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Wind turbine blade recycling: Experiences, challenges and possibilities in a circular economy

J.P. Jensen[a,b,*], K. Skelton[a,b]

[a] Department of Development and Planning, Rendsburggade 14, 9000 Aalborg, Denmark
[b] Siemens Gamesa Renewable Energy, Fiskergade 1-9, 7100 Vejle, Denmark

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ABSTRACT

The wind power industry is a fast growing, global consumer of glass fiber-reinforced plastics (GFRP) composites, which correlates with the industry's rapid growth in recent years. Considering current and future developments, GFRP waste amounts from the wind industry are expected to increase. Therefore, a sustainable process is needed for dealing with wind turbines at the end of their service life in order to maximize the environmental benefits of wind power. Most components of a wind turbine such as the foundation, tower, gear box and generator are already recyclable and treated accordingly. Nevertheless, wind turbine blades represent a challenge due to the type of materials used and their complex composition. There are a number of ways to treat GFRP waste, depending on the intended application. The best available waste treatment technologies in Europe are outlined in this paper. However, there is a lack of practical experiences in applying secondary materials in new products. A Danish innovation consortium was addressing this waste with a predominant focus on the blades from the wind power industry. The outcomes from the consortium and the various tested tools are presented in this paper as well as the secondary applications that were proposed. The outcomes are structured using Ellen MacArthur's circular economy diagram. The "adjusted" diagram illustrates the potentials for a continuous flow of composite materials through the value circle, where secondary applications were developed in respect to "reuse", "resize and reshape", "recycle", "recover" and 'conversion'. This included applications for architectural purposes, consumer goods, and industrial filler material. By presenting the outcomes of the consortium, new insights are provided into potential forms of reuse of composites and the practical challenges that need to be addressed.

1. Introduction

The total wind power capacity installed at the end of 2016 was 153.7 GW which was enough to cover 10.4% of the EU's total electricity consumption in a normal wind year [1]. With a cumulative capacity of 153.7 GW and a project lifetime of 20 years, the total number of wind turbines installed in Europe is around 77,000 (assuming an average wind turbine capacity of 2 MW).

The EU's binding target for increasing the renewable energy share to 27% by 2030, and its commitments to cutting greenhouse gas emissions by 80–95% as of 2050, emphasizes wind power's important role in the future energy mix.

However, a growing amount of wind turbines will be decommissioned, considering that:

- The standard lifetime of a wind turbine is 20–25 years;
- There are increasing repowering opportunities i.e., replacing old components/models with newer and more efficient components/models [2].

A sustainable process for dealing with wind turbines at the end of their service life is needed in order to maximize the environmental benefits of wind power from a life cycle perspective. Most components of a wind turbine such as foundation, tower, components of the gear box and generator are already recyclable and treated accordingly. Nevertheless, wind turbine blades represent a challenge due to the materials used and their complex composition.

1.1. Objectives and paper structure

The aim of this paper is to explain the state of the art in how industry is addressing the challenges associated with composite waste and the ways in which composite waste from wind turbines can be managed according to best available technologies. We begin by providing a

* Correspondence to: Department of Planning, Aalborg University, Rendsburggade 14, 9000 Aalborg, Denmark
E-mail address: jonaspj@plan.aau.dk (J.P. Jensen).

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review of composites use in the wind industry, including material composition of the blades and current and future market forecasts. We then discuss the challenges related to composites recycling and outline the current waste treatment methods.

Next, the outcomes are described of the Danish innovation consortium, GENVIND that was operative between 2012 and 2016. Outcomes include an overview of the different methods used for sectioning and recycling wind turbine blades as well as the secondary applications that were proposed. The outcomes are structured using Ellen MacArthur's circular economy system diagram that illustrates the potentials for a continuous flow of composite materials through the value circle, where secondary applications were developed in respect to "reuse", "resize and reshape", "recycle", "recover". We conclude by presenting other ongoing consortiums in the industry related to composites, hereunder a shift in the wind industry from "producer responsibility" to "industry responsibility" by means of partnerships and sustainability clusters.

1.2. A note on methodology

The information presented in this paper is based on our experiences working in the industry (three and six years, respectively), our participation in the GENVIND innovation consortium, and other similar networks and research projects in association to both of our Industrial PhDs. Important sources have been obtained from researchers, the original equipment manufacturers (OEMs), operators and maintainers (O&Ms), waste handlers and those that use the recyclates from blade waste. Recent, peer reviewed literature supplements the information contained herein.

