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NATURAL FIBERS, THINKING OUT OF THE BOX

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Abstract

Most people are aware of what natural fibers are but few know of the diverse capability of this natural resource and, unfortunately, industry pressures over the past several years to reduce costs focused on trying to refine well established technologies using glass or wood fibers, or to a certain extent, injected molded polymers. It has only been through recent pressure by some of the larger OEM's that natural fibers have been gaining broader interest for both their performance and environmental benefits as compared to older, more comfortable, based technologies.

Cost versus performance is a delicate balancing act. Fortunately, natural fibers go a long way on striking a balance between both of these most common demands. When considering performance, natural fibers offer an unlimited range of lighter weight possibilities for interior and exterior applications. Most common today, natural fibers are commingled into a nonwoven mat with fiberized, thermo plastic polymers such as polypropylene and polyester for use in common interior applications that include door panels, center consoles, pillars, and inserts. However, advancements in the range of available natural fibers and specialty polymers, along with a continuous improvement of the nonwoven process, are now providing for greater heat stability to meet the elevated requirements for overhead systems, package trays, and topper pads. Increased demands for occupant safety give further reason to consider natural fibers as few other materials provide the same impact characteristics with the base material. For exterior applications, natural fiber mats used as the base material in sheet molding compounds will find their way into bumper reinforcements, wheel well liners, and under hood applications.

The industry historically focused on direct material cost. In this simplified approach natural fibers seldom will come out to be the low cost alternative but when considering the benefits derived from one-step processing the end cost of the finished component becomes highly competitive through a reduction in both capital and the growing cost of internal labor. One also has to consider the practical economic and environmental benefit by being able to reclaim factory waste, and eventually, end-of-life components.

Introduction

Natural fiber reinforced thermo plastics were first used in North American automotive interior trim applications in 1998. Produced in non-woven mats for compression molded components, natural fiber composites (NFCs) provided for good physical properties, reduced weight, shorter cycle times, simplified manufacturing, and of course, they could be recycled. Initial applications included a door insert, package tray, and overhead components for heavy truck.

The transportation industry was excited about the technology. Joint partnerships were formed and expanded capacity was planned. It appeared that NFCs were poised to replace long established "in the box" products such as wood fiber reinforced thermoplastics, wood fiber based phenolic thermo sets, and would also threaten glass fiber in RIM and SMC applications. In reality, the down turn in the economy, beginning in 1999, would slow a broader adaptation of NFCs. Companies were downsizing, relocating manufacturing to reduce labor, and few were investing capital in new technologies. Growth was slow and it would not be until later in 2003 that interest would be renewed.

Underwriting this revival has been an excruciating slow realization by world leaders that it is they who are responsible for implementing laws that recognize the need to lessen our dependence on limited resources and the importance of protecting our environment. Lead by Europe's end-of-life recovery mandate for manufacturers and the need to commonize technologies for global markets, several North American Universities, OEMs, and raw material suppliers have become more visible in their efforts to expand the utilization of renewable materials that include NFCs, although they lag behind Europe's efforts by several years. In addition, there are coordinated lobbying efforts to relax laws that would, again, allow the growing of industrial hemp in the United States were currently it has to be purchased from Canada or Europe.

While the use of natural fibers is being advanced on many fronts this paper will cover the following:

- Defining NFCs used in North America,
- Current NFC applications in North America,
- Performance improvements made to NFCs for more demanding applications,
- Understanding the true component cost of NFC based products.

Defining Natural Fiber Composites

Bast fibers such as kenaf, hemp, and jute are the most common fibers found in North American vehicle components. Flax and the leaf fiber sisal have been used but at a much lower percentage. In comparison, flax is the predominate fiber in Europe followed by hemp, kenaf, sisal, and jute. The driving factors behind the choice of fibers in the US have been the consistency of the processed fiber quality, price, and availability. Not listed randomly, the consistency of the fiber quality is the most critical characteristic. Programs such as BIOMAT in Europe and ARAOSV (Affordable Resins and Adhesives from Optimized Soybean Varieties) under the US Department of Energy have brought together the growers, processors, chemical suppliers, and the end manufacturers to better understand and optimize the benefits of soy oil based resins which includes the evaluation of natural fibers.

