

DAMAGE DEVELOPMENT AROUND MOULDED-IN HOLES IN FLAT BRAIDED COMPOSITES

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ABSTRACT

Textile techniques like overbraiding offer the possibility to perform some function integration during the composite fabrication stage. As an example, it is possible to integrate axes or holes necessary to transfer loads to the composite structure. Moreover, this prevents drilling and therefore fracturing load-carrying fibres at a latter stage. However, this means a local reorientation of the fibre and therefore a change in properties. This paper proposes a model for the reorientation of the fibres around a moulded-in hole. A subsequent finite element analysis shows the influence of this reorientation on the stress situation around the hole. Validation on pressed glass-PPS specimens loaded under tension shows that the proposed model is able to predict damage initiation in the vicinity of the hole.

INTRODUCTION

The Liquid Composites Moulding manufacturing technology offers the potential of producing composites structures in small series. Two steps can be distinguished in this technique: the manufacture of a dry fibre preform, and the injection of the resin into the preform. Various technologies can be used for both steps. Textile technologies are well suited for reproducible fibre placement on the preform, with controlled fibre orientation and concentration. One of these techniques is overbraiding, as illustrated in Figure 1.



Figure 1: Overbraiding (Courtesy Eurocarbon).

The fibre bundles are braided on a mandrel, which can be used as inner mould for the injection of the resin. In addition, load-carrying element like bolts and holes can be included in the structure during the braiding stage, where the fibres are reoriented around a temporary

cylinder, leading to moulded-in holes. This feature seems to offer great benefits from an engineering point of view, preventing extra fabrication stages after moulding. Moreover, such technique prevents fibre cutting, which potentially reduces the structural integrity of the composite product.

Beside evident advantages, the application of moulded-in holes also induces locally high and low fibre concentrations, as well as a strong fibre reorientation. Successfully applying this technique therefore requires detailed knowledge of the continuously varying fibre orientation and concentration in the preform.

This paper proposes a model for the relation between the change in fibre architecture around the moulded-in hole and the composite properties. For this purpose, a two-step approach is proposed. The fibre architecture around the hole is characterised by a geometrical model. This representation forms the basis for a meso-scale Finite Element model enabling a detailed stress analysis around the moulded-in hole. As a first step, the model is validated on a woven glass-PPS laminate with a moulded-in hole, loaded in tension.

MESOSCOPIC MODEL OF A MOULDED-IN HOLE

The model proposed is based on the following principles:

1. The description of the in-plane orientation of the bundles starts from the equations for streamlines around a cylinder (in 2D). This technique based on the work by Ng et al (1) was adapted to take into account the variation of bundle cross-section, as well as allowing bundle gap closure. Figure 2 illustrates the boundaries of the bundles around a cylinder.

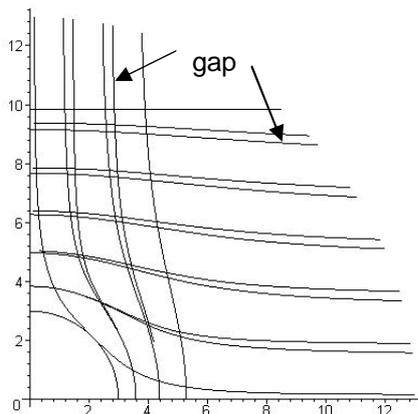


Figure 2: Modified Streamlines around a cylinder.



Figure 3: Unit cell

2. Volumes of hexagonal cross-section are generated around these streamlines, derived from a unit cell as displayed in Figure 3. The unit cell geometry depends on the weave pattern chosen. This unit volume is rotated, scaled and skewed at each location to represent the local tow geometry.
3. The material properties for the modelled tows are derived by implementing the method of Hashin and Rosen (2).
4. The orthotropic material properties are assigned to each meshed volume, depending on its orientation and concentration.

The defined geometry is transferred to the Finite Element package Ansys for meshing the geometry with solid elements and applying the loading. Figure 4 shows the geometry of a plain weave with a moulded-in hole, before meshing.

