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Recycling of shredded composites from wind turbine blades in new thermoset polymer composites

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ABSTRACT

As the energy produced from wind increases every year, a concern has raised on the recycling of wind turbine blades made of glass fibre composites. In this context, the present study aims to characterize and understand the mechanical properties of polyester resin composites reinforced with shredded composites (SC), and to assess the potential of such recycling solution. A special manufacturing setup was developed to produce composites with a controlled content of SC. Results show that the SC in the composites was well distributed and impregnated. The composite stiffness was well predicted using an analytical model, and fibre orientation parameters for strength modelling were established. The stress-strain curves revealed composite failure at unusual low strain values, and micrographs of the fracture surface indicated poor adhesion between SC and matrix. To tackle this problem, chemical treatment of SC or use of an alternative resin, to improve bonding should be investigated.

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1. Introduction

One of the targets of the European energy and climate policy is to increase the energy consumed from renewable resources to 20% by 2020. As a result, the European Wind Energy Association (EWEA) predicts that the consumed wind energy will increase from 5,3% in 2010 to 15.7% by 2020 and will continue to rise to 50% by 2050 [1]. In 2010, 72,000 wind turbines [2] were providing electricity across the European Union (EU) countries, representing a capacity of 84,3 GW (GW) [3]. At the end of 2014, this capacity was raised to 128,8 GW [4]. Due to the rapid development of the technology, the blade length has grown from 18 m in a 600 kW turbine in year 1990 to around 85 m in a 8000 kW turbine in year 2015. Altogether, this development means that the mass of decommissioned wind turbine material is ever increasing [5]. While some of the wind turbine materials are recyclable (such as the metal parts in the tower, gearbox, and blade hub) [6,7], the blades made of thermoset polymer composites represent a challenge. As one of the central objectives of the EU are to maximise recycling and to phase out landfilling of non-recyclable waste, it is obvious that wind turbine blades need recycling solutions [8].

Wind turbine blades are typically made from continuous glass fibre reinforced polymer composites. E-glass fibres, a low cost glass fibre grade combining high strength (2 GPa) and moderate stiffness (76 GPa), are used together with a thermoset polymer matrix such as epoxy, polyester or vinylester. Sandwich constructions, consisting of multiaxial composite laminates, together with balsa wood or polyvinyl chloride (PVC) foam, are used for the outer shell and for the shear webs in the blades, see Fig. 1. Uniaxial composite laminates are used for the load carrying beam. These glass fibre laminates have a typical fibre volume content of 50% (corresponding to a fibre weight content of 70%) [9]. Wind turbine blades have a predicted life time of 20–25 years.

End of life solutions for wind turbine blades can be compared by the amount of re-processing needed. Few re-processing steps of the blades are needed to extend their service life. After 20–25 years, where the blades still have some residual strength [10], they can be taken down, refurbished and re-installed [11]. Without too many further reprocessing steps, sections of blades can also be reused [12]. The field of such applications is however limited. The mechanical properties of the different composite materials in the blade are precisely designed to fulfil the requirements of a blade. In addition, the specific shape and dimensions of blade sections make their reuse in new structural applications challenging. Heavier re-processing of blades is costly, but widens the number of possible applications for the recovered materials. Such solutions include shredding the composite materials, or separating the glass fibres from the polymer matrix using thermal and chemical processes [11,13,14]. Shredding of composite materials, also called mechanical recycling, is the simplest method, and the only solution that has been brought to a commercial level [15–17].

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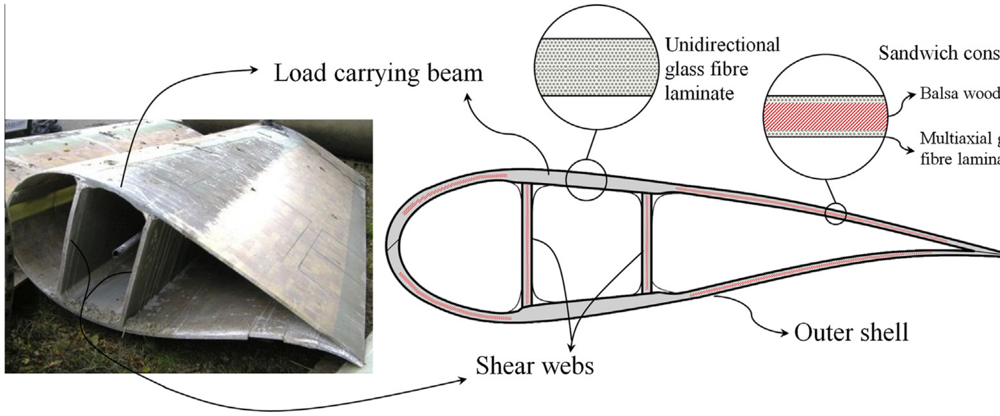

