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Industrial re-use of composites

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What to do with obsolete rotor blades?

An industrialized technology for re-using end-of-life (EoL) thermoset composite products (Figures 1 and 2).

End-of-Life thermoset composites

For decades the composite industry was faced with a recycling challenge for End-of-Life (EoL) thermoset composites. The thermosetting matrix in these products is cross-linked and therefore cannot be melted like a thermoplastic. This makes it impossible to regain the original components (fibers, matrix, fillers, core materials) without damage [1].

The amount of EoL thermoset composites is relatively small when compared to other waste streams: for The Netherlands it was calculated in 2017 to be 4.5 kton, mainly coming from pleasure yachts [2]. However, it is a waste stream that cannot be recycled yet in an industrial manner to its original components. Most EoL thermoset composite products are polyester boat hulls and windmill rotor blades. Viewing the increased use of wind energy in future it is expected that this waste stream will increase significantly in future [3] (Figures 3 and 4).

Principle of structural re-use

In the period of 2015 to 2016 the Professorship of Polymer Engineering (Windesheim University of Applied Sciences) developed the principle of the structural re-use of EoL thermoset composite products [4]. This method is based on keeping the composite structure intact but machining the EoL product into smaller parts, strips or flakes. These smaller parts must have an oblong shape (sufficient L/D-ratio) so that it can act as reinforcing elements in new products. In this manner the properties of the EoL composite, mechanical strength, stiffness and water resistance, remain unimpaired and can be used in the new product (Figure 5).

Due to the necessary embedding of the strips and or flakes, additional virgin resin is required. This method implies that the new products will be relatively heavy and be somewhat simple in shape eg. profiles, beams or plates. This combination of properties: high strength, high water resistance, relatively heavy and simple-shaped can be used successfully in infrastructural applications. Thermoset composites materials have outstanding resistance to outside conditions [5] and therefore will result in products with a long service life. The method of structural re-use of EoL thermoset composite products has been successfully proven in infra-structural demonstrators like retaining walls, guiding structures for funneling canal boats into locks, crane-mats and bridge decks [6] (Figures 6–8).

Retaining walls

EoL composites were manufactured for retaining walls near the Beatrix lock-gate in Almere, The Netherlands [7]. 80 profiles, each with a length of 3.5 meters were produced using two steel molds. The cross-sectional dimensions of the profiles were 40 × 250 mm with a tongue-and-groove detailing (Figure 9).

Into the mold, a glass injection mat was charged along with a layer of UD-glass reinforcement on which the EoL flakes and strips were applied. On top of this, a second layer of UD-reinforcement was placed and the glass injection mat was closed around it. Then the vacuum foil was applied. Injection was made using a polyester resin that was pigmented brown to give the profile a wood-like appearance. Profiles have been tested mechanically and the same bending strength was found as the profiles of azobé wood, that are generally used for these applications. The profiles were installed in 2017 by vibrating into the soil without any damage being incurred. Inspections and tests in

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FIGURE 1

Obsolete windmill rotor blades.

FIGURE 2

Cross section of retaining wall profiles made with strips and flakes of re-used EoL composite.

2019, two years after installation, showed no signs of degradation or loss in strength (Figure 10).

Guiding beams

For the guiding of ships in canals near bridges or lock gates, guiding structures are installed. These structures consist of a steel frame with horizontal guiding beams. These beams are normally made of tropical hard wood (e.g. azobé) and have typical dimensions of 200 × 200 × 4000 mm. Four guiding structures built in Delfzijl (The Netherlands) in 2019 had the lowest two rows made of re-used EoL thermoset composite. The lowest two rows of guiding beams are located around the water level because at this location the tropical hardwood beams suffer most from fungi attack. The other rows above the water level are made of tropical hardwood.

The strength needed to resist a possible ship collision for a single beam is defined as a force of 440 kN when mounted at a support distance of 1800 mm. To achieve this, additional layers of UD-glass reinforcement had to be incorporated in the beam. A prototype beam was tested and a maximum force of 515 kN was recorded. After this successful test 112 meters of guiding beams were produced using a steel mold with an RTM injection process (Figure 11).

