Bringing Science to Life

Test Methodologies for Determining Energy Absorbing Mechanisms in Automotive Composite Material Systems

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Outline

- Motivation
- Test Fixture Design
- Fixture Validation
- Test Observations
- Future Directions

Crashworthiness

- "Crashworthiness" - The ability to absorb energy and be survivable for the vehicle occupants
- Energy is absorbed through controlled failure mechanisms and failure modes
- Accurate computer simulations are needed to design safe vehicles
- Specific energy absorption
  - energy absorbed per unit mass of crushed material

$$SEA = \frac{W}{V\rho}$$

Automotive Materials

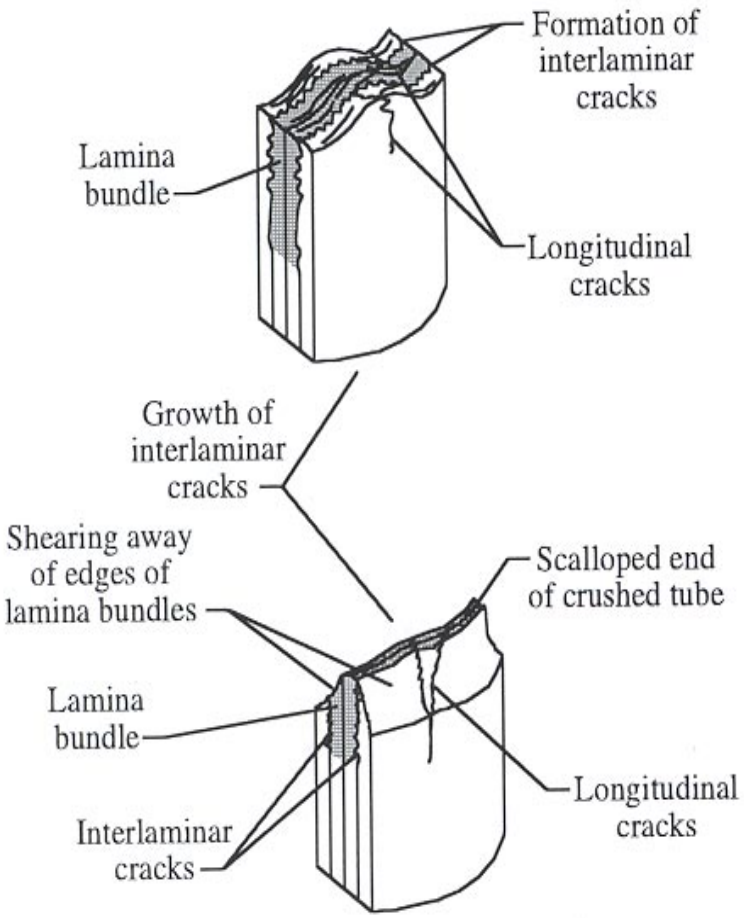
- Economy and weight
- Composite materials
  - lighter than metals
  - high strength-to-weight and stiffness-to-weight ratios
  - fatigue and corrosion resistant
  - brittle response
  - fail through a sequence of fracture mechanisms
- Metals
  - ductile response
  - fail through buckling or folding like an accordian
  - extensive plastic deformation

Tube Crushing

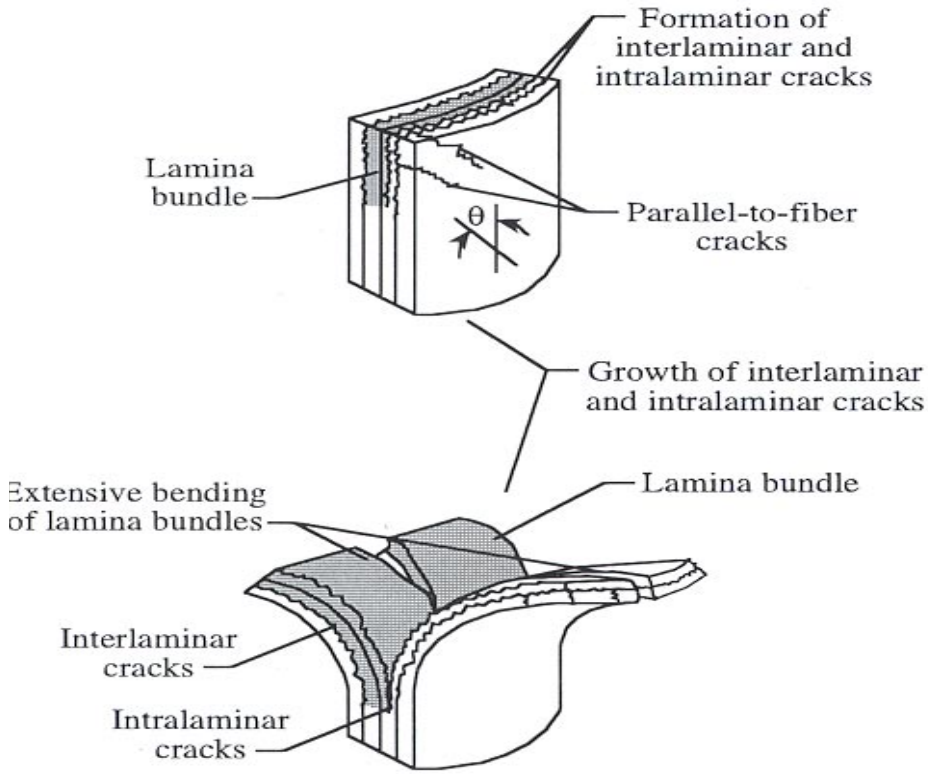
- Extensive studies have been conducted to investigate the progressive crushing of composite tubes
- Identified failure mechanisms
  - fragmentation
  - splaying (frond formation)
  - delamination
  - axial splitting
  - brittle fracturing
  - progressive folding

