Postbuckling and growth of delaminations in composite panels

This example illustrates the application of the use of the VCCT and the PRX-VCCT fracture criteria in Abaqus/Standard and the VCCT fracture criterion in Abaqus/Explicit to predict the postbuckling response, onset, and growth of delaminations in laminated composite panels.

This page discusses:

Products: Abaqus/Standard Abaqus/Explicit

Application description

Delaminations are a primary failure mode for laminated composite materials. The delamination growth is more prominent under compressive loading since it results in buckling of a sublaminate leading to the delamination growth. The particular problem considered here is described in Reeder (2002). The results from the VCCT debond approach in Abaqus are compared to the experimental results. In addition, the results using the PRX-VCCT approach are compared to the ones using the VCCT approach.

Geometry

A flat 9.0 in (228.6 mm) × 4.5 in (114.3 mm) composite panel with a centrally located 2.5 in (63.5 mm) diameter delamination is studied in this example, as shown in Figure 1.

Materials

The panel is made of a AS4/3501-6 graphite/epoxy composite material system for which the typical lamina properties are given in Table 1. The laminate stacking sequence for the panel is $[(\pm45/90/0)_2/\pm60/\pm15]_S$. The critical fracture toughness for Modes I, II, and III at the delamination interface are also given in Table 1.

Boundary conditions and loading

The panel is subjected to compressive loading along its long axis. The overall dimensions of the model with boundary conditions and loading can be seen in Figure 1.

Abaqus modeling approaches and simulation techniques

The delamination is placed at the interface between the 5th and 6th ply (between 45° and −45°). The delamination region is modeled using two superimposed shell elements with contact constraints defined to prevent penetration of elements. The Benzeggagh-Kenane mixed-mode failure criterion (Benzeggagh and Kenane, 1996) is used to determine the growth of delamination based on the strain energy release rate computed using VCCT.

Analysis Types

Both static and dynamic analyses are performed.

Mesh design

The finite element model is created with fully integrated first-order shell elements (S4). The finite element mesh for the model is shown in Figure 2 with the circular delamination at the center.

Loads

The loading consists of a prescribed displacement of 0.03 in (0.76 mm) at the top edge of the panel.

Solution controls

To achieve a stable delamination growth in Abaqus/Standard, a small amount of damping is specified for the interface where delamination growth occurs (see Automatic Stabilization of Rigid Body Motions in Contact Problems). There are no solution controls specified in the Abaqus/Explicit analysis.

Results and discussion

The final deformed configuration of the composite panel obtained from Abaqus/Standard is shown in Figure 3. The postbuckling in the panel section cut along the long axis is illustrated in Figure 4. A contour plot of the bond status variable BDSTAT obtained from Abaqus/Standard indicating the growth of delamination is shown in Figure 5. The load-strain predictions are compared with the experimental data presented by Reeder (2002) in Figure 6. The predictions from VCCT are in agreement with the experimental results. The onset of delamination growth predicted by the VCCT debond approach in Abaqus is within 10% of the experimental data. The energy dissipated to stabilize the delamination growth is less than 4% of the total strain energy, as shown in Figure 7. In addition, the load-strain prediction using PRX-VCCT is compared to the one using VCCT in Figure 8. Using PRX-VCCT produced a clearer delamination initiation point than using VCCT.

The deformed configurations obtained from Abaqus/Explicit are shown in Figure 9 and Figure 10. Delamination growth obtained from the Abaqus/Explicit analysis is shown in Figure 11. The force-displacement responses differ slightly from the Abaqus/Standard results, as shown in Figure 12, but show reasonable agreement.

Input files

nasa_postbuckle_vcct_1.inp

Postbuckling analysis of a composite plate using Abaqus/Standard.

nasa_postbuckle_xpl_vcct.inp

Postbuckling analysis of a composite plate using Abaqus/Explicit.

nasa_postbuckle_prx-vcct.inp

Postbuckling analysis of a composite plate using the PRX-VCCT fracture criterion in Abaqus/Standard.

References

Benzeggagh, M., and M. Kenane, "Measurement of Mixed-Mode Delamination Fracture Toughness of Unidirectional Glass/Epoxy Composites with Mixed-Mode Bending Apparatus," Composite Science and Technology, vol. 56, p. 439, 1996.

