CHAPTER 7

Opportunities for Composites from Agro-Based Resources

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CONTENTS

1. INTRODUCTION

Until about 1920, the Western world greatly depended on the use of agro-based resources for materials. With the coming of plastics, high performance metals, ceramics, and other synthetics, the use of agro-based derived materials lost its market share. We are now aware that our landfills are filling up, our resources are being depleted, and our planet is becoming polluted. Because of this, there is renewed interest in technologies that are considered to be environmentally friendly and products that are biodegradable, and recyclable.

There is a greater awareness of the need for materials in an expanding world population with increasing affluence. It took all of recorded history for the world population to reach 1 billion in 1830. In 1930, it had doubled to 2 billion. While it took 100 years for the population to increase to 1 billion people by 1930, at the present rate, the population will add 1 billion people every 11 years.

It is estimated that by the year 2000, 25% of the population of China will become "middle class." This represents more people than the entire population of the United States. If the desire for materials in this growing segment of China equals the middle class of other countries, there will be a great need for new materials.

China is only one example of the large new markets that will open up for new materials. Asia, Mexico, South America, and Eastern Europe are also "emerging" as indstial consumers that will seek new materials.

2. FIBER SUPPLY

In any commercial development, there must be a long-term guaranteed supply of resources. In the case of agro-based composites, these resources include fiber, labor, water, energy, and processing equipment. In order 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 at meeting all the needs of the present generation without compromising the ability of future generations to meet their needs. It encompasses, in the present case, a continuous production of fiber, considerations of multi-land use, and conservation of the total ecosystem.

There is a wide variety of agro-based fibers to consider for utilization. All of them should be considered for composites to take advantage of unique fiber properties each plant type has to offer, not just because we have 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. Desire does not drive markets! Producers and manufacturers of agro-fibers must explore common interests and, where possible, prepare an enterprise-driven long range strategic plan for development and promotion of an agro-fiber industry (Rowell, 1994b).

Chapter 1 gives the inventory of some of the larger sources of agricultural crop fiber that could be utilized for composites. The traditional source of agro-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 requires considerations of 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 alive until needed. With any annual crop, harvesting must be done at a certain time and storage/drying/cleaning/separating will be required. This will almost certainly increase costs of using agro-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 to restrict the use of wood, alternate sources of fiber are needed if there is to be a natural fiber industry in those countries.

As world population increases, there will be a greater need to grow grains to feed people. For every ton of grain harvested, there is 3 to 5 times that weight in stalk fiber. So, as the need for grain increases, the supply of stalk fiber also increases.

Other large sourcesof fib er can come from recyclingagro-fiber based products, such as paper (Figure 7.1), waste wood, and point source agricultural residues such as rice hulls from a rice processing plant, sunflower seed hulls from an oil processing unit, and bagasse from a sugar mill (Rowell et al., 1993). Approximately 60% of the volume of solid waste in an average municipal waste stream consists of agro-based resources such as paper and paper-based products, wood, and yard wastes. There are also potentially millions of tons of wood fiber in timber thinnings, industrial wood waste, demolition waste, pallets, and pulp mill sludges. Recycling paper products back into paper requires wet processing and removal of inks, inorganics, 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.

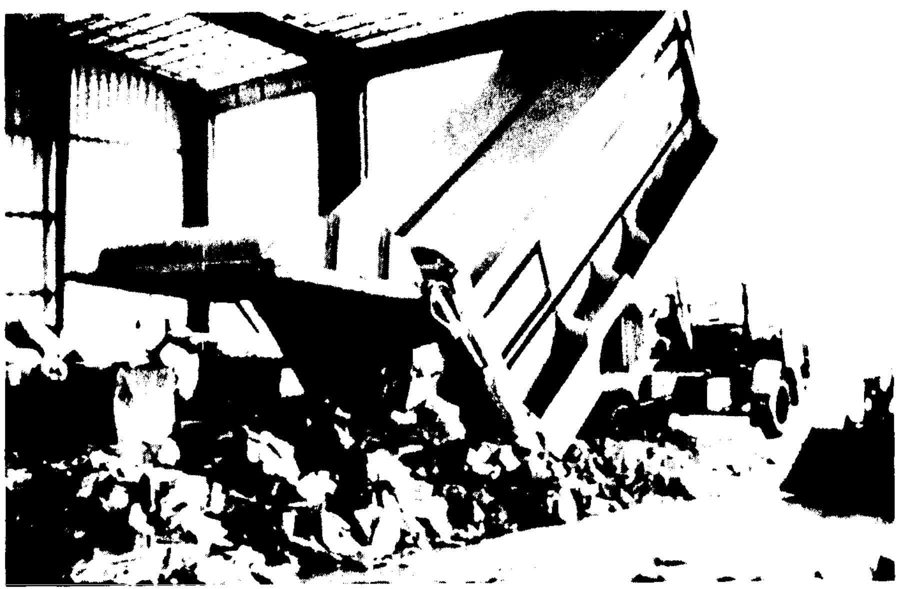


Figure 7.1 Agro-based resources ready for recycling into composites.

3. POTENTIAL COMPOSITES FROM AGRO-RESOURCES

For this chapter, a composite will be defined as any combination of two or more resources held together by some type of mastic or matrix. Composites can be classified in many ways: by their densities, by their uses, by their manufacturing methods, or by other systems. For this paper, they will be classified by their uses. Eight different use classes will be covered: (1) geotextiles, (2) filters, (3) sorbents, (4) structural composites, (5) non-structural composites, (6) molded products, (7) packaging, and (8) combinations with other materials. In some cases, one type of composite can be used for more than one use. For example, once a fiber web has been made, it can be directly applied as a geotextile, filter, or sorbent, or it can be further processed into a structural or non-structural composite, molded product, used in packaging, or combined with other resources.

