Example Problem 2

Helius:MCT™ Version 2.0 for Abaqus
July, 2009

Abstract

This example problem demonstrates the pre-failure nonlinearity feature on a single element model. Longitudinal shear stress/strain curves from models with pre-failure nonlinearity turned on and off will be compared to the experimentally measured data that was used to generate the reduced shear modulus values. Then, results from a composite tube model will be used to show how pre-failure nonlinearity influences model deformation.
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Table of Contents

FIREHOLE TECHNOLOGIES ADVANCED COMPOSITES ANALYSIS

Helius:MCT™ Example Problem 2

Pre-failure Nonlinearity Demonstration

E2.1 Introduction

Typical unidirectional fiber-reinforced composite materials exhibit nonlinear longitudinal shear stress/strain (σ_{12} vs. ε_{12} and σ_{13} vs. ε_{13}) behavior prior to matrix/composite failure. The source of this nonlinearity is assumed to result from the accumulation of sub-microcracks in the matrix constituent. It is further assumed that these sub-microcracks affect only the longitudinal shear modulus, while the remaining moduli are unaffected.

To reduce computation time, Helius:MCT uses a series of three discrete reductions in the matrix and composite shear moduli to model the nonlinear longitudinal shear stress/strain behavior. These reductions occur prior to ultimate matrix failure and are optimized to fit the measured shear stress/strain curve for the given material. It should be noted that an experimentally measured longitudinal shear stress/strain curve is required in order to model the nonlinear behavior of the material.

This example problem demonstrates the pre-failure nonlinearity feature on a single element model. Longitudinal shear stress/strain curves from models with pre-failure nonlinearity turned on and off will be compared to the experimentally measured data that was used to generate the reduced shear modulus values. Then, results from a composite tube model will be used to show how pre-failure nonlinearity influences model deformation.

For further information related to the Helius:MCT pre-failure nonlinearity feature, refer to Appendix A.4 of the User's Guide and section 5 of the Theory Manual.

Note: The models used in this example problem use solid elements (C3D8R) with composite sections which are not fully supported in Abaqus version 6.7. Hence, the provided input files should be run with version 6.8.

E2.2 Single Element Model

Problem Description

The simplest method of demonstrating the longitudinal shear stress/strain response of a composite material is to constrain and load a single element such that the longitudinal shear stress component is much greater than the remaining stress components. A state of pure shear stress can be obtained by loading an element as shown in Figure 1. To obtain this loading in the finite element model used for this problem, the nodal boundary conditions and loading shown in Figure 2 and Figure 3 were used. The magnitudes of the loads shown in Figure 3 are identical.

