SNAP-BACK INSTABILITY OF LAMINATED COMPOSITES BRIDGED BY Z-REINFORCEMENTS

Xiaole Li & Gilles Lubineau
Email: Xiaole.li@kaust.edu.sa, Gilles.lubineau@kaust.edu.sa
Mechanics of Composites for Energy and Mobility Laboratory (Composites Lab), King Abdullah University of Science and Technology (KAUST)

جامعة الملك عبدالله للعلوم والتقنية

King Abdullah University of Science and Technology

Mechanics of Composites for Energy and Mobility

Overview

The present work focuses on the delamination behaviors of laminated composites toughened by reinforcements in the laminate's normal direction (namely the z-reinforcements). Emphasis is put on the snap-back instability when the bridging force of z-reinforcements starts to be decreasing during the delamination of such structures. We aim to gain insights into the toughening mechanisms and the snap-back instability that may guide the design in the context of interface toughening.

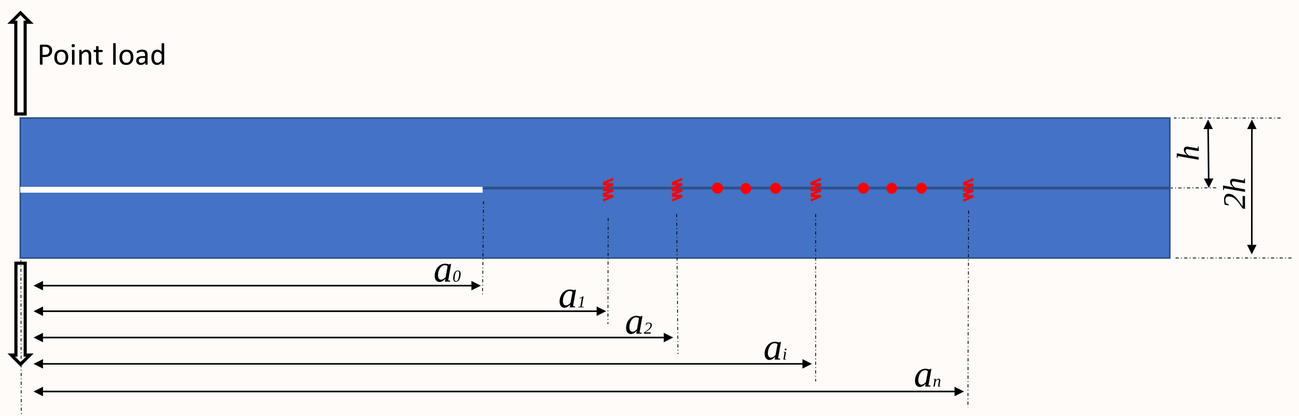

Fig. 1. The configuration and boundary conditions of the studied DCB with descritely distributed bridging actions.