Reeder, J., S. Kyongchan, P. B. Chunchu, and D. R. Ambur, "Postbuckling and Growth of Delaminations in Composite Plates Subjected to Axial Compression," 43rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Denver, Colorado, vol. 1746, p. 10, 2002.

Tables

Table 1. Properties for AS4/3501-6 graphite/epoxy material.

Property	Value
E_1	18.500 × 10^6 lb/in^2 (127.554 kN/mm^2)
E_2	1.640 × 10^6 lb/in^2 (11.307 kN/mm^2)
G_{12}	0.871 × 10^6 lb/in^2 (6.005 kN/mm^2)
G_{13}	0.871 × 10^6 lb/in^2 (6.005 kN/mm^2)
G_{23}	0.522 × 10^6 lb/in^2 (3.599 kN/mm^2)
ν_{12}	0.30
G_{IC}	0.46863 lb/in (0.08207 N/mm)
G_{IIC}	3.171825 lb/in (0.55546 N/mm)
G_{IIIC}	3.171825 lb/in (0.55546 N/mm)

Figures

Figure 1. The flat composite panel.

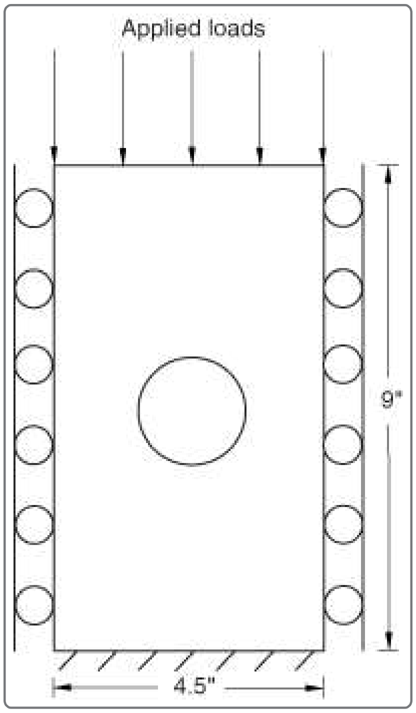

Figure 2. The meshed NASA panel model.

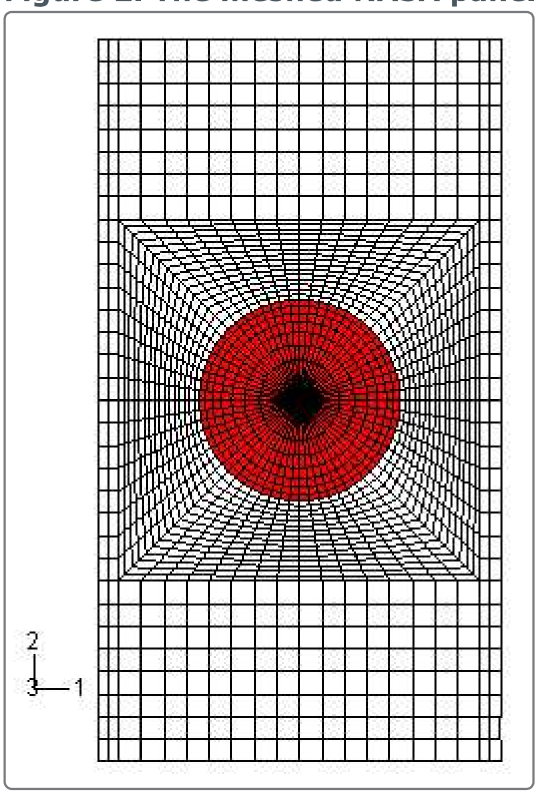

Figure 3. The final deformed configuration (Abaqus/Standard).

