FLOW BEHAVIOUR OF RECYCLED THERMOPLASTIC COMPOSITES PROCESSED BY LOW-SHEAR MIXING

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Introduction
A recycling solution for thermoplastic composites has been introduced and comprises the following steps: shredding of laminated scrap into flakes of about 20 mm; melting and blending of those flakes to a dough using a low shear mixing device; and compression moulding of the resulting dough [1]. The first studies of this process showed that the doughs are concentrated suspensions of fibre bundles similar to LFT charges. A clear understanding of their flow behaviour is crucial for proper manufacturing of recycled components. This work aims to understand the flow behaviour of the doughs during compression moulding, and compare it to the known flow of concentrated fibres suspensions.

Materials
In this study, quasi-isotropic laminated scrap made from woven fabric reinforced carbon/PPS (C/PPS) was collected at various aerospace companies. Scrap material was then comminuted using a multiple shaft shredder to obtain flakes of about 20 mm. The flakes were mixed with polymer granulates to lower the fibre volume fraction from 50% to 25%. During mixing, flakes first tend to delaminate, followed by a disentanglement of the woven structure. The loose bundles eventually filamentise depending on the mixing quality. Resulting doughs are concentrated suspensions of slender particles that range from single fibre to bundles containing up to 3000 fibres. The typical dimensions of the doughs are ∅90 mm x 150 mm when pushed out of the mixer. At this stage, the porosity fraction in the doughs is high. In the recycling process, the doughs are quickly transferred to a mould for compression moulding. During pressing, most void pockets are compressed (phase 1) prior to squeezing of the material (phase 2). For this study, the doughs were pre-pressed until the first phase finishes and then are cooled to room temperature. The pre-pressed doughs measured 90 x 150 x 16.5 mm^3. Specimens measuring 60x20x16.5 mm^3 (LxWxH) were cut and placed in an instrumented squeeze flow setup installed in a universal testing machine similar to the experiments in [2]. The specimens were heated in the squeeze flow setup to 320°C before the testing.

Results
Plane strain squeeze flow tests were performed at constant rate — 3.16 mm/s, 1 mm/s and 0.316 mm/s. Visual inspection of all specimens show a globally affine behaviour during squeezing. Additionally, a specimen was tested at 0.001 mm/s, a speed that is expected to be low enough for achieving matrix-fibre segregation [3]. It resulted in the matrix percolating through a motionless fibre network. For all tests, a no-slip condition was observed at the walls (see Figure 1), similarly to GMT [4] or chopped woven C/PPS semipreg [2].
Figure 2 displays a stress-strain plot of the squeezed specimens where each type of line corresponds to a compression rate. For all rates but 0.001 mm/s, the curves exhibit three distinct phases. For a mould opening ratio $h/h_0>0.8$, several effects regarding the loading of the setup (low loads, setup friction) is assumed to be dominant. Additionally, specimens still had some porosity prior to testing. It has been found that that these void pockets close at the start of the test, thus it is advised not to use the data from this range. From $h/h_0=0.75$ to 0.5, the material response can be closely approximated by a power law behaviour, as expected from previous work [2,4]. For this range, the squeeze flow experiments were modelled assuming an incompressible single-phase flow and the material to behave as a power law fluid.

The power law indices were found to be n=0.50±0.03 for different ratios h/h_0 in the considered range, which is in agreement with affine flow of these types of fibre reinforced polymers [2,4]. Upon further closure of the mould, for $h/h_0<0.4$, the slope of the curves increases and approaching the slope of the specimen compressed at a rate of 0.001 mm/s. In the latter case, the fibre bed was fully percolated and the response corresponds to the compressive response of the fibres only [3,5]. Therefore, specimens squeezed at a rate of $\dot{h}$=0.316, 1 and 3.16 mm/s seem to show a beginning of percolation at these large strains, even though visual inspection does not reveal it.

Figure 1: *Picture of a specimen after squeezing. The dots on the surface were marked prior testing to determine whether the material slips at the walls.*

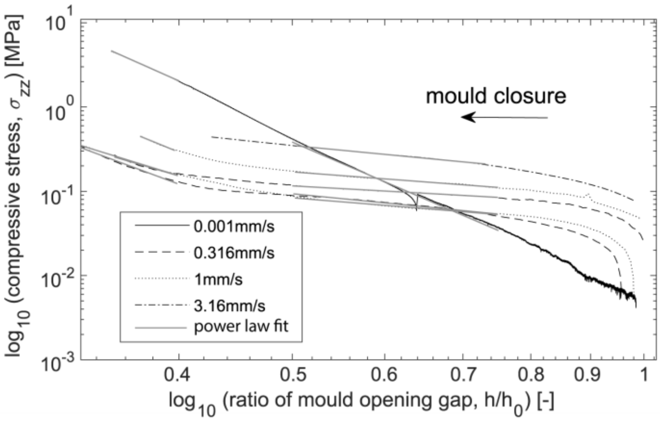

Figure 2: *Experimentally observed axial stress vs. mould opening.*

Future work

Future work will take a closer look at the behaviour at large strain, as well as whether this behaviour also exists when real components are manufactured. A study of the effect of degree of mixing of the suspension, fibre length and fibre fraction on the flow behaviour of the doughs will be carried out. At the same time, a larger squeeze flow setup will be used to test larger specimens to check for size effect. The squeeze flow setup presented here is limited by its size — 60x60 mm^2 — which imposes specimen sizes close to, or even smaller than, the fibre length.

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