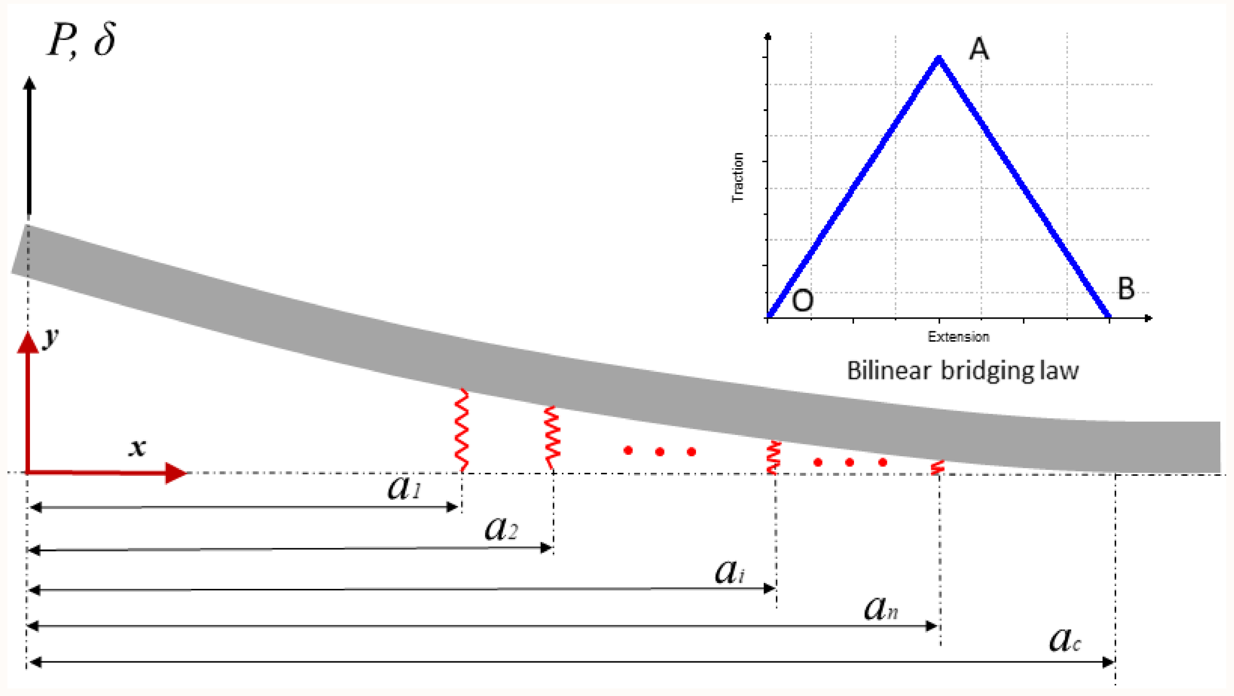

Fig. 2. The schematic on the deformation of the half DCB corresponding to the studied case. ac is the instantaneous crack length during crack propagation

Formulations

Governing equation

$$\begin{cases} w(a_n) = \dfrac{-P+\sum_{j=1}^{n} F_i}{\kappa A G_{xy}}(a_n - a_c) + \dfrac{P-\sum_{j=1}^{n} F_i}{6E_{xx}I}(a_n^3 - a_c^3) + \dfrac{\sum_{j=1}^{n} a_i F_i}{2E_{xx}I}(a_n^2 - a_c^2) + \dfrac{C_n}{2E_{xx}I}(a_n - a_c) \\ w(a_i) = w(a_{i+1}) + \left(\dfrac{\sum_{j=1}^{i} F_j - P}{\kappa A G_{xy}} + \dfrac{C_i}{2E_{xx}I}\right)(a_i - a_{i+1}) + \dfrac{P-\sum_{j=1}^{i} F_j}{6E_{xx}I}(a_i^3 - a_{i+1}^3) + \dfrac{\sum_{j=1}^{i} a_j F_j}{2E_{xx}I}(a_i^2 - a_{i+1}^2) \\ i = n-1, \cdots, 1 \end{cases}$$

E_{xx} and G_{xy}: longitudinal elastic modulus and shear modulus of beam arms, A: area of the beam cross-section, I: the cross-sectional moment of inertia, κ: Timoshenko shear coefficient, C_i (i=1…n): parameters expressed by bridging forces, a_c: crack length, a_i (i=1…n): crack length corresponding to i_{th} bridging reinforcement phase, $w(a_i)$: deflection of beam arm on i_{th} bridging reinforcement phase, P: applied force, F_i: bridging force.

LEFM criterion

$$\frac{1}{bE_{xx}I}\left(Pa_c - \sum_{j=1}^{n} F_j (a_c - a_j)\right)^2 + \frac{4}{\kappa G_{xy}A}\left(P - \sum_{j=1}^{n} F_j\right)^2 - G_{Ic} = 0$$

in which b is the width of the beam and G_{Ic} is the mode-I fracture toughness of neat DCB.

