Structural re-use of end-of-life thermoset composites

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A new technology is presented for re-using end-of-life (EoL) thermoset composite products.

What to do with obsolete polyester yachts?

During the last two decades, several processes were investigated and developed for the recycling of thermoset composites. An overview was presented during the ACMA meeting in Paris in March 2016 [1]. However, to date no recycling method exists for thermoset composites in the sense that the raw materials (thermoset resin, reinforcing fibers) can be regained in a useful form. At the moment the so-called ‘cement-kiln route’ is accepted in Europe as a recycling method for thermoset composites [1,2], although only the combustion energy and the silicium dioxide present in the EoL thermoset composite are regained in a cement oven with this method.

This article presents a new technology for the beneficial re-use of end-of-life (EoL) thermoset composite products. This methodology, which was financed by a government grant, was developed by the Professorship for Polymer Engineering of Windesheim University of Applied Sciences in Zwolle, The Netherlands.

Because at present only a European study on EoL volumes was available by the AVK [3], a Windesheim study zoomed in on the volumes of EoL thermoset composite products in The Netherlands. The outcome was that at present, in the Netherlands, 4.5 kt per year of EoL thermoset composite products can be found in the market that are suitable for the newly developed re-use principle. This mainly concerns polyester yachts, windmill rotor blades, silos and corrugated panels. It is already known that the volume of EoL polyester yachts alone will increase in the coming 15 years to 4.0 kt/year [4,5]. With a clear market potential in view, a method was developed that makes use of the mechanical strength and resistance to corrosion that are still present in end-of-life material.

Principle of structural re-use

The principle of the structural re-use of EoL thermoset composite products is based on the use of long, oblong elements gained from EoL products which are embedded in virgin material. To achieve maximum stiffness, a high fill rate is desired and, therefore, the amount of virgin embedment material (resin) is limited. Because of their oblong shape, the elements can contribute to reinforcing the new products, as is schematically illustrated by Figures 1 and 2. The first material consists of re-used material in the form of granulate (green, indicated with subscript ‘r’ from ‘re-used’) embedded in a polymer matrix (yellow, indicated with subscript ‘m’). The other material is composed by embedding re-used material in the form of

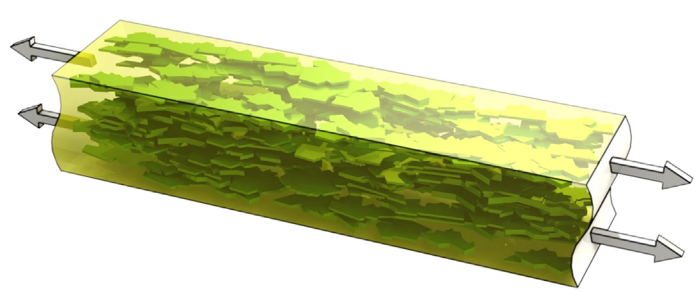

FIGURE 1
Product filled with granular re-used material.

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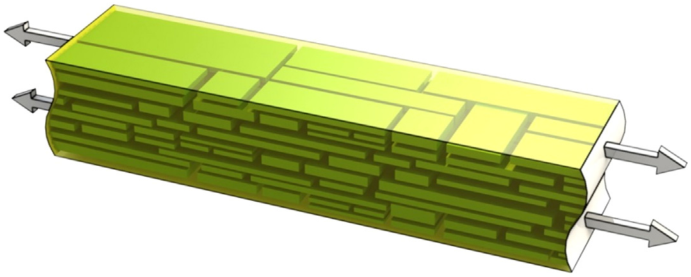


FIGURE 2
Product filled with oblong re-used material elements.

oblong elements, again embedded in virgin material. Using classical micromechanical models [6], the stiffness (E-modulus) and the strength of the resulting new composite product (indicated with subscript 'c') can be predicted.

Effective modulus of elasticity : (based on series model)
$$E_c \approx (E_r \cdot E_m)/(v_r \cdot E_m + v_m \cdot E_r) \quad (1)$$

Effective tensile strength :
$$\sigma_c < \sigma_m \quad (2)$$

Effective modulus of elasticity : (based on parallel model)
$$E_c \approx v_r \cdot E_r + v_m \cdot E_m \quad (3)$$

Effective tensile strength :
$$\sigma_c \approx v_r \cdot \sigma_r \quad (4)$$

TABLE 1
Theoretically predicted properties.

Shape of re-use	E_c (GPa)	σ_c (MPa)	Behavior
Granular	5.2	10[a]	Brittle
Oblong	11.5	150	Tough

[a] Estimate based on stress concentrations on microscale.

