials that can be used in order for a “greener” canoe. Many Industrial

Engineering courses will be used when building the canoe as well as analyzing the results. A cost analysis will be conducted in order to show that a natural composite canoe is more economical than using carbon fiber.

Background

Canoes have been around for at least 3000 years and originated with the Polynesian culture. [11] The Polynesians originally made canoes from dug out logs and have evolved over the years to be designed from various materials. It is not until recently that both consumers and manufacturers are finding different ways to make these watercrafts.

Many canoe manufacturers make great products that are functional and responsive. However, the processes and materials that go into making these products are detrimental to the environment and can be very inefficient. These materials range from wood and plastic to aluminum and composite materials. Supplemental materials also range from different types of adhesives to waterproofing materials.

Bamboo was and still is used to make boats and canoes in Asia because it grows plentiful and is extremely strong and lightweight. It is a grass and can be bent relatively easily. As cultures became more sophisticated it was discovered that different materials could be used to produce these boats.

Some of these materials include plastics and composites. However, after experimenting and researching, it was found that natural fibers can be used which provide the same structural integrity as these other materials. With natural fibers, the only thing necessary is enough land and harvest capability so it can be planted and eventually harvested. The carbon footprint is

greatly reduced, as there are minimal synthetic processes that go into planting and harvesting natural fibers. Some of the fibers, which have similar properties of carbon and glass fibers, include: Flax, Hemp, Jute, and Pineapple. Figure 1 shows a comparison of some natural fibers in raw form before being processed.

Figure 1: Comparison of natural fibers

When producing composites, resins are always an associated product because they need some form of adhesive to saturate the fibers and bond the fabric. Many of these leading companies produce resins that are synthetic and harmful to the environment. However, there are actually a couple of companies that are creating natural resins that are plant based instead of petroleum based. These companies claim that they are as strong as the leading petroleum based resins. With a plant-based resin, the carbon footprint is greatly reduced.

Literature Review

"Sustainability means ensuring human rights and well-being without depleting or diminishing the capacity of the earth's ecosystems to support life, or at the expense of others well-being." [9] Sustainable development has been increasing in the past years as alternative manufacturing processes and products, which reduce the carbon footprint, are being investigated. Companies have started looking into renewable energy and sustainable efforts, which reduce the carbon footprint and greenhouse gasses. However, if there is no method of maintaining these efforts, there will be no way to continue the search for renewable energy. According to an energy-based economic development program there is a way to improve our situation with "job creation, alternative energy, industry development, economic and energy diversification, energy efficiency savings, and greenhouse gas savings." [3] During 2009, the American Recovery and Reinvestment Act gave over $50 billion towards finding alternative energy, green jobs, and energy efficient solutions. However, if there was no way to regulate all these initiatives and implement the standards of this energy-based economic development program, this money could be compromised and go to waste. [3] This is a big issue because if there is no way to regulate these initiatives and standards, the money spent will not be worth the efforts. This means that there needs to be standards to follow when developing these alternative methods and jobs. If the benefits of these alternative methods and jobs maximized, the carbon footprint will start declining worldwide.

One reason natural fibers are being used is because they are carbon neutral. This means that they release the same amount of carbon dioxide they absorb. A second advantage of using

natural fibers is that "during processing, they generate mainly organic wastes and leave residues that can be used to generate electricity or make ecological housing material. And at the end of their life cycle, they are 100% biodegradable." [10] Natural fiber technology is arising because of its potential to replace glass fibers. [7] It is much better on our environment as well as economy to produce natural fibers rather than glass fibers. Table 1 shows some statistics when comparing the production of 1 kg of hemp fibers and 1 kg of glass fibers.

Parameters	Hemp fiber	Glass fiber
Power consumption (MJ)	3.4	48.3
CO_2 emission (kg)	0.64	20.4
SO_x emission (g)	1.2	8.8
NO_x emission (g)	0.95	2.9
BOD (mg)	0.265	1.75

Table 1: Environmental parameters in production of hemp and glass fibers

Because carbon fibers require such a high amount of energy to produce with little reusable materials, the use of natural fibers are being explored. "It has been demonstrated that the energy needed for production of natural fibres is, on average, more than half of the amount needed for synthetic fibres." [4] Figure 2 shows the amount of energy required to produce fibers. It is clear that carbon requires substantially more energy to produce compared to sisal, flax, hemp, and glass. Looking further, glass still requires much more energy to produce when compared to the natural fibers. Because of the vast difference, these fibers need to be explored for their feasibility in the use for composites. Natural fibers are much easier to produce and are completely renewable. Because of this they, produce much less emissions and harmful toxins.

