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Novel extraction techniques, chemical and mechanical characterisation of *Agave americana* L. natural fibres

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ABSTRACT

The work describes the manufacturing and tensile static behaviour of natural fibres produced with novel extraction techniques. The fibres are extracted using two new methods, one consisting of immersing the blades of the *Agave* leaves in water for 10–13 days in a container, and another sustainable extraction process during which the *Agave* leaves are buried in earth for 90 days. Single fibre tensile tests have been performed at four gauge lengths to assess the effect of the gauge length over the tensile strength and Young's modulus. The results have been analysed through a two-parameter Weibull distribution to quantify the degree of variability in fibre strength and Young's modulus at different gauge lengths for the two extraction methods. Strong sensitivity of the mechanical properties of the fibres has been observed based on the production methods used.

1. Introduction

Lignocellulosic fibres are readily available in large quantities in many countries, and represent a continuous renewable source of biodegradable and relatively low-cost structural materials [1]. Natural fibres play an important role in developing high performance fully biodegradable novel green materials, which will be key to solve some of the current ecological and environmental problems [2,3]. Vegetable fibres originating from plant stems such as hemp, sisal, jute, kenaf, flax and *Agave americana* provide an interesting alternative to man-made fibres in composites structures. These bio-based materials are low cost, low density, possess acceptable mechanical properties, and are biodegradable and prone to recycling [4–6]. Recently, a substantial body of work has been performed to understand the mechanical characteristics of new lignocellulosic fibres such as okra [7,8], *Posidonia oceanica* [9], Artichoke [10] and *Grewia tilifolia* [11]. Other natural fibres considered in open literature as alternative reinforcement are Chakshir [12], *Arundo donax* L. [13], Marshmallow [14] and *Sansevieria ehrenbergii* [15]. The automotive [16], building [17] and packaging [18] industries have invested R&D resources for the development of new materials reinforced with natural fibres or powders, backed on this by EU and international directives [19]. Many authors have however reported that natural fibres are generally affected by large scattering of the distribution of their mechanical properties due to experimental test conditions, characteristics of the plant and type of extraction of the natural fibre [20–26]. The *A. americana* (Fig. 1a) is possibly the most weather-resistant of all the *Agave* plants, which explains its wide geographical distribution. *A. americana* produces flowers 5–8 years after being planted [27]. The leaves of the plant are thick, with a grey-blue colour, sharp spines on the edges and dimensions up to 1.80–2.30 m long and 0.25 m wide (Fig. 1b). Edge spines are shaped like fishhooks, while tip spines can be more than 25 mm long [3]. The leaves are tough and rigid, and can yield fibres (*pita*), which are suitable to produce ropes, matting, coarse cloth and embroidery of leather. Msahli et al. [28] evaluated the physical and mechanical properties of *A. americana* fibres, demonstrating their potential to be used as textile fibres and fibre reinforcement for polymer matrix-based composites. Fibres can be extracted mechanically, chemically, or by immersion in water (running water [29], seawater [29,30] and distilled). When using the latter technique, the leaves are subjected to hydrolysis [29–32]. Bessadok et al. [33,34] have produced *Agave* fibres (*Americana* L.) using a different process, consisting in a

