Progress in Polymer Science 71 (2017) 91–143

Contents lists available at ScienceDirect

Progress in Polymer Science

journal homepage: www.elsevier.com/locate/ppolysci

Recent advances in vegetable oil-based polymers and their composites

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ARTICLE INFO

Article history:
Received 11 August 2016
Received in revised form 14 August 2016
Accepted 16 August 2016
Available online 3 January 2017

Keywords:
Vegetable oil
Polymer composites
Triglycerides
Nanocomposites
Bio-based polymers

ABSTRACT

The development of viable alternatives to petroleum-based polymeric materials is a compelling contemporary challenge attributable to environmental concerns and the effects of fluctuating oil prices. Triglycerides, the primary components of vegetable oils, are an abundant, renewable, and widely investigated alternative feedstock for polymeric materials. Efforts are made on a global scale to develop innovative technologies to transform these natural resources into novel monomers and polymers. Some of these technologies have already generated competitive industrial products with properties comparable to conventional petrochemical polymers. Fillers and fibers have also been incorporated into these bio-based polymer matrices to improve the physical and thermal-mechanical properties of the resulting composite materials. The development of multifunctional composite materials facilitates the application of these materials in new areas, *e.g.*, sensors, structural parts, medical device, construction units, flame retardant parts. This article reviews recent advances in polymeric materials from vegetable oils in terms of preparation, characterization, and properties. Nano-composites and fiber reinforced composites based on bio-polymers matrices will also be reviewed. This chapter will conclude with an overview of current and potential future applications of these materials in packaging, automotive, construction, electrical, and medical devices.

Contents

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http://dx.doi.org/10.1016/j.progpolymsci.2016.12.009
0079-6700/

List of acronyms

BD	1,4-butanediol
BPA	bisphenol A or 2,2-bis(4′-hydroxyphenyl)propane
DBU	1,8-diazabicycloundec-7-ene
DMA	dynamic mechanical analysis
DMPA	dimethylol propionic acid
ELO	epoxidized linseed oil
EMI	2-ethyl-4-methylimidazole
ESO	epoxidized soybean oil
IPDI	isophorone diisocyanate
IPN	interpenetrating polymer networks
MDEA	N-methyl diethanol amine
MDI	methylene diphenyl diisocyanate
MWCNT	multiwall carbon nanotubes
PEG	poly(ethylene glycol)
PEG-800	polyethylene glycol-800
PO	propylene oxide
PU	polyurethane
SWCNT	single-wall carbon nanotube
TBD	1,5,7-triazabicyclo[4.4.0]dec-5-ene
TDI	toluene diisocyanate
T_g	glass transition temperature

1. Introduction

Polymers have taken on a vital role as materials in modern applications in almost every sector of manufacturing, including aerospace, automotive, marine, infrastructure, medical devices, consumer products, and sports equipment. The advantage of polymers compared to other materials can be attributed to their tunable properties, easy processability, high strength/density ratios, resistance to chemical and physical degradation, and low cost [1–9]. Worldwide, the consumption of polymers grows at an annual rate of 5%, with a total annual consumption exceeding 300 million tons [10]. Traditionally, petrochemical resources provide most of the monomers for the industrial production of plastics. Plastics manufacturing accounts for approximately 7% of the global oil and gas consumption [11]. Petrochemical resources are non-renewable and long-term will not provide enough feedstock at economically viable costs. Furthermore, markets are sensitive to disruptive price fluctuations caused by various economic and political factors. Environmental concerns (minimizing air, water, and soil pollution) and the non-degradable nature of most synthetic polymers pose significant challenges for sustainable development. These factors initiated the development of innovative technologies for novel polymeric materials from renewable feedstocks. The utilization of renewable raw materials is one of the 12 principles of green chemistry originally postulated by Paul Anastas and John Warner [12]. This review summarizes recent advances in the preparation, characterization, and properties of polymers from vegetable oils. Nano-composites and fiber reinforced composites with matrices made from relevant bio-based polymers are also covered. Finally, current and potential future application of these polymers and polymer composites are discussed.

The most extensively used renewable feedstocks are natural oils, polysaccharides (starch and sugars), wood (lignocellulose), and proteins [13–17]. Of these materials, triglyceride oils are one of the most advantageous options because they are readily availability and offer easy processing, chemical functionality, and relatively low cost. For example, 108 million metric tons of soybeans were harvested in USA in 2014 [18,19]. The utilization of these natural oils to produce novel valuable materials adds value to these low cost agricultural feedstocks in support of US growers [20].

Global efforts are being dedicated to developing innovative technologies to transform triglyceride oils into novel monomers and polymers with physical and thermo-mechanical properties comparable or better than those of their petrochemical counterparts [21,22]. Also, bio-polymer matrices can be reinforced with inorganic or organic fillers (*e.g.*, particles and fibers) from either synthetic or natural sources to form high-performance composite materials. These composites can be designed with multifunctional properties, such as dielectric properties or antibacterial properties, making them suitable materials for sensors or biomedical devices [23–26].

Almost every plant produces oil, the respective amount ranging from traces to as much as 70–80 wt.%. The highest level of oil is generally found in plant seeds (Table 1) [27]. Sustainable sources of vegetable oils are available around the world [28].

Vegetable oils (Fig. 1) are esters formed by glycerin and different fatty acids containing from 8 to 24 carbon atoms and between 0 and 7 carbon-carbon double bonds, depending on the plant type and climatic conditions of growing [24,29]. The structures of the most common fatty acids found in vegetable oils are provided in Table 2. Their fatty acid composition distinguishes the vegetable oils, including the stereochemistry of the double bonds, the degree