3.1 Geotextiles

Geotextiles mean the use of fabrics in association with the earth (see Chapter 13). The 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 (Figure 7.2, Rowell, 1993). 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 that produces a mat in which the fibers are mechanically entangled (Figure 7.3). 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.

Numerous articles and technical papers have been written and several patents have been issued on both the manufacture and use of nonwoven fiber mats containing combinations of textile and lignocellulosic fibers or lignocellulosic fibers alone. Combinations of long and short fibers can be used to make geotextiles, which can reduce the total cost of these composites.

Geotextiles have a large variety of uses. These can be used for mulch around newly planted seedlings (Figure 7.4). 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 homesites or along highway embankments (Figure 7.5). 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.

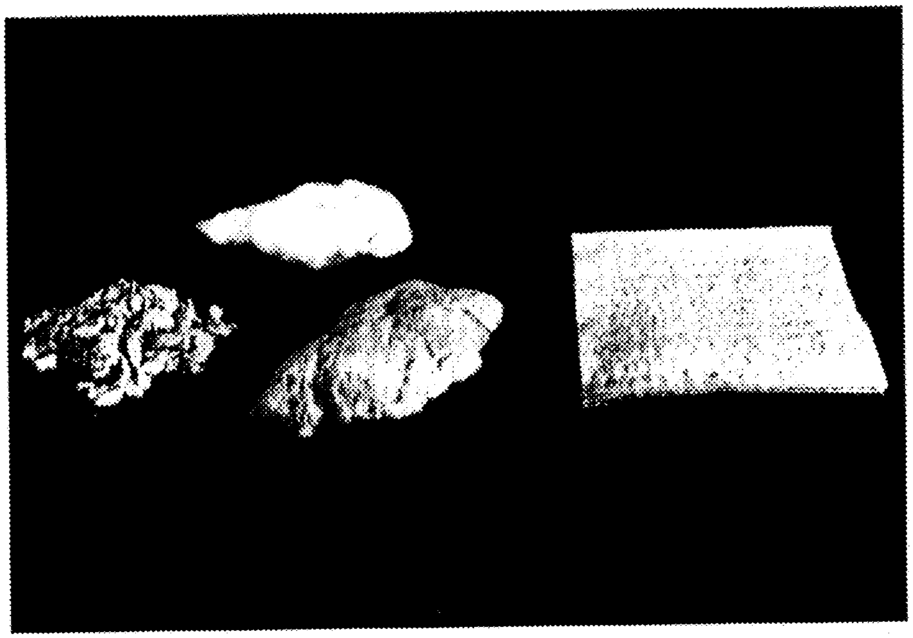


Figure 7.2 Mat-forming process combining short fibers with long binder fibers.

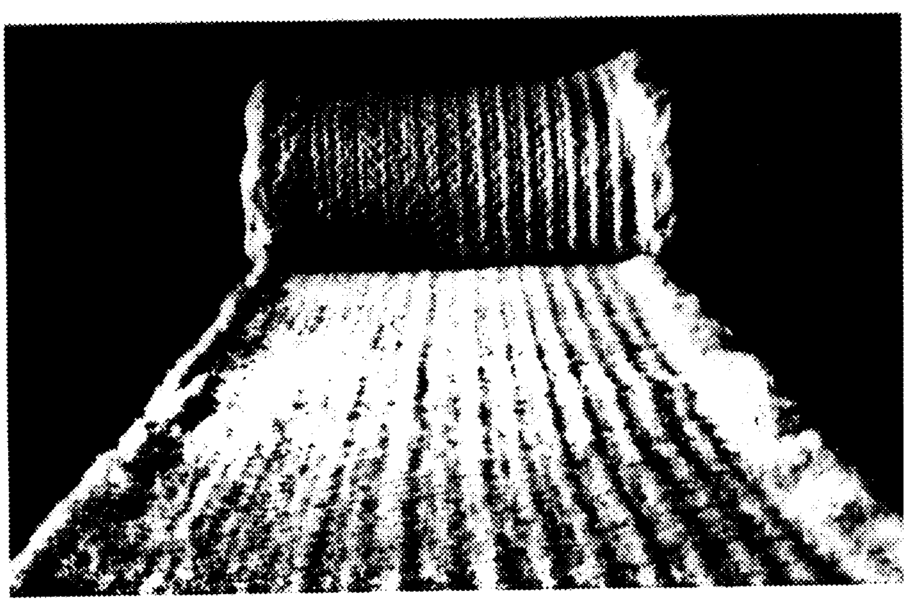


Figure 7.3 Continuous needled mat ready for pressing into complex shapes

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 (Figure 7.6). It is important to restrain slippage and mixing