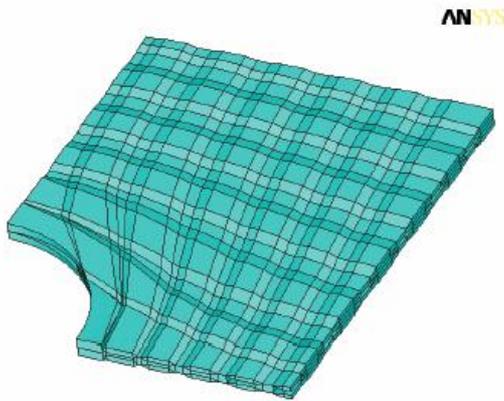


Figure 4: The solid model of the moulded-in hole.

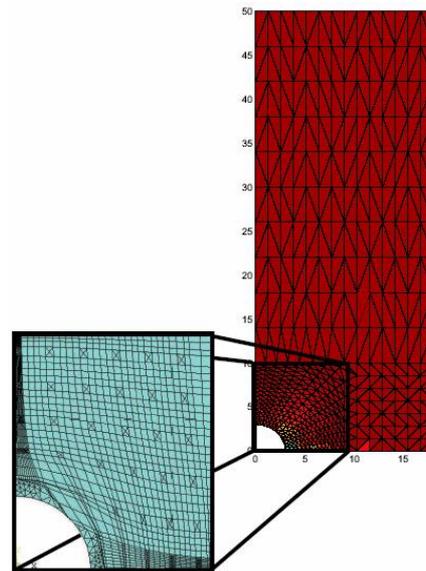


Figure 5: FE Model for tensile test

In order to apply the loading, only the region around the moulded in hole is modelled according to the method shortly described above. Averaged properties based on the classical lamination theory are used in the region far from the hole. Figure 5 shows an illustration of an FE mesh for a tensile test simulation.

VALIDATION ON TENSILE TESTS

The mesoscopic model of a glass plain weave was first validated by subjecting 6 layers thick glass-PPS specimens without moulded-in holes to a tensile loading. An average of 22.98 MN/m² for 5 specimens was measured, with a standard deviation of 0.6 MN/m². An approximation using the classical lamination theory gave a value of 25.4 MN/m². The mesoscopic model presented in this paper gave a value of 22.4 MN/m² and showed that the model proposed provides a good geometrical representation of the plain weave used.

Specimens with moulded-in holes were produced with the same glass plain weave with PPS. Dry fabric was laid on a purpose built aluminium mould, through which pins with conical heads could be pushed. Sheets of PPS were laminated between each fabric layers. Figure 6 shows the reorientation of the dry fibre bundles before consolidation, with its typical pseudo unidirectional regions.

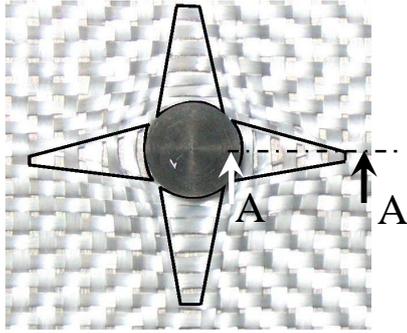


Figure 6: Fibre reorientation around a moulded-in hole, showing 'pseudo UD' regions.

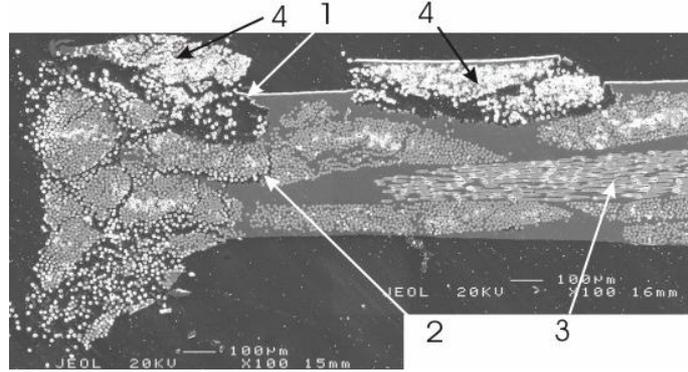


Figure 7: SEM of the A-A cross-section in Figure 6 after multiple cracking

A SEM picture of a cross-section (Figure 7) after failure shows the high fibre volume fraction and the unidirectional character of the obtained composite in the vicinity of the moulded-in hole. Tensile tests with these specimens show that the fibre concentration is also dominant when it comes to the occurrence of the first damage. The first crack induces a splitting of the first two longitudinal bundles beside the hole, as sketched in Figure 8. At the force at which cracking initiates, the finite element model shows a Von Mises stress in the intertow matrix (Figure 9) equivalent to the yield stress of the matrix. Subsequent damage events involved matrix cracking, splitting various bundle, as shown on the SEM in Figure 7. Shortly after, a fibre bundle fractures, followed by the final fracture of the specimen.

