ORIENTATION, DISPERSION AND LENGTH REDUCTION OF FIBRES IN LONG GLASS FIBRE REINFORCED INJECTION MOULDING

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ABSTRACT

Within this paper we show an in depth investigation into the moulding of short and long glass fibre reinforced composites. Short fibre orientation is predicted within Autodesk Simulation Moldflow Insights to a high accuracy. Fibre dispersion and fibre length for long fibre reinforced materials is shown to be highly effected by the injection moulding screw, in particular within the compression zone.

1 INTRODUCTION

Fibre reinforcement of commodity polymers is a well-established method for the manufacture of components with significantly increased mechanical performance compared to their unfilled counterparts. Mechanical properties of any moulded component are highly dependent on fibre orientation, in the case of short fibre (250 μm long), alongside fibre length distribution and overall fibre dispersion for long fibres (up to 30 mm in pellet form).

In this paper we investigate the fibre orientation, dispersion and length distribution developed within the nozzle and moulded centre gated disc geometry, Figure 1, moulded from 20, 30 and 40 wt% Polypropylene and 40 wt% nylon 6. This investigation includes both experimental and numerical analyses, with simulation conducted in Autodesk Simulation Moldflow Insights. The degree of fibre breakage and fibre dispersion has also been considered experimentally via microCT.

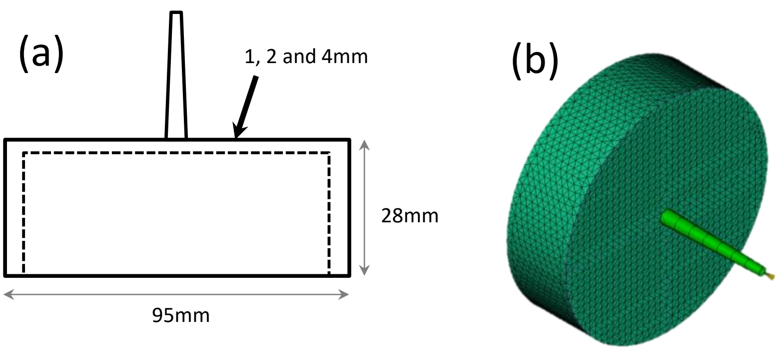


Figure 1: Centre gated disc geometry: a) sample details b) Moldflow mesh

Primary goals of this work are:

1. To compare the differences and similarities between short and long fibre orientation developed within the disc region of the sample

2. To evaluate, in long fibre reinforced case, the fibre length distribution at various locations within the moulding, including the sprue and nozzle sections
3. To evaluate, in the long fibre reinforced case, the fibre dispersion at various locations within the moulding, including the sprue and nozzle sections
4. To evaluate, in the long fibre reinforced case, the fibre dispersion at various locations along the screw of the injection moulding machine
5. To assess the mechanical performance predictions within Autodesk Simulation Moldflow compared to experimental deformation

2 FIBRE ORIENTATION

Samples of 40 wt% short glass fibre reinforced nylon 6 were moulded from Rhodia 216 v40 using material suppliers moulding conditions. Post injection, samples were extracted at 2 locations along the flow path on the main disc section, denoted locations C and D in Figure 2, and fibre orientation measured using the University of Leeds in-house optical technique [1, 2].

