Composites from Agri-Based Resources

Roger M. Rowell

Abstract

A composite is any combination of two or more resources held together by some type of mastic or matrix. The mastic or matrix can range from a simple physical entanglement of fibers to more complicated systems based on thermosetting or thermoplastic polymers.

There is a wide variety of agri-based resources to consider for composites, including recycled, waste, and virgin fiber. There are also a wide variety of composites that can be produced including geotextiles, filters, sorbents, structural composites, nonstructural composites, molded products, packaging, and combinations with other materials.

New agri-based composites can take advantage of the properties of these resources as well as other resources, such as plastics, metals, and glass, that can be combined to meet end-use specifications. These new composites make it possible to explore new applications and new markets in such areas as packaging, furniture, housing, and automotive products.

Introduction

There is renewed interest in the use of agri-based resources for composite materials. This resource includes wood, agricultural crops and residues, grasses, water plants, and a wide variety of waste agri-mass including recycled wood, paper, and paper products.

In any sustainable development, there must be a long-term guaranteed supply of resources. To insure a continuous fiber supply, management of the agricultural producing land should be under a proactive system of land management whose goal is both sustainable agriculture and the promotion of healthy ecosystems. Ecosystem management is not a euphemism for preservation, which might imply benign neglect. Sustainable agriculture denotes a balance between conservation and utilization of agricultural lands to serve both social and economic needs, from local, national, and global vantage points. Sustainable agriculture does not represent exploitation but rather is aimed toward meeting all the needs of the present generation without compromising the ability of future generations to meet their needs. It encompasses continuous production of fiber, considerations of multiland use, and conservation of the total ecosystem.

A wide variety of agri-based fibers should be considered for composites, to take advantage of unique fiber properties each plant type has to offer, not just through a desire to promote one fiber over another. Unless one particular fiber has some advantage in the market, it will be replaced with whatever resource has the market advantage. That market advantage can be based on many elements such as availability, price, or performance. Producers and manufacturers of agri-fibers must explore common interests and, where possible, prepare an enterprise-driven long range strategic plan for development and promotion of an agri-fiber industry (5,6).

The traditional source of agri-based composites has been wood and, for many countries, this will continue to be the major source. Wood has a higher density than annual plants so there will be more bulk when using agricultural crop fiber. There are also concerns about the seasonality of annual crops which require harvesting, separating, drying, storing, cleaning, handling, and shipping. In the present system of using wood, storage costs can be reduced by letting the tree stand

The author is Project Leader, USDA Forest Serv., Forest Prod. Lab., Madison, Wis.

alive until needed. With any annual crop, harvesting must be done at a certain time and storage, drying, cleaning, and separating will be required. This will almost certainly increase costs of using agri-based resources over wood depending on land and labor costs. However, in those countries where there is little or no wood resource left or where restrictions are in place concerning the use of wood, alternate sources of fiber are needed if there is to be a natural fiber industry.

Other large sources of fiber can arise from recycling agri-fiber based products such as paper and paper products, waste wood, and point-source agricultural residues (5). In 1993, of a total of 206.9 million tons of municipal solid waste, approximately 32.8 million tons were yard waste (8.1% by volume or 15.9% by weight), 13.7 million tons were wood (6.8% by volume or 6.6% by weight) and 77.8 million tons were paper and paper board products (30.2% by volume or 37.6% by weight) (3). Recycling paper products back into paper requires wet processing and removal of inks, inorganic, and adhesives. Recycling these same products into composites can be done using dry processing (thus eliminating a waste water stream) and all co-existing resources can be incorporated into the composite. Point-source fibers represent resources such as rice hulls from a rice processing plant, sunflower seed hulls from an oil-processing unit, and bagasse from a sugar mill. There was approximately 1,145 million tons of straw (wheat, rice, oat, barley, rye, flax, grass, etc.) generated in the world in 1991 along with 90 million tons of stalks (corn, sorghum, cotton, etc.), 75 million tons of sugarcane bagasse, and 150 million tons of other agri-wastes including core, bast, linters, leaf, and grasses (l).

Table 1.—Composition of some common fibers.

