Impact Energy Absorption in Novel, Lightweight Sandwich Panels with Metallic Fibre Cores

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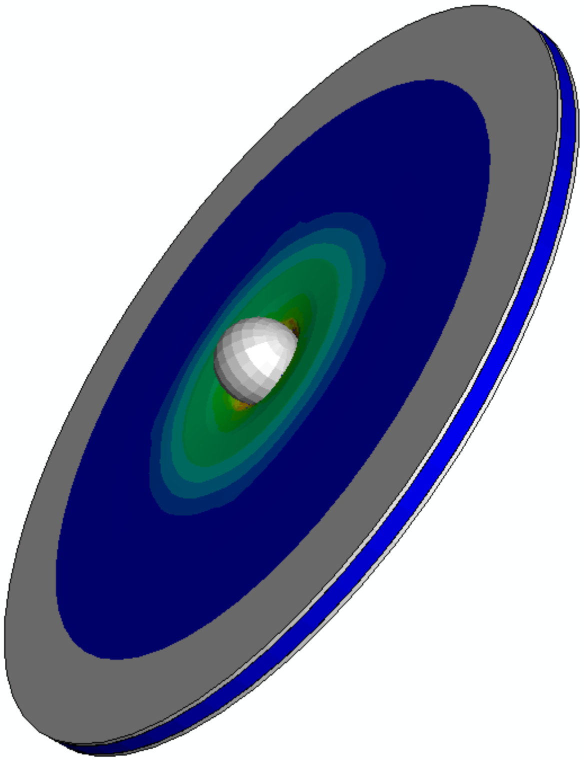


Core Materials and Sandwich Structures Seminar,

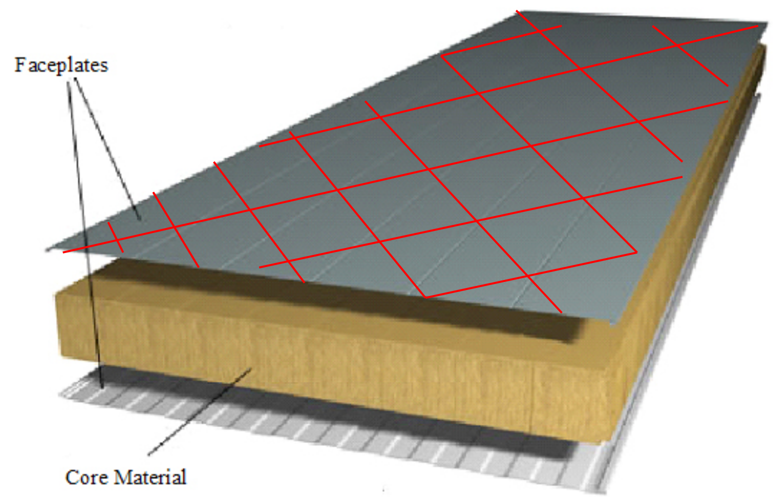
Department of Engineering,

University of Liverpool

CONTENTS

Sandwich Panels - Faceplates

- High Young's Modulus
- High Tensile and Compressive Strength
- High Impact Resistance



