Mold Filling Simulations for RTM: Influence of the Scatter of Preform Permeability

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SUMMARY: This paper describes the incorporation of variability of preform permeability data into a mold filling simulation software (PAM-RTM from ESI-group).
The input for the statistical parameters of the local permeability scatter can be obtained from a large number of permeability measurements [1] or by simulation based on textiles modeled with WiseTex software [2,3]. Internal textile geometry, needed for these models, can be obtained by using micro CT measurements [4].
Assigning permeability values to each element in a finite element model can be done in a totally random way [5] or in a correlated way. In this paper, the interaction of the correlation function, the assigned local permeability scatter and the resulting global permeability scatter is discussed based on Monte-Carlo simulations. This information can then be used to simulate a distribution of permeability over a 3D shaped preform for a part under consideration to prevent poor gate and vent locations.

KEYWORDS: Permeability scatter, correlated distribution, mold filling simulation

INTRODUCTION

As the RTM technique is still gaining lot of interest to produce textile composite parts using thermoset and thermoplastic materials, simulations for this kind of process are also important to lower the amount of inferior parts. A common important parameter for both material families is the permeability of the textile preform. Measurements on undeformed preforms, in a flat mold geometry with dimensions 0,3 by 0,3 meter resulted in a standard deviation of 22% for the permeability of the textile [1]. This permeability is valid for the whole preform and will be called global permeability from now on. This is the first important reference value.
Second source of information can be data obtained on the internal geometry of a textile. Using X-ray microcomputer tomography, a scatter for the spacing between yarns in a 3D textile preform of 6% has been found [4]. Dimensions of the yarns of the same kind of textile resulted a scatter of 16%. With this information, a textile internal geometry model can be built within the textile modeling software WiseTex. Models built with this software can serve to calculate mechanical properties and also local permeability of fabrics [3]. Within this investigation, additional scatter due to mold shapes is not considered.

AIM OF THIS PAPER

In this paper, the main scope is to look for the correlation between the scatter of the local permeability value and the scatter of the global permeability value. The local permeability can be defined in two ways.

- First of all, a totally random normal distribution for the permeability along the longitudinal direction can be used with a coefficient of variation of 20%.
- A second possibility is assigning the local permeability values in a correlated way. In these cases, permeability changes between neighboring zones are limited through a correlation function. Also for this case, only scatter for permeability is implemented for the longitudinal direction. Within this investigation, this function is an exponential function taking into account the distance between the centers of gravity of the two considered zones, namely $\text{maximum deviation} = e^{-A \cdot \text{distance}}$. This function is characterized by a correlation value A [1/m], which is an unknown parameter. Increasing A, increases the permeability change between the considered zones.

IMPLEMENTATION

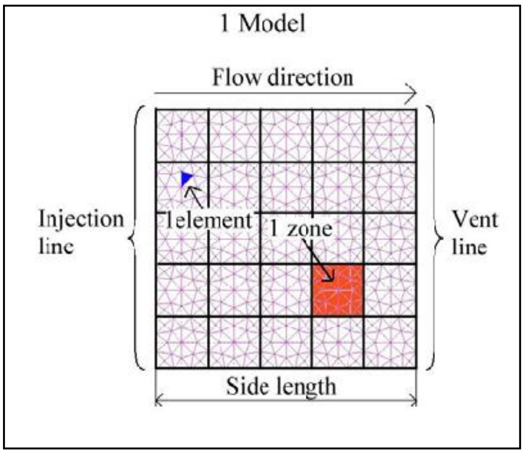

Fig. 1 Important terms for this investigation

In order to assign different permeabilities to a textile to be simulated using PAM-RTM, it is necessary to divide the textile preform model in zones (see Figure 1). In this investigation, only square mold models are considered. The meshing program subdivides each zone in a number of elements. This subdivision is characterized by the mesh density, this is the amount of elements /m². To each zone, the permeability in flow direction can be assigned in a totally random way. The permeability along the transverse direction is kept constant and equal to the average permeability of the longitudinal direction. All elements in one zone have the same permeability vector.

To obtain scatter for the global permeability, the Monte-Carlo technique is used. A certain amount of input files, each describing one model for the mold filling simulation software, is generated and solved by a pre-processing program. To be able to run these Monte Carlo simulations with PAM-RTM in an automatic way, batch programming was used. While PAM-RTM is solving the model, it generates a set of output files. The global permeability for each model is calculated from the corresponding output file (= filling as function of time) generated by PAM-RTM. This is done using the solution for Darcy's law in the one-dimensional case $K = \frac{0{,}5.L^2.\mu.\phi}{\Delta p.t}$ where K = global permeability [m²], L = side length [m], μ = resin viscosity [Pa.s], ϕ = porosity [ ], Δp= pressure drop [Pa] and t = filling time [s].