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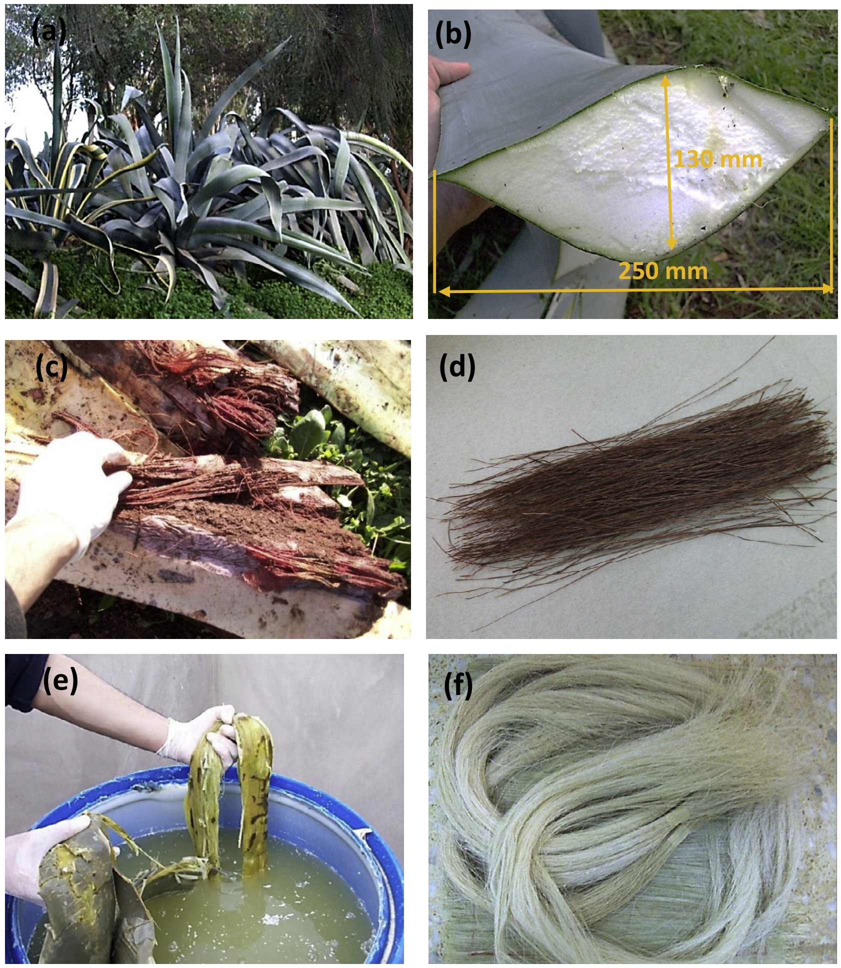

Fig. 1. (a) Example of *Agave americana* L. from the region around Guelma (Algeria) and (b) its cross-section view. (c) Extraction from the ground of the plant buried after 90 days; (d) type of fibre obtained from this manufacturing process. (e) *Agave* leaves immersed in water for 10–13 days; (f) type of fibre obtained from the water immersion technique.

pre-treatment of the leaves with a pectinase solution (*Aspergillus aculeatus*). The most known *Agave* fibres are probably the sisal ones, extracted from *Agave Sisalana* L., and Henequen, extracted from *Agave Forcroydes* L. [29]. A common purpose within the R&D community is to identify extraction techniques that are economically viable, but retain the chemical and physical properties of the natural material [35]. Between the different methods used in this case, it is worth noting the immersion of samples in water to extract *G. tilifolia* fibres [9], or the use of mechanical tools for the *Sanseveria cylindrical* [36] and *A. americana* [37].

This work describes two novel environmentally sustainable methods for the extraction of *Agave* fibres. The first manufacturing technique consists in burying in the ground the *Agave* leaves at a depth of 30–40 cm for a period of three months (Fig. 1c). The second method is based on the modification of a classical approach to produce *Agave* fibres by water immersion of closed leaf blades, using this time a container (barrel) to confine the leaves for a period of 10–13 days (Fig. 1e). Using both techniques it is possible to achieve a total bio-degradation of the natural matrix of the leaves, allowing the fibres to be separated. The strength of the fibres obtained from using these methods was evaluated as a function of gauge length using Weibull statistics, while fracture surfaces through scanning electron microscopy (SEM) have been also observed. Weibull statistics has been often used to analyse mechanical data from natural fibres [38,39].

2. Materials and methods

2.1. Extraction procedure for A. americana L.

The fibres have been separated from the *A. americana* leaves collected from the Mountain of Maouna at Guelma City, Algeria. The leaves contain a single bundle of fibres along the leaf length supporting the cellular tissue, which constitute also the vascular system of the leaf [40]. The fibres were obtained from leaves buried under a layer of soil between 30 cm and 40 cm deep for three months (Fig. 1c and d) (first method). The second extraction method consisted in immersing the leaves in a barrel for a period of 10–13 days (Fig. 1e and f). The use of a closed barrel accelerates the biodegradation process of the leaves matrix due to the rapid development of the bacteria in a closed environment with reduced water vaporisation. The washed *A. americana* have been dried for 72 h in sunlight, and then stored inside vacuum-proofed plastic containers before testing. The separated *A. americana* components are shown in Fig. 1d and f.

2.2. Optical and scanning electron microscopy

Like the majority of natural fibres, *A. americana* strands show in general a non-uniform cross section and irregular shape. These fea-