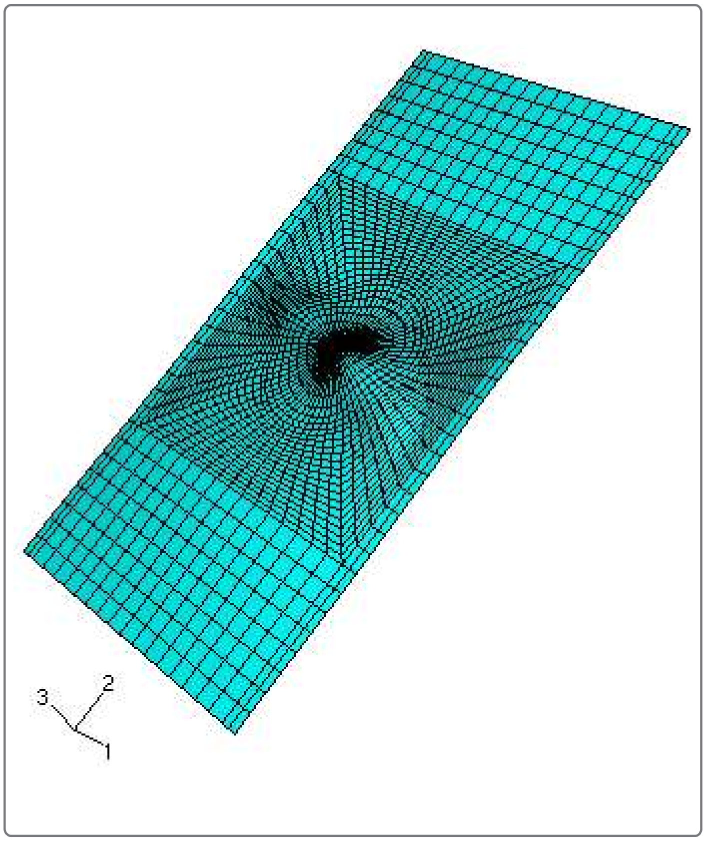

Figure 4. The postbuckling in the panel section (Abaqus/Standard).

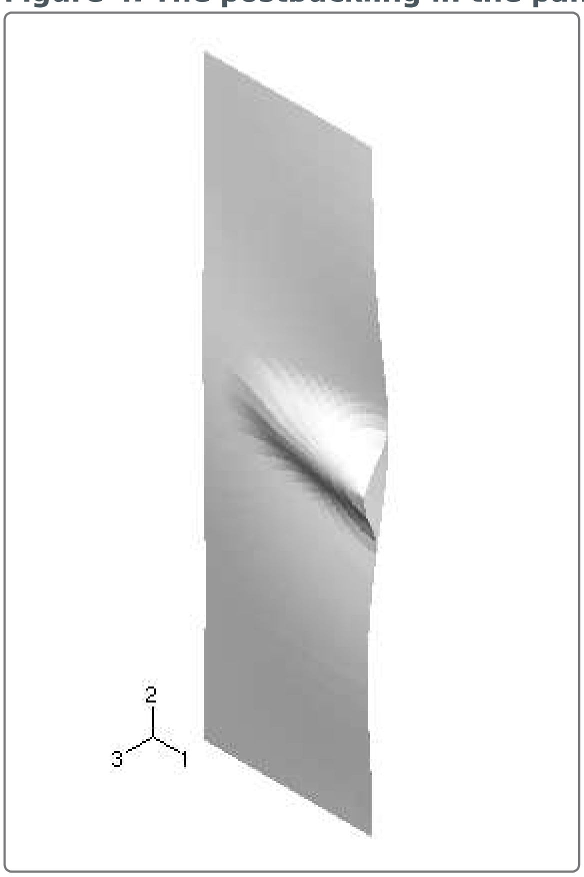

Figure 5. The growth of delamination (Abaqus/Standard).

