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Compressive behaviour of natural fibre composite

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ABSTRACT

This paper presents findings from a comprehensive study aimed at the development of sustainable natural fibre composites (NFC) for civil engineering. It focuses on the compressive behaviour in an elastic region and post collapse behaviour of NFC tubes. Deformation and fracture behaviour were examined experimentally and an influence of the reinforcement arrangement and tube design on mechanical performance was analysed. The correlation between the reinforcement arrangement, material compressive strength and a fracture mode was established: The compressive modulus and ultimate stress of NFCs increased with the reinforcement orientation angle. The highest stress and modulus was observed for the reinforcement oriented at 10° to the main axis, which were four times higher than transversely oriented reinforcement. Four compression collapse modes were observed for the tested NFC tubes, namely microbuckling, diamond shape buckling, concertina shape buckling and progressive crushing, which are closely related to the geometries of tube architectures.

1. Introduction

Renewable construction materials bring benefits throughout the life cycle of buildings, such as, the reduction of embodied energy, increase in energy efficiency during use, reduction of waste and other unique properties (e.g. insulation and breathability) [1,2]. Bast fibre composites are seen as an alternative to wood or glass fibre composites in applications for door elements, roof panels, car bodywork and interior elements in many engineering sectors [1,3–5]. Add reference to the Composites B about NFC degradation.

The advantages of natural fibre composites (NFC)s include specific tensile and impact performance, low density and fibre renewability, while some disadvantages include moisture and ultraviolet light resistance and a relatively high price at the current low volume production [6,7]. NFCs are not considered as materials withstanding compression and they perform better under tensile loading, which is usually investigated [8–10], but in order to be applicable in construction industry other properties need to be examined, e.g., fire resistance [11]. Moreover, in real life applications, compressive loads are unavoidable, e.g., in tensile-compressive coupling of flexural deformation, unbalanced stacking sequence of a laminate or if residual stresses are present in the composite. Therefore, a performance of NFCs under compressive load should be analysed. A composite tube, either with round or square profile, is a versatile element in all aspects of engineering. This study focuses on a compressive behaviour of natural fibre composite tubular shells in the elastic region and the post collapse progression, which are considered of importance for energy absorbing structures and safety considerations. A series of tubular hemp composites were processed by filament winding and tested in order to investigate the fracture mechanisms during compressive loading.

2. Materials and methods

2.1. Materials selection

Hemp yarns were supplied by Cyarn Ltd. These types of yarns are processed by retting in water, bleaching and ring spinning in order to form twisted yarn. Unsaturated polyester resin was used together with cobalt in aliphatic ester accelerator (1 wt%) and methyl ethyl ketone peroxide catalyst (1.5 wt%). The density of the cured resin is 1.12 g/cm^3 at 25 °C. Samples were cured at 120 °C and post cured for 24 h at 100 °C in accordance with BS ISO 3597-1:2003. Mechanical properties of the resin are: tensile strength σt = 53 MPa, tensile modulus E = 3.7 GPa and compressive strength σ_c = 42 MPa tested in accordance with the standard BS ISO 527.

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2.2. Tube processing

The processing routes used for composite tube construction include the pultrusion, pullwinding and filament winding, which all rely on the tensioning of a processed reinforcement. Therefore, the yarns or filaments used should be able to withstand processing loads. Unlike most synthetic man-made fibres, which are produced continuously, natural fibres (NF) are inherently short. NF length is not only limited by the length (height) of plants, but also by the extraction procedures and natural defects of natural fibres. NFs are combined into yarns either by twisting of the aligned sliver or by wrapping it with an additional synthetic fibre, in order to produce NF reinforcement continuously.

Tubular samples were prepared with pin filament winding technique. The equipment was designed and built to accommodate use of natural fibre in laboratory scale (Fig. 1). The production was mainly controlled by two step motors synchronised together with a Q Drive supplied by the Applied Motion Products, which allowed for the control over winding angle and processing speed. A consistent yarn tension was facilitated by mechanical means. Prior to the processing, the yarns were dried at 80 °C for 24 h in order to remove moisture from the yarns (ranging from 7% to 10%). The yarns were then fed through the series of loops and were wound in accordance with the selected program. After the winding procedure, the samples were manually impregnated with resin.

The mould with wetted-out stacking, was covered with NV153 perforated release fabric, and wrapped with HST400 thermo shrinking tape supplied by Tygavac Ltd. Then, the samples were placed on a rotating stand (Fig. 2) throughout gelling and curing process, in order to prevent gravitational resin agglomeration. The thermo shrinking tape applied a uniform external pressure while kept in the oven for 15 min at 120 °C. Subsequently the samples were removed by collapsing molds and were post-cured at 100 °C for 24 h in a vacuum oven.