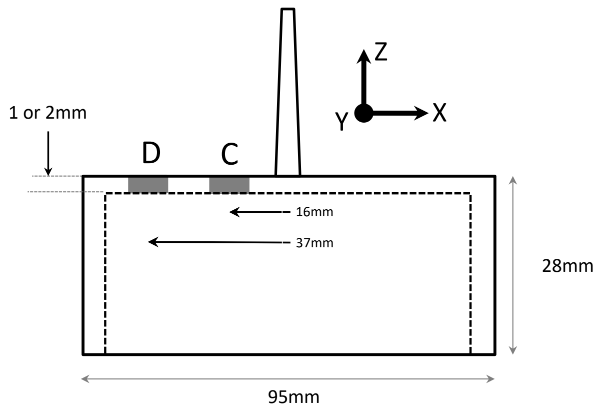


Figure 2: Fibre orientation measurement locations

Fibre orientation predictions were also conducted within Autodesk Simulation Moldflow Insights, were parameters for fibre orientation prediction models provided by previous work [3]. Fibre orientation predictions and measurements comparisons are shown in Figure 3 and show a high degree of accuracy when using the RSC fibre orientation model with parameters of k = 0.15 and c_i = 0.006, and an inlet boundary condition of transverse orientation in the core at the location of injection.

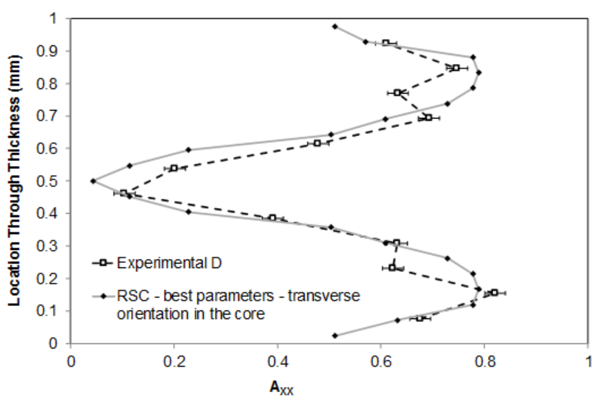


Figure 3: Fibre orientation distribution predictions and measurements

3 FIBRE BREAKAGE

Samples of 20, 30 and 40 wt% long glass fibre reinforced PP were moulded from Sabic Stamax using material suppliers moulding conditions. Post injection samples were extracted at locations within both the sprue and main disc section of the component and fibre length measurements conducted. Fibre length predictions within Autodesk Simulation Moldflow insights were also conducted, using the inbuilt fibre breakage model with default parameters. Figure 4 shows a typical fibre length distribution within the main disc section of the moulding, where the initially 12 mm long fibres have been significantly reduced in length to an average of 2.28 mm.

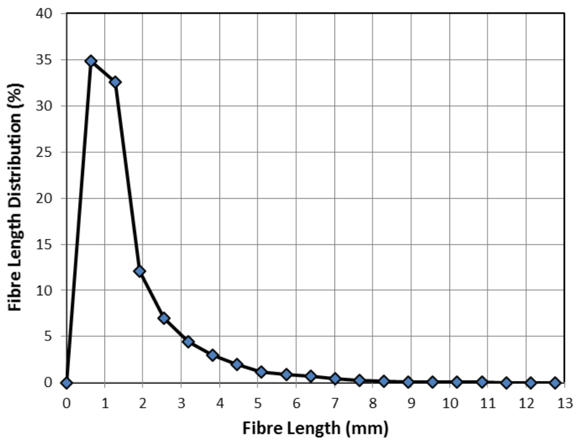


Figure 4: Fibre length measurement within the main disc section

Figure 5 shows the fibre length predictions at the same location as in Figure 4, with the default inlet conditions (a) and a fibre length distribution inlet condition based on measured air shots (b). Here is shown the importance of inlet condition, where a 12 mm fibre length at the point of injection in the default model shows a poor prediction of the actual fibre length distribution.

