Opportunities for composites from recycled wastewood-based resources: a problem analysis and research plan

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Abstract

There are many opportunities to produce composites from recycled biobased fiber. The fiber can be used alone to make low-cost and high-performance composites, combined with inorganic materials, or combined with other recycled materials, such as plastics, to produce mixtures, compatibilized blends, and alloys. This report describes the resources available; problems associated with collecting, sorting, cleaning, breakdown, classification, and blending of the recycled resources; and process considerations for forming various types of composites. We propose a framework for research to utilize biobased resources in the waste stream through the development of technologies that will produce composite products and commodities. Research in these areas can result in new lines of products that are cost effective, designed to meet end-use requirements, and environmentally compatible.

In 1986, the United States generated approximately 158 million tons of solid waste, almost 50 percent of the world's total (8). Solid waste in the United States is projected to increase by 1.4 percent per year to 193 millions tons by the year 2000 (3,4). The associated annual estimated capital and operating costs in handling this waste will exceed $120 billion by 1997 (2). It is estimated that 53 percent of this waste stream consists of wood-based resources and other cellulosic material. Most of the total solid waste resource is lost, as only about 17 million tons, or 9 percent, was recycled in 1986 (4).

We are being buried in our own residential and commercial discards. This is a waste of resources, energy, space, and labor. Collectively, these discards are labeled as waste, which suggests that these materials have no value or, frequently, a negative value, even though quite the opposite is true. Much of what is called waste is in fact a resource in the wrong place or in the wrong form. This includes wood, paper, metal, glass, and plastic. These resources require an investment in energy to be upgraded to usefulness again. It makes sense to recycle when the energy saved by recycling exceeds the energy expended on recycling. For example, in 1986 the United States exported almost 4 million short tons of wastepaper to Taiwan, Korea, Mexico, and Japan (1), where it was used to make new paper products in a process that uses only 40 percent of the energy required to manufacture the original paper from virgin wood (8).

The practice of extracting and collecting waste is

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TABLE 1. — *Estimated portion of substances in municipal solid waste in 1986.*[a]

Source	Municipal solid waste	
	(%)	($\times 10^6$ tons)
Paper/paperboard	38.8	61.2
Newspaper	(6.3)	(9.9)
Corrugated	(7.9)	(12.5)
Mixed	(21.9)	(34.5)
Magazines	(0.7)	(1.1)
Yard waste	18.2	28.7
Metals	4.9	7.7
Food waste	14.7	23.2
Glass	7.8	12.3
Plastics	8.8	13.8
Textiles	3.4	5.4
Wood	2.6	4.2
Rubber/leather	0.4	0.6
Miscellaneous inorganics	2	3.1

[a] Total municipal solid waste in 1986 was 158 million tons (5). The data in this table were taken from several sources; consequently, the numbers do not add up to 100 percent or to 158 million tons.

growing — the problem is a lack of markets for these materials. The problem analysis presented in this paper proposes to develop and expand new and existing markets using wastewood, paper, and plastics. This complements goals set by the Environmental Protection Agency (EPA) to reduce waste, reuse materials, increase recycling from 9 to 25 percent, generate energy, and reduce landfill. New EPA landfilling regulations will close 60 percent of the nation's landfills over the next 5 years, making resource conservation efforts even more important.

Wastepaper offers a far-reaching opportunity to reclaim valuable materials for new products. Substantial components of the waste stream are assorted wood-based resources that could be recycled to produce new composites. However, the technologies needed to exploit these resources have not yet been developed.

The purpose of this report is to propose a framework for research to develop the technologies needed to utilize wood-based and other cellulosic resources in the waste stream. The composites could address a broad spectrum of end-use applications, from commodity products geared to large markets whose performance requirements are minimal, to low volume, high value added specialty products that must meet rigorous performance requirements.

The research framework deals with both commercial and residential wood-based resources entering the recycling stream. These include newspapers, packaging, other forms of wood-based fiber products, industrial and residential solid wood wastes, and wood-based composite waste in all forms. The research framework also considers resources that coexist with wood-based resources, including a variety of plastics and other nonwood materials that "contaminate" the wood-based resource.