2. Composites and the wind industry

Composite materials are used in a range of industries including the wind industry. The industry experiences growth rates in the use of GFRP composites [3], which correlates with the industry's rapid growth in recent years. In this section the structure and material composition of wind turbine blades is explained. Following, a description of the current material markets for glass and carbon fibers is provided, as well as the market forecasts for composite use in blades and decommissioning projections.

2.1. Blade structure and material composition

Wind turbine blades are considered a composite structure, consisting of various materials with different properties. Although material compositions vary between blade types and blade manufacturers, blades are generally composed of the following (see Fig. 1):

- Reinforcement fibers e.g., glass, carbon, aramid or basalt;
- Polymer matrix e.g., thermosets such as epoxies, polyesters, vinyl esters, polyurethane (PUR), or thermoplastics;
- Sandwich core e.g., balsa wood or foams e.g. polyethylene terephthalate(PET);
- Coatings e.g., polyethylene (PE), PUR;
- Metals e.g., copper wiring, steel bolts.

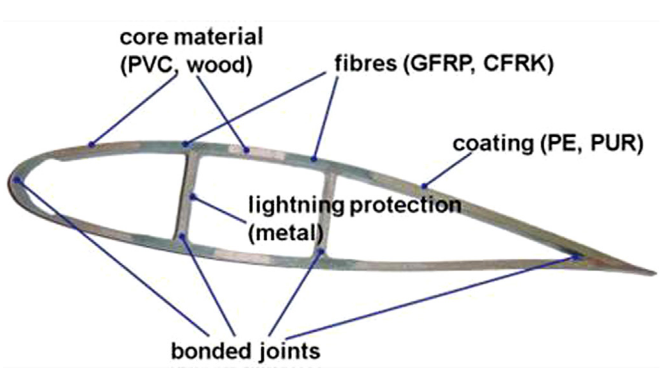

Fig. 1. Lateral cut of wind turbine blade showing material use in the blade [4].

The combination of fibers and polymers, also known as glass fiber reinforced polymer (GFRP) composites, represents the majority of the blades material composition (60–70% reinforcing fibers and 30–40% resin by weight). GFRP composites are advantageous due to a couple of reasons e.g:

- GFRP combine properties of high tensile strength with low density (high strength-to-weight ratio) to withstand the mechanical load requirements and to optimally perform aerodynamically;
- GFRP provide resistance to fatigue, corrosion, electrical and thermal conductivity important for the long product lifetime;
- GFRP enable cost effective manufacturing of longer and lighter blade structures;
- GFPR can easily be affixed with add-on components (lightning protectors, leading edge protection, and heating systems) to improve performance.

When thermoset GFRP composites are cured however, the polymers become cross-linked and undergo an irreversible process that makes recycling difficult.

2.2. Material usage per blade type

The average values for blade mass per unit rated power (t/MW) are shown in Fig. 2 and based on aggregated data from fourteen OEMs [5]. The figure shows a slightly increasing ratio until turbine models above five MW. Mass reductions are seen in the larger blade types for a number of reasons, spanning more efficient designs, lower safety factors, lighter materials and improved manufacturing techniques [5].

Waste from the blades at the end of their life contributes to the largest fraction of composite waste. However, composite waste also arises in the manufacturing processes such as dry fiber cut-offs, cured composites cut-offs from blade edges and root ends as well as grinding dust from the finishing process. Test blades, accidental damages enroute to site and defects after installation are other minor sources of blade waste. Waste values vary based on manufacturing process and turbine models. Fig. 3 provides an overview of other blade waste sources from a life cycle perspective [5].

2.2.1. Material markets for glass & carbon fibers

Glass fiber represents the primary material in wind turbine blades. According to a market report by the German associations AVK and CCeV [6], Europe's production volumes in GFRP steadily grew by 2.5% in 2015, reaching 1069 million tonnes. This correlates to 25% of the world's total production volumes and represents the highest level in

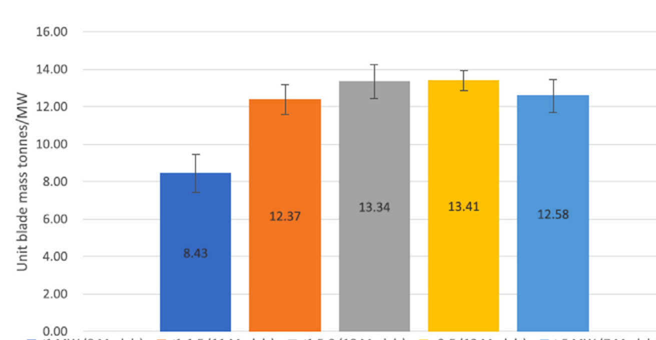

Fig. 2. Blade mass per unit rated power for the different turbine sizes [4].