Energy Efficient and Sustainable Building Enclosures Using Bio-based Materials

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Abstract

Biocomposites are finding applications in the construction industry due to their low cost and environmental acceptability. Two of the major cost drivers for composites are labor and raw materials. Plant derived raw materials can be used to manufacture fiber reinforced composites. The suitability of bio-based raw materials in composite products for building envelope enclosures need to be investigated. Natural fibers can be used as reinforcements in both thermoset and thermoplastic composites. Soy based thermoset resin system is ideal for automated composite manufacturing process like pultrusion because of the increase in line speed. The improvement in the interfacial properties of these new materials will enhance the mechanical and hygrothermal characteristics. This will overcome the performance limitations in terms of acceptable specific strength and durability. Development of sustainable bio-based materials will lead to low cost, energy efficient and low maintenance building products.

Keywords: Biomaterials, natural fibers, soy-based resin, composites, pultrusion

Introduction

Composite industry is growing fast and consumes over 20% of the total nationwide shipments. However, composite materials represent only a small percentage of the entire civil infrastructure market. Widespread application in this construction market is still limited by the cost of the raw materials and labor. With the growing opportunities to use pultruded composites in civil structural applications, the development of increasingly cost effective raw materials is of great interest. Alternative plant derived raw materials and its use in composite products is becoming an active research subject.

Biobased products rely upon plant-derived materials as their main ingredients. They are made from a renewable resource and generally do not contain environmentally damaging substances. By using biobased products, the user is avoiding reliance on petroleum resources. A bio-based product has a bio-material content of 90% or more wherein the non-biobased content is incidental to the overall product performance and made necessary only because a bio-based equivalent does not yet competitively exist in the market place.

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Current State of the Art

Development of new bio-based raw materials and automated composite manufacturing processes will lead to affordable and energy efficient new building products.

Vegetable Oil based Resins

Unsaturated triglyceride oils such as soybean, crambe, linseed and castor oil constitute one major class of renewable resources. The main composition of these oils is saturated and unsaturated fatty acids. Besides food source, they also have wide industrial application. Directly using these fatty acids or their derivatives from some chemical modification, typical applications are in painting, coating, varnishes, cosmetics and polymer industry. This renewable triglyceride oil can be polymerized to form elastomeric network and represent alternative material resources to petrochemical based resin. Among the renewable triglyceride oils, soybean oil is attracting more and more attention for industrial application because it is readily available for large amount production.

The largest category of industrial soybean oil use is in plastics and resins. Epoxidized Soybean Oil (ESO) is mainly used as plasticizer or stabilizer to modify the properties of plastic resins such as thermoplastic Polyvinyl Chloride (PVC). ESO can be used as a reactive modifier and diluents of the epoxy resin system. ESO also shows potential use as an efficient toughener when big particle second phase rubber is formed for epoxy application. Several researchers investigated anhydride cure (Rosch and Mulhaut, 1993), and conversion of the epoxidized soybean oil into flexible, semi-flexible and rigid cross-linked polyester using various approaches (Javni and Petrovic, 1997; Crivello and Narayan, 1992). The polymerization is strongly dependent on the nature of anhydride curing agents and catalysts. These studies show the potential for the synthesis of new polymers derived from renewable soybean oil. More recently, researchers began to explore the feasibility to manufacture polymer and composites from epoxidized soybean oil. Crivello et. al. (1997) reported the fabrication and mechanical characterization of glass fiber reinforced UV-cured composites from epoxidized vegetable oils. So far, the wide structural applications of ESO are still limited because of its low cross-linking density and mechanical performance. The development of soy based resin for structural application is still a challenge for polymer and composite industry.

