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INVESTIGATION OF INTERSONIC DELAMINATION IN CURVED COMPOSITE LAMINATES UNDER QUASI-STATIC LOADING

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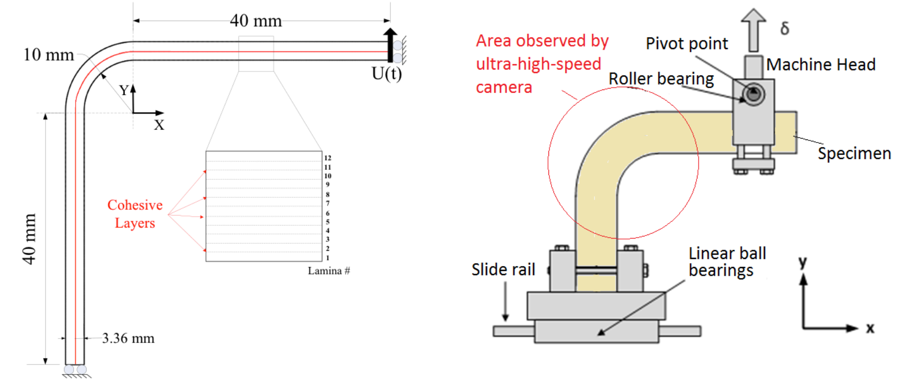
L-shaped composite laminates are encountered as flanges of composite ribs and spars in aerospace industries. Due to the curved geometry, interlaminar normal stresses (ILNS) are induced at the curved region together with the well-known interlaminar shear stresses (ILSS) (Fig.1). As a result, delamination can be initiated and propagated under a combination of ILSS and ILNS, which is a recent problem in the engineering applications. It has been shown that the delamination of L-shaped composite laminates is unstable [1] and dynamic effects become dominant during the delamination propagation [2] under quasi-static loading. In this study, the delamination of L-shaped composite laminates is studied numerically using cohesive zone method (CZM) and compared with the recent experimental results using ultra-high speed camera.

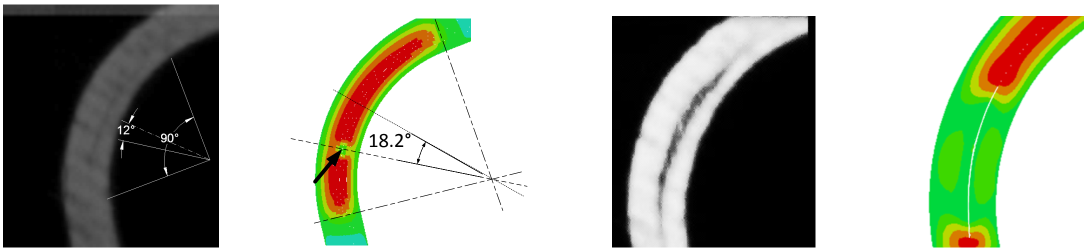
The L-shaped composite specimen is made of 12 layers of woven fabric CFRP plies with arm length of 40 mm, inner radius of 10 mm and the thickness of 3.36 mm. In the numerical study, a 1D-line cohesive interface element using Xu-Needleman CZM [3] is firstly implemented into ABAQUS/Explicit via VUEL usersubroutines [4]. The interface elements are located in every interface between the layers as shown in Fig. 1a. The interface properties are obtained experimentally. The specimen is clamped at the bottom of the lower arm wheras the specimen is pulled by displacement controlled loading from the tip of the right arm (Fig 1). The experimental setup is shown in Fig. 1b. The specimen is free to translate in the X-axis whereas the head is pulled around the pivot points to give the same boundary conditions as that in the finite element model. The curved region is observed by an ultra-high speed camera with 500,000 fps during the experiment.

Both the numerical study and the experiment shows that the delamination initiates in the curved region and propagates as a single crack between the 5^{th} and 6^{th} plies as shown in Fig.2. In addition to the interface of the initiation and the fracture pattern, the angular location of the initiation site is also captured by the numerical analysis successfully as shown in Fig.2a – top. The numerical and the experimental results are also found to be in good agreement in terms of load-displacement curves with regard to stiffness and failure load.



(a) (b)

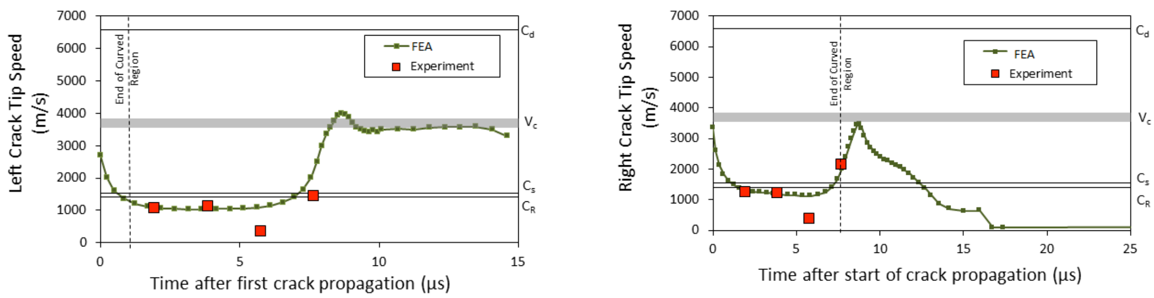
Fig. 1 (a) L-shaped composite specimen dimensions, boundary conditions and the location of cohesive elements for the numerical study and (b) experimental set-up.



(a) (b)

Fig. 2 Experimental high-speed photo and finite element snapshot of normal stress contours at (a) instant of delamination initiation and (b) during delamination propagation.

The crack tip speed data during delamination propagation phase is shown in Fig. 3. The experimental data is shown as square symbols, numerical results are shown as the green line whereas C_d, C_s and C_R are dilatational, shear and Rayleigh wave speeds of the material in the ply direction. The crack propagation takes place at sub-Rayleigh waves speed at the corner and reaches intersonic speeds after t = 6 μs for both crack tips near the arms. A sustained crack tip speed around Vc = 3800 m/s is observed during the simulations as shown by a thick grey line in the figures. In the numerical results, corresponding shear Mach waves are observed at intersonic speeds. The experimentally calculates speeds from photos (shown as square symbols) are found to be in good agreement.



(a) ()

Fig. 3 Crack tip speed as a function of time graphs obtained by FEA and experiments for (a) left and (b) right crack tip speeds.

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