(a) (b)

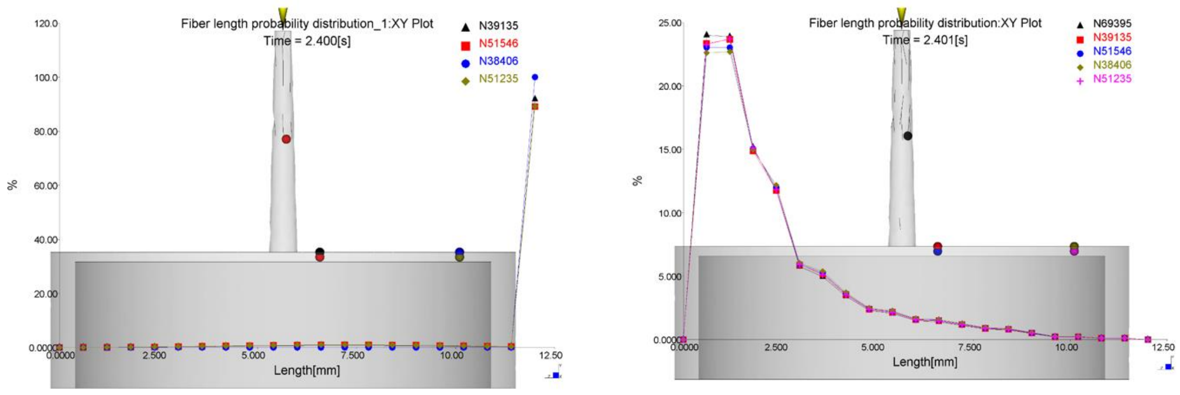


Figure 5: Fibre length predictions within the main disc section

4 FIBRE DISPERSION

As part of the long fibre investigation two different nozzle geometries were examined in terms of fibre dispersion. Fibre breakage and dispersion of long fibres has been shown to be highly dependent on the early stage of the injection moulding process [4, 5]. Geometries of the nozzles are shown in Figure 6, which includes a 3 and 6 mm nozzle exits with a 60^{o} inclusive angle at the nozzle entry and a main nozzle internal diameter of 10 mm.

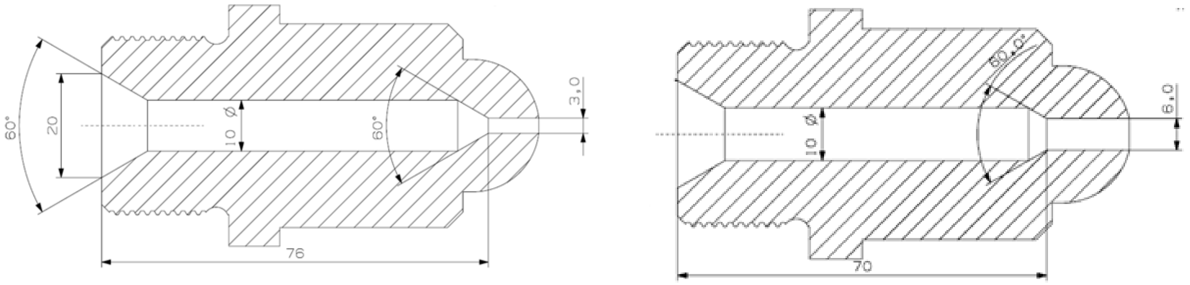


Figure 6: Nozzle geometries for long glass fibre breakage and dispersion analysis

MicroCT has been used to visualize fibre dispersion within the nozzles, where the 6 mm nozzle shows fibre alignment through the exit in the direction of flow whereas the 3 mm nozzle shows a constriction resultant from fibre interation near the exit, Figure 7.

(a) (b)

