Short Course on Design and Testing of Polymer Composite Products 2003

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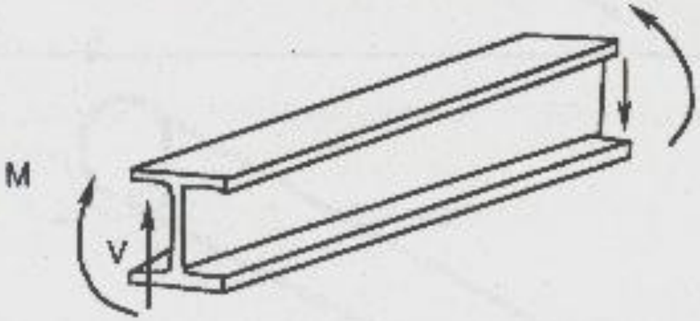
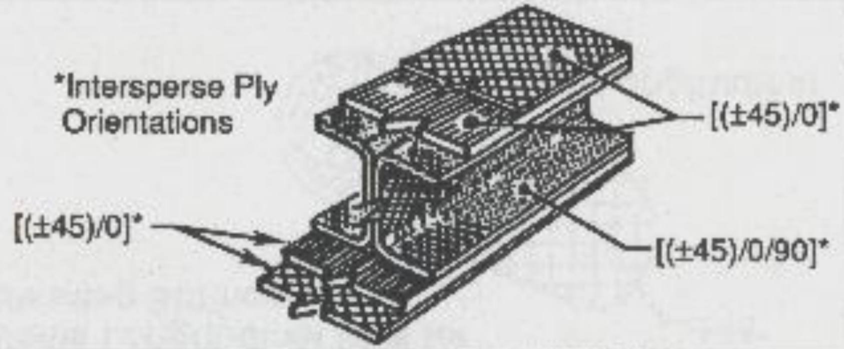
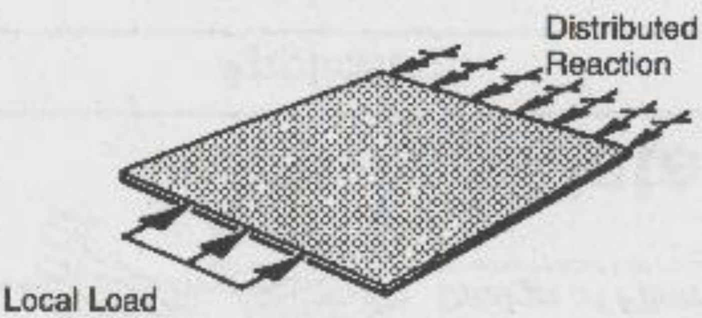
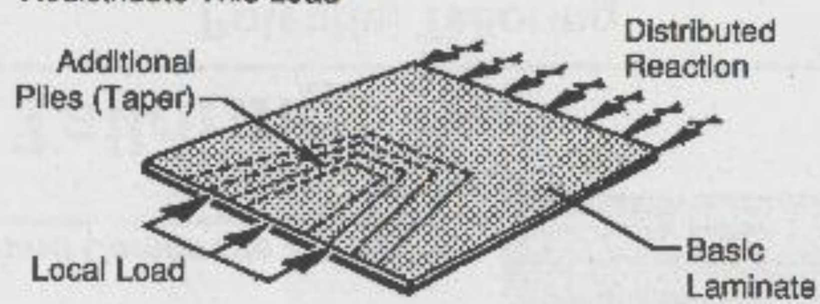
TESTING OF COMPOSITE MATERIALS/STRUCTURES

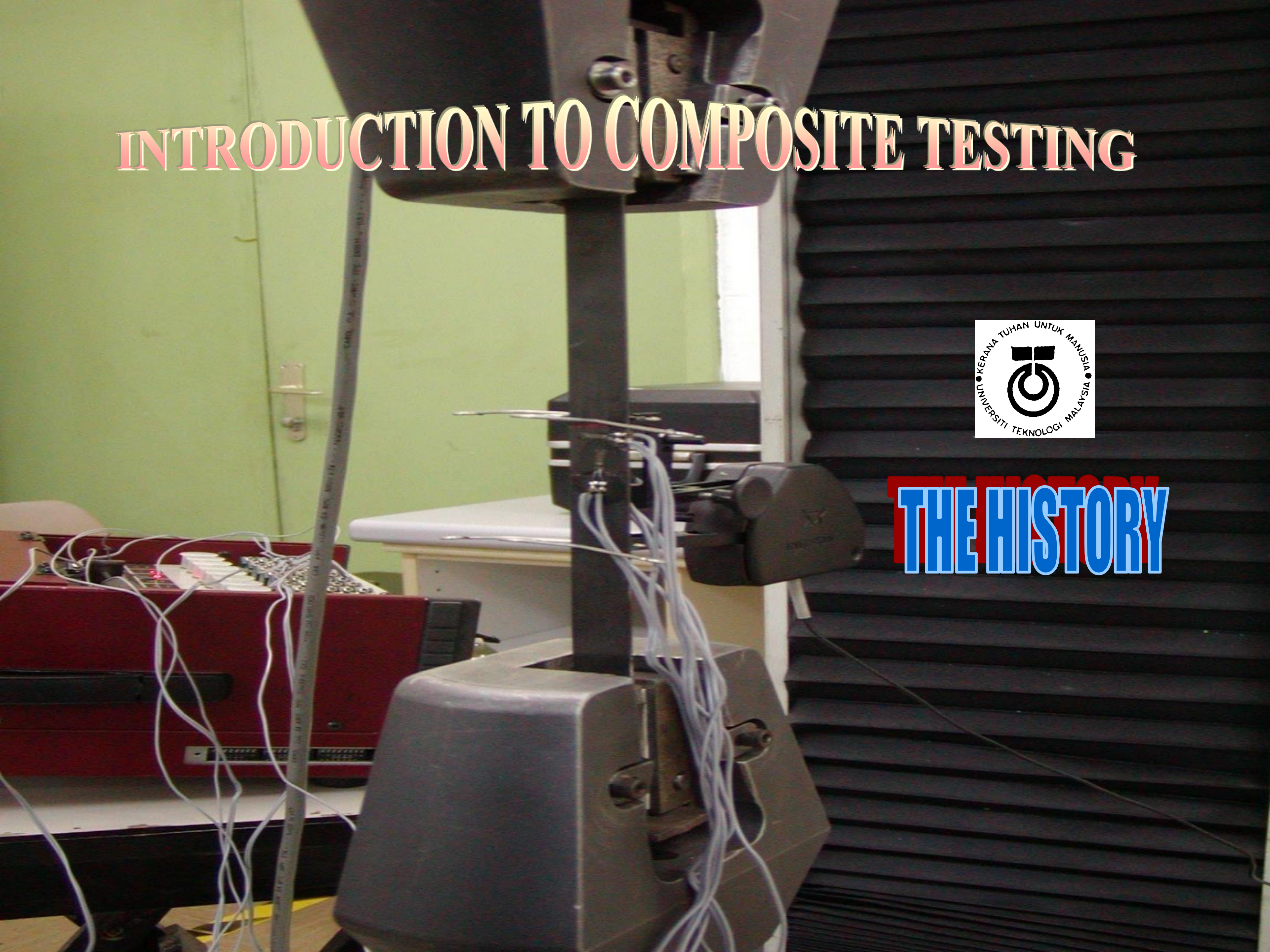
Designing FRP as Structural Member

Application	Potential Tailoring
Beam Subjected to Bending and Shear  	• Include 0° Plies in Cap to Efficiently Sustain Bending Induced Axial Loads • Include ±45° Plies in Web (to Sustain Shear Loads) and in Caps (to Stabilize Flanges). 
Panel Subjected to Local Load  	• Within the Basic Laminate, Distribute Sufficient Additional 0° Plies to React Local Load, Plus ±45° Plies to Redistribute This Load 

OVERVIEW

- INTRODUCTION TO COMPOSITE TESTING
- MECHANICAL PROPERTIES
  - ✓ TENSILE
  - ✓ COMPRESSION
  - ✓ SHEAR
  - ✓ FLEXURAL
  - ✓ BONDED AND BOLTED JOINTS STRENGTH
  - ✓ IMPACT
- TEST PLANNING

INTRODUCTION TO COMPOSITE TESTING



THE HISTORY

THE HISTORY

- Initially used metals Test Methods
  - ✓ Homogenous
  - ✓ Isotropic
- Composites require special consideration
  - Nonhomogenous (Layered)
  - Anisotropic (typically Orthotropic)
- Early composites development limited to Aerospace Companies
- Each company developed its own procedures
- Testing further complicated by continually emerging new materials
  - ✓ Glass
  - ✓ Carbon
  - ✓ Aramid (Kevlar)
  - ✓ Boron
  - ✓ Epoxies etc.
- General standards for testing composite materials still do not exist.

PROBLEMS WITH COMPOSITES

- **Influences of material Orthotropy – more properties required than isotropic materials**
- **Laminated construction**
- **Unidirectional composites are extremely strong and stiff in one principal direction and weak and flexible in the other**
- **Temperature and moisture dependent properties**

THE IMPORTANTS OF MECHANICAL TESTS

- QUALITY CONTROL
- QUALITY ASSURANCE
- COMPARISONS BETWEEN MATERIALS & SELECTION
- DESIGN CALCULATIONS
- PREDICTION OF PERFORMANCE UNDER CONDITIONS OTHER THAN THOSE OF THE TEST
- INDICATORS IN MATERIALS DEVELOPMENT PROGRAMMES
- STARTING POINTS IN THE FORMULATION OF THEORIES

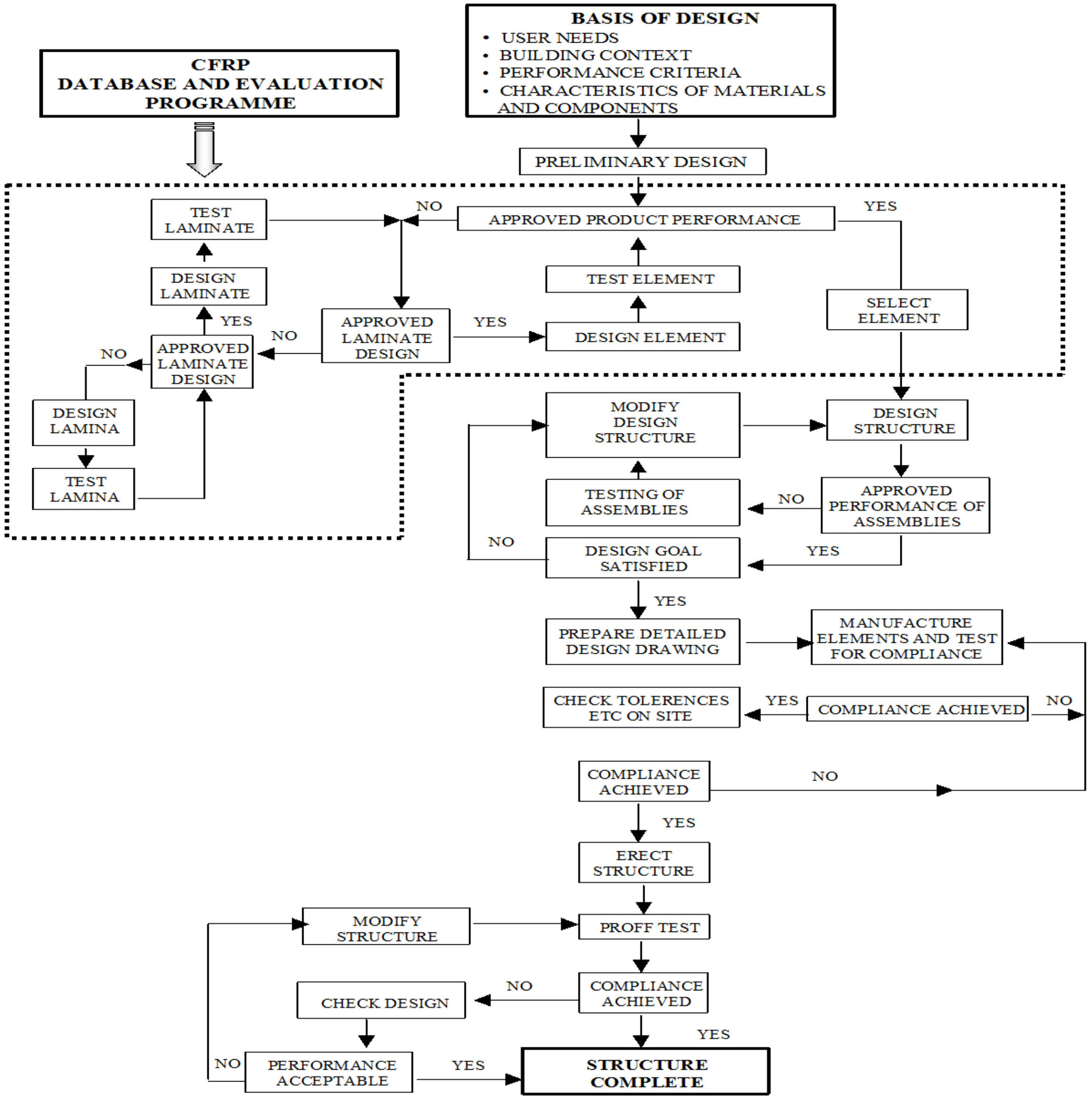
Preliminary Testing Recommended Prior to Large Test Programme

- Vendor Data
- Screening Tests
- Preliminary Design Data
- Final Design Data

Lamina and Laminate Data

- Typical Procedure
  - ✓ Characterize lamina properties first
  - ✓ Use Classical Lamination Theory to Predict Laminate Properties and Behaviour
  - ✓ Perform limited laminate tests to verify theoretical predictions
  - ✓ Perform tensile, shear, impact, bonding etc.