This behaviour is compared with that of a specimen with drilled hole. In this case, multiple matrix cracking occur at the boundary between bundles as sketched in Figure 10.

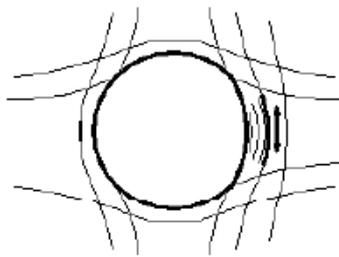


Figure 8: Representation of the growth of the first crack

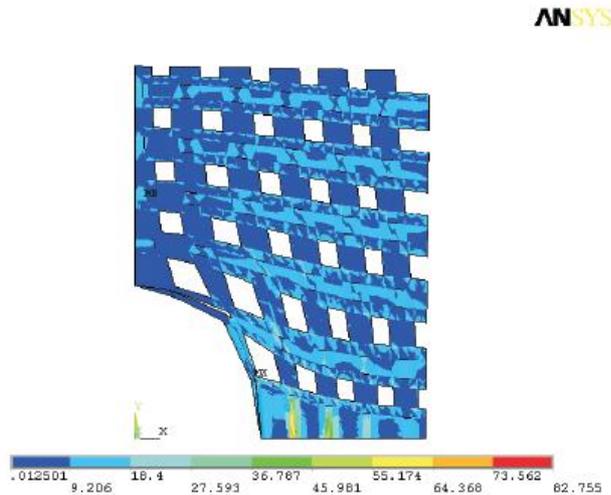


Figure 9: Von Mises stress in the intertow matrix

Further growth of such cracks occurs while the load is increased, prior to bundle fracture and sudden specimen fracture. It is worth adding that the initiation of damage in the specimens with moulded-in holes occurs at a lower load than for the one with drilled holes. The final fracture occurs at a similar load. An obvious question will be the influence of a pin filling the hole on the damage mechanisms. It is expected that the effect on the moulded-in holes will be larger than for the drilled holes, as it should reduce the tendency to split the bundles in the unidirectional region.

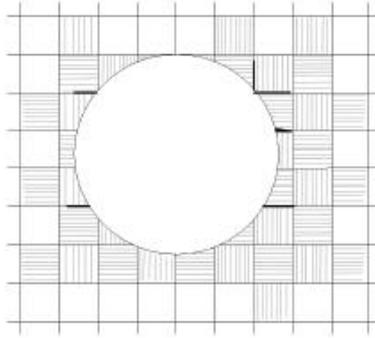


Figure 10: Representation of the first cracks around a drilled hole.

CONCLUSION

A mesoscopic model of the fibre redistribution of a woven cloth around a moulded-in hole is presented in this paper. Most characteristic is the formation of 'pseudo unidirectional' regions with high fibre concentration around the hole. Based on the mesoscopic model, a finite element model is built to analyse the stresses around a moulded-in hole. Some validation work on Glass-PPS showed that the model has the potential to predict the onset of damage. Further damage development was characterised experimentally but not yet validated at this moment. It shows that for the configuration used, the moulded-in hole do not give any clear strength advantage. The authors expect different conclusions when the hole is filled with a cylinder. Future work involves evaluating the damage predicting capability of the proposed model with different fibre architecture, as well as exploring the influence of a pin filling the hole.

REFERENCES

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1. Ng, S.P., Tse, P.C., Lau, K.J. *Composites, Part B: Engineering*, **32**: 139-152 (2001)
 2. Hashin, Z., Rosen, B.W. *Journal of Applied Mechanics*, 223-232 (1964)