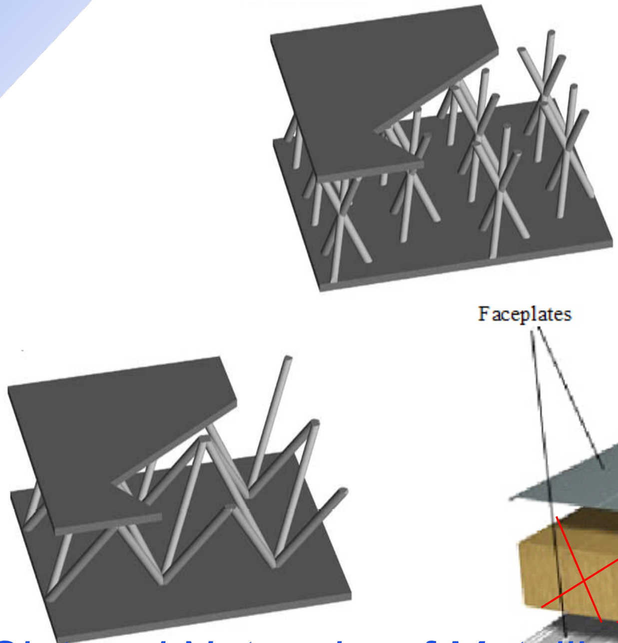
Aluminium

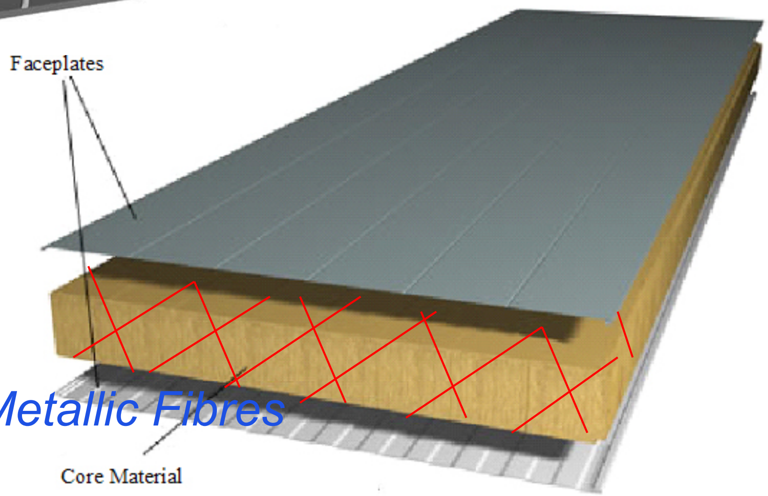
Steels, including Stainless Steels

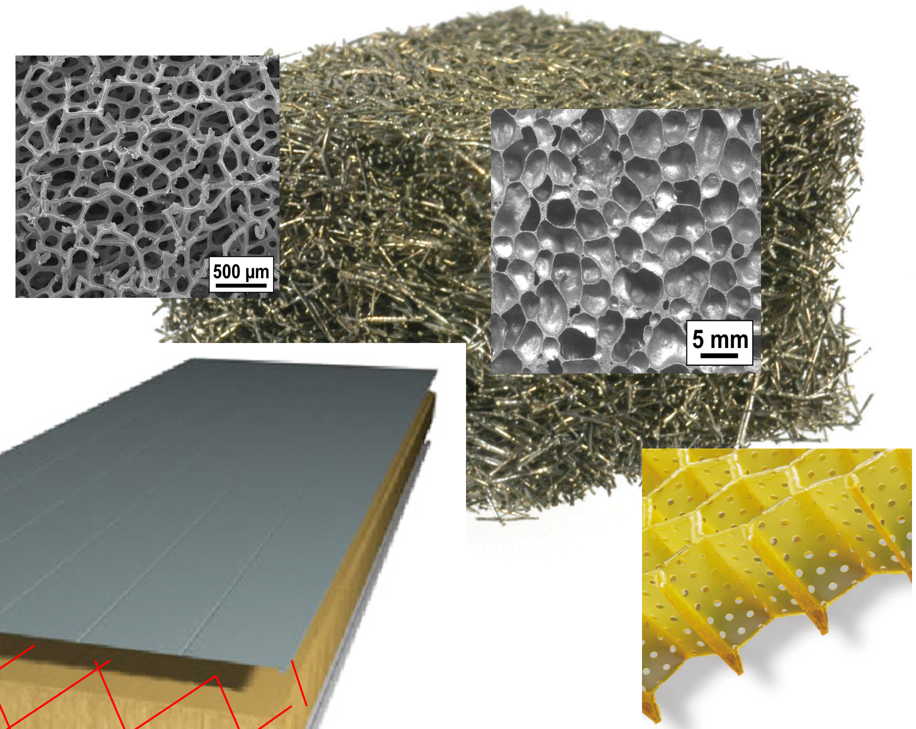
Fibre Reinforced Plastics

➢ Sandwich Panels – Common Core Materials

A Novel Core Material



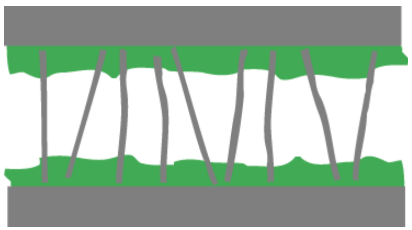


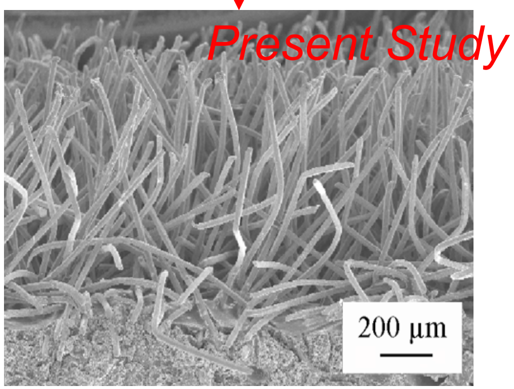


- ➢ Sintered Networks of Metallic Fibres
  - ➢ Low Density
  - ➢ Relatively High Stiffness (Perpendicular to the plane of the faceplates)
  - ➢ Relatively High Shear Modulus

➢ Lightweight Sandwich Panels with Metallic Fibre Cores

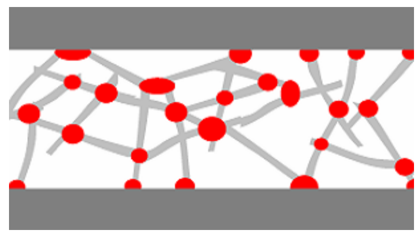
HSSA f~0.08

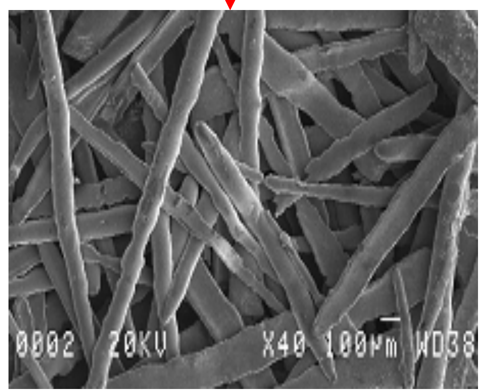




- 0.2 mm thick 316 Faceplates
- 316 fibres-Vertically Aligned
- ~25 µm diameter
- ~1 mm length
- f~0.08

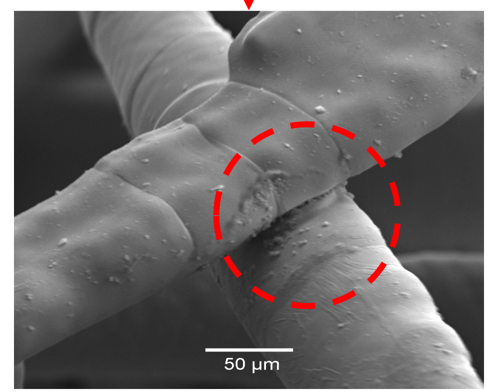
Short Fibre 3-D Array Brazed f~0.15





- 0.2 mm thick 304 Faceplates
- 304 fibres
- ~60 µm diameter
- ~5 mm length
- f~0.15

