IMPLEMENTATION OF A FIBRE KINKING MODEL FOR DAMAGE GROWTH WITH FRICTION: HANDLING MESH OBJECTIVITY

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Summary: In the current paper we propose a mesh objective numerical model which is able to capture the main mechanisms of fibre kinking

ABSTRACT

A model for the longitudinal response of laminated fibre-reinforced composites during compressive damage growth is implemented in a Finite Element (FE) package and validated for mesh objectivity.

The numerical way to solve the stress equilibrium and stress compatibility equations simultaneously in an FE framework is presented. The results show that the current model is mesh-size-independent even for highly distorted meshes. The current numerical model can be used to predict the kinking response accounting for the correct energy absorption.

1 INTRODUCTION

It is necessary to predict the crash response of composites in order to increase its usage in the automotive industry in a cost-efficient way. In order to maximize the energy absorption of composite materials some fibres must be oriented longitudinally with the loading directions. In this orientation fibres fail mainly by kinking[1] which is good for energy absorption but difficult to predict the response. Currently, there are no numerical models able to capture all the mechanisms involved in the kinking response of fibre composite materials.

However, to predict the crash response, it is necessary to have a kinking model in an FE framework that captures the mechanisms of kinking. This model must be mesh-size-independent in order to correctly account for the energy dissipation.

In the current paper we propose a mesh-objective numerical model which is able to capture the mechanisms of fibre kinking

2 MODEL

The current model builds upon previous development coupling damage with the friction[2] induced at crack closure. It is combined with fibre kinking theory to provide a 3D constitutive law which gives the full response from initiation to crushing in longitudinal compression.

The fibre kinking response is found from solving simultaneously the stress equilibrium, Eq. (1), between applied global stresses and nonlinear local stresses resulting from the nonlinear constitutive law of the material in the kink-band Eq. (2). The actual rotation of the fibres in the kink-band is resolved from Eq. (3) the strain compatibility

$$\sigma_{11} = \left[\sigma_{22} sc + \tau_{12}(c^2 - s^2) - \tau_{12m}\right] / (sc) \tag{1}$$

$$\tau_{12m} = G_{12}\gamma_{12m}(1-d) + d\tau^{friction} \tag{2}$$

$$f(\gamma_{12m}) = \varepsilon_{11m}c^2 + \varepsilon_{22m}s^2 - \gamma_{12m}cs - \varepsilon_{11} = 0 \tag{3}$$

2.1 Implementation

The model described previously was implemented into a user subroutine, VUMAT, in the commercial FE code ABAQUS. In order to solve the stress equilibrium and the strain compatibility it is necessary to use a root-finding method, e.g. bisection method.

2.2 Mesh Objectivity

The challenge with damage models is that they have a softening response, which makes it necessary to deal with the strain softening behaviour. A cube of side L=1 mm was meshed with one element (1x1x1) and successively refined till (5x5x5). When more elements are added, the softening response is mesh dependent, Figure 1