Types of wastewood composites

A comprehensive waste management program must consider several options to deal with solid waste. These consist of waste reduction, recycling, waste-to-energy schemes, and disposal (6). Several options, however, such as burning and landfilling, may be restricted in the future. Therefore, the remaining options for use of waste resources are to make new products or to use them for composting, chemicals, or liquid fuels. Research could have the greatest economic impact in recycling waste resources for new products. Increased use of recycled biobased resources would allow markets for fiber composites to grow without adding to demand for timber. Industry would benefit by producing quality composites that use less expensive raw materials.

Table 1 shows the national availability of resources in the waste stream. To be utilized, these materials must be separated from the waste stream and made available to the processing industry. Industry must be assured of a steady and reliable stream of raw materials for products. Thus, the amount of these materials directed from the waste stream will ultimately be a question of local inventories, collection costs, and raw material costs.

Our primary focus here is on research opportunities to convert wastewood and other unrecycled fiber into composites. The objective of producing a new composite from recycled resources is either to make the composite less expensive or to improve its performance. Performance is improved when two or more materials are combined in such a way to result in synergism — the composite is then better than its individual parts. For example, the strength properties of a natural product like wood are limited by irregularities such as knots, uneven growth, and juvenile wood. When wood is reduced to particles or fibers and then recombined in a matrix, the influence of the irregularities is diluted and strength properties exceeding those in the original state can be achieved. In some cases, combinations that initially may seem unpromising reveal an economic potential as a result of their enhanced performance.

The list of potential combinations is virtually limitless. We will consider three basic types of composites that can be made by combining recycled wood with 1) other biomass fiber, 2) plastics, and 3) inorganics. Recycled wood can also be combined with other materials such as metals and glass, but the major impact lies in these three types of combinations.

Wood-biobased fiber composites

Wood is not the only biobased resource in the waste stream. Other biobased resources include agricultural fiber, yard waste, agricultural residues, and water plants. Yard waste, a major source of biobased fiber that is now mainly considered for composting, is a vast resource that could be combined with wastewood for composites. Unwanted plants in lakes and waterways create a large waste stream that could also be considered as a valuable source of industrial fiber if they could be collected and processed economically and combined with the wood-based resource for composites.

Wood-plastic composites

One possible product from waste stream materials is a wood-plastic composite. Most research has combined wood flour with thermoplastics to form extrudable wood/plastic or compression-molded composites. Many other opportunities exist in this area, so it is important to consider the quantity and types of plastics found in the waste stream. Table 2 shows the total production of durable and nondurable plastics in 1990.

Many types of plastic composites, commonly known as reinforced or filled plastics, have already established a vast array of successful commercial markets. In the automobile sector alone this represents a market of 750 million pounds (340 million kg) per year. For years, wood flour has been used in "black phenolics" in appliances. The use of wood flour and other hard cellulosics in aliphatic polyesters has created a large market in molded wood for doors and in furniture for simulated wood designs. The use of fillers in polyvinyl chloride (PVC) has created a wide variety of vinyl tiles for flooring. The proposed research program should extend some of these markets and create new ones.

The main types of plastics are thermoplastics, which melt when heated and solidify upon cooling, and thermosets, which are cross-linked and unable to melt. Thermosets are more difficult to reformulate into new products than thermoplastics. Thermoplastics can be simply mixed with wood fiber and the mixture heated. The plastic material melts, but the wood fiber and plastic components remain as distinct phases. One example of this technology is reinforced thermoplastic composites, which are light weight, have improved acoustical and heat reformability properties, and cost less than comparable products made from plastic alone. These advantages make possible the exploration of new processing techniques, new applications, and new markets in such areas as packaging, furniture, housing, and automobiles.

A second way to combine wood fiber and plastics is to use a compatibilizer to make the hydrophobe (plastic) mix better with the hydrophil (wood). The two materials remain as separate phases, but if delamination and/or void formation can be avoided, the properties of the composite can be improved.

A final combination for wood fiber and plastic is in products that can best be described as wood-plastic alloys. In this case, the wood and plastic become one material and cannot be separated. Wood-plastic alloys are possible through fiber modification and grafting research.

If the wood fiber is made thermoplastic through grafting chemistry, the grafted wood fiber and plastic can be thermoformed without the use of a thermoplastic additive.

Composites with inorganic materials

Another major future recycling opportunity to utilize wastewood and other postconsumer waste is to blend proportionate amounts of these materials with inorganic materials. The most apparent and widely used example is cement. Portland cement, when combined with water, immediately begins to react in a process called hydration to eventually solidify into a stonelike mass. When fine sand and coarse stone, the traditional aggregates, are blended with the cement and water paste, the materials are bound together to form concrete. The strong bond between the paste and the aggregate occurs as each cement particle establishes a type of surface growth that spreads by linking with other cement particles and the aggregate.