In formulas (1), (3) and (4) the volume fractions of the components are used, which are indicated with the symbol 'v'.

The following example shows that only by using oblong elements a reinforcing action is obtained. When re-used material is added in a granular form (like e.g. powder) only a stiffening effect is obtained, although the strength decreases (Table 1).

$E_m = 3$ GPa $\quad \sigma_m = 50$ MPa (e.g. non-reinforced polyester)

$E_r = 20$ GPa $\quad \sigma_r = 300$ MPa (e.g. glass fabric reinforced polyester)

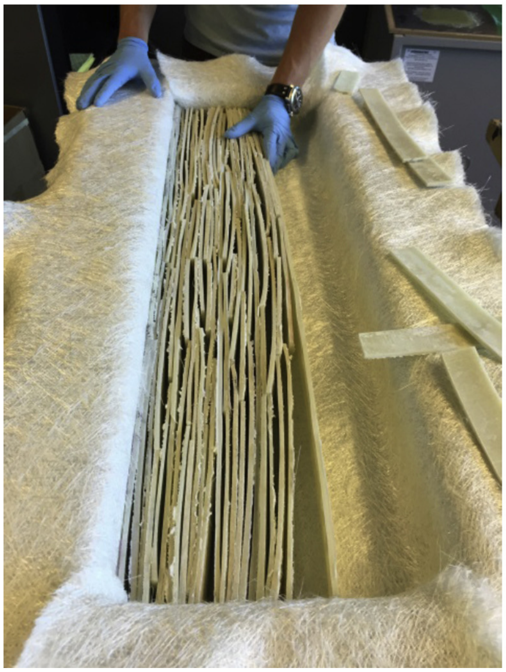
$v_r = 0.5 = 50\%$
(half of the total volume consists of re-used material)

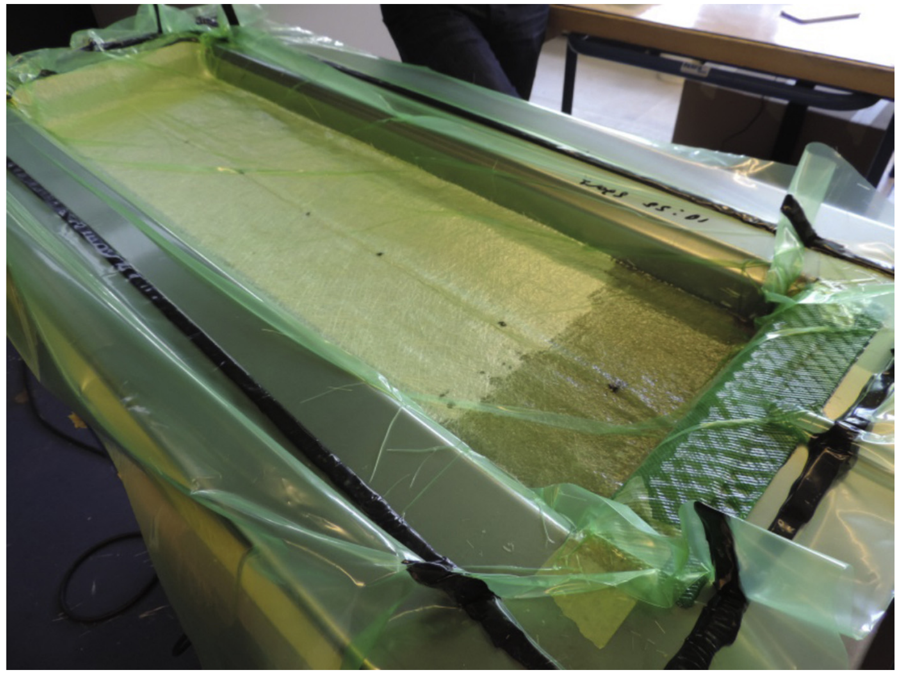
Structural re-use in practice

The principle of structural re-use of EoL thermoset composite products in practice is illustrated by the following series of images. In the first step, the hull of an obsolete polyester boat is processed into large panels (see photos below).

In the second step, these panels can be sawn into long strips or shreddered into large flakes.

Finally, vacuum-infusion is applied to make a new composite profile based on the re-used material. The reinforcing elements are infused with virgin polyester resin and additional virgin glass reinforcement.

