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Optimizing a recycling process of SMC composite waste

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Abstract

Investigations about the recycling of sheet moulding compounds (SMC) waste as incorporation material for thermoplastic polymer matrix are reported in this paper. A new efficient process is developed in order to strongly increase the reinforcement glass fraction of SMC leading to good mechanical performance of the new thermoplastic compounds. The overall process is composed of two main steps: mechanical and chemical. The second stage is characterised in terms of optimization and capability by means of experimental design and statistical process control techniques for finding the optimal chemical conditions and validating the process.

1. Introduction

Unsaturated polyester resins are some of the most widely used thermosetting materials in the composites industry (automotive and electrical) (Valette and Hsu, 1999). Commercial interest in glass fibre reinforced polyester composites is principally due to their high strength-to-weight ratio and low cost. Current environmental concerns lead to an increasing development of plastics recycling (Buggy and Farragher, 1995), with the objectives of saving raw materials and also, according to recent European regulations, of limiting the use of landfilling to waste with poor biodegradability. Non recyclable SMC materials widely employed are questioned, a simplified scenario, maybe, but that is the spirit of emerging European waste legislation: Under the guiding concept of extended producer responsibility (EPR), under which manufacturers will be responsible for the environmental impacts of products throughout their life cycles, legislators wish to put the onus for after-life disposal on those in the original supply chain. Moreover, the producer may be responsible not only for the waste itself, but also for risk assessment and for possible harm to humans and the environment (Reinforced Plastics, 2003).

Because the automotive sector is among the largest users of composites, the Brussels legislators have targeted this area first. Their end-of-life vehicles (ELV) directive requires that by 1 January 2015, a minimum of 95% of a vehicle by weight should be re-used or recovered and/or that 85% of it should be re-used or recycled (Reinforced Plastics, 2003, 2001).

For sheet moulding compounds (SMC), the waste grew from 10^8 kg in 1984 to 3.6×10^8 kg in 2000 (Butler, 2001), notably due to end-of-life products. The thermosetting character of SMC coupled with an heterogeneous composition (typically by weight: 20–25 wt% of polyester matrix, 20–25 wt% of glass fibres and 50–55 wt% of calcium carbonate filler) requires the development of new methods of waste management as a matter of valorisation, by example, of one or all parts of each SMC component.

Much of the published work on thermoset recycling discusses polyester-based sheet compositions, for which three main recycling technologies have been considered, involving granulation, incineration and chemical recovery of the polymer matrix (Reiss, 1992; Thermoset Plastics Product Recycling, 1993; Bell, 1993; Collister, 1992; Farrisey et al., 1991). Some steps of these technologies, such as size reduction (Keldermann, 1993; Schaeffer and Plowgan, 1994; Petterson and Nilsson, 1994) and fluidised bed incineration (Kennerly and Kelly, 1998; Pickering and Kelly, 2000; Bream and Hornsby, 2001) preserve the reinforcement

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in a form that can be used again in a new composite, while others concern the recovery of the chemical energy remaining in the resin.

The present work focus on the optimization of a new process allowing the production of obtain ground SMC fractions with characteristics optimised for their introduction as reinforcing fillers in thermoplastic polymers (Pickering and Kelly, 2000; Bream and Hornsby, 2001; Anonymous, 2002; Reygrobellet, 2000; Perrin et al., 2005). In such discontinuous-fibre composites, the performances and properties strongly depend on the properties of the glass fibres (fibre type, volume fraction, fibre aspect ratio, fibre orientation, fibre dispersion and compatibility with the host matrix).

Therefore, the proposed treatment of SMC waste is based on a two-step approach which aims to obtain the longest fibres and the highest fibre content in the final product (about 40%wt). An initial shredding step with a slight crushing (from 2 to 10 mm of average length) (allowing extraction of the fibres from the embedding polyester matrix) is followed by a selective dissolution of calcium carbonate in an acid bath (in order to increase significantly the amount of fibres). The optimization of this process is made by a two-step optimal experimental design approach, followed by a validation of capability by statistical process control. The results of this approach are given in term of process effectiveness, glass fibre length and glass fibre content in the final SMC ground fraction.

