Growing the materials of the future

Bamboo fibres for light and strong composite materials

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In order to reduce the negative impact of global warming and the dependency on non-renewable materials, the rational exploitation of natural resources and the development of environment friendly new technologies are essential. BelSPO has since a few years been supporting research at KU Leuven in a joint program with two leading Vietnamese universities, to develop bamboo fibres for lightweight, structural composite materials.

Environment friendly materials

Nowadays, rational exploitation and use of sustainable natural resources are a necessity and they will play a crucial role in the near future (e.g. environmental legislation and recycling targets). For this reason, there is an increasing interest in so-called renewable materials, to which category natural fibres clearly belong.

Light-weight and strong natural fibre composite materials are an efficient alternative for energy saving in transport applications. Composite materials, often shortened to “composites”, are still relatively new materials. Most composites have strong, stiff fibres embedded in a thermoset (e.g. epoxy or polyester resin) or thermoplastic (e.g. polypropylene) matrix. These polymers are weaker in comparison with the fibres, but when the two phases are combined it is possible to make a light and strong composite material, where the fibres carry the majority of the loads and the polymers protect the fibres from e.g. abrasion and prevent the fibres from buckling.

Traditionally, glass and carbon are the most common fibres to reinforce polymer composites with a great acceptance due to their good mechanical properties. Nevertheless, they are non-renewable materials and their production has high energy consumption.

Due to their abundant resources and environmental superiority, natural fibres have already become commercially available in the fabrication of some industrial polymeric composite structures, like interior door panels in cars. Several studies involving life cycle assessment (LCA) have been performed to compare glass fibre composites and natural fibre composites. These studies agree that natural fibres are likely to be environmentally superior to glass fibre in each phase of the life cycle of the composites:

- Production phase: In terms of fossil energy consumption, the production of natural fibre, including cultivation, harvesting and fibre treatment is much more energy efficient than the production of glass fibre; consequently, the release of carbon dioxide is reduced.

- Use phase: In transport applications, the light-weight natural fibres (density around 1.4 as compared to 2.5 for glass fibre) improve fuel efficiency, thus reducing emissions during the use phase of the component.

- End of life: natural fibres are combust-able and in many cases biodegradable, thus they can be easily incinerated or decomposed in the natural environment. In case they are combined with a thermoplastic matrix, they can also be easily recycled mechanically (e.g. by grinding and injection moulding into a new product), with reduced fibre breakage.

Nowadays at Katholieke Universiteit Leuven (KU Leuven), an ambitious research program carried out in the Composite Materials Group, has the aim to use natural fibres from different parts of the world (coconut from Vietnam, jute from Bangladesh, flax from Belgium and bamboo from Colombia and Vietnam), to be used as a reinforcement in composite materials to substitute synthetic fibres like glass in several applications. More information can be found at: *http://www.mtm.kuleuven.be/Onderzoek/Composites/*

Why bamboo?

Bamboos belong to the Gramineae family, which essentially means that they are grasses, naturally growing plants with an enormous capacity of self-restoration without reseed, and not trees as is generally believed. A total of 1200 species and 90 genera of bamboos are known in the world and are present mainly in Asia and South America.

From the engineering point of view, this fantastic plant has a unique structure, which resembles that of a unidirectional, fibre-reinforced composite with many nodes along its length. Bamboo is a structurally smart plant, the reinforcing fibres are oriented along the bamboo's culm, whereas in the nodes the fibres become entangled in a complicated manner to produce nodes that provide additional reinforcement to the culm. Moreover its fibres are placed in a pattern that gives the best mechanical performance with a minimum of material. Although bamboo culms are as such very interesting and useful construction materials, used at a large scale in countries where they occur, the fibres are the really strong part of the culm and when extracted they could very effectively be used as reinforcement fibres in composites.

Bamboo is also an effective plant in terms of global warming prevention. It releases 35% more oxygen and sequesters 4 times more of CO_2 from the air per hectare and year than a young forest (60 tons CO_2/ha.y). Other environmental advantages include:

- Fast growing rate (up to 21 cm/day) and giant bamboo species reach culm heights over 20 m, so a large biomass is produced in a short amount of time

- Renewable material that can be harvested after only 3 years

- Preservation of the soil from erosion and conservation of the level of the rivers where it grows

- The fibres can be recycled or landfilled for biodegradation

- The fibres require much less energy for cultivation and extraction than is used for synthetic fibres

Our project aims at further developing and finalizing the technologies to produce bamboo fibres ready for use in composites.

