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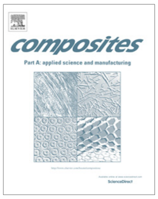

Novel aligned hemp fibre reinforcement for structural biocomposites: Porosity, water absorption, mechanical performances and viscoelastic behaviour

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ABSTRACT

This paper examines the thermal and mechanical behaviour as well as moisture absorption of aligned hemp composites using hemp/PLA wrap spun yarns. Uniaxial composites were fabricated with 30 mass% hemp using compression moulding. The properties of composites in terms of hemp fibre orientation (aligned and random), off-axis angle and alkali treatment were investigated. It was found that the testing direction influenced the mechanical properties of the composites. Compared with all the fabricated composites, the aligned alkali hemp/PLA yarn composite possessed the best mechanical properties, including tensile, flexural and impact strengths, lower porosity and water absorption. The water absorption for all composites was higher than for neat PLA, both at room temperature and 80 °C. The PLA in its treated composites had higher crystallinity, which was attributed to effective heterogeneous nucleation induced by hemp. Based on SEM observation and theoretical analysis of DMTA data, there was a favourable interfacial adhesion in all composites.

1. Introduction

The potential of natural fibres as reinforcement in composite materials is well recognized due to their attractive mechanical properties which enhance the possibility of producing eco-friendly materials. Natural fibres such as hemp and flax are already used in the automotive industry to reduce weight, cost and environmental impact. Hemp is an upcoming European industrial crop [1], with good mechanical fibre properties which can be cultivated with a low consumption of fertilizers and almost no pesticides [2]. Concerning the matrix in the composites, the industrial trend for natural fibre composites is giving more importance to a thermoplastic matrix, rather than a thermosetting matrix [1,3].

Polylactic acid (PLA) is the most important biothermoplastic for applications requiring biodegradability. It shows also quite good properties appropriate for applications that do not require long-term durability or high mechanical performance at higher temperatures. The mechanical properties of the PLA can be improved by using reinforcements like natural fibres in order to increase its potential use in many industrial applications [4,5]. Therefore, because of the attractive properties of hemp fibre, it was used as reinforcement for PLA composite in the presented study.

The main application of natural fibres is today mainly in non-structural composites as they are mostly available as randomly oriented nonwovens [1,3,6]. The fibre orientation (i.e. alignment of the fibres) must be controlled to ensure that the fibre mechanical properties are efficiently utilized in order to attract industrial interest as an alternative to the traditionally applied synthetic fibres (e.g. glass fibres). It is evident that PLA/hemp fibre composites can compete with glass fibre composite regarding stiffness, whereas for tensile and impact strength, the properties are still not on a satisfactory level [7–12]. Previous studies have demonstrated that the full reinforcement potential of natural fibres can be exploited in bio-composites if an aligned fibre orientation is used [12,13]. Natural fibres are naturally discontinuous; therefore natural fibre reinforcements reported so far are based on twisted spun staple yarns, which are produced by spinning methods, mainly ring spinning. These spun yarns tend to be highly twisted, which leads to fibre misalignment due to their helical paths around the yarn axis. This misalignment contributes negatively to the mechanical properties of the resultant composites. Another negative impact of yarn twist is that it tightens the yarn structure, rendering resin impregnation difficult [14]. Therefore, in the textile industry a broad range of techniques for the alignment of natural

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fibres have been developed and optimised to produce yarns with controlled fibre orientations by reducing or replacing twist in yarns. Goutianos and Peijs [14] tried to produce flax yarns with the minimal level of twist for manufacturing aligned composites. Shah et al. [15] used a sizing agent to substitute the use of twist in roving and yarn. Zhan and Miao [13] studied the effect of wrapped spun yarn with low twist for reinforcement purpose.

Our previous study [12] investigated the mechanical properties of composites manufactured from PLA/hemp co-wrapped hybrid yarn prepregs. Here we used continuous PLA filaments, which were used to wrap a low twist hemp yarn. The composites made from the hybrid yarn with higher wrapping density showed improvements of mechanical properties due to lower porosity. However, the porosities of composites were between 6 and 9 vol.%, and the porosity fraction was still high even if the fibre volume fraction was low, which could be due to several factors. Porosity is difficult to avoid in natural fibre composites and influences on the composite properties, yet how to control the porosity has so far only received limited attention. Thus, research on how to decrease the amount of porosity is warranted.

In the current paper, we discuss the development new hybrid yarns with low twist for high performance natural fibre-reinforced composites suitable for use in structural or semi-structural applications and with lower amount of porosity. The overall was to study the mechanical properties of these novel aligned hemp fibre yarn composites and investigate the effect of a range of relevant parameters such as prepreg type such as nonwovens and hybrid yarn prepregs with different off-axis angles (0°, 45° and 90°) and fibre treatment.

