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Interaction of textile variability and flow channel distribution systems on flow front progression in the RTM process

C. Kracke [a,*], A. Nonn [a,*], C. Koch [a], M. Nebe [a], E. Schmidt [a], S. Bickerton [b], T. Gries [c], P. Mitschang [d]

[a] BMW Group, Ohmstraße 2, Landshut, Germany
[b] Centre for Advanced Composite Materials, Department of Mechanical Engineering, The University of Auckland, Private Bag 92019, Auckland 1020, New Zealand
[c] Institut für Textiltechnik, RWTH Aachen University, Otto-Blumenthal-Str. 1, 52074 Aachen, Germany
[d] Institut für Verbundwerkstoffe GmbH, Erwin-Schrödinger-Str., Gebäude 58, Kaiserslautern, Germany

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ABSTRACT

The high volume production of carbon fibre reinforced plastics needs cost efficient and robust processes. This paper investigates the influence of local textile variation on flow front progression in resin transfer moulding (RTM). To quantify the textile variation, the textile has been tested with laser triangulation, to achieve the thickness profile map of the flat textile preform. This preform is placed in a transparent flow visualisation tool and an oil is injected into the mould via two different flow channel distribution systems. The flow front progression of the fluid is continuously measured from both sides with two cameras. Furthermore, to demonstrate the influence of defects like folds from the draping process on the local filling behaviour, the textile is prepared with an artificial fold, made of additional non-crimp fabric (NCF) strips. The results show how different defects in the textile influence the local filling behaviour and how the additional flow channel distribution system can decrease the effect of these defects.

1. Introduction

This paper focuses on the RTM process, in which a thermoset is injected into a fully-rigid form. The process is used to manufacture large, complex, three-dimensional shell parts. An example of such a part is the side frame of the BMW i3 car body. The part is divided into different sub preforms, to achieve an efficient material input ratio and an optimal layup for local load paths. Each preform has an individual layup and that layup is draped to three dimensions in the preforming process. During the draping of a flat textile onto a three-dimensional shell structure occasionally imperfections such as folds may be induced. Therefore, mainly the preforming process defines the resulting fibre distribution. Folds lead to a local accumulation of fibres and can change the corresponding permeability of the textile. This influences not only the processability but also the mechanical performance of the part. Therefore, methods for quality assurance to detect and quantify these imperfections are important.

In this paper a method to non-destructively measure textile defects, in this case folds, is investigated. In the next step the measured textiles are injected with rape seed oil, to show how these defects influence the flow front progression in RTM. Furthermore, flow channels distributed over the tool surface are used to improve the filling behaviour to achieve a reproducible filling pattern.

2. State of the art

A common process chain to manufacture high performance carbon fibre reinforced plastic parts in high production numbers consists of the process steps stacking, preforming and RTM [1] as depicted in Fig. 1.

It is evident, that robust processing steps are very important for a reliable quality of semi-finished products such as flat stacks, preforms as well as complex shaped parts. A structured overview of possible defects in fibre reinforced plastic parts is given by Potter [2]. The distinction is made between variability in processing and variability in material. In the presented process chain, both material variability of single plies and preforming-process induced variability such as misalignment of fibres add up to the input material variability of preforms for the RTM process.

Methods to characterise the textile performance during the thermoset injection include a variety of permeability measurement methods as summarised by Sharma [3]. Usually an average permeability is derived from experiments and compared to simulation models. Most methods do not account for local material

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* Corresponding authors.
E-mail address: christoph.kracke@bmw.de (C. Kracke).

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Fig. 1. RTM process chain form single plies to parts.

imperfections such as gaps or misaligned fibres. However, the knowledge of the spatial distribution of material variability is beneficial input for simulation tools. Comas-Cardona et al. [4] use an optical method for glass fibre single layers as in [5], to predict local permeability.

Draping during the preforming process is one source of variability in material-properties of preforms, as for example described by Bickerton et al. in [6]. The influence of shearing of textiles on permeability is described e. g. by Endruweit in [7] and Pierce in [8]. Besides the preforming induced textile variations, many variations are already introduced when the individual textiles utilised in a preform are manufactured. Mesogitis et al. present an extensive review of material properties variability in composites manufacturing. In particular, fibre volume content (FVC) is identified as a dominant factor for effects in the different processing steps [9]. Hence, every variation leading to local FVC changes decreases the robustness of the RTM process.