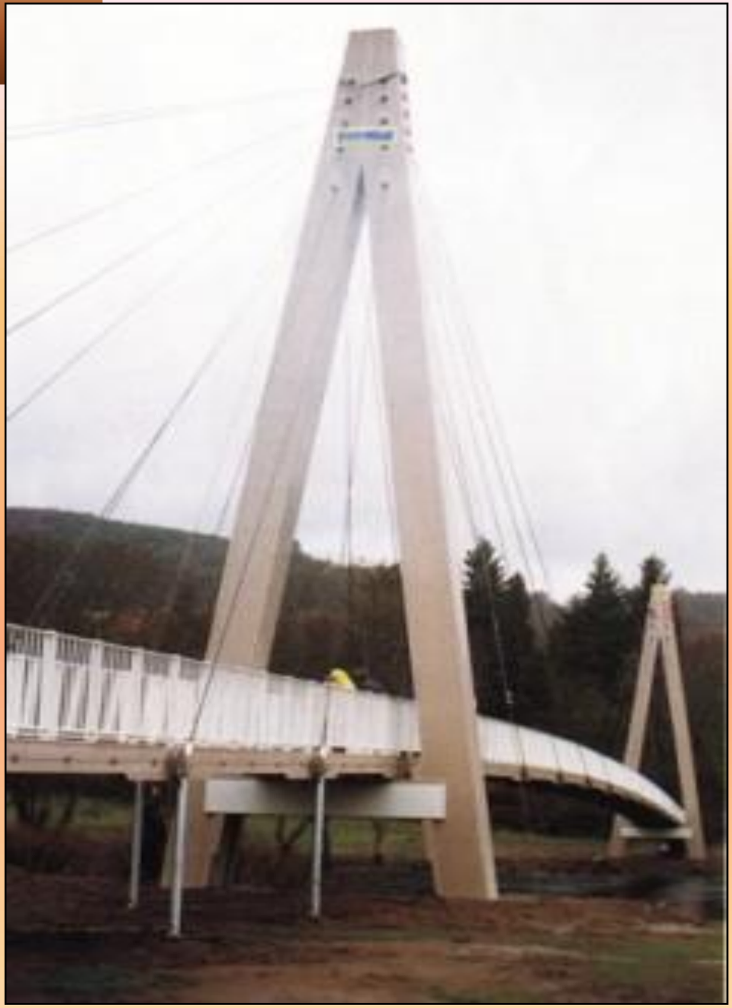
TESTING PROGRAMME



FLOW DIAGRAM OF THE DESIGN AND CONSTRUCTION PROCESS

Topics to be Covered For Each Test Method

- ASTM or applicable Test Methods
- Specimen geometry
- Fibre orientation
- Grips and Fixtures required
- Instrumentation



Mechanical Properties

- Tensile
- Compression
- Shear
- Flexural
- Bonded & Bolted Joints
- Impact

Tensile Test

AXIAL TENSION

- Axial tensile testing of unidirectional composites is a challenge
  - Difficult to transmit load from testing machine to the composite
  - Interlaminar shear strength is much lower than uniaxial tensile strength
  - Shear failure in the gripping region is a common problem
- Glass/epoxy or aluminium tabs are usually bonded to each end of straight-sided specimens
  - Distributes gripping forces
  - Protects composite from surface damage
  - Use large bond area to minimize shear stresses
- The thinner the specimen, the better
- Dog bone shaped specimens are not recommended

TRANSVERSE TENSION

- Transverse tensile testing is not difficult
- Care is required to protect breakage due to handling use thick specimens
- Tabs not usually required

TENSILE TESTING – RECTANGULAR COUPONS

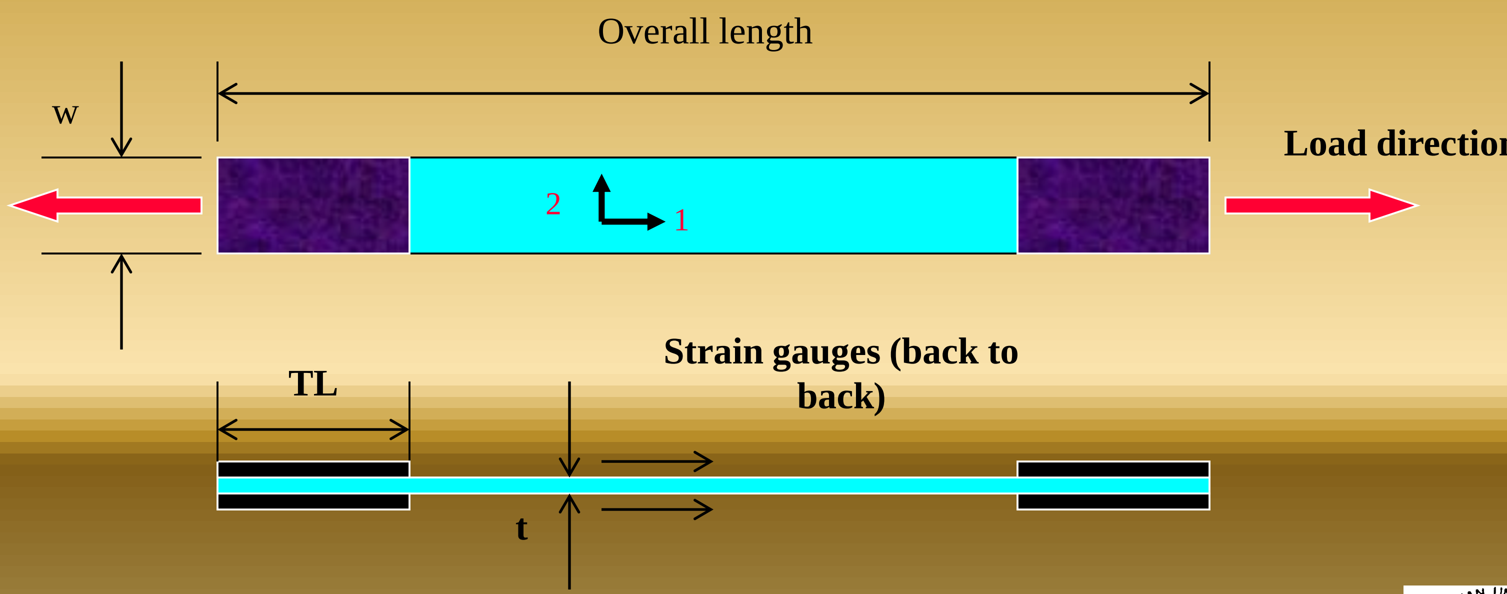
- **Specifications:**
  - ✓ **ASTM D3039**
  - ✓ **ISO 527-5:1997**
  - ✓ **ISO 527-4:1997**
- **Geometry:**
  - ✓ **250 mm x 25.4 mm (most common geometry)**
- **Fibre Orientation:**
  - ✓ **Unidirectional, Off-axis, Crossply, Quasi-isotropic, etc**
- **Instrumentation:**
  - ✓ **Extensometer or strain gauges (needed to monitor strain)**
  - ✓ **Biaxial strain gauges required for Poisson's ratio**

Specimen Geometry (ASTM D3039 Rectangular Coupons)

Fibre orientation	Recommended Specimen Width, w	Gauge length, GL
0º (angle)	12.7 mm	138 mm
90º (angle)	25.4 mm	125 mm
0/90º (angle) Balanced crossply	25.4 mm	138 mm

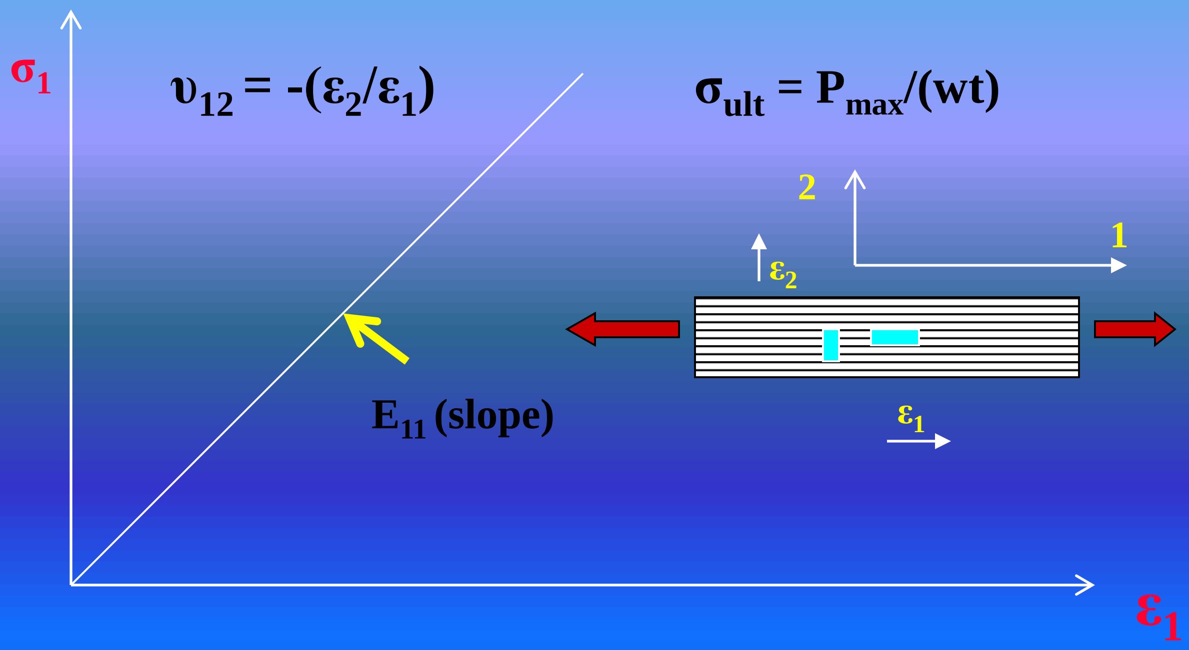
TL – end tab length

Specimen Geometry (ASTM D3039 Rectangular Coupons)



TENSILE PROPERTIES

- **Evaluation of E_{11}, υ_{12} and σ_{ult} in longitudinal direction.**



Tensile Test on CFRP Pultruded Plate

Specimen geometry 15mm x 228mm x 1.2mm

Ultimate tensile load = 55 kN

Ultimate tensile strength = 2700 MPa

Ultimate tensile strain = 1.8 %

COMPRESSION TESTING

- **Test set up must be designed to Preclude Buckling**
- **Test methods:**
- **IITRI (Illinois Institute of Technology Research Institute)**
- **ASTM D695**
- **Geometry:**
- **152.4 mm (length) x 25.4 mm (width)**
- **Max. width (38.1 mm)**
- **Thickness range 3.048 mm to 6.35 mm**
- **Fibre orientation:**
- **Unidirectional (0º or 90º), Cross ply (0º,90º), Quasi-isotropic, etc.**
- **Grips and Fixtures:**
- **IITRI Compression Test Fixture required**
- **Instrumentation:**
- **Back to back strain gauges recommended to monitor potential bending during test.**