Currently in Colombia there are already 51.000 ha of bamboo under cultivation and there is a potential of 2 million ha of plantations where 85.000 people are involved (see figures 1 and 2). The Bamboo species *Guadua angustifolia* is one of the largest and most economically important bamboos in the Western Hemisphere due to its excellent mechanical properties, large size, exceptional timber qualities and natural durability.

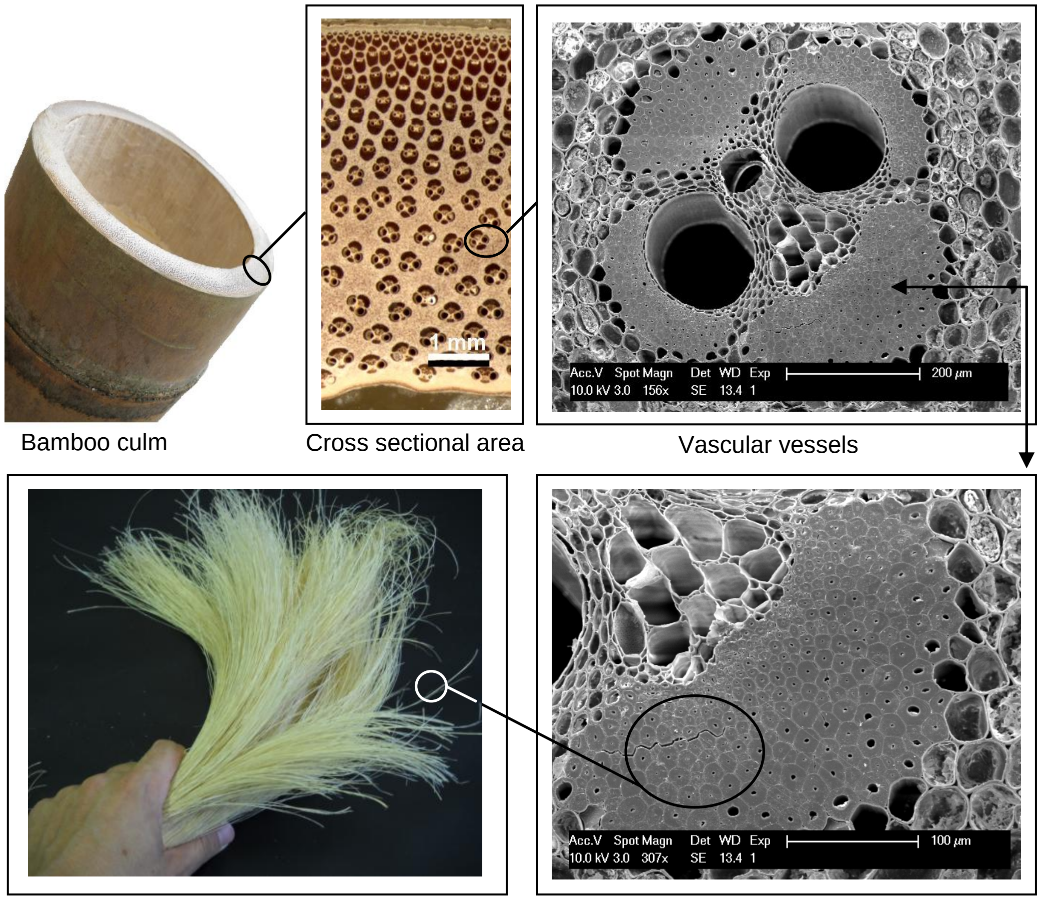
In Vietnam, the area covered by bamboo is currently more than 700,000 ha, constituting of various species, among which Dendrocalamus membranaceus Munro, which is being investigated in our project.

Figure 1: Typical bamboo plantation. Source picture: http://www.flickr.com

Figure 2: Bamboo culm (species *Guadua angustifolia*)

Why bamboo fibres?

The fibres are the most important structural part of the bamboo culm and are responsible for its outstanding performance. They are distributed throughout the culm, being more numerous in the outer part and becoming scarcer towards the inner part of the wall, to withstand extreme environmental conditions. Figure 3 illustrates the hierarchical structure of the culm, especially the fibre distribution inside the culm wall and the location of the fibre bundles or technical fibres, which are the target of the extraction.



