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Tensile and fatigue characterisation of textile cotton waste/polypropylene laminates

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A B S T R A C T

Short fibre based cotton flocks from end-of-life jeans fabric (denim twill weave) were introduced in an amount of 16 wt.% in a polypropylene (PP) matrix using a specifically designed manufacturing process to preserve as much as possible the properties of the cotton waste during injection moulding. This involved a first phase of binding the cotton flocks on polyvinyl acetate (PVAc) support, then pelletizing them with PP and finally extruding the final composite. The resulting composites were subjected to morphological, tensile and fatigue characterisation with stress levels from 50 to 90% of ultimate tensile strength. Results indicated that injection moulding offered a sufficient uniformity of properties to the composite, albeit with some occurrence of pull-out during loading. In particular, the tensile performance exceeded that of the pure matrix in a measure compatible with the amount of fibres introduced. In addition, tensile fatigue loading up to 5000 cycles evidenced a limited amount of degradation for maximum applied stresses up to 70% of composite tensile strength.

1. Introduction

In the frame of the wide interest raised in recent years by the application of plant fibres to the reinforcement of polymer matrices, some work on cotton fibres was also performed, mainly on the possible use of newly extracted ones, as a by-product of the textile industry. In particular, works on thermoplastic matrix composites reinforced with cotton fibres elicited some potential for these materials [1,2]. Thermogravimetric studies of cotton fibres suggested that cellulose decomposition would occur between 240 and 400 °C, with 90% of the process taking place above 300 °C: this is compatible with the maximum temperatures applied for polypropylene in injection moulding, which are around 190 °C or slightly above [3]. Some applications have been proposed for cotton fibre reinforced polymers for gear materials, as a replacement for phenolic/paper laminates, for their excellent properties in cleavage fracture [4]. This has suggested some possible use for these materials in the field of tribology [5] and also, due to their unexpected wear resistance, as the reinforcement of fly-ash based geopolymers [6]. Cotton has also some other merits, which go beyond the textile use and may suggest its larger application, for example as a phytoremediating crop to reduce pollution from heavy metals, such as lead [7]. On the other side, while being the most diffuse natural fibre in the textile industry, cotton, which is extracted from seed hair obtained from *Gossypium* spp., is not usually considered very stiff, being constituted by very thin filaments, very hydrophilic as the consequence of their very high cellulose content (often above 90%). Comparisons of cotton fibres with other fibres in terms of composite properties proved rather deceptive, as it was the case for example with ramie [8]. Attempts were performed to overcome structural limitations from cotton fibres by directly laminating a mixed fabric (cotton/kapok) in a composite [9], a procedure which is only limited to thermoset matrices though, in terms of recyclability, thermoplastic matrices would be preferable, such as polypropylene, which in fact has received considerable attention for the production of plant fibre composites, especially aimed at automotive applications [10–12]. In the particular case of cotton waste introduction, an attention to coupling agents with thermoplastic matrices, such as maleated anhydride with high density

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polyethylene (HDPE), has been also recently demonstrated [13]. However, the problem appears far to be resolved for the specific properties (high hydrophilicity, tendency of flocks to accumulate disorderly on a surface) of cotton waste.

On a positive note, it is important to consider that high temperature degumming, which is a typical industrial procedure, involving mercerization with sodium hydroxide, leads to a virtually complete removal of lignin and hemicellulose and to the almost exclusive presence of crystalline cellulose I in cotton fibres [14]. This would suggest that employing waste cotton from textile products as filler in polymer matrices could have some merit, also in terms of providing a second life to textile waste, therefore resulting in a reduction of relevant environmental impact, especially when the matrix itself is obtained from industrial waste [15]. Almost all nonwovens require a chemical binder to provide structural integrity. Polyvinyl acetate (PVAc) was the first successful synthetic binder used in substantial volume to fit this request for its distinctly superior adhesive properties, strength, and performance, so to be used as sizing agent for cotton and binder for nonwoven fabrics in textile industry. It has been reported in the literature how PVAc can be used as binder in natural fibres [16]: in particular, it has been recently demonstrated that the bamboo fibres can adsorb phenol formaldehyde (PF) based resin in a different content if PVAc is added in the emulsion used for the soaking and impregnation of the natural fibre [17]. A study on the introduction of cotton waste in recycled polyethylene terephthalate (PET) aimed at the production of compression moulded parts suggested the prominent importance of plasticizers, such as 2-phenyl phenol and glycerol, on the tensile and flexural properties of composites [18]. In this respect, a characterisation study was carried out also on cotton denim waste by simply compression moulding chopped fabric into a polypropylene matrix, with very limited fibre content (up to 10 wt.%). The results were interesting, though a wide presence of microvoids was observed, which limited the final performance of the composite [19]. Moreover, the fabrication of composite panels including cotton fibres in a polyester matrix and aimed at semi-structural applications (e.g., car door panels) indicated that the introduction of cotton textiles instead of plain woven fibres offered a significant resistance to moisture to the composite, in some instances even increasing the performance of conditioned laminates with respect to dry ones [20].