- All of the different failure mechanisms contribute to the overall energy absorption of the structure

Tube Crush Modes

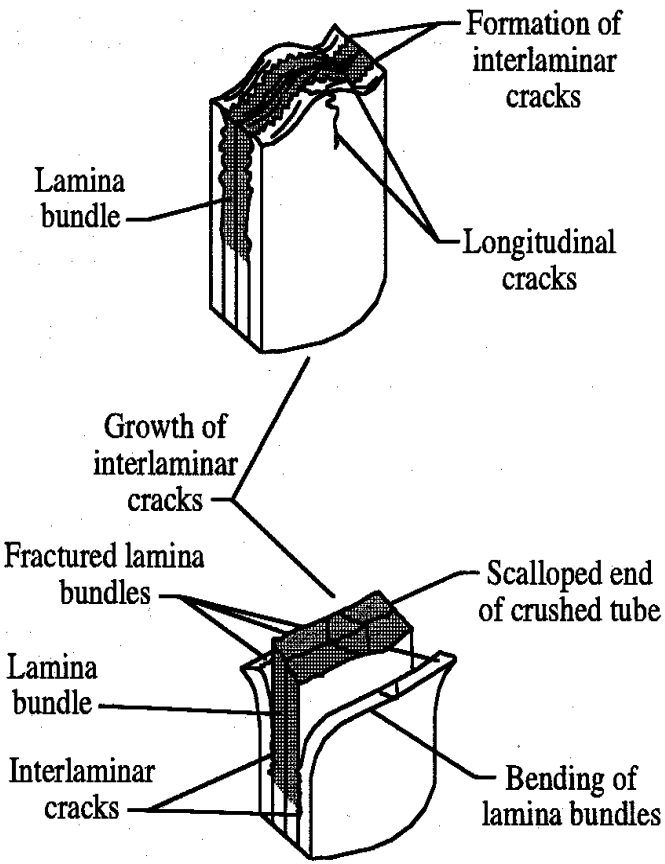


Fragmentation

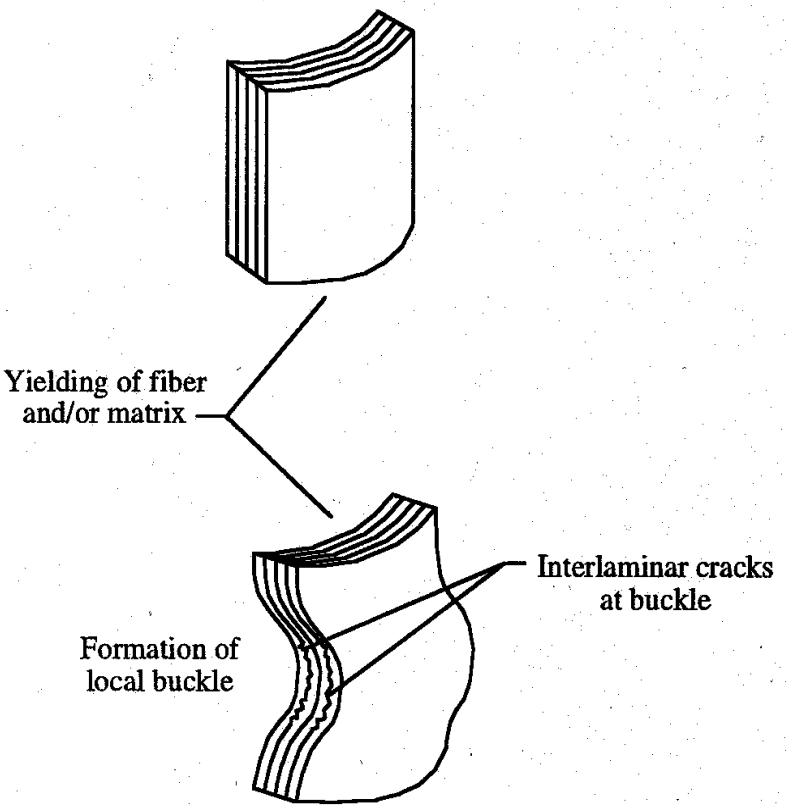


Splaying

Tube Crush Modes



Brittle Fracturing



Progressive Folding

Plate Compression

- Yuan and Viegelahn (1991)