Crane mats

On building sites crane mats are used to obtain a stable work area on which heavy cranes and other machinery can operate. Generally, crane mats are composed of beams of tropical hard wood. The choice for this material is based on the requirements on strength, wear resistance and durability to wet conditions. The crane mats that are depicted in the photo below have outer dimension of 1 × 5 m and are composed of five azobé beams with dimensions 200 × 200 × 5000 mm that are assembled using five steel bars.

In cooperation with Welex (manufacturer of crane mats in The Netherlands) a crane mat was made of beams that were built up from EoL thermoset composite. An RTM-infusion process was used to make the beams. In the mold first layers of quadraxial glass reinforcement and UD glass reinforcement were applied after which the core was built up from flakes of EoL composite. The five holes of 30 mm diameter for the assembly of the beam into a crane mat were directly formed in the beam using tubular inserts. The crane mat was tested in various severe use conditions. The crane mat made of EoL composite performed very well, showed good resistance to wear by the vehicles and was easy to clean after a dirty job.

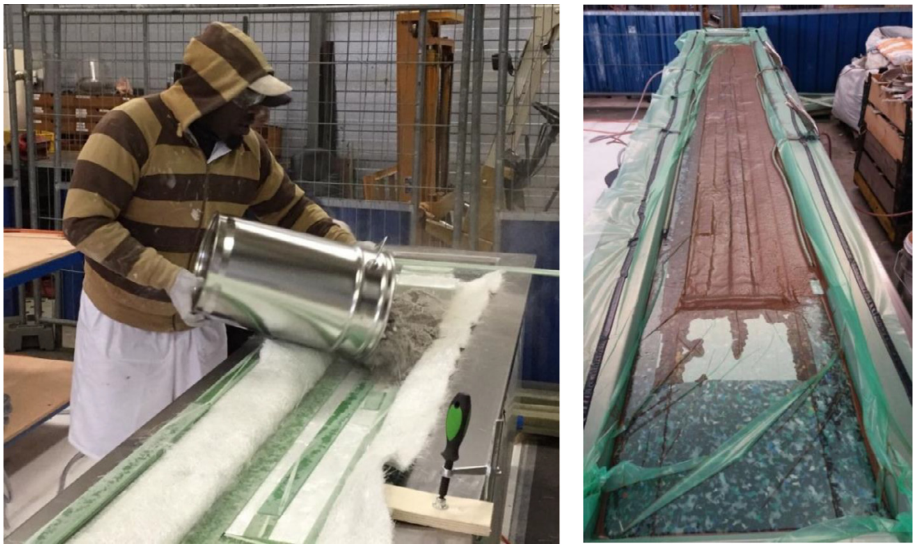

FIGURE 3

Production of profiles using EoL composite by vacuum infusion.

FIGURE 4

Installation of retaining wall by vibrating profiles with EoL composite into the soil.

FIGURE 5

Guiding structure with two lowest rows of beams made of EoL composite.

FIGURE 6

Cross section of guiding beam made of EoL composite.

Design rules

Generally for building applications in Europe the Eurocode is used. There is not a specific Eurocode that is dedicated to composites. In The Netherlands a specific recommendation for design with composites is available [8] but only for composites made of virgin materials. However, the general methodology from the Eurocode can be followed irrespective of the origin of the raw materials from which it is built. This is described in the European standard EN 1990. In this standard, in Annex D (Design assisted by testing) it is described in what manner material properties can be determined using a test program. Based on extensive testing of EoL thermoset composite in this manner, to date the following conclusions can be made for the design with these materials:

Designing on long-term loading (creep) and fatigue should be avoided for the part of re-used EoL in a product. For these loading types continuous virgin fiber reinforcement must be incorporated in the product to ensure resistance to creep and fatigue.

For design on stiffness and strength (with the exclusion of creep and fatigue) the formulas can be used, where the conversion factor is set to 0.9. For this, it is required that the re-used EoL composite is compatible with the virgin resin in which it is embedded (e.g. good adhesion) and that the virgin resin used is resistant to the conditions of use of the new product and is properly cured.

Business case

A business case consists of several components that determine whether a business is attractive for industry or not. Traditionally

FIGURE 7

Crane mats in use at a building site (photo by courtesy of Welex).

