A COMPUTATIONAL METHOD FOR THE PREDICTION OF DAMAGE AND DELAMINATION IN COMPOSITE PIPES

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ABSTRACT

This work is supported by Alcatel Space who needs a numerical tool for the prediction of the behaviour of composite pipes in presence of defects. A first step in this direction is to be able to predict the evolution of the damaging during a thermo-mechanical loading. To decrease the cost of such a non-linear 3D computation, an efficient computational strategy has to be studied. Regarding the pipe degradations, the problem can be simplified. The main defects and degradations are located at the edge of the pipe, so a simple elastic beam model is used to compute the stresses and the strains at the heart of the pipe. Then a local analysis is conducted on the edge zone using a non-linear 3D computation. A special treatment of the edge zone is done because the edge problem remains too costly.
Two different models cohabit in this strategy and boundary conditions have to be extracted from the beam solution to be imposed on the 3D edge model. This link must not generate spurious effects near the linking zone (spurious damage for example). The link must contain the Saint-Venant solution and to obtain this solution the exact beam theory developed by Ladevèze and Simmonds is used. Let's remark that it is very difficult to build such a link with a classical beam theory.
Regarding the edge zone, each elastic 3D resolution is solved using an axisymmetric preconditioner. The problem linked to this preconditioner is uncoupled in a set of 2D problems. For that a Fourier series expansion of the displacement field and the loading is done. This Fourier expansion allows to uncouple the 3D problem because of the material layout. The transfer from the 3D problem to the 2D ones is performed by a FFT and its inverse.
This strategy has been illustrated on carbon fabric composite pipe modelled using the meso-model developed by Ladevèze and extended to fabric plies by Hochard.

1 INTRODUCTION

During the manufacturing process of RTM composite pipes, some defects appear such as delamination, transverse cracking, etc. . These defects are not taken into account during the design stage. Industrials such as Alcatel Space which supports this study, must decide if in presence of defects a pipe is usable or must be rejected. For the moment many pipes are rejected but this decision is very expansive. That's why an adapted computational strategy to predict the influence of defects is required. A first step in this direction is to be able to predict efficiently the evolution of the damaging state in a composite pipe. Then defects will be included and the influence of the temperature on the behaviour of the material will be added. This paper develops , in a linear case, the main ingredients that are needed to lead an efficient computation in the non-linear case.
To avoid a costly complete non-linear computation, the problem is simplified regarding the degradations localization in RTM composite pipes (G969/RTM6). Defects and damaging is assumed to be localized at the edge of the bar, so a simple elastic beam theory is used to compute the solution at the heart of the pipe. Some boundary conditions are built with the beam solution and imposed on the 3D non-linear edge model to be able to catch the edge effect.
In the first part, the linking technique is presented. It is based on the exact beam theory. In the second part, the 3D edge model is solved efficiently using a Fourier series decomposition that allows to uncouple the 3D problem.

2 THE LINK PROBLEM

2.1 The link problem

The link between the beam theory and the 3D model must no generate spurious damage near the linking zone. For that, the information included in the linking technique must be the Saint-Venant solution of the problem. The problem becomes to be able to build the Saint-Venant solution from the beam theory. It is difficult with a classical beam theory (Euler Bernoulli for example) but very easy with the exact beam theory (Ladevèze [1]). The figure 1 shows the evolution of the radial stress in a [0/90/0] beam in bending for different linking techniques (one based on Saint-Venant and three based on a classical beam theory). With link based on a classical theory, spurious stress appear near the linking edge.

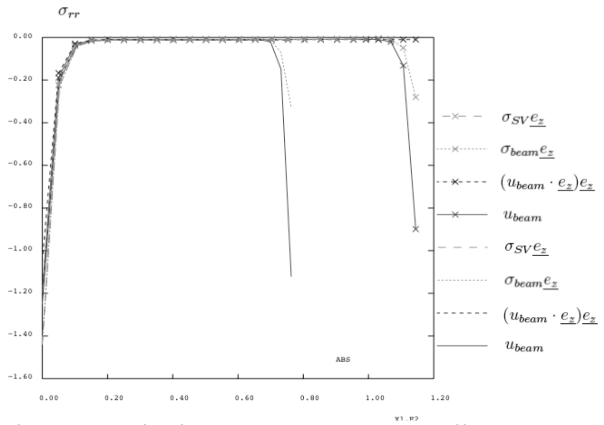

figure 1: [0/90/0] beam in bending - different link techniques

2.2 The exact beam theory

Generalized quantities are defined to produce the same Saint-Venant solution for two different loadings having the same generalized quantities. The Saint-Venant solution is given by the following expression :

$$U_{sv} = \tilde{u} + \tilde{\omega} \wedge m\vec{M} + \mathbb{A}\tilde{T} + \mathbb{B}\tilde{M} + z_d$$
$$\sigma_{sv}\vec{e_z} = \mathbb{A}^0\tilde{T} + \mathbb{B}^0\tilde{M} + Z_d$$

where the tilde notation stands for generalized quantities. The generalized displacements and stresses are solutions of the following 1D problem.