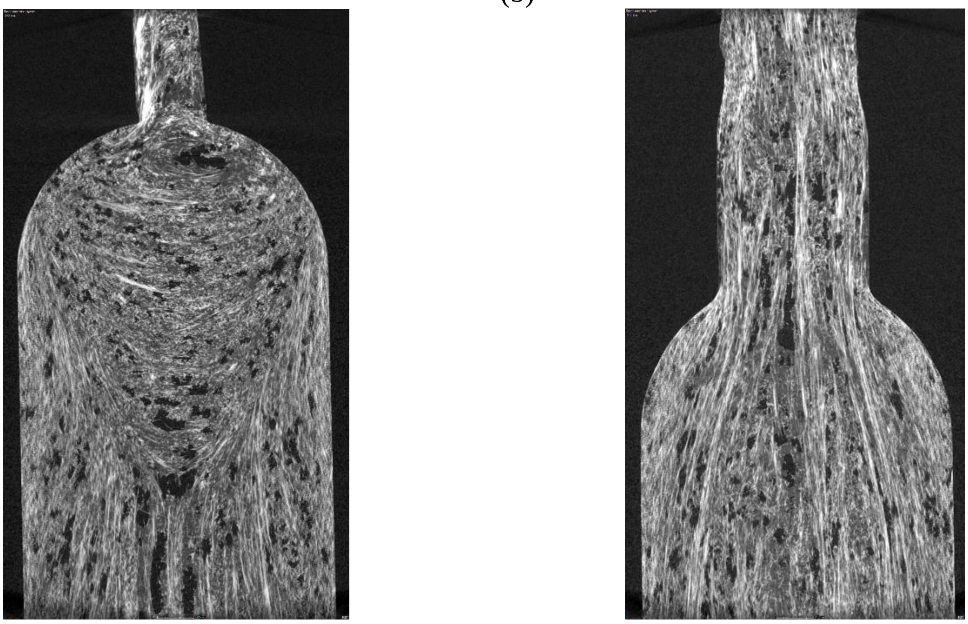


Figure 7: MicroCT centerline sections of 3 mm (a) and 6 mm (b) nozzle regions

Considering the region at the base of the nozzle, closest to the screw, the historical effect caused by the screw geometry is demonstrated. Here clusters of fibres can be seen to spiral down the length of the nozzle. Significantly, for this 40 wt% 12 mm initial fibre length PP, large numbers of long fibres remain in bundle form, Figure 8.

(a) (b)

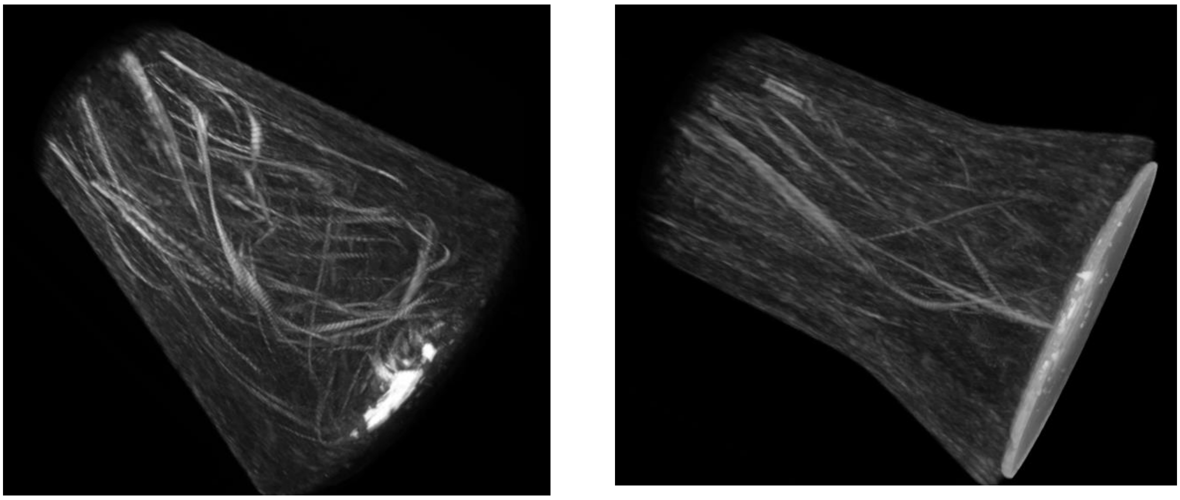
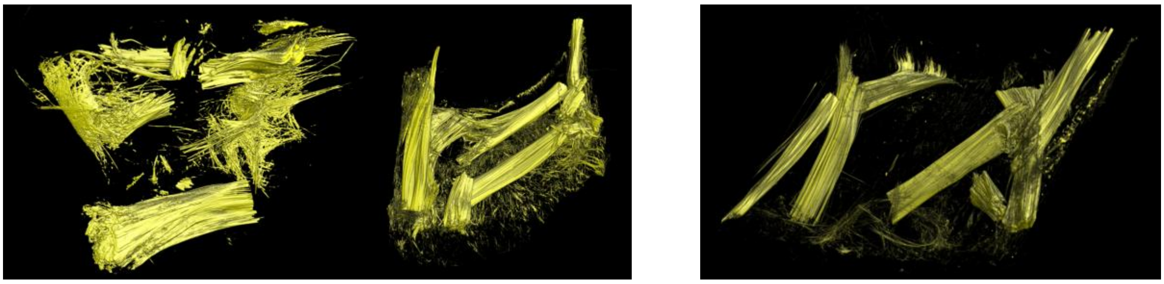