  - Very simple design
  - Large frictional effects

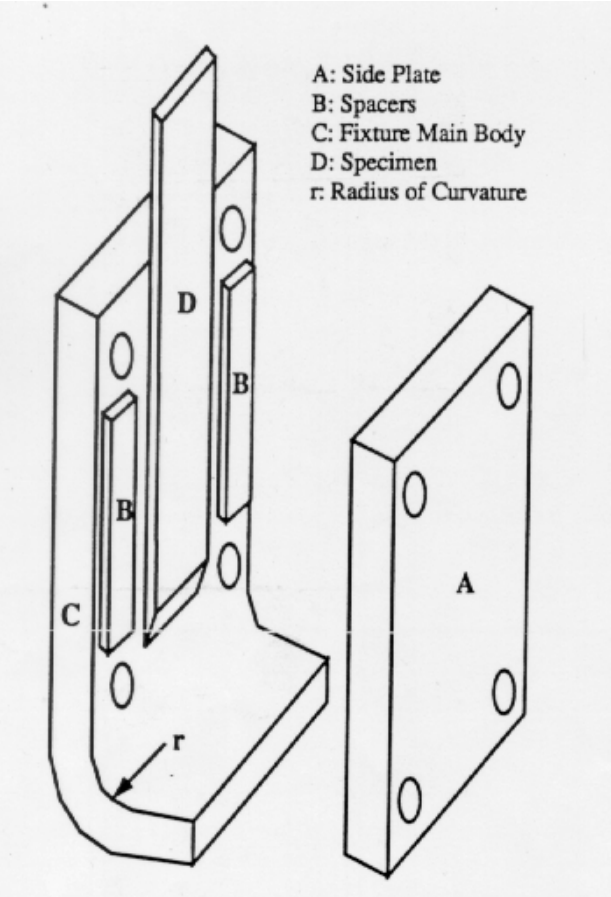


Figure 7. - Fixture of the Curling Test

Plate Compression

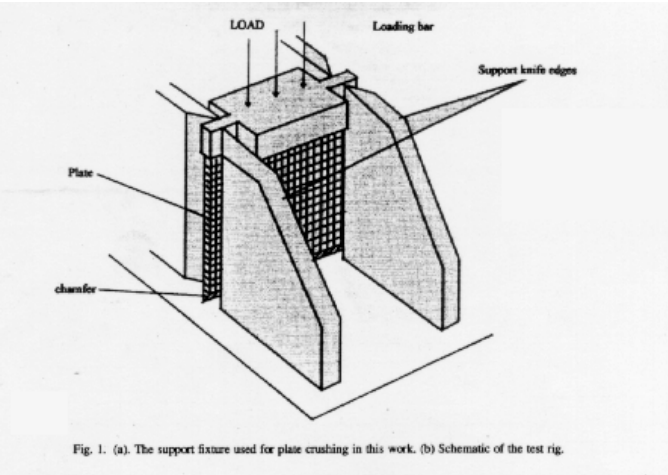


Fig. 1. (a). The support fixture used for plate crushing in this work. (b) Schematic of the test rig.

Daniel, et al
(1999)