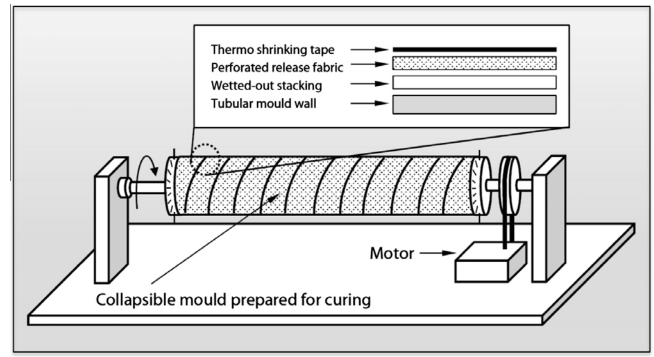

Fig. 2. Diagram of the sample rotating stand used during gelling and curing.

2.3. Testing

The cured samples were machined to the dimension of 45 mm height and 45 mm outer diameter. This geometry was used to prevent the creation of a global off-axis Euler buckling mechanism of the tube, while testing was carried out [12]. For each configuration, two repetitions and three test pieces were developed. Before testing, both ends of samples were squared, polished and covered with PTFE paste to diminish lateral stress concentration caused by a friction between sample and compression plates (Fig. 3). Tests were conducted on Instron 5585 universal testing machine at a compression rate of 0.5 mm/min. The compressive stiffness, ultimate compressive strength and mode of fracture were recorded. Fibre density and yarn Tex values were measured using buoyancy method with pycnometer on the 10 m samples (ISO 2060:1994). The diameter of the yarn and fibre were measured on composite cross-sections with an optical microscope. Rectangular test pieces with unidirectionally arranged reinforcement were tested in accordance with the BS EN 527 standard. Test pieces ($250 \times 25 \times 150\ mm^3$) were statically loaded in tension at 2 mm/min crosshead speed until failure.

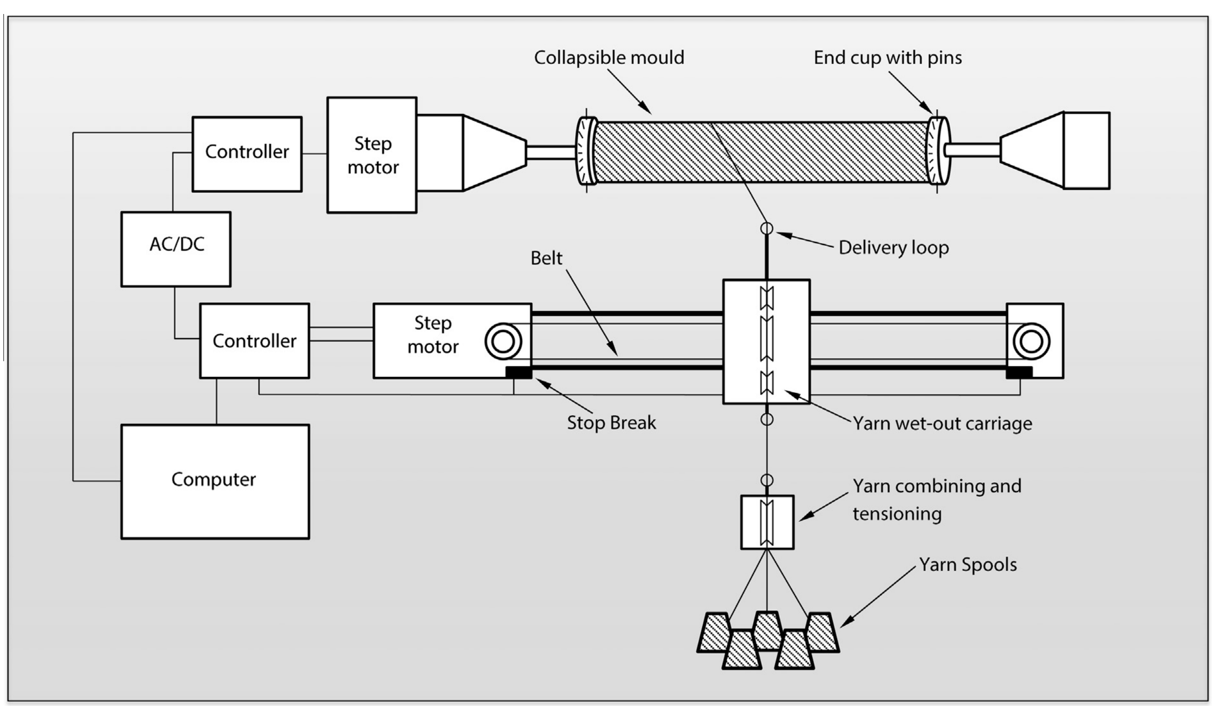

Fig. 1. Diagram of the filament winding set-up used for NFC tubes preparation.