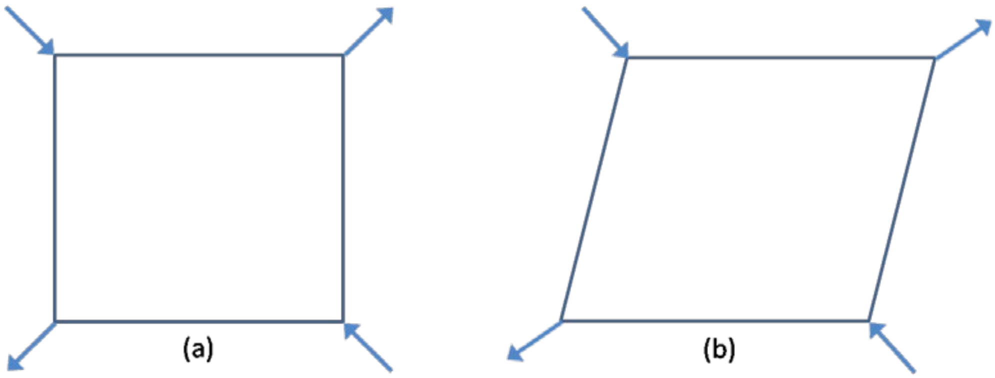
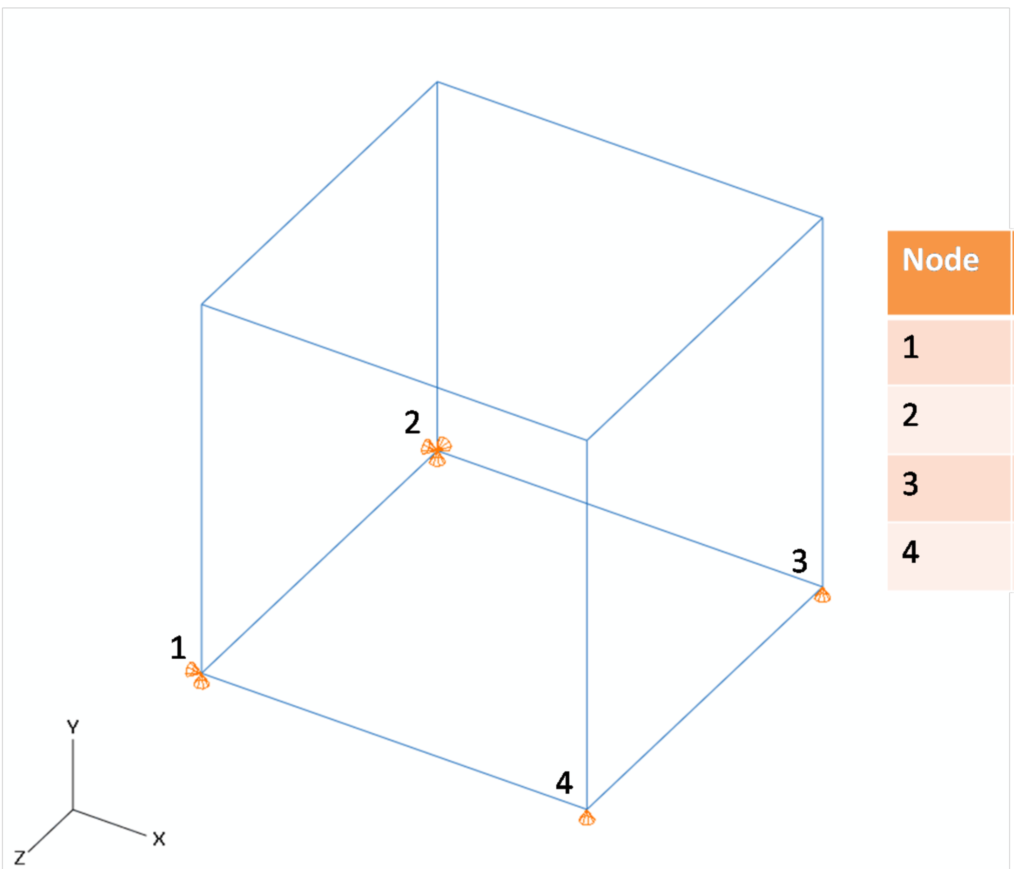


Figure 1: Pure shear stress loading on (a) undeformed shape and (b) deformed shape



