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Characterization of flax fiber reinforced soy protein resin based green composites modified with nano-clay particles

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Abstract

In this research, fully environment-friendly, sustainable and biodegradable 'green' composites were fabricated using modified soy protein concentrate (SPC) resins and flax yarns and fabrics. The modified SPC resin was prepared by blending SPC with nano-clay particles, and then cross-linked using glutaraldehyde. The modified SPC resin showed significantly improved mechanical properties. Flax fiber was used as the reinforcement, in both yarn and fabric forms, individually, to fabricate 'green' composites. The unidirectional flax yarn reinforced SPC resin composites showed longitudinal tensile failure stress of 298 MPa and Young's Modulus of 4.3 GPa. These 'green' composites also exhibited excellent flexural properties in the longitudinal direction. The flexural stress was 117 MPa and the flexural modulus was 7.6 GPa. Flax fabric reinforced composites had failure stress of 62 MPa and 82 MPa in the warp and weft directions, respectively. The Young's Modulus values, in both directions, were around 1.2 GPa.

Keywords: Environment-friendly; Biodegradable composites; Nano-composites; Green composites; Soy protein resin; Plant-based fibers

1. Introduction

When two or more materials with different properties are combined together, they form a composite material [1]. The properties of composite materials, in general, are superior in many respects, to those of the individual constituents. This has provided the main motivation for the research and development of composite materials. The properties of polymeric composite materials are mainly determined by three constitutive elements: the resin, the reinforcement, such as particles and fibers, and the interface between them. According to the reinforcement used, composite materials can be broadly classified into fiber reinforced composites and particle-based composites [2]. Initially developed for aerospace applications several decades ago, composite materials have found applications in almost all spheres of human life such as sports gear, medical, military, automobile, civil infrastructure, etc. [3].

Most currently marketed composites are made using synthetic fibers and polymers that are made using petroleum, an unsustainable fossil fuel, as feedstock. They are not biodegradable and thus, pose a serious disposal problem at the end of their life. Composites, being made of two dissimilar materials, cannot be easily recycled or reused. As a result, biodegradable bio-based polymer products have attracted much attention in recent years [4–7]. Plant-based polymers such as soybean protein and starch are sustainable, yearly renewable, environmentally friendly and can be fully degraded by natural means. They can also be modified to improve their properties further for use as resin.

Soy protein products have been used as resins to fabricate 'green' composites [3–8]. The commercially available soy protein concentrate (SPC) consists of about 70% protein, 20% carbohydrates, ash and crude fiber [3]. Soy protein offers several advantages compared with traditional

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petroleum based polymers. The manufacturing process for soy protein products is environment-friendly and there are no toxic chemicals used or toxic gases released during processing [3–5]. Soybean is an annual crop and is abundantly available worldwide, so the cost of raw materials is extremely low. The polar amino acids in soy protein, such as cysteine, arginine, lysine etc. can be used for SPC modification to improve its mechanical and thermal properties, and moisture resistance. Some companies have used soy protein based materials for furniture. With improved mechanical and physical properties, they have the potential for a wider application range such as computer casings, packaging and panels for auto interior. In this research, SPC was modified using nano-clay particles and then cross-linked with glutaraldehyde to improve its mechanical and physical properties.

Compared to synthetic fibers, natural plant-based fibers have several specific advantages. These natural fibers have low cost, high specific mechanical properties, good thermal and acoustic insulation, and biodegradability [7,9–11]. Since all plant-based fibers come in short length, they need to be twisted together to form yarns to obtain suitable continuous forms. Yarns can be woven or knitted to obtain desired bidirectional properties.

