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Pultruded glass fiber/bio-based polymer: Interface tailoring with silane coupling agent

Hongyu Cui [a], Michael R. Kessler [b,*]

[a] Dept. of Materials Science and Engineering, Iowa State University, Ames, IA, United States
[b] School of Mechanical and Materials Engineering, Washington State University, Pullman, WA, United States

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ABSTRACT

Economical glass fiber reinforced polymer composites were developed from biorenewable resins utilizing a highly automated pultrusion process. The composites were successfully pultruded with a self-built table-top pultrusion machine. The interfacial interaction of the composites was significantly improved after surface modification with a silane coupling agent. The optimum silane concentration was determined by testing the mechanical properties of the pultruded fiber reinforced composites. Composites reinforced with fibers that were treated with a 3% silane solution exhibited the best properties in both DMA and flexural tests.

1. Introduction

The applications of fiber reinforced polymer (FRP) composites have grown significantly since 1960s because of their excellent overall properties which are either comparable to or better than many traditional metallic materials. FRPs possess superior properties in terms of light weight, high specific strength and stiffness, excellent environmental resistance, high electrical insulation, and low thermal expansion [1]. Over the years, FRP composites have found increasingly wide applications in a variety of fields, such as in the aerospace, transportation, construction, chemical engineering and electrical industries. In the early days, advanced composite materials were mainly used in military and government aerospace industries where cost is not a major concern. In recent years, the application of high performance FRPs has grown steadily in construction of civil infrastructure and has begun to challenge the dominant position of traditional materials. The development and advantages of FRP applications in the building and civil infrastructure have been reviewed thoroughly by Hollaway [2,3]. FRPs are finding increasing use for rehabilitation, seismic retrofitting and upgrading of concrete bridges as ways to extend the service life of existing structures. However, the use of composites are still limited because of their high material and manufacturing costs. With the growing opportunities for composite materials in structural applications, the development of inexpensive composites is of great interests.

Pultrusion is a cost-effective, automatic process for the production of continuous composite parts with constant cross-sectional profiles [4]. Fig. 1 provides a schematic representation of the pultrusion process. During pultrusion, fibers are impregnated with resin by being pulled through a resin bath or a resin injection chamber. The wet fibers then pass through a hot die, where the resin undergoes polymerization. Multiple heating zones are used along the die, depending on the type of resin used. Pultrusion has a number of advantages over other composite manufacturing methods:

- Increased strength because the fibers are aligned in the tension state.
- Highly automatic process with little manual interface, so that it is possible to efficiently produce high fiber volume composites with consistent quality.
- Low cost, typically 80–90% of the cost for pultruded profiles are the raw material costs.

Based on these advantages, pultrusion is the technique of choice for the production of glass fiber reinforced composites when low cost and good mechanical properties are required.

Growing concerns regarding the limited petroleum resources, the volatile price of oil, and the environmental impact of fossil feedstocks have led to an increasing demand for the development of polymeric materials from sustainable resources. Vegetable oils

* Corresponding author. Tel.: +1 5093358654.
E-mail address: MichaelR.Kessler@wsu.edu (M.R. Kessler).

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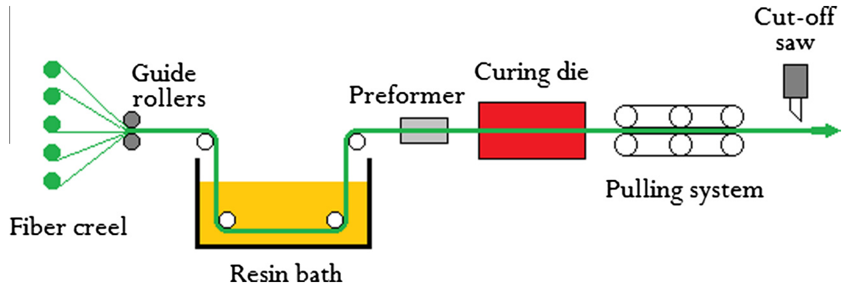

Fig. 1. Schematic diagram of pultrusion. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Materials used in this study.