2. Materials and methods

2.1. Materials

Two types of staple fibres were used in this study: hemp and PLA fibres. The PLA staple fibre, provided by Trevira GmbH (Hattersheim, Germany), had a fineness of 1.7 dtex and a mean fibre length of 38 mm. Based on the manufacturer's information; the PLA fibres were made from PLA Polymer 6202D from NatureWorks®, Cargill Dow LLC (Minnetonka, USA). This thermoplastic has a density of 1.24 g/cm^3, a melt temperature of 160–170 °C, and a glass transition temperature of 60–65 °C. The hemp in the form of baled loose staple fibres (genus species Cannabis Sativa L) was supplied by Hempage AG (Adelsdorf, Germany). According to the manufacturer's information, the average diameter of the hemp fibre was 20–40 μm and had a mean fibre length of 30 mm. The hemp fibres were treated by 4 wt% NaOH solution for 1 hr, rinsed with distilled water until it was neutral and finally dried at room temperature for 48 h. In addition, a 18-tex PLA multifilament yarn, provided by Trevira GmbH (Hattersheim, Germany), was used as wrapping yarn in the wrap spun yarns.

2.2. Methods

2.2.1. Wrap spinning of hybrid yarns

The preferred yarn structure has the reinforcing fibres straight and parallel to the yarn axis. Wrap spinning can be used to produce such a yarn [13]. PLA/hemp hybrid wrap spun yarns were produced by using a laboratory spinning machine from Mesdan S.p.A., (Brescia–Italy) and a laboratory yarn twist machine from DirecTwist, AGTEKS Co., Ltd., (Istanbul, Turkey). The hemp and PLA fibres arrived at our laboratory in baled loose fibre form. The PLA fibre and the hemp fibre were weighed to the desired proportion (30 mass%) and the fibre mixture was then fed into the carding machine. During carding, the longer PLA fibre supported the shorter hemp fibre and provided the necessary fibre-to-fibre cohesion to get a web suitable for further processing. The blended PLA/hemp web was carded three times to parallelize the fibres and achieve sliver uniformity. Then the sliver was fed through a roving frame, where the strands of fibre were further elongated. The sliver was drawn twice after carding to achieve the required roving linear density. Although it was possible to create hybrid yarns with low twist, the cohesion of the fibres was very low because PLA/hemp roving had a false twist, which means that they could not form a roving of sufficient integrity. Moreover, the rowing is too weak to be able to be collected alone in the roving machine. In order to collect the roving without causing breakage in the roving machine, the processable PLA filaments were used as a processing carrier for the PLA/hemp roving in the final step. Then the roving was wrapped by PLA filaments in the twisting machine. The wrap yarn was spun to the nominal count of 550 tex, and it had a wrapping intensity of 200 turns/m. These wrappings provide better protection for the reinforcing fibres during further processing, such as weaving [16] or making a prepreg. The yarn structure obtained from the wrap spinning used is shown in Fig. 1.

2.2.2. Preparation of prepreg and composites

Before compression moulding, multilayer unidirectional prepregs were prepared by winding the hybrid yarn around a 19 × 19 cm^2 rectangular steel frame. The off-axis fibres were oriented at different angles including 0°, 45° and 90°. In order to investigate the effect of random fibre orientation on composites, non-woven PLA/hemp prepreg was produced through carding and the blended PLA/hemp web was carded three times. The prepreg mats were first dried in a vacuum chamber (0.9 mbar; 70 °C) for at least 18 hours before compression moulding. The prepreg was then covered by a Teflon sheet to prevent sticking of the matrix to the surface of the mould, and then it was placed into a pre-heated steel mould with a 20 × 20-cm^2 square cavity, and 10 mm depth. The composites were formed by pressing the prepreg at 195 °C and at 1.7 MPa for 15 min. The thickness of produced composite samples was between 2 and 3 mm. Neat PLA sheets to be used as reference material were made by melting PLA fibres under the same processing conditions. Specimens for the mechanical testing were cut by GCC LaserPro Spirit laser cutting machine according to the standards given below. Before performing the testing, the specimens were conditioned for at least

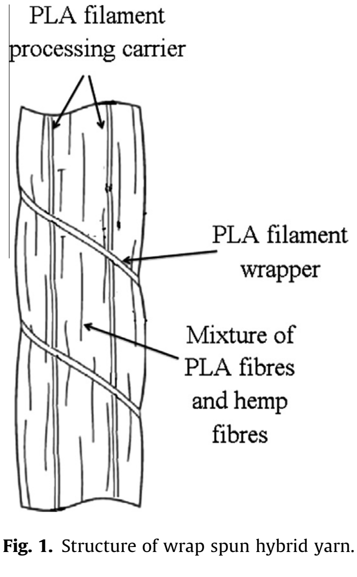

Fig. 1. Structure of wrap spun hybrid yarn.