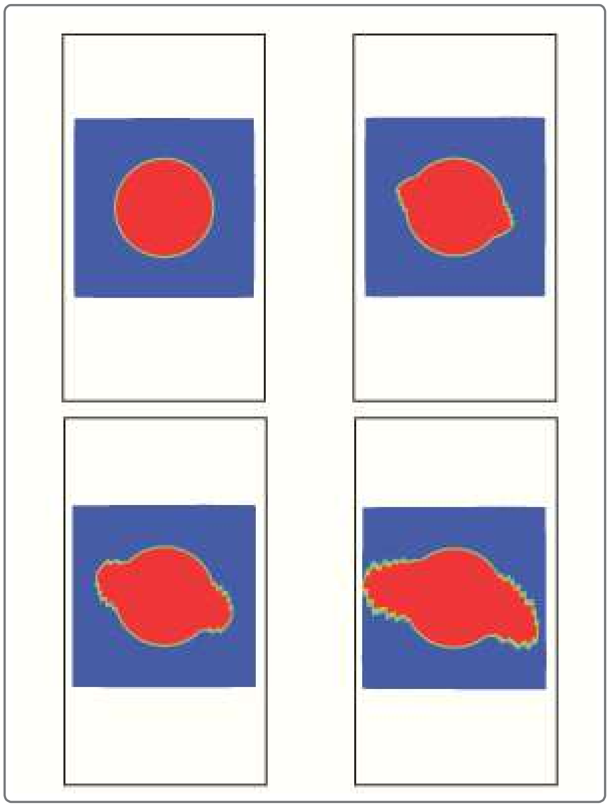

Figure 6. The load-strain predictions compared with experimental data.

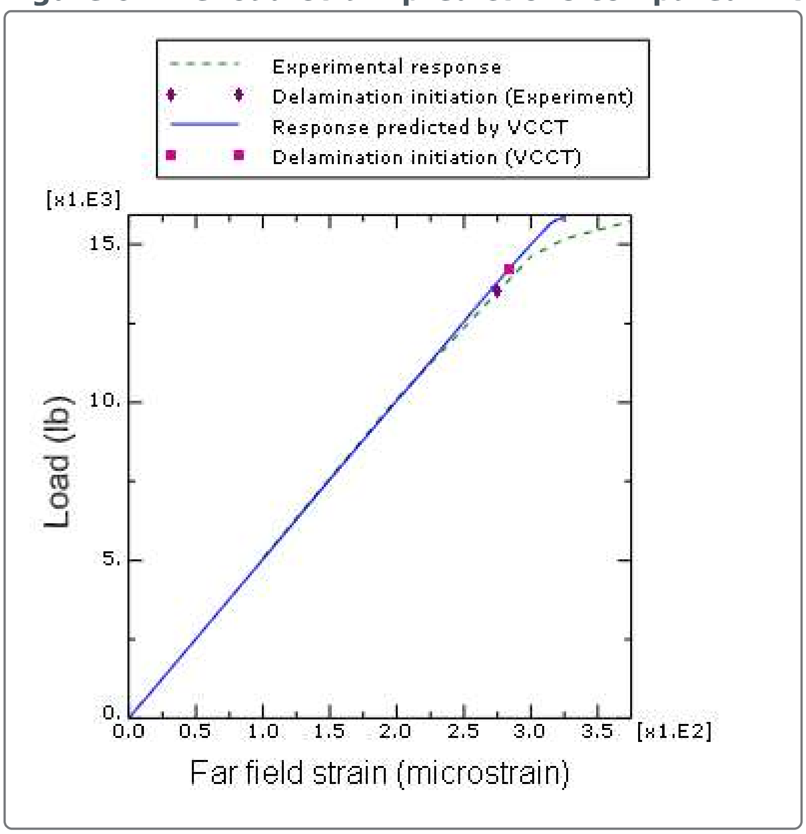

Figure 7. The energy dissipated to stabilize the delamination growth.