Material	Parts by weight	Specification	Supplier
Dilulin	30	Dilulin monomer, modified linseed oil	Cargill, MN
DCPD	70	Dicyclopentadiene monomer	Sigma–Aldrich, WI
Catalyst	0.125	2nd Generation Grubbs' catalyst	Sigma–Aldrich, WI
Lubricant	5	Tech Lube SR-150-W2	TECHNICK, NJ
Filler	10	ASP-400p, Kaolin clay	BASF, GA
Glass fiber	N/A	Continuous E-glass, 56 yield	Pella, IA
MCS	N/A	Norbornenylethyldimethylchlorosilane, silane coupling agent	Gelest, PA

are ideal raw materials for the polymer industry because of their ready availability, structural variety, chemical versatility and relatively low cost. The major components in vegetable oils are triglycerides which contain several reactive sites and functionalities that can be utilized in a variety of synthetic transformations. Over the past ten years, a series of bio-based polymers has been synthesized and developed from vegetable oils using various polymerization methods [5,6]. Among them, a copolymer that was prepared from modified linseed oil (Dilulin) and dicyclopentadiene (DCPD) by ring opening metathesis (ROMP) polymerization shows promising mechanical properties [7,8]. In addition, the low viscosity of the copolymer and its fast cure kinetics make it a good resin candidate for the pultrusion process. Pultrusion is the most cost-effective manufacturing method, and combined with low-cost biorenewable resins allows for the production of inexpensive composites for structural applications.

It is well known that the ultimate properties of composite materials depends not only on the properties of the constituent materials (e.g. matrix and fiber reinforcement), but also on the interphase and interface between the matrix and reinforcement [9]. Good interfacial adhesion allows effective stress transfer from the matrix to the reinforcement and increases the ultimate strength of the composite. Surface modification with silane coupling agents [10–12] is widely used to improve the interfacial adhesion in glass fiber reinforced polymer composites. Silane coupling agents are difunctional organic compounds which are able to form covalent bonds with both the inorganic reinforcement and the polymer matrix.

In this research, we pultruded Dilulin/DCPD copolymers to produce low-cost, bio-based composites with good mechanical properties. The resin formulation and pultrusion process parameters were optimized based on performance. Surface modification of

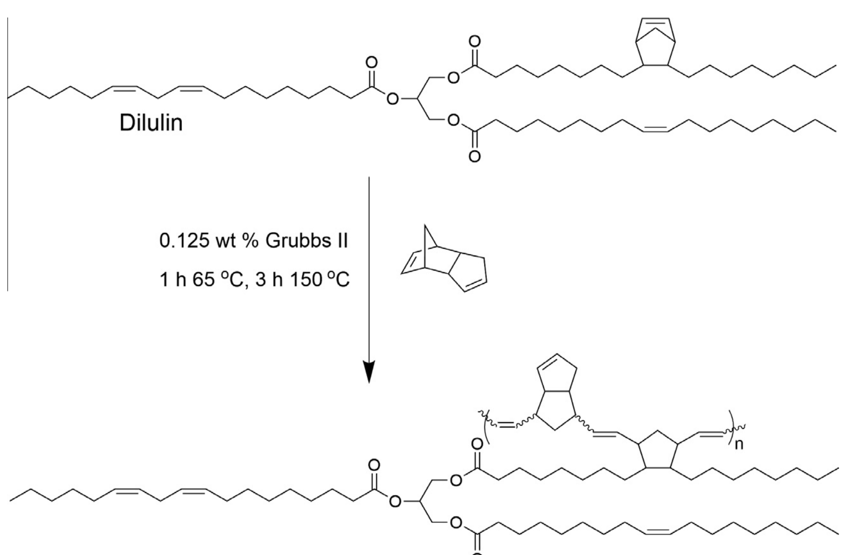

Fig. 2. ROMP reaction of Dilulin and dicyclopentadiene.