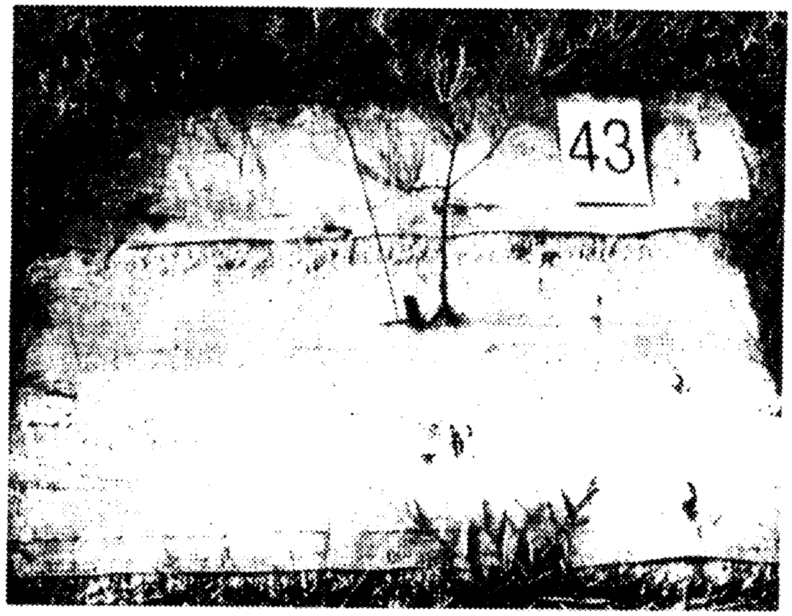


Figure 7.4 Mulch mat in place to control the growth of weeds around a newly planted tree sapling.

Figure 7.5 Agro-based geotextile in use to help prevent erosion on a steep slope.

of the different layers by placing separators between the various layers. Jute and kenaf geotextiles have been shown to work very well in these applications but the potential exists for any of the long agro-based fibers.

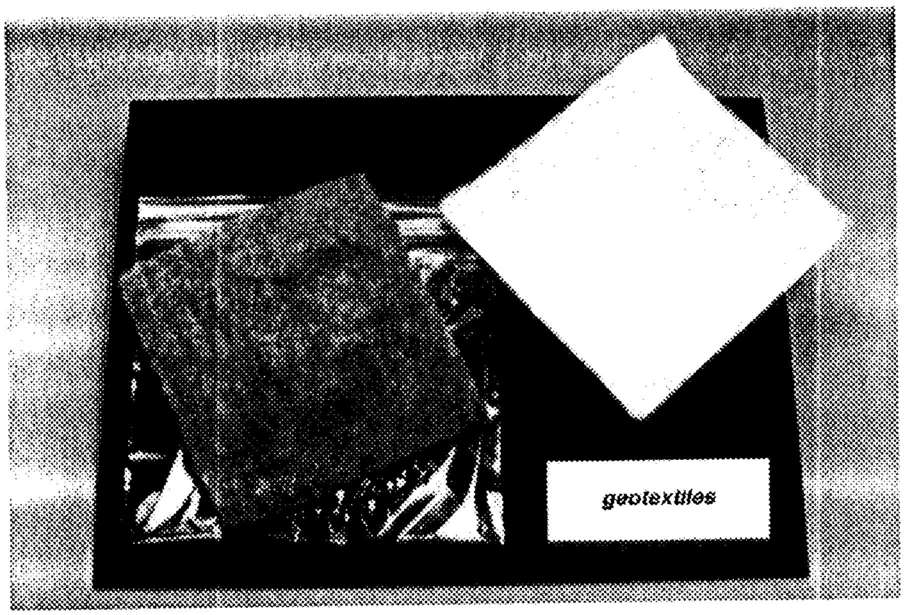


Figure 7.6 Examples of agro-based geotextiles.

It has been estimated that the global market for geotextiles is about 800 million square meters, but this estimate has not been broken down into use categories, so it is impossible to determine the portion that is available for natural geotextiles.

3.2 Filters

Medium and high density fiber mats can be used for air filters. The density of the mats can be varied depending on the size and quantity of material being filtered and the volume of air required to pass through the filter per unit of time (Figure 7.7). Air filters can be made to remove particulates 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 filtering aids to take particulates out of waste and drinking water or solvents. The fiber can be modified to selectively remove desired contaminates (see Chapter 13).

3.3 Sorbents

Tests are presently underway for use of agro-based sorbents to remove heavy metals, pesticides, and oil from rain water runoff in several cities in the United States (Figure 7.8). Medium and high density mats can also be used for oil spill clean up pillows. It has been shown that agro-based core material from kenaf or jute will

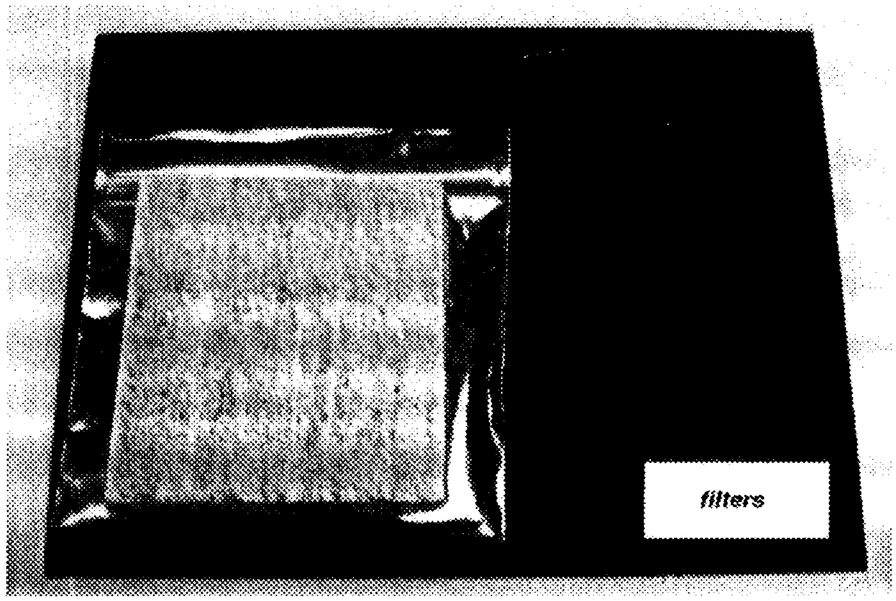


Figure 7.7 Agro-based fiber mats can also be used as air, water, or solvent filters

preferentially sorb oil out of sea water when saturated with sea water. There are many other potential sorbent applications of agro-fiber/core resources such as removal of dyes and trace chemicals in solvents and in the purification of solvents (see Chapter 13).

