NON-WOVEN FABRIC COMPOSITES: A POTENTIALLY HUGE MARKET FOR COIR FIBER IN AUTOMOTIVE AND BUILDING CONSTRUCTION MATERIALS

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Introduction

Whole Tree Inc (WTI) is a triple bottom-line company that was incorporated in November, 2008 to commercialize technology developed and patented at Baylor University. WTI seeks to identify abundant renewable resources in under developed countries that can be grown by poor farmers but are under-utilized at present. Using research and development, WTI creates innovative applications that provide large markets at good price points for these currently under-utilized renewable resources. In this paper, the research and development work that has been done to create large new markets for coir fiber will be presented.

Fig.1 Typical pile of waste husks in tropical regions

Over 50 billion coconuts grow annually around the world, making coconuts an abundant, renewable resource, with 95% owned by poor coconut farmers who make less than $500/year.[1] Coconut milk or oil is the primary commercial product from the coconut, with a small fraction of the coconut shell used to make activated carbon and most of the rest used to make charcoal, with a very low price point. A significant percentage of the husks from these coconuts are discarded and burned as trash, since the primary markets for coir fiber from the husks are mattress stuffing in China and twine and rope production in India and Sri Lanka. The annual demand is much smaller than the annual supply, making coir fiber an abundant, under-utilized renewable resource, as seen in Figure 1. WTI's goal has been to identify large new applications for coir fiber that take full advantage of its unique properties and therefore command a significantly higher price point than the ~$200/MT that is currently paid.

Unique Properties of Coir Fiber that Give it Competitive Advantages

The first step in Baylor University and WTI's R&D was to determine what are the unique properties of coir fiber that could give it a competitive advantage in the marketplace. Some results were obtained from technical literature and some were the result of research performed at Baylor University, with whom WTI partners. A summary of the findings is as follows:

- Coir fiber is the ONLY natural fiber that is derived from a fruit rather than a leaf, stem, or branch of a plant.
- Coir fibers derive their properties from their function in nature, which is to protect the coconut (or seed of coconut tree) from breaking on impact after a 20-25m fall and from the environment, including some resistance to fire.

Figure 2. Coir fiber, PP fiber, and coir:PP nonwoven fabric

Figure 3. PE fiber, PP fiber, and PE:PP nonwoven fabric

- Coir fibers are the most lignin rich natural fibers, with a lignin content of 35%, compared to most woody fibers and materials at ~5-15%.[2] Lignin has a chemical structure similar to a phenolic resin, which is hard and resistant to oxidation (or burning).
- The chemical structure of lignin makes it indigestible for fungi and other kinds of micro-organisms. This means that coir fiber is not easily degraded by various kinds of microorganisms, including those abundant in the air, and therefore, does not have the odor problems that are associated with many natural fibers.[3] Further evidence of this resistance to pests if found in the lack an any requirements to spray coir fiber before it is shipped to the United States. There is simply no pest or odor problem with coir fiber.
- The high lignin content also makes the coir fiber very resistant to fire, with the fibers typically charring on the surface but not burning across the thickness. In fact, lignin fibers are usually self-extinguishing, at least for horizontal burn tests like those used for automobile parts.[4]
- Coir fibers derived from the husks are unusually ductile, with an elongation of more than 20% in tension, which gives the husks a large energy absorbing capacity on impact.[5] This is remarkably better than most natural fibers which have an elongation of 1-2% in tension.[6]
- Coir fibers have a tensile strength of ~120 MPa, which is moderate in comparison to other natural fibers, better than some but less than others.[6]
- Coir fibers have a relatively low tensile modulus of elasticity (for same reason they have a high ductility)[6].
- Coir fibers have diameters that typically range from 150μm-200μm[7], compared to most natural and synthetic fibers with diameters of 50μm. Since the bending stiffness of all fibers depend on "D^4", where D is the fiber diameter, the flexural rigidity of coir fibers, which is given by $E_f I$ (E_f = flexural modulus; $I = \pi D^4/4$) is much higher for coir fiber than most natural or synthetic fibers due to its much larger diameter. As a result, coir fiber has a high resilience in bending. ***Resilience*** is the property of a ***material*** to absorb energy when it is deformed elastically and then, upon unloading to have this energy recovered.
- Coir fibers come naturally with a thin, high molecular weight waxy coating.[8] The waxy coating gives excellent chemical compatibly between coir fiber and polymeric fibers such as polypropylene (PP) and polyethylene (PE).