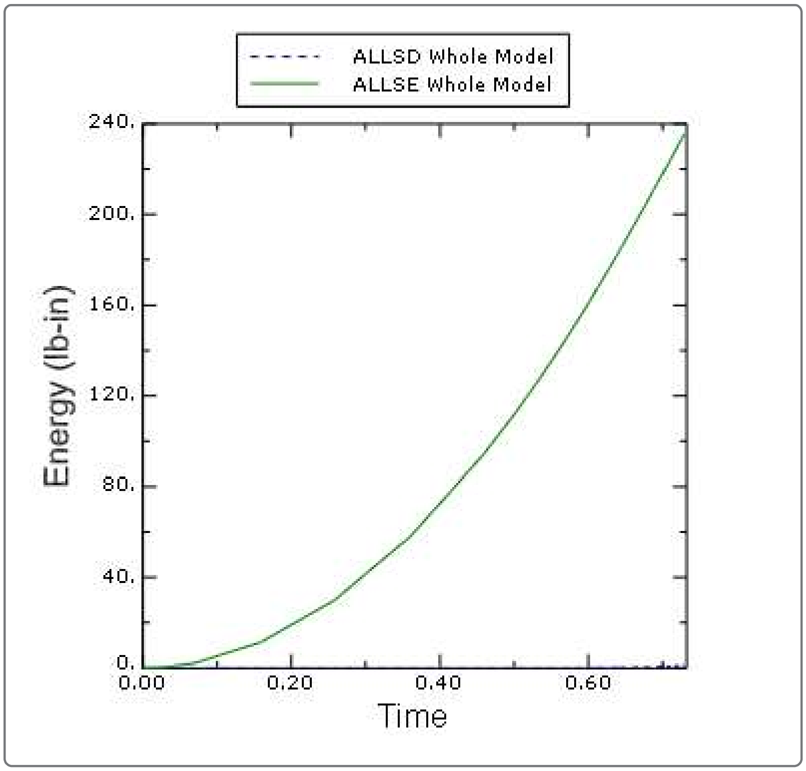

Figure 8. Comparison of the load-strain predictions using PRX-VCCT and VCCT.

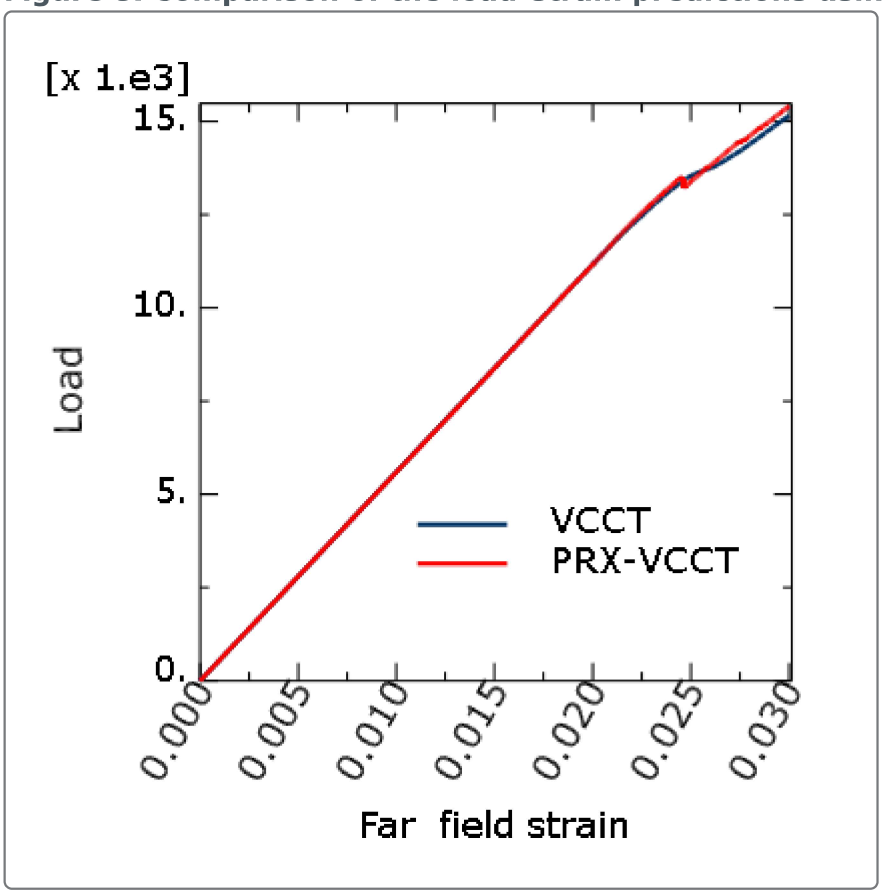

Figure 9. The final deformed configuration (Abaqus/Explicit).

