THESES

1. Thesis

It was shown that the correction function derived by using the Winkler-type elastic foundation for the strain energy release rate of composite beams with midplane delamination and when the upper and lower arms exhibit the same mechanical properties under mixed-mode I/II condition may be written as:

$$f_{W2} = 5.42\left(\frac{h}{a}\right)\left(\frac{E_{11}}{E_{33}}\right)^{\frac{1}{4}} + 2.45\left(\frac{h}{a}\right)^{2}\left(\frac{E_{11}}{E_{33}}\right)^{\frac{1}{2}}. \qquad (1)$$

The classical solution of WILLIAMS for the mode-I double-cantilever beam specimen including the Winkler-type elastic foundation resulted in the following term:

$$f_{W} = 15.36\left(\frac{h}{a}\right)\left(\frac{E_{11}}{E_{33}}\right)^{\frac{1}{4}} + 4.92\left(\frac{h}{a}\right)^{2}\left(\frac{E_{11}}{E_{33}}\right)^{\frac{1}{2}}. \qquad (2)$$

The difference between Eqs. (1) and (2) may be explained by the theorem of parallel axes. The present formulation considers that the reference plane with respect to bending coincides with the midplane of the model. This fact resulted in a four times higher second order moment of inertia of the uncracked region of the model in comparison with WILLIAMS' formulation. This indicates that the generalization of WILLIAMS' solution for mixed-mode I/II problems is unjustified. The difference between the two solutions was demonstrated by using the models of SCB, SLB and MMB specimens.

2. Thesis

The global mode decomposition method was completed with the Winkler-Pasternak foundation, transverse shear, Saint-Venant and crack tip shear deformation effects in that case when the upper and lower arms of the model exhibit the same mechanical properties and the delamination is symmetrically located along the beam thickness. The individual components of the strain energy release rate are:

$$G_I = \frac{M_I^2 (12 + f_{W2} + f_T + f_{SV})}{b^2 h^3 E_{11}}, \qquad (3)$$

$$G_{II} = \frac{M_{II}^2 (9 + f_{SH2})}{b^2 h^3 E_{11}}. \qquad (4)$$

***2.1** It was shown that the Winkler-Pasternak elastic foundation (f_{W2}), transverse shear (f_T) and the Saint-Venant (f_{SV}) effect improves only the mode-I, while the crack tip shear deformation (f_{SH2}) contributes only to the mode-II strain energy release rate.*

***2.2** Using the developed strain energy release rate expressions (Eqs. (3) and (4)) and the finite element method the coefficient of the Pasternak foundation parameter was determined. It was found to be a constant value (ω=2.5).*

2.3 *The results of the solution were compared with existing beam, plate and finite element solutions, respectively. It was found that the present solution gives the reasonably good description of both the compliance and the strain energy release rate and in each case shows similar relationship to the finite element solution.*

2.4 *Mode-II (ELS, ONF) and mixed-mode I/II (SLB, SCB) experimental tests were performed on unidirectional glass/polyester composite specimens with midplane delamination to demonstrate the applicability of the developed beam model, which was found to be suitable to reduce the experimental data.*

3. Thesis

An improved expression was derived for the compliance of composite beams, which accounts for the Winkler-Pasternak foundation (f_{W1}), transverse shear (C_{TIM}), Saint-Venant (f_{SV}, C_{SV}) and crack tip shear deformation (f_{SH1}) effects, in that case when the arms of the model exhibit the same mechanical properties and the delamination is symmetrically located along the beam thickness:

$$C = C_{EB} + C_{TIM} + \frac{f_I^2 a^3}{2bh^3 E_{11}}\left(f_{W1} + \frac{f_{SV}}{2}\right) + \frac{f_{II}^2 a^3}{2bh^3 E_{11}} f_{SH1} + C_{SV} . \qquad (5)$$

3.1 *The application of Eq. (5) was demonstrated through models of unidirectional SCB, SLB and MMB specimens. The obtained results were compared with results by finite element calculations and existing analytical models. It was shown that the developed compliance expression ensures the desired accuracy.*

3.2 *The applicability of Eq. (5) was demonstrated through experiments performed on unidirectional glass/polyester composite ELS, ONF, SCB and SLB specimens. In each case the result of Eq. (5) was in good agreement with the measured compliance values.*

4. Thesis

A novel mixed-mode I/II test configuration was developed, which is called the over-leg bending (OLB) specimen. The OLB specimen is the modified version of the traditional single-leg bending (SLB) coupon.

4.1 *The applicability of the test was demonstrated by using unidirectional glass/polyester specimens with midplane delamination. The compliance and the individual strain energy release rate components of the novel configuration were derived by the help of the developed beam model.*

4.2 *A remarkable advantage of the test is that the large displacements (which play a dominant role in composites with low flexural modulus) can be avoided and the crack propagation can be easily controlled (in contrast with the SLB and SCB coupons). The test gives essentially a linear elastic response and simple reduction techniques can be applied for data evaluation. A relative drawback of the test is that the mode-ratio may be varied only with a small degree.*

5. Thesis

A combined analytical-experimental approach was developed to investigate the fiber-bridging effect in unidirectional mode-I double-cantilever beam specimens with midplane delamination.

5.1 *The beam theory-based solution is suitable to predict the number of bridging fibers and the bridging force. The application of the model is slightly time-consuming, however the calculation may be performed (in contrast with the previously developed numerical and semi-empirical approaches) by the help of some essential material properties, such as the fiber diameter* d_f *and elastic modulus of the fibers* E_f.

5.2 *A numerical solver for the application of the model was developed in the code MAPLE. The applicability of the model was demonstrated by using unidirectional glass/polyester double-cantilever beam specimens. It was shown that the number of bridging fibers follows a hyperbolically decreasing trend as the crack advances, while the bridging force reaches a peak value and then it tends to a steady-state value. In comparison with the results of a semi-empirical solution the obtained results are quite similar.*

6. Thesis

6.1 *It was established that in the case of the DCB, ELS, SCB and SLB specimens the critical load at crack initiation approximately exhibits a hyperbolic behavior against the crack length. In contrast, the critical force has approximately a parabolic nature in the case of the ONF and OLB coupons. The latter may be explained by the eccentrically introduced load between the two supports and that the characteristic distance is the length of the uncracked region instead of the crack length.*

6.2 *The critical displacement at crack initiation showed approximately a parabolic dependence on the crack length in each specimen type (DCB, ELS, ONF, SCB, SLB and OLB). In the case of the ELS and SCB specimens the limitation of the large displacements was established and the reasonable range of the crack length was indicated.*

6.3 *It was shown that the smallest critical displacement occurs in the ELS coupon if* $a=0.53L$*, which is eventually the limit of crack stability (*$a \geq 0.55L$*).*