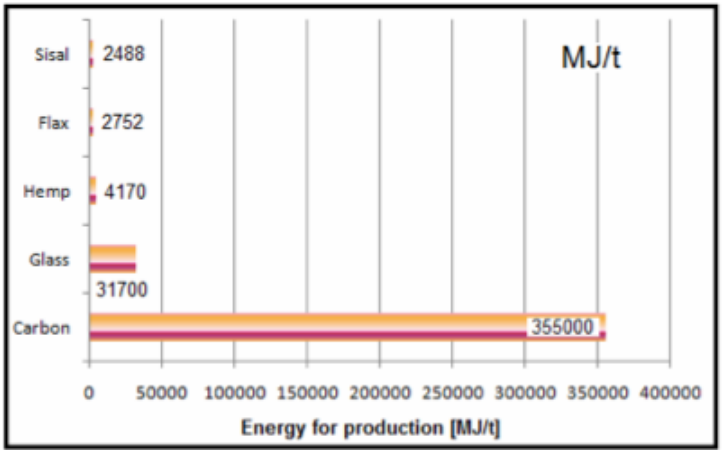

Figure 2: Energy required to produce fibers (Source: University of Catania, Italy [4])

Canoes vary in material and weight, and it is up to the paddler to decide which kind of canoe to use or buy. Many beginners choose a canoe based on the price while experienced paddlers who know what they want will end up paying a little more in order to end up with a canoe that fits his or her needs. There are four basic variations in canoe material, which include: Aluminum, wood, plastic, and composite materials.

Aluminum is a common material used for manufacturing canoes and was thought of as "the standard for decades." [2] Aluminum canoes are inexpensive to manufacture as well as extremely durable. For someone who wants a canoe that will last with very little maintenance, aluminum is the canoe of choice. One of the downfalls of an aluminum canoe is the weight associated with it. These canoes can be upwards of eighty to ninety pounds. However, these canoes are becoming less popular as different materials are being used to produce canoes. As you can see from Figure 3, a typical aluminum canoe does not need a synthetic waterproofing agent. However, shaping the aluminum into a canoe can require energy and equipment that pollutes the environment.

Figure 3: Aluminum Canoe

Wood canoes are popular because of the versatility of use and types of wood to make them out of. There are many different types of wood to use depending on what one wants the canoe to look like or how light that person might want to make his or her watercraft. Many enthusiasts choose to construct or purchase a wooden canoe because it is easily customizable and there are various ways to make them. Most people would agree that wooden canoes aesthetically look better because the grains are visible and it is a natural look. Figure 4 is a depiction on a typical wooden canoe. Some enthusiasts will even go as far as making a wooden canoe by hand as opposed to purchasing it from a store. While these kinds of canoes might be heavier than overs, they are oftentimes the canoe of choice because of the superior look that is produced.

Figure 4: Wooden Canoe

Plastic canoes seem to be widely used solely because of the cost and resistance to wear and tear. While they are heavy and less responsive, they are one of the cheapest ways to manufacture a canoe. Manufacturers will use injection-molding techniques, which is quick and effective as well as producing the exact same canoe every time. Plastic canoes are popular

because they are easily accessible for purchase or rent. Many outdoor stores or rental companies will carry some form of plastic canoe. They can get banged up and scratched up and it does not compromise functionality or aesthetics. Figure 5 is a depiction of a typical plastic canoe. They usually come in a couple of configurations with many different color options. Because they are made from plastics, they are cheaper to manufacture but more harmful to the environment during the process.

Figure 5: Plastic Canoe

Composite canoes are becoming much more popular and desirable for any paddler because of the lightweight and high performance properties associated with them. Composite canoes can range from 20 pounds to 40 pounds. Compared to an 80-pound aluminum or plastic canoe, this is extremely desirable for most enthusiasts. Because of this lightweight property, these canoes become very responsive on the water enabling any paddler to make sharp turns or maneuvers. In addition, these canoes are much easier to transport. This can be a very desirable trait when one has to carry his or her canoe from one body of water to the next. However, lightweight canoes come with a price. They are one of the most expensive forms of canoe on the market. Because of the price and resources used to produce carbon fiber, it is expensive. Figure 6 shows the aesthetic difference of a carbon fiber canoe and natural composite canoe. The

natural composite canoe is made from flax fibers instead of carbon fibers.