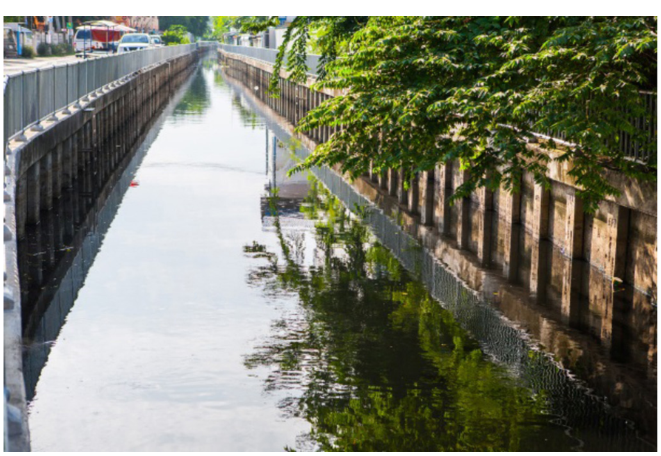


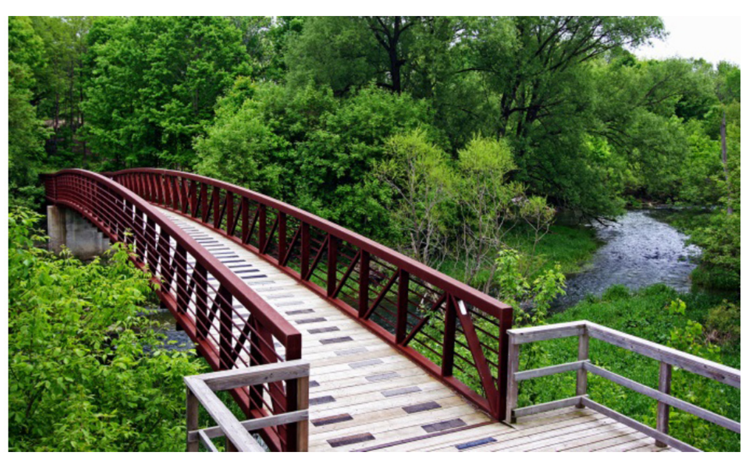


Possible products and applications

The new composite material based on EoL elements has regained the mechanical strength of the old composite. Moreover, since thermoset composites are known to have very long service lives [7] the new product based on re-used material still has an outstanding resistance against corrosion. However, there are two main drawbacks of the method of re-use. Firstly, it is not possible to make very light products because of the need to embed the re-used elements. The embedment results in extra virgin resin and reinforcement in order to make the re-used material contribute to the mechanical strength of the new product. Secondly, because the re-used elements are rather large and inflexible, it is difficult to create new products with complex shapes. The new products will, therefore, be confined to straight, non-complex shapes, e.g. profiles, panels and boards.

Typically infrastructural applications are found to be very suitable for such type of products, e.g. retaining walls for canals and decking for bridges.





However, as a result of the very solid buildup of the new products from re-used thermoset composites, other advantages appear: high compression strength, impact strength and resistance to local loading. The combination of high mechanical strength and outside durability makes support panels for cranes or heavy vehicles promising applications.

Source: Courtesy of Welex.

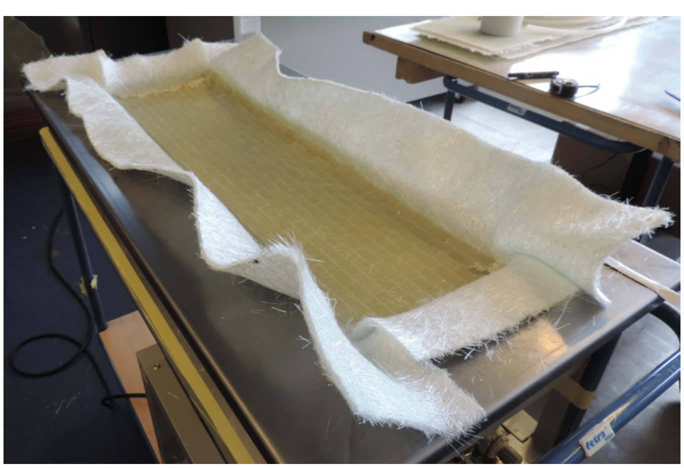
To investigate adhesion, a test panel was produced with 40 mm strips with flat surfaces (by omitting the peel-ply layers). Moreover, a test panel was produced using 1000 mm strips that had been cut from a polyester boat hull without any surface treatment. Finally, a test panel was produced with 200 mm strips placed vertically instead of flatwise. In all test panels the strips were oriented in the length direction of the test panel and the strips were placed staggered with respect to the neighboring strips (both horizontally and vertically).