A special category of concrete is structural lightweight concrete. Because lightweight concrete is made entirely or partially with lightweight aggregates, such as burnt clay, pumice, expanded blast furnace slag, and expanded vermiculite, its principal unique property is lower density compared to concrete with a normal weight. This makes lightweight concrete attractive for reducing dead loads in structures with concrete floors or roof fills. Generally, lightweight concrete also has superior insulating properties. Concrete made with wastewood will also exhibit light weight and a high insulating value. Besides wastewood, other postconsumer wastes such as glass and plastic can also be used as a concrete aggregate. Depending on the type or types of aggregate used and the proportionate blend of materials in the resulting concrete, the end properties may differ somewhat, but generally, such concrete would be classified as low to medium strength.

Other inorganic waste materials can also be added to the mix or used independently to produce a different kind of composite material. Flue-gas gypsum, now being produced in very large quantities because of

TABLE 2. — *Production of all types of plastics in 1990.*[a]

Plastic	Durable	Nondurable
	- - ($\times 10^6$ lb.)[b] - -	
ABS	720	492
Acrylics	550	201
Alkyd	300	20
Cellulosics	5	75
Epoxy	450	14
Nylon	190	300
Phenolic	1,870	957
Polyacetal	100	43
Polycarbonate	100	320
Polyester (thermoplastic)	50	2,037
Polyester (unsaturated, reinforced)	1,000	227
High-density polyethylene (HDPE)	1,750	6,055
Low-density polyethylene (LDPE and LLDPE)	930	9,426
Polypropylene (PP)	800	7,332
Polystyrene (PS)	480	5,773
Polyvinyl chloride (PVC)	5,500	3,812
Polyurethane	3,000	384
Thermoplastic elastomers	200	384
Urea and melamine	1,200	239
Total	19,190	37,707
Other plastics, including exports	4,583	
Total sold in United States	61,480	

[a] Source: (7).
[b] 1 pound = 0.4535 kg.

Clean Air Act regulations, is the result of introducing lime into the combustion process to reduce sulphur dioxide emissions. It is projected that by 1995, more than 100 U.S. power plants will be producing gypsum. Flue-gas gypsum has the potential of being used in lieu of mined gypsum for composites.

Recyclability of composites

Finally, in all the planning for using recycled resources to produce composites, a major consideration must be the recyclability of the composite itself. Any research must include cradle-to-grave analyses of all the products and processes developed as part of the program. Can each composite be recycled in the future? What problems will their reuse create? Unlike most metals and glass and some plastics, wood-based composites cannot be recycled without the loss of some properties. In developing new composites from recycled resources, it seems prudent to assure that some new products can themselves be recycled and not pose an immediate solid waste management problem. In other cases, especially in structural composites, the materials should not reappear in the waste stream for many years. This extension of service life also reduces the amount of resources consumed and placed in the waste stream.

Many references in the scientific literature involve research on the combination of virgin wood with plastics and inorganics. For the most part, the composites that are now produced with wood come from virgin fiber. Much of the technology developed for these composites can be applied to make composites using recycled resources.

Components of problem analysis

The problem analysis is subdivided into four general components, broadly defined as inventory, process, product, and economics.

Inventory

The inventory of waste products available for recycling is the basic question that will determine the commercial success of composites developed from research. The difference between theoretically available national waste streams and actual local wastes is currently being addressed by local jurisdictions as they mobilize to meet their waste management challenges. The research plan will provide local jurisdictions with information on markets and technologies for products from recycled waste. The jurisdictions will use their own inventory data as they review the research results.

Process

A broad spectrum of crucial fundamental science questions are posed when making the step between developing a satisfactory understanding of the inventory and developing processes that might be employed to make new materials from waste resources. It is essential to know the physical and mechanical properties of the individual components; the required data are not available for recycled wood or wood fiber. A first step must be to increase our understanding of how the history of prior use influences wood and wood fiber physical properties (such as fiber length and wettability), mechanical properties (tensile strength, flexibility), and chemical properties (particularly in terms of surface chemistry). Unfortunately, the limited information available on these properties is focused on various types of virgin wood fiber. Although these data provide base line properties, they do not provide information on what happens to these fibers as they are used and reused in various material processing and use environments. In addition, if these wood particles or fibers are to be used in combination with other matrices such as plastics or inorganics, we must have a reasonably complete understanding of their interfacial properties so we can optimize stress transfer between the wood particle and the matrix material.