Figure 6: Carbon Fiber Canoe vs. Flax Fiber Canoe

While some canoe companies are getting into the composite industry, which might increase the carbon footprint, Mad River Canoe is taking their first steps towards a sustainable canoe. They call it the Malecite Eco and it is manufactured with almost 70% natural materials. This canoe is made with corn-based clear gel coat, which is applied to the outside of the canoe to help with waterproofing. The hull (or body) material is made from fiberglass surrounded with hemp. This fiberglass is set between the inner and outer hemp layers in order to add stiffness and protect from impact. Wood components are used in creating much of the trim (gunwales) and seats. While their canoe is not 100% natural, they are making big steps in the canoe world. [6] This is a big step for the canoe industry because natural composite canoes are still in the early stages of development. Few companies are making flax composite canoes in Europe, like EcoComposites in Spain and Flaxland in the United Kingdom, however it is still a very new process in the United States. Figure 7 shows Mad River Canoe's Malecite Eco. It is a concept idea and they are exploring alternative methods and materials to continue a line of natural composite canoes.

Figure 7: Malecite Eco Canoe from Mad River Canoe

Some might not believe that a natural composite canoe is as strong as a fiberglass or carbon fiber canoe. However, the material properties might be able to justify this accusation as incorrect. The Young's Modulus, or stiffness, of fiberglass ranges from 50-90 GPa and the density is about 1.9 g/m^3. [5] This can be compared to flax with a stiffness range of 50-70 GPa and density of about 1.45 g/m^3 and hemp with a stiffness range of 30-60 GPa and density of about 1.45 g/m^3. [4] As these numbers show, the natural fibers are similar to fiberglass and when woven together can be very comparable to fiberglass.

Natural fibers have a high potential to eliminate other forms of composites because of their mechanical properties when compared to carbon fiber and glass fiber. Some of the benefits include biodegradability, lower cost, and lighter weight. [1] A study was conducted that looks at the mechanical properties of natural fibers and is then compared to carbon fiber and glass fibers using renewable resins. The study looked at different ways to orient flax fibers in order to provide the best results using different resins and different amount of layers. It was concluded that a woven flax fabric with layers oriented at 0^o provided similar mechanical properties as glass

fibers. It was also concluded that "these composites can even compete with glass fiber composites in terms of stiffness, especially when their specific properties are considered. The low weight of the natural fiber (without glass fiber) gave lighter composites." [1]

Design

Solution Approach

There were many factors that went into the design phase of these canoes. Being as there are not many companies building natural composite canoes, it was difficult to follow a specific, proven, design. The first requirement in the design phase was to become familiar with common canoe manufacturing processes and materials used. As mentioned earlier, many materials used include: aluminum, plastic, wood, and carbon fiber. The next step was to research natural fibers and materials that would be suitable for canoe construction. Thirdly, once all the research was done, building the canoes was the next step. And finally, once this was done, an economical analysis was completed in order to show the benefits of using natural fibers compared to carbon and glass fibers.

Goals

The main goal of this project was to manufacture two sixteen-foot canoes made from 100% natural materials. It was later found to be extremely difficult and the scope was changed to making the canoe from 80% natural materials. A second goal was to show that manufacturing natural composite canoes could have the same, if not similar, strength to weight ratio as carbon fiber canoes. In other words, the canoes needed to be stiff enough for use in the water as well as being light like carbon fiber canoes. Another goal was to show that manufacturing natural

composite canoes are economical and would save money by using natural materials. This was an important goal because the canoes needed to be economically just in order to make it feasible to start constant manufacturability. Lastly, decreasing the carbon footprint was a major concern. Because carbon fiber is so harmful to the environment, producing canoes with nearly zero carbon emissions was a major benefit. It shows that there are steps being taken towards a greener future.