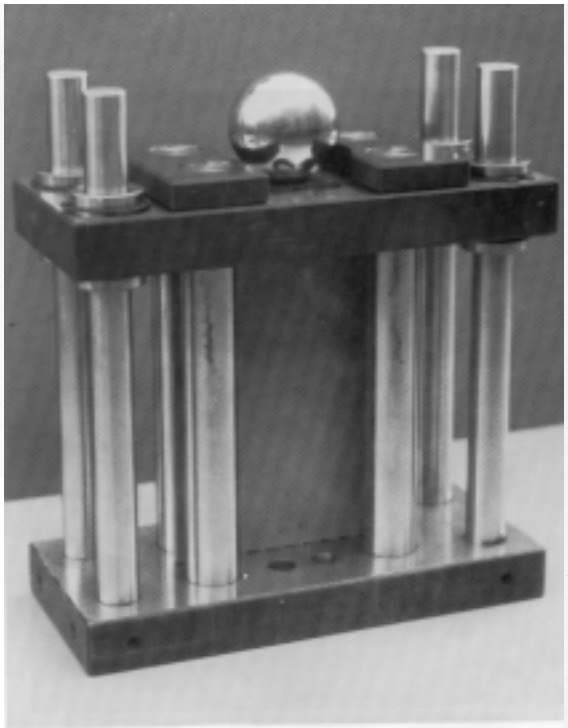


Figure 2.6 New test fixture configured for full scale specimens.

Lavoie and Morton
(1993)

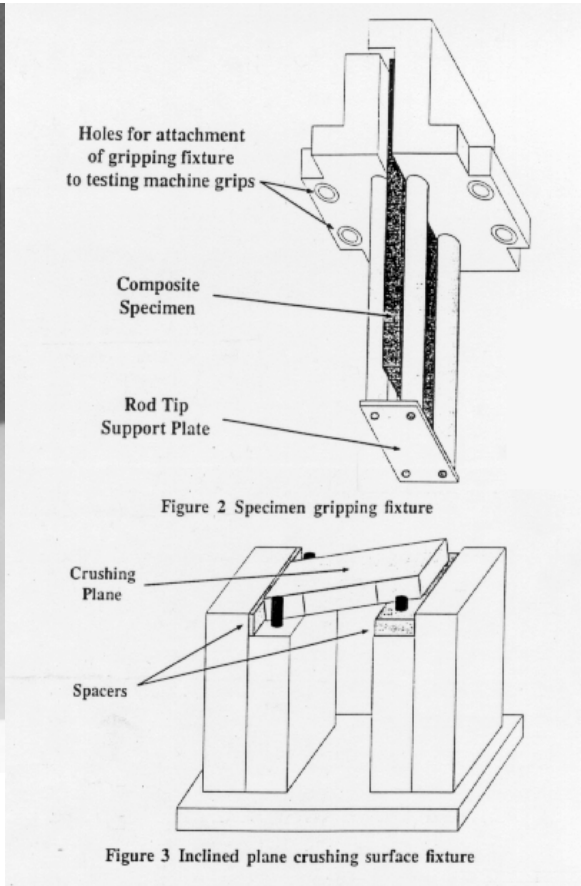


Figure 2 Specimen gripping fixture

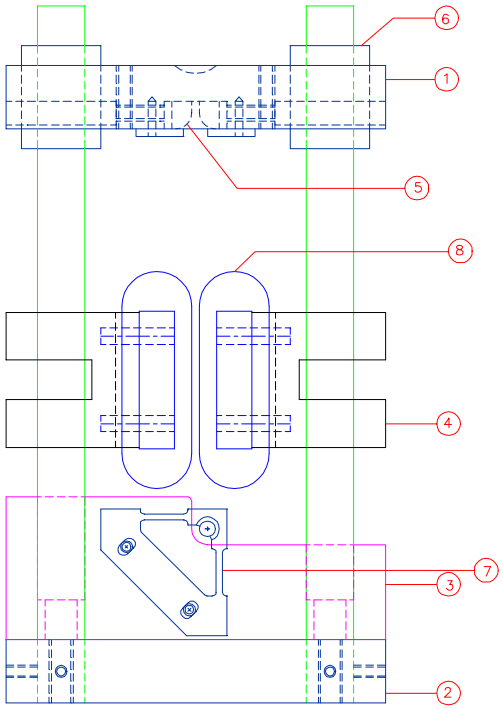
Figure 3 Inclined plane crushing surface fixture

Fleming and Vizzini
(1993)