FIGURE 8

Crane mat made of EoL composite tested in practise.

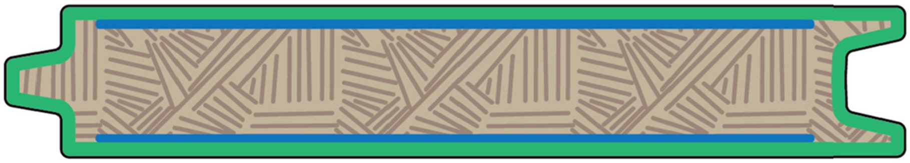

FIGURE 9

Cross section of profile for retaining wall built up with a core of EoL composite.

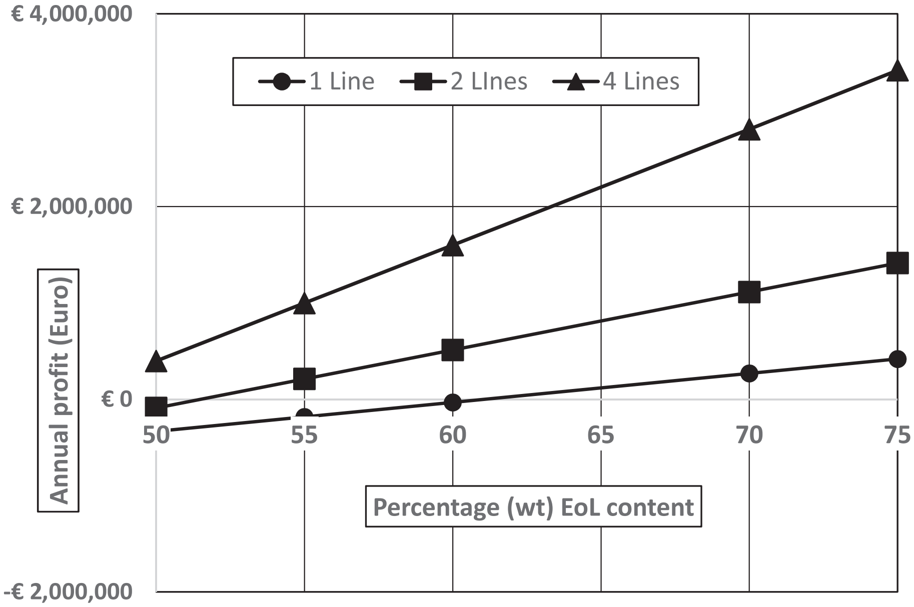

FIGURE 10

Graph of annual profit for the production of profiles with EoL composite core.

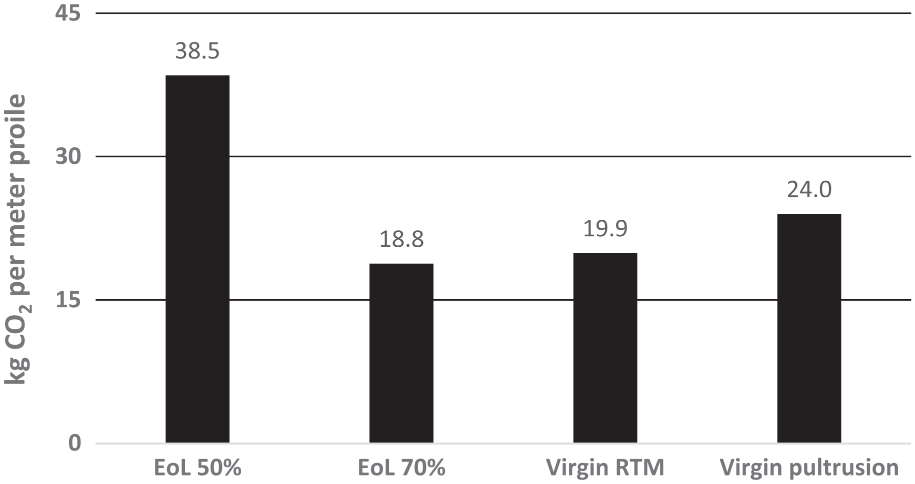

FIGURE 11

Graph of CO_2 footprint per meter profile for different profile build up.

the major component is economic profitability. This means whether products can be sold for a price that leaves a profit for the company and is attractive for the market. However, with increasing demands on products being sustainable, the aspect of sustainability must be taken into account for the business case as well because non-sustainable products will eventually be penalized or even forbidden in future. For example, in The Netherlands from 2023 the policy of the government is to purchase only sustainable products.