Constraints

There were some constraints during the manufacturing process of this project. The first, and most notable, would be the equipment needed to manufacture the canoes. Some equipment and materials that were in the initial design process were expensive and not readily available. The first step in manufacturing this canoe was obtaining the mold. The mold was received by a local boat builder/engineer who made the canoe mold. This man first needed to make a model of it and then actually build it. This was a difficult and time-consuming task, yet extremely important to the construction of the canoe. Next, vacuum bag and vacuum pumps were difficult to come by. This resulted in alternative ways to manufacture the canoe. The manufacturing process had to be tailored to the fact that some equipment was not available and could not be used. This caused many issues that needed to be dealt with, including how long it would take to manufacture the canoes.

Time required to manufacture the canoe was another constraint. The resin that was used had specific pot times and cure times. The pot time is the time from when the two-part resin is mixed (resin and hardener) to the time it starts to congeal. The cure time was the time required for the resin to fully dry and harden. Between these two times, seven hours was required. This

meant that after the layup process was completed, seven continuous hours needed to be allotted for the canoes to dry and harden.

Workspace availability was an issue that had to be dealt with. Because of the size of the canoes, a large space was needed for the manufacturing process. In addition to a large physical workspace, because the nature of the project, the only place these canoes could be manufactured was on campus in one of the labs. This required the actual manufacturing process to occur once all the classes were over and the students had left. This did not prove to be a big inconvenience but did require some additional planning.

Cost was the last, and biggest, constraint faced during this project. One of the goals was to manufacture the canoes while keeping cost at a minimum. This required much research to find the materials that would be suitable for a canoe while not spending too much money. Because cost was a constraint, this project took much longer than anticipated. However, the results were better because more research was done at looking into alternative materials.

Materials Used

When manufacturing the canoes, natural materials were a big focus in order to achieve some of the goals. After much research and testing, the materials in Table 2 were used for the construction of the canoes.

Material	Used For
Flax/Hemp Fabric	Canoe Skin
EcoPoxy Resin Epoxy	Soy Based Epoxy
Balsa Wood	Core Design
Bamboo	Core Design

Table 2: Materials Used for Canoes

As seen from Table 2, the fabric used to skin the canoe was made from a flax and hemp weave. This fabric was then soaked with a natural epoxy resin. The resin is soy based instead of petroleum based and can be reused if processed correctly. The resin is from a company called Eco Poxy Systems and it compares to the leading brands of epoxy resins. For the core of the canoe, balsa wood and bamboo were used in creating a natural core.

Core Design

As mentioned earlier, these natural fibers have similar properties of fiberglass and carbon fiber. That being said, they do not have the same properties and actually, have lower stiffness properties. Because they are not as stiff, a core design was essential in order to give the canoes added stiffness. For a core design, balsa wood and bamboo were used instead of a typical foam core design. The balsa wood was for the bottom of the canoe and the bamboo was used as ribs going up the walls of the canoe. With this design, a natural composite canoe was possible and stiff enough to venture into the waters. Figure 8 shows an overhead view of the core design without bamboo. This illustration shows how the bamboo is sandwiched between the two pieces of fabric.

Figure 8: Core design incorporating fabric and balsa wood

Lessons Learned

After the completion of these canoes, there were many lessons learned throughout the entire process. One major lesson learned was about proper and improper manufacturing methods. For the first canoe, plastic was placed on top of the fabric and then filled with water. The purpose of this was to allow the fabric to take the shape of the mold instead of sagging. However, after this was done, the canoe was not stiff enough. It was discovered afterwards that the resin must cure at room temperature. Using water to push the fabric to the mold, the curing temperature moved from about 70 degrees Fahrenheit to about 45 degrees Fahrenheit. This was a major problem and was the leading factor for the first canoe to not turn out well. Later, the canoe mold was split in half and a combination of air drying and vacuum bagging was used. As seen from Figure 9, a plastic sheet was placed over the canoe while it was being filled with

water. Figure 10 shows the canoe in a vacuum bag, which is the ideal way to manufacture these canoes.

Figure 9: Canoe being filled with water

Figure 10: Canoe curing using a vacuum bag

Another lesson learned through this process was about the type of weave used for the fabric. The original design was to use a herringbone weave for the fabric. After completing the first canoe, it was determined that this weave was not ideal for using in a canoe. Instead, a tighter weave like twill or a 0°/90° orientation would be best suited for this application. Please see Figure 11 for a comparison of these weaves.