As performing a mold filling simulation with PAM-RTM is still taking some time, the amount of simulations for the Monte Carlo implementation is limited to 1000. With this amount, it is already possible to draw some conclusions. Influences of different parameters will be checked on the correlation between the average standard deviation for the local and global permeability. Those parameters are (see also Figure 1):

- The number of zones considered along 1 side
- The side length of the mold cavity
- The mesh density
- The correlation value A (only in the correlated cases)

The scatter for the local permeability will be characterized as follows: first of all, the standard deviation of all the permeability values assigned to the different zones within one model is calculated. This is done for all the models and in this way, an average standard deviation for the local permeability can be calculated.

The scatter for the global permeability is obtained from the length of the 95% probability interval of the global permeability distribution. Out of the length of this interval, a standard deviation for the global permeability can be obtained.

IMPLEMENTATION OF RANDOM PERMEABILITY DISTRIBUTION

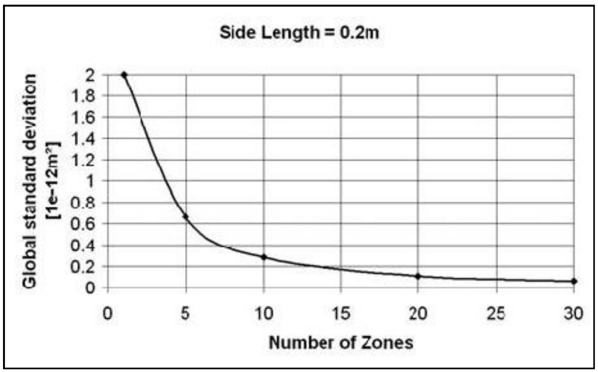

Fig. 2 Influence of number of zones

As the distribution of the permeability values with average value 10.10^{-12} m² and standard deviation 2.10^{-12}m² to the different zones is done in a totally random way, the average local standard deviation is always around 2.10^{-12}m². Analyzing different inputs for the parameters resulted in Fig. 2. The side length of the model is 0.2 meter. Out of Fig. 2, one can conclude that the number of zones along a side plays an important role. The standard deviation for the global permeability is smaller if more zones along a side are considered. For infinite number of zones, the standard deviation for the global permeability will be zero. This can be explained by the fact that the smaller the zones are, the smaller the region to have the average permeability value and the smaller the influence on the global permeability. In the mold filling, the small low permeable zone will be surrounded by resin and will not affect the flow front, as it would be the case for a large area with a low permeability. The situation as discussed above (random distribution of permeability values) is not realistic, because in nature, there doesn't exist parameters, which have infinite gradients as function of position. To have realistic models, a correlation function have been implemented in the preprocessing software of PAM-RTM to assign the permeability values to the different zon

IMPLEMENTATION OF CORRELATED PERMEABILITY

To define the permeability in a correlated way, the following technique is applied. First of all, a correlation matrix is calculated between all the zones present in the model by applying the correlation function between the two considered zones. This matrix has to be multiplied by the variance to obtain the covariance matrix V. This matrix is a symmetric, positive definite matrix, which can be Cholesky decomposed. This mathematical decomposition method is applied to obtain a lower triangular matrix L and its transpose which results in $V = L.L^T$. Next to this, a column vector Z has to be generated, which is a Gaussian vector with zero mean and covariance matrix I, with I the identity matrix. Since all the values in the matrix Z are mutually uncorrelated, a Gaussian random number generator can be used to sample the values making up the vector Z. Consider now the vector Y defined as follows: $Y = L.Z$. Applying the expectation operator yields:

$$E(Y) = L.E(Z) = 0 \quad E\left(YY^T\right) = L.E\left(Z.Z^T\right).L^T = L.I.L^T = L.L^T = V \tag{1}$$

Eqn. 1 proves that this technique can be used to define the permeability in a correlated way, if the average value for the permeability is added to each element of the matrix Y, these values can be assigned to the corresponding zone in the considered model.