Sustainability of products can be achieved by using raw materials from renewable resources or using recycled or re-used materials. However, the use of materials from bio-based, recycled or re-used origin alone is not enough to unsure sustainability. Also the energy needed for production and the CO_2 production that is related to the production of the product must be acceptable.

For the analysis of the economical profitability of structural re-use of EoL thermoset composite the profile for retaining walls is considered. The cross-section of this profile is depicted in the figure below. It has an effective width of 250 mm and a thickness of 40 mm. The outside skin is build up from a virgin glass reinforced polyester laminate containing a 900 g/m^2 random reinforcement (glass mat, green in the picture) and a 900 g/m^2 UD-reinforcement of 200 mm width (blue in the picture). The core is formed by re-used EoL thermoset flakes that are bound by a polyester resin.

From the production of the infra-structural demonstators it had become apparent that manual production was too costly for economic profitability. Trials were carried out by the industry partners using the automated production technique pultrusion with a very positive outcome.

A calculation tool was developed to analyze the profitability of a factory that produces these profiles with a pultrusion-based continuous process with a production speed of 15 m/hour. Cost for the production are based on raw material cost, energy consumption, labor cost, depreciation of machinery, rent of production space and overhead. For the sales it is assumed that a sales factor of 1.3 is applicable in comparison with the market price of the identical profile made of tropical hard wood (azobé). This means that the product made of re-used EoL thermoset composite can be sold for a 30% higher price than the traditional tropical hard wood profile. This higher sales price is confirmed to be acceptable by water municipalities in The Netherlands and is based on the longer life time in wet conditions.

Variables in the tool are the percentage by weight in the profile of EoL material and the number of production lines. The diagram below shows the annual profit as a function of percentage EoL. This is done for production facilities with 1, 2 and 4 production lines respectively.

From the analysis it follows that already with one production line the facility becomes profitable when the content of EoL material in the profiles is 65% by weight. With more production lines the profitability becomes higher as the number of persons working in the pilot plant weighs heavily in the calculation. From the trials by the industry partners using a pultrusion set-up it was found that an EoL content of 70% by weight is possible in the profile under consideration.

For the profile also the CO_2 footprint was analyzed. For this, the ECO-Calculator of EuCIA was used. This tool evaluates the CO_2 footprint of product 'from cradle to gate', which means considering the effect of the raw materials used and the production process. Using this tool the CO_2 emission per kg of this product is calculated for two percentages of EoL content by weight (50% and 70%, respectively). Moreover, the CO_2 emission per meter profile was analyzed when the profile with the same mechanical performance was made using only virgin raw materials, either as a profile made with an RTM-process with a PET-foam core ór as a hollow profile with shear webs inside made with a pultrusion process. The results of the analysis is given in the graph below.

Obviously, the amount of CO_2 for the production of a meter profile is strongly related to the percentage of re-used EoL thermoset composite used. This is mainly connected by the amount of virgin resin that is used to embed the EoL composite flakes. When compared to the profiles that are made completely by using virgin materials the 'kg CO_2 per meter profile' becomes lower when the amount of re-used EoL thermoset composite is 70% by weight or higher.

Conclusions

The methodology of structural re-use of EoL thermoset composites that has been developed by Windesheim offers the possibility of industrial re-use. By several infrastructural demonstrators it has been shown that strong, robust and water-resistant products can be made. A set of design rules have been developed according to the Eurocode to evaluate structural behavior of products made with re-used EoL thermoset composites. Moreover, the production can be done in an industrial manner using a pultrusion type of process. The lower labor cost of such a process and the high percentages of EoL-content in the new products with this process offers possibilities for profitable production and sales of products. It has been shown that the percentage of EoL material in the new product is the key parameter for both profitability and low CO_2 emission during production.

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