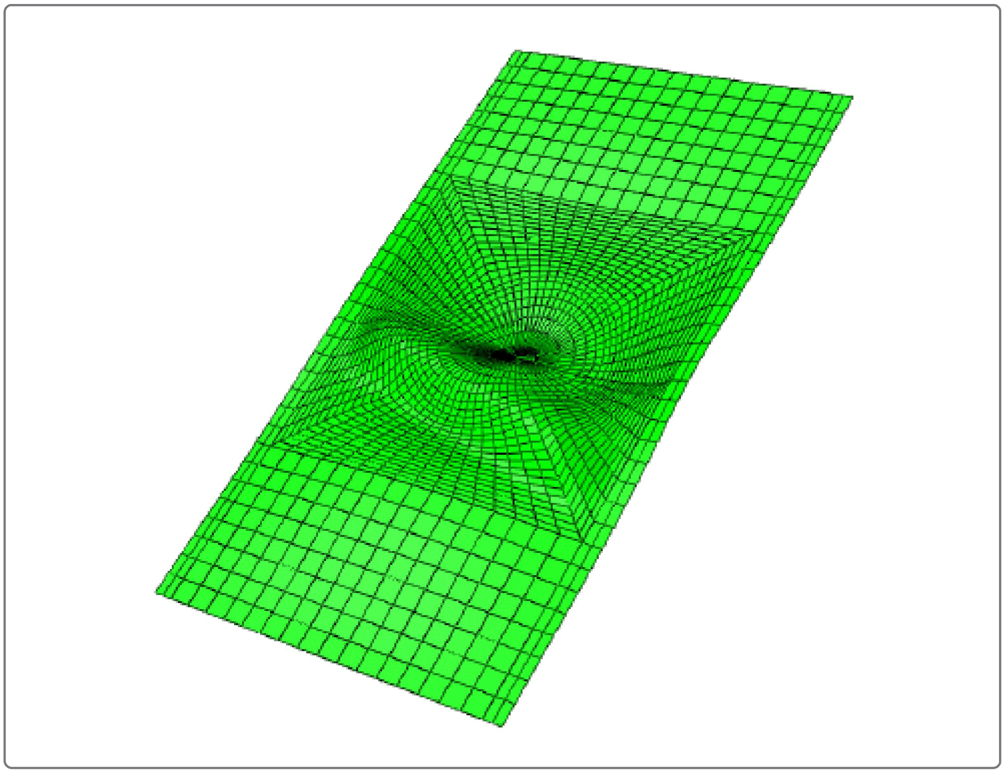

Figure 10. The postbuckling in the panel section (Abaqus/Explicit).