Bamboo culm — Cross sectional area — Vascular vessels

Extracted bamboo (technical) fibre as is used for reinforcing composite materials — Bamboo fibre bundles in the culm

Figure 3: the hierarchical arrangement of the fibres inside the bamboo culm

For large scale exploitation, there are significant positive environmental impacts during the production of bamboo fibres. The energy required to produce a natural fibre mat (about 10 MJ/kg), is less than one-fifth of the energy required to produce a glass fibre mat. An important aim of the ongoing project is to provide an alternative for particularly glass fibres, whose annual global production reaches about 5 million tons. If the full potential 2 million ha of plantations in Columbia would be utilised, this would amount to a potential annual production of bamboo fibres of 4 million tons in Colombia only.

However, it is technically difficult and expensive to extract fine, long and straight technical bamboo fibres. Only few efforts have been carried out worldwide to extract long bamboo fibres from the culm. Actual processes are currently applied at laboratory scale and use either chemicals or high pressure, also negatively affecting the quality of the fibres.

In the first stage of the current project, a novel continuous mechanical process was developed to extract bamboo fibres without chemicals. The quality of these new fibres was verified through mechanical tests proving the effectiveness of the new process, which is currently operating at pilot scale at a rate of approximately 1 kg of fibre per hour. These tests have confirmed that bamboo fibres are indeed a suitable alternative to be used as reinforcement in composite materials, with strength and stiffness on a weight basis very similar to glass fibre.

Bamboo fibre composites

Bamboo fibre composites were also produced at laboratory scale using untreated and chemically-treated fibres (NaOH) to evaluate the effectiveness of the reinforcing material. Good results were achieved with untreated fibres in epoxy resin. The fact that chemical treatment is not necessary in case of commonly used epoxy resin, obviously reduces the cost and strengthens the environmental advantages of bamboo fibre.

Figure 4: Bamboo fibre composite plate

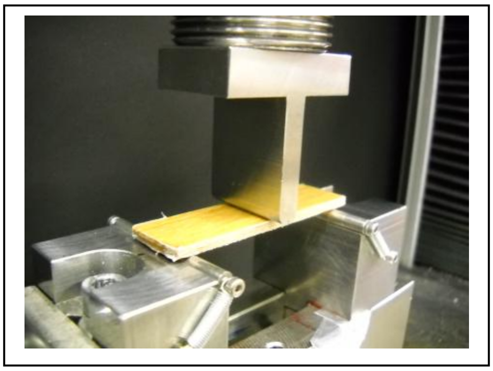


Figure 5: Bamboo fibre composite plate, tested in 3 point bending

Our next challenge is to prepare the discontinuous bamboo fibres for high-end composite applications by offering them in the form of a pre-form or pre-impregnated material ("prepreg"), ready for the production of composite parts. Newly conceptualized lab scale operations have to be mechanized and put into line with the continuous extraction process. We will particularly focus on the processes of refining (cleaning) and fibre alignment to produce continuous uni-directional prepreg.

Applications:

Composite materials are used in high performance products that need to be lightweight such as automobile parts, windmill blades, boat hulls, bicycle frames and aerospace components. Advanced manufacturing techniques such as preforming allow the alignment of the fibres to suit specific design requirements and to increase the strength and resistance to deformation of the final product. Glass fibre reinforced plastics are the most common type of polymer composites.

Bamboo fibres and their composites can be compared with glass fibres in terms of specific mechanical properties (normalized to the materials density). The development of a preform or prepreg of unidirectionally aligned bamboo fibres will allow us to use existing technologies to produce high performance composite parts, with the advantage of having a renewable material. This is especially interesting for the transportation industry where the fulfillment of environmental regulations and weight reduction are important aspects.

Figure 6. Applications of natural fibre components in automotive parts. Picture source: http://www.ircomas.org

Figure 7. Recent application of natural fibres in bicycle frames for increased material damping. Picture source: http://www.lineo.eu/

Figure 8. Application of natural fibres in tennis rackets. Picture source: http://www.lineo.eu/

Natural fibres are emerging as good alternative reinforcing materials for the future. Rational exploitation and use of sustainable natural resources are now a necessity and natural fibres will play a crucial role in the relatively short term. Bamboo *Guadua angustifolia* fibres from Columbia and *Dendrocalamus membranaceus Munro* fibres from Vietnam appear like valuable resources with a high potential thanks to their excellent mechanical properties and large scale availability. This warrants the further development of bamboo fibre composites.