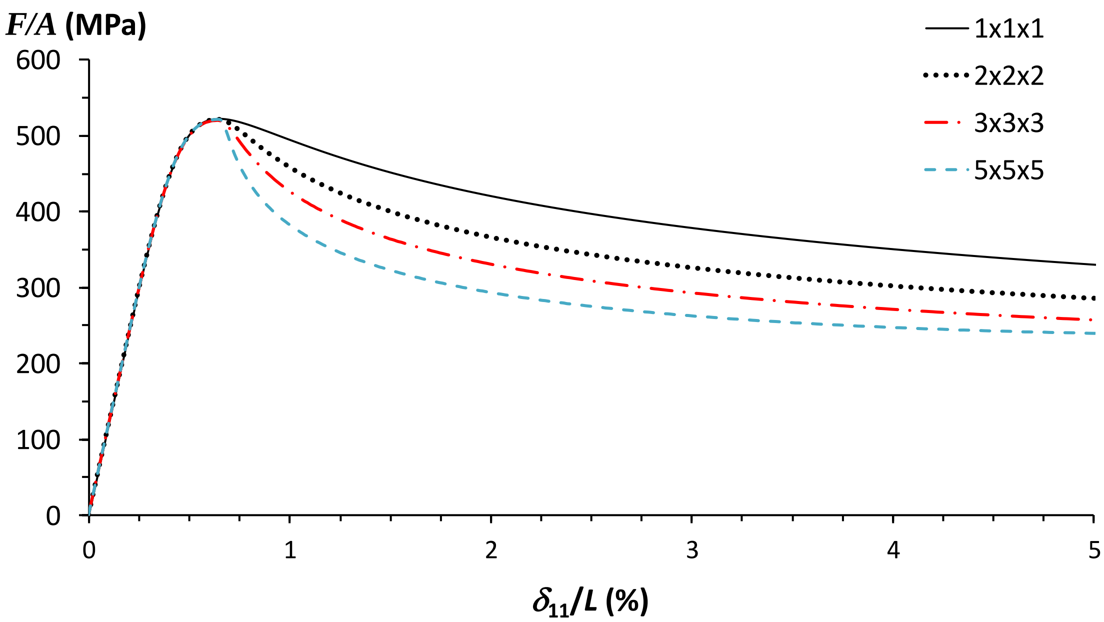

Figure 1: FE model responses showing the mesh dependency issue

In the method used, the strain in the kink-band is distributed (smeared) over the whole element. When softening starts, i.e. when the peak stress has been reached, the strain in the kink-band is smeared over entire element. For the detailed implementation please refer to [4].

3 RESULTS

In this section only the tougher challenge for the model is presented. Irregular or badly shaped meshes may affect the localization of the fracture into a kink-band as well as the measure of the effective size of the element and consequently affect the objectivity of the results. In spite of this, the results are converging quite well considering the highly distorted mesh and the amount of softening, Figure 2.

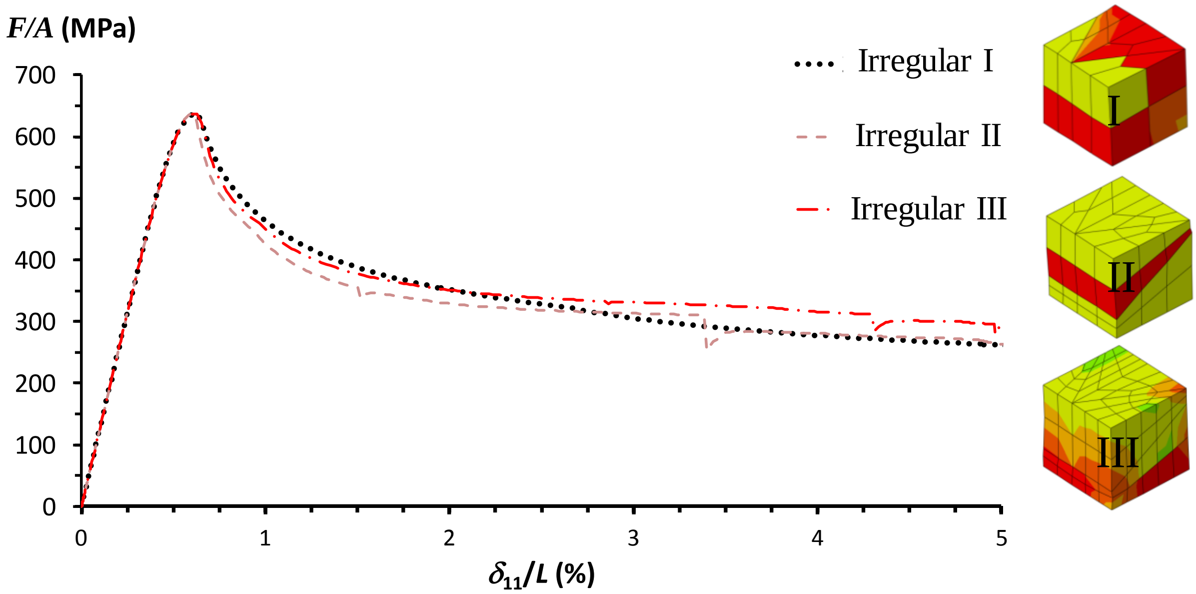

Figure 2: Three levels of discretization of highly distorted elements: Mesh and Damage at 3% strain and respective responses

4 CONCLUSIONS

A fibre kinking model was successfully implemented and validated for highly distorted mesh showing successfully mesh convergence.

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