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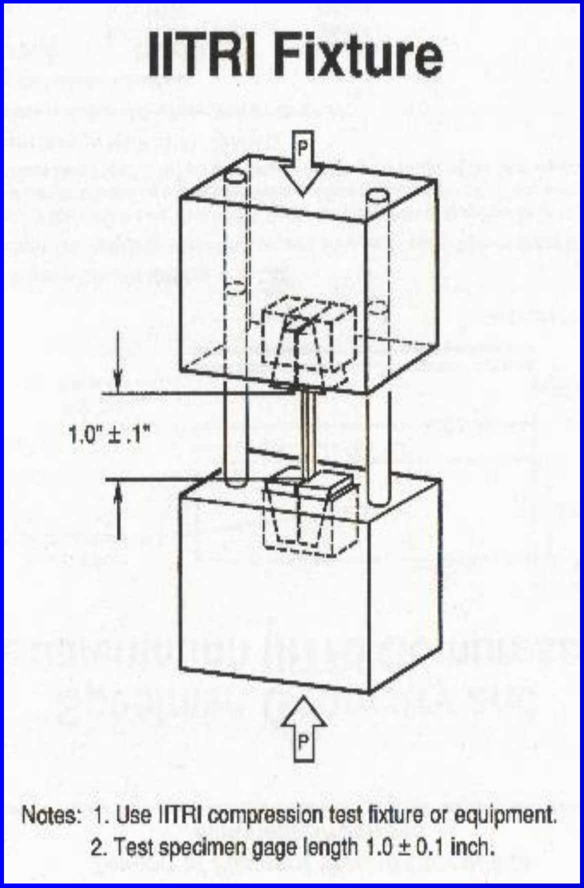
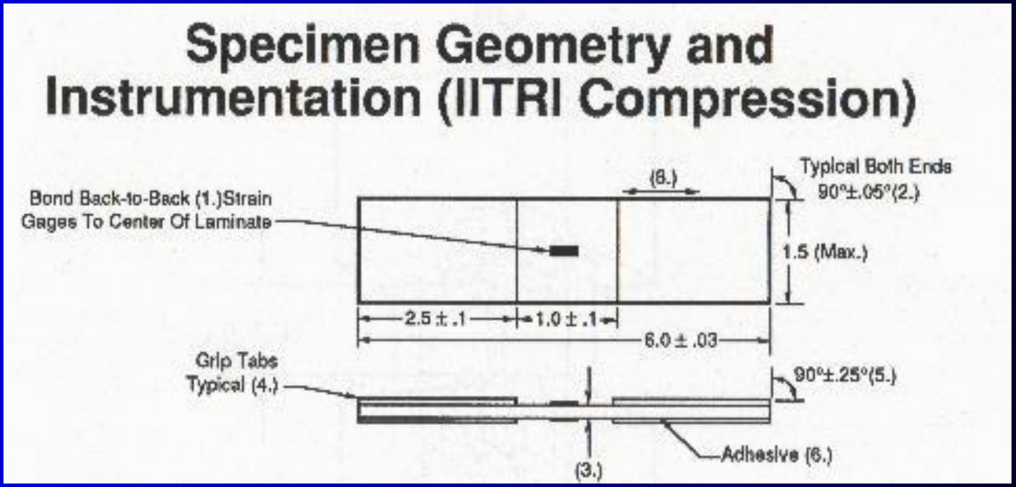
COMPRESSION TESTING





Longitudinal Compression Strength, F_{CL} = P/wt

Compression Modulus, E_C = secant modulus at –0.25% strain due to nonlinear stress-strain curve.

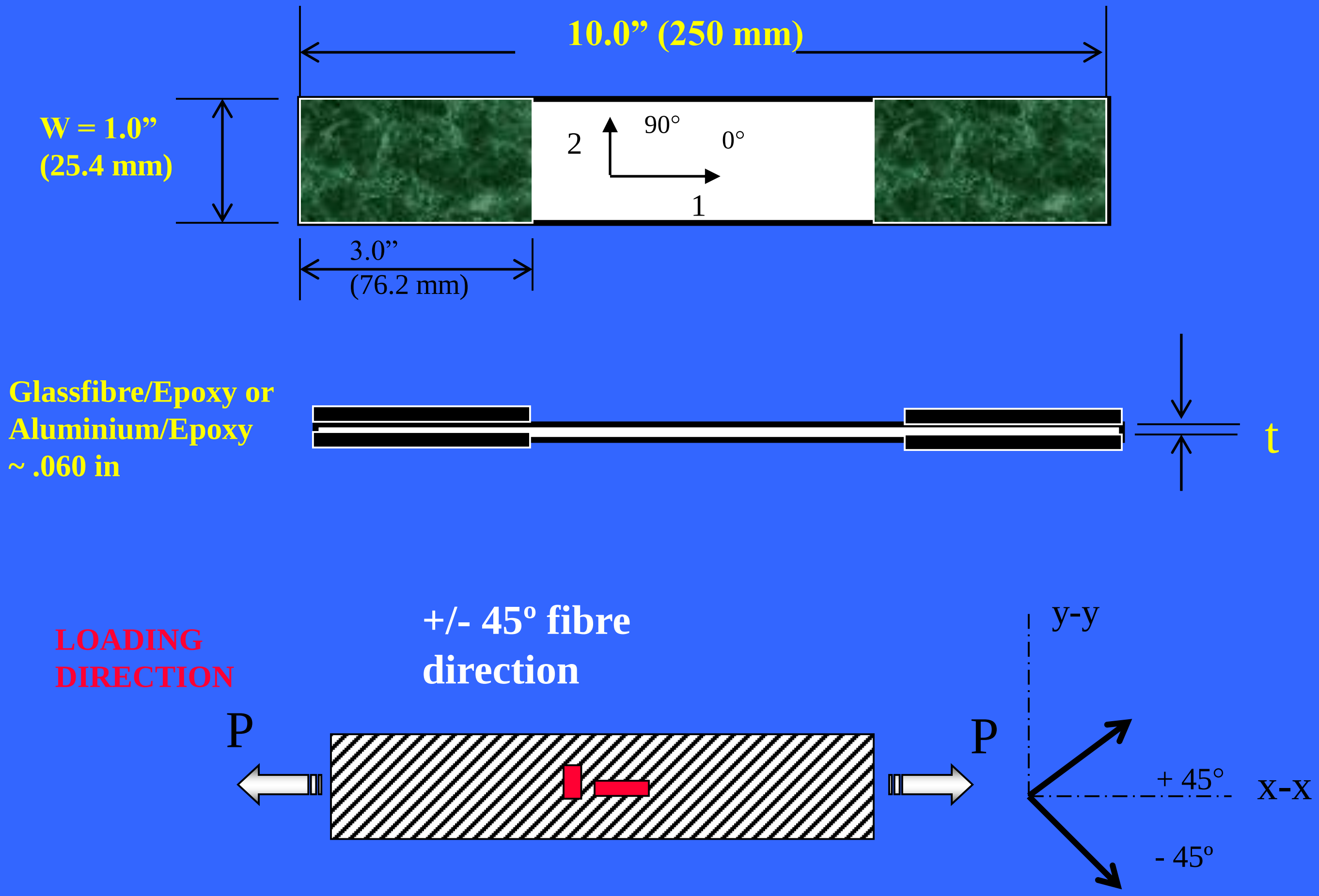
SHEAR TESTING

- Various Methods Available
  - ✓ +/- 45° Tensile coupon
  - ✓ Iosipescu
  - ✓ Rail Shear
  - ✓ Interlaminar (Short Beam Shear)

Shear Testing +/- 45 Tensile Coupons

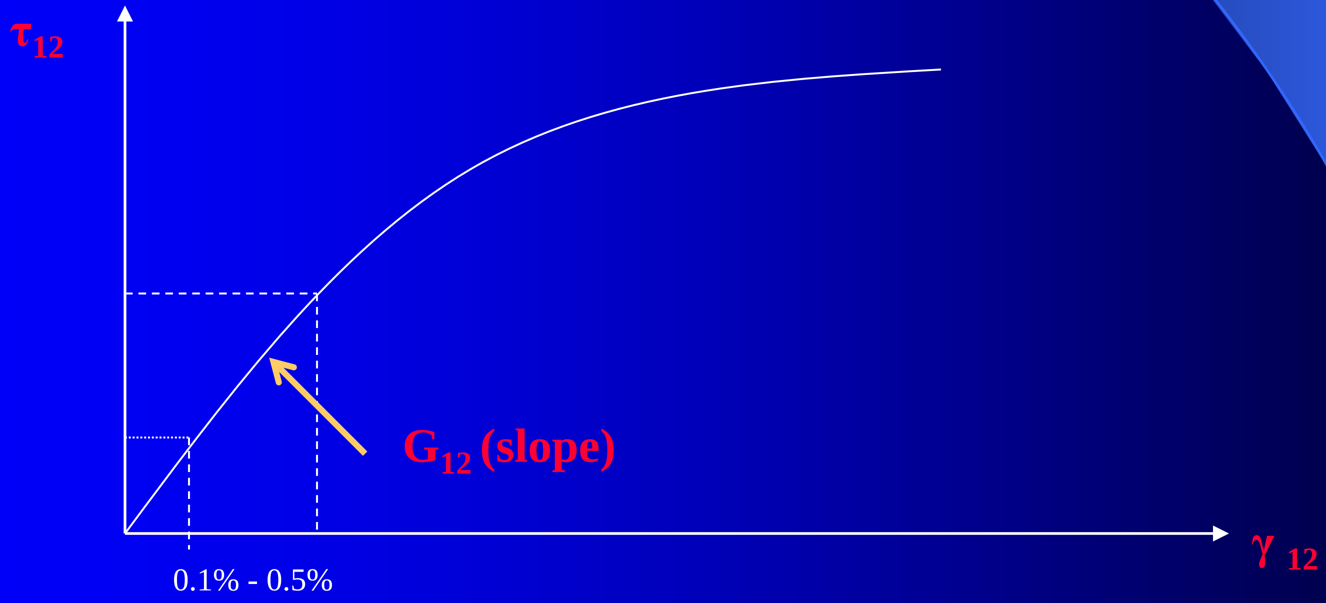
- Specification:
  - ✓ ASTM D3518
- Geometry
  - ✓ 250 mm x 25.4 mm (most common)
- Fibre orientation:
  - ✓ +/- 45 lay-up only
- Grips and Fixtures:
  - ✓ Mechanical or Hydraulic wedge grips required
- Instrumentation:
  - ✓ Biaxial strain gauges required if shear modulus and shear strain are desired
- Very similar to rectangular tensile specimen testing
- Test method only provide lamina properties
  - ✓ τ_{12}, γ_{12} and G_{12}

SHEAR TEST SPECIMEN GEOMETRY



SHEAR PROPERTIES

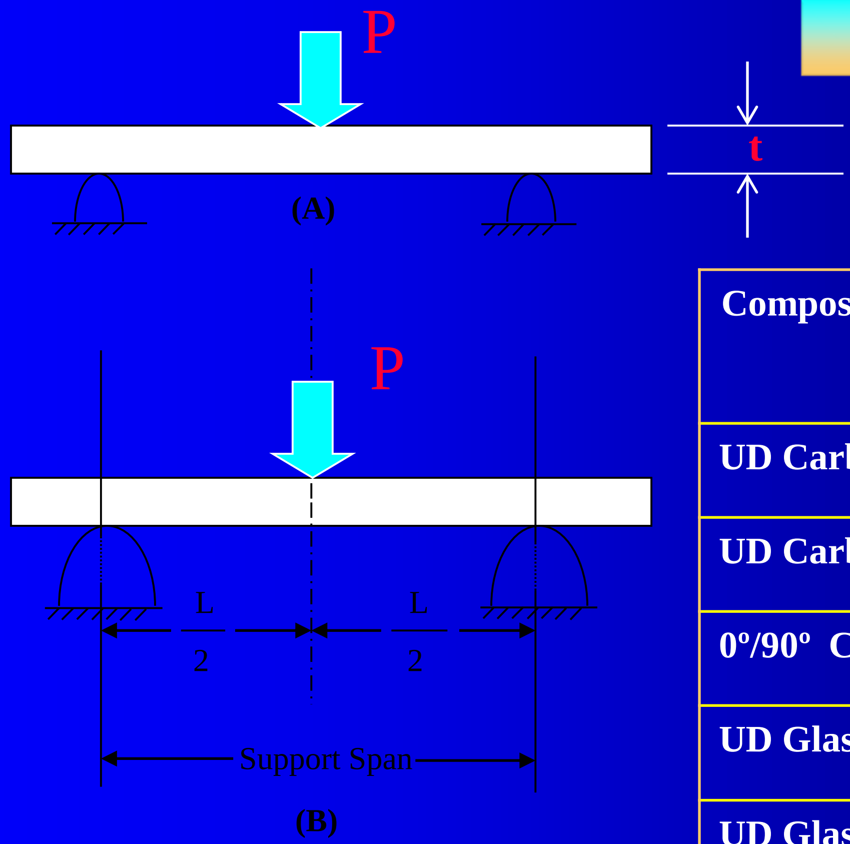
- Shear stress, $\tau_{12} = +/- \sigma_{xx}/2$
- Shear strain, $\gamma_{12} = \varepsilon_{xx} - \varepsilon_{yy}$
- In Plane Shear Modulus, $G_{12} = \sigma_{xx} / 2(\varepsilon_{xx} - \varepsilon_{yy})$
- In Plane Shear Strength, $S_{12} = P_{max}/(2wt)$



FLEXURAL TESTING

- **SPECIFICATION :**
  - ✓ASTM D790
- **GEOMETRY :**
  - ✓Length Dependent on Thickness
  - ✓Span to Thickness Ratio of 16 to 1 is Recommended if Ratio of Tensile Strength to Shear Strength is Less Than 8 to 1.
  - ✓Span to Thickness Must Be Increased if Tensile Strength to Shear Strength >8.
- **FIBER ORIENTATION :**
  - Essentially Any Orientation Can Be Tested
- **GRIPS AND FIXTURES :**
  - Three and/or Four Point Flexure Fixture With Variable Span Setting Required (3 Point Most Common).
- **INSTRUMENTATION :**
  - ✓Deflectometer Required if Accurate Measurement of Mid Span
  - ✓Only Load Versus Machine Crosshead Travel Recorded for Most 3-Point Flexure Tests
  - ✓Flexural strength determined by this method cannot be used for design data
- **Data typically used for :**
  - ✓Quality control
  - ✓Process verification testing
  - ✓Specification purposes
  - ✓Comparative type testing

