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Mechanical properties of insulators for Accelerator Magnets
WAMSDO 14/11/2011

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Outline

- Accelerator Magnet Insulation
- Nb_3Sn Insulation
- Glass fibre/epoxy composites
- Irradiation
- Low Temperature
- Test Methods
- Summary

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Accelerator Magnet Insulation

- Resistive Magnets
  - ~Mylar, glass fibre, epoxy resin
  - ~2mm thick
- NbTi Superconducting Magnets
  - ~Kapton & epoxy
  - ~40µm thick
- Nb_3Sn Superconducting Magnets
  - ~S-glass fibre, epoxy resin, cyanate ester
  - ~400µm thick

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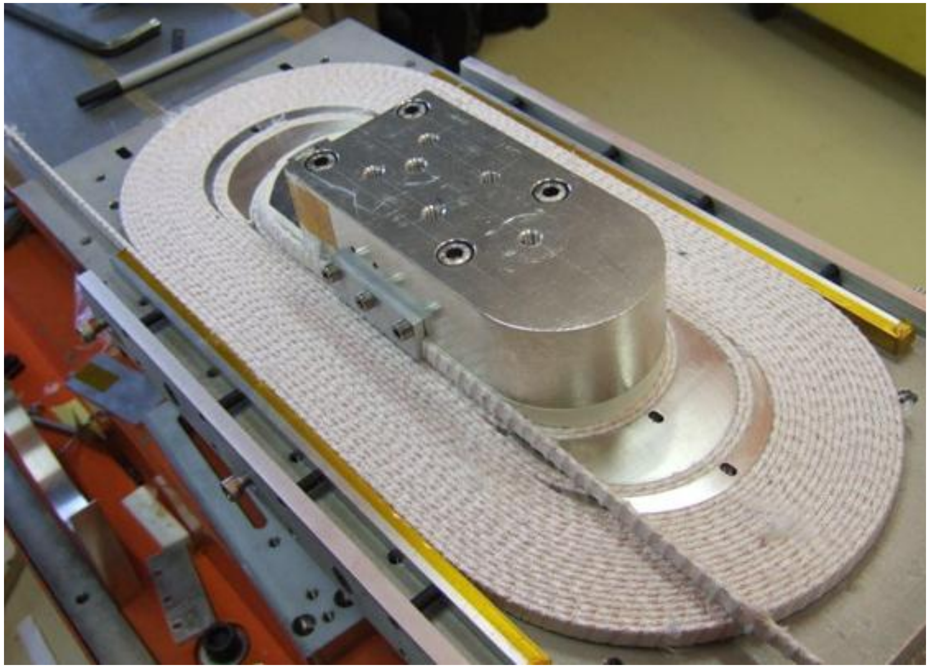
Nb_3Sn Insulation used in Short Model Coils

- S-glass tape
- Post heat treatment vacuum impregnation with epoxy resin



Useful to recap glass fibre/polymer composites

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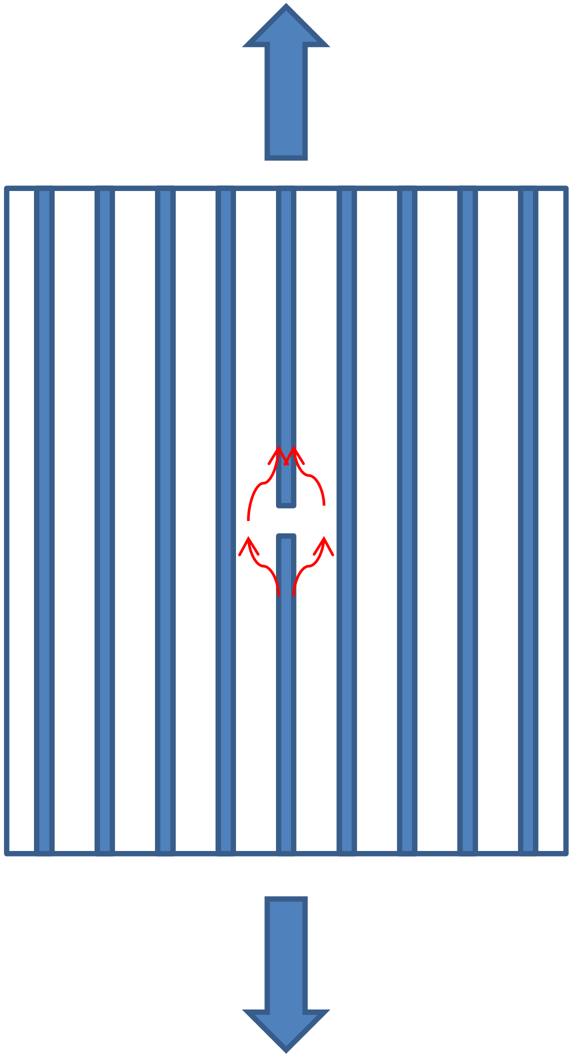
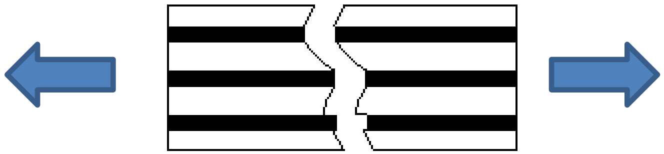
Glass fibre/epoxy composites