Epoxidized methyl soyate (EMS) and epoxidized allyl soyate (EAS) resin system were recently synthesized at University of Missouri-Rolla (Zhu et. al. 2002). These materials consist of mixtures of epoxidized fatty acid esters. The epoxidized soybased resins provide better inter-molecular cross-linking and yield materials, which are stronger than the materials obtained with commercially available epoxidized soybean oil. The curing behavior and glass transition temperature were monitored with a Differential Scanning Calorimeter. Standardized tests showed that soy-based resin has mechanical properties comparable to Shell Epon resin. The epoxidized soybased resin system holds great potential for environmentally friendly and low cost raw materials in fabrication of epoxy composites for structural applications.

Natural Fibers

Engineers have long searched for plant fibers with optimal material properties for structural purposes in composite materials. Fibers obtained from plants such as hemp, kenaf, sisal, or flax when combined with suitable resins can give cost effective materials for many applications. However, proper preparation of natural fibers is required prior to their use (Bolton, 1994). Lamy and Baley (2000) presented a detailed method to predict the stiffness of flax fibers in epoxy composite materials. A comparative study between different types of natural fiber polyester resin composites for strength and cost has been reported (D'Almeida, 2001). Natural fibers if utilized properly can impart higher strength to weight ratio to the fiber-reinforced composites. The main drawback is low processing temperatures due to potential fiber damage. However, the specific gravity of natural fibers is significantly lower than that of glass fibers. The physical properties of natural fiber composites are comparable to oriented stranded board (OSB) and plywood commercially available in the market. In recent years, researchers have begun to explore the feasibility of manufacturing fiber reinforced polymer composites using natural fibers (Mohanty et. al 2002). Williams and Wool (2000) reported natural fibers reinforced soybean oil in polyester resin.

Manufacturing of Biocomposites using Pultrusion

The pultrusion process can be used for load bearing members of the construction market. This process is the fastest and most cost effective composite manufacturing process and is well suited to high volume production of structural applications. In the pultrusion process, many uniform cross-section profiles can be manufactured continuously as long as raw materials are supplied. Fiber reinforcement can take form of any one or combination of several types such as rovings, mats, fabrics and cloths. This variety of available reinforcement allows much design flexibility thus allowing a part to be customized to a specific application. The pultrusion technology also improves composite properties compared to other methods because the fibers are under tension as the resin cures and are tightly bonded to each other. When the composite material is put under mechanical load, the load is taken immediately by the high strength fibers. Glass fiber reinforced pultruded soy based composites have been developed and investigated at the University of Missouri-Rolla (Chandrashekhara et. al. 1999; Zhu et. al. 2001). The lubricity of the soybean oil significantly reduces the pull force. Mechanical tests show that the pultruded composites with soybased resin system possess comparable structural performance characteristics such as flexural strength, modulus and impact resistance. Further research will be based on using biobased fibers for pultrusion process.

Future Research Directions

To meet the building codes, energy efficient housing materials and construction should be evaluated and studied. Because of the low density of plant fiber, a plant derived product will always be thicker than one reinforced with the same mass of glass fiber. This will lead to energy efficient panels for building enclosures. The viability of the bio-based materials in terms of energy efficiency and moisture resistance need to be addressed. Also, the connection issues of composite wall panels need to be studied.

Hygrothermal Effects on Energy Efficiency

Damage caused by uncontrolled moisture accumulation in building enclosures greatly concerns the construction and energy conservation communities. A comprehensive method for selecting building materials and designing assemblies that have superior energy and moisture performance need to be implemented A thorough understanding of building component relationships within a wall system and how they influence hygrothermal performance need to addressed. Mold growth assessment tools also need to be investigated. Specific construction solution for a specific climate should be implemented with use of system engineering approach by usage of advanced modeling tools.

Simulation Methods for Building Energy Analysis

Building energy simulation is important for the study of energy efficiency in buildings. Computer simulation programs are effective analytical tools for building energy research. Research studies need to be carried out to develop simulation techniques and to investigate the energy performance of buildings. The future trend of energy efficiency standards will depend on the support of simulation techniques. The thermal and energy performance of bio-based products for different environmental conditions need to be evaluated.

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