FLEXURAL SPECIMEN TEST SETUP
3 POINT LOADING



Composite reinforcement	Alignment fibre to the beam axis	L/t
UD Carbon fibre	0º	40/1
UD Carbon fibre	90º	25/1
0º/90º Carbon fibre	0º/90º	25/1
UD Glass fibre	0º	20/1
UD Glass fibre	90º	20/1
0º/90º Glass fibre	0º/90º	20/1
0º/90º Aramid fibre	0º/90º	16/1

Flexural Properties

Flexural Strength is given by:

$$f_F = 1.5PL/wt^2$$

Flexural Modulus is given by:

$$E_F = L^3m/4t^3$$

w – specimen width, mm

P – load at failure, N

L – span between supports, mm

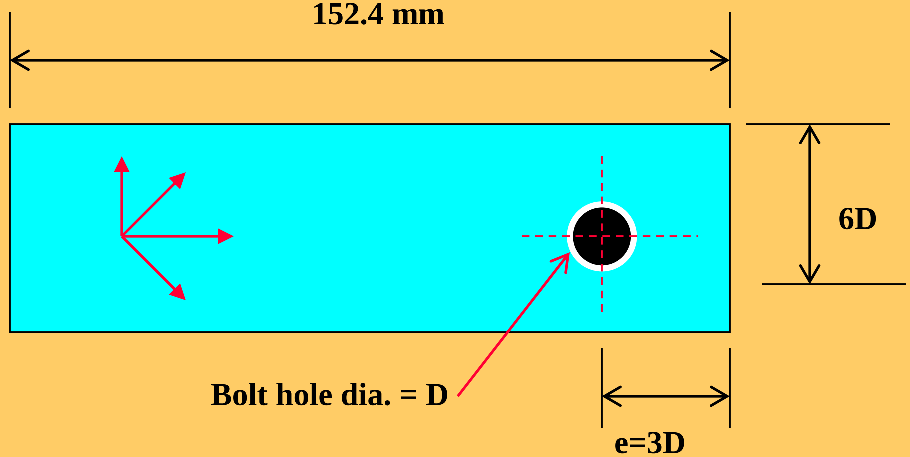
m – slope of linear load/deflection graph (N/mm)

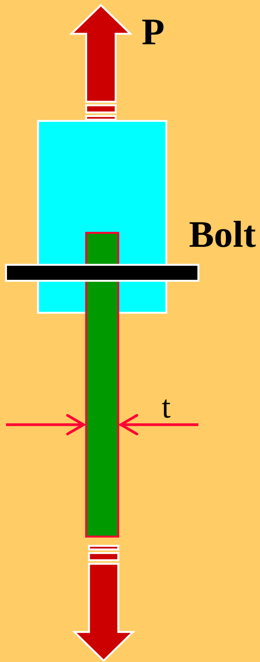
t – specimen thickness, mm

BOLT BEARING TESTING

- **Two most common test:**
  - Double shear (Pin Bearing) and Single Shear
- **Specifications:**
  - ASTM D953 "Bearing Strength of Plastics"
- **Geometry:**
  - 152.4 mm x 6 times Bolt Diameter Width (not ASTM)
  - 6.35 mm Diameter Hole Most Common
- **Fibre Orientation:**
  - Quasi-Isotropic or other Layups representative of actual structure
- **Grips and Fixtures:**
  - Mechanical or hydraulic wedges grips required
  - Bearing loading fixture and bolt required
- **Instrumentation:**
  - No special instruments required
  - Load versus head deflection typically recorded.

Double Shear (Pin Bearing) Test Configuration





F_{BR} = P/Dt

Where,

P = Failure load, N

D = Bolt diameter, mm

t= specimen thickness

F_{BR} = bearing stress, N/mm^2

Bolt Bearing Test

Failure load, F_f = 45 kN

Failure mode = CFRP shear out

Bolt dia. = 10 mm

Mild steel plate thickness = 2 mm
bonded to CFRP Plate

CFRP Plate
Bolted Both End

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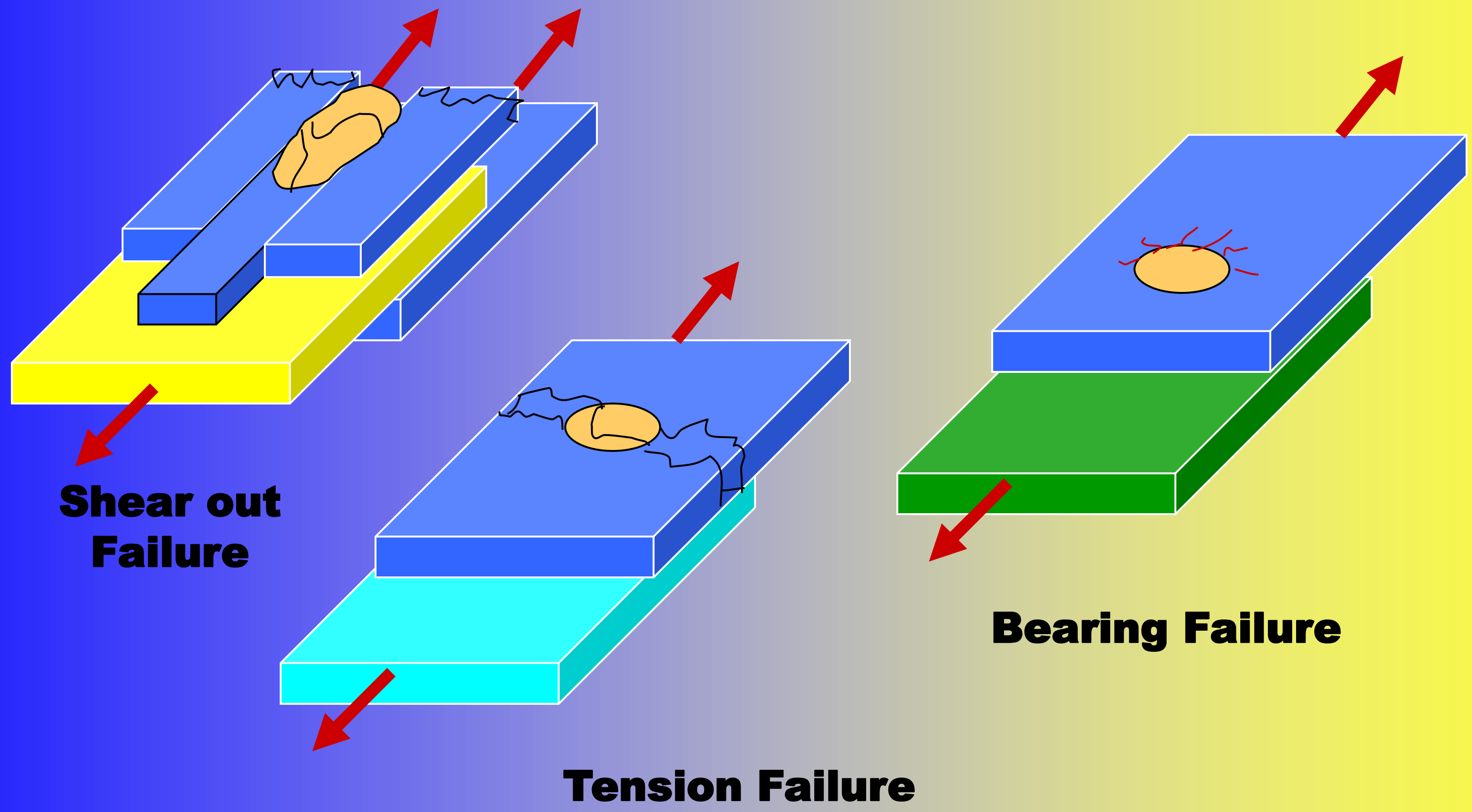
MODES OF FAILURE FOR BOLTED JOINTS



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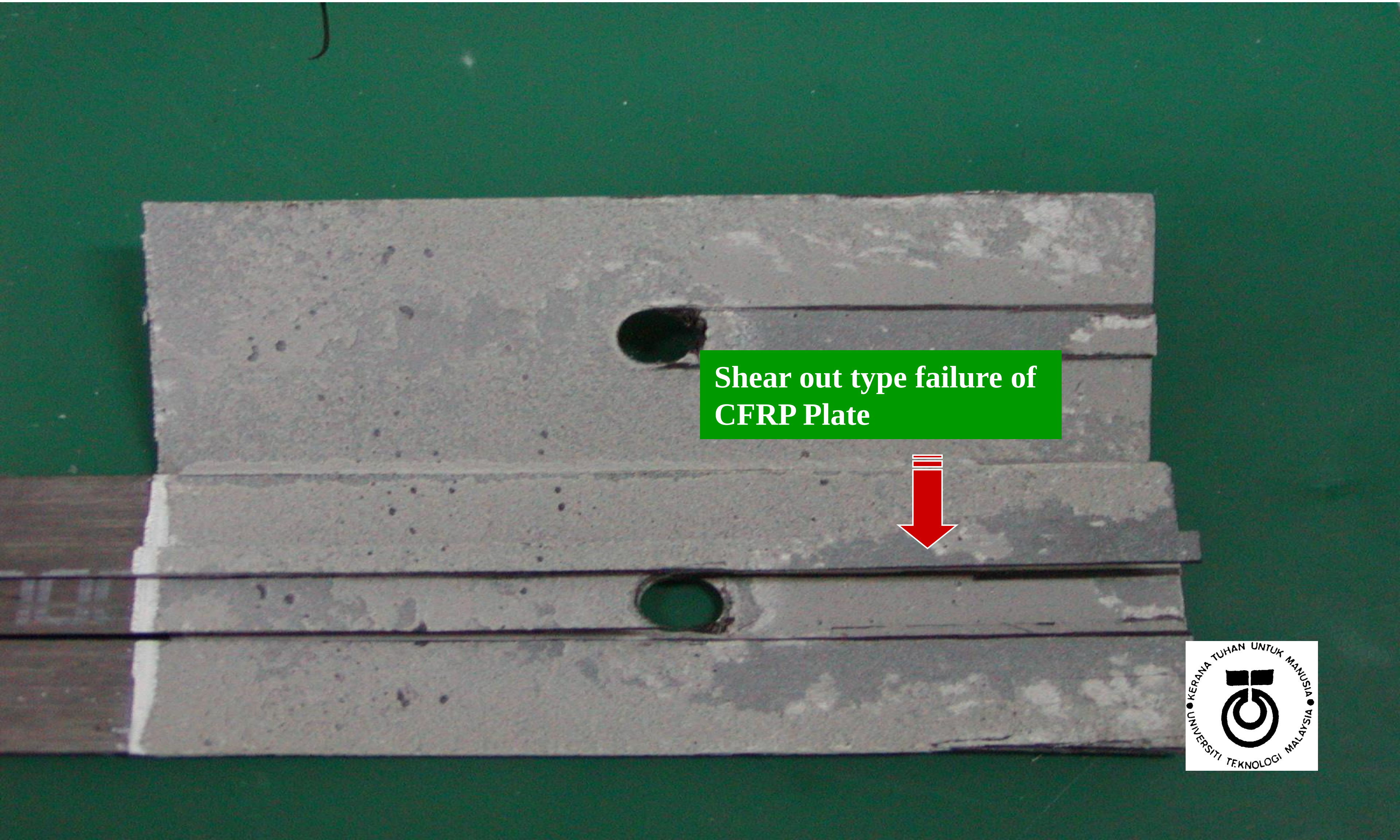
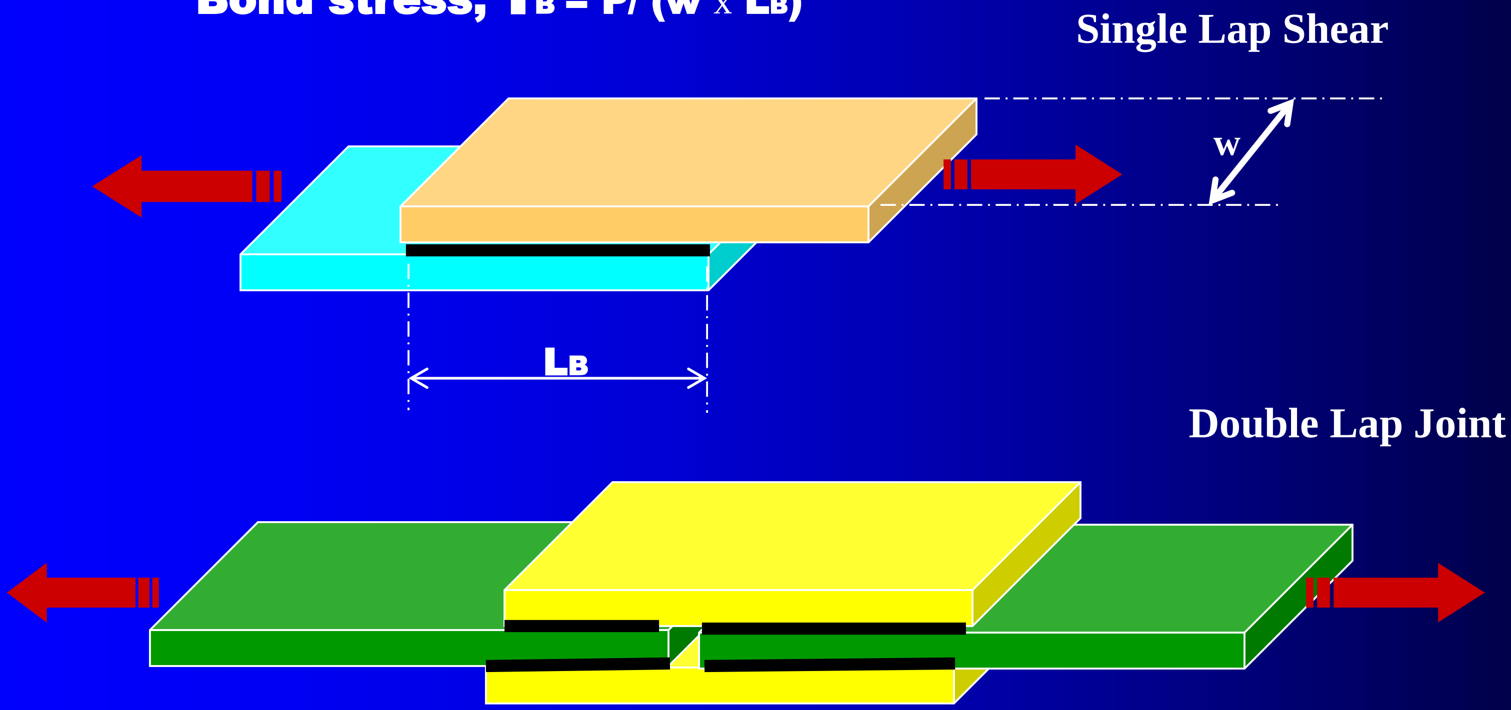
Shear out Failure of CFRP Plate