Short Fibre 3-D Array S.S Sintered f~0.15

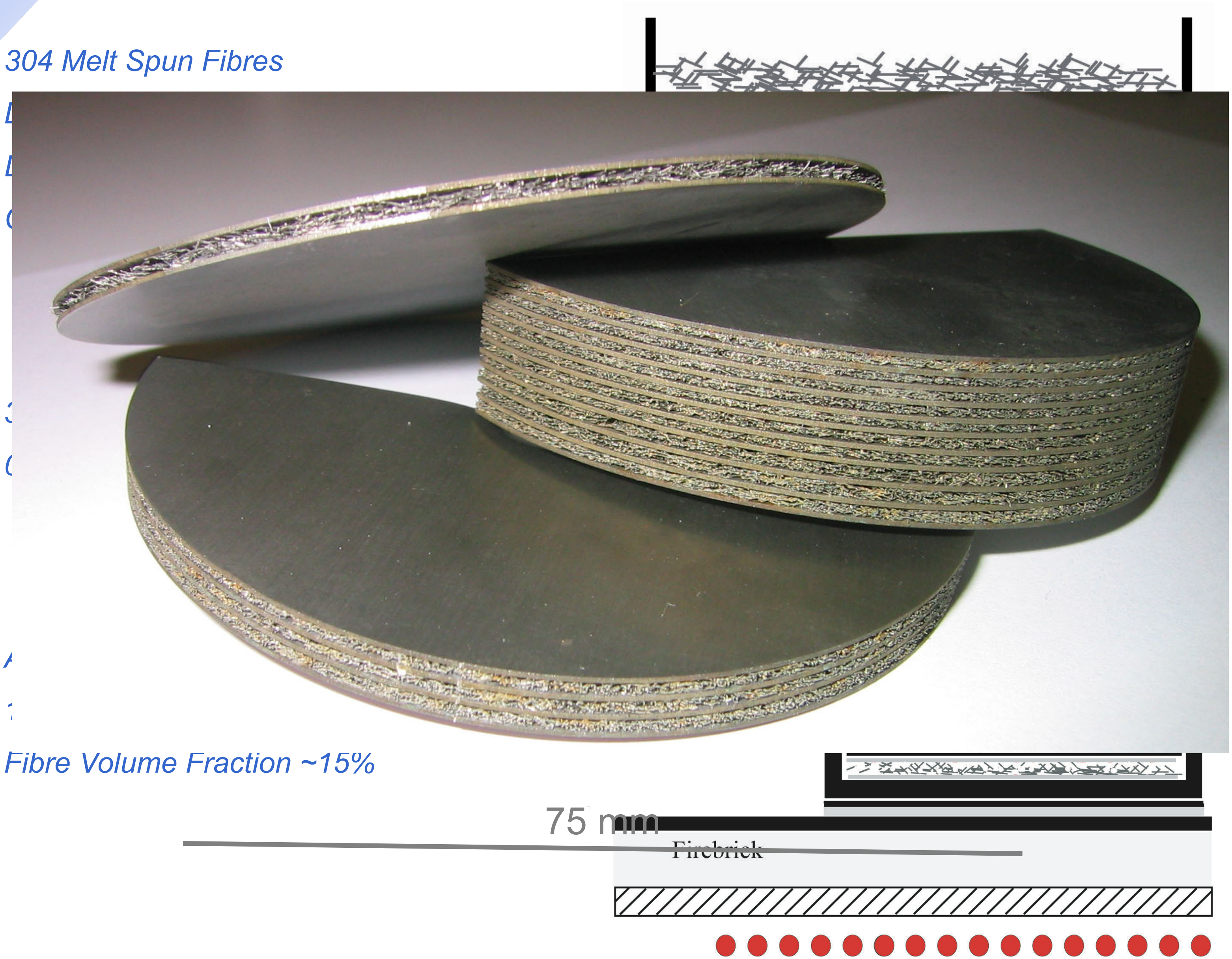


- 0.4 mm thick 304 Faceplates
- 304 fibres
- ~60 µm diameter
- ~5 mm length
- f~0.15