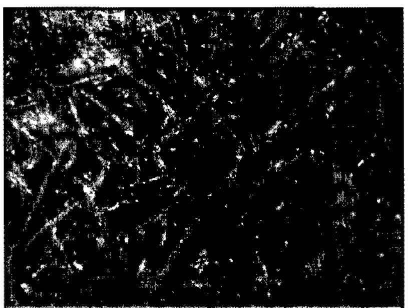

Figure 4. Rigid web of coir fiber and melted PP

Furthermore, the fibers are relatively rough, giving some mechanical/frictional supplement to the chemical bonding between coir fibers and matrix polymeric materials that are non-polar such as PP

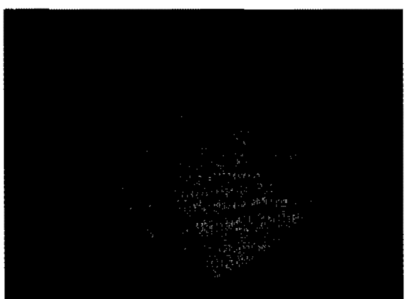

Figure 5. Cutout of molded and shaped coir:PP non-woven

and PE. The practical consequence of this is that coir fibers are easily wetted by other non-polar polymers such as PE and PP. It is as if the coir fiber comes with its own sizing or interfacial compatiblizer to give excellent wetting with PP, PE and other non-polar polymers

In summary, the coir fiber is seen to have a very unique set of physical and mechanical properties that should make it an excellent candidate to be used in polymeric composite materials, either solid plastics or non-woven fabric composites.

Non-Woven Fabric Composites: An Idea Application that Utilizes Coir Fibers' Unique Properties

The second step in Baylor University and WTI's R&D process was to identify applications that could take advantage of the unique combination of properties described above. Non-woven fabric composites represent an attractive possibility since they are widely used in the automotive and building materials industries. To make a non-woven fabric composite, two or more types of fibers are blended together and subsequently deposited with random orientations (and no weaving) to form a fluffy mat. The fluffy mat then passes through a roll to increase the density to the desired value, typically between 0.05 and 0.2 g/cm^3. Either needle punching (but not weaving) or adhesives can be used to bind the fibers together in the felted material. The felted materials produced are called "carded and needle punched" or "air laid" respectively. Needle punched materials use fibers that are 5-7.5 cm in length while air laid typically used fibers that are 1-2 cm in length. Examples of needle punched, felted material are seen in Figure 2 for polypropylene and polyester and in Figure 3 for polypropylene and coir fiber. The blend is 50:50 for both materials. Note that the coir fibers are much larger than the polypropylene or polyester synthetic fibers.

In the selection of fibers for blending, typically a lower melting point thermoplastic such as polypropylene is used in combination with a higher melting point thermoplastic such as polyester or a thermosetting fiber such as coir fiber. The non-woven fabric composite felted material is subsequently heated to a temperature in the processing window, which is above the melting point of the thermoplastic fiber (180C for polypropylene) and below the degradation temperature of the coir fiber (230C), and then compression molded. The lower melting point polypropylene fibers flow and effectively "bond" together the higher melting point coir fibers into a more rigid web, as seen in Figure 4. The mold both shapes and cools the heated, non-woven fabric, resulting in a rigid part at ambient temperature with the shape of the mold, as seen in Figure 5. The bulk density after compression molding is typically between 0.4 and 1.0 g/cm^3. A wide variety of parts with simple or complex shapes can be manufactured economically using compression molding of non-woven fabric composites.