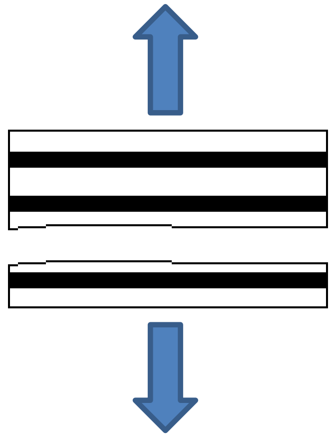


- A composite formed of Glass fibres in an epoxy resin matrix
  ~Fibres are strong and stiff in tension
  ~Matrix is weaker and compliant
  ~The matrix can form a bridge around a damaged fibre
- The matrix/fibre bond is critical to the composite's performance
- The mechanical performance is dependent on fibre orientation with respect to the applied load

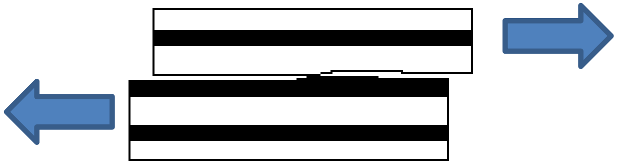
Important failure modes



Axial (0°)



Transverse (90°)



Shear

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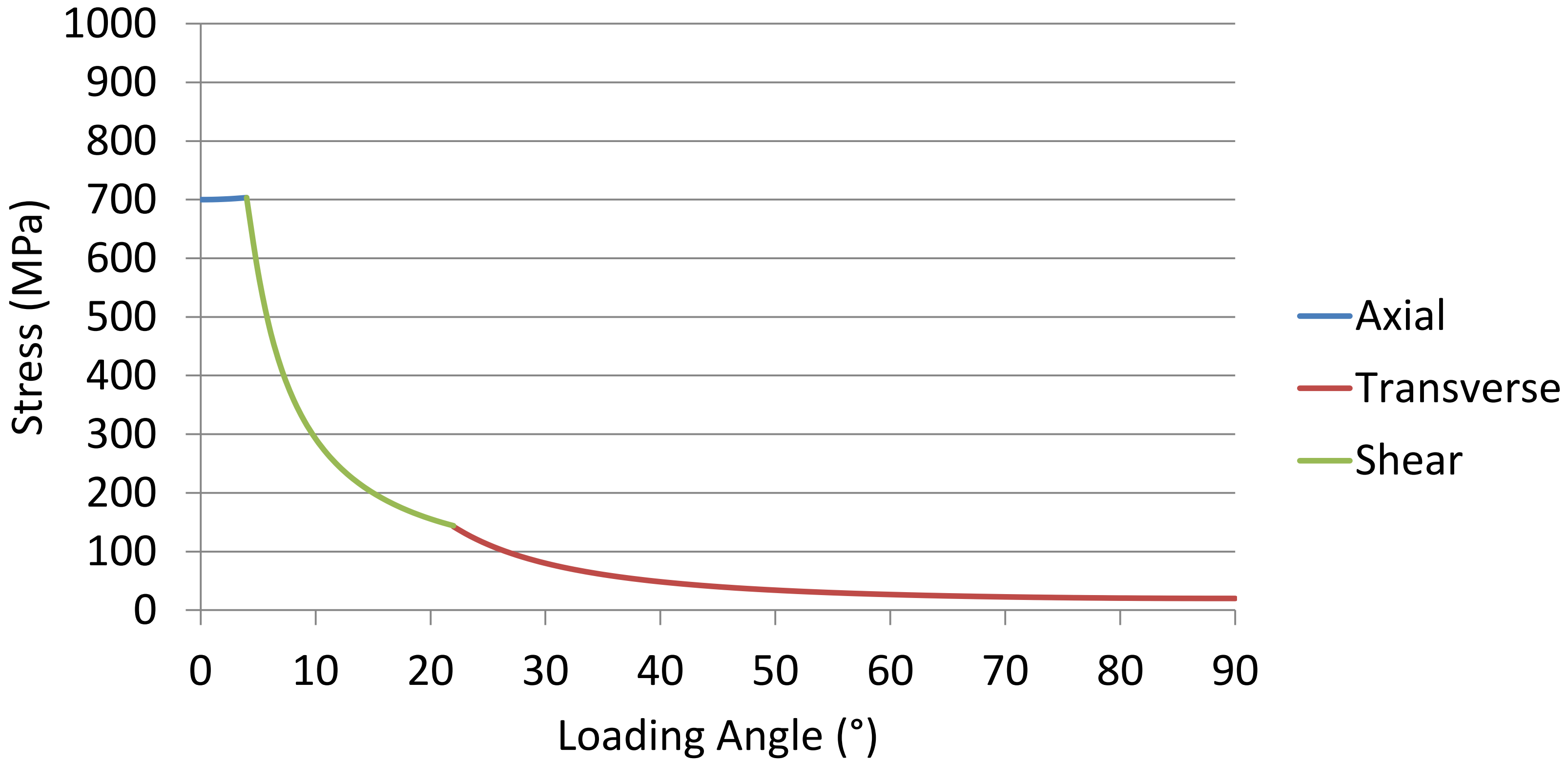
Failure stress dependence on loading angle using maximum stress criterion



Radiation types

Several types of high energy radiation:

- Charged particles - Electrons and Protons and Alpha particles
  Ionisation – also results in charge separation
- Neutrons – particles with energy but no charge
  - Fast Neutrons - deposit energy by collisions and displacement reactions
  - Slow Neutrons - capture and nuclear transformation
- Electro-magnetic Radiation - Gamma Photon
  - Ionisation and excitation

- Important to note that different types of radiation have different affects on materials which makes comparisons difficult.
- Ideally irradiate with the species of radiation the magnet will see in service

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Radiation Effects in Resins

- Changes in Mechanical properties
  - Particularly matrix dependent properties such as flexural strength and shear strength
  - Generally in a composite the polymer will be radiation damaged well before the fibre is damaged
- Activation
  - Samples may become activated
  - Difficult to handle and transport

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Irradiation Facilities

- Through the Advanced European Infrastructures for Detectors at Accelerators (AIDA):
  - DESY, CERN, JSI, KIT & UCL

http://aida.web.cern.ch/aida/activities/access/

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Irradiation Facilities – Proton and Neutron

Location	**Type**	**Energy**	**Flux/cm2**	**Source of information**
PS-CERN	Protons	24GeV/c	10^16	1
Karlsruhe	Protons	24MeV	10^15	1
Jyvaskyla+Helsinki	Protons	10-50MeV	3x10^14	1
IHEP Protvino	Protons	70GeV		3
PS-KEK	Protons	12GeV		1
TRIGA reactors Vienna and Ljubljana	Neutrons +gamma		8x10^15	1
LBNL cyclotron	Protons		10^13p/second	2
JINR Russia	Neutrons	13-15MeV	1.5x10^12n/s	5

Sources:

1 Paul John Dervan, SLHC Meeting Genoa 2005; 2 S Mattafirri LBNL; 3 Y Ivanyushenkov CCLRC;

4 C Trautmann, GSi; 5 A D Kovalenko;JINR

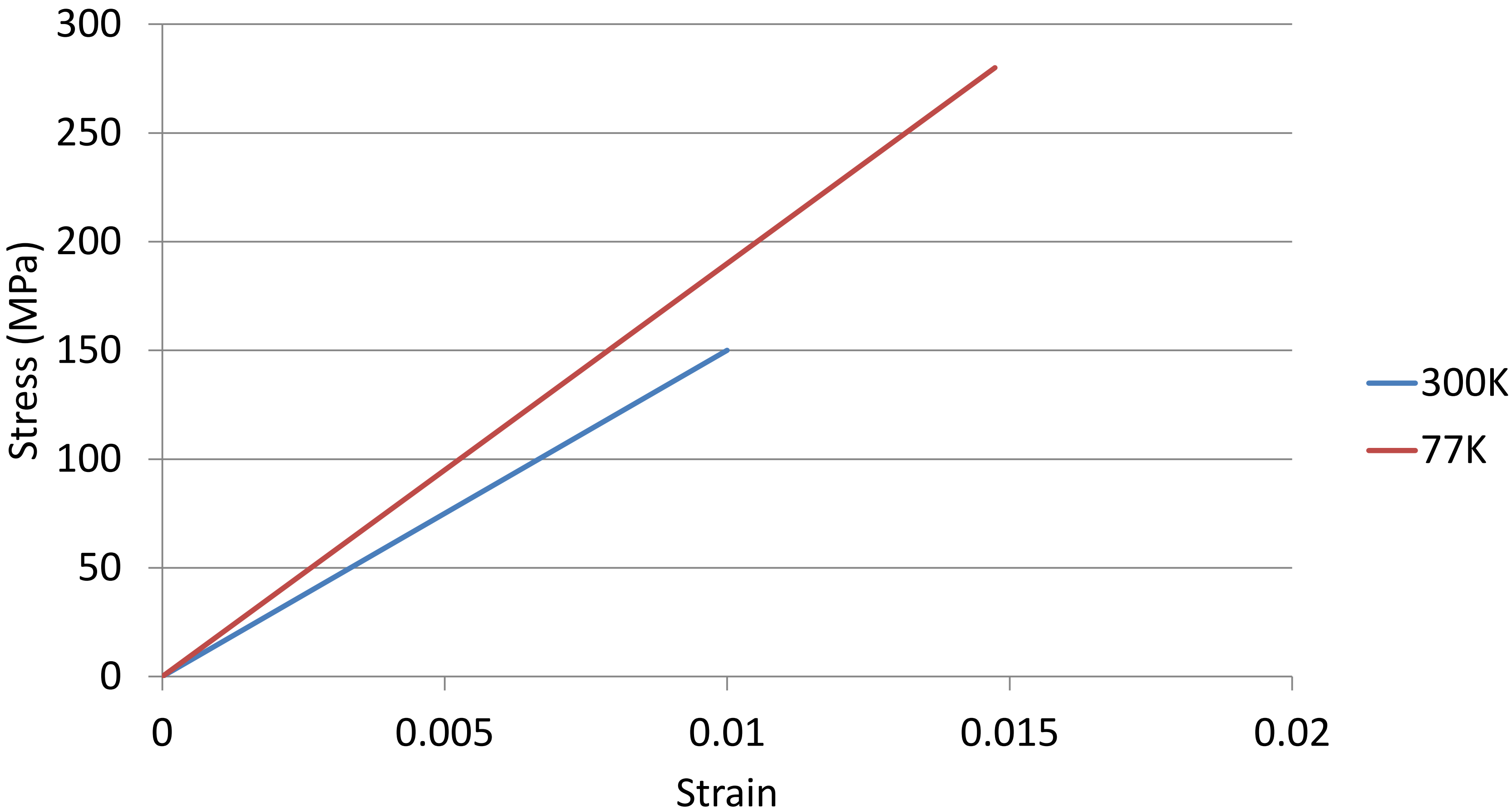
Irradiation Facilities – Gamma and electron

Location	Type	Energy	Flux/cm2	Source of information
BNL USA Co-60	Gamma			1
Munich Co-60	Gamma			4
Brunel Co-60	Gamma			
Trieste	Electrons	900MeV		1
Oslo	Electrons	15MeV		1
…				

Temperature

- Ideally test specimens should be irradiated and tested at their operating temperature
- Testing at 4k is very expensive
  - Cryogens
  - Staff time
  - Cryostats etc
- Testing at 77k is a compromise