Fiber type	Cellulose	Lignin	Pentosan	Ash	Silica
	(%)				
Stalk fiber					
Rice	28 to 48	12 to 16	23 to 28	15 to 20	9 to 14
Wheat	29 to 51	16 to 21	26 to 32	4.5 to 9	3 to 7
Barley	31 to 45	14 to 15	24 to 29	5 to 7	3 to 6
Oat	31 to 48	16 to 19	27 to 38	6 to 8	4 to 6.5
Rye	33 to 50	16 to 19	27 to 30	2 to 5	0.5 to 4
Cane fiber					
Sugar	38 to 48	19 to 24	27 to 32	1.5 to 5	0.7 to 3.5
Bamboo	26 to 43	21 to 31	15 to 26	1.7 to 5	0.7
Grass fiber					
Esparto	33 to 38	17 to 19	27 to 32	6 to 8	--
Sabai	--	22	24	6	--
Reed fiber					
Phragmites communis	44 to 46	22 to 24	20	3	2
Bast fiber					
Seed flax	43 to 47	21 to 23	24 to 26	5	--
Kenaf	45 to 57	15 to 19	22 to 23	2 to 5	--
Jute	45 to 53	21 to 26	18 to 21	0.5 to 2	--
Core fiber					
Kenaf	37 to 49	15 to 21	13 to 24	2 to 4	--
Jute	41 to 48	21 to 24	18 to 22	0.8	--
Leaf fiber					
Abaca (manila)	60	8 to 15	13	1.1	--
Sisal (abaca)	47 to 62	7 to 9	21 to 24	0.6 to 1	--
Seed hull fiber					
Cotton linter	80 to 85	--	--	0.8 to 2	--
Wood fiber					
Coniferous	40 to 45	26 to 34	7 to 14	<1	--
Deciduous	38 to 49	23 to 30	19 to 26	<1	--

Features of lignocellulosics

Lignocellulosics are three-dimensional, polymeric composites made up primarily of cellulose, hemicelluloses, and lignin. Table 1 shows the composition of many different types of agri-libers (1 ,4); Table 2 shows fiber dimensions; Table 3 shows tensile strength. This

Table 2.—Dimensions of common lignocellulosic fibers.

Fiber type	Fiber dimension		
	Length	Average length	Width
	(mm)		
Cotton	10 to 60	18	0.02
Flax	5 to 60	25 to 30	0.012 to 0.027
Hemp	5 to 55	20	0.025 to 0.050
Manila hemp	2.5 to 12	6.0	0.025 to 0.040
Bamboo	1.5 to 4	2.5	0.025 to 0.040
Esparto	0.5 to 2	1.5	0.013
Cereal straw	1 to 3.4	1.5	0.023
Jute	1.5 to 5	2.0	0.02
Deciduous wood	1 to 1.8	1.2	0.03
Coniferous wood	3.5 to 5	4.1	0.025

Table 3.—Tensile strength of some agri-based fibers.[a]

Fiber	Tensile strength
	(GPa)
Kenaf	11.91
Hemp	8.95
Wood	7.48
Sisal	6.14
Cotton	3.54

[a] All single fiber strength except sisal, which is fiber bundles.

type of data is critical to select a certain fiber for a specified use. While this type of data exists in the literature for some types of agri-fibers, the data is incomplete. There needs to be a concerted effort to expand the database to include ail potential fiber sources.

Potential composites

Eight different use classes will be considered: geotextiles, filters, sorbents, structural composites, nonstructural composites, molded products, packaging, and combinations with other materials. There is some overlap between these use classes. For example, once a fiber web has been made, it can be directly applied as a geotextile, falter, or sorbent, or processed further into a structural or nonstructural composite, molded product, used in packaging, or combined with other resources. There are opportunities to improve the performance of a composite by improving the performance of the source fiber.

Geotextiles

Long bast or leaf fibers can be formed into flexible fiber mats, which can be made by physical entanglement, nonwoven needling, or thermoplastic fiber melt matrix technologies. The two most common types are carded and needle-punched mats. In carding, the fibers are combed, mixed, and physically entangled into a felted mat. These are usually of high density but can be made at almost any density. A needle-punched mat is produced in a machine that passes a randomly formed machine-made web through a needle board and produces a mat in which the fibers are mechanically entangled. The density of this type of mat can be controlled by the amount of fiber going through the needle board or by overlapping needled mats to give the desired density.

