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Feasibility of using straw in a strong, thin, pulp moulded packaging material

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ABSTRACT

Packaging is a ubiquitous commodity that is being used in increasing quantities. This increased use has led to a problem with disposal, with increased quantities of used packaging being sent to landfill. One sustainable solution suggested is the use of biobased, biodegradable packaging. An example of this is paper based pulp moulded products which have been used previously for a number of packaging applications. In this paper the feasibility of replacing paper fibre with waste cereal straw fibre is examined. The aim was to produce materials that could be used to form flat, round trays, such as those used in supporting shrink wrapped food items. The material was required to have properties that matched existing alternatives, such as expanded polystyrene, in terms of physical and mechanical characteristics but with an enhanced level of biodegradability. The data showed that the pulp moulded material containing up to 80% straw performed significantly better compared to expanded polystyrene in tensile properties (modulus of 0.47 MPa for an 80% straw mix compared to 0.16 MPa for EPS). Modulus under bending was shown to be lower for straw based materials compared to EPS (0.015 MPa compare to 0.035 MPa). Adjustments in product thickness allowed performance parameters to be met. Wet end addition of chemicals was successfully used to provide water resistance without affecting other variables. In addition to exhibiting good performance characteristics the pulp moulded material was shown to be biodegradable, exhibiting 20% mass loss after only 4 weeks covered in unsterile soil.

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1. Introduction

Single use packaging materials are a ubiquitous feature of modern society and, in the United Kingdom, have shown rapid increase in their use. However, with recent legislative pressures, such as those described in the European Union Landfill directive, (European Union, 1999) and other societal consumer concerns (Hall et al., 2010), alternative biobased solutions to petrochemical based plastic packaging are being sought. In terms of managing waste at the end of life of the product, enhanced biodegradability of biobased packaging is an essential asset (Siracusaa and Rocculib, 2008; Song et al., 2009) as many packaging materials are not reused but thrown into waste – with these non biodegradable products adding to the land fill burden. A key attribute of a biobased packaging product should, therefore, be an improvement in biodegradability over existing alternatives. However, biodegradable items can cause contamination in plastic recycling and ideally therefore, the whole product should be biodegradable at the level of either a community or household composting regime (Davis and Song (2006)). One currently used form of biobased packaging moulded paper pulp packaging (Gurav et al., 2003; Zabaniotou and Kassidi, 2015), where the packaging is mainly used for its cushioning properties (Eagleton and Marcondes, 1994; Hoffmann, 2000). Other studies (Gurav et al., 2003) have investigated the strength properties of biobased moulded packaging created via wet forming. Wet forming uses a water borne pulp fibre suspension shaped in a mould with simultaneous or subsequent (based on the equipment used) dewatering and drying. Wet formed packaging material of this type has mainly used recycled paper and cardboard fibre, although in some cases, such as food contact, this is not deemed viable due to contamination from inks etc. in the pulp. An alternative to waste paper would be pure Kraft pulp but this may not be economically viable. However, other non-wood based lignocellulose feedstocks, such as cereal straw, could be used to produce the pulp. Each year approximately 1.45Mt of cereal straw (Glithero et al., 2013) are reincorporated into arable soil. This is partly as a waste manage-

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ment issue although the straw does also serve as a soil amendment and improver. On availability grounds, straw can therefore be considered a good candidate as a raw material in biobased materials. In terms of packaging, straw based packaging applications have been developed (Vargas et al., 2012) although, to the author's knowledge, the particular use of straw in the manufacture of thin sheet materials, does not appear to have been reported. These thin sheet materials, commonly made from expanded polystyrene are frequently used to help support products in food applications, such as the round trays used in packaging to support cakes, pastries or pizzas to stop bending of items during shrink wrapping and display. The current study is part of a larger project to develop a flat, round straw based tray that could be used for the applications noted above.

In terms of moving a biobased product to commercial viability the product must perform mechanically at least as well as an established alternative but also be biodegradable. This paper therefore investigates the feasibility of using straw pulp to produce material suitable to form a pulp moulded, flat, round tray by testing the materials' and products' mechanical and biodegradation properties. Expanded polystyrene products are used as a comparative benchmark for required properties.