Tensile properties of glass fibre/epoxy in fibre direction at 300k and 77k



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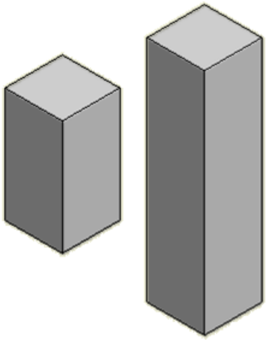
Test Methods

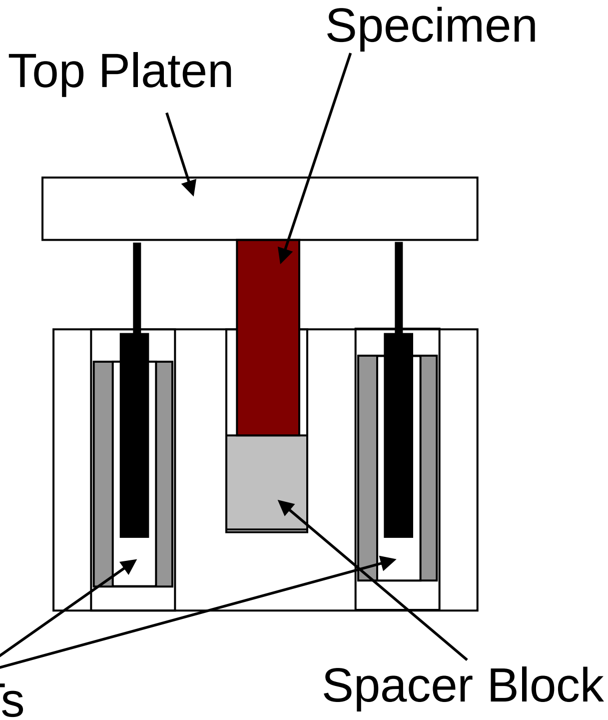
- Choose a test method that is appropriate for the property of interest.
- Recommend using standard tests where practical with as few changes as possible:
  - performing a standard test at low temperature instead of room temperature
- Irradiated materials
  - Before and after measurements
- 5+ tests to get statistical significance

Compression Tests – ASTM D695

Strength
12.7 x 12.7
x 25.4

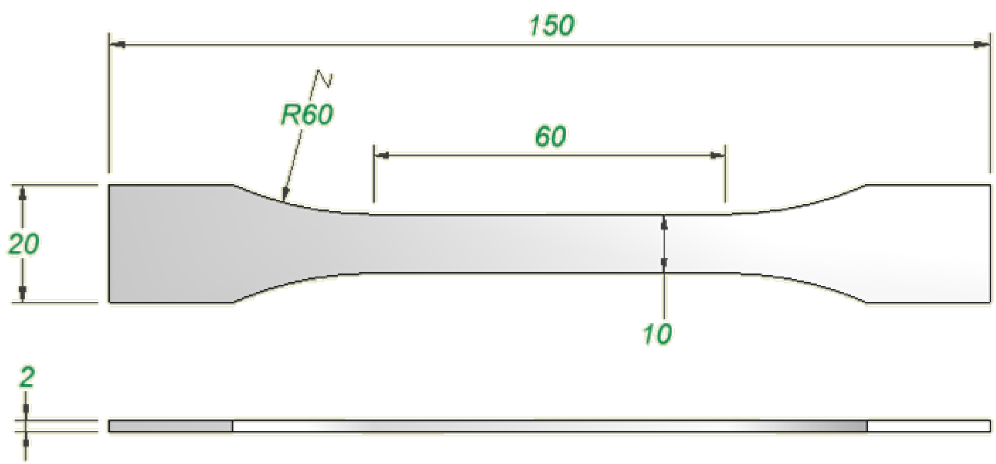


Modulus
12.7 x 12.7
x 50.8

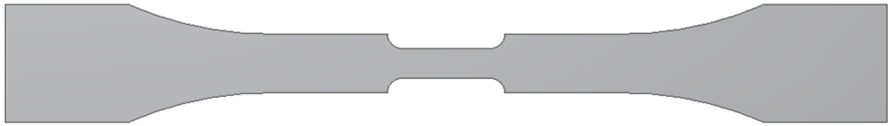


Tensile Testing - Glass reinforced plastics - Determination of tensile properties

BS 2782-10: Method 1003: 1977 EN 61
Plastics — Part 10: Glass reinforced plastics — Method 1003: Determination of tensile properties



As mentioned earlier fibre direction with respect to loading direction is critical



It may be necessary to waist the sample to ensure it does not fail in the grips.