Node	Constraint
1	Ux=Uy=0
2	Ux=Uy=Uz=0
3	Uy=0
4	Uy=0

Figure 2: Single element nodal displacement boundary conditions

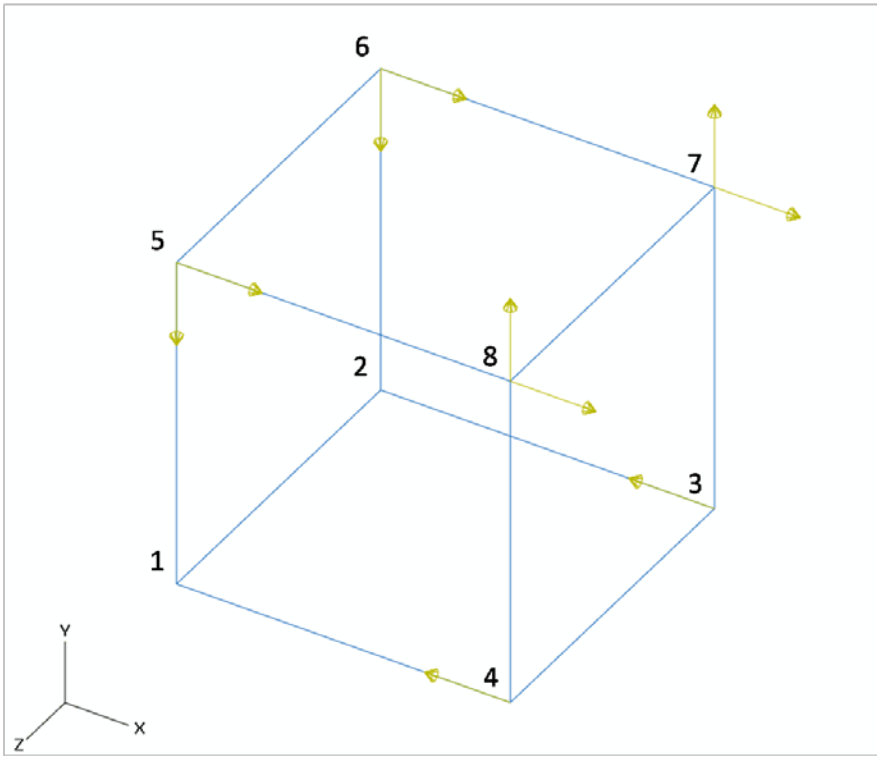


Figure 3: Single element nodal loading

The model uses the properties of a SilEglass1200tex-MY750 unidirectional glass/epoxy composite with the fibers oriented in the x-direction. The measured shear strength of the material is 73 MPa. A single 3-dimensional solid element (type C3D8R) was used with 1 integration point.

Based on the given loading, boundary conditions, material, and orientation, the only non-zero *composite* stress component is σ_{12}.

Results

In what follows, three sets of longitudinal composite shear stress/strain (σ_{12} vs. ε_{12}) data are compared: experimental data[1], data generated from the finite element model with progressive failure on and pre-failure off, and data generated from the finite element model with both progressive failure and pre-failure on. Results from this comparison highlight the effects of using the pre-failure feature in Helius:MCT.

The longitudinal composite shear stress vs. strain data is shown in Figure 4. The black line represents the experimental data, the red line represents the data generated with pre-failure nonlinearity off, and the green line represents the data generated with pre-failure nonlinearity on. With pre-failure turned *off*, the shear stress in the model increases linearly up to the composite shear strength of 73 MPa, at which point the matrix constituent fails instantly. The deformation matches the experimental deformation to a strain of about 0.006, but quickly diverges as the strain increases beyond 0.006. With pre-failure turned *on*, the shear stiffness undergoes three discrete reductions prior to failing at 73 MPa. These reductions in the shear stiffness are applied to the matrix constituent and subsequently directly decrease the shear stiffness of the composite. This gradual reduction in the shear stiffness allows the model to deform in a manner that is much more consistent with the measured data. At failure, for example, the strain with pre-failure off is ≈ 0.013, the strain with pre-failure on is ≈ 0.04, and the experimental strain is 0.04.

