TRACTION-SEPARATION LAWS ON THE APPLICATION OF COHESIVE-ZONE MODELS TO DELMINATION BEHAVIOUR OF COMPOSITE MATERIAL

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1 Introduction

In the last decades, cohesive-zone models (CZM) have been widely used to simulate crack initiation and/or propagation between two surfaces, such as delamination in composite [1]. But the use of cohesive elements poses numerical difficulties related to the definition of some cohesive parameters, the choice of softening constitutive laws, etc [2].

In this work, specimens made of carbon-epoxy were tested under DCB (mode I) and ENF (mode II) loadings. The crack propagation was simulated by a 3D model with cohesive elements using LS-dyna software to investigate the effect on the accuracy of the simulation of the cohesive zone length: l_{CZ}, the interfacial strength: σ_{max}, the interface stiffness: K_0, and the traction-separation load curve (TSLC).

2 Results and discussions

Fig 1 shows different shape of TSLC. The area under TSLC is equal to fracture toughness G_C at which crack growth occurs. For the composite tested, the toughness measured by DCB and ENF equals to $G_{IC} = 0.516 N/mm$ and $G_{IIC} = 1.88 N/mm$

Note that the following values were usually used in the literature for carbon-epoxy composite:

$\sigma_{I,\max} = 40MPa; \sigma_{II,\max} = 80MPa; K_0 = 2\times10^5 N/mm^3$

They would be considered as reference values.

2.1 Length of cohesive zone: l_{CZ}

l_{CZ} is defined as the distance from the crack tip to the point where σ_{max} is reached. It is well known that at least two elements within l_{CZ} are necessary to guarantee an accurate simulation with CZM [3]. In the case of slender structure under mode I and mode II loadings, l_{CZ} can be estimated by [4]

$$l_{cz,I} = \sqrt[4]{E_I' h^3 G_{IC} / (\sigma_{I,max})^2} \quad (1)$$

$$l_{cz,II} = \sqrt{E_{II}' h G_{IIC} / (\sigma_{II,max})^2} \quad (2)$$

Where E_I' and E_{II}' are equivalent elastic modulus for mode I and mode II, respectively. The values obtained by Eq.(1) and Eq.(2) with reference values are compared with the results from numerical simulation (NS) in Fig.2. It can be observed that the values of l_{CZ} from Eq.1 and Eq.2 are too high compared to numerical ones, which increases slightly with element size l_e. In order to get more elements within l_{CZ}, l_e =0.25mm for DCB (5 elements in l_{CZ}) and l_e =0.5 mm for ENF (7 elements in l_{CZ}) have been chosen for the studies described in the following sections.

2.2 Cohesive law

Herein, the simulation was carried out by applying different cohesive law (Fig.1) with the same reference values. The slope of all P-δ curves obtained by numerical simulation, k^{NS}, is almost the same for a given loading case. k_I^{NS} of DCB is a little greater than experimental value k_I^{EXP}, but no difference between k_{II}^{NS} and k_{II}^{EXP} for ENF. Concerning the maximum load, $P_{I,\max}^{NS}$ for DCB are 4%-10% higher than $P_{I,\max}^{EXP}$, whereas $P_{II,\max}^{NS}$ for ENF 3.8%-10.9% lower than $P_{II,\max}^{EXP}$. Trapezoidal and linear-parabolic laws always give maximum and minimum value of the maximum load P_{max} in both of DCB and ENF simulation.

2.3 Maximum interfacial strength: $\sigma_{\max}$

The effect of $\sigma_{\max}$ on P_{max} and k is illustrated by Figure 3 and Figure 4, where the simulation was realized by keeping K_0 constant and varying $\sigma_{\max}$ in a large range. It is shown that for DCB, there are a few differences on $P_{I,\max}^{NS}$ and k_I^{NS} when $\sigma_{\max}$ changes from 10 to 60MPa. But too small $\sigma_{I,\max}$ leads to decrease of these values, whereas too high $\sigma_{I,\max}$ brings out an important error in P_{max}. For ENF, $P_{II,\max}^{NS}$ increases with $\sigma_{II,\max}$, but k_{II}^{NS} remains nearly constant except for certain cases of exponential law.

2.4 Interface stiffness

The interface stiffness should be large enough to provide a reasonable stiffness but small enough to reduce spurious oscillations of traction in an element. If $\sigma_{I,\max} = 40MPa, \sigma_{II,\max} = 80MPa$, P_{max} and k increase firstly and then become stable with increasing K_0 whatever loading mode (to see Fig.5 and Fig.6). Trapezoidal law always gives the highest value of P_{max} in both of DCB and ENF simulation.

