EFFECTIVE PERMEABILITY AVERAGING SCHEME: HETEROGENEOUS PREFORMS WITH ANISOTROPY EFFECTS IN LIQUID COMPOSITE MOLDING

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Extended Abstract

In the domain of composite manufacturing, Liquid Composite Molding (LCM) is a group of processes that share the common principle of a resin (matrix) being infiltrated through a porous medium (reinforcement) inside a mold. In the interest of predicting the expected resin flow, process engineers can resort to numerical simulations: several packages are available which adopt a finite element approach to compute and visualize the resin flow inside the mold in 2D or 3D domain. Resorting to 2D elements computation leads to huge computational savings, and is generally a viable option since composite parts have a much smaller thickness than in-plane dimensions. Since reinforcements typically consists in several layers of fabric laid upon one another, to capture the layup heterogeneity into a 2D mesh the permeability information from all the plies has to be integrated into one resulting in-plane permeability tensor, which is assigned to each element of the shell. This need led to the development of permeability averaging schemes. The simplest scheme, the Arithmetic Average (K_{AA}), averages the permeability of plies through the thickness into one resulting value, but neglects totally the presence of any through-thickness flow between adjacent layers [1]. However, there are situations where through-thickness flow can affect the value of the overall in-plane permeability of the preform, especially in presence of big differences in layer permeability [2]. To address this simplification, Calado et al [3] proposed an Effective Permeability (K_{TF}) averaging scheme that can be applied to one-directional infusion of heterogeneous preforms. This scheme can provide an in-plane averaged permeability value while still taking into account the presence of through-thickness flow.

In the present work, the Effective Permeability (K_{TF}) scheme is initially applied to some test cases and its accuracy and limitations are discussed. New capabilities are then added to the initial scheme to formulate a Generalized Effective permeability scheme (K_{GTF}), which can address a wider range of scenarios. The first addition to the scheme is the capability to address the presence of off-axis anisotropic plies in the stack. When an anisotropic fabric is subjected to a one-directional resin infusion that is not aligned to a principal direction of permeability, an entrance region develops where the overall velocity of the resin is higher, before the flow reaches a uniform velocity profile. This behavior was modelled into the Generalized Effective Permeability (K_{GTF}) algorithm to allow to study how the presence of anisotropy and different layer orientations affect the effective permeability of the preform. The accuracy of the model is assessed by comparison with 2D numerical simulations.

The second extension to the scheme is the possibility of having non-constant thickness layers in the stack. It is common practice in some applications to have a linear change in thickness of a preform, which is typically achieved with the technique of ply drop-off. This situation can also be taken into account by the Generalized Effective Permeability (K_{GTF}) scheme by assigning a linearly varying thickness to each layer.

Some validations are carried out by comparison with full 3D simulations to assess the accuracy of the Generalized Effective Permeability (K_{GTF}) scheme against the Arithmetic Average (K_{AA}) scheme.

Finally, a series of parametric studies are performed using the Generalized Effective Permeability (K_{GTF}) scheme as a tool to investigate the influence of through-thickness on the in-plane permeability of preforms for different values of: in-plane and through-thickness permeability, thickness, degree of anisotropy, in-plane dimensions, layup sequence.

As an example, Fig. 1 shows how the effective permeability changes when the same set of layers are laid up in different sequences, and how the value evolves as the averaged flow front position ($\bar{l}$) progresses across the length (L) of the preform. The parameters are reported in Tab. 1, where Kxx and Kt are the in-plane and through-thickness permeability respectively, h is the thickness of the layer, n is the number of layers. Since the presence of through-thickness flow is caused by the interaction between adjacent layers, the sequence in which layers are laid affects both the maximum magnitude and the $\bar{l}/L$ extent of the difference between the K_{GTF} and K_{AA} schemes, as the latter neglects the presence of through-thickness flow.

When the Generalized Effective Permeability (K_{GTF}) scheme is correctly applied, it can also be used in substitution of the Arithmetic Average (K_{AA}) scheme for the purpose of numerical mold filling simulations, allowing to retain some information about three-dimensional effects (through-thickness and in-plane flow) at the affordable cost of two-dimensional computation.

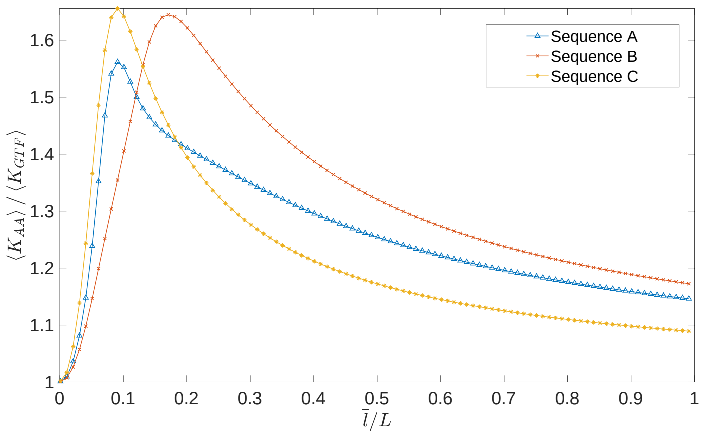

Figure 1: *K_{AA} / K_{GTF} ratio for three different layup sequences for the same set of layers*

Sequence	n	h_i [mm]	<Kt> [m^2]	Kxx1 [m^2]	Kxx2 [m^2]	Kxx3 [m^2]
A	3	2	1e-13	1e-9	1e-11	1e-10
B	3	2	1e-13	1e-9	1e-10	1e-11
C	3	2	1e-13	1e-11	1e-9	1e-10

Table 1: *Parameters for Fig. 1 test case*

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