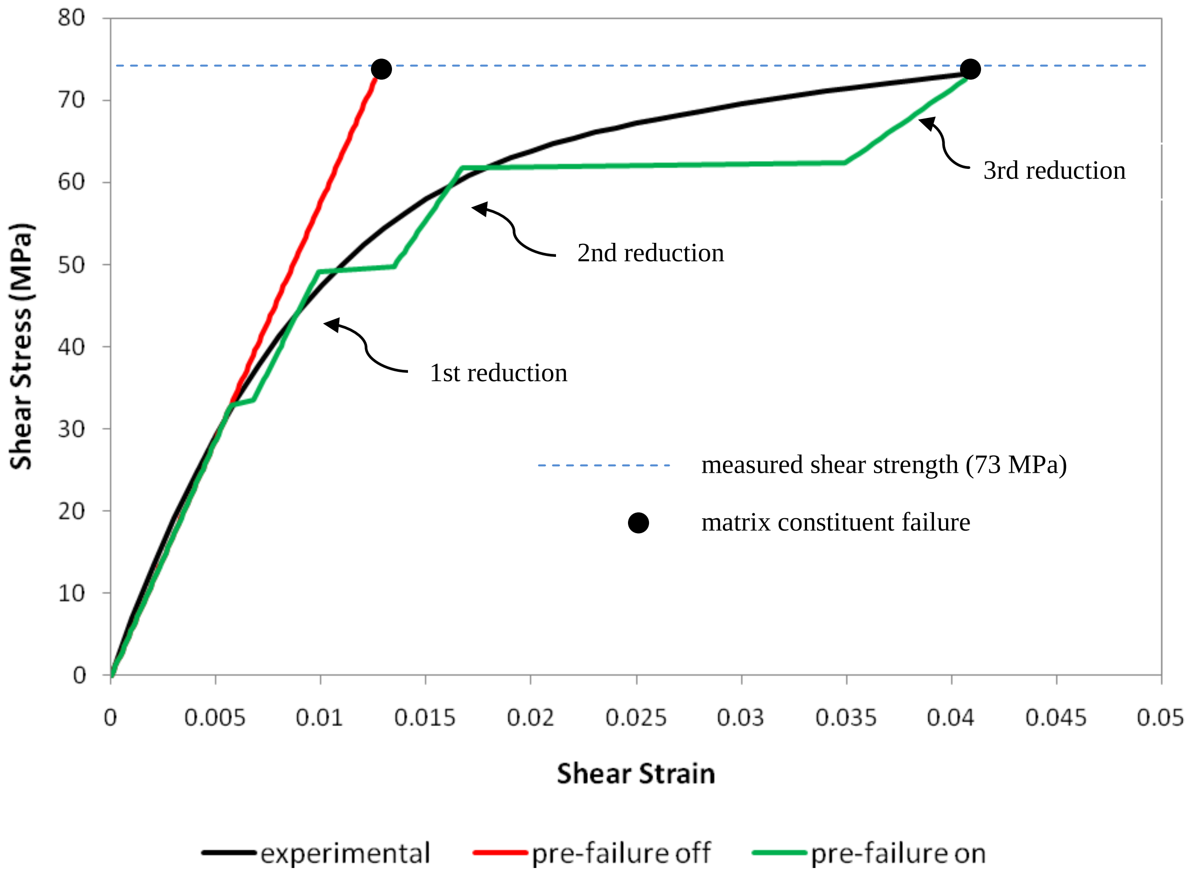


Figure 4: Comparison of measured and numerical longitudinal shear stress vs. shear strain

The above results highlight two important considerations when using pre-failure nonlinearity:

1. The deformation is much more accurate when the pre-failure nonlinearity feature is used.
2. The shear strength of the material is not affected by pre-failure nonlinearity.

The decision to use pre-failure nonlinearity depends on several factors such as loading, boundary conditions, and material nonlinearity. In general, if longitudinal shear strains are significant and the material exhibits significant material nonlinearity, then using pre-failure nonlinearity is recommended. If, on the other hand, longitudinal shear strains in the model are not significant and the material exhibits insignificant material nonlinearity, then using pre-failure may not be beneficial. Keep in mind that using pre-failure will typically increase computational effort and analysis run time so it should not be used if it is not needed.

E2. 3 Composite tube

Problem Description

While a single element is useful for demonstrating the shear stress/strain response of a composite material, it is not practical in the sense that actual structures are not modeled using a single element. To demonstrate the effects of using the pre-failure nonlinearity feature in a more realistic structure, a composite tube will be analyzed.

The tube is shown in Figure 5 and has an inner radius of 50 mm, a wall thickness of 5.9 mm, and a length of 120 mm. A boundary condition is applied to the bottom surface that restricts displacement in all directions. A moment is applied to the reference point shown in Figure 5 and a constraint links the reference point to the top surface so that the tube is loaded in torsion. A unidirectional layup is used with the fibers oriented in the hoop direction and SilEglass1200tex-MY750 is the material. Reduced integration solid elements (C3D8R) are used with one integration point through the thickness.

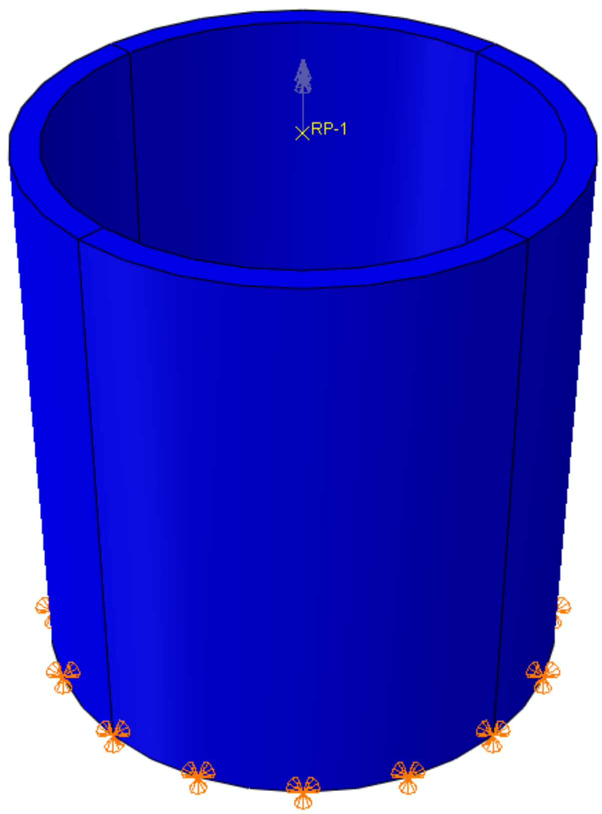


Figure 5: Composite tube

Results

Figure 6 shows the displacement of the nodes located on the outer radius of the top surface of the tube for cases when pre-failure is turned off and when it is turned on. The displacement of the model run without pre-failure is linear up to a displacement of 0.0016 m, at which point matrix constituent failure occurs throughout the model. With pre-failure on, the displacement is linear up to a displacement of 0.00071 m, then diverges from the pre-failure off results as a consequence of the three discrete reductions in shear stiffness that occur prior to matrix failure. Note the significant difference in displacements at failure between the two curves. With pre-fail off the displacement is 0.0016 m and with pre-fail on the displacement is 0.0052 m.