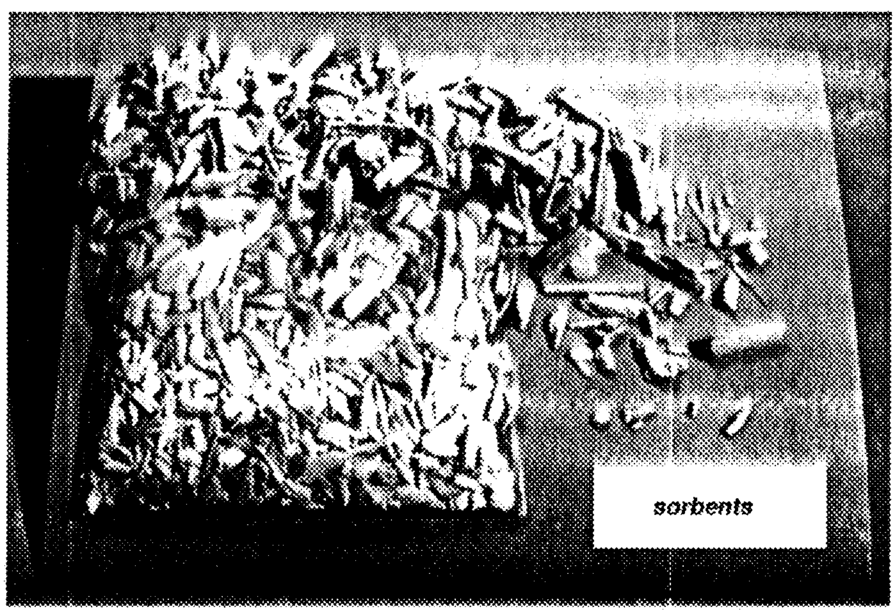


Figure 7.8 Kenaf pith (core) used for oil spill cleanup.

The fiber can be modified and used as a chromatographic solid phase support to selectively separate organic and inorganic chemicals. It is also possible to use core fiber materials as sorbents in cleaning aids such as floor sweep. While this is not a composite as such, it is another way agro-based resources can be used as sorbents.

Lignocellulosic fiber can also be compressed and converted to activated carbon for use as a sorbent. Again, it is not a composite as defined in this report but another outlet for agro-resources in the area of sorbents.

3.4 Structural Composites

A structural composite is defined as one that is required to carry a load in use

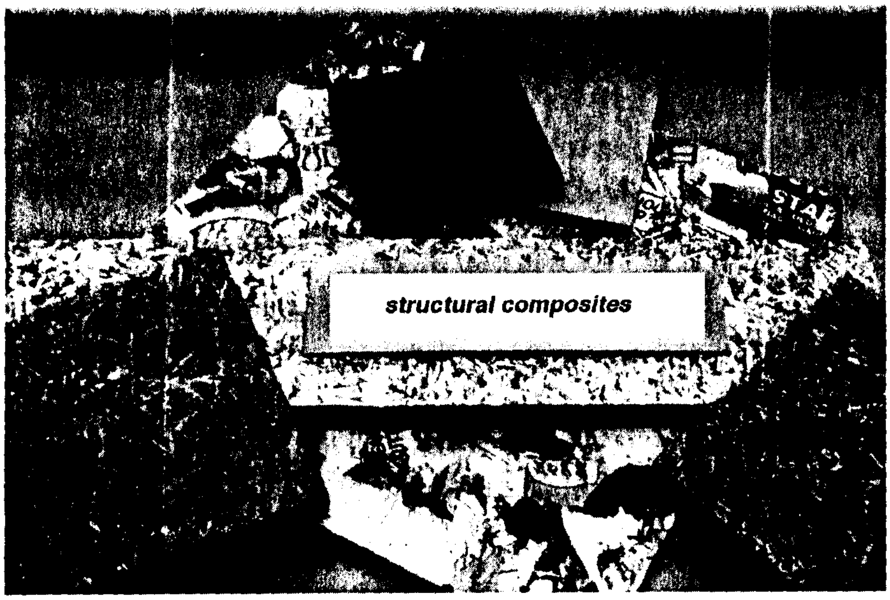


Figure 7.9 Examples of many types of structural composites made using Thermosetting resins.

(Figure 7.9). In the housing industry, for example, these represent load bearing walls, roof systems, subflooring, stairs, framing components, furniture, etc. In most, if not all cases, performance requirements of these composites are spelled out in codes and/or in specifications set forth by local or national organizations.

Structural composites can range widely in performance from high performance materials used in the aerospace industry down to wood-based composites which have lower performance requirements. Within the wood-based composites, performance varies from multi-layered plywood and laminated lumber to low cost particleboard. Structural wood-based composites, intended for indoor use, are usually made with a low cost adhesive which is not stable to moisture while exterior grade composites contain a thermosetting resin that is higher in cost but stable to moisture. Performance can be improved in wood-based as well as agro-based composites by using chemical modification techniques to modify fiber properties such as dimensional stability, biological and ultraviolet resistance, and stability to acids and bases, or treated with conventional fire retardant and/or decay control chemicals (see Chapter 11).

3.5 Non-Structural Composites

As the name implies, non-structural composites are not intended to carry a load in use. These can be made from a variety of materials such as thermoplastics, textiles, and wood particles, and are used for such products as doors, windows, furniture, gaskets, ceiling tiles, automotive interior parts, molding, etc. (Figure 7.10). These are generally lower in cost than structural composites and have fewer codes and specifications associated with them.