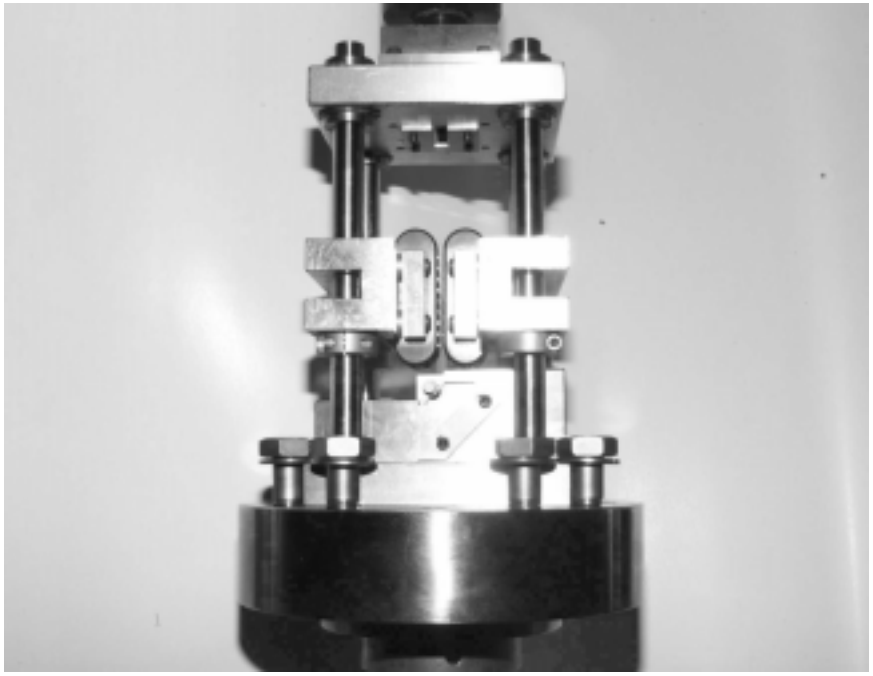
- Wider specimens
- Fully side-supported
- Flat crush profile

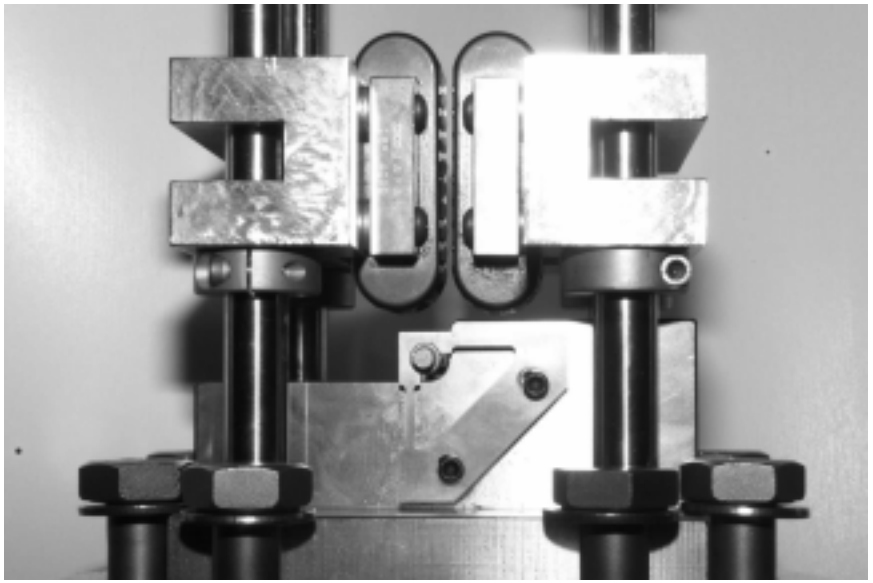
Test Fixture Design

- Isolate splaying mode observed in tubes by testing plates
- Investigate effects of:
  - plate width
  - plate thickness
  - strain rate
  - contact profile shape
  - contact profile constraint
- Features
  - observable crush zone
  - long crush length
  - interchangable contact profile
  - profile constraint
  - out-of-plane support