The importance of the fluctuation of material properties increases with high production numbers. Koch et al. [10] investigate different non-crimp fabric stitching types to optimise impregnation in the RTM process. Furthermore, the relevance of lab scale testing for characterising textile behaviour in 3D high pressure RTM applications is pointed out. High deviations in preform permeability results are observed, even for an optimised carbon fibre NCF stitching pattern. Nonn et al. [11] investigate the variation of textile properties, especially the influence of local NCF gap width and spatial preform thickness variation on flow front shape in short shot unidirectional 2D RTM parts. A non-destructive testing concept is utilised which allows a qualitative characterisation of local FVC in the size of textile or preform imperfections as small as single heavy/bulky rovings. It is evident that one of the key factors to investigate the effects of textile variability on the processing behaviour of composites is testing of the material prior to processing due to the influence of a varying local FVC on the draping and injection process. is. A suitable measurement concept to allow fast and non-destructive measurements of flat carbon fibre semi-finished products is introduced in [12].

The resin distribution in the mould of the RTM tool is commonly assisted by a flow channel distribution system, which is implemented on the mould surface. This helps to reduce the injection pressure and leads to reduced tooling costs. These flow channels reduce the longest distance the fluid has to flow through the preform due to intentional race tracking in the flow channels. This is exemplarily shown in [13–17]. The effect of defects on the flow front progression has been investigated in [18,19] in regard to the accuracy of the used filling simulation softwares. The results show how a flow front reacts to a solid obstacle in the flow path.

Comparable channels are used in injection moulding, to transport the fluid simultaneously to the different moulds. According to [20], flow channel cross section size and form is designed in regard to fluid shear stress distribution, part thickness, flow length, part mass and volume. This results in a circular cross section shape as an optimum for heated flow channels. Similar influences are observed in the RTM process and discussed in [21], where it is shown how the optimal flow channel cross section size is dependent on the permeability of the textile. This observation is supported by the investigation of different race tracking channel widths by Bickerton et al. in [13,14]. The flow front shape changes with a smaller channel width, which indicates a relation between flow channel cross section size and textile permeability.

While there are limited sources for the interaction between flow channels and textiles in the RTM process, [22] investigates different injection gates in regard to cross section shape and length. The results show that the length of the flow channel is particularly important, while an influence of the cross section shape and size could not be observed.

In [16,17], based on the optimisation approach described in [15], a method to find the optimal flow channel distribution is shown. The mesh describing the cavity is reduced to a flow resistance, basically consisting of the coordinates and textile permeability of each element. This enables a topology optimisation of the flow channel distribution in the mould. However, no investigations have been made into the interaction between local preform variability and flow channels on the mould surface. Furthermore, previous optimisation studies have only considered the position and layout of the flow channels, but not the cross section shape and size, and their interaction with the variability occurring within the textile reinforcement. In summary, it is important to investigate the interaction between textile properties and flow channels in the RTM tool in regard to the injection reliability. This includes local variation in the filling path as well as injection time.

3. Experimental approach

The target of the experimental program is to investigate the influence of local textile variability on flow front progression. The theoretical FVC in the RTM mould in regions where layers of the preform are partially folded can increase to >70%. The corresponding local permeability change will influence the flow front progression. Preform samples have been manually prepared with additional NCF strips to demonstrate the level of influence folds have on the flow front progression and how they interact with the flow channel distribution system.strips. A multi-directional stack layup is used. All flat preforms (hot pressed stacks) are non-destructively tested with laser triangulation to measure the local thickness. The measured preforms are placed inside a two-sided transparent mould. The mould is injected with a substitute fluid, to continuously observe the flow front progression. These experiments provide data for discussion of how textile variations influence the process and which characteristics are most critical for process robustness. Furthermore, they also enable discussion how a reproducible flow front distribution can be achieved by the use of flow channels.

3.1. Design of experiment

To investigate the different parameters, a full factorial design with three repetitions per configuration is used. Fig. 2 shows a schematic overview of each experimental configuration. Two different versions of a flow channel distribution system are used. Additionally to the general textile variation, 24 preform samples have been prepared with an artificial fold. The fold is created with additional fibres, cut out strips from the NCF material, to achieve two different, higher FVCs. Two different fold directions are used, in 0° and 90° to the flow front. Every preform has been characterised with the laser triangulation method in a testing cell and subsequently injected in the flow visualisation tool.