A new non-woven fabric composite made of coir fibers and recycled polypropylene fibers has been developed at Baylor University, who has filed a utility patent that is currently pending.[9] Baylor University has licensed this international patent to WTI to be commercialized and WTI has further refined the technology to support this new non-woven fabric composite material called CoirForm. The unique properties of the coir fiber are reflected in the unusual combination of properties of CoirForm non-woven fabric composite material. CoirForm is (1) resistant to environmental degradation, is (2) not attacked by microbial organisms that give odor problems (a common problem with many natural fibers), is (3) resistant to burning, has (4) excellent formability and impact strength and has (5) excellent flexural rigidity (or bending stiffness).

CoirForm's commercial potential can be seen by comparing it to one of the most popular non-woven fabric composites used in industry today. With some adjustments in processing temperature and pressure, CoirForm can be seamlessly substituted for the PE:PP non-woven material that is widely used in automotive and building construction materials. Because coir fibers are much stiffer than polyester fibers, CoirForm compression molds to a lower density (~0.5 g/cm^3) than does the polypropylene/polyester non-woven (~0.9-1.0 g/cm^3). A wide range of densities can be achieved in CoirForm by varying the compression molding temperature and pressure. The tensile strength and flexural modulus are seen to increase with increasing density in compression molded flat test specimens, as seen in Figure 6 for CoirForm and PE:PP non-woven material.

The lower density for compression molded CoirForm means that a felt with an areal density of 1000 g/m^2 will compression mold to a thickness of ~2mm whereas the polypropylene/polyester will compression mold to a thickness of ~1mm. The flexural rigidity of a material is determined by $E_f \cdot I$, where E_f is the flexural rigidity and I is the moment of inertia, calculate as [width x (thickness)^3/12] for parts with rectangular cross-sections. Though the CoirForm material has a lower flexural modulus (because of its lower density) it will have a much higher flexural rigidity due to its greater thickness, as seen in Figure 7.

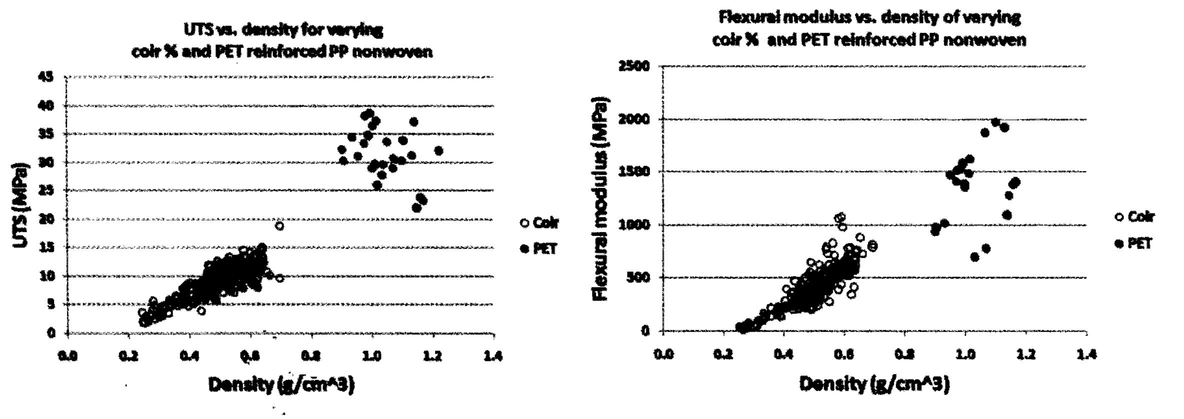

Figure 6. UTS and E_f comparison of compression molded coir:PP and PET:PP

Automotive Applications of Non-woven Fabric of Polypropylene and Coir Fiber

Non-woven fabric composites are widely used in the automotive industry to make interior parts for automobiles. For example, non-woven fabric composites are used to make door panels, headliners, dashboards, trunk liner and wheel wells. An average of approximately 30 kg of non-woven fabric composite material is used in each mid-sized automobile, making this a substantial market in the United States and worldwide. The most common non-woven composites are made from polypropylene/polyester and polypropylene/glass, though there is a growing interest in the use of natural fibers such as hemp, kenaf, flax, jute and coir with polypropylene. Coir's properties as described above make it a particularly attractive candidate for use in non-woven fabric composites.