➢ Lightweight Sandwich Panels with Metallic Fibre Cores

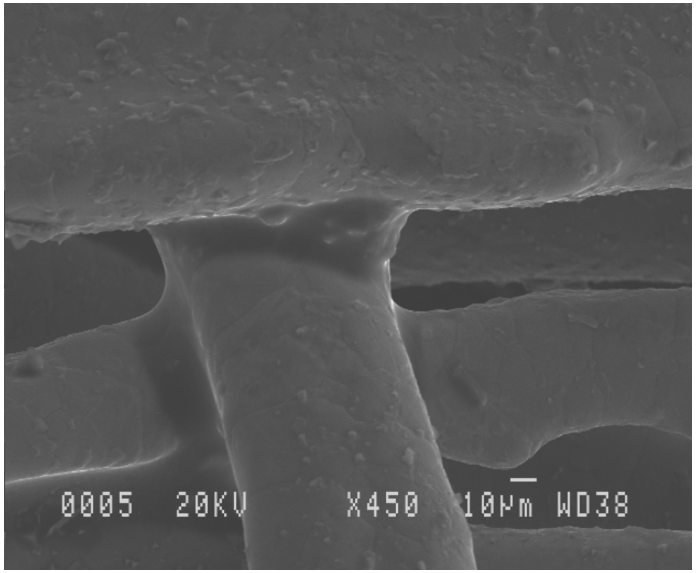
➢ Manufacture & Handling

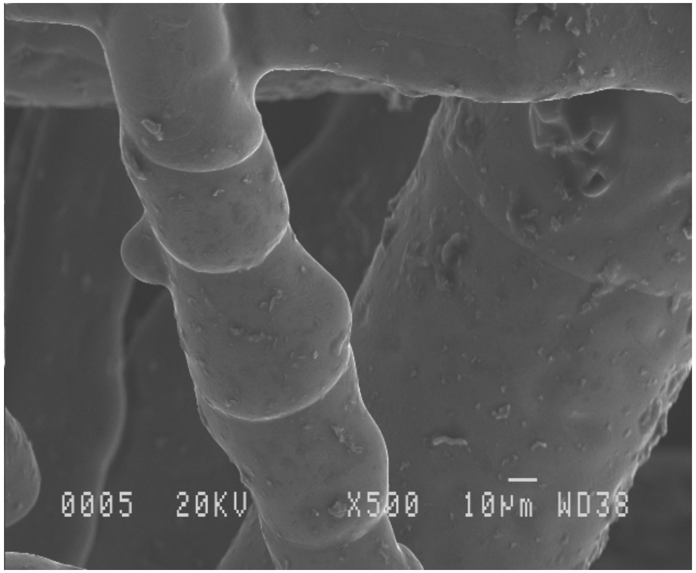
304 Melt Spun Fibres

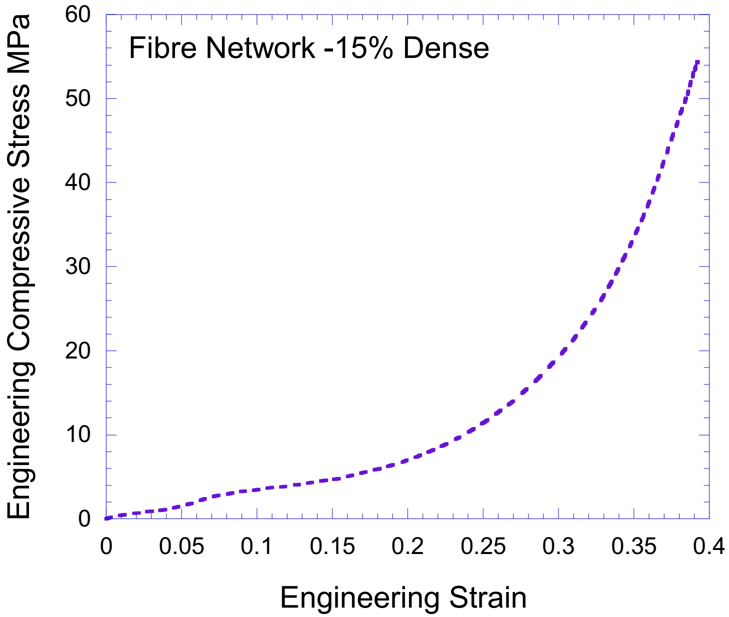


Fibre Volume Fraction ~15%

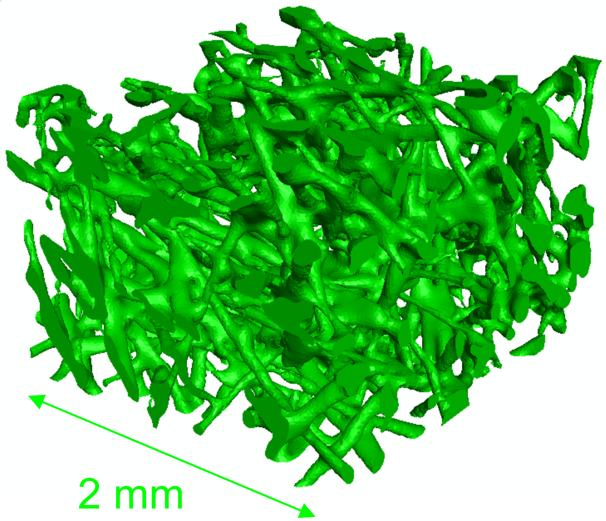
➢ *Fibre Network Characterisation*