2. Experimental

2.1. Materials

SMC composite panels ($500 \times 500 \times 4$ mm^3) provided by St Gobain Vetrotex International company were moulded by Compositec SA. Resulting samples constitute model SMC production waste, similar in composition to automotive panels. They contain a relatively low loading (23 wt%) of randomly oriented short E-glass fibres (standard length 4.5 mm), about 55 wt% calcium carbonate and 22 wt% polyester resin.

2.2. Description of the process

As stated in Section 1, the process to optimize consists of two steps (Fig. 1): a slight grinding of the SMC panels followed by a selective dissolution of the ground SMC, in order to finally obtain a filler compound for thermoplastic polymers reinforcement.

Smaller parts of the SMC composites ($50 \times 50 \times 4$ mm^3) are first introduced into a rotary cutter mill (Rotoplex-Alpine) equipped with three blades and an out-screen grid 12 mm in diameter. Only one pass was conducted, the residence time being less than 25 min with efficiency equal at about 95% at 1500 rpm. Such conditions allowed us to obtain glass fibres 2–10 mm in length (Perrin et al., 2005) which is comparable to those of commercial glass fibres used for reinforcing thermoplastic polymers.

The dissolution step was conducted in a 5 L Becher vessel with a propeller agitator. This vessel was filled with an acid buffer solution bath in order to selectively dissolve the calcium carbonate present in the ground SMC. The buffer solution consists of 85 vol.% orthophosphoric acid (H_3PO_4) and NaOH. This buffer has a low cost and a low hazardous nature, but it also can be recycled relatively easily (see Section 3.3).

Therefore, in order to obtain an efficient dissolution of the calcium carbonate from the ground SMC, the buffer pH was adjusted to the first pK_a of the triacid (pH 1.9). From the theoretical predominant diagram of $CaCO_3$ species as a function of pH, we can deduce that in the selected buffer solution (pH 1.9), only the following global dissolution reaction will occur (1):

$$CaCO_3 + 2H_3PO_4 \Longleftrightarrow Ca(H_2PO_4)_2 + CO_2 + H_2O \quad (1)$$

CO_2 was not a free gas, but the molecule was dissolved in water by controlling the pH, which ensures no impact of global warming.

Also, the main specimens of acid could only be H_3PO_4 and $H_2PO_4^-$, which does not lead to precipitate in combination with sodium ions from NaOH or calcium ions from $CaCO_3$ (2–3).

$$Ca^{2+} + 2H_2PO_4^- \Longleftrightarrow [CaH_4(PO4)_2] \quad (2)$$

$$Na^+ + H_2PO_4^- \Longleftrightarrow [NaH_2PO_4] \quad (3)$$

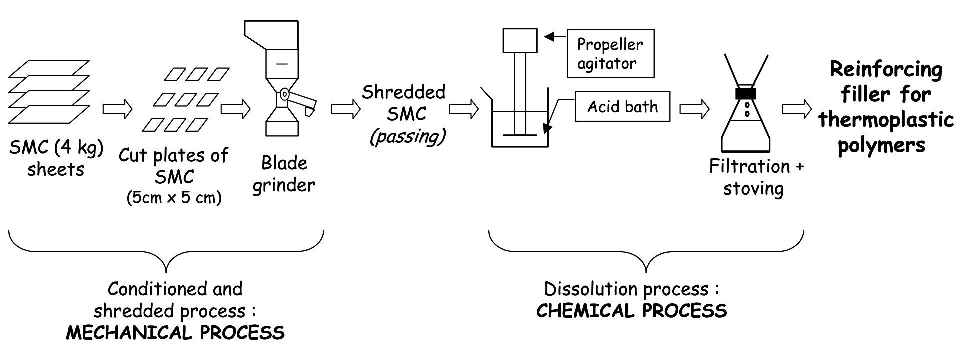

Fig. 1. SMC waste recycling process.