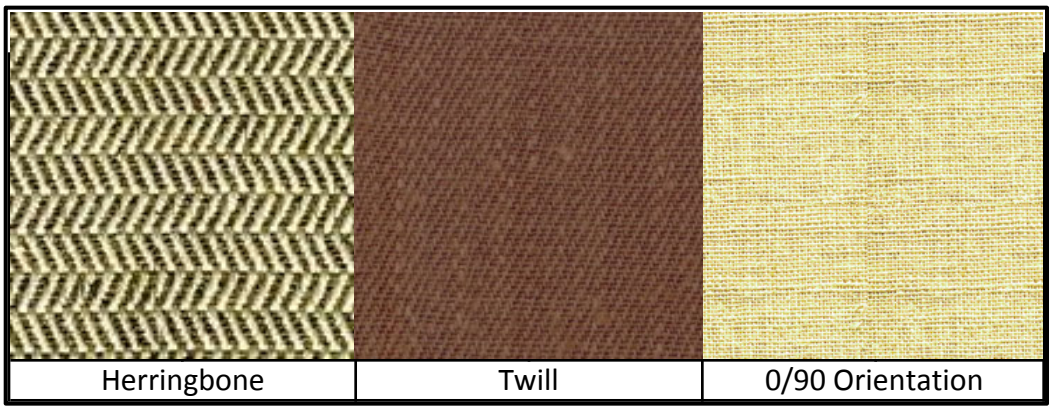

Figure 11: Comparison of Herringbone, Twill, and 0/90 Orientation weaves

Improved Design

After discovering concepts and methods that were optimal, the second canoe was manufactured. The main difference in the second canoe was the core design. The original canoe only had balsa wood on the bottom and was not stiff enough in the sides. In order to fix this problem, ribs needed to be inserted to add stiffness and rigidity. Bamboo ribs were used to accomplish this task. In order to get the bamboo to take the shape of a rib, heat was added to bend into the exact shape it needed and then cold water cooled it down and allowed it to keep the shape.

Methodology

The methodology approach taken for these canoes goes as follows. First, identifying current materials and methods used to manufacture canoes. This was important in determining how they are already made and possible improvements. Next, extensive research was conducted to find natural materials with similar properties as fiberglass and carbon fiber. In addition, core materials were looked into in order to find suitable materials to accomplish this design. The main materials that were looked into were flax, hemp, jute, bamboo, and balsa wood. The next step in the process was to manufacture an eco-friendly canoe followed by an economical analysis. This last step was very important to show because it gives justification to manufacture natural composite canoes by showing how much the boating community would save.

In addition to these steps taken, project management was a big factor in this project. A project plan with deadlines was essential to keep on track so the canoes were finished in time. Human factors and ergonomics was a subject area that needed attention as well. In order for the majority of the population to fit in this canoe, seat height needed to be specified as well as the thwart and yoke design. Figure 12 shows a basic design and some of the components of a canoe.

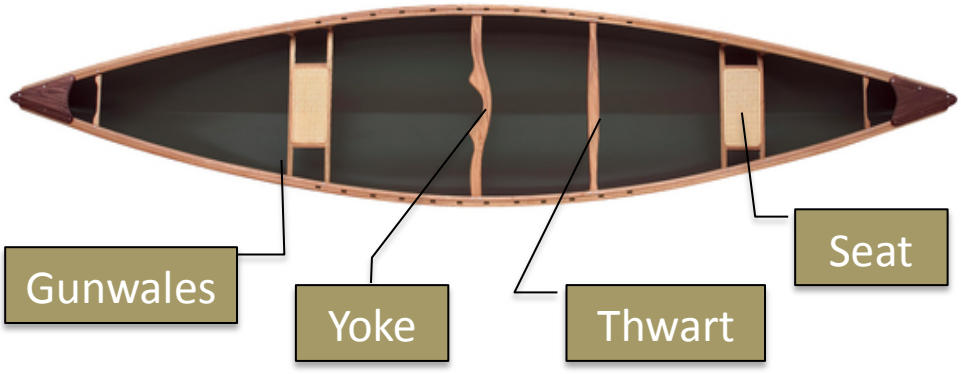

Figure 12: Basic schematic of a canoe

Design of experiments was another methodology approach used for the canoes. If this canoe were to be mass-produced, there would need to be standardization in the manufacturing process. This would lead to consistent products every time. One way consistent canoes can be manufactured would be to use a vacuum bag for the curing process. This would help eliminate any bubbles in the material and give a smooth finish every time.