To take advantage of the high tensile strength and low weight of the wood particle or fiber as a true reinforcing phase in the composite will likely require us to modify the wood and/or the matrix to optimize stress transfer, minimize stress concentrations, and maximize final material properties. Interfacial quality is likely to be enhanced through the introduction of chemical bonds across the interface or through increased secondary interactions as well as the use of wetting agents to make different types of materials compatible. For several reasons (for example, cost, process simplicity, and recyclability), the latter approaches are more attractive and can be achieved through either fiber or polymer modifications. Although various modification options have been extensively studied, the emphasis has been on reaction chemistry and gross composite mechanical properties. Very little insight into interfacial properties has been gained from these studies to date.

Processing recovered waste materials into usable products involves special challenges because of the heterogeneous and dispersed nature of the supply. To serve as a useful source of industrial feedstocks, processing steps must be followed. Wastes have to be 1) collected, 2) sorted by gross categories, 3) cleaned of contaminants, 4) broken down into usable and easily transportable sizes, 5) classified, 6) blended with other waste or virgin materials in the desired mix, 7) formed into a shape ready for final processing, or 8) molded, pressed, or extruded under heat and pressure into the desired product. The proposed research will deal primarily with steps 4 to 8.

Product

Product consideration is the next element of the problem. Economics, performance, and available resources will determine what type of composite is needed. Products will have to meet certain physical characteristics. A goal of this phase of the research is to determine the combination of materials required to achieve these characteristics. Testing procedures will be developed to evaluate each composite and guide research direction. For each composite, research will also be carried out to determine the product's reusability and its long-term environmental impact.

Economics and marketing

Economic analysis is intertwined with the elements just discussed. Its role is to provide basic market information in areas where new or modified composite materials will compete and provide cost and revenue information on prototype processes resulting from the basic research. The economic analysis of alternative techniques and processes forms an integral part of this program.

Research approach

The various approaches to recycling are based on the premise that government, universities, and the private sector are in a cooperative partnership. Government alone cannot logically mandate the increased use of recyclable resources without the technical knowledge and understanding of markets needed for the successful use of recycled products. For example, government-mandated recycling programs have increased the supply of recycled materials beyond the demand of the industries that utilize them. Market distortions and price collapse have ensued. New, larger markets are needed that industry, the ultimate producer and user of marketable composites, should share in developing as a full partner in the research process.

Inventory considerations

Economic considerations require knowledge about what is available in the waste stream, on both the national and local levels. In collecting data for this problem analysis, it became obvious that reliable inventory data did not exist for many types of waste streams. Existing data are currently being generated by local jurisdictions. Initial research efforts should be directed toward specific wood-based (and other resources that can be combined with wood) waste streams that can be collected, separated, and used to make composites. The quantity and quality of various wastes need to be analyzed in detail before a meaningful economic study can be done on the feasibility of producing composites from wastes.

Process considerations

Collection. — The first process step is material collection. Currently, wastes are generally collected and disposed of as part of municipal functions and are often available for little or no charge to a prospective user. Conceivably, as markets for wastes become developed, municipalities may seek to recover costs of collection. Any economic analysis for end-product formulation should therefore consider costs for raw material collection.

Sorting. — The utility of wastes for industrial composite applications may increase with the degree of waste homogeneity. Many communities are currently developing processes and technologies to extract resource materials from the waste stream. By identifying the minimum sorting standards for an application, the waste handlers will be able to adjust their operations accordingly.

Cleaning. — The cleaning of recycled plastics is being intensively studied by the Plastics Recycling Foundation, Inc. A system is now available for the removal of paper labels, paper adhesives, and aluminum inserts in many lids for just two major plastics, polyethylene terathylate (PET) soft drink bottles and high density polyethyelene (HDPE) milk and water bottles. Dirt and gravel particles are also removed by the hydroclones incorporated in these cleaning processes. Because cleaning increases costs, the issue is what degree of cleanliness is needed to make the plastics usable.

