



Vegetable fibres from agricultural residues as thermo-mechanical reinforcement in recycled polypropylene-based green foams

Mònica Ardanuy^{a,*}, Marcelo Antunes^b, José Ignacio Velasco^b

^a Department of Textile and Paper Engineering, Universitat Politècnica de Catalunya, C/Colom 11, E-08222 Terrassa, Barcelona, Spain

^b Centre Català del Plàstic, Universitat Politècnica de Catalunya, C/Colom 114, E-08222 Terrassa, Barcelona, Spain

ARTICLE INFO

Article history:

Received 11 May 2011

Accepted 10 September 2011

Available online 17 October 2011

Keywords:

Cellulosic fibres

Agricultural residues

Recycled polypropylene

Foams

ABSTRACT

Novel lightweight composite foams based on recycled polypropylene reinforced with cellulosic fibres obtained from agricultural residues were prepared and characterized. These composites, initially prepared by melt-mixing recycled polypropylene with variable fibre concentrations (10–25 wt.%), were foamed by high-pressure CO₂ dissolution, a clean process which avoids the use of chemical blowing agents. With the aim of studying the influence of the fibre characteristics on the resultant foams, two chemical treatments were applied to the barley straw in order to increase the α -cellulose content of the fibres. The chemical composition, morphology and thermal stability of the fibres and composites were analyzed. Results indicate that fibre chemical treatment and later foaming of the composites resulted in foams with characteristic closed-cell microcellular structures, their specific storage modulus significantly increasing due to the higher stiffness of the fibres. The addition of the fibres also resulted in an increase in the glass transition temperature of PP in both the solid composites and more significantly in the foams.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

In the last years, problems related to environmental issues such as the low degradability and biodegradability of plastics, the shortage of landfill space, the use of increasingly more scarce petroleum-based fossil sources, and the emissions generated during incineration, combined with an increasing environmental awareness, have motivated an extensive research on environmentally friendly materials. A particular interest has been given to the use of fibres obtained from renewable vegetable sources in polymer composite materials (Satyanarayana et al., 2009; Thomas and Pothan, 2009; Claramunt et al., 2010; Ardanuy et al., 2011). Although these fibres have been used in polymer composites for many years, they are experiencing resurgence as alternative reinforcements to more conventional and common ones like glass or carbon fibres, or even other inorganic fillers. Vegetable fibres have several advantages, such as their availability, renewable nature, low cost production, easy recyclability, low density, low thermal expansion coefficient, good thermal and acoustic insulation, and high flexural and tensile modulus, among many others (Satyanarayana et al., 2009). Despite their potential advantages, the application of natural fibres in the field of composites remains insignificant compared to that of previously mentioned glass or carbon-based materials (Mohanty et al., 2001). Although

natural fibres exhibit a set of important advantages, the development of composites based on natural fibres is often blocked by their polar and hydrophilic nature, making it harder to attain a good compatibility with the matrix. This explains the need of surface modifying the fibres by means of chemical or physical processes, or a combination of both. Among the first, the use of alkaline bases such as sodium hydroxide is often considered as a standard chemical pre-treatment to a more elaborated process (Maréchal, 2007).

Among the possible sources of cellulosic fibres, agricultural residues such as barley or wheat straw come as a good alternative due to their low cost and renewability (Curvelo et al., 2001; Averous and Boquillon, 2004; Alemdar and Sain, 2008; Ardanuy et al., 2010). Only in Spain, the agricultural sector annually produces around 35 million metric tons, of which around 10 million are barley straw (Cala et al., 2003). The use of agricultural residues as a viable fibre source for the reinforcement of polymer composites can reduce the need of burning or decomposing these wastes, and can provide low-cost alternatives to wood fibre composites, as well as open-up new markets for the agricultural industry (Johnson et al., 1997; Mishra and Sain, 2009).

Like wood, barley straws are primarily composed of cellulose, hemicelluloses and lignin. However, they also contain significant amounts of pectins, proteins and ashes. The typical composition of barley straw fibres is: 33–45.5% of cellulose, 21–28.5% of hemicelluloses, 10–21% of lignin and 3–7% of silica. In comparison with wood, straws contain less cellulose and lignin, and higher hemicellulose amounts. Morphologically, straw fibres have an

* Corresponding author. Tel.: +34 937398158; fax: +34 937398101.

E-mail address: Monica.ardanuy@upc.edu (M. Ardanuy).

average length of 1.5 mm and an average diameter of 13 μm , i.e., a fibre length to diameter aspect ratio of around 110 (Schott et al., 2001; García-Hortal, 2007). Some of the advantages linked to the use of these fibres in composites include the use of an agricultural by-product, hence their reduced cost (cheaper than wood), and the possibility of chemically treating them at low temperature. In addition, these fibres commonly contain high amounts of silica, which could be beneficial for fire retardancy applications. One of the drawbacks of these fibres lies in the liquid effluent generated in the production of the non-wood pulps. So, although the systems for recovering chemical products and energy in the non-wood pulp factories are similar to the wood ones, the quantity and quality of the generated effluent is significantly different, mainly due to the high silica content of these materials (Torrades et al., 2008). Nevertheless, various procedures have been developed for removing the silica (Tutus and Hüdaverdi, 2003a, 2003b) and for treating the effluents using different technologies such as chemical (Moraes et al., 2006), biological (Ragunathan and Swaminathan, 2004) or advanced oxidation processes (Andreozzi et al., 1999).