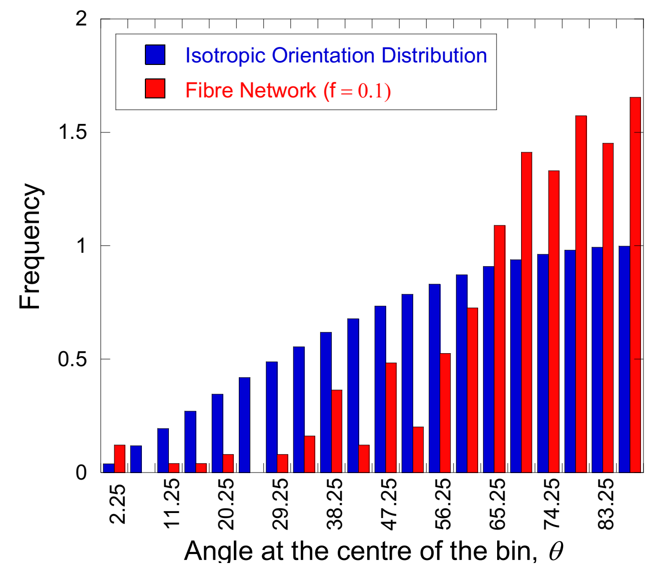






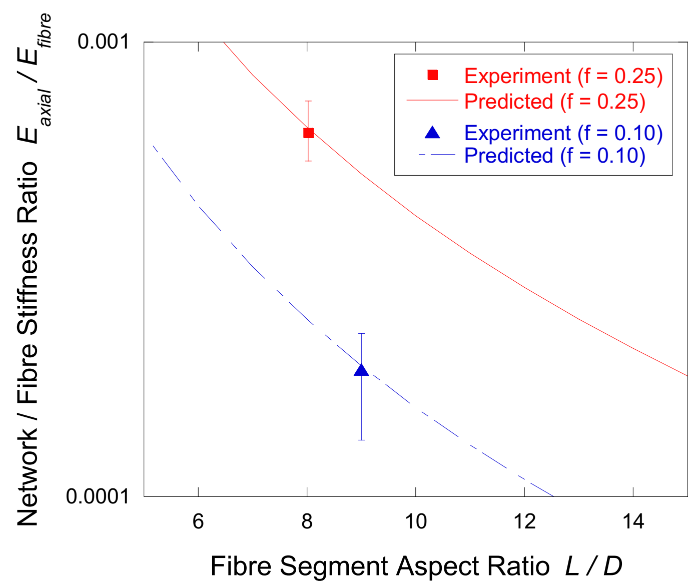
➢ Fibre Network Characterisation





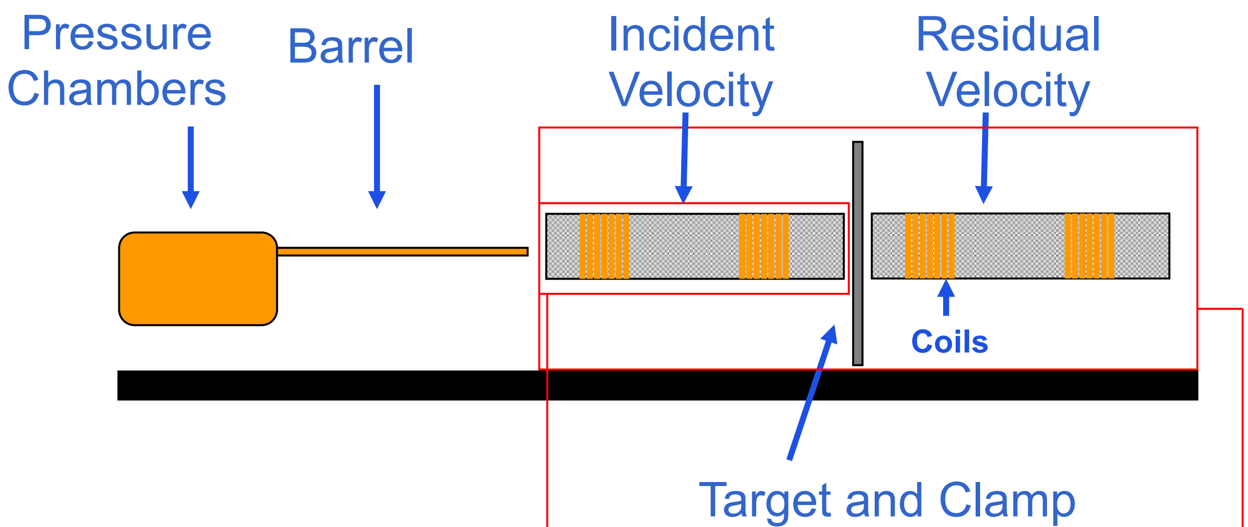
Clyne-Markaki Model

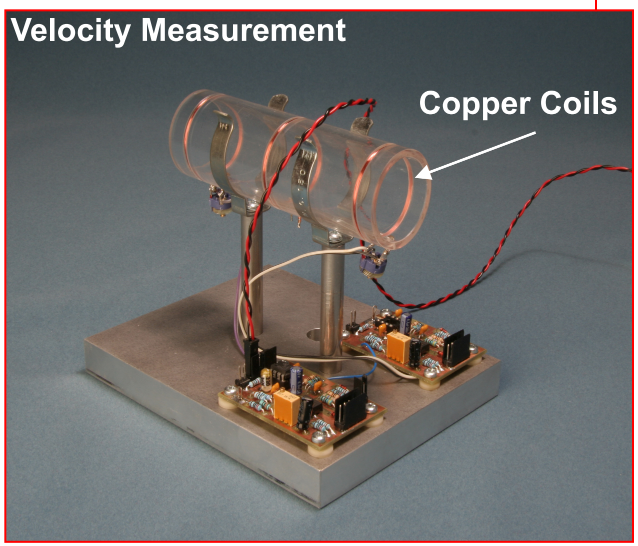
$$E_{axial} = \frac{3E_f f}{8\left(\frac{L}{D}\right)^2}\left[\frac{\sum_i^n N_{\theta_i}\cos\theta_i}{\sum_i^n N_{\theta_i}\sin^2\theta_i}\right]$$