Non-structural composites can be produced by a variety of processes including extrusion, thermo-pressing, pultrusion, sheet molding, and injection molding.

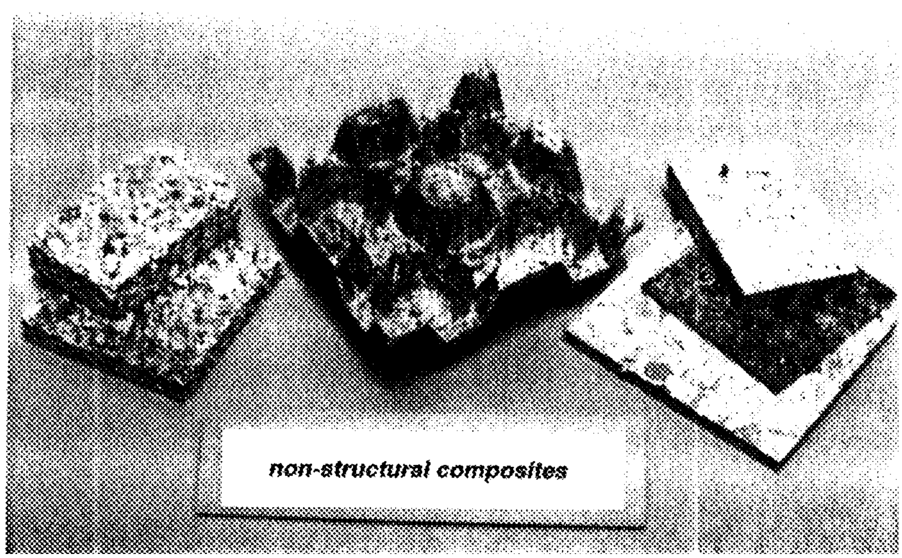


Figure 7.10 Examples of non-structural composites made using a thermoplastic matrix,

3.6 Molded Products

The present wood-based composite industry mainly produces two-dimensional (flat) sheet products. In some cases, these flat sheets are cut into pieces and glued/fastened together to make shaped products such as drawers, boxes, and packaging. Flat sheet wood fiber composite products are made by making a gravity formed mat of fibers with an adhesive and then pressing (Figure 7.11). 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 type composites, it is possible to make complex shaped composites directly using agro-based long bast fibers.

Figure 7.11 Agro-based mat being pressed into a complex shape

In this technology, fiber mats are made similar to the ones described for use as geotextiles, except during mat formation an adhesive is added 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 are possible (Figure 7.12). These molded composites can be used for structural or non-structural applications as well as packaging, and can be combined with other materials to form new classes of composites. This technology will be described later.

3.7 Packaging

"Gunny" bags made from jute have been used as sacking for products such as coffee, cocoa, nuts, cereals, dried fruits, and vegetables for many years. While there are still many applications for long fiber for sacking, most of the commodity goods are now shipped in containers. These containers are not made of agro-fibers today but there is no reason why they cannot be (Rowell, 1994a). Medium and high density agro-based fiber composites can be used for small containers, for example, in the tea industry and for large sea-going containers for commodity goods (Figure 7.13). These composites can be shaped to suit the product by using the molding technology described previously or formed into low cost, flat sheets and made into containers.

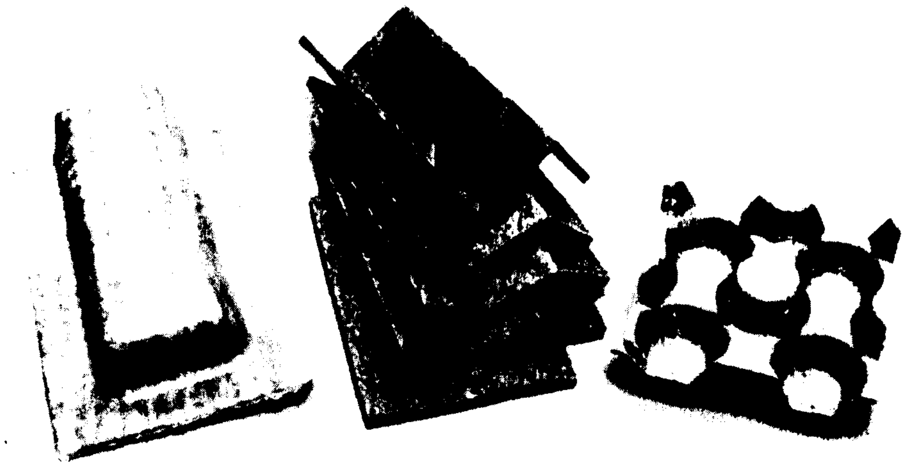


Figure 7.12 Examples of complex shaped structural or non-structural composites.