These medium- to high-density fiber mats can be used as geotextiles. Geotextiles have a variety of uses, such as mulch around newly planted seedlings. The mats provide the benefits of natural mulch; in addition, controlled-release fertilizers, repellents, insecticides, and herbicides can be added to the mats as needed. Research results on the combination of mulch and pesticides in agronomic crops have been promising.

The addition of such chemicals could be based on silvicultural prescriptions to ensure seedling survival and early development on planting sites where severe nutritional deficiencies, animal damage, insect attack, and weed problems are anticipated. Medium-density fiber mats can also be used to replace dirt or sod for grass seeding around new home sites or along highway embankments. Grass or other type of seed can be incorporated in the fiber mat. Fiber mats promote seed germination and good moisture retention. Low- and medium-density fiber mats can be used for soil stabilization around new or existing construction sites. Steep slopes, without root stabilization, lead to erosion and loss of top soil.

Medium- and high-density fiber mats can also be used below ground in road and other types of construction as a natural separator between different materials in the layering of the back fill. It is important to restrain slippage and mixing of the different layers by placing separators between the various layers.

Filters

Medium- and high-density fiber mats can be used for air falters. The density of the mats can be varied, depending on the size and quantity of material being faltered and the volume of air required to pass through the falter per unit of time. Air filters can be made to remove particulate and/or can be impregnated or reacted with various chemicals as an air freshener or cleanser.

Medium- to high-density mats can also be used as faltering aids to take particulate out of waste and drinking water or solvents.

Sorbents

Tests are presently underway to to use agri-based sorbents to remove heavy metals, pesticides, and oil from rainwater runoff in several cities in the United States. Medium- and high-density mats can also be used for cleaning oil spills. It has been shown that agri-based core material from kenaf will preferentially absorb oil out of seawater when saturated with water. There are many other potential sorbent applications of agri-fiber/core resources such as removal of dyes, trace chemicals in solvents, and in the purification of solvents.

It is also possible to use core materials as sorbents in cleaning aids such as floor sweep granules. This is not a composite, as such, but it does represent another way agri-based resources can be used as sorbents.

Structural composites

A structural composite is defined as one that is required to carry a load in use with minimal creep. These would include fiberboards, particleboard. clipboards, stmndboards, and flakeboards, for example, that use a thermoset matrix. In most, if not all cases, performance requirements of these composites are spelled out in codes and/or in specifcations set forth by local or national organizations.

Traditionally, structural agri-based composites are made in flat sheets but they can also be made in any desired shape using the mat technology described earlier and an adhesive which will be described later.

Nonstructural composites

As the name implies, nonstructural composites are not intended to carry a load in use, and creep mayor may not be a problem. The furnish can be the same as structural composites but the matrix may be thermoplastic. These are generally lower in cost than structural composites and have fewer codes and specifications associated with them.

Molded products

As was stated before, the present wood-based composite industry mainly produces flat sheet products. In some cases, these flat sheets are cut into pieces and glued or fastened together to make shaped products such as drawers, boxes, or packaging. Flat sheet wood-fiber composite products are made with a gravity-formed mat of fibers and adhesive, and then pressing. If the final shape can be produced during the pressing step, then the secondary manufacturing profits can be realized by the primary board producer. Instead of making low-cost, flat sheet composites, it is possible to make complex-shaped composites directly using the long bast fiber.

In this technology, fiber is combined with an adhesive, either by dipping or spraying the fiber before mat formation or added as a powder during mat formation. The mat is then shaped and densified by a thermoforming step. Within certain limits, any size, shape, thickness, and density is possible.

These molded composites can be used for structural or nonstructural applications as well as packaging, and can be combined with other materials to form new classes of composites. This technology will be described later.