PRE- AND POSTPROCESSING RESULTS

Fig. 3 shows the preprocessing results for different parameters. The number of zones along the length of the model is kept constant and equal to 5. Out of this figure, one can conclude

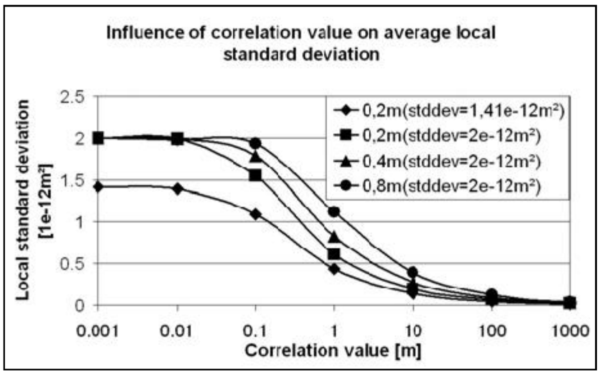

Fig. 3 Pre-processing results

- The larger the correlation value, the smaller the standard deviation for the local permeability.
- For the same correlation value, the standard deviation for the local permeability is larger for larger models. This is due to the fact permeability can change more if larger distances are possible within the model. If the distance between two points is equal to the correlation value, the maximum change in local permeability value is 63% of the reference standard deviation.
- The smaller the correlation coefficient, the more random the model becomes. For correlation value = 0, there is no correlation (= random distribution).
- The local standard deviation changes linearly with the applied reference standard deviation

After generation of 1000 files with locally distributed permeability values according to the reference distribution and using the correlation value, one obtains a distribution for the filling times of the model and hence also a distribution for the global permeability. From this distribution, the standard deviation is calculated and displayed in Fig. 4 in case of 5 zones and a side length of 0.2m. As conclusion, one can say the larger the correlation value, the smaller the standard deviation for the local permeability. All the values all over the model are almost the same. Of course, these values are chosen out of the reference distribution. For this reason, the global permeability distribution has a standard deviation, which is equal to the standard deviation of the reference distribution. This investigation shows that the standard deviation for the global permeability is allows equal or lower than the reference standard deviation.

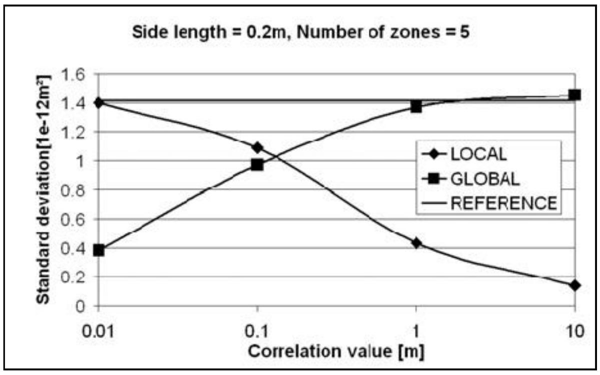

Fig. 4 Global versus Local standard deviation

CONCLUSIONS

For this investigation, still a lot of influences can be examined. Out of a large amount of simulation cases and investigation of the local permeability, it should be possible to define the correlation value. Together with the reference distribution for the local permeability, a general idea of the scatter on the global permeability will be possible to obtain. In future, implementing the scatter in the transverse direction has to be done. Next step in this investigation is to implement this scatter for arbitrary pieces and to allow a viscosity change.

REFERENCES

1. K. Hoes, M. Vanheule, H. Sol, "Statistical distribution of permeability values of different porous materials", *Proc. of The Tenth European Conference on Composite Materials (ECCM-10), 2002*

2. E. Belov, S.V. Lomov, I. Verpoest, T. Peters, D. Roose, K. Hoes, H. Sol, R.S. Parnas, "Modeling of permeability of Textile Reinforcements – Lattice Boltzmann method ", *Proc. of the Society for the Advancement of Material and Process Engineering EUROPE (SAMPE EUROPE 2004),2004*

3. S.V. Lomov, I. Verpoest, "Modeling of permeability of Textile Reinforcements – Lattice Boltzmann Method", *Proc. of the Society for the Advancement of Material and Process Engineering EUROPE (SAMPE EUROPE 2004),2004*

4. F. Desplentere, S.V. Lomov, D.L. Woerdeman, I. Verpoest, M. Wevers, P. Szucs, A. Bogdanovich, “ Geometrical characterization of 3-D warp-interlaced fabrics”, *Proc. of the Society for the Advancement of Material and Process Engineering USA (SAMPE USA 2003),2003*

5. A. Long, F. Robitaille, C.D. Rudd, I.A. Jones, “Modeling strategies for Textile Composites,” *Proc. of the Internatial Conference on Composite Materials (ICCM 14), 2004*

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1. Hoes K. , D.D., M. Vanheule, H. Sol. *Statistical distribution of permeability values of different porous materials*. in *ECCM10*. 2002.