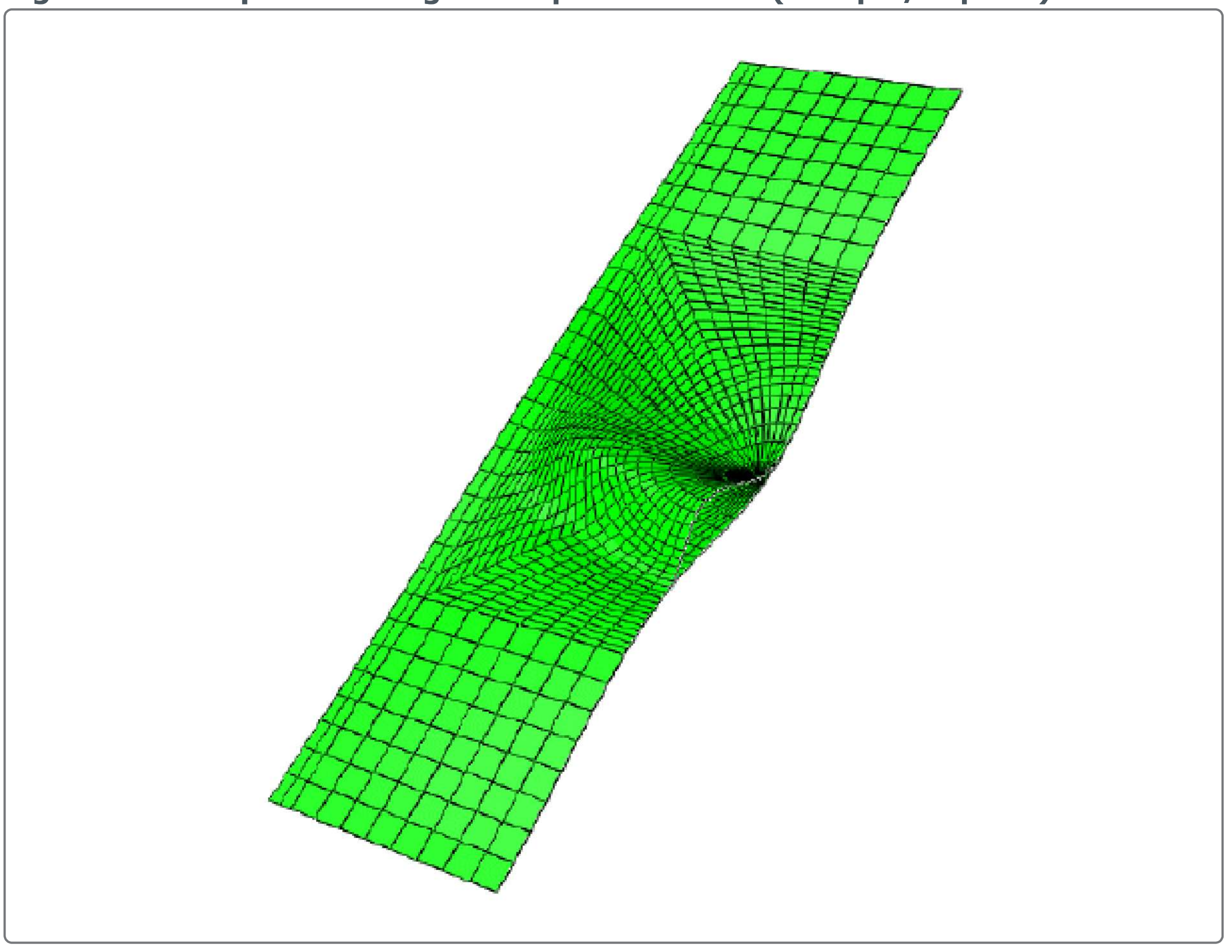

Figure 11. The growth of delamination (Abaqus/Explicit).

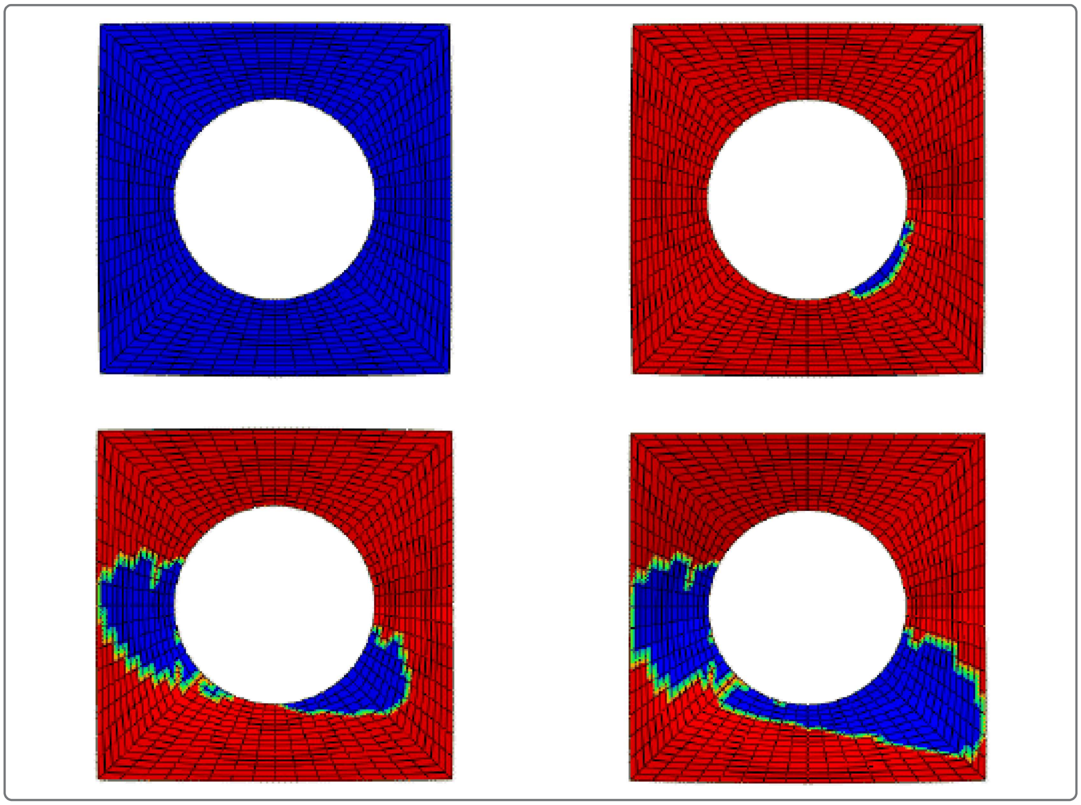

Figure 12. The force-displacement response comparison between Abaqus/Explicit and Abaqus/Standard.