For cryogenic testing smaller versions of these test specimens are sometimes used.

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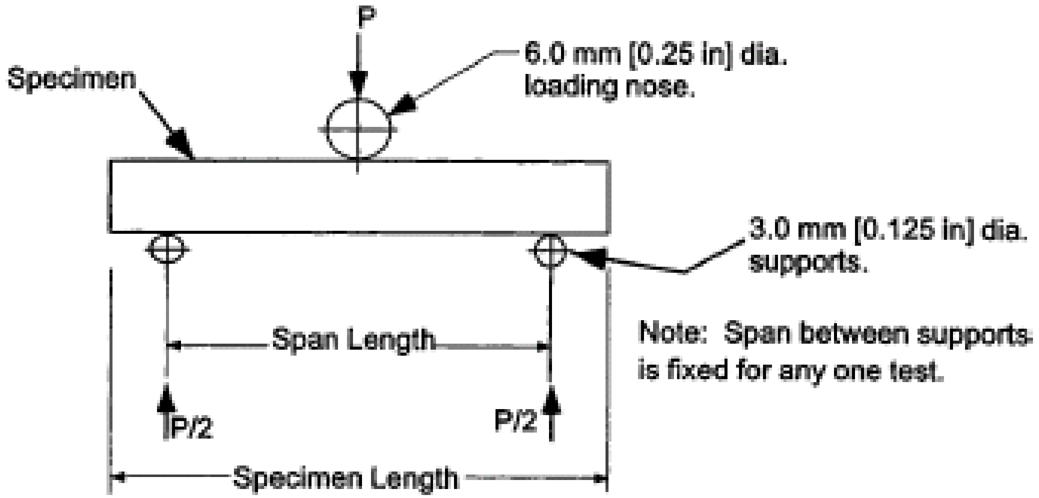
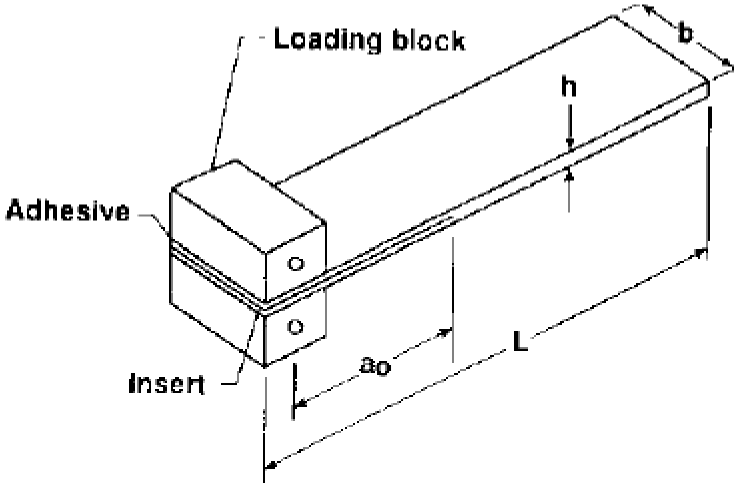
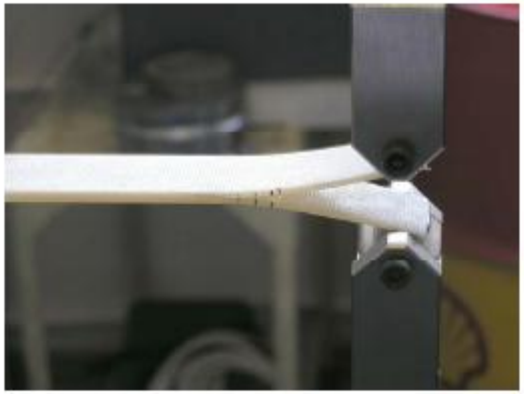
Short beam Shear Strength
ASTM- 2344



length 6 x thickness, span 4 x thickness and width 2 x thickness
Recommended thickness =4mm
→ Recommended sample size = 24mm x 8mm x 4mm

