MEASUREMENT OF CURVED AND SHEARED PERMEABILITY

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Introduction

Two methodologies for measurement of permeability are presented. The first pertains to in-plane one-dimensional flow around a curved tool. Right-angle bend tools were prepared with various curve radii. These tools were oriented for horizontal flow and the effects of gravity for such a flow test were studied. The second test method is a trellis-type tool, used to induce intra-plane shear into a composite reinforcement. A point-infusion three-dimensional permeability test (ellipsoidal flow) is then performed on the sheared sample, to determine the permeability in all three principle components as a function of the shear angle. These two measurement methods allow determination of the permeability of actual composite part geometries (i.e. often double curvature) and subsequent flow simulation. Such flow simulation is enhanced when local permeabilities are modified to account for fabric bending and shear.

All tests were performed with a carbon uni-directional weave and canola oil as the test fluid.

Curved Permeability

Curved tools were manufactured with radii of 25, 16, and 3 mm. One-dimensional infusions were performed on each of these tools, using eight-ply (all warp orientation) reinforcement samples measuring 125 mm in length and 76 mm in width. In order to homogenize the effect of gravity on resin flow, the tool was turned on its side, with infusion under a vacuum bag (Fig. 1). Each sample was placed with three regions: 1) the non-curved initial 50 mm (along the sample length) region of the sample (R_1), the curved sample region ($R2$), and a non-curved region at the end of the flow direction (R_3, the balance of the length to the 125 mm sample end). Flow times were recorded as when the slowest point in the fluid flow front crossed positional lines corresponding to the end of each region.

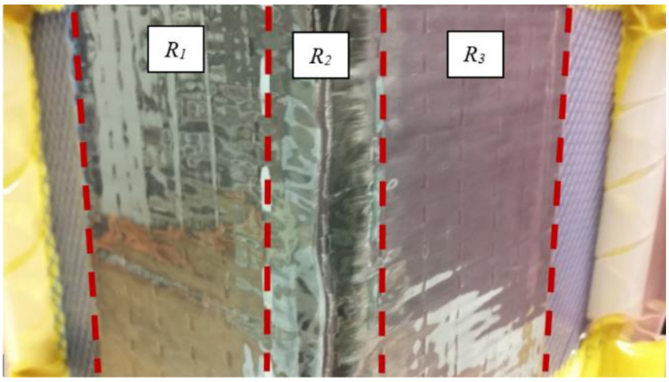

Figure 1: *Curved tool testing and three defined regions.*

As this reinforcement is highly rigid (low compressibility), the one-dimensional form of Darcy's Law, assuming a linear pressure gradient was used to solve for the local permeability (K) given that location's recorded flow front velocity. This permeability was evaluated by the average velocity for each of the three regions and is plotted in Fig. 1(a), as the average for six tests. R_2 is the lowest permeability of all three regions, owing likely to the compaction of the reinforcement and added tortuosity of the flow due to the compression. The non-curved regions R_1 and R_3 should theoretically result in similar permeabilities, but higher K was seen in R_3. The suspected cause for this was the gradually increasing effect of gravity, pushing more flow down to the bottom and lifting the bag off the tool. A separate test was conducted to characterize the effect of gravity on such horizontal flow, but with no curvature. A

74.5% increase in K was noted in those tests, when comparing the average velocity from 0 to 50 mm of flow, to that velocity from 50 to 125 mm. This reduction was used to correct both the curved tool R_3 K values, as well as R_2 K values by linear interpolation (Fig. 1(b)). The resulting R_2 K values were then separated by the curvature radius for each test, yielding a roughly linear model between the two (Fig 1(c)). As expected, the greater the radius, the less local fiber compaction, and thus the greater the permeability.

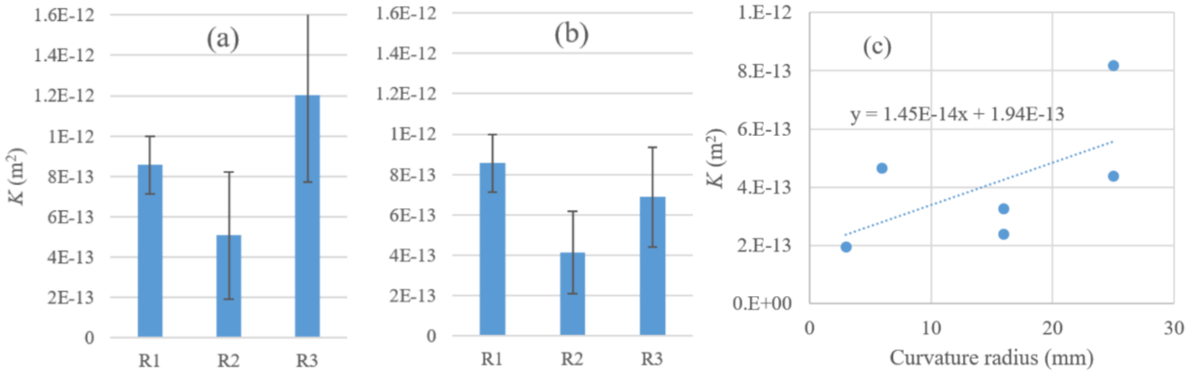

Figure 2: *Permeability results for a) average in each region across all 6 tests, b) corrected for effects of gravity at later flow lengths, c) curved region R_2 as a function of curvature.*

Sheared Permeability

A challenge to permeability measurement of a sheared sample is how to maintain the shear angle throughout sample preparation and loading into a tool. A methodology was developed to characterize all three principle directions of the permeability tensor of a sheared sample in one test.

Eight layers of the reinforcement were cut to 250 x 250 mm squares, with 50 mm square corners cut away. A thermoplastic binder film (Pellon 807 Wonder-Web) was cut into 25 mm wide strips, which were placed at the edges between each of the reinforcement plies, where the trellis tool bars clamp down upon the reinforcement (Fig. 3). A trellis tool similar to that used in other draping studies, was employed to shear the 8-layer samples to shear angles of 0, 16°, and 37°. Once all loaded in the trellis tool, metal support plates were placed on top and under the reinforcement (within the confines of the trellis tool) to apply a small consolidation load, and the entire tooling was heated in an oven to 200° C for 30 minutes to melt the binder. Then the tool is cooled and opened, resulting in a preformed sample which maintains the applied shear angle yet needs no binder in the center of the sample where the permeability testing is to be performed. The sample was then placed between thick acrylic plates and tested for permeability in a three-dimensional flow test as outlined previously [1].

Figure 3: *Shear trellis tool (left) and three-dimensional permeability test with the sheared sample (right).*

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References

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