Natural fibers that are being used in North American vehicle applications today originate as non-woven mats. These mats are a homogeneous blend of longer natural fibers (60-80mm in length) and fiberized thermo plastic polymers, mainly polypropylene, that are mechanically entangled through a needling process. While this can be done on both carding and air lay systems, carding is the most prevalent form for producing NFCs.

Although this technology is not new in the US, the process was modified in Europe to handle the unique challenges of cleaning, opening of vascular bundles, and orientation of the natural fibers without damaging them and maintaining the integrity of the fiber length. It is the ability to layer these longer fibers, in linear alignment, that is critical to achieving higher tensile and flexural properties in the finished, compressed substrate. An imbalance of impurities (core/dust), shorter fibers, or more fibers being vertically orientated through the needling process will weaken the composite. Mats are produced in weight ranges varying from 400 g/m^2 to 2400 g/m^2.

Processing requires pre-heating the mat and compression molding the finished component in tools maintained at ambient temperatures. NFCs are produced in various forms that allow for contact heating, forced hot air heating, and infrared heating. At an optimum processing temperature of 200º C the NFC material is transferred into the press where it is cold formed at a nominal pressure of 55 psi. Components are commonly trimmed in the tool as permitted by part geometry.

Meeting the varying physical properties of the different interior components is accomplished several ways. Mats are produced in blends of 50% natural fiber and 50% synthetic fiber. In general, there is a linear trend where increasing the weight of the NFC mat also increases the physical properties. However, the ratio of natural fibers to synthetic fibers, the type of natural fiber, the type and chemical make up of the synthetic fiber, and the needle punch density of the mat allows for a complete manipulation of the physical characteristics. Note that the optimum strength properties are achieved with a maximum natural fiber content of 50%. The NFC mats used today are typically tailored for each application.

In concert with developing the proper composition and weight it is critical to establish the proper press density to obtain the optimum physical properties. Assuming that the material has been properly heated, under or over compression of an NFC mat will cause wide inconsistencies in the tensile and flexural properties. Too little consolidation makes the product weak and over consolidation retards stiffness. The finished press density of a 50/50 blend of material can be calculated using the formula ((2.2046 ÷ 1800) x the material weight in grams m^2). As an example an 1800 gsm product has a nominal press density of 2.2 mm. Adjustments are made to the press densities based on the overall composition and allowances are made for the different types of cover materials that are introduced into the tool.

Current Applications

Early vehicle applications initially focused in areas that utilized one of the most significant performance values that NFCs provide. Components requiring improvement to side impact protection such as full door panels, uppers, inserts, and ABC column covers. NFCs eliminated the need for secondary energy absorption attachments due to their inherent impact characteristics. Initial work on package trays also played an important roll in the development and commercial entry of composite formulations that provided protection from mold and mildew growth for the life of the vehicle.

Today, you will find natural fiber composites being extensively used throughout vehicle programs in European and North American vehicles in both interior and exterior applications. Interior components include door panels, bolster inserts, ABC column covers, package trays, center columns, trunk trim, and seat backs. Exterior applications include underbody trim panels.

In non-automotive markets, NFCs are finding their way into farming equipment, construction vehicles, and non-commercial light aircraft. Natural fiber composites are an excellent material fit for aircraft interiors where the weight to strength ratio is an extremely important design consideration.

Improving Overall Performance

From the extraction of raw materials through drilling and mining, converting them to a usable form, processing into finished components, life operation, and disposal costs there is a tremendous amount of energy expended. Most of which involves the release of $C0_2$ emissions into the environment.

Natural fibers offer a practical solution to reversing this trend in two areas. They require less energy to grow, process, integrate into finished goods, and either to reuse or dispose of them. Secondly, by being less in weight they reduce the amount of operational energy (fuel consumption) associated with all forms of transportation. The net effect is that $C0_2$ emissions are lowered and so are the overall costs. However, to provide for greater use in vehicle components the physical properties of NFCs will need to improve.

Temperatures are increasing for the environmental testing of interior trim components and new processes are being adapted for the skinning and foaming of door panels that require greater stability of the NFC substrate. Improving the quality and consistency of the natural fiber itself is the most important aspect but the shorter term approach is to direct attention to the thermo plastic fibers. Studies by FlexForm Technologies were conducted using polypropylenes with a lower melt flow index and two others with enhanced with chemical additives (PP1A and PP2A). In each case there was an improvement in the tensile, flexural, and heat deflection properties of the NFC with PP2A providing the best results. (Table 1)

The first commercial application benefiting from an enhanced NFC will be the door substrates in the 2005 Mercedes 164/251 coming out in the fall of 2004. Testing is also underway to determine whether these types of enhancements with allow for NFCs to displace glass fiber based overhead systems as well as meeting the demands of package trays and load floors.