Alongside the use of natural fibres obtained from renewable sources as low cost reinforcements in polymer composites, a second key challenge regarding polymer materials lies on the development of increasingly lighter components with improved specific properties to be used in demanding applications (construction, automotive, aerospace, etc.) (Rodríguez-Pérez, 2005; Klempner and Sendjarevic, 2004). A possible strategy combines the weight reduction obtained with foaming the base material with the incorporation of functional fillers such as cellulose fibres, which primarily act as mechanical reinforcements, counteracting the loss in mechanical properties with foaming, ultimately resulting in materials with improved specific mechanical properties (Bledzki and Zhang, 2001). In some of our previous works we have shown that the addition of different nanometric and micrometric-sized fillers to polypropylene and later foaming resulted in materials with unique characteristics apart from the improved specific mechanical properties, such as thermal or electrical conduction, or even fire retardancy (Antunes et al., 2009, 2010a,b,c, 2011). We have also shown that through a careful control of the foaming process it is possible to obtain foams with improved specific properties, particularly developing foams with micrometric-sized cells, conventionally known as microcellular foams, by means of a pressure-quench CO_2 dissolution foaming process (Antunes et al., 2010d).

Scarce work has been published concerning the study of polymer foams with natural fibres. Some of the existing work has been focused in analyzing the influence of incorporating micrometric and nanosized cellulose fibres obtained from different sources (wood, hemp, jute, barley, etc.) on the structural, thermal, mechanical and morphological characteristics of polymer foams (Silva et al., 2010; Eichhorn et al., 2010). It has been found that the addition of increasingly higher amounts of cellulosic fibres decreases the cell size of the foamed materials due to a heterogeneous cell nucleation effect promoted by the fibres, which, combined with the mechanical reinforcement effect of the cellulose fibres, dramatically improves the energy absorption of the foams during compressive loading.

In this work, we have tried to develop novel reinforced lightweight composites by introducing untreated or chemically-treated cellulosic fibres obtained from barley straw into a recycled polypropylene matrix. Particularly, we used quick and low cost sodium hydroxide-based treatments in order to increase the α -cellulose content of the fibres, and found out that these pre-treatments were enough to promote the formation of foams with finer cellular structures and improved dynamic-mechanical-thermal properties. Apart from the incorporation of cellulosic fibres obtained from low cost straw into a recycled PP matrix for the preparation of composites with improved properties, the novelty of this work lies in the

development of foams from these composites by means of a solid-state pressure-quench CO_2 dissolution foaming process, which, among some of its advantages, uses an environmentally-friendly physical blowing agent instead of chemical blowing agent additives (Klempner and Sendjarevic, 2004).

2. Experimental procedures

2.1. Materials

A polypropylene (PP) material specifically formulated for foaming applications, referred to as PP_f, was prepared by melt-compounding in a co-rotating twin-screw extruder (Collin Kneuter 25X36D, L/D = 36), 50 phr of a high-melt-strength PP grade (PP-HMS) with the commercial name of *Daploy WB130HMS* (manufactured by *Borealis*), and 50 phr of a recycled PP, with talc (1.0 phr). The PP-HMS had a melt flow rate of 2.1 dg/min measured at 230 °C and 2.16 kg and a melt strength and melt extensibility at break, both determined at 200 °C using the Rheotens test, of 34 cN and 220 mm/s, respectively.

A constant temperature of 165 °C and screw speed of 160 rpm were used. After exiting the extruder die, the extrudates were water-cooled, pelletized and dried.

Barley straw (*Hordeum vulgare*) was obtained from local sources (Terrassa, Spain).

2.2. Treatment of the barley straw

In order to extract cellulose fibres with a high percentage of α -cellulose, two types of chemical treatments were performed on the previously cut (3–5 cm length) and dried (at 60 °C) as-received barley straw (named UTF). The first treatment was performed cooking the cut barley straw in a sodium hydroxide solution (0.14 g of NaOH/g of dried barley straw) at 160 °C for 3 h in a pulp digester. Anthraquinone was added as catalyzer. The fibres obtained at the end of this procedure, for now on known as ATF fibres, were washed, filtered, dried and mechanically crushed with a mill.

The second treatment was performed in two steps: first of all the cut barley straw was soaked in a water solution at 165 °C for 2 h inside a pulp digester. These hydrolyzed fibres were then soaked in a sodium hydroxide solution using the same conditions as in the first treatment. The obtained fibres (PATF) were washed, filtered, dried and mechanically crushed using a mill.

2.3. Compounding and foaming processes

The polypropylene pellets (PP_f) were blended with both the treated and untreated fibres using a *Brabender Plasti-Corder* mixer. The temperature and screw speed were 180 °C and 60 rpm respectively and the processing time was 4 min. The compounded composites were quickly placed after removing from the *Brabender* mixer into a square mold (15 × 15 cm²) with a thickness of 2 mm and compression-molded by heating at 180 °C applying a pressure of 35 bar using a hot-plate press IQAP-LAP PL-15. Once cooled under pressure (35 bar) using recirculating water, circular samples with a diameter of 36.5 mm were directly machined employing a circular cutting tool and used as solid precursors. Three composites were prepared with a nominal concentration of PATF fibres of 10, 20 and 25 wt.%: PP10PATF, PP20PATF and PP25PATF, respectively. For comparison, a fourth formulation was prepared with a nominal concentration of untreated fibres (UTF) of 20 wt.% (PP20UTF).

The solid precursors were foamed by initially saturating CO_2 in a high-pressure autoclave and later allowing the material to grow

Download English Version:

<https://daneshyari.com/en/article/4472151>

Download Persian Version:

<https://daneshyari.com/article/4472151>

[Daneshyari.com](https://daneshyari.com)