Fig. 1. Wind turbine blade structure and material. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Mechanical recycling of composites consists of successive grinding or cutting steps to reduce the materials to fragments of few millimetres. The visual aspect of the resulting shredded composite (SC) is a mixture of short individual fibres, longer fibre bundles partly impregnated with matrix material, and clusters of materials, see Fig. 2.

In the perspective of using SC in new polymer composites, previous work has found that high SC quality is crucial, and that the most valuable fractions are the ones with a high glass fibre content and with long fibres [16,18]. Research on methods to separate the different fractions present in SC has been conducted and techniques using air, gravity or vibration have been developed [18].

The reuse of SC in new thermoset polymer composites has mainly been studied in order to reduce the amount of virgin glass fibres in existing composite systems. This contributes to a lower cost of the product, without having to change the original composite manufacturing procedure [18–23]. So far, however, only a few studies have studied the performance of thermoset polymer composites manufactured with SC as the only reinforcing part [23–26].

In the context of assessing the potential of mechanical recycling of wind turbine blade materials, the objective of this study is to understand and predict the reinforcement effect of SC in new polymer composites. SC from uniaxial glass fibre composites, originating from a wind turbine blade, will be classified into fractions using manual sieving, and then characterized by combustion and microscopy. Composites will be manufactured using SC as the only reinforcing part. The gravimetric and volumetric composition of the composites will be determined. The mechanical properties of the composites incorporating various amount of SC will be measured, and analysed using micromechanical models for composites.

Fig. 2. Shredded composite. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Materials and methods

The shredded composite (SC) material in this study comes from the load carrying beam of a 26 m long wind turbine blade manufactured by LM Wind Power. Before shredding, the blade was subjected to dynamic testing from December 2000 to May 2001. Glass fibre composite laminates with dimensions of 200 mm long, 200 mm wide and 22 mm thick were cut out from the load carrying beam, see Fig. 1. The glass fibre volume content of the composite laminate before shredding was measured to be 50 vol%. The composite laminate was shredded using a Bolen Super Tomahawk (grinding process based on rotating cylinder hammer, main frame screen with 20 mm hole size). Fig. 2 shows the SC as received.

A thermoset polyester resin was selected to manufacture the new polymer composites. This choice was made in order to avoid mixing different types of resins, since polyester is also the resin used in the composite laminate. An orthophtalic polyester resin (Polylite 413-575) was chosen, and it was pre-accelerated and initiated with 1.5 wt% of Butanox HBO-50.

2.1. Characterisation of SC

The SC was divided into three fractions: a fraction containing the SC as received, and two fractions named fine and coarse, separated by manual sieving with a sieve of 1.5 × 1.5 mm square hole sizes.

To determine the matrix coverage on the glass fibres, in addition to the diameter and length of the fibres, the three SC fractions were observed with a scanning electron microscope (SEM, TM1000 Hitachi). The glass fibre content of the SC fractions was determined by combustion, using a so-called burn off test. A material sample was placed in a crucible, it was weighed, and then burnt at 565 °C for 2 h, and finally, it was weighed again. The difference in weight of the sample before and after combustion, allows calculating the glass fibre weight content in the SC fractions.

2.2. Manufacturing of composites

In order to manufacture composites containing different contents of SC, a special vacuum infusion setup was implemented. The wanted weight contents of SC in the new polymer composites were set to 10, 20 and 30 wt%. In order to obtain these weight contents with a vacuum infusion process, the weight of the manufactured composite plates need to be controlled. For that, a rectangular metal frame with dimensions of 300 × 400 × 7 mm, and with holes along the short sides of the frame was used.

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