Available online at www.sciencedirect.com
ScienceDirect
Composites: Part A 39 (2008) 624–639
composites Part A: applied science and manufacturing
www.elsevier.com/locate/compositesa

Modelling the application of wood fibre reinforcements within liquid composite moulding processes

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Received 13 March 2007; received in revised form 1 August 2007; accepted 20 August 2007

Abstract

Liquid composite moulding (LCM) processes are commonly used techniques for the manufacture of advanced composite structures. This study explores the potential of wood fibres as reinforcement for LCM preforms, considering mats produced using dry and wet methods. The compaction response and permeability of these mats were measured as a function of fibre volume fraction, results being compared with a typical glass fibre reinforcement. The reinforcement permeability and compaction response data were used to model two LCM variants, resin transfer moulding (RTM) and injection compression moulding (I/CM). A consolidation model approach is applied here to simulate both RTM and I/CM processes, addressing a simple mould geometry. The RTM and I/CM clamping force traces, flow rates, and gate pressures are also measured. The simulation results have been compared with experiments completed for wood and glass fibre reinforcements at two different fibre volume fractions. It was found that at similar fibre volume fractions, the wood fibre mats produce longer mould filling times, and require larger forces to compact.

Keywords: A. Wood; E. Preform; E. Tooling; Liquid composite moulding

1. Introduction

In recent years a number of researchers have been involved in investigating the exploitation of cellulosic fibres as load bearing constituents in composite materials. The use of these materials in polymer composites has increased recently due to their low cost compared to the synthetic alternatives, their ability to be recycled, and the fact that they compete well in terms of specific stiffness and strength [1–9]. Natural fibres are classed according to their source; plants, animals or minerals. In general, it is the plant fibres that are used to reinforce plastics in the composite industry. By far the most abundant source are wood fibres extracted from trees [10].

Many researchers have investigated the use of thermoplastic polymers as matrix materials for natural fibre composites [11–14]. The processing of natural fibre thermoplastic composites most commonly involves extrusion of the ingredients above the melt temperature of the matrix, followed by shaping operations such as injection moulding and thermoforming. Natural fibre reinforced thermosets are processed by relatively simple processing techniques such as hand lay-up and spraying, and the liquid composite moulding (LCM) methods. A number of other methods such as centrifugal casting, cold press moulding, filament winding, pultrusion, reinforced reaction injection moulding, rotational moulding, and vacuum forming have been attempted [15], but their use for natural fibre composites is reported very rarely in the literature. In general, the reinforcements are impregnated with the thermosetting resins and then exposed to high temperature for the cure reaction to take place.

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1359-835X/$ - see front matter
doi:10.1016/j.compositesa.2007.08.023

Using LCM techniques with natural plant fibre reinforcements provides additional technological, economical, ecological and environmental benefits. The term liquid composite moulding covers a wide range of composites manufacturing processes such as resin transfer moulding (RTM), resin infusion (a.k.a. vacuum assisted RTM), and injection compression moulding (I/CM). In general, all LCM processes involve placement of a fibrous reinforcing material within some form of closed mould. The fibrous material, or preform, is then compacted before being impregnated with a thermoset resin. The preform offers resistance to flow (quantified by permeability), which has great influence on the time required to fill a mould and resin flow patterns within. Once the mould is filled, cure of the thermoset polymer is initiated, and the part is removed from the mould when rigid enough. Both permeability and the compaction behaviour of reinforcements are vital for the modelling of mould filling processes [16–18].

During the resin infusion process, a catalyzed thermoset resin is sucked into a mould cavity bounded by a flexible bag using a vacuum pump. On the other hand, the matrix is pushed with external pressure into a rigid mould cavity during the RTM and I/CM processes. In RTM, the mould is closed to the final thickness before injection, while in I/CM, the mould is closed to an initial thickness where all the required amount of matrix is injected. Mould filling is completed by a squeezing operation, the mould being progressively closed to the final cavity thickness. If the process parameters are carefully designed, I/CM offers the potential to reduce fill times and clamping forces [19].

The fundamental goal of our research is the characterisation and utilisation of discontinuous wood fibre mats which have been proposed for use as reinforcements for LCM processes. The wood fibre reinforcements considered in this study have been carefully characterised with regard to permeability and compaction response, such that their application to a wide range of LCM processes can be evaluated. A consolidation based modelling approach is applied here, utilising the data gathered from the compaction and permeability tests. Experimental studies on RTM and I/CM filling are also presented here, comparing mould clamping force traces, evolution of injection flow rates and gate pressures of two different types of wood fibre reinforcements (dry and wet formed mats). These results are compared to a typical glass fibre mat used for LCM processes, commonly known as Continuous Filament Mat (CFM). RTM and I/CM simulations are also compared with the experiments. This paper is an important contribution towards the utilisation of renewable resources into a fast growing and popular family of thermoset composite manufacturing processes.

2. Experimental: characterisation

2.1. Materials preparations

Wood fibres have several advantages over glass fibres. For example, they are generally lighter, renewable, biodegradable, and have lower cost. Radiata pine (*Pinus radiata D. Don*) is classified as a soft wood. It has been widely used as the predominant source of fibre for the pulp and paper industry, and as a raw material in other major wood using industries [20]. The wood fibres considered here are 3–4 mm long and 30–40 μm diameter (an aspect ratio of approximately 1:100). The equilibrium moisture content of these fibres at standard conditions of 23 °C and 50% relative humidity is found to be 10% by weight. To use wood fibres as reinforcement for composite materials, these fibres can be separated and formed into mats. Two types of wood fibre mats are discussed here. The dry formed mats were prepared using a dry mat former (DMF) and the wet formed mats were produced using a standard paper dynamic former (PDF). Complete details on the manufacturing of these mats can be found in our previous paper [21].

The optical images provided in Fig. 1 show that the dry mat formed products were in-plane isotropic (Fig. 1a). The mat produced by the dry mat former has larger channels for fluid flow as compared to the PDF mat (Fig. 1b). The PDF machine produces a more aligned fibre mat due to the deposition of fibres onto a rotating drum which is integral to the process [21].

Fig. 2 presents SEM images which demonstrate the differences at the fibre level between the dry (Fig. 2a) and the wet formed mats (Fig. 2b), and the CFM (Fig. 2c). Fig. 2 demonstrates that latency removal (treatment of fibres at high temperatures) not only removes curls and extractives, but also removes flake like fines on fibre surfaces [21–23]. These extractives and fines are likely to affect fibre to fibre friction, which may have an influence on compressibility.

2.2. Experimental equipment

A two piece aluminium mould was installed in an Instron 1186 testing machine (depicted in Fig. 3). The upper platen was attached to a 200 kN load cell, and the lower platen was attached to the moving Instron crosshead. The Instron was used to control the cavity thickness and closing speed, and provided adequate mould clamping force for all experiments. The mould has a central fluid inlet gate. A pressure transducer and check valve were positioned at this gate. The valve prevented fluid flow out of the mould during compaction tests and the moulding experiments, allowing the central gate pressure to be recorded. The pressure pot containing the test fluid was mounted on a set of weighing scales attached to the data acquisition computer, which monitored the amount of fluid entering the mould cavity. A temperature sensor was placed inside the mould cavity to record any change in temperature, and hence fluid viscosity. Mineral oil (Mobil Vacuoline 1405) was used in this study as the test fluid to simulate a thermoset resin. The oil viscosity was measured to be between 0.095 and 0.066 Pa s, for a temperature range of 14–23 °C. All experimental data was collected using "Bluehill" data acquisition software on the Instron system.