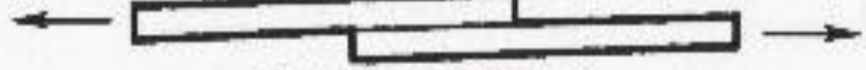


ADHESIVELY BONDED JOINT TESTING

Bond stress, $T_B = P/(w \times L_B)$



Failure of Single-Lap Bonded Joints With Brittle and Yielding Adherends



Low Load Level

Deformation of Adherends Under Moderate Load

Brittle Adherend

"Interlaminar" Failure of Filamentary Composite Adherends

Yielding Adherend

High Load Level (Metal Adherends)

Permanently Deformed (Metal) Adherends After Failure of Adhesive

CFRP/CONCRETE PULL OUT BOND TEST

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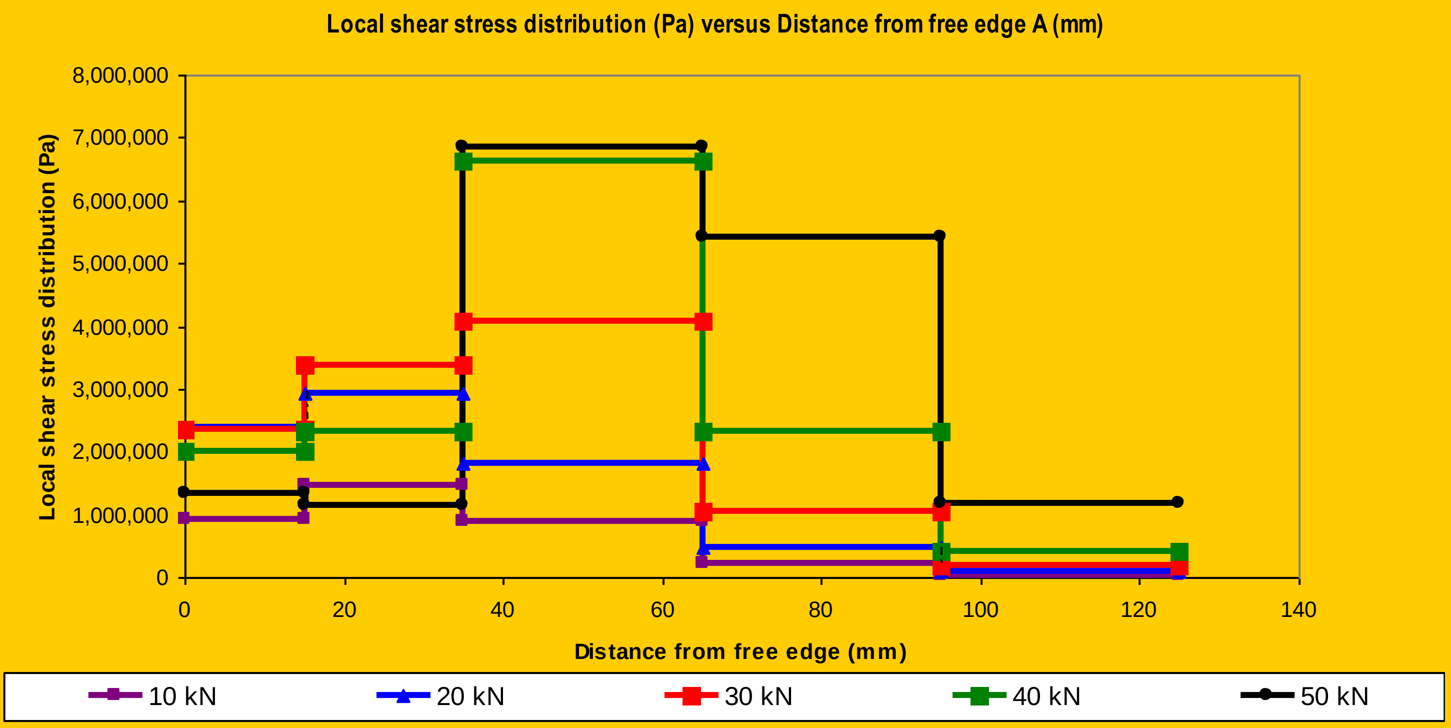
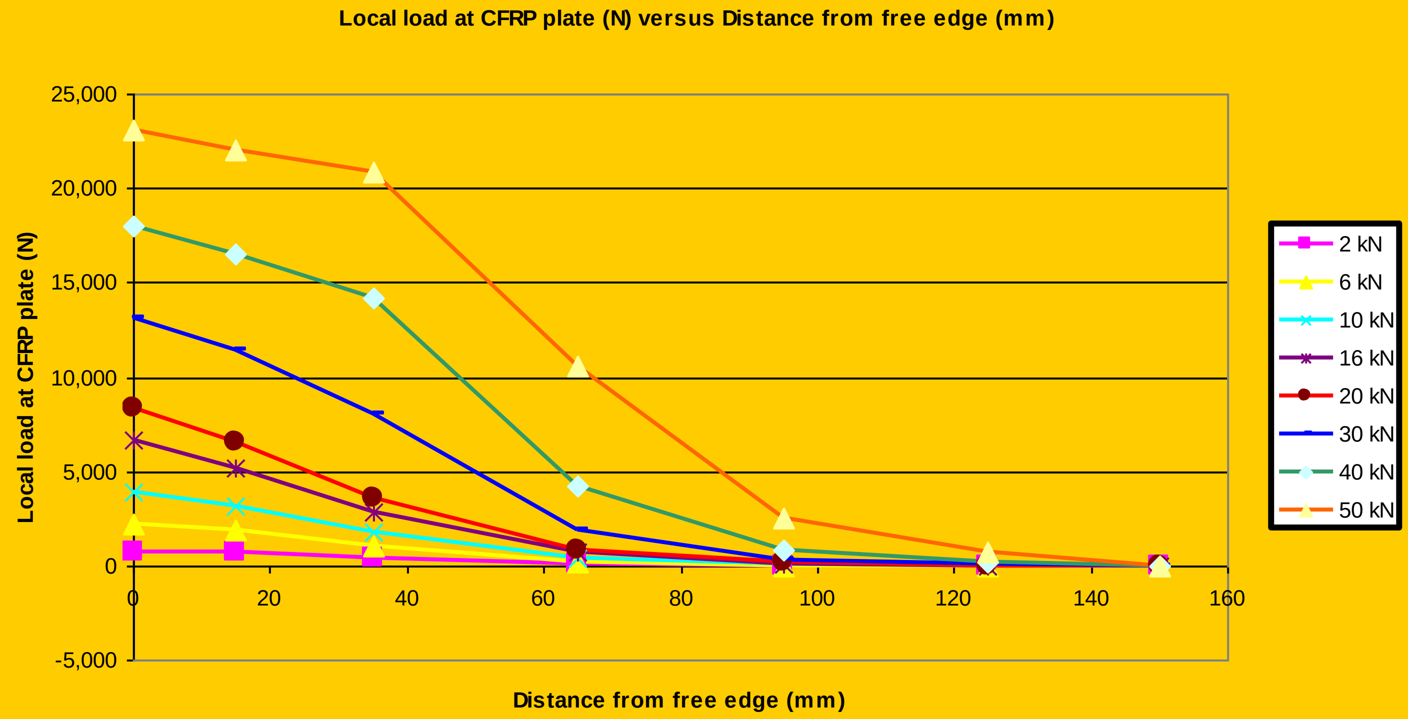
CFRP/CONCRETE PULL OUT BOND TEST



CFRP/CONCRETE PULL OUT BOND TEST



IMPACT TESTING

IMPACT TEST

- **IMPACT PROPERTIES**

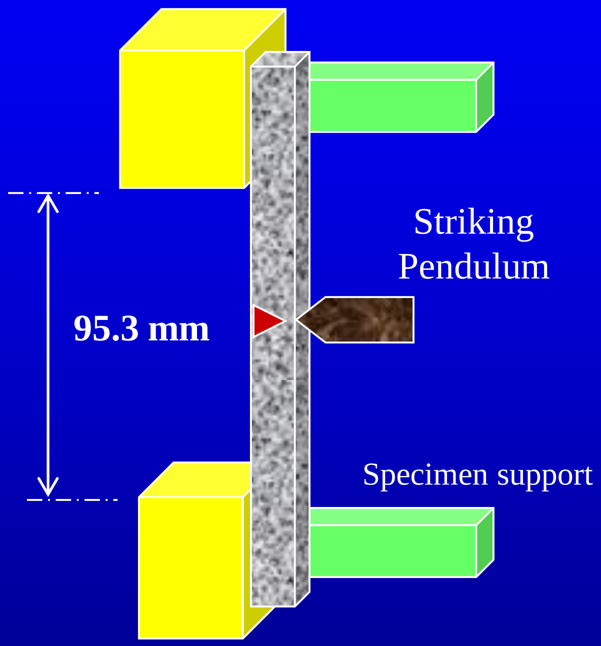
The impact properties of a material represent its capacity to absorb and dissipate energies under impact shock loading such as dropping of a hand tools and high speed collisions.

- **TEST STANDARD**

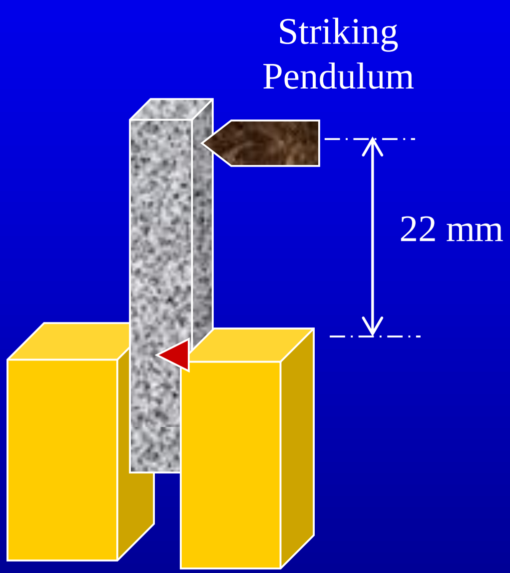
- **Charpy Test Method – ISO 180/ASTM D-256**
- **Izod Test Method – ISO 179/ASTM D-6110**
- **Drop Weight Impact Test**

- **The results of impact tests do not produce basic material property data that can be used for any design purposes. The results are useful in investigating the failure modes, energy absorption capabilities and also in the areas of quality control & materials development programme.**