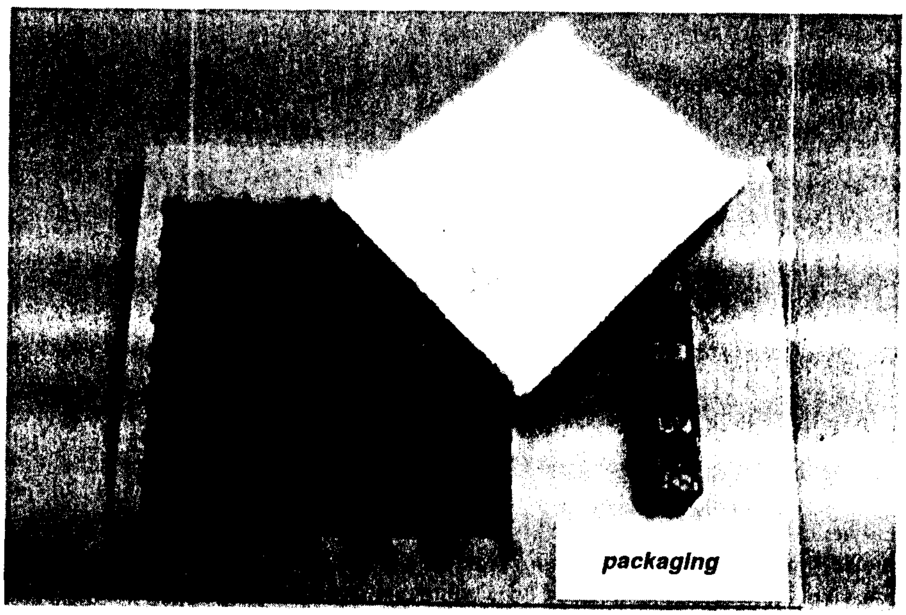


Figure 7.13 Lightweight packaging using "Spaceboard" (see Chapter 10) or mats for nesting-type packaging.

Agro-based fiber composites can also be incorporated into 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 agro-fiber fabrics and mats can be overlayed with thermoplastic films such as polyethylene or polypropylene to package such products as concrete, foods, chemicals, and fertilizer. Corrosive chemicals require the plastic film to provide water resistance and reduce degradation of the agro-based fiber. There are also many applications for agro-based fiber as paper sheet products for packaging. These vary from simple paper wrappers to corrugated, multi-folded, multi-layered packaging.

3.8 Combinations with Other Resources

It is possible to make completely new types of composites by combining different resources. Leaf, bast, and/or stick fiber can be combined, blended, or alloyed with other materials such as glass, metals, plastics, and synthetics to produce new classes of materials (Figures 7.14 and 7.15). The objective is to combine two or more materials in such a way that a synergism between the components results in a new material with much better properties than the individual components.

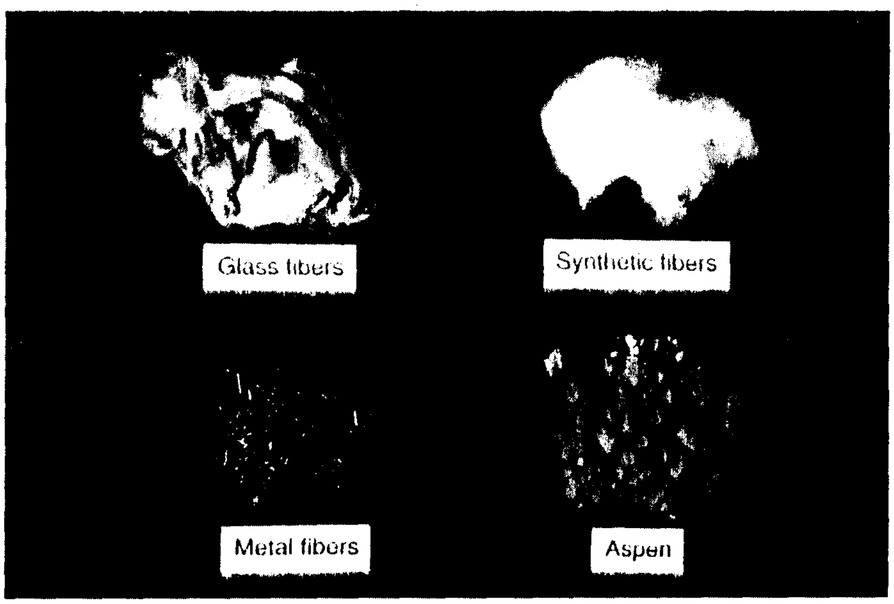
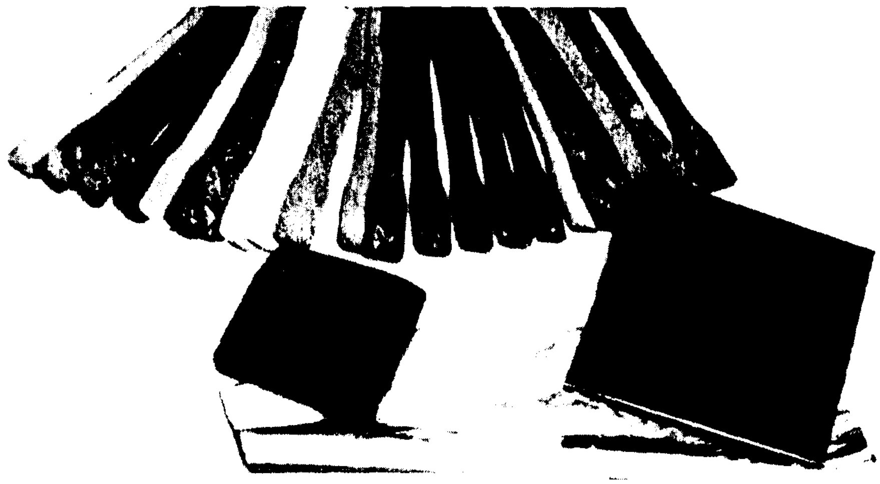


Figure 7.14 Many different types of fibers can be combined in a mat to enhance the performance of a composite.

