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Effect of process parameters on mechanical recycling of glass fibre thermoset composites

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Abstract

High demand of glass fibre reinforced thermoset composites has led to manufacturing and end of life waste. Mechanical recycling is currently a mature, rapid process in recycling such waste at an industrial scale. Unlike manufacturing processes, the effect of key process variables on recyclate quality is not well understood. In this study analysis of variance was used to establish the key mechanical granulator process variables that influence energy demand and recyclate quality. Two different granulator technologies were also compared. This information is vital in selecting conditions for running recycling processes and in assessing the potential market for the generated recyclate.

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Keywords: composites; recycling; mechanical recycling;

1. Introduction

Composite materials are in demand in critical industrial sectors such as aerospace, automotive and wind energy due to their lightweight, excellent fatigue resistance and high corrosion resistance properties [1]. Glass fibre reinforced plastic (GFRP) composites constitute around 98% of composites by volume in the United Kingdom and European composites production [2, 3] and present a major legacy challenge for composite waste management.

The heterogeneous nature of composite material makes recycling very challenging. In addition, most composites used in mechanically demanding applications use thermoset matrix which cannot be melted and remoulded. Currently, the main disposal route for composite waste in the UK is through landfill [4, 5]. With increasing legislation pressure for a landfill ban, advancement of composite recycling technologies is needed. According to End of Life Vehicle Directive (2000/53/EC) the allowance for landfilling of end of life vehicles reduces from 15% in 2006 to only 5% in 2015 [6]. Taken together these recycling drivers and challenges imply that large volume recycling of GFRP needs urgent attention.

Current recycling technologies for glass fibre composites are divided into mechanical, thermal, chemical and electrical methods. Mechanical recycling involves size reduction of composite waste into different size of recyclates through milling processes [7]. The most common technique is a hammer mill process [8, 9]. The basic principle of the hammer mill machine is that the material is downsized through impact and shear action until the fragments can pass through predefined size of milling screen holes. Generally, the recyclates are in forms of flakes, fibre-rich and resin-rich fractions. Thermal methods consist of fluidised bed and pyrolysis processes. Conventional and microwave pyrolysis disintegrate the matrix part of composite material in the absence of oxygen using oven and electromagnetic radiation heating respectively, at a temperature around 300-700 °C [10, 11]. In a fluidised bed process, composite waste is heated rapidly using an air stream to enable matrix decomposition [12]. Chemical recycling immerses glass fibre composite waste in a suitable solvent such as water, acid and alcohol at a

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particular pressure and temperature to liberate the fibres [13]. However, thermal and chemical methods are best suited for recycling of glass fibre composites due to low temperature resistance of the glass fibres, which leads to severe fibre strength degradation [13, 14]. Rouholamin et al [15] used electrical discharge to disintegrate composite waste in an aqueous solution. In a study by Hohenstein Institute in Germany, microorganisms were used to degrade matrix part of a composite [16]. However, these processes have low processing rate. To date, mechanical method is the industrial scale process available for recycling GFRP waste [7].

Recyclates obtained from mechanical recycling can be incorporated in close loop or cross sector applications. For instance, Filon Products and Hambleside Danelaw recycle their in-house manufacturing waste and incorporate it back to valley gutter products [17]. It has also been reported that, mechanical strength of polymer based mortar products can be improved by incorporating around 4-8% by weight of glass fibre recyclates to replace sand aggregate fillers [18]. Despite these few promising applications, there is an urgent need to widen the market opportunities of mechanically recycled GFRP.

The hammer mill technique has been extensively used in the agricultural sector for size reduction of biomass materials such switchgrass, corn stover and wheat straw [19, 20]. Factors that influence the energy performance of hammer mill machines are divided into machine and material related parameters [19-21]. Examples of the machine parameters are screen size and operating speed. Material parameters depend on the throughput, initial and final product size. These parameters affect internal circulation and residence time of the material inside the cutting chamber.

In mechanical recycling of composites, effect of operating parameters on process energy demand and recyclate quality was a knowledge gap identified for this research. This information is important to assess reusability of the recyclates in potential close loop or cross sector applications.

1.2. Research aim

This study's aim was to investigate the effect of operational parameters on process energy demand and quality of recyclates in mechanical recycling of glass fibre composites. Three control factors investigated were hammer mill screen size, material thickness and material size. Performance of two different granulator technologies was also compared. The vision is to develop the knowledge base for selecting optimum parameters to minimise energy footprint and to predict recyclate quality.

2. Methodology

Mechanical recycling glass fibre reinforced unsaturated polyester waste was done using a Wittmann MAS1 granulator. The idea was to investigate effect of operational parameters based on Taguchi experimental design. Selected responses were specific process energy demand and associated recyclate characteristics. Electrical power and material residence time in the cutting chamber were used as a basis in determining the overall energy demand. The recyclates from each trial were analysed in terms of resin content, fibre length distribution and weight fraction based on particle size. Two different mechanical recycling technologies were compared by processing GFRP scrap waste from a boat manufacturer.

3. Experimental Procedure

3.1. Effect of operational parameters

A Wittmann MAS1 granulator, as shown in Figure 1 was used. The machine has a 180 mm rotor diameter and is powered by a motor rated at 2.2 kW. The rotational speed was 200 rpm. The granulator screen was located below the cutting chamber and was interchanged into sizes of 4 mm and 6 mm. The gap between the granulator blades and the chamber was about 5 mm.

In this study, operational parameters selected to be studied were plate thickness, plate size and screen size. The experimental design was an L4 Taguchi orthogonal array and the runs are shown in Table 1. Each experimental run was repeated three times. The material used in this study was glass fibre reinforced unsaturated polyester panels, manufactured from glass fibre mats with random fibre orientation. The panels were manufactured by hand lay-up technique and supplied by Production Glassfibre. Average thicknesses of the panels were 3 mm and 5 mm. The panels were cut into two different sizes using a diamond tile cutter.

a) b)

Fig. 1. Wittmann MAS1 granulator (a) machine; (b) rotor blades cutting chamber [22]

Table 1. L4 Taguchi orthogonal array

Run	Plate thickness	Screen size	Plate size
T1	3 mm	4 mm	45mm x 40 mm
T2	3 mm	6 mm	45 mm x 60 mm
T3	5 mm	4 mm	45 mm x 60 mm
T4	5 mm	6 mm	45mm x 40 mm

Throughout all trials, the 3-phase voltage and current were recorded using a Fluke 434 power meter. The meter was clamped to the three phase wires of the granulator. The basic (no-load) power was measured before the panel insertion in every trial.

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