IMPACT TEST METOHDS

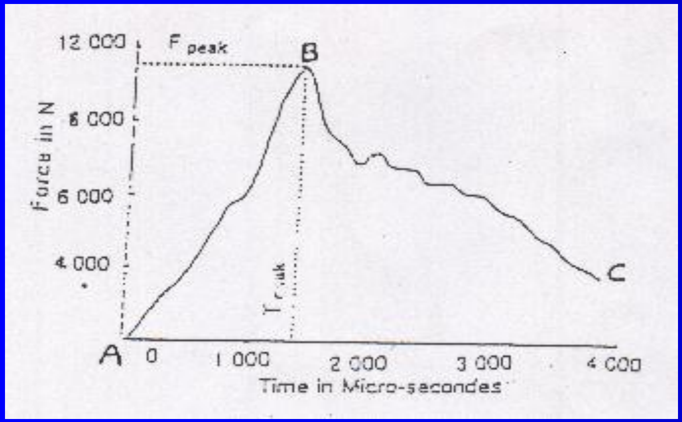


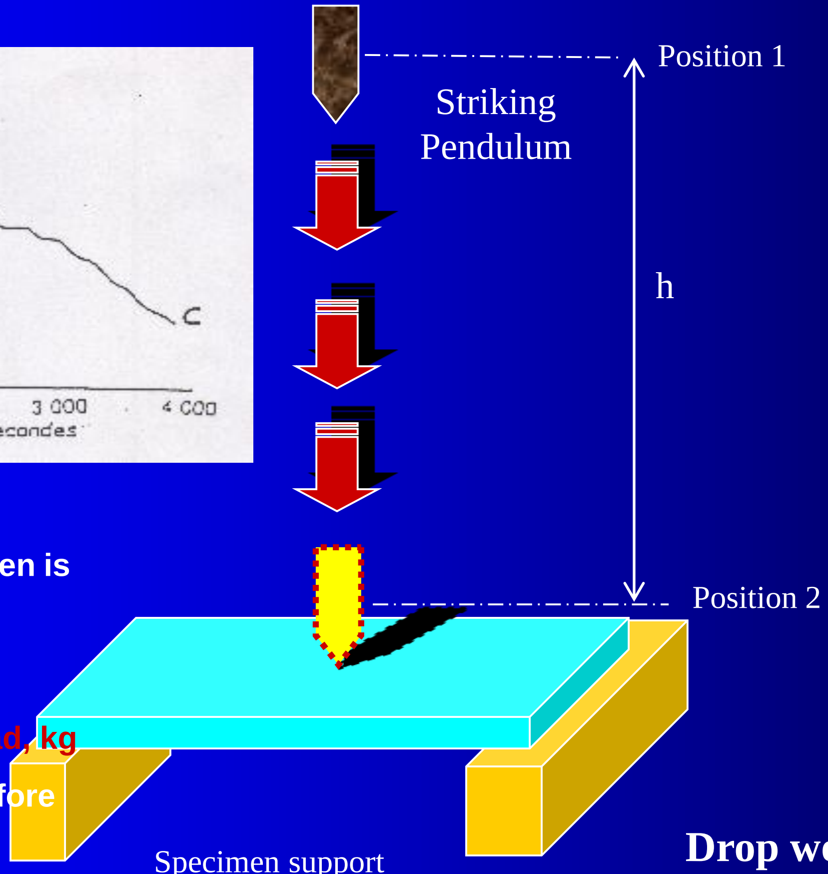
Charpy impact test



Izod impact test

IMPACT TEST METOHDS





Drop weight impact test

Energy absorbed by specimen is

$U = \frac{1}{2}\, m\,(v_1^2 - v_2^2)$ Joule

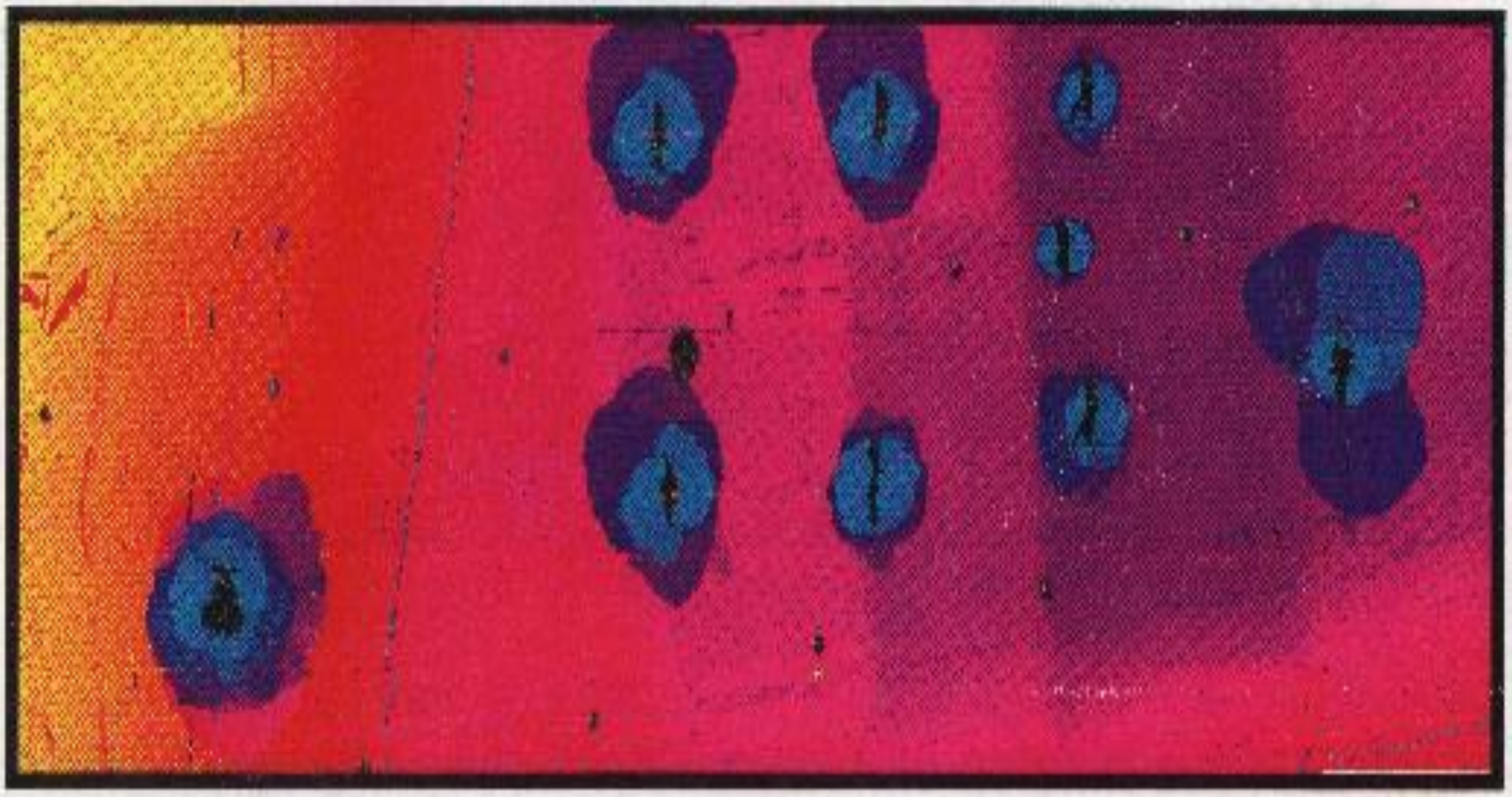
Where:

m = mass of the striking head, kg

v_1 = velocity of mass just before impact, m/s ($v_1 = \sqrt{2gh}$)

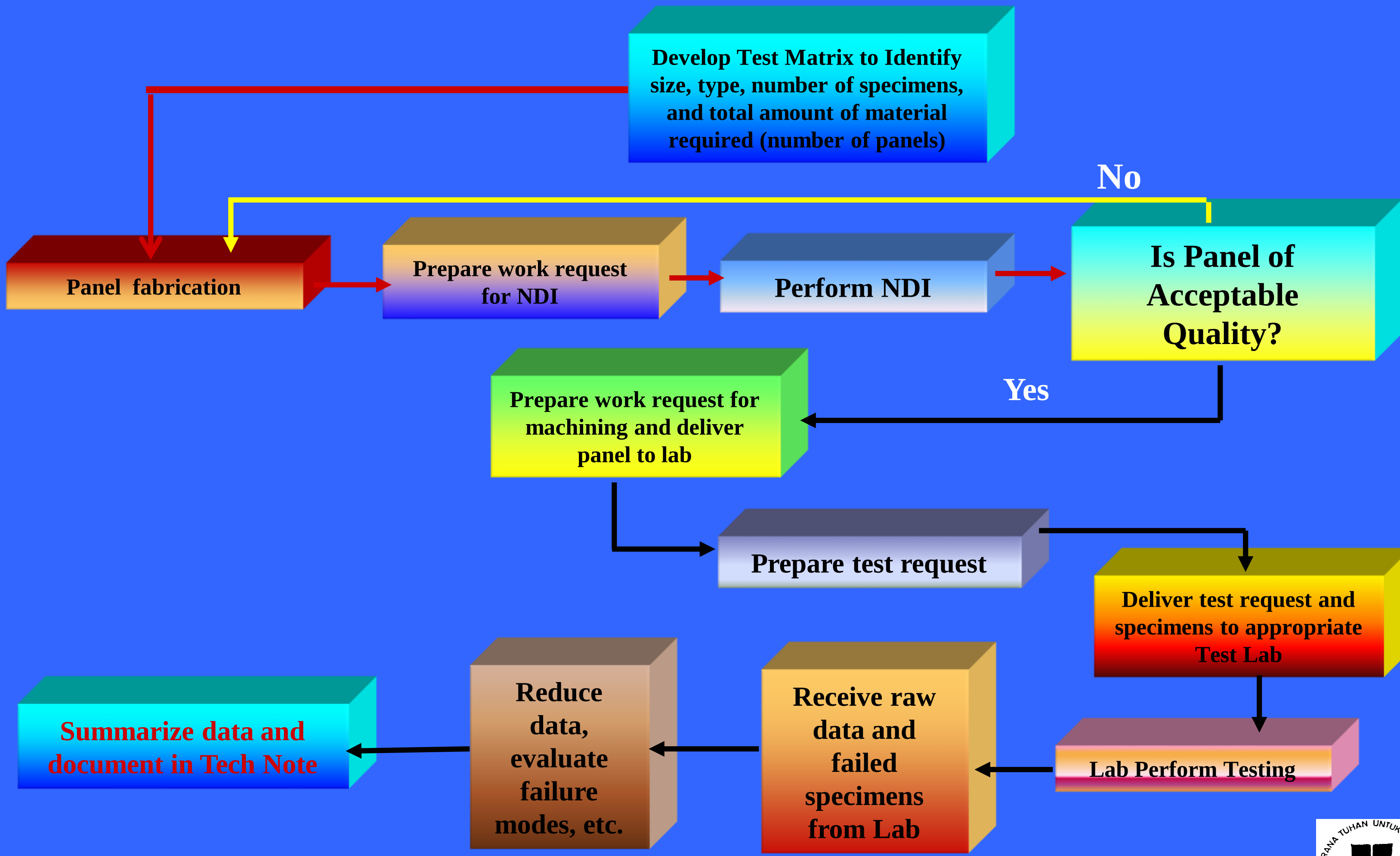
v_2 = velocity of mass just after impact, m/s

NDT RESULT ON CFRP PLATE UNDER IMPACT LOAD

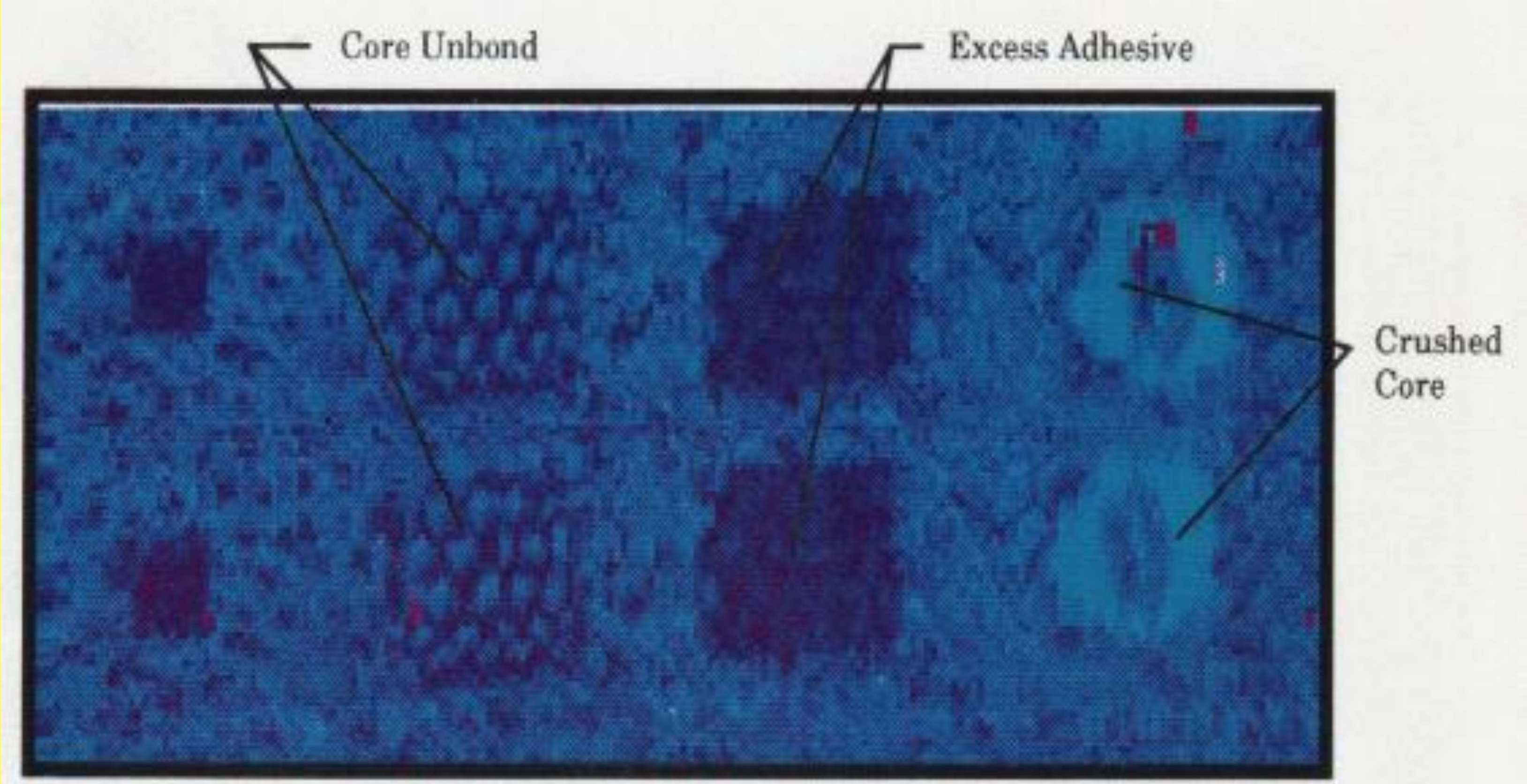


Ultrasonic P/E Depth C-scan of Impact Damage in a Carbon Epoxy Composite Laminate.