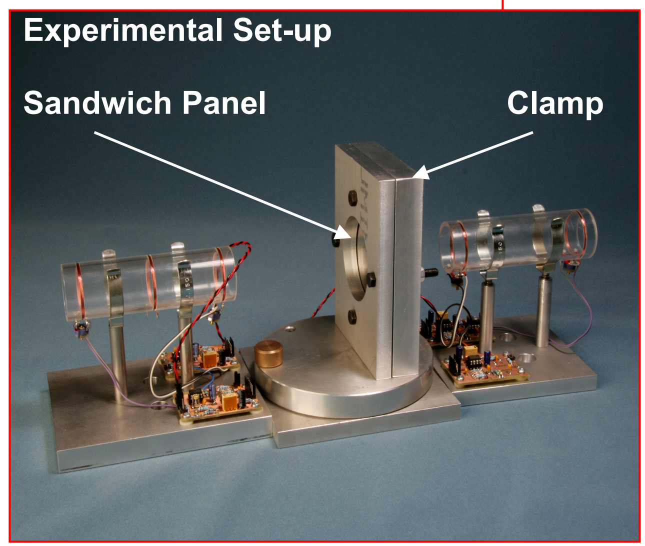


➢ *Impact Test Facilities*

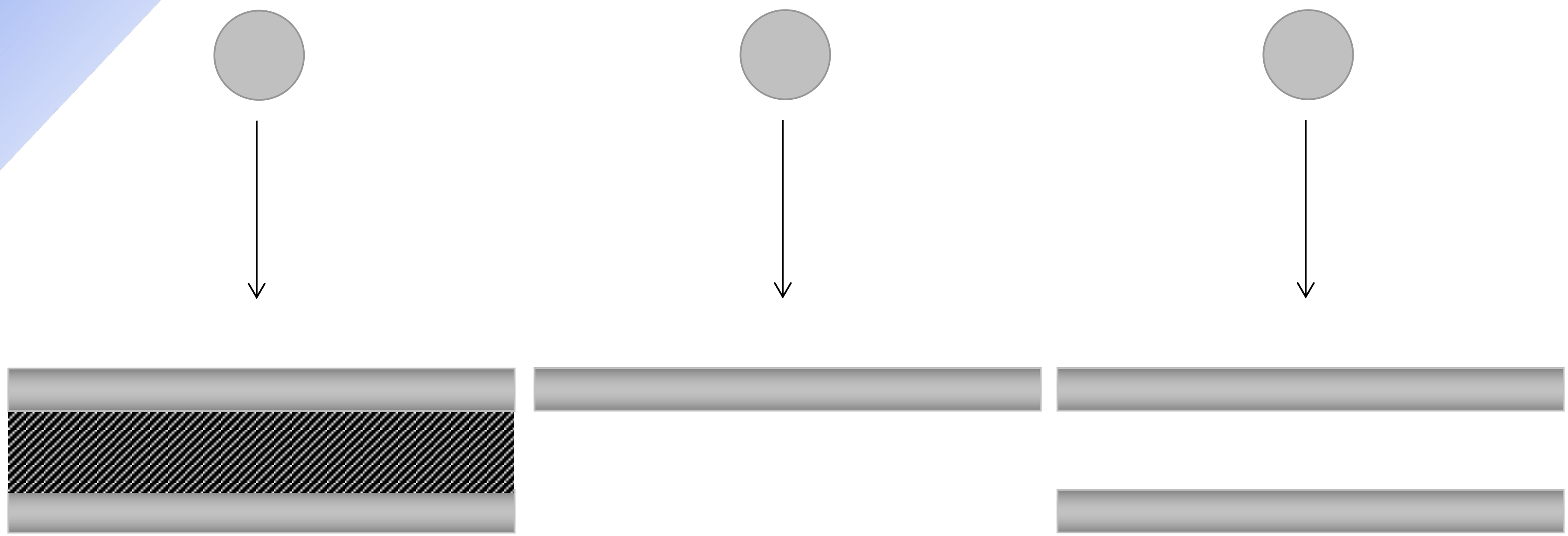
Gas Gun Schematic







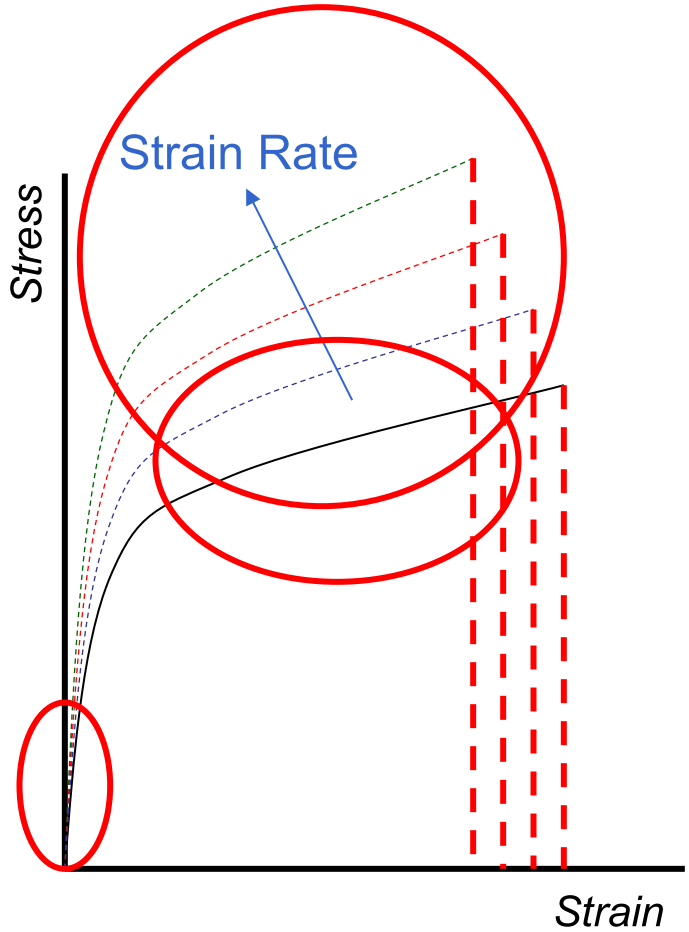
➢ *Experimental Programme*



- 8 mm Diameter Projectile
- 2 g Mass
- Hardened Steel – Martensitic Outer Layer
- Impact Speeds ~ 80–600 m/s

➢ Numerical Modelling

➢ Faceplate Material Model



Elastic Properties:

Young's Modulus

Poisson's Ratio

Plastic Properties:

Stress v Strain Curves (von-Mises)

Johnson and Cook Plasticity

Rate Dependency:

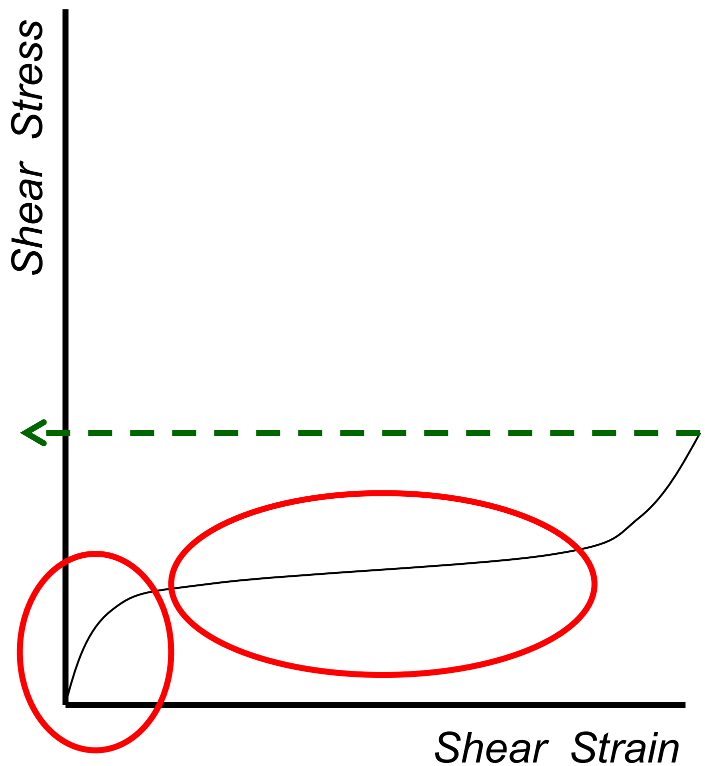
Yield Ratio/Rate-hardening constant

Fracture Criterion:

Critical Strain

➢ Numerical Modelling

➢ Core Material Model – VUMAT Sub-routine (Zhou & Louca)



Elastic Properties:

Young's Moduli

Poisson's Ratios

Plastic Properties:

Stress v Strain Curves

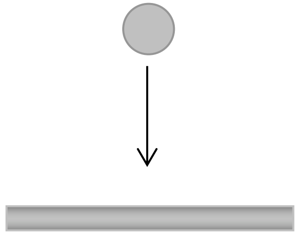
Fracture Criterion:

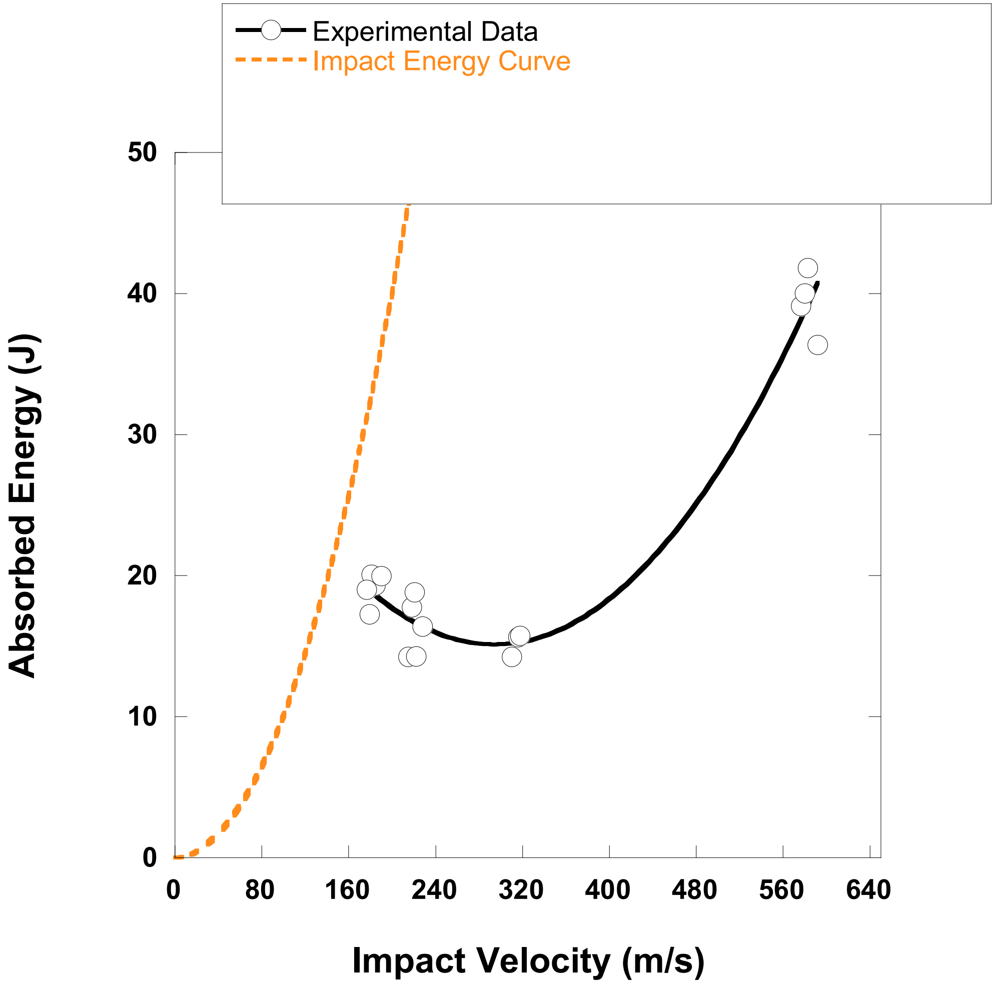
Critical Shear Stress

➢ VUMAT sub-routine

- *Anisotropic Compressible Continuum*
- *Quadratic Shear Stress-based Failure Criterion*
- *No Flow Stress Rate-Dependence*
- *No Fracture Strain Rate-Dependence*

➢ *Single Faceplates – Experiments and Predictions*





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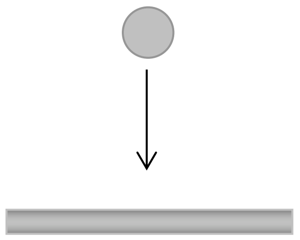

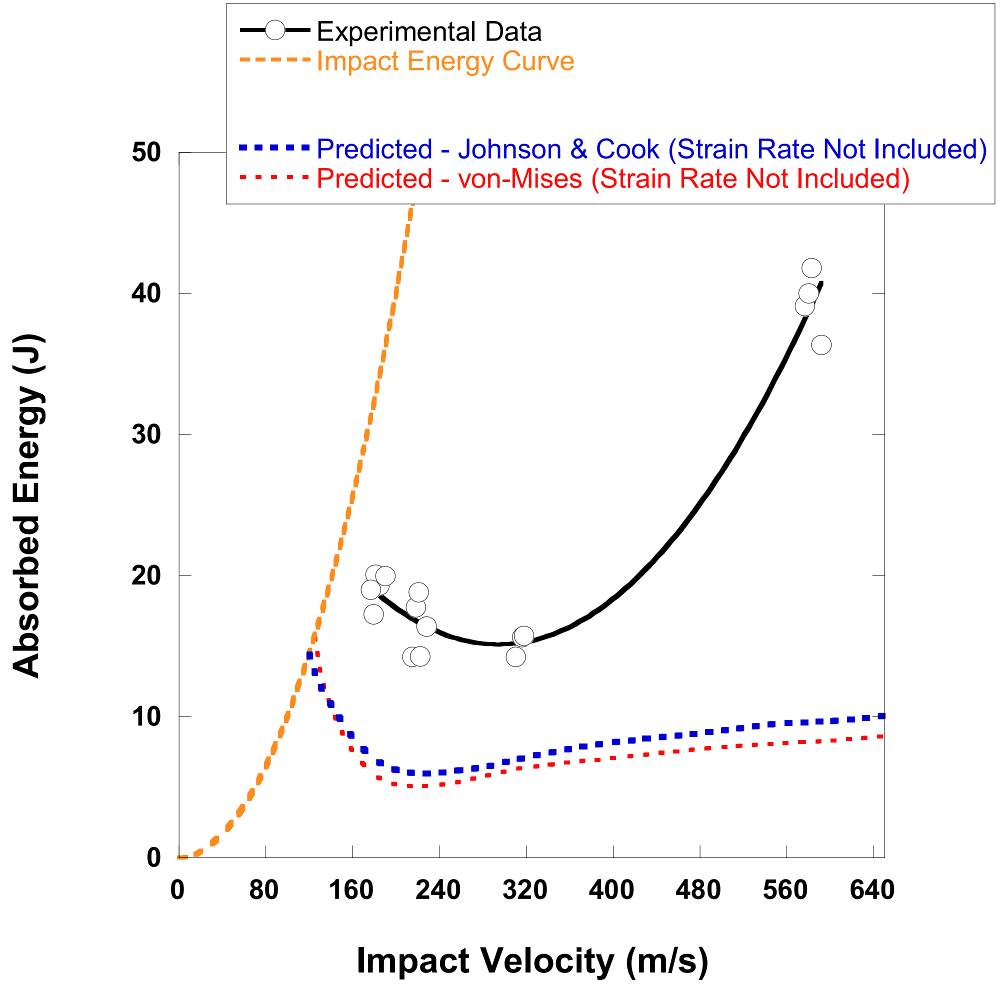

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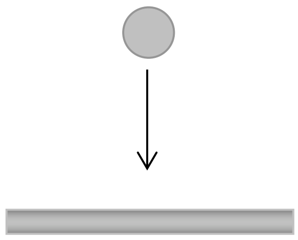