The production of CoirForm from coconut husk to a 2 meter wide roll of needle-punched, felted material is seen in Figure 8. This material can be cut into suitable sized pads that can then be pre-heated and compression molded into automobile parts. The density of the CoirForm after compression molding will depend on the temperature and pressure used, with the temperature ranging from 180C to 230C and the pressure varying from 0.35 to 1.50 MPa. The modulus of elasticity and tensile strength will increase with increasing density as seen in Figure 6.

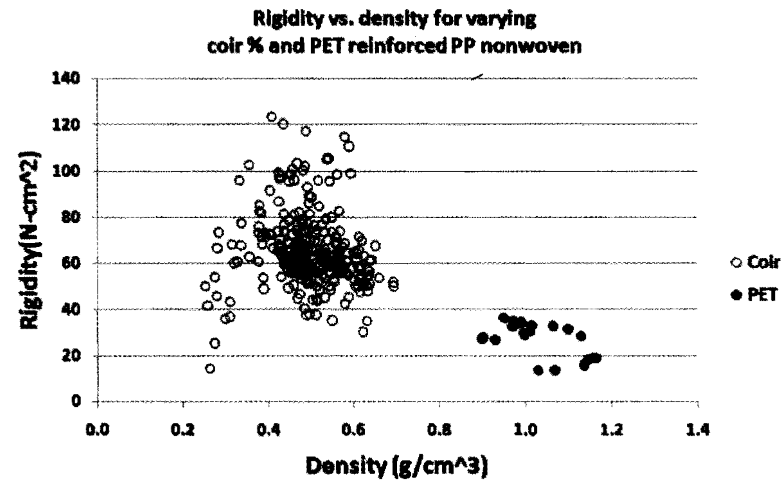

Figure 7. Specific rigidity comparison of compression molded coir:PP and PET:PP

Since most non-woven fabric composite materials use 50% polypropylene fiber and 50% fiber with a higher melting point or degradation temperature, the initial work on CoirForm has focused on this 50:50 blend. However, it is possible to make CoirForm with richer concentrations of coir fiber, up to 80%. As the percentage of coir fiber increases from 50% to 80%, the elastic modulus (or stiffness) of the CoirForm composite increases monotonically, as seen in Figure 8 and Table 2. The coir fibers are stiffer than the polypropylene fibers that they are replacing. However, the tensile strength decreases with increasing coir fiber content, as seen in Figure 8 and Table 2. The polypropylene flow during compression molding provides the load transfer path from one coir fiber to the next. Reducing the amount of polypropylene provides fewer load transfer points, reducing the strength of the CoirForm.

Table 1. Direct comparison of CoirForm and PE:PP compressed non-woven

		Coir: PP	PEP: PP	
Areal density		1000	1000	g/m^2
Unpressed Bulk Density	ρ	0.16	0.32	g/cm^3
Pressed Thickness		0.20	0.10	cm
Pressed Bulk Density	ρ	0.5	1.0	g/cm^3
Tensile Strength	UTS	12	36	MPa
Specific Tensile Strength	UTS/SG*	24	36	MPa
Tensile Modulus	E_t	690	2500	MPa
Specific Tensile Modulus	E_t/SG	1380	2500	MPa
Elongation	ΔL/L	20	27	%
Flexural Modulus	E_f	470	1400	MPa
Specific Flexural Modulus	E_f/SG	950	1400	MPa
Flexural Rigidity**	$E_f I$	330	120	N-cm^2
Specific Flexural Rigidity**	$E_f I$/SG	660	120	N-cm^2

Finally, there is a small difference in the mechanical properties observed in the machine direction versus across the machine direction. For a roll, the machine direction would be the direction of rolling and across the machine direction would be the width of the roll. This is likely due to some non-randomness in the deposition of fibers due to the moving platform onto which they are deposited. Examples of this anisotropy in elastic modulus are most easily seen in Figure 6B for the PET:PP.