Breakdown. — For most collected and sorted materials, some type of breakdown is required, i.e., densification, sizing, and/or reduction (possible preparation for further cleaning and separating). Material is broken down by hogs, hammermills, grinders, refiners, fluidizers, or pulping. In general, the reason for breakdown is to convert the material into a more useful form for transport and storage, mixing/blending, and forming.

Specific research objectives should include 1) developing systems for optimum shredding and/or grinding of thermoplastics for use in wood-plastic composites, 2) improving existing fiberizing to maintain fiber integrity, and 3) developing systems to break down short and odd-length material (for example, demolition, construction, and land-clearing wood).

Classification. — The targeted composite product types will establish classification parameters for raw materials. To maintain the composite performance properties, appropriate breakdown technologies will need to be matched with materials and targeted end-products. Classification of the waste resource will organize the materials, technologies, and products into an effective system that can be analyzed for economic feasibility.

Blending. — Blending fibers, binders, fillers, and additives is critical to the production of successful composites. Although many wet processing systems are available, little is available for adequate dry processing.

Specific research objectives should include developing inexpensive methods for dry blending solids with solids and with low and high viscosity liquids and developing methods for transporting dry-blended materials.

Forming. — After composite components have been blended, the form of the blend may need to be altered prior to the next production step of molding, pressing, or extruding. The best example of this is the formation of nonwoven mats prior to molding. In this technology, plastic and/or wood fibers are woven by a set of needles that repeatedly pierce the mat. The needles do not sew the fibers together but overlap and interweave them more or less randomly using barbs on the ends of the needles. This process mixes two or more fibrous materials to give a homogeneous mat that can be placed in a mold or press and processed into the desired final shape.

Specific research must be done to 1) determine the feasibility of nonwoven mat technology for forming specific composite materials, 2) determine the economics and production rates attainable with forming technologies and compare them to alternative production techniques, and 3) investigate new forming techniques that are used for other similar materials.

Molding/pressing/extruding

These processes convert composites into their final permanent shapes. Pressing is currently used for the production of particleboard, flakeboard, and similar products. The term pressing is used to describe the formation of flat sheets of material, whereas molding describes the formation of more complex shapes, using the same technology of pressing with temperature-controlled platens or molds. Extrusion is a process developed for plastics. It can be used with mixtures of wood and plastics of appropriate composition and properties. The composite feed material is heated and compressed by a screw device, which forces it through an orifice that defines its shape.

Proper functioning of an extruder requires a precise match of the formability of the feed material with the machine operation. Thus, it is critical that a homogeneous mixture of materials of known properties and composition be used in this process. Other plastic-forming technologies are blow molding, injection molding, and shape molding. Whether these processes will be applicable to new composite materials will depend upon the rheological properties of the composites.

Research in this area will include: 1) determining the optimum heat and pressure cycle for producing each composite material, 2) determining the complexity of shapes that may be formed from a given material (e.g., the minimum radius of curvature obtainable and the minimum and maximum moldable thicknesses), 3) determining the optimum production rates for a given material, 4) identifying optimum mold release agents for a given material, 5) investigating modification of extruder technology to accept a broader range of melt viscosity profiles with increased production rates, 6) investigating the feasibility of blow molding and shape molding technology for composite production, and 7) investigating the use of foaming or gassing agents that can provide voids in the material core when using an extrusion process. Research on foaming and gassing agents in the extrusion process can reduce overall densities with minor strength loss. Thus, the investigation of optimum core voiding is a necessary area of research.

Product considerations

The final result of the research program as outlined in this research plan will be the production of prototype composites. The physical and mechanical properties of these composites will be tested and the economics of their production analyzed. For example, some of the composites envisioned should be decay resistant and dimensionally stable. These composites might be of interest to wood products companies for use in such products as millwork, outdoor furniture, or landscape timbers. Other composites, because of their moldability, might be good candidates in the areas of packaging or indoor furniture.

Researchers must interact with manufacturers and consumers to compare the properties and production costs of the prototype composites with existing and prospective products to determine if the composites might perform better or be less expensive. If changes or improvements are needed for these prototypes to be successful, this information must be relayed to the research team. In turn, the researchers should attempt to modify the process or revise the prototypes to meet process and product needs. In this way, we can generate not only new composites but also composites that are useful to manufacturers and consumers. As such a research program develops, formal partnerships will hopefully arise between the researchers and companies interested in producing the new composites. Including this feedback loop ensures that useful products result from research efforts.