TEST PLAN

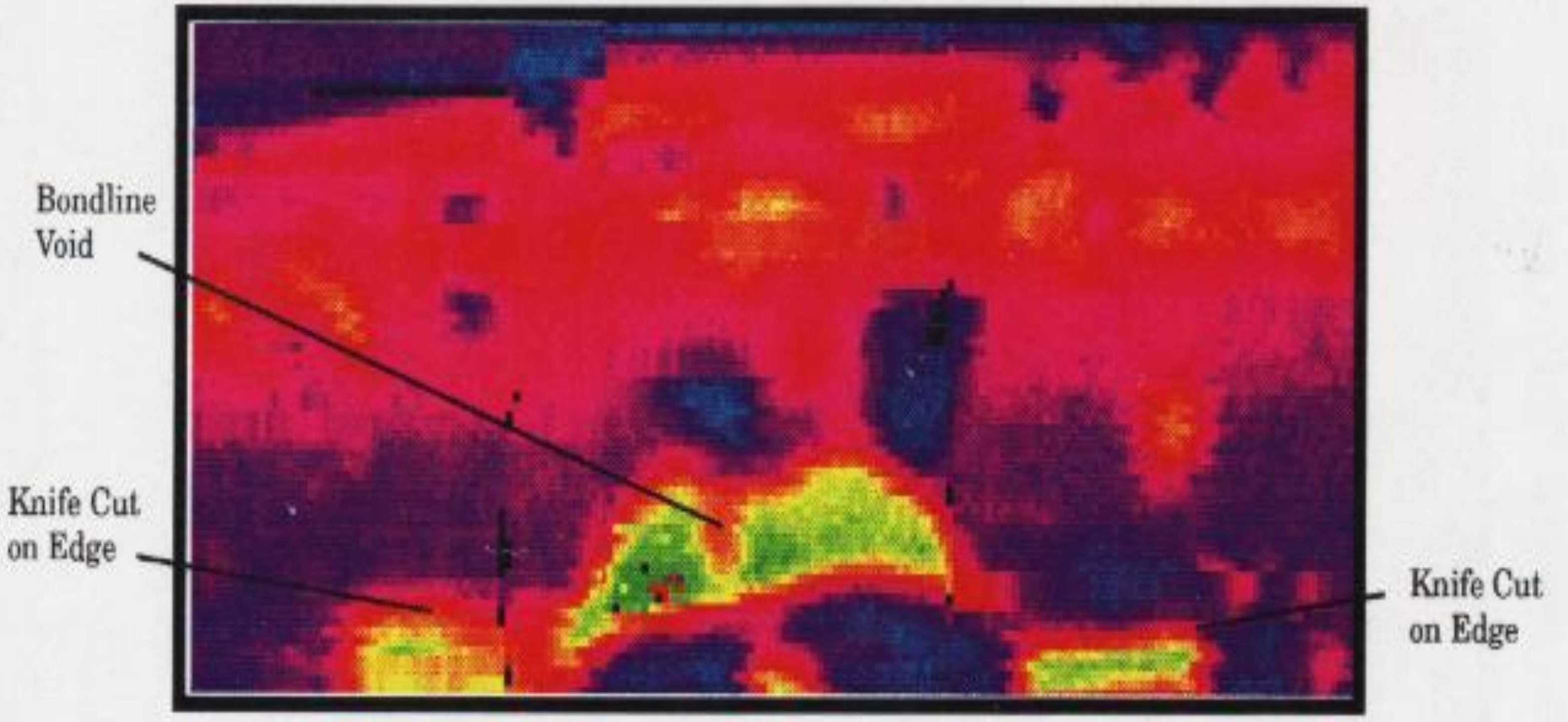

Develop Test Matrix to Identify size, type, number of specimens, and total amount of material required (number of panels)
No
Panel fabrication
Prepare work request for NDI
Perform NDI
Is Panel of Acceptable Quality?
Yes
Prepare work request for machining and deliver panel to lab
Prepare test request
Deliver test request and specimens to appropriate Test Lab
Lab Perform Testing
Receive raw data and failed specimens from Lab
Reduce data, evaluate failure modes, etc.
Summarize data and document in Tech Note

NDI ON TEST SAMPLE



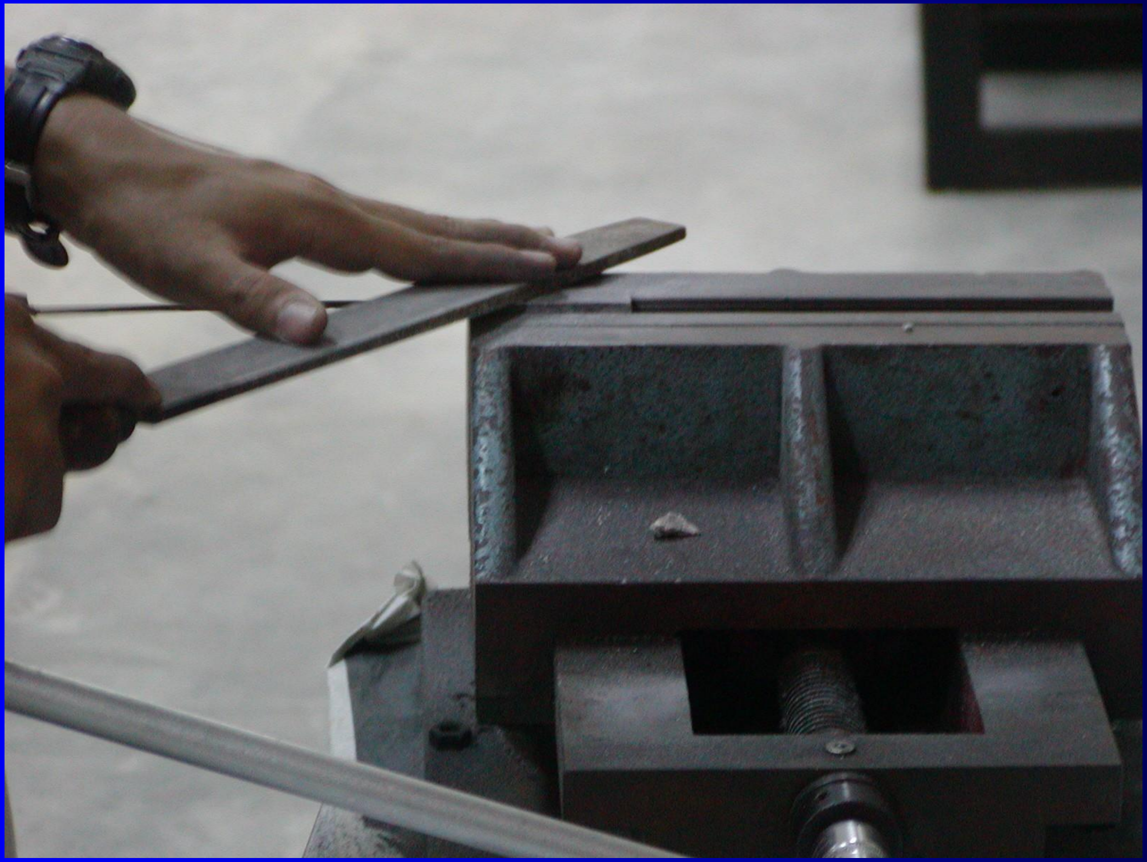
Pulse-echo Amplitude C-scan of Adhesive Bondline Voids in a Composite Assembly.

NDI ON TEST SAMPLE



Ultrasonic Resonance C-scan of Voids in an Adhesive Bondline.

TEST SAMPLE PREPARATION



TEST SAMPLE PREPARATION

STRAIN GAUGE INSTALLATIONS

When bonding the strain gauge, the most suitable adhesive should be selected for each application. A typical installation procedure is described below using the fast-curing type adhesive CN.

1. Preparation

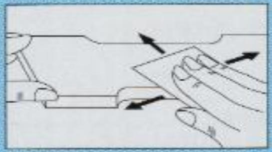
The following items are required for bonding and lead wire connection: Strain gauge, bonding adhesive, connecting terminals, test specimen, solvent, cleaning tissue for industrial use, soldering iron, solder, abrasive paper (120 - 320 grit), marking pencil, scale, tweezers, extension lead wire, polyethylene sheet, nipper.

2. Positioning

Roughly determine the location on the test specimen where the strain gauge is to be bonded.

3. Surface preparation

Before bonding, remove all grease, rust, paint, etc., from the bonding area. Sand an area somewhat larger than the bonding area uniformly and finely with abrasive paper. Finish the surface with #120 to 180 abrasive paper for steel, or #240 to 320 for aluminium.



4. Fine cleaning

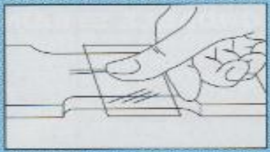
Clean the bonding area with industrial tissue paper or cloth soaked in a small quantity of chemical solvent such as acetone. Continue cleaning until a new tissue or cloth comes away completely free of contamination. Following the surface preparation, be sure to attach the gauge before the surface becomes covered with an oxidizing membrane or becomes newly contaminated.

5. Applying bonding adhesive

Drop the proper amount of adhesive onto the back of the gauge base. Usually one drop of adhesive will suffice, but you may increase the number of drops according to the size of the gauge. Use the adhesive nozzle to spread the adhesive over the back surface thinly and uniformly.

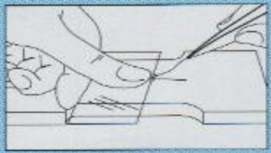
6. Curing and pressing

Place the gauge on the guide mark, place a polyethylene sheet onto it and press down on the gauge constantly using your thumb or a gauge pressing device. This should be done quickly as the curing process is completed very fast. The curing time varies depending on the gauge, test specimen, temperature, humidity and pressing force. The curing time under normal conditions is 20 - 60 seconds.



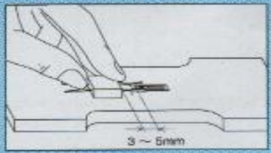
7. Raising the gauge leads

After curing completely, remove the polyethylene sheet, and raise the gauge leads with a pair of tweezers.



8. Bonding connecting terminals

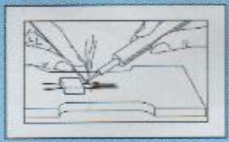
Position the proper size connecting terminals adjacent to the bonded gauge. A distance of 3 - 5 mm generally allows for easier wiring later.



9. Soldering and wiring

Solder the junction area for both the gauge leads and the connecting terminals with a round-shaped leads, taking care to prevent excessive tension during measurement. To connect the extension lead wire, solder the lead wire to the connecting terminals. Cubic and foil strip type connecting terminals are ready for application. The detail is described in a later section.