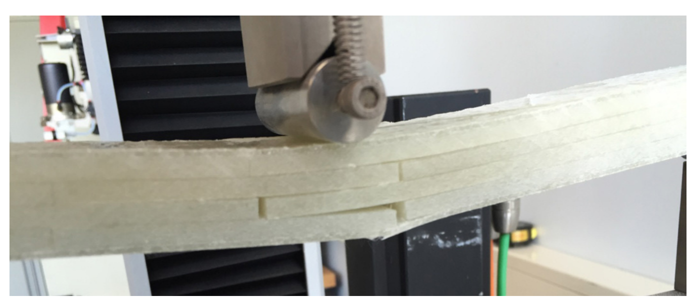
Investigation of properties by using strips

To investigate the effect of the length of strips on reinforcement, a series of panels was made and tested. To allow for an academic comparison, instead of EoL-material we used virgin glass reinforced polyester laminate with a thickness of 5 mm and peel-ply on both sides. From this, laminate strips were cut with a width of 20 mm and used as reinforcing elements in a test panel with the dimensions $L \times W \times T = 1000 \times 300 \times 23$ mm. Incorporating four layers of these strips positioned flatwise results in a reinforcing core of 20 mm. A surrounding shell of about 1.5 mm thickness was created using an infusion glass mat of 2×450 g/m^2. The final panels were produced by means of infusion with an orthophtalic polyester resin using reinforcing strips in the core with lengths of 40 mm, 80 mm, 200 mm and 1000 mm, respectively. The photo shows the incorporation of the fourth layer of 40 mm strips just before it was covered with the infusion glass mat.

Length of strips used as reinforcement of core (mm)	40	80	200	1000
Virgin GRP strips with peel ply, 4 layers placed flatwise	X	X	X	X
Idem, but without peel ply	X			
Virgin GRP strips with peel ply, 1 layer placed vertically			X	
Strips of $5 \times 40 \times 1000$ mm that have been cut from boat hull				X

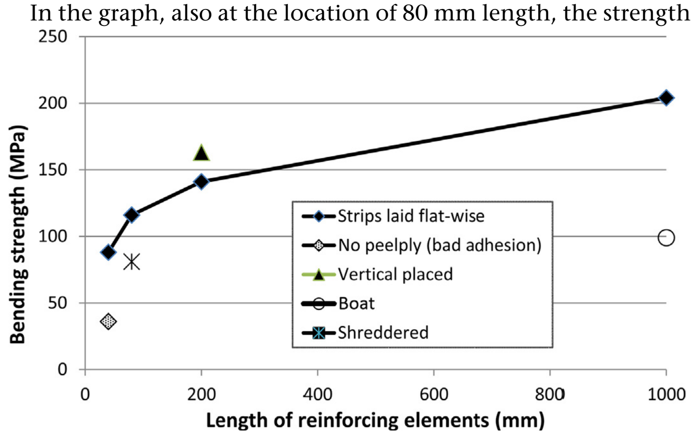
From each test panel samples were cut in length direction with the dimensions $L \times W \times T = 360 \times 50 \times 23$ mm. Tests were repeated 5 times. The samples were tested in three-point bending in accordance with ISO 178. The photo shows the testing of a sample with strips of 80 mm in length.





The graph below shows a clear correlation between the bending strength and the length of the strips in the core. With sufficient strip length the bending strength reaches over 200 MPa. The negative effect of bad adhesion on bending strength is seen in the case of the 40 mm strips where the peel-ply has been omitted: the bending strength is as low as 36 MPa. Also the relatively low strength using strips cut from the polyester boat-hull of 99 MPa can be contributed to bad adhesion. During the test these strips delaminated at the gelcoat side, showing a smooth delamination surface. By placing the 200 mm strips vertically, however, an improvement of the bending strength is observed.

In the graph, also at the location of 80 mm length, the strength



is given of a panel that made of flakes. That strength was found to be 81 MPa. The flakes were made by shredding EoL thermoset composite in such a way that a mean flake length of roughly 80 mm was obtained.

Shredding may be a more economical way of machining EoL thermoset composites into reinforcing elements than sawing or water cutting, although this has to be investigated further. Shredding is a very promising method because a large quantity of EoL composite products can be machined at low cost.

The next step. . ...

Based on the mechanical properties of the newly obtained composite materials and the pressure in the market to come up with a solution for EoL composite materials, a trial was initiated by the province of Flevoland to produce and to place 20 meter of retaining wall in Lelystad. In this project together with the Dutch composite industry, Windesheim will continue to study the economic feasibility of the new method and monitor the long term properties of the material for the future success of industrialization and commercialization of the technology.

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