Packaging

Agri-based packaging has been used for many years as bags, boxes, and containers. They are lightweight, recyclable, and low in cost. Agri-based fiber composites can also be used in returnable containers where the product is reused several times. These containers can range from simple crease-fold types to more solid, even nestable, types. Long agri-fiber fabric and mats can be overlayed with thermoplastic films such as polyethylene or polypropylene to be used to package such products as concrete, foods, chemicals, and fertilizer. Corrosive chemicals require the plastic film to make them more water resistant and reduce degradation of the agri-based fiber. There are also many applications for agri-based fiber as paper sheet products for packaging. These vary from simple paper wrappers to corrugated, multi-folded, multi-layered packaging.

Combinations with other resources

It is possible to make completely new types of composites by combining different resources. It is possible to combine or blend leaf, bast, and/or stick fiber with other materials such as glass, metals, plastics, and synthetics to produce new classes of materials. The objective will be to combine two or more materials in such a way that a synergism between the components results in a new material that is much better than the individual components.

Glass and agri-based fiber composites can be made using the glass as a surface material or combined with lignocellulosic fiber. Composites of this type can have a very high stiffness-to-weight ratio. The long bast fibers can also be used in place of glass fiber in resin injection molding or used to replace (or in combination with) glass fiber in resin transfer molding technologies. Problems of dimensional stability and compatibility with the resin must be addressed, but this could also lead to new markets for property enhanced agri-based materials.

Metal films can be overlayed onto smooth, dimensionally stabilized fiber composite surfaces or applied through cold plasma technology to produce durable coatings. Such products could be used in exterior construction to replace aluminum or vinyl siding, markets where agri-based resources have lost market share.

Metal fibers can also be combined with stabilized fiber in a matrix configuration in the same way metal fibers are added to rubber to produce wear-resistant aircraft tires. A metal matrix offers excellent temperature resistance and improved strength properties, and the ductility of the metal lends toughness to the resulting composite. Application for metal matrix composites could be in the cooler parts of the skin of ultra-high-speed aircraft. Technology also exists for making molded products using perforated metal plates embedded in a phenolic-coated fiber mat, which is then pressed into various shaped sections.

Bast or leaf fiber can also be combined in an inorganic matrix. Such composites are dimensionally and thermally stable, and they can be used as substitutes for asbestos composites. Inorganic bonded bast fiber composites can also be made with variable densities that can be used for structural applications.

One of the biggest new areas of research in the value-added area is in combining natural fibers with thermoplastics (9). Since prices for plastics have risen sharply over the past few years, adding a natural powder or fiber to plastics provides a cost reduction to the plastic industry (and in some cases increases performance as well) but to the agri-based industry, this represents an increased value for the agri-based component. Most of the research has concentrated on using a compatibilizer to make the hydrophore (plastic) mix better with the hydrophil (lignocellulosic) material. The two components remain as separate phases, but if delamination and/or void formation can be avoided, properties can be improved over those of either separate phase. These types of materials are usually referred to as natural fiber-thermoplastic blends.

In the case of fiber-plastic composites, the cost of natural fibers are, in general, much less than that of the plastic. High fiber loading can result in significant material cost savings. The cost of compounding is unlikely to be much more than for conventional mineral/inorganic-based materials presently used by the plastics industry. Due to the lower specific gravities of the cellulosic-based additives (~ 1.4, compared to ~2.5 for mineral-based systems), composite properties that consider the weight of the composite is an advantage that may have implications in the automotive and other transportation applications. Furthermore, plastic-natural fiber produces about 20 percent more pieces than the same weight of plastic-glass fiber. Cellulosic fibers are soil and nonabrasive, and high filling levels are possible. Reduced equipment abrasion and the subsequent reduction of retooling costs through the use of agricultural-based fibers is a factor that will be considered by the plastics industry when evaluating these natural fibers. It is not expected that agri-based fibers/fillers will completely replace conventional fibers/fillers. We do, however, believe that these natural materials will develop their own niche in the future.