Agro-based fiber/glass fiber composites can be produced with glass as a surface material or combined as a fiber with lignocellulosic fiber (Figure 7.16). Composites of this type often have a very high stiffness-to-weight ratio. The long bast fibers can also be used in place of glass fiber in many different types of liquid composite molding (LCM) systems such as resin transfer molding (RTM), resin injection molding (RIM), structural reaction injection molding (SRIM), and sheet molding compounding (SMC) (Figure 7.17). All of these techniques include a fibrous mat mixed with a liquid resin, which is polymerized to form a reinforced fiber composite.



combinations *with other*
materials

Figure 7.15 Combinations of agro-based fibers with thermoplastics, rubber, and metals.

in almost all present industrial applications, the fiber used is glass and the resins include polyesters, vinyl ester, polyurethane, phenolics, melamines, phthalates, alkyds, isocyanates, epoxides, acrylates, and silicones. Agro-fibers are lower in specific gravity, higher in specific tensile strength, lower in cost, and less energy intensive to process, so they are well suited to these types of technologies. The biggest single application of these technologies today is in automotive parts but there are growing markets in medical, sporting, space, tank, tub, boat, and corrosion-resistant equipment. Problems of dimensional stability and compatibitily with the resin must be addressed but this could also lead to major new markets for agro-based resources.

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

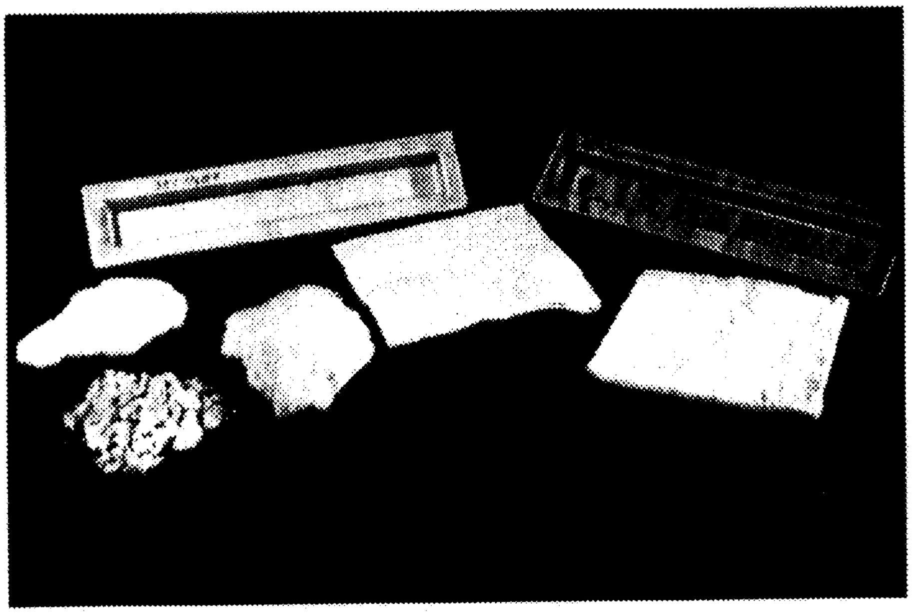


Figure 7.16 Combinations of agro-based fibers with fiberglass,

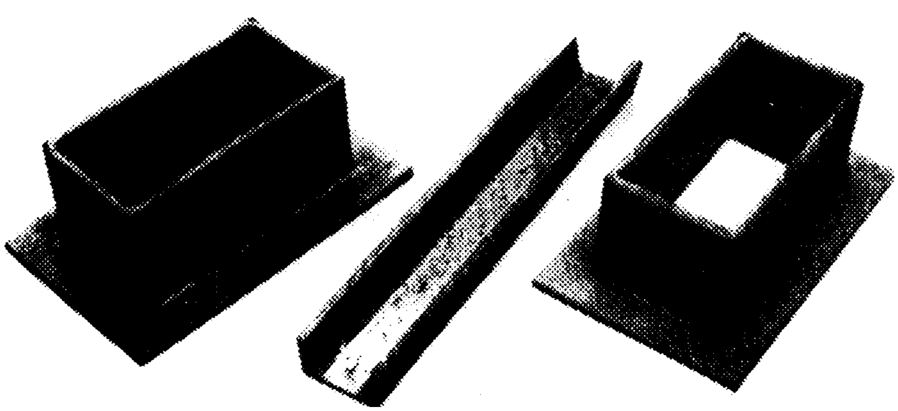


Figure 7.17 Resin transfer molding using (left) jute, (center) kenaf, or (right) fiberglass.

asbestos composites.Inorganic-bond 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 (Sanadi et al., 1994 a,b,c, see Chapter 12). Since prices for plastics have risen sharply over the past few years, addition of 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 agro-based industry, this represents an increased value for the agro-based component. Most of the research on these types of composites has been concentrated on the use of compatibilizers to make the hydrophobe (plastic) mix better with the hydrophil (lignocellulosic). 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.

Another combination of fiber and thermoplastics is in products that can best be described as fiber-plastic alloys (Rowell et al., 1994a,b). In this case the fiber and plastic become one material and it is not possible to separate the two components. Fiber–plastic alloys are possible through fiber modification and grafting research. This can be done by considering that agro-based fibers consist of a thermoset polymer (cellulose) in a thermoplastic matrix (lignin and the hemicelluloses). The glass transition temperature (T_g), however, 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 for thermo-molding at temperatures below decomposition. If a reactive thermoplastic is then reacted with the modified bio-based 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, it would be possible to produce agro-based films and foams.

4. INTEGRATED PROCESSING METHODOLOGIES

4.1 Multi-Fiber Processing Technology

One way to optimize the yield of any agro-based resource is to make use of all parts of the plant, The scheme shown in Figure 7.18 gives possible processing pathways that lead to the composite products identified in this chapter that can come from each fraction of the plant, The entire plant (leaves, stock, pith, roots) can be used directly to produce structural and non-structural composites. By using the entire plant, processes such as retting, fiber separation, fraction purification, etc. can be eliminated, which increases the total yield of plant material and reduces the costs associated with fraction isolation. This also gives the farmer a different option for crop utilization; that is, transporting the entire plant to a central processing center rather than getting involved in plant processing.