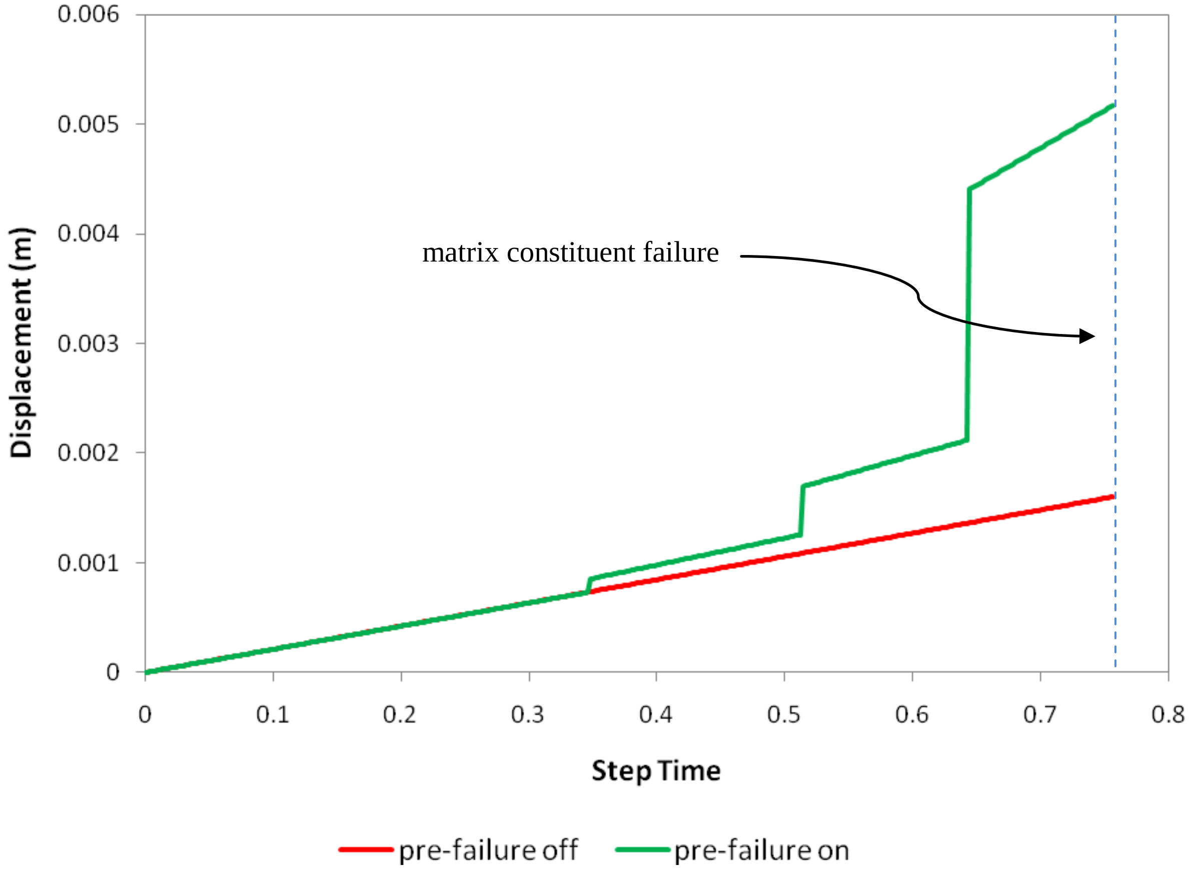


Figure 6: Comparison of top surface displacement with pre-failure off and on

The following input files were used to generate the results discussed here and may be downloaded from the Firehole Technologies User Portal for user reference:

- SingleElement_PreFail_Off
- SingleElement_PreFail_On
- Tube_PreFail_Off
- Tube_PreFail_On

Reference

Hinton M.J., Kaddour A.S., and Soden P.D., *Failure Criteria In Fibre Reinforced Polymer Composites: The World-Wide Failure Exercise*. Elsevier Ltd., Oxford, UK (2004).