Results

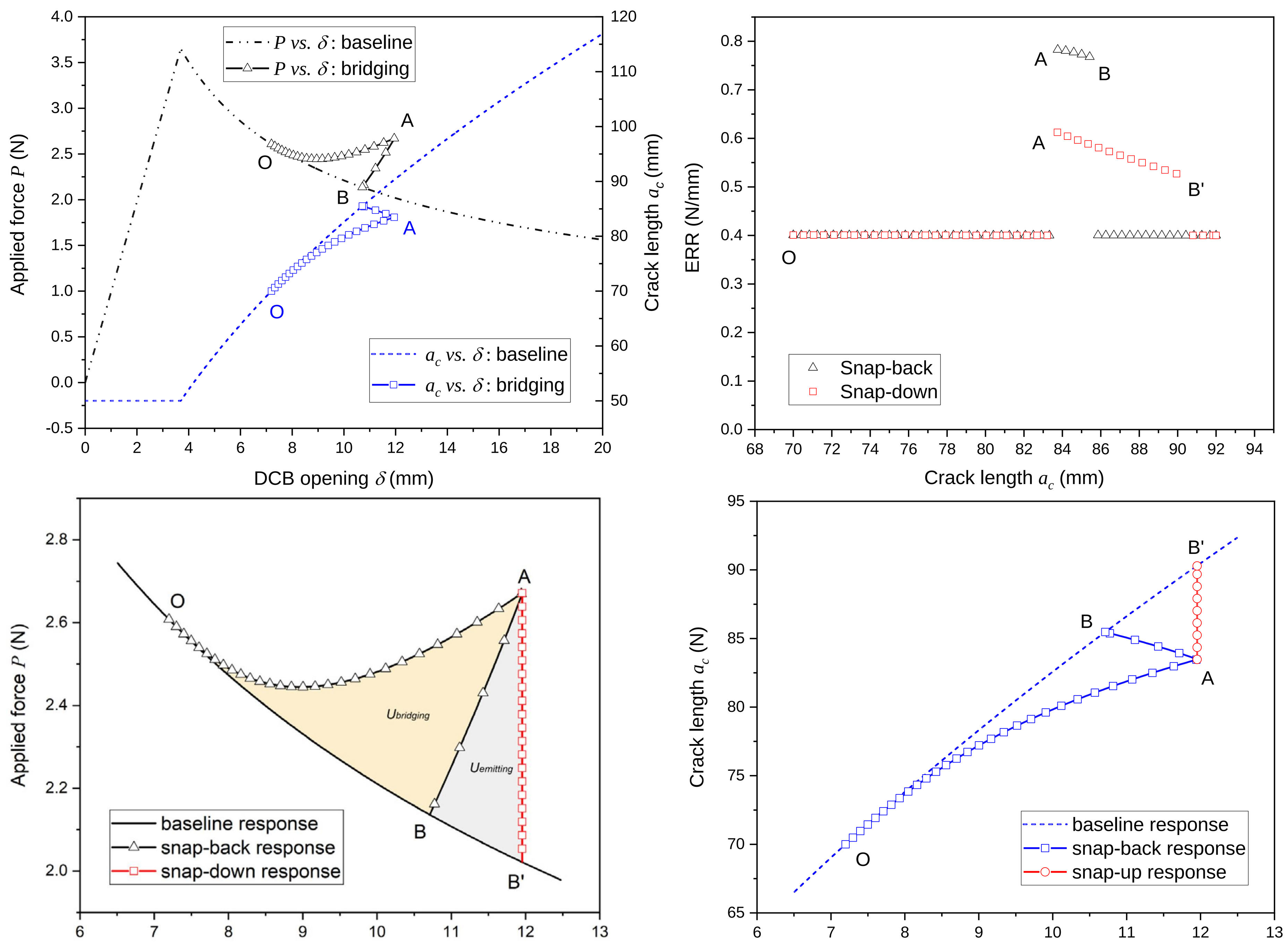

Fig. 3. Fracture responses of the DCB with single bridging action. (a) The P vs. d curve (the left coordinate axis) and the ac vs. d curve (the right coordinate axis) showing how the bridging actions take effect on the structural response of the DCB during crack propagation and the crack trapping mechanisms of bridging and the post-peak crack propagation process. (b) R-curves of the studied DCB in the cases of snap-back and snap-down (70 mm < ac < 92 mm), showing how the transition from pure intrinsic toughness to a combination of extrinsic and intrinsic toughness. (c) The closeup of P vs. d curve ranging from d = 6.5 mm to d = 12.5 mm, together with the snap-down P vs. d response when the DCB is subjected to deflection-controlled loads. The bridging energy and emitting energy are highlighted. (d) The closeup of the ac vs. d curve ranging from d = 6.5 mm to d = 12.5 mm, together with the snap-up ac vs. d response when the DCB is subjected to deflection-controlled loads. The crack propagation shows a discontinuous acceleration in the latter case.

