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EFFECT OF INPUT PROPERTIES ON THE PREDICTED FAILURE OF A COMPOSITE PRESSURE VESSEL USING A MULTISCALE MODEL

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ABSTRACT

Composite materials are very useful for applications that require high structural integrity and when light weighting of a system is desirable, such as for composite pressure vessels (CPV). The current approach to evaluate their strength however is still based on the knowledge of the damage process in metal structures, i.e. crack propagation. It is thus very important to have a better understanding of the actual damage mechanism involved in composite structures in order to perform a reliability assessment. This essentially would give crucial insights for new and more effective structural designs.

When unidirectional carbon fibre composite specimens are loaded in the axial direction, failure initiation occurs in the form of randomly distributed fibre breaks. This leads to the creation of fibre break clusters and eventually results in the failure of the specimens [1-4]. A similar process also occurs on the load bearing layer of CPVs, i.e. the hoop layer, since the load acting in this case is similar to the tensile load on unidirectional specimens.

A multiscale fibre break model (FBM) developed at Mines ParisTech has shown relatively good comparison to the experimental observations by computed tomography (CT) technique, however, it was mentioned that a better description of T700 fibre properties is necessary as it may affect the accumulation process of the fibre breaks [5]. Therefore, further study on fibre strength characterisation can provide insights on the actual fibre strength variation and thereby also improve the quality of the failure predictions of the FBM. Different attempts have also been carried out to study the effect of loading rate using the FBM which gives a positive indication to further develop the model [7].

$$P(\sigma) = 1 - \exp\left\{-\left(\frac{L}{L_0}\right)\left(\frac{\sigma}{\sigma_0}\right)^m\right\} \quad (1)$$

Eq. 1 shows the standard 2-parameter Weibull distribution equation typically used to represent strength distribution of brittle fibres. Where, $P(\sigma)$ is probability of fibre failure, L being the characteristic gauge length, L_0 the reference gauge length, σ the fibre strength, σ_0 the scale parameter and m the shape parameter or Weibull modulus. In a recent study by Islam et al [8-14], they have quantified the expected uncertainty in the parameters of the fibre strength distribution arising due to the effect of different causes such as sampling randomness and measurement uncertainty. The sample size used for this study was similar to the sample size popularly used by previous researchers for determining the representative fibre strength Weibull distribution. This knowledge about the uncertainty in input fibre properties can be used to predict the variability in the predictions of composite strength models for the strength and damage behaviour of composite materials and

structures. In this paper, an attempt has been made to understand the variability in the predicted failure of CPVs using the FBM, as a result of the expected variability in the input fibre properties.

For this, further work has been carried out to extend the use of the FBM for predicting the strength of composite pressure vessels. A reduced volume method has been developed to increase the computation speed by reducing the number of degree of freedoms in a simulation [15, 16]. This method has justified the use of the FBM to be assigned only at the hoop layer of a CPV and has also been favourably validated with an improved NOL ring experiment [17]. An investigation of the stacking sequence and fibre volume fraction of a type IV CPV has also been carried out in collaboration with The University of Southampton, which resulted in another favourable comparison with the experiment [18]. These are very critical parameters for the FBM, as it affects the stress state of the hoop layer. It is important to be mentioned here that the focus of this study is to determine the effect of fibre strength distribution parameters on predicting the failure of a type IV CPV. The comparison has been done using the T600S fibre properties determined in 2005 and the T700S fibre properties with corresponding uncertainty that has been determined through an experimental and statistical study recently. Nevertheless, the difference in stiffness in the fibre direction of the different fibre types is not significant; see table 1, but the difference in their failure strength behaviour is significant. The parameters of the fibre strength Weibull distribution for T700S fibres along with corresponding uncertainty obtained by Islam et al are given in Table 2.

Table 1: Material properties for the FBM [5]

Composite	C_{11} (MPa)	C_{22} (MPa)	C_{66} (MPa)	m	σ_0 (GPa)
T600S/epoxy [1]	149080	13974	5470	5.62	4.32
T700S/epoxy [6]	151090	11375	4500	4	5.8

Table 2: Fibre strength distribution parameters with uncertainty

Fibre type	Shape (m)	Scale (σ_0) (GPa)
T700S [8-12]	3.8 ± 1.0	4.4 ± 0.5

Four mesh configurations have been investigated to find the most efficient to characterise the strength of CPV, see figure 1. The third configuration succeeded to give a reliable prediction of failure with an acceptable computation time using the cluster provided from Mines ParisTech. This configuration has been used to evaluate accumulation process of fibre breaks and the scatter of the burst pressure.

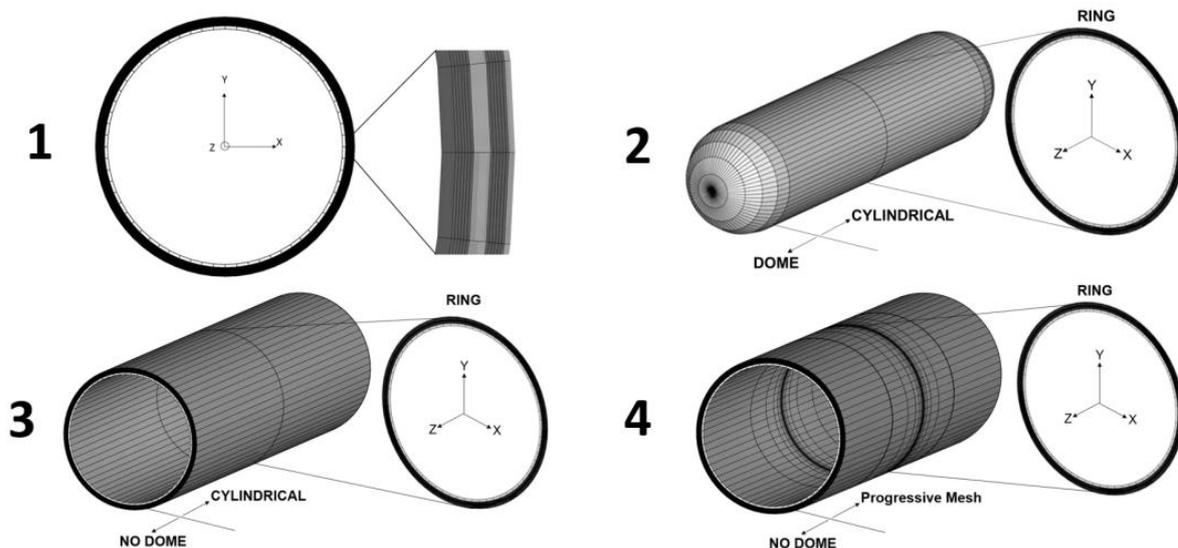


Figure 1. Different mesh configurations used for modelling the CPV

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