Test Fixture Design





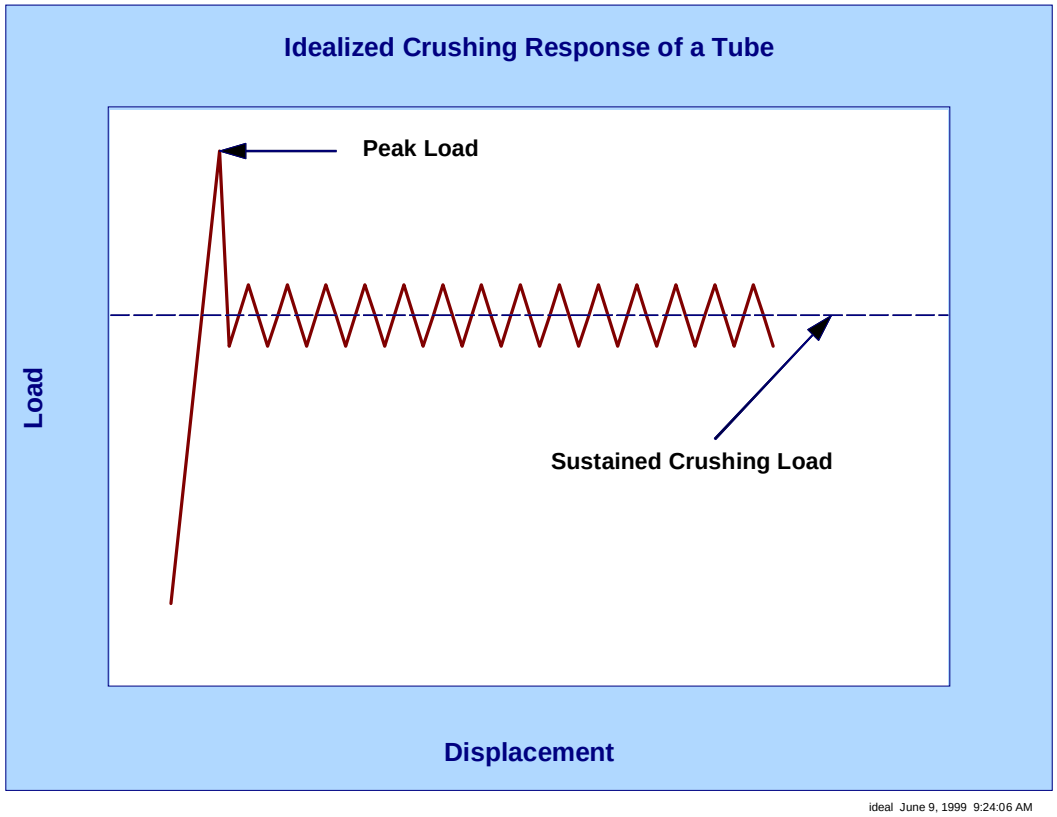
Fixture Validation

- Conducted preliminary testing on candidate automotive composite material systems
  - Graphite/Epoxy cross-ply laminates
    - Panel designations: CP1 and CP2
    - Akzo Fortafil prepreg #602 (50K tow)
  - Graphite/Epoxy triaxial braid
    - Panel designation: #10-13
    - 0/+30/-30 fiber orientations
    - Akzo #556 carbon fiber with Ashland Hetron 922 epoxy
  - Glass-reinforced continuous strand mat
    - Panel designation: CSM
    - Baydur polyurethane resin

Fixture Validation

- Nominal specimen dimensions
  - length: 178 mm (7 in.)
  - width: 50 mm (2 in.)
  - thickness: 3 mm (1/8 in.)
- Crush initiator used was a 45° chamfer
- Loading rate: 5.0 mm/min (0.2 in/min)
- Profile radius: 6.4 mm (0.25 in.)
- Maximum displacement was 50 mm (2 in.)

Idealized Response



Specific Energy Absorption

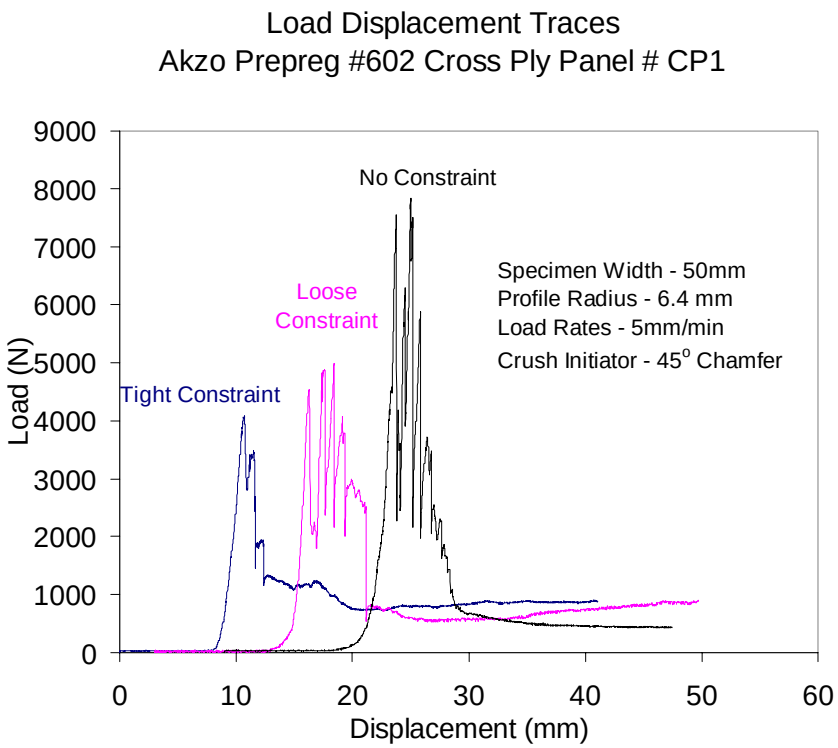
$$E_s = \frac{W}{V\rho}$$

W = total energy absorption
= area under curve
V = volume of crushed material
ρ = density