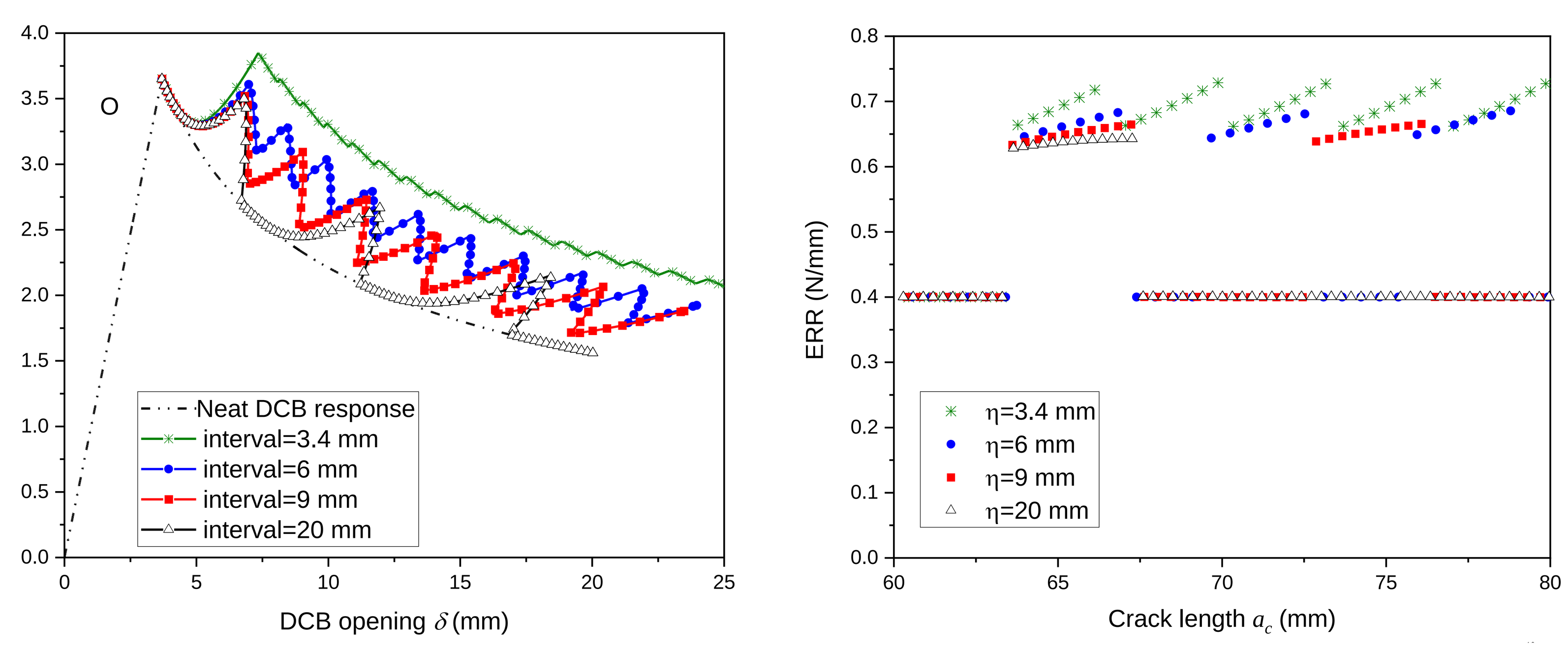

Fig. 4. The structural responses of the DCB in the presence of discretely distributed bridging actions with different characteristic spacing parameter k3 of bridging. h = 2 mm for the present DCB.