$$\frac{d\tilde{T}}{dz} + f_d = 0$$
$$\frac{d\tilde{M}}{dz} + \vec{e_z} \wedge \tilde{T} = 0$$
$$\begin{pmatrix} \tilde{\gamma} \\ \tilde{\chi} \end{pmatrix} = \lambda \begin{pmatrix} \tilde{T} \\ \tilde{M} \end{pmatrix} + \begin{pmatrix} z_d \\ Z_d \end{pmatrix} with \begin{cases} \tilde{\gamma} = \tilde{u}_{,z} + \vec{e_z} \wedge \tilde{\omega} \\ \tilde{\chi} = \tilde{\omega}_{,z} \end{cases}$$

3 THE EDGE PROBLEM

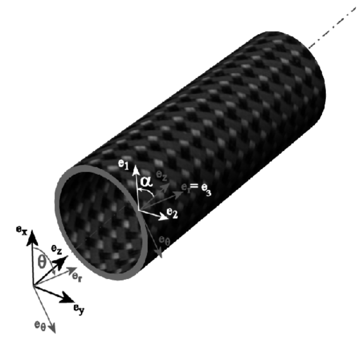

figure 2: material layout

The 3D edge problem described on figure 2, is uncoupled to be solved more efficiently (Allix [2]). For that let us remark that developing the pipe leads to a standard laminate plate. It means that the Hooke matrices in the cylindrical basis are constants. The displacements en loadings are expanded in Fourier series and included in a variational formulation. It can be proved that solving the 3D problem is equivalent to solve a set of 2D problems and some FFTs. These 2D problems are coupling two modes in cosines and in sinus, that's why the finite elements used have two times more unknowns than in 3D. A prototype finite element code has been implemented with Matlab. The figure 3 shows the evolution of the shear stress in a [30/-30/0/-30/30] pipe in bending and clamped at one edge with a titanium sleeve.

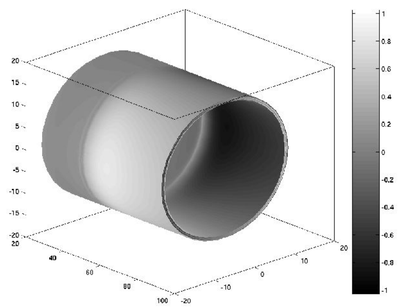

figure 3 : shear stress in a [30/-30/0/-30/30] pipe in bending

This Fourier formulation is available for axisymmetric pipes, so it is used as a preconditioner to solve the problem of pipe including damaging. Regarding to the non-linear computation, each linear step is solved with a preconditioned conjugate gradient. The transfer between the 2D problems and the 3D one is performed by some fast Fourier transforms.

The material is modelled using the meso-model developed by Ladevèze (Ladevèze [3], Allix [4]) and extended to fabric plies by Hochard (Hochard [5]).

4 CONCLUSION

This paper presents an efficient computational strategy to predict the evolution of damage and delamination in composite pipes. This is a first step toward the prediction of the influence of defects on the behaviour of RTM bars. This strategy can be divided into two key points.

The first point assumes that the solution at the heart of the pipe is independent of the degradation that occurs at the edges. That's why a simple elastic beam model is used. This model is based on the exact beam theory and thus gives the Saint-Venant solution of the bar. This Saint-Venant solution is the best way to link the beam model to the 3D edge one.

The second point allows to uncouple a 3D axisymmetric problem in a set of 2D Fourier problems. An efficient strategy is built to solve such axisymmetric problems. Because the real pipe with defects is not axisymmetric, this last problem is solved using a preconditioner.

This strategy has been implemented in Matlab and illustrated on an industrial case : a [30/-30/0/-30/30] pipe (G969/RTM6) in bending and clamped on one edge with a titanium sleeve.

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