It is evident that increasing the profile of use for plant fibre composites would require information about fatigue behaviour: it has been suggested from early studies that the architecture of reinforcement plays a significant role on fatigue resistance [21]. It is worth noting that cyclic loading occurs in most engineering applications and the great majority of mechanical failures are attributed to this type of loading. For natural fibre based composites, there has been a great deal of work focused on determining static mechanical properties, but very limited studies related to fatigue [22]. This is particularly critical whenever the production process does lead to the considerable presence of defects and non uniformity in the characteristics of textile reinforcement, which has been often the case for plant fibre composites, where low cost and easily available products are used, such as for example jute hessian cloth [23]. Despite the interest of this topic, only limited coverage exists on fatigue properties of plant fibre composites, particularly concentrating on oligocyclic fatigue loading. The existing studies raised some concern on the ability of plant fibre composites to preserve their stiffness, after even a few cycles at moderate levels of load, an event that is also due to the presence of considerable strain gradients during loading between fibre and matrix [24]. In this case, tensile fatigue has been selected to concentrate on the ability of the interface to withstand with no substantial damage a moderate number of tensile–tensile cycles at a low frequency, to avoid effects on matrix stability due to heat accumulation in the laminate [25]. Tensile fatigue is the object of a specific standard, in particular ASTM D 3479/D 3479M-12 "Standard Test Method for Tension–Tension Fatigue of Polymer Matrix Composite Materials".

In this work, jeans short fibre based flocks, coming from differentiate waste collection, have been injection moulded in an as-received polypropylene matrix using a specifically designed manufacturing process to preserve as much as possible the properties of the cotton waste without further degrading it. The obtained composites were subjected to morphological, tensile and fatigue characterisation. The amount of fibre introduced was low, around 16 wt.%, which was largely due to the difficulties of the process acting directly from ground cotton waste with no other processing of the textile: on the other side injection moulding provided a sufficient uniformity to the composite, whose suitability to cyclic load applications was investigated.

2. Materials and methods

2.1. Composites production

The objective of this production was to validate the initial suitability of the method proposed, which involved treatment of a limited amount of waste collected cotton fibres into a thermoplastic matrix by the use of a suitable binder.

For this purpose, end-of-life denim was collected and washed to remove any trace of extraneous materials: after this, it was subjected to garneting to produce denim fibres, with most fibres having length between 10 and 20 mm: natural tendency to entanglement, also due to the prevalent cellulosic nature of the fibres, leads to material being disposed in flocks. In the event jeans short cotton fibre based flocks, as well as other kinds of low density natural fibres flocks, are directly mixed to thermoplastic granules in an extruder, a very poor homogeneity could be obtained. This because the mentioned flocks tend to float over the granules and only a limited amount of them is able of being captured by the extruder screws, in order to be mixed with the given polymer. This leads to obtaining in the extrudates low concentration regions alternated to high concentration ones, even when twin screw extruders are used with counter rotating movements [2].

To prevent the described phenomenon, cotton jeans flocks, whose as-received aspect is depicted in Fig. 1, have been wetted in a water solution containing 5 wt.% of vinyl acetate (Vinavil) for about 1 h and subsequently densely packed in a square shaped mould (260 mm × 260 mm) inside a compression moulding machine

Fig. 1. Appearance of cotton flocks as received from differentiated waste collection of end-of-life jeans.