Another option is to separate the higher value long fiber from the other types of shorter fiber for use in value-added products. When the long fiber is separated, the by-product is a large amount of short fiber and pith material that can be used for such products as sorbents, packing, lightweight composites, and insulation. By

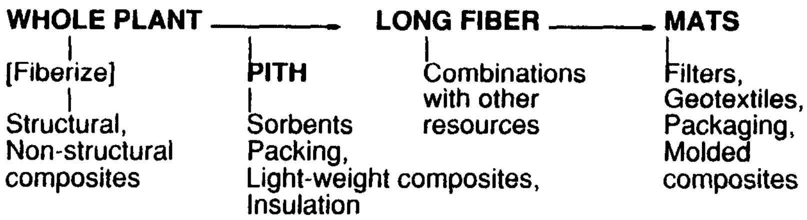


Figure 7.18 Multi-functional fiber separation scheme.

utilizing the by-product from the long fiber isolation process, the overall cost of long fiber utilization is reduced. The isolated long fiber can then be used to make mats that have value-added applications in filters, geotextiles, packaging, molded composites, and structural and non-structural composites.

More than one plant type can be processed at the same time using this scheme. Without the need to separate different agricultural resources, the costs of sorting and storage are reduced. Recycled natural fiber can also be used in this scheme. Desired product output and resource costs will drive this type of multi-fiber use technology.

4.2 Multi-Product Processing Technology

The key issues in the agro-fiber processing arena are what to collect, how to collect it, and what to make from what has been collected. In the preceding section, we discussed how eight different types of composites can be made utilizing different parts of the plant. We now offer a system for collection and processing of agro-based resources to produce a wide variety of products based on the same principle as a petroleum refinery. In this scheme, fiber for composites is just one of the product options available.

In the petroleum refinery, crude oil is brought into the refinery and management uses the computer to decide what products will be made, based on market demand. The same program could be applied to the agro-based industry. Our present paradigm of processing agriculture resources is to compartmentalize each segment of the industry rather than integrate them into one encompassing system.

Figure 7.19 shows the basic concept of an agro-refinery. In any geographic area, all agro-based resources are brought to the refinery. No predetermined markets are assumed and, as with the petroleum refinery, decisions as to processing and final product selection are made by market demands. From the cities within the geographic area come recycled paper products, waste wood, grass, leaves, and other agricultural wastes (Rowell et al., 1993). From the rural area come these same resources along with all agricultural resources. No separation of grain from cob or stock is made on the farm. Everything is cut off at the ground and brought in. From the industry in that area comes industrial wastes that can also be processed in the refinery. The refinery then has many options to produce food, feed, fiber, or fuel, or use the material as a substrate for fermentation, chemical production, or compost. The market structure determines what processing will be done and the best decisions based on total needs will be made. Since it has been shown that farm land must have some of the crop residue left as nutrient, it is important that part of the products produced include some type of compost. The compost produced could be improved over the original plant residues by enrichment with other needed ingredients.

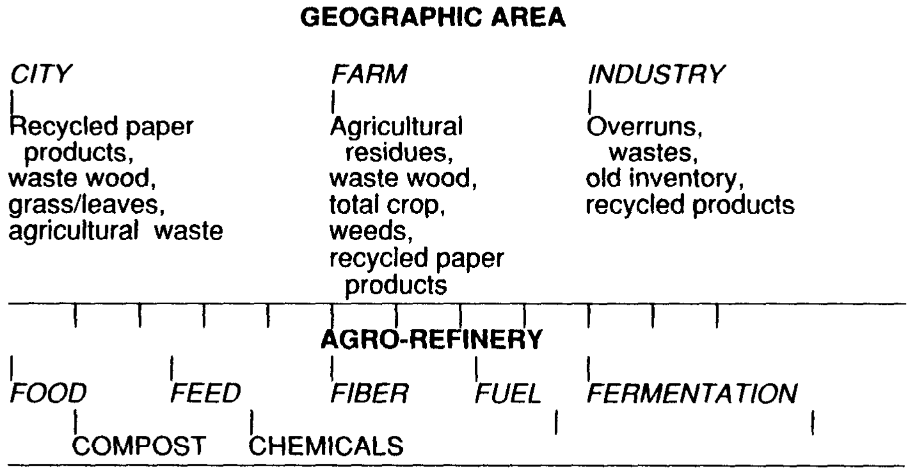


Figure 7.19 Concept of an agro-refinery.

Our present paradigm in the food production industry is to grow grain for food and use the residue for feed. In many parts of the United States, however, there is excess grain and there are schemes to burn grain for fuel. Plants, such as kenaf, are now grown for fiber on lands that once were used to grow grain. We have, for generations, used herbicides to remove weeds from food and feed crops, but, if we are after fiber, the “weeds” may be the best crop. There are schemes to ferment grains to ethanol for use as an additive to gasoline. There are also schemes to convert agro-based resources to methanol, phenols, and other chemicals.

In our scheme, all producers and consumers work together to manage resource production, utilization, and waste management. It expands the concept of sustainable agriculture to include all needs on a long range basis.

Rather than these product decisions being made in advance and individual manufacturing facilities built to produce only one product, the agro-refinery would be the central processing and decision making hub for the entire agro-based industry. It would be the recycling center for agro-waste resources as well as the processing center for all agricultural resources in the region and would lead to many more options for the use of this valuable resource.

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