ADVANCED BEAM MODEL FOR FIBER-BRIDGING IN UNIDIRECTIONAL COMPOSITE DOUBLE-CANTILEVER BEAM SPECIMENS

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Summary In the present work we develop a model based on linear beam theory incorporating elastic foundation and bridging effects in composite DCB specimens. The model is applicable for fiber-bridging [1] modeling in the case of optional number of bridgings. Traditional DCB test on unidirectional glass/polyester specimens was carried out providing input data for the analysis. The model is suitable to predict the nonlinear bridging law, the total force exerted by the bridgings and the total number of bridging fibers.

ANALYSIS OF THE BRIDGED DCB SPECIMEN

We provide closed-form expressions for the compliance of unidirectional composite DCB specimens. The model incorporates the Winkler-type foundation [2] (classical solution of Williams) and the effect of fiber-bridging. The foundation stiffness can be related to the through-the-thickness moduli of the specimen. The bridgings were represented by elastic beams, described by their tensional stiffness and initial length. Fig.1 shows the model of the DCB specimen including one bridging. Based on the present model the following equation can be derived for the specimen compliance:

$$C_{DCB} = \frac{8a^3}{bh^3E_{11}}[1+1.92\left(\frac{h}{a}\right)\left(\frac{E_{11}}{E_{33}}\right)^{\frac{1}{4}} + 1.22\left(\frac{h}{a}\right)^2\left(\frac{E_{11}}{E_{33}}\right)^{\frac{1}{2}} + 0.39\left(\frac{h}{a}\right)^3\left(\frac{E_{11}}{E_{33}}\right)^{\frac{3}{4}}] + \\ -\frac{P_1}{P}\frac{[(3a(L_1^2+L2^2)-(L_1^3+L_2^3))\lambda^3+6a(L_1+L_2)\lambda^2+3\lambda(L_1+L_2+2a)+6]}{6\lambda^3 I_y E_{11}} = C^0_{DCB} - C^{FB}_{DCB} \quad ,(1)$$

where the term C^0_{DCB} is the specimen compliance based on the Winkler foundation model [3]. The term C^{FB}_{DCB} accounts for fiber-bridging in the delaminated region. The fracture toughness can be obtained by differentiating Eq.(1). We must differentiate all the quantities which are dependent on the crack length in Eq.(1). This is a quite complex problem, and cannot be solved analytically. However the location of bridgings $L_1(a)$ and $L_2(a)$ are linear functions of the crack length a, the force $P_1(a)$ as the function of crack length is difficult to obtain. Hence the term resulting from the derivative of the second term C^{FB}_{DCB} in Eq.(2) is denoted symbolically by G_I^{FB}, thus the fracture energy:

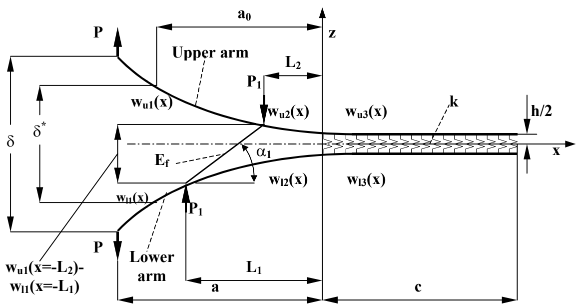

Fig.1.
For the analysis of the fiber-bridging in the DCB specimen

$$G_I = \frac{12Pa^3}{b^2h^3E_{11}}[1+1.28\left(\frac{h}{a}\right)\left(\frac{E_{11}}{E_{33}}\right)^{\frac{1}{4}} + 0.41\left(\frac{h}{a}\right)^2\left(\frac{E_{11}}{E_{33}}\right)^{\frac{1}{2}}] - G_I^{FB}. \quad (2)$$

Eq.(1) can be generalized for optional number of bridgings. According to our analysis the compliance of the bridged DCB specimen has the following from:

$$C_{DCB} = \sum_i^n \{\lambda^3[4Pa^3 + P_i(L_{2i}^2(L_{2i}-3a)+L_{2i-1}^2(L_{2i-1}-3a))] + 6\lambda^2[a(2Pa - P_i(L_{2i}+L_{2i-1}))] + \\ +3\lambda[4Pa - P_i(L_{2i}+L_{2i-1}+2a)] + 6(P-P_i)\}/(6P\lambda^3 I_y E_{11}) \quad , \quad (3)$$

where n is the number of bridgings, L_{2i}, L_{2i-1} are the location of bridgings at the upper and lower arms, P_i are the forces exerted by the bridgings.