Flax is a staple, i.e., short, non-continuous, fiber having irregular polygonal cross-section and hollow structure. It consists of about 81% cellulose, 14% hemicellulose, 3% lignin and 4% pectin [3–5,9]. Cellulose is a linear polysaccharide consisting of D-glucopyranose rings connected by β-(1,4)-glycosidic linkages. Hydrogen bonding and the inherent stiffness of cellulose polymer chains lead to strong chain interactions and a high degree of crystallinity, making it an ideal fiber-forming polymer [12]. Hemicellulose is also a polysaccharide consisting of chain branching and lower degree of polymerization ($\mathrm{DP} = 100$) than the cellulose molecule [9]. Hemicellulose is mainly responsible for thermal degradation, moisture absorption and biodegradation of the fiber [13]. Lignin is a hydrocarbon and acts as cement in the fiber. Pectin is a polysaccharide, which has a DP between hemicellulose and cellulose [12].

Flax fiber has a lower density than glass fiber and, as a result, has a comparable specific strength [13]. Spun yarns made from flax fibers have been used for fabricating unidirectional yarn reinforced ‘green’ composites [5]. Staple fiber yarns are twisted during spinning to increase the cohesion (or friction) between fibers and localize the micro damages within the yarn leading to higher failure strength [3–5,14]. Yarn spinning also provides continuous length of natural fibers for easy fabrication of composites. Woven fabrics have also been used as reinforcement for composites [3,4]. Woven fabrics have two sets of yarns interlaced at right angles. The yarns running in the longitudinal direction are referred to as warp or end and the yarns in the transverse direction are referred to as weft or fill. Balanced woven fabrics have the same number of yarns per cm, yarn count and spacing in both warp and weft directions and, as a result, give uniform tensile properties in both longitudinal and transverse directions. Woven fabrics offer several advantages such as good impact resistance, damage tolerance, toughness and the ease of manufacturing [3,4,15–17]. Flax yarn and fabrics were used in this research to fabricate environment-friendly ‘green’ composites using modified soy protein concentrate based resins.

2. Experimental

2.1. Materials

SPC, under the brand name of Arcon® S, was obtained from Archer Daniels Midland Company, Decatur, IL. Analytical grade glycerol and sodium hydroxide (NaOH) were obtained from Fisher Scientific, Pittsburg, PA. Glutaraldehyde (GA), 25 wt% solution in water, was provided by Aldrich Chemical Company, Milwaukee, WI. All chemicals were used directly without any further purification. Cloisite® Na^+ was obtained from Southern Clay Products, Inc., Texas. Flax yarn and woven flax fabric were provided by Sachdeva Fabrics Pvt. Ltd., New Delhi, India.

2.2. Fiber and yarn characterization

Fiber specimens were conditioned at 65% R.H. and 21 °C (ASTM D 1776–98) for three days, prior to characterizing their cross-sections. Single fibers were separated from the yarn and embedded in a suitable potting epoxy resin. After curing, the epoxy resin specimen with fibers embedded in it, was cut into sections with approximately 2 mm thickness in the direction perpendicular to fiber axis. Fiber cross-sections were then determined by observing the epoxy resin specimens using Olympus optical light microscope (model BX51).

Flax yarn was characterized for its diameter, linear density and thermal and tensile properties. Yarn specimens were conditioned (ASTM D 1776–98) for three days, prior to characterizing their properties. Twenty yarn specimens with a length of 40 mm were used to measure their diameters using the optical light microscope. The average of these measurements was used for calculating the mean diameter of the flax yarn. Yarn linear density was characterized according to ASTM D 1059-97. The conditioned yarn was cut to 1 m length and weighed using an electrobalance (Cahn, model 29). Ten specimens were measured and the average weight, W, in grams, was used for calculating the yarn linear density.

$$\mathrm{Yarncount} = \frac{W \times K}{L} \tag{1}$$

where L is the length of the yarn in meters; K is a constant, which equals 9000 m/g for denier and 1000 m/g for tex.

Yarn specimens were tensile tested on Instron universal testing machine, model 1122 (ASTM D 2256-02). Tests were performed using a gauge length of 50 mm and a strain rate of $0.5\ \mathrm{min}^{-1}$. Twenty specimens were tested to obtain the yarn tensile properties.