Figure 8: MicroCT of nozzle base of 3 mm (a) and 6 mm (b) geometries

5 FIBRE BREAKAGE AND DISPERSION ALONG THE SCREW

Screw pull out tests were conducted in collaboration with KU Leuven, Belgium. 20, 30 and 40 wt% PP Sabic Stamax was moulded using 20 mm and 25 mm Arburg Allrounder injection moulding machines. Following moulding the machine was allowed to cool before removal of the nozzle. The barrel was then reheated to 160 ºC in all zones and the screw removed by a hydraulic ram and samples collected along the screw section. Figure 9 shows a series of microCT images along the screw from the feeding zone (1 and 2), compression zone (3, 4, 5 and 6) and metering zone (7).

(1) (2) (3)



(4) (5) (6) (7)

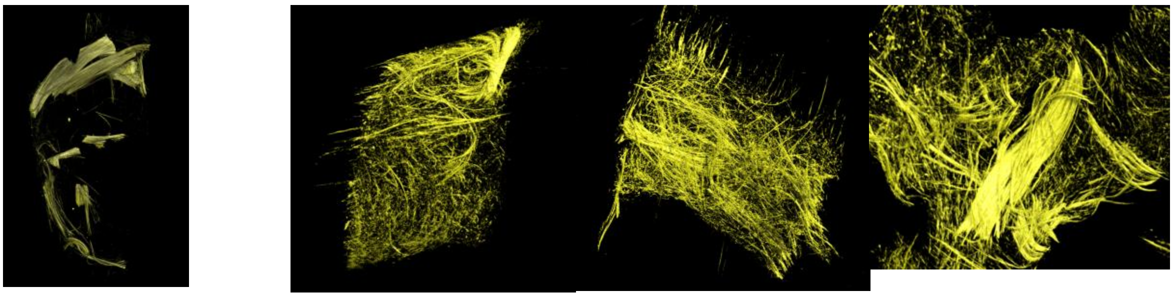


Figure 9: MicroCT of samples extracted along the screw

Based on early results shown above, the predominant factor in fibre breakage during the injection moulding process appears to relate to the compression zone of the screw, 3 to 6.

6 CONCLUSIONS

Short glass fibre orientation has been shown to be predictable using the reduced strain closure model within Autodesk Simulation Moldflow Insights. However, parameters need to be carefully selected and an injection point boundary condition of transverse fibres within the core is required.

For long fibres, prediction of fibre lengths within injection moulding components requires an input fibre length distribution at the point of injection due to the assumption that initial fibre length is that of the pellet. Ideally this input would be based on theoretical values instead of the measured version shown here.

Fibre distributions within mouldings, sprues and nozzles show a historical effect of the screw with spiraling clusters of fibres particularly within the nozzle region. This effect can be track back along the screw via microCT of screw pull out tests where the compression zone shows the highest degree of fibre dispersion and breakage.

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