Cross-Ply Panel # CP1

- Predominant damage mechanism was delamination

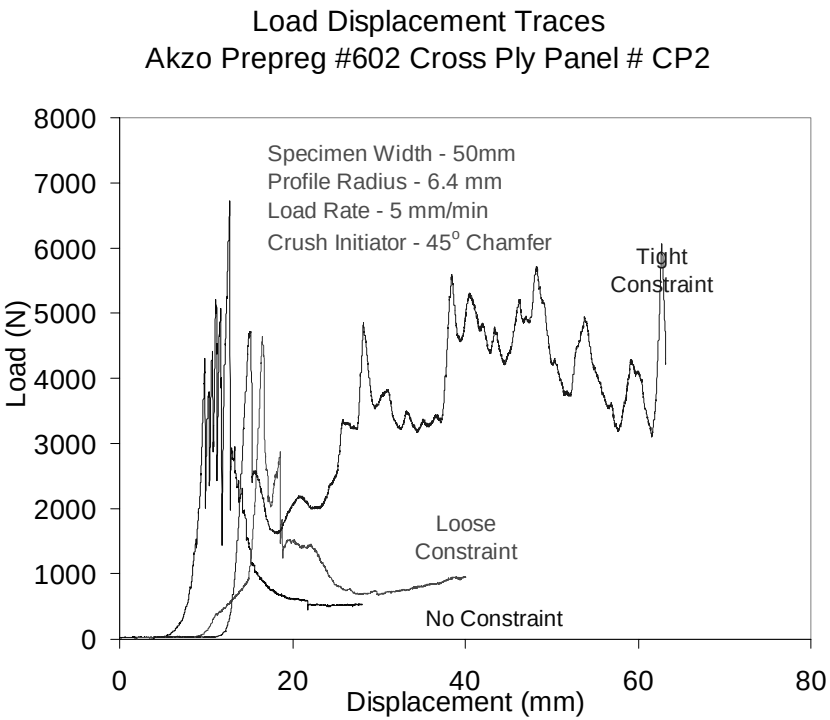
Constraint	Spec.	Initial Peak Load (N)	Sustained Crush Load (N)	SEA (J/g)
None	CP1-4	5489	5280	11.1
	CP1-5	7562	4372	13.8
Loose	CP1-1	4532	3581	19.9
	CP1-2	4617	4194	21.2
	CP1-3	3807	3505	13.6
Tight	CP1-6	4421	5039	25.5
	CP1-7	4092	1103	5.2



Cross-Ply Panel # CP2

- Predominant damage mechanism was delamination
- Lower SEA than panel # CP1

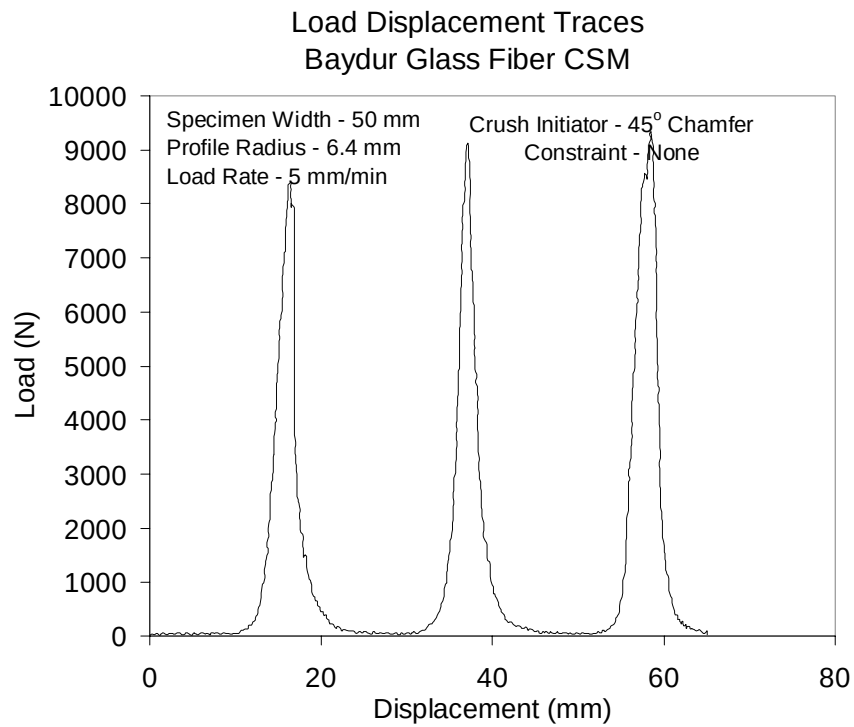
Constraint	Spec.	Initial Peak Load (N)	Sustained Crush Load (N)	SEA (J/g)
None	CP2-1	5962	3971	7.9
	CP2-2	4310	3259	7.1
Loose	CP2-3	4595	2176	6.3
	CP2-4	4437	1463	6.9
Tight	CP2-5	4670	4619	20.1
	CP2-6	4583	3020	15.1