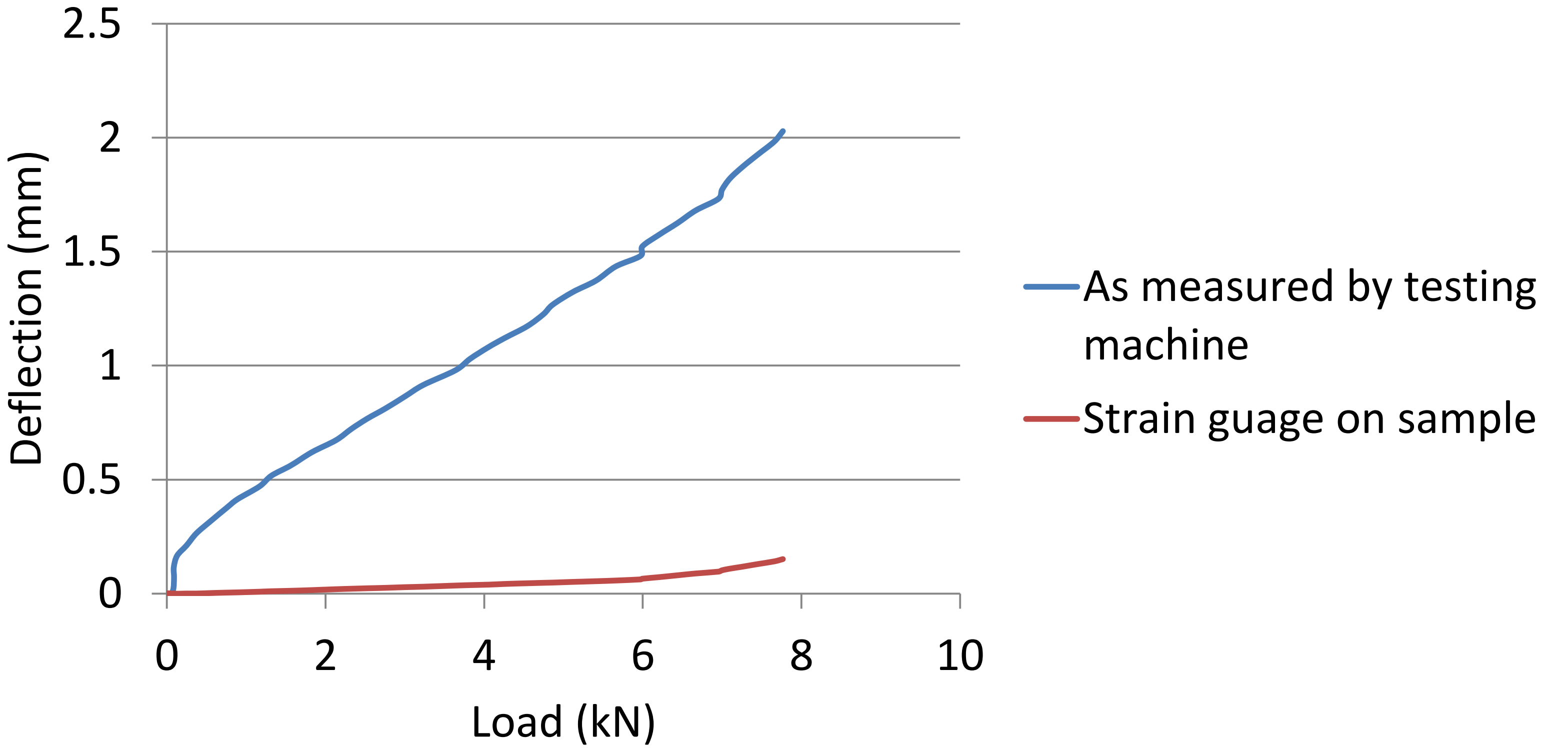
Work of Fracture – ASTM D5528





125mm long, 20mm wide, 3mm thick

Strain Measurement



If interested in modulus it is critical to measure movement of sample not overall movement of testing machine

Summary

- Insulating materials used in accelerator magnets face high radiation loads
- Irradiation degrades the mechanical behaviour of the insulating material
  - Polymers greatly affected
- In order to test the affect on the mechanical behaviour the appropriate test should be selected
  - Test performance before and after irradiation
- Strain measurement of sample is necessary if interested in modulus of material