2. Materials and methods

2.1. Preparation and characterisation of raw materials

Wheat straw (*Triticum aestivum* cv Solstice) was selected as the straw component. The straw was cut into pieces smaller than 5 cm and then refined using a 30 cm pressurised refiner (Andritz Sprout Bauer). Briefly, this refining process consisted of the followingn steps;

The straw was fed via a cooker screw into a 60 l digester, with a nominal residence time of 60 s in the cooker screw and digester. Steam pressure in the cooker/digester was maintained at 0.94 MPa using steam at 390 °C. On leaving the cooker/digester, the straw was fed, via a second screw feed, into the refiner, and passed between two 30 cm diameter refiner plates, with a parallel bar configuration, to form the fibre (fuller details can be found in Ormondroyd et al., 2016).

The starting straw and resultant pulp pre-mix were chemically characterised as follows:

2.1.1. Wax/Extractives

Replicate samples were extracted with toluene, acetone, and methanol (4:1:1) for 8 h using soxhlet extraction (at least 50 solvent cycles). Wax/extractive content were calculated and expressed as percentage on a dry weight basis.

2.1.2. Klason lignin

Tappi standard method 222 (Tappi, 2006) was used to determine lignin concentration in the samples. This method used acid hydrolysis of the polysaccharides in 72% sulphuric acid leaving the lignin in solid form. Lignin content was expressed as percentage on dry weight basis.

2.1.3. Alpha cellulose and hemicellulose

The alpha cellulose and hemicellulose contents of the samples were determined by analysis of holocellulose isolated using the sodium chlorite method (Browning, 1967) This used acidified sodium chlorite to delignify the samples leaving holocellulose, which was extracted using 17% sodium hydroxide. Following neutralisation with acetic acid and washing with water and methylated spirit, the alpha cellulose was separated by filtration. Composition was determined gravimetrically as a percentage of original dry weight. Hemicellulose content was determined by neutralisation of the filtrate and precipitation of hemicellulose via addition of copious ethanol. Following drying of the hemicelluloses the composition was determined gravimetrically as a percentage based on original dry weight of sample.

2.1.4. Ash

Oven-dried material was ashed in a muffle furnace at 525 °C for 16 h, with the ash content calculated as a percentage on dry weight basis

2.2. Pulp moulding

The pulp for the moulding of the material was prepared in a mixing tank of a proprietary pulp moulder (Valueform, UK) utilising a plain transfer moulding process. Kraft paper pulp fibre was obtained from commercial dried sheets which were pulped in water before adding to the straw fibre pulp at three differing ratios – a base 100% straw mix, a 80/20 straw/Kraft mix and a 60/40 straw/Kraft mix. To these mixes an anti-foaming agent (Percol, BASF) and a water repellent additive (Basoplast, BASF) were added. The water repellent additive was included to decrease the water absorbance of the final product, although some samples without added water repellent were produced to test the efficacy of the additive. The anti-foaming agent was added to stop a foam or froth forming in the pulp as this was found to cause holes in the product during the moulding cycle. Although the exact details of the moulding cycle are not reported for potential commercial reasons, the procedure consisted of immersion of the mould into the pulp, filling of the mould, vacuum removal of water and pressing of the pulp using proprietary cycling schedules. The moulded material was dried by hot air convection in an oven at 100 °C for 30 min.

2.3. Characterisation of pulp

The pH, drainage and particle size distribution of the pulp were measured prior to moulding. The drainage of the pulp was assessed using Canadian Standard Freeness of the pulp following the method described in ISO 5267-2 (ISO, 2001). Particle size distribution was determined by drying the pulp to a fibrous state, with no agglomerations, and then sieving through a sequential series of wire mesh sieves with frequency allocation based on mass fraction.

2.4. Characterisation of moulded material

In the investigation detailed in this paper the 100% straw mix did not produce a moulded product that was suitable for use or analysis. Therefore, only samples representing the 80/20 and 60/40 mix were analysed in terms of physical characteristics, mechanical properties (tensile and flexural properties, water absorbency and biodegradation. Due to limitations placed by the dimensions of the product, in this case a round tray, non-standard testing procedures were used in some instances. To validate the study, controls of similar existing products were tested in the same way as the moulded products.

2.4.1. Physical characterisation

The thickness of the product material was determined using digital callipers and reported as a mean value of at least 5 replicates per sample. The density of the material was determined gravimetrically.

2.4.2. Mechanical testing

The tensile properties of the product materials (conditioned at 20 °C and 65% relative humidity (RH)) were determined using an Instron testing machine (Instron, High Wycombe, UK) using a 5 kn

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