A Bio-based fibre-reinforced plastic pedestrian bridge for Schiphol

Joris SMITS
Architect, Lecturer Delft University of Technology,
The Netherlands
J.E.P.smits@tudelft.nl

Joris graduated at the TU Delft where he combined Civil Engineering and Architecture. His understanding of structural design has profoundly defined him as an architect. He has designed a wide range of bridges and has won prizes all over the world. His designs are rational yet expressive. Since 2012 he combines his architect's practice with a lectorship at TU Delft.

Rafail GKAIDATZIS
Architect, Delft University of Technology
Delft, The Netherlands
Rafail.Gkaidatzis@rhdhv.com

Rafail is an architect specialized in structural design. He completed his MSc in Building Technology at Delft University of Technology and his undergraduate studies in Architecture in Greece. His research interests lie in the area of structures, ranging from bio-based innovative materials to computational design, with a focus on sustainability and structural performance

Summary

The present paper investigates the improvement of the environmental impact of fibre-reinforced plastics, used in load-bearing applications by increasing their renewable content and decreasing their embodied energy. To achieve that, the consisting raw materials of these plastics which are based on non-renewable resources, are substituted by alternative less energy intensive materials produced from biological renewable resources. The research focuses on the potentials of natural fibres for a successful substitution of artificial fibres used as reinforcement in load-bearing polymer composites, while bio-based resins and natural core materials are analysed as well. The result of the research is applied on a real case scenario of a lightweight structure, a pedestrian bridge in Schiphol Logistics Park, a logistics zone under development adjacent to Amsterdam's International Airport.

1. Introduction

Reinforced plastics, being composed of materials based on petrochemical resources such as glass fibre and petroleum-based resins have raised concerns regarding their unsustainable and non-renewable origins, though they have lower CO_2 footprint in comparison with other traditional materials. Thus, in the last decade significant research and progress was done one the substitution of the constituent materials of plastic composites with organic elements based on renewable resources.

Naturally occurring fibres and bio-based resins have entered already major industries aiming to reduce the environmental impact and the embodied energy of plastics. Specific industries that invested successfully in "green" plastics are the automotive, industrial design and consumer product packaging. In the building industry, bio-plastics are at an early stage of development while a few limited applications include mainly non-structural elements such as cladding components, flooring materials and connections, in which normally it is only the resin which consists of a percentage of renewable content. Considering load-bearing applications, the use of organic ingredients in reinforced plastics is even narrower with every progress being at the level of research.

Natural fibres derived from different parts of plants, have drawn during the last decade the attention of engineers as possible renewable candidates for substituting conventional artificial fibres. Specifically, long fibres that are extracted from stalks of particular species exhibit exceptional mechanical properties that reach commonly used glass fibre. However, poor durability, based primarily in increased moisture absorption from their environment, proves to be the main drawback. In order to overcome this issue, scientist experiment with different fibre treatment methods, which mainly involve chemical products that modify the fibre. Although most of these processes succeed in increasing durability of natural fibres they have not been yet introduced in the textile industry.

On the contrary, artificial fibres are principally based on non-renewable resources and are classified into mineral, polymeric and metal. Fibre production methods employ extrusion of a molten material through fine microscopic holes which form the fibre. Compared to natural fibres, man-made fibres are characterized by higher mechanical performance and durability which allows their use as reinforcement in structural components.

The second main constituent in fibre-reinforced plastics is the resin. Conventional resins, such as polyester and epoxy are based on non-renewable petrochemical products and have an increased environmental impact. However, in the recent years bio-based resins were developed as an environmental friendly alternative. Bio-based resins can be generally classified in biodegradable and durable. Biodegradable resins consist of organic renewable substances (cellulose, starch, etc.) but similar to natural fibres, they are not durable and thus used only in short-lived applications, such as packaging and consumer products.

Durable bio-plastics are normally based on vegetable oil and overcome poor durability by being blended either with conventional plastics or nano-additives that reduce brittleness and improve moisture and heat resistance. Having long-lasting properties, durable resins are used in applications with longer service life requirements.

Being at an early stage of development, the use of natural fibre-reinforced plastics in structural applications would be ideally tested on a lightweight small-scale structure. Therefore, a short-span pedestrian bridge was chosen as a possible structure, on which these innovative materials could be applied. Nevertheless, in this project the design of the pedestrian bridge had the opportunity to be constructed and installed over a small canal close to the area of Amsterdam's International Airport.

The design of the bridge is developed following three basic guidelines: cost efficiency, structural efficiency and aesthetics (plasticity). A crucial factor that determines all above factors is the mold of the structure. Having a single unit as final product, obviously directs the design to simple and not labor intensive mold solutions in order to keep the framework cost relatively low. Optimization of the structural performance of the bridge, achieved by experimenting with different shapes, is important not only for minimization of the material used but also in order to achieve a safe structure. Finally, the aesthetical result was also considered important, mainly in terms of expressing the plasticity of the material.

2. Conclusions

The substitution of the conventional consisting materials of fibre-reinforced plastics by renewable plant fibres and bio-based resins is a practise that although was primarily investigated decades ago, only the last decade have drawn increasingly the interest of different industries. However, the drawbacks of these materials which are based on biological resources prohibit their use in specific sectors, such as the construction. Despite the exceptional mechanical properties of specific natural fibres (flax, jute, hemp) that compete even glass fibre, low durability is their main disadvantage. Excessive moisture uptake, pour compatibility with common resins and low resistance to fire and UV result in premature decrease of their mechanical properties.

Fibre treatment methods proved to be a promising solution to improve durability issues, yet they are still under development. Additionally, chemical treatments increase the non-renewable content and the embodied energy of the product, whereas they have certain toxicity and cost. Thus, alternative biological methods, such as sea water treatment are being researched and developed as cost-effective, sustainable solutions.

Considering the environmental impact of cellullosic fibres, agricultural processes from soil preparation until harvest of the plants should also been researched in detail as part of a life-cycle analysis of a textile. For instance, the effect of a chemical fertilizers and pesticides on water and soil quality is only one negative aspect of modern agriculture. It becomes clear that the renewable origin of natural materials should not ensure necessarily their characterization as sustainable. Each step of the fibre production process should be analysed in depth and compared with conventional non-renewable based materials. Further research is also required in the field of treatment methods that would eliminate biodegradability of biological products. Until these methods are introduced in the industry and applied on textile products, natural non-durable plant fibres and biodegradable resins are prohibited in load-bearing and durability-demanding structural applications.