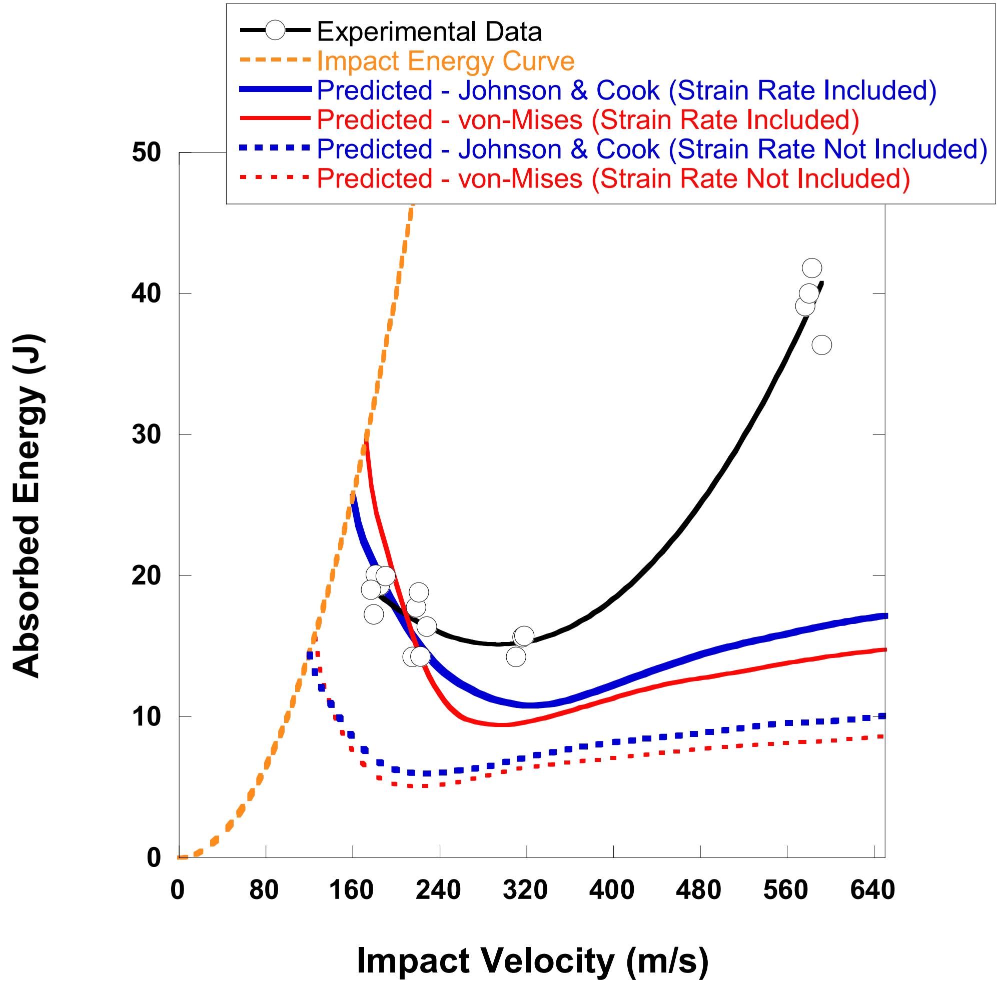

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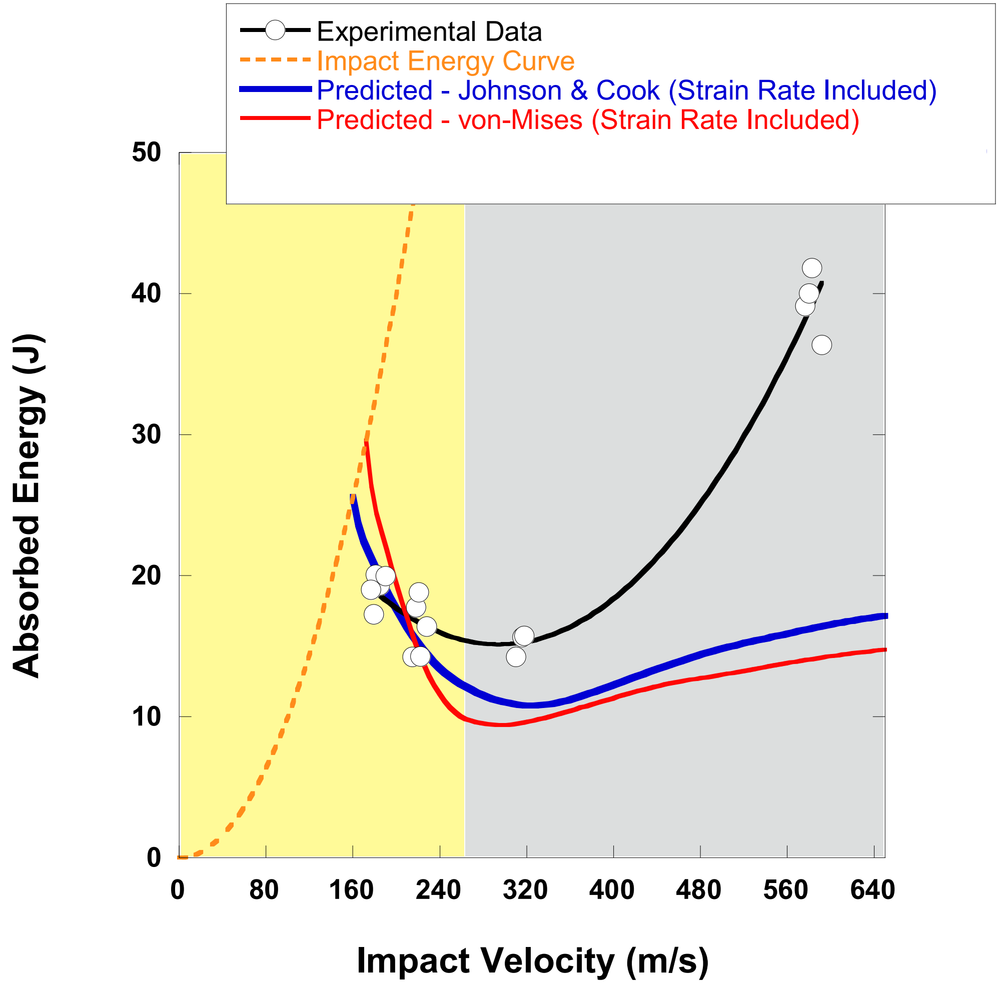

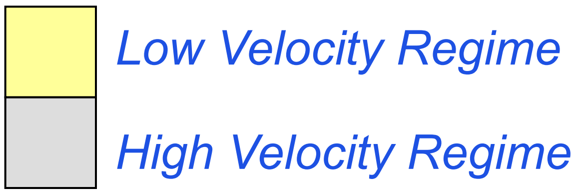

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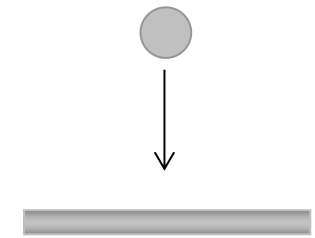