Current Status of Commercialization of the Non-woven Fabric Composite CoirForm

Whole Tree, Inc. is currently doing joint-development projects with three major automotive companies and one major tier-one parts maker and are in discussions with a two other tier-one parts makers and one additional automotive company to start joint-development projects. Most automotive companies are eager to make greener products, but do not want to pay a premium for the greener parts. WTI is capable of supplying non-woven fabric composite material that is greener with either price parity or sometimes a reduction in price. American companies are also intrigued by the possibility that using coir fiber can increase the quality of life for poor coconut farmers, which is one of the major core values for WTI since its inception. WTI is optimistic that there will be parts made with CoirForm in the 2011 models of automobiles made in the United States.

Early work in the use of CoirForm in building materials is also very promising. There are many

Table 2. Mechanical property results comparison of various blends of coir:PP and PET:PP

Approximate values at 0.5 g/cm^2			
Coir	Ef	Ef*I	UTS
%	MPa	N*cm^2	MPa
20	379	64.6	7.0
40	379	71.8	8.6
50	379	64.6	10.3
60	552	93.3	10.3
80	478	78.9	8.6

building materials that are widely used today that can be replaced by CoirForm to provide a greener and/or less expensive alternative with comparable performance. It is anticipated that this market could be larger than the automotive market described in this paper. Hopefully, we can share some success stories in this area at the APCC's bi-annual meeting in 2012.

Supply Chain Development Work – Looking for Partners!

A worldwide supply chain will be developed between August 2010 and July 2012 to be able to provide the necessary volume of clean, coir fiber cut to 5.0-7.5 cm lengths. To supply the markets that Whole Tree is developing, it will be necessary to produce a large, consistent supply of non-woven fabric composite felted material. The supply chain development work will involve three tasks: (1) determining the variability of coir fiber obtained from diverse countries around the world; (2) developing a consistent process for milling the fiber from the husks clean coir fibers in 5-7.5 cm lengths; and (3) developing the necessary process control in carding and needle punching to produce non-woven fabric composites from coir and polypropylene fibers so that automobile parts with consistent quality can be produced.

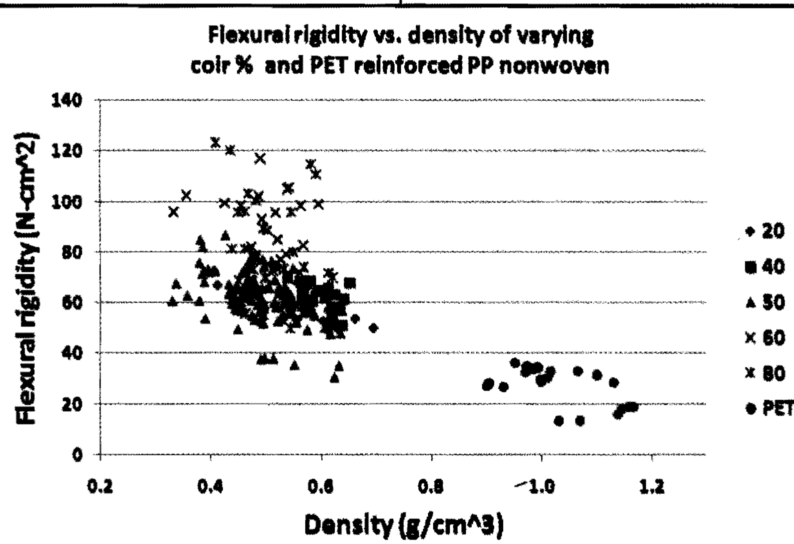

Figure 8. Mechanical property results comparison of various blends of coir:PP and PET:PP

We are looking for some interested people to help us secure a diverse supply of coir fiber with the following variables:

- Location (at least six different countries)
- Type of tree (we would like to get fibers from hybrid and tall trees)
- Time of harvest (over time range of three months—early, usual, late)
- Exposure to sun (does time in sun and rain degrade fiber properties)

We will be running 1200 tensile tests on a wide range of fibers using the four variables above to determine how much variability is present and how we can best minimize this variability.

We are also exploring various equipment options for cleaning and milling fibers to 5-7.5 cm lengths with minimal damage to the fiber properties. We would very much like to visit with you about this matter, or we can be contacted at:
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The work to optimize the needle punching of non-woven fabric composites with coir will be done with our local production partners in Waco, Texas, Hobbs Bonded Fibers.

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