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A critical review on recycling of end-of-life carbon fibre/glass fibre reinforced composites waste using pyrolysis towards a circular economy

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ABSTRACT

The rapid utilization of carbon fibre reinforced composite (CFRC) and glass fibre reinforced composite (GFRC) in main sectors, such as automobile, aerospace, wind turbines, boats and sport parts, has gained much attention because of its high strength, light weight and impressive mechanical properties. Currently, the increasing amount and handling of composite waste at their end-of-life (EoL) has a negative impact on resources conservation and the environment. Pyrolysis, a two-step process, appeared as most viable process to recover not only valuable materials but also produce fuel and chemicals. However, the testing facilities and optimized operation of composite waste in pyrolysis processes to produce materials with low energy consumption and acceptable mechanical properties are still under development and discussion before commercialization. The aim of this article is to review the studies on CFRC/GFRC recycling via pyrolysis processes and highlight their technical challenges and re-use possibilities in high performance composites. The forthcoming commercialization challenges and respective market potential to recyclates using the pyrolysis process will be addressed. This study will also introduce the strong connection between recycling and re-usability of fibres which would help to explain the concept of circular economy and cradle-to-cradle approach. Finally, based on updated studies and critical analysis, research gaps in the recycling treatments of fibrous composite waste using pyrolysis processes are discussed with recommendations.

1. Introduction

1.1. Circular economy and global challenges

The developed industrial countries are generating a considerable amount of polymeric waste (Bhadra et al., 2017; Yazdanbakhsh et al., 2018; Holgersson et al., 2017; Das and Tiwari, 2018). The resources are depleted through a conventional process of materials which results in economic loss (Naqvi et al., 2018). The circular economy brought an emerging concept which restores and regenerates the material by an efficient design (Zhong and Pearce, 2018). This concept aims to protect products and materials at their highest effective utility while minimising negative impacts (Akanbi et al., 2018). In a sustainable society, the recovery of materials and energy by following circular economy is a challenging task (Kirchherr et al., 2017), (Hoogmartens et al., 2018).

Among polymeric wastes, fibre-reinforced composite (FRC) materials have huge world-wide production and consumption because of their utilization in various fields such as construction, aeronautics, aviation industry, oil and gas, sporting goods, wind industry (Lefeuvre et al., 2017) and (Erden and Ho, 2017). FRC materials have a high strength, a high durability, low weight and a high flexibility in shapes making them interesting as alternative to steel and other materials. The growth in the FRC industry not only increased its production and consumption but will also lead to a high amount of end-of-life (EoL) materials. The conservation and recycling of end-of-life scrap FRC has become an important challenge for a sustainable circular economy.

Modern FRC materials originated in the early 1950s with the utilization of carbon fibre, glass fibre which has polyester matrix resin as its constituents. They are widely used in the manufacturing of boats, early cars and water tanks. Following are the core examples of composite application such as, wind energy (Fig. 1a), marine application (Fig. 1b), automotive part (Fig. 1c), biomedical applications (Fig. 1d) (Erden and Ho, 2017).

As an example, the forecast for the fibre reinforced composite materials market in the US for different application segments is depicted in Fig. 2. The market grew by 6.3% to reach value of $ 8.2 billion in 2014 from the previous years. Economic indicators and market dynamics suggested that composite material will grow much faster and

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Fig. 1. FRC composite application, (a) Wind turbine, (b) tidal energy sector, (c) coil spring manufactured by Audi, (d) wheelchair (Erden and Ho, 2017).

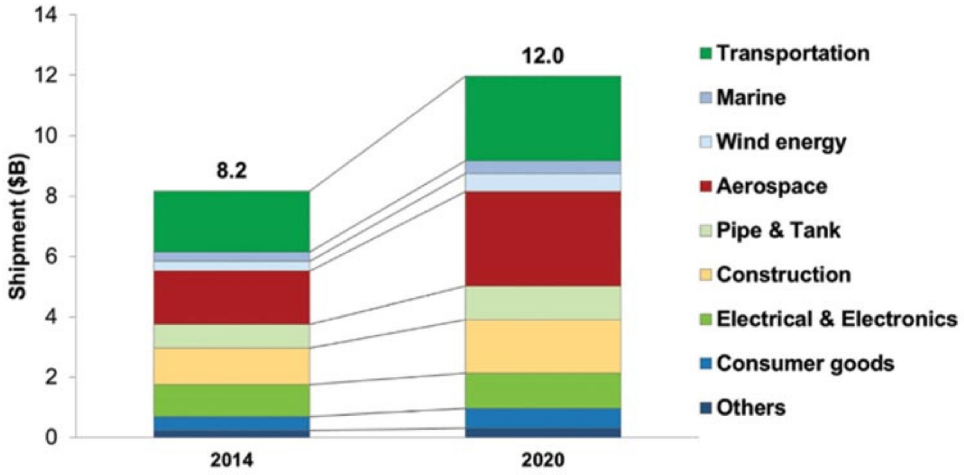

Fig. 2. US FRC market forecast by application segment.

dominating materials are carbon fibres, glass fibres in the reinforcement segment and polyester resin in the resin segment. By 2020, this composite materials market is expected to touch $ 12 billion with a compound annual growth rate of 6.6% majorly in aerospace, transportation, construction, wind energy and electrical & electronic industries.

However, currently the handling and recycling of the FRC materials (carbon fibre reinforced composite, CFRC/glass fibre reinforced composite, GFRC) by meeting environmental limitations, governmental legislation, production cost, management of resources and economic opportunity are vital global challenges. It is well understood that turning these composite wastes into a valuable resource and closing the