Results

The original canoe was a great learning experience however, it did not turn out as expected. There were a couple factors that caused the canoe to turn out poorly. One factor was using the wrong resin. The resin used was not meant for marine applications and did not provide the stiffness required for the canoe. The second factor that caused the canoe to turn out poorly was how the fabric was cured. A vacuum could not be used because there was not enough material to encompass the entire canoe, so it was decided to put a sheet of plastic inside the canoe and fill it with water. The idea behind this was that it would help push the fabric to the mold and give it a nice shape. It was later determined that this was not a good decision because the resin needed to cure at a certain temperature. Bringing the temperature down to about 45 degrees Fahrenheit resulted in poor curing. Figure 13 is a picture of how this was accomplished.

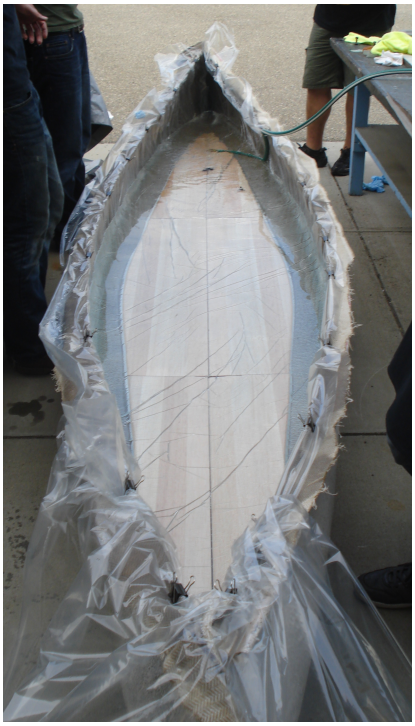

Figure 13: Canoe filled with water in order to take the shape of the mold

After the first canoe was completed, analysis was done and processes were re-thought. There needed to be a better way to manufacture a canoe that would give great results and stiffness. The first thing that was done was to order the correct resin. This was a big mistake that should have been caught the first time. However, it was a great learning experience to know that not all resins have the same stiffness. Once the first layer was finished, ribs needed to be inserted going up the walls of the canoe. There was much deliberation, but after some experiments, it was decided to use strips of fabric as the ribs. This provided enough stiffness for the walls of the canoe. Then the balsa core was placed on the floor of the canoe later to be covered by a second layer of fabric. The canoe was manufactured by splitting the mold and laying up each half. Once the two halves were finished, the canoe was put back together and sealed.

Conclusion

Canoeing is and always has been a growing hobby. Enthusiasts are finding new ways to make canoes lighter and stronger. But what they might not realize is that some of the methods and materials used are extremely harmful to the environment. With the use of natural composite fibers, the harmful toxins being released into the atmosphere are drastically reduced. In addition to this, they still have the strength to weight ratio needed for use on the water. Because the natural fibers are not as strong as carbon fibers, extra precautions and structural support needed to be added to the canoes. A core design was essential in order to get added stiffness on the bottom of the canoe. Using a balsa wood core provided this stiffness with little added weight. In addition to the core design, the canoe needed ribs going up the walls. To accomplish this, fabric was used for ribs, which also added much stiffness. Although natural fibers are not as strong as carbon fibers, canoes can still be constructed with natural fibers. However, extra structural precautions needed to be addressed.

There are many benefits to using and manufacturing a natural composite canoe. Because the materials are natural and sustainable, there is a great reduction of the carbon footprint. In addition, they are much cheaper to purchase and, for some materials, import. If the United States grew and harvested natural fibers such as jute, hemp, and flax there would be no need for import tariffs. Currently the tariff rate is six percent on all natural fibers being imported to the country. [8] If the United States did not have to pay these tariffs, they would save a lot of money just for import fees.

Natural composite canoes are very new to industry. They are still in the early stages and not many companies or individuals are making these types of canoes. However, once the

manufacturing process is perfected and other small problems are solved, natural composite canoes will be very desirable.

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