Glass Fiber CSM

- Finite length fractures across entire specimen width
- Profile constraint resulted in specimen buckling

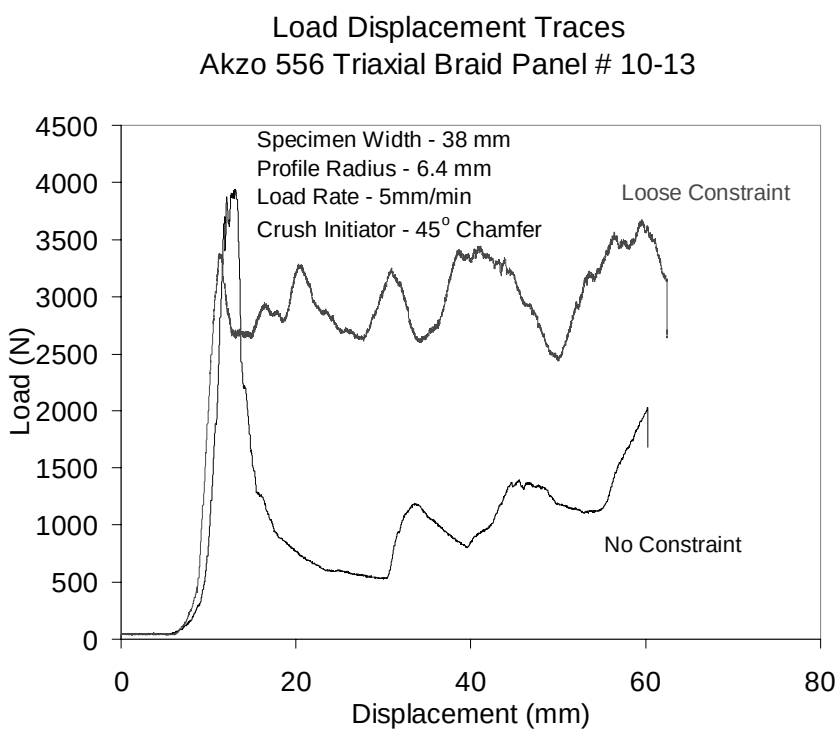
Constraint	Spec.	Initial Peak Load (N)	Sustained Crush Load (N)	SEA (J/g)
None	CSM-1	7478	4829	10.8
	CSM-2	8156	4444	9.7
	CSM-3	8334	4561	10.1



Tri-Axial Braid

- Localized crushing, fiber fracture on tensile side, fiber buckling on the compressive side

Constraint	Spec.	Initial Peak Load (N)	Sustained Crush Load (N)	SEA (J/g)
None	0-7	4233	1917	7.4
	0-8	3674	1001	6.9
Loose	0-6	3490	2417	14.2
	0-9	3366	2934	20.2



Test Observations

- A test fixture has been developed for conducting progressive crush tests on composite plates
- Different damage mechanisms can be activated depending on the condition of the profile constraint
- Modifications to the basic specimen geometry are required when testing material systems having a low axial stiffness
- Future testing will investigate the progressive crush behavior of chopped carbon fiber composites
- Experimental results are being used to develop analytical models for predicting the crashworthiness of automotive composite structures

Chopped Carbon Fiber

- Test variables
  - Profile radius: 0.25 in. and 0.50 in.
  - Load rate: 0.2 in./min.
  - Constraint: none, loose, tight
- Specimen variables
  - Width: 0.5 in., 1.0 in., 2.0 in.
  - Areal weight: 150 gsm, 300 gsm
  - F.V.: 40%, 50%
  - Fiber length: 1.0 in, 2.0 in.

Areal Weight (gsm)	V_f (%)	Fiber Length (in.)
300	50	1
300	40	1
300	50	2
300	40	2
150	50	1
150	40	1
150	50	2
150	40	2

Missing Links

- "Where is the energy?" (Ron Averill, MSU)
  - Splaying mode or frond formation is only part of the total energy absorbing process
  - Alternative tests are needed to isolate and quantify the other damage mechanisms that absorb energy
- Are the damage mechanisms and SEA rate dependent?
  - Results from tube testing show that the dynamic SEA is less than the static SEA
  - Experimental data is needed at intermediate and higher strain rates