Soldering gauge leads



Soldering extension lead wire

Tensile Test on CFRP Pultruded Plate

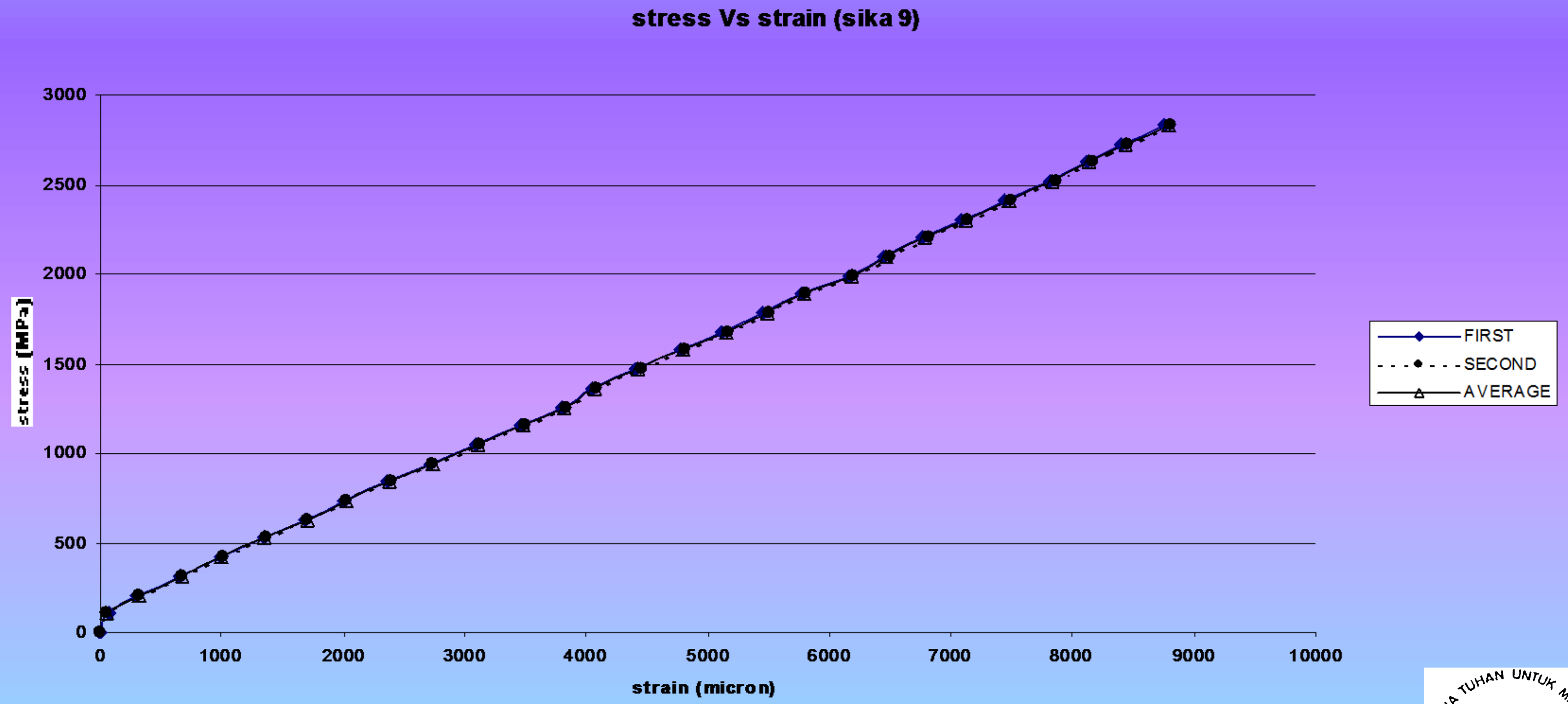
Specimen geometry 15mm x 228mm x 1.2mm

Ultimate tensile load = 55 kN

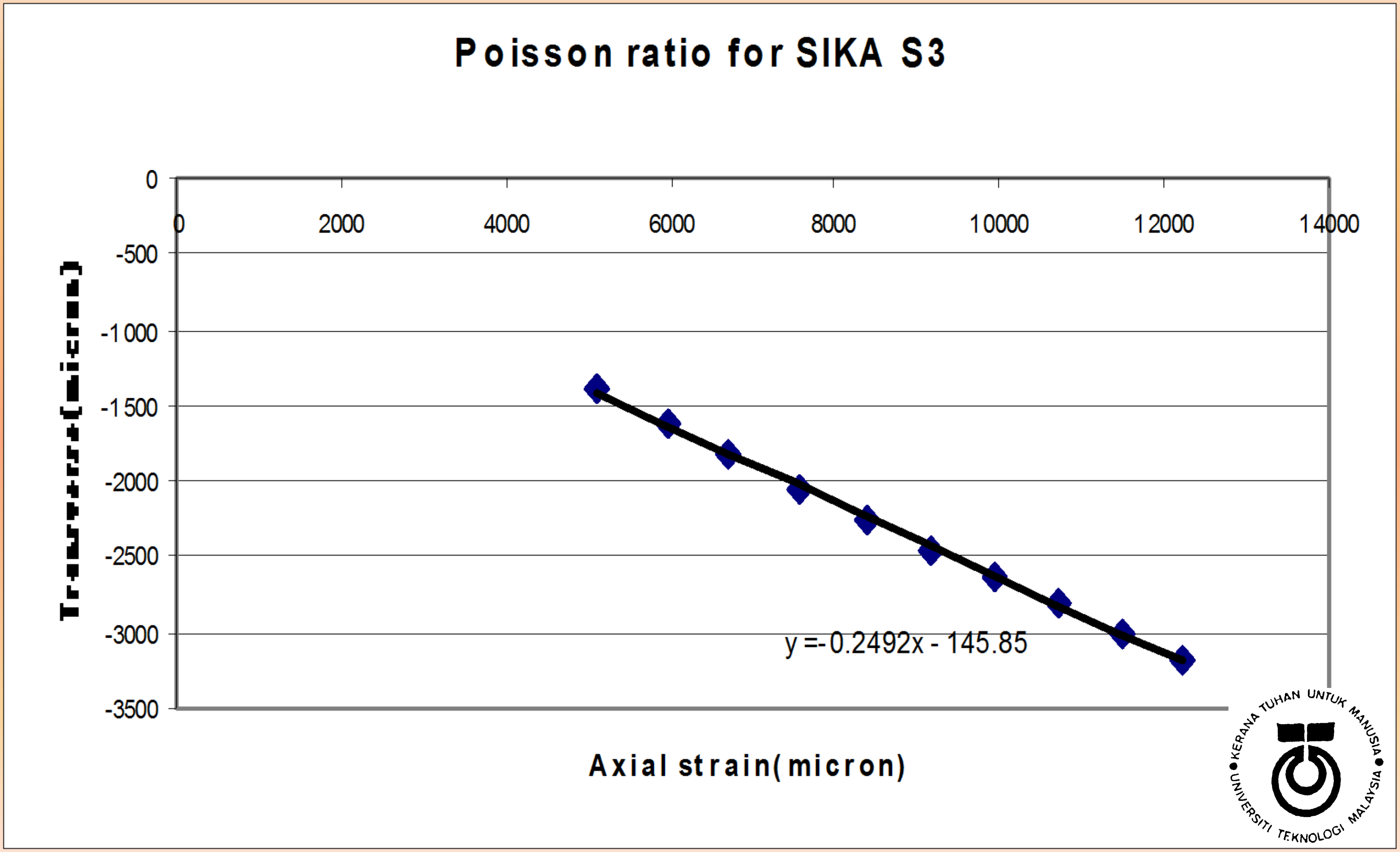
Ultimate tensile strength = 2700 MPa

Ultimate tensile strain = 1.8 %

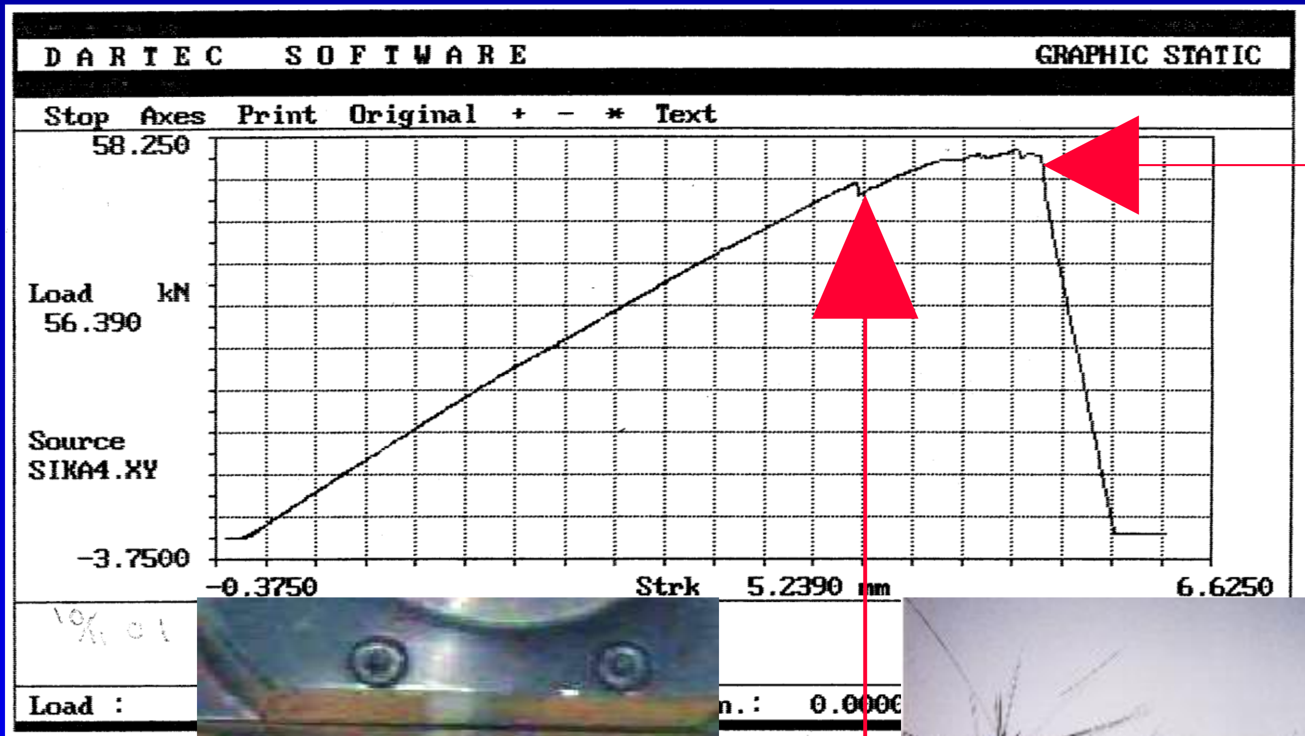
Stress-strain Curve for Pultruded CFRP Plate



Poisson Ratio



Mode of Failure - CFRP *Pultruded*




thank you very much for your attention
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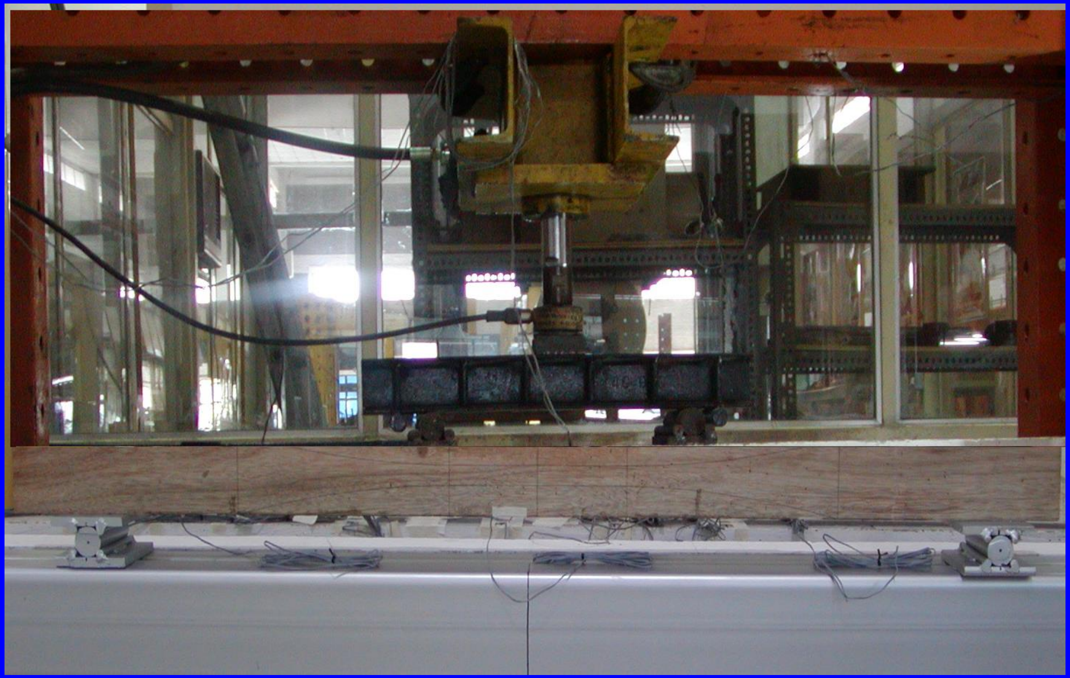
DEMO – TESTING 1

- TENSILE TEST ON CFRP SAMPLES
- Location: Makmal Struktur dan Bahan, Fakulti Kejuruteraan Mekanikal, UTM
- Person In-Charge: Shukur Hj. Abu Hassan/Dr. Amran Alias

DEMO – TESTING 2

- FLEXURAL TEST ON TIMBER BEAM STRENGTHENED WITH CFRP SHEET
- Location: Makmal Struktur dan Bahan Fakulti Kejuruteraan Awam, UTM
- Person In-Charge: Dr. Abd. Rahman Mohd Sam (FKA)



DEMO – TESTING 3

- 1. Determination Degree of Cure of Polymer Composite using Diferrential Scanning Calorimetry (DSC)
- 2. Weathering Test on FRP
- 3. Chemical Resistance Test on FRP

- Location: Makmal Pemprosesan Polimer Fakulti Kejuruteraan Kimia & Kejuruteraan Sumber Asli, N14, UTM
- Person In-Charge: Dr. Abdul Razak Rahmat (FKKKSA)