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Why are designers fascinated by flax and hemp fibre composites?

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ABSTRACT

Flax and hemp fibres have been increasingly used as reinforcement in polymer composites. First, an overview is given of the technical arguments which convinced designers of consumer goods to use these fibres. In particular, their composites show higher specific stiffness than glass fibre composites in both tension and plate bending and only slightly lower values than carbon fibre composites in plate bending. Moreover, flax and hemp fibres possess a much higher vibration damping capacity, making them excellent candidates for applications in sporting goods or musical instruments. Secondly, the paper describes how designers relate to the non-technical characteristics of these natural fibres. Many concrete examples are given from different application domains in consumer goods: sports, mobility, music and sound, furniture and interior design. The fascination of designers for these bio-based materials combined with the recent introduction in the market of new, composites-oriented preforms of flax and hemp fibres, is rapidly increasing the number and variety of composite products using flax and hemp fibres as reinforcement.

1. Introduction

Polymers have joined the class of structural materials some one hundred years ago, with the invention of phenolic resins by Baekelandt, followed soon by a growing number of thermoset and thermoplastic synthetic polymers. They offered unusual properties, compared with the at that time well known structural materials like metals, wood, glass and ceramics: they were light, colourful and rather easy to process. However, for many structural applications, their stiffness and strength was not sufficient. It is hence not surprising that already Baekelandt has been 'reinforcing' his brittle phenolics with cotton fibres, and that soon after the development of polyester resins, they have been reinforced with glass fibres [1].

Although composite materials have been around for quite some time, glass fibre composites since the 1930s and carbon fibre composites since the 1960s, they have not been noticed as a breakthrough new material by the general public until their appearance in sporting goods in the late 1970s. Their first use, almost simultaneously, in civil aircraft structures remained virtually unnoticed, and it was only at the start of the new millennium, when both Airbus and Boeing announced their A380, A350 and B787 projects, that one could read in all newspapers about this 'new' material, that was expected to revolutionise the design and manufacturing of the aircraft of the future. In the meantime, composites had become common materials in many sports applications: all professional cyclists ride 'carbon' bikes; Formula 1 racing became the playground for engineers reducing the weight and improving the aerodynamic (and crash) performance of their cars; sailing yachts, tennis rackets, golf sticks... they all use intensively and sometimes exclusively composites.

The visibility of composite materials has not been limited to sporting goods and aerospace applications. Already in the 1960s, designers massively discovered the potential of what they called 'fibreglass', in fact a glass fibre reinforced plastic, mostly polyester. In the exhibition "From Bakelite to Composite", in the Design museum Gent (Belgium) in 2002 [1], we showed the whole evolution of the designers' interest in composites, starting with Charles and Ray Eames' glass fibre–polyester armchairs (DAR, PAW and others) from 1948 as displayed in Fig. 1, evolving in furniture designs by Philippe Starck, Marc Newson, Jasper Morisson, Stefano Giovannoni and many more at the beginning of the new millennium. In the book, edited on that occasion [1], it is shown clearly how furniture designers reacted promptly on the appearance of this new material being seduced by its lightness, colourfulness, easy drapability into complex shapes and its accessibility, as experimenting with it only required some very simple and inexpensive

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Fig. 1. Charles and Ray Eames, experimenting with 'fibreglass' in 1948, while making "La Chaise" © Eames Office [1]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

tools. Eames' fibreglass armchair just came a few years after the very first use of glass fibre composites in military aircraft during the second world war. Also Alberto Meda's Light-light chair (1984) [2] and Pol Quadens' C06 chair (1995) [3]), at that moment 'the lightest chair in the world', were developed in parallel with the significant increase of carbon fibre composites in civil aircraft, bicycles and tennis rackets.

The composites industry is seeing a revolution in the past fifteen years: automation and acceleration of manufacturing processes, increasing use of thermoplastic matrices, availability of powerful design and simulation tools, reduction of the cost difference between glass and carbon fibres (from a factor of 50 in the early 90s to about 10 now) all led to the penetration of composites in ever more applications. Moreover, bio-based composites, in which natural fibres are combined with bio-based or synthetic polymers, made their entrance into the world of composites. A new 'composites and design' exhibition is under preparation, a collaboration between Design museum Gent and KU Leuven-LUCA School of Arts, and will be opening in spring 2018. As a stepping stone to this exhibition, and to highlight one of the aforementioned recent evolutions, the exhibition "Synthetic by nature" which was held in April 2015 at Design museum Gent (Belgium) showed about 50 products using flax or hemp fibre reinforced composites in a wide range of application domains, from cars and bikes over ski's and fishing rods to chairs and tables [4].

This paper aims at explaining why bio-based composites, and more specifically flax and hemp fibre reinforced composites, are attractive materials for all these application domains, and how designers see much more than just technical advantages in using these materials.

2. Why flax and hemp composites are attractive for designers of consumer goods

From the start of a design project, technical aspects are part of the concept. They can be predominant, with the engineer playing a major role in the design process, and the technical requirements being predominant in the materials choice, in the definition of form and shape of the product and in its manufacturing process. Even then, they are closely linked with the many components of the design concept: shape, colour, haptics being the sense of touch and feel, references to other products, meanings, worlds…, societal aspects of the product. The environmental impact is just one concrete aspect of the latter, as are the country of origin, the labour conditions in the different parts of the value chain, etc. Some of the non-technical characteristics of the materials and of the manufacturing processes along the value chain from raw material to product, will be discussed in the last part of this paper, namely when furniture and interior design goods made from flax and hemp composites will be presented. It should however be underlined that all technical and non-technical aspects of materials play a role in the material selection and further design process, be it in a different relative importance, specific for each product.

Starting with the technical characteristics, the mechanical properties are most often looked at first. The stiffness of flax fibres compares very well with that of glass fibres, be it for a density which is almost two times lower (see Table 1). Determining the stiffness of natural fibres is, in contrast to synthetic fibres like glass and carbon, not straightforward, for two reasons.

Firstly, the natural fibres as used in composites, are composed of a number of elementary fibres, glued together by a 'middle lamella', the composition of which varies for different types of natural fibres (for flax and hemp this is mainly pectin). When quoting the stiffness of flax or hemp, it is hence important to mention explicitly whether the measurement was done on a technical or an elementary fibre. In this issue of Composites Part A, a method is proposed, the impregnated fibre bundle test (IFBT) [5], to measure the stiffness of flax and hemp fibres, and by extension all natural fibres, in a similar way as is done for glass and carbon fibres, namely when they are impregnated by a polymer resin [6–9]. Following this procedure, reliable stiffness data relevant for the behaviour of flax and hemp fibres as reinforcement in composites can be obtained.

Secondly, the flax fibres show a non-linear stress strain curve, with a transition point to a lower tangent modulus at strains

Table 1
Mechanical properties of fibres: for bio-based fibres, typical values for both technical fibre data (lower values) and elementary fibre data (higher values) are quoted [14–18].

Property	E-glass	Carbon (T300-T700)	Flax	Hemp	Bamboo	Jute
Density [g/cm^3]	2.55	1.8	1.45	1.48	1.4	1.46
Tensile strength [MPa]	2000–2400	3530–4900	800–1500	550–900	750–950	400–800
Stiffness [GPa]	70–74	230	55–75	40–65	30–50	10–30
Specific strength [MPa cm^3/g]	780–940	1900–2700	550–1030	370–600	535–680	275–550
Specific stiffness [GPa cm^3/g]	27–29	128	38–52	27–44	21–36	7–21
ε [%]	3	1.5–2.1	1.5–2	1.6	1.9	1.8

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