Another combination of fiber and thermoplastics is in products that can best be described as fiber-plastic alloys (7). In this case the fiber and plastic become one material and it is not possible to separate them. Fiber-plastic alloys are possible through fiber modification and grafting research. This can be done if you consider that agri-based fibers consist of a thermoset polymer (cellulose) in a thermoplastic matrix (lignin and the hemicelluloses). The glass transition temperature (T_g) of the dry natural thermoplastic matrix is higher than the decomposition temperature of the fiber. If the T_g were lowered through chemical modification, it should be possible to thermoplasticize the lignin and possibly the hemicelluloses to use thermomolding at temperatures below decomposition. If a reactive thermoplastic is then reacted with the modified biobased fiber, it should be possible to form fiber/thermoplastic alloys. It is also possible to thermoplasticize cellulose, but then the strong, stiff, reinforcing thermoset structure is lost. If the cellulose were also plasticized, would be possible to produce agri-based films and foams.

Combining agri-fibers with other materials provides a strategy for producing advanced composites that take advantage of the enhanced properties of both types of resources. It allows the scientist to design materials based on end-use requirements within a framework of cost, availability, recyclability, energy use, and environmental considerations. These new composites make it possible to explore new applications and new markets in such areas as packaging, furniture, housing, and automotive.

Conclusions

There is considerable interest in developing newer materials or composites that can reduce the mess to the environment. In light of petroleum shortages and pressures for decreasing the dependence on petroleum products, there is an increasing interest in maximizing the use of renewable materials. In general, the economics of material substitution has to be favorable for widespread acceptability of newer materials. The use of agricultural waste resources-particularly annual growth crops-and recycled fiber not only provides a renewable source but could also generate a nonfood source of economic development for farming and rural areas as well as the utilization of recycled fiber for products other than paper.

Literature cited

1. Atchison, J.E. 1983. Data on Non-Wood Plant Fibers, Pulp and Paper Manufacture, Vol. 1: Properties of Fibrous Raw Materials and their Preparation for Pulping. M.J. Kocurek, series ed. Joint Textbook Committee of the Paper Industry, 4.
2. ________. 1991. Worldwide capacities for non-wood plant fiber pulping-increasing faster then wood pulping capacities. Nonwood plant fiber pulping, Prog. Rept. No. 19. TAPPI, 1, 1991.
3. Franklin Associates. 1994. Characterization of municipal solid waste in the United States: 1994 update. Rept. No. EPA 530-S-94-042. U.S. Environmental Protection Agency, Washington, D.C.

4. McDougall, G.J., I.M. Morrison, D. Stewart, and J.R. Hillman. 1993. Plant fibres: Botany, chemistry and processing for industrial use. J. Sci. Food Agric. 62:1-20.
5. Rowell, R.M. 1993. Opportunities for composite materials from jute and kenaf. International consultation of jute and the environment. ESC:JU/IC 93/15,1. Food and Agricultural Organization of the United Nations.
6. ________. 1994. International task force on diverse jute applications. ESC:JU/EGM 94/7. Food and Agricultural Organization of the United Nations. 9 pp.
7. ________, J.L. O'Dell, and T.G. Rials. 1994. Chemical modification of agri-fiber for thermoplasticization. *In:* Proc. Pacific Rim Bio-Based Composite Symp. Vancouver, B.C., Canada. pp. 144-152.
8. ________, H. Spelter, R.A. Arola, P. Davis, T. Friberg, R.W. Hemingway, T. Rials, D. Luneke, R. Narayan, J. Simonsen, and D. White. 1993. Opportunities for composites from recycled wastewood-based resources: A problem analysis and research plan. Forest Prod. J. 43(1):55-63.
9. Sanadi, A.R., D.F. Caulfield, and R.M. Rowell. 1994. Reinforcing polypropylene with natural fibers. Plastic Engineering Vol L(4):27-28.

The Use of Recycled Wood and Paper in Building Applications

***These papers were presented during a conference sponsored by the USDA Forest Service and the Forest Products Society, in cooperation with the National Association of Home Builders Research Center, the American Forest & Paper Association, the Center for Resourceful Building Technolog, and* Environmental Building News.**

Madison, Wisconsin, September 1996

Proceedings No. 7286

Forest Products Society
2801 Marshall Court
Madison, WI 53705-2295
(608) 231-1361
(608) 231-2152 fax
http://www.forestprod.org/

The opinions expressed are those of the authors and do not necessarily represent those of the USDA Forest Service or the Forest Products Society

Proceedings No. 7286

ISBN 0-935018-88-3

Printed in the United States of America.

9703500