The prototype composites envisioned in this research program could span the entire range of costs and performances of biobased materials. This should give the most opportunity to expand the use of recovered resources. At the high end of the spectrum, industry also has the opportunity to produce new composites of such high value that it makes economic sense to produce them from virgin materials. Thus, this proposed research program may enhance the overall use of wood-based resources as well as other resources.

The availability and costs of virgin and recycled resources are constantly changing. Research is needed on composites that may be of commercial interest in the future, if not the present. New resources, such as agricultural fiber and agriculture wastes, may become an important source of raw material as logging of virgin fiber is restricted as a result of environmental considerations. The price of petroleum-based plastics may also change.

The development of new techniques and equipment may lead to the invention of greatly improved composites. For example, extruders capable of effectively utilizing mixed plastics in an extruded composite would greatly expand the raw material base and reduce the price of such composites. Research on these innovative materials and methods should be started now to provide new products for the future.

Types of composites. — The technology needed to produce a specific composite will depend on the type of composite desired. Establishing the performance properties required in a new composite is the first step in determining what type of composite is to be produced. Product type, economics, performance, and available resources will determine the type of process operations for study.

Wood-biobase fiber composites: Research is needed to determine 1) the quality and quantity of usable fiber in the biobase resource, 2) the level of biobase resources that can be blended with recycled wood fiber feasibility of nonwoven mat technology for forming specific composite materials, 2) determine the economics and production rates attainable with forming technologies and compare them to alternative production techniques, and 3) investigate new forming techniques that are used for other similar materials.

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for specific composites, and 3) the mechanical properties of each prototype composite produced.

Wood-plastic composites: Products with complex shapes can be produced using such methods as extrusion technology, nonwoven needling, and thermoplastic fiber melt matrix technology. Extrusion technology allows wood-plastic composites to be made by thermal forming. Currently, most extrusions that use wood or other lignocellulosic materials use the wood component in the form of a powder; the wood acts as a low-cost filler. The contribution of wood to strength is much higher if the wood component is in the form of a fiber. Wood-plastic composites can also be made by forming flexible fiber mats, which can be made by nonwoven needling, or by using thermoplastic fiber melt matrix technologies. The mats can be pressed into any desired shape and size. The plastic can act as the binder that holds the mat together. A high performance adhesive can be sprayed on the fiber before mat formation, added as a powder during mat formation, or be included in the binder fiber system. Any size, shape, thickness, and density is theoretically possible. With fiber mat technology, a complex part can be made directly from a wood-plastic fiber blend. Present technology requires the formation of flat sheets prior to the shaping of complex parts.

The creep caused by thermal deformation restricts recycled thermoplastics to composites for nonstructural uses. However, thermoplastics can be converted to thermosetting materials by chemical modifications of the polymers, i.e., by oxidation or grafting, followed by crosslinking reactions. Thus, it is possible to make structural products using recycled thermoplastics.

Research in this area will require us to 1) develop laboratory methods for converting wastewood and waste plastics into forms suitable for subsequent extrusion and nonwoven web processing, 2) identify product applications and the extent to which properties need to be modified in these applications, 3) determine the limits of using wood fiber in extrusion technology in combinations with thermoplastics, 4) determine the limits of using thermoplastics as binder fibers in nonwoven mat technology to produce formable, flexible, and thermoformable mats, 5) determine the chemistry needed for alloying thermoplastics with chemically modified wood fiber, 6) determine chemical and mechanical properties of composites produced and the effect of formulation and process variables on these properties, 7) study the conversion of thermoplastics into thermosetting materials, and 8) establish technology transfer and industrial-scale trials and preproduction runs.

Wood-inorganic composites: It is likely that the class of wood-inorganic composites with the greatest short-term potential for developing large-volume markets is concrete and cement-bonded structural and nonload-bearing products. In concrete, the wood would be used completely or partially as the coarse and/or fine aggregate to produce a low- to medium-strength concrete. As a coarse aggregate, chunky wood particles, platey wood chips, or coarsely shredded fiber bundles are the most obvious particle forms for research. Sawdust, finely shredded fiber bundles, wastepaper fibers, and pulp sludge are the primary candidates for use as fine aggregate. Other inorganic materials that should be included as potential raw materials for concrete and cementitious-bonded products are glass, plastics, flue-gas gypsum, chemical gypsum, steelmill slag, and fly ash.