EXPERIMENTAL

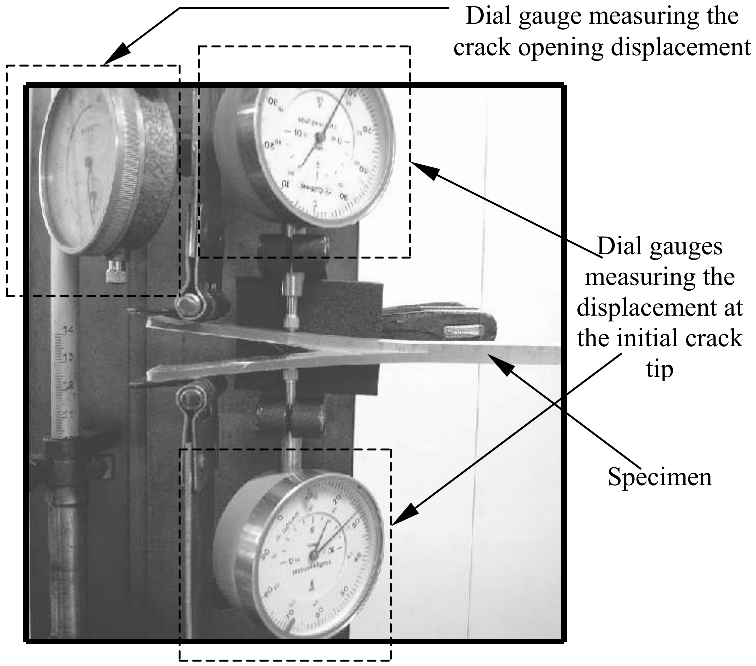

Fig.2.
Experimental setup for DCB testing

The DCB test was performed on glass/polyester specimens as shown by Fig.2. The results of the experiments are shown in Fig.3. Initiation and propagation tests were carried out. Initiation tests proved the accuracy of the Winkler model. On the other hand the Winkler foundation model gives misleading result if the fiber-bridging during propagation is not taken into account for. This model significantly overpredicts the experimental compliance and fracture energy, as shown by Fig.3.

CONCLUSIONS

The overpredictions were attributed to the fiber-bridgings. The experimental data was analysed using the present beam equations. The developed model is suitable to predict the total force exerted by the bridgings and the total number of bridging fibers. Both quantities have a peak value after crack initiation and a steady-state value during crack propagation. Furthermore the present model can used to determine the nonlinear bridging law approximately.

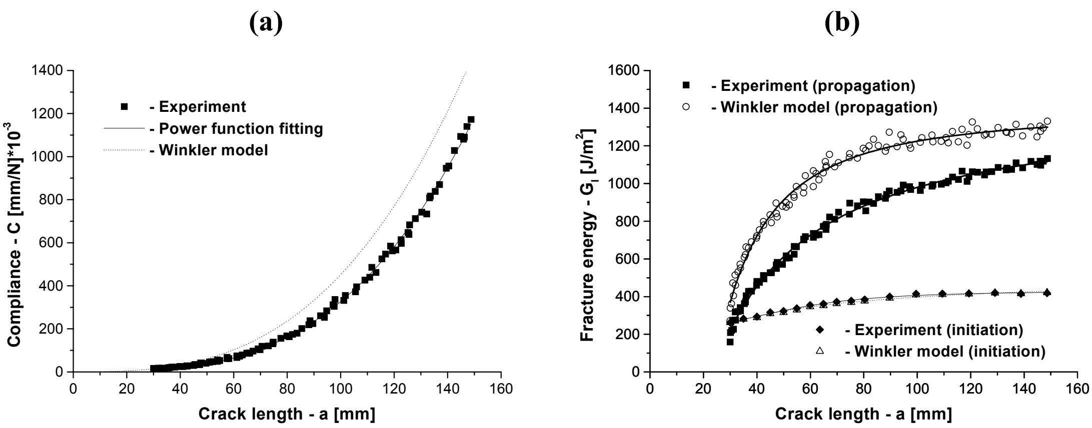

Fig.3.
Compliance from experiment and analysis (propagation) **(a)**. Initiation and propagation R-curves, comparison between experiment and analysis **(b)**

References

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[3] Olsson R. A simplified improved beam analysis of the DCB specimen. *Composites Science and Technology* **1992**;43;329-338