3 Conclusions

In order to guarantee accurate results of simulation, the mesh size of cohesive element has to be chosen so as to obtain at least two elements within the length of cohesive zone. Moreover, if small value of the interfacial strength and stiffness is preferable, the following conditions have to be respected:

$\sigma_{I,max} \geq 50\%\ Z^+$ (traction strength in the thickness);

$\sigma_{II,max} \geq S_{13}$ (shear strength in the plane 1-3) ;

$K_{I,0} \geq 2E_{33}/t$ and $K_{II,0} \geq 4G_{13}/t$

Where E_{33} is Young's modulus in the thickness; G_{13} the modulus in the plane 1-3 and t is the thickness of each arm separated by the crack in DCB and ENF.

If these parameters have been correctly determined, the effect of different shapes of the traction-separation load curve on the slope of load-displacement curve can be neglected. Trapezoidal law and linear parabolic law always give maximum and minimum value of the maximum load P_{max}.

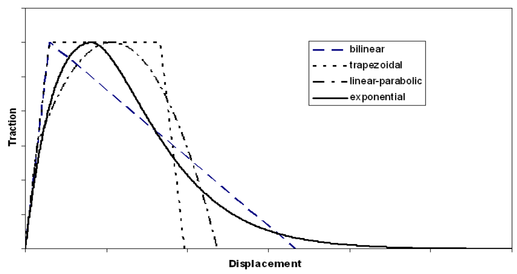

Figure 1: different shape of TSLC

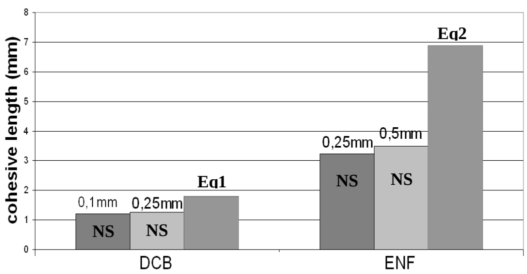

Figure 2: Values of L_{cz} determined by Eq1-2 and NS

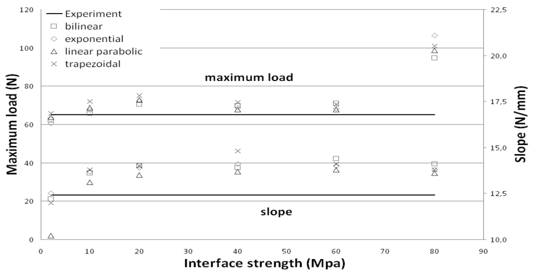

Figure 3: Effect of σ_{max} on P_{max} and k for DCB

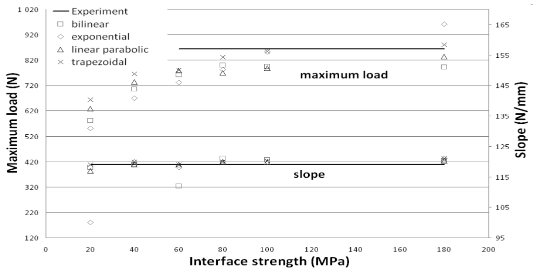

Figure 4: Effect of σ_{max} on P_{max} and k for ENF

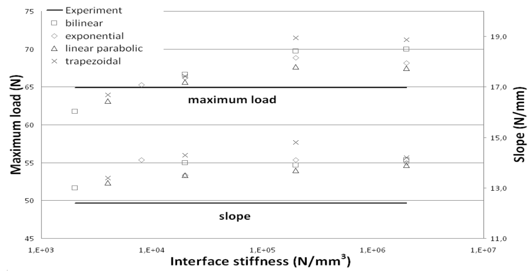

Figure 5: Effect of K_0 on P_{max} and k for DCB

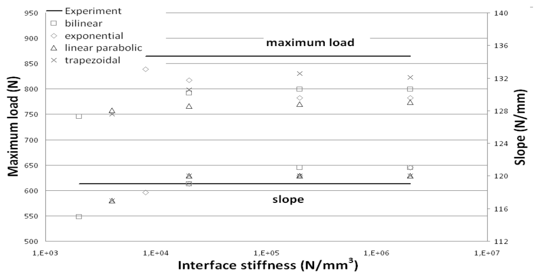

Figure 6: Effect of K_0 on P_{max} and k for ENF

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