NFCs will also eventually show up in thermo set applications as well. Natural fiber mats are being evaluated as an alternative reinforcement medium to glass in Bayer's Baypreg® F process and Ford Motor Company is evaluating their use in sheet molding compounds. At half the specific gravity of glass, natural fibers offer significant weight savings without a detrimental loss in physical properties. NFCs possess none of the negative handling attributes associated with glass fibers.

True NFC Component Cost

If you just take the per pound cost of an NFC it will be 33-50% more than wood fiber reinforced thermoplastics, wood fiber based phenolic thermo sets, and glass. However, to fully evaluate the true cost of NFCs it is necessary to look at the final cost of the finished component.

Processing NFCs requires less capital. A low forming pressure of 55 psi reduces press costs and permits the use of aluminum tooling, at any volume, providing for savings compared to steel tools required for heat forming and/or high pressure molding. Being less abrasive NFC's cause less wear to tooling lowering the costs for preventative maintenance.

One-step processing allows for a further reduction in capital, materials, and labor by removing the need for secondary operations. Taking advantage of the molten polymer in the NFC mat allows for in-mold bonding of various cover materials and back side attachments. Both are accomplished using compatible chemistries to the base polymer in the NFC and eliminates the need for secondary adhesives. As the part is also completely stable coming out of the forming tool it can be immediately moved into trimming, punching and assembly operations. Taking further advantage of the thermoplastic substrate allows for direct heat tacking of sound dampening materials or other components as needed.

The average cycle time for heating, material transfer, and removal of the molded component is 55 seconds. To maintain this rapid pace it is common to use a forced, hot air oven to preheat the NFC up to 130ºC then transferring the sheet in a primary contact oven to bring it up to the processing temperature of 200ºC. Value added NFCs provide for options to use strictly forced, hot air systems, infra red, or convection ovens that provide for shorter heating cycles without a preheating stage.

Consideration also has to be given to the value of reducing component weight and the ability to reclaim trim waste. Saving weight translates into improved fuel efficiency and keeping factory waste out of the ground is not only good for the environment it also saves costs related to disposal. With the launch of the Mercedes program in August 2004, the first trim waste recovery program will be implemented. An estimated 1.2 million pounds of material annually will be shredded and used to improve the physical properties of extruded decking.

As the market continues to experience the upward spiraling of costs related to materials produced from non-renewable resources exploiting this particular benefit of NFC's will become increasingly important to controlling component costs.

Summary

Utilization of natural fiber composites is in the very beginning stages. While economic and, to some extent, performance demands have slowed the integration of NFCs into the mainstream of automotive applications and other markets, their use is gaining momentum. With ongoing advancements in the processing techniques of the raw fiber and with the help of expanded development efforts of new chemistries, for both thermoplastic and thermoset matrices, NFC's will continue to broadened their acceptance in both interior and exterior applications.

Key to this expanded growth is the increasing awareness of the need for technologies that are not based on limited, carbon based resources, materials that expose individuals to health hazards, or products that create long term biodegradability concerns. Taking greater environmental responsibility is more than just reducing the waste we put into our lands, oceans, and air it is realizing that there is long term economic value to the full circle practices of renewability and reusability. With Europe leading the way North American manufacturers need to take heed as it will not be long before end-of-life responsibility becomes mandated here as well.

Natural fibers will play a major role in the future of manufacturing. Taking the time now to understand all of the advantages that they offer will help provide for their successful evolution.

Data

Table I: Enhancing NFC Physical Properties

Material	Tensile Strength psi	Flexural Modulus psi	Heat Deflection 66 psi / C	IZOD Impact in / ft-lb
1600 g/m² *50% Natural Fiber / 50% PP*	*(ASTM D638-94B)*	*(ASTM D790-92)*	*(ASTM D648-98)*	*(ASTM D526)*
18 mfi PP (baseline)	3798	252343	158	3.61
4 mfi PP	4195	395475	158	4.73
PP1A	4141	390986	170	4.38
PP2A	5494	513931	168	1.86