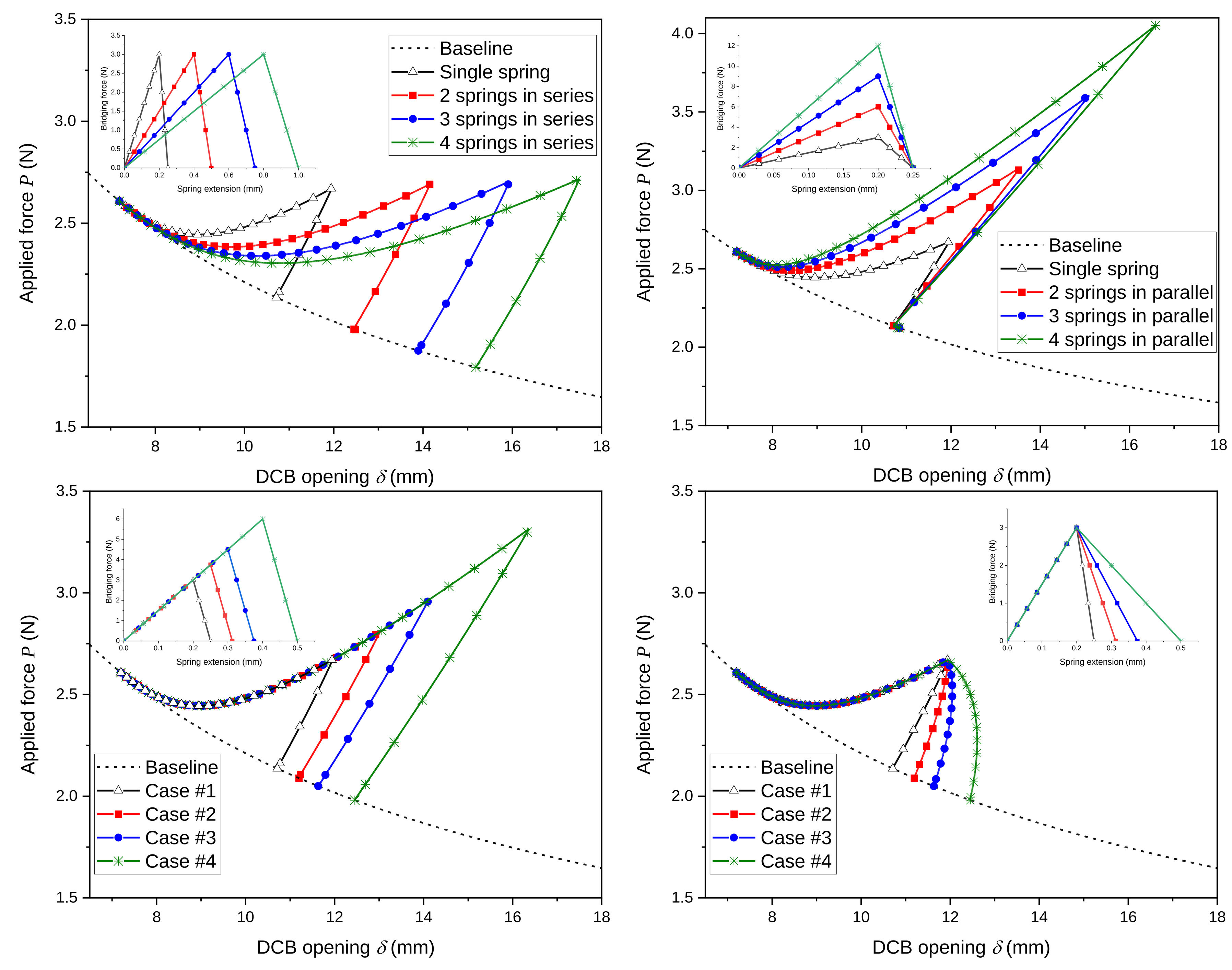

Fig. 5. The structural responses (P vs. d) of the DCB with bridging actions of changing wf (w0 and a1 are kept) to evaluate the effect of k1.

$$\varsigma = \frac{U_{emitting}}{U_{bridging} + U_{emitting}}$$

$$\lambda = \frac{P_0}{t_0}\left(\frac{w_f}{w_0}\right)^2$$

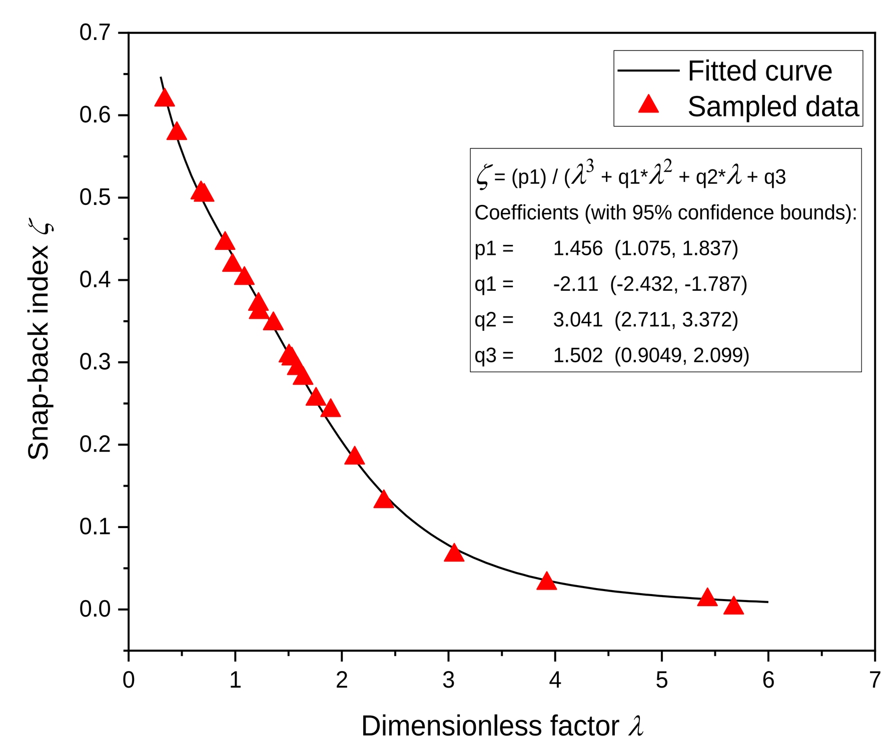

Fig. 6. Variation of the snapback index with the proposed dimensionless quantity λ.

Conclusion

This study provides fundamental insights into the bridging mechanisms and the associated physics behind snap-back instability in laminates or joints that are instrumental in the development of rational concepts for toughening interfaces by triggering bridging. The established theoretical framework can be used in the evaluation and design of laminated composites or joints with bridging in a reliable, more accurate, and fast manner. The developed model uses springs with bi-linear responses to mimic the characteristic bridging behaviors when the bridging events occur discretely along the interface.

Reference:

Li, X., Lu, S., & Lubineau, G. (2021). Snap-back instability of double cantilever beam with bridging. International Journal of Solids and Structures, 233, 111150.