Research will focus on optimizing the mix for the intended application and expected durability of concrete made with wood and postconsumer wastes. Any evaluation of the mechanical and physical properties must address such issues as water/cement ratio, proportions of aggregate/sand/cement, aggregate type or types, aggregate size, and duration and type of curing. Conventional concrete admixtures or additives that alter water/cement ratios, workability, strength, curing, and cement-to-aggregate bonding should also be investigated to determine whether the same benefits apply to concrete made with wood and inorganic materials. Typical admixtures or additives are superplasticizers, silica-fume, and calcium chloride. Others should be identified through research.

Research will also include obtaining basic and applied scientific information on mechanical, thermal, fatigue, dynamic, and durability properties or behavior of composite materials.

Some unique properties of concrete made with wood aggregates are its light weight load-supporting capability beyond failure, high modulus of toughness (a measure of ability to absorb energy from crashes and impacts, such as ballistic missiles), resistance to earthquakes, good insulating properties and vibration damping characteristics, and low coefficient of thermal expansion. These properties are particularly important for such applications as industrial and residential construction, highway and airport pavements, bridges, noise walls along highways and temporary highway construction traffic barriers (New Jersey walls), sign and guard rail posts, retaining walls and impoundments, concrete floors in agricultural buildings, poured blocks and short logs for building construction (lightweight concrete log cabins), landscaping products, and sidewalks, slabs, and parking pads. Once the mechanical and physical limitations of this special type of concrete are fully understood, the potential applications are limited only by imagination and economics.

Concrete made exclusively from sawdust and Portland cement can also find broad applications provided that its limitations are fully recognized. The principal use of sawdust concrete may be as an insulating material and as floor topping. The specific research needs in this area relate to drying shrinkage, moisture movement, and long-term durability.

Thin-sheet cement products can be made using recycled paper as reinforcing fibers. Coated grades of wastepaper are least suited for use in papermills. Consequently, we need to look beyond the paper industry for markets for different grades of wastepaper. Potential applications for wastepaper-cement products include cladding panels, partition components, ceilings and walls, garden fencing, silo lining, greenhouse panels, duct work, drainage and irrigation channels, tiles, pipes, water troughs and fittings, and laboratory surfaces.

Another source for composites is cellulose reclaimed from paper recycling wastewater (sludge). Recycling of wastepaper generates large amounts of unusable sludge (as much as 30% of input weight). The solid content of this material, 3 to 6 percent by weight, consists primarily of cellulose fibers and Kaolin clay. After dewatering to 25 to 40 percent solids, sludge is disposed of mainly through land filling. Disposition of the sludge currently poses a major challenge to the paper recycling industry. Presently, about 5 million tons per year are dumped in U.S. landfills, and the impact of this waste to underground aquifers is of major concern. Economic means to recycle this material need to be developed. Composites of Portland cement and cellulose fibers reclaimed from paper recycling wastewater are potentially useful materials for the construction of building blocks, wall boards and panels, shingles, fire retardants, and fillers for fireproof doors.

Another inorganic material, gypsum, is currently mined and used in the production of board products. Two potentially large alternate sources of gypsum from recycling operations hold promise for composite board products: flue-gas gypsum and chemical gypsum. Flue-gas gypsum is generated by technology that uses lime to capture sulphur dioxide. The Clean Air Act of 1990 mandates that coal-fired power plants implement technologies to reduce acid rain by lowering emissions of sulphur dioxide and other gases. According to recent information, 111 power plants will be affected by the law in 1992, and 500 power plants may be affected by 1995. Chemical gypsum is a waste byproduct of acid production plants. A number of these plants are in operation in the southeastern United States. Some chemical gypsum could be slightly radioactive and must be deactivated and cleaned before use. By combining chemical or flue-gas gypsum with wood fiber or particles (and other solid wastes), composites could be developed for the building products industry. An especially attractive product is as an alternative to wallboard (sheet rock) that has improved properties. Research is needed to find safe and economical uses for gypsum, which currently poses a serious environmental challenge.

Another source of inorganic material is expanded blast furnace slag, which is formed during steel production. When ground, slag is converted into a material with cementitious properties. When combined with recycled fiber and possibly other solid wastes, ground slag could be used to produce exterior and durable composite products for the construction industry.

Specific areas of research on wood-inorganic composites include: 1) mechanical and thermal properties, fatigue-fracture properties, and dynamic properties and behavior of concrete made with wastewood aggregates and other postconsumer wastes; 2) long-term durability of concrete made with wastewood aggregates and other postconsumer wastes; 3) drying shrinkage and moisture movement in wood aggregate concrete; 4) use of ground steelmill slag in combination with wastewood fibers and other postconsumer wastes for structural products; 5) use of flue-gas and chemical gypsum in combination with recycled fibers for composite board products; 6) use of cellulose fibers reclaimed from wastewater of paper recycling for concrete and cement-bonded structural building products; 7) use of wastepaper fibers from coated and mixed wastepapers as reinforcing fibers for assorted thin-sheet cement products; 8) reinforcement of concrete with recycled wood fibers; 9) production of "shotcrete" from recycled wood fibers; and 10) production of flowable fills from shredded wood fiber bundles and wastepaper sludge.

Testing. – Each composite outlined in this research plan needs to be evaluated by a series of tests. The specific tests will depend on the material and its intended end use. This would include testing properties such as modulus of rupture, modulus of elasticity, flexural modulus, compressibility, and internal bond. The American Society for Testing and Materials (ASTM) test methods should be used wherever available and appropriate. For example, the following tests and methods are applicable: static bending and tensile strength, ASTM D790; cantilever bending, ASTM D747; puncture impact, TAPPI T803; Izod impact, ASTM D256; and heat deflection temperature, ASTM D648.

Other matters for evaluation include paintability, glueability, thermal expansion, dimensional stability, weathering, decay resistance, flammability, performance in service (simulated conditions such as cycling under load in an environmental test chamber), freezing/thawing cycles, and outdoor exposures for extreme climates. Perhaps the most important properties to test in plastic composites are long-term creep under small or intermittent loads and early transformation from ductile to brittle failure.

Each composite will need to be tested to conform to materials specifications as outlined in ASTM and other standards and building codes. This will be critical before any product can be specified for construction.

Another category of testing for this research plan is more fundamental in nature. This category will consist of tests to elucidate the basic chemical and physical mechanisms that determine the properties of the composite. Such tests will use sophisticated equipment such as spectrophotometers, electron microscopes, electron dispersive x-ray analytical tools, and nuclear magnetic resonance instruments.

Recyclability. – Additional research is needed to determine the feasibility of reusing composites to form new composites. A life-cycle analysis needs to be conducted for each proposed composite to determine the environmental impact with each use.

We will need to determine 1) the loss in properties (mainly physical) after each use of the wood fiber, 2) the appropriate proportion of recycled wood fiber to virgin fiber in relation to loss of properties, 3) the best way to reuse wood fiber to minimize loss of properties, and 4) test procedures for recyclability.

Economic considerations

The role of economic research in this program is twofold – to provide information on those markets where new or modified composite materials will compete; and to provide cost and revenue information on prototype processes resulting from the basic research.

Information on markets maps out the business terrain that new products will have to traverse. Identifying areas where new processes and products can be most competitive requires knowledge of existing product cost structures. Likewise, targeting products with properties that will be compatible with existing requirements requires knowledge of existing performance standards. Market research will be conducted to categorize existing products by their cost and performance. The size of various potential composite product markets will also be determined. This will help establish research priorities aimed at targeting markets for the greatest volume of waste products.

Information on process economics will be needed to direct research within realistic economic parameters. As fundamental process relationships between process variables (such as particle size, moisture content, composite mix proportions, matrix type, and press temperature and residence time) and product properties (such as strength, stiffness, and dimensional stability) are determined, economic models will be developed. These models will be used to test the economic consequences of process modifications to achieve a balance between the often conflicting objectives of attaining high property values at low cost. The economic consequences naturally include unit costs, but of equal importance to the success of a concept is the element of productivity. The tradeoffs between productivity, high performance, and low unit costs require models to monetarily quantify the process. An iterative procedure between the basic research and the economic modeling is envisioned in which researchers will receive feedback on the economic consequences of proposed modifications.

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Departments

Cover

The old sign came down and another is up with our new name — the Forest Products Society — and logo, at the International Office in Madison, Wisconsin. We feel the new logo represents many aspects of the forest products industry. If you look closely you can see a variety of shapes — tree, roofline, truss, a log cross section, and a laminated member — to mention a few. Perhaps you can find more. For more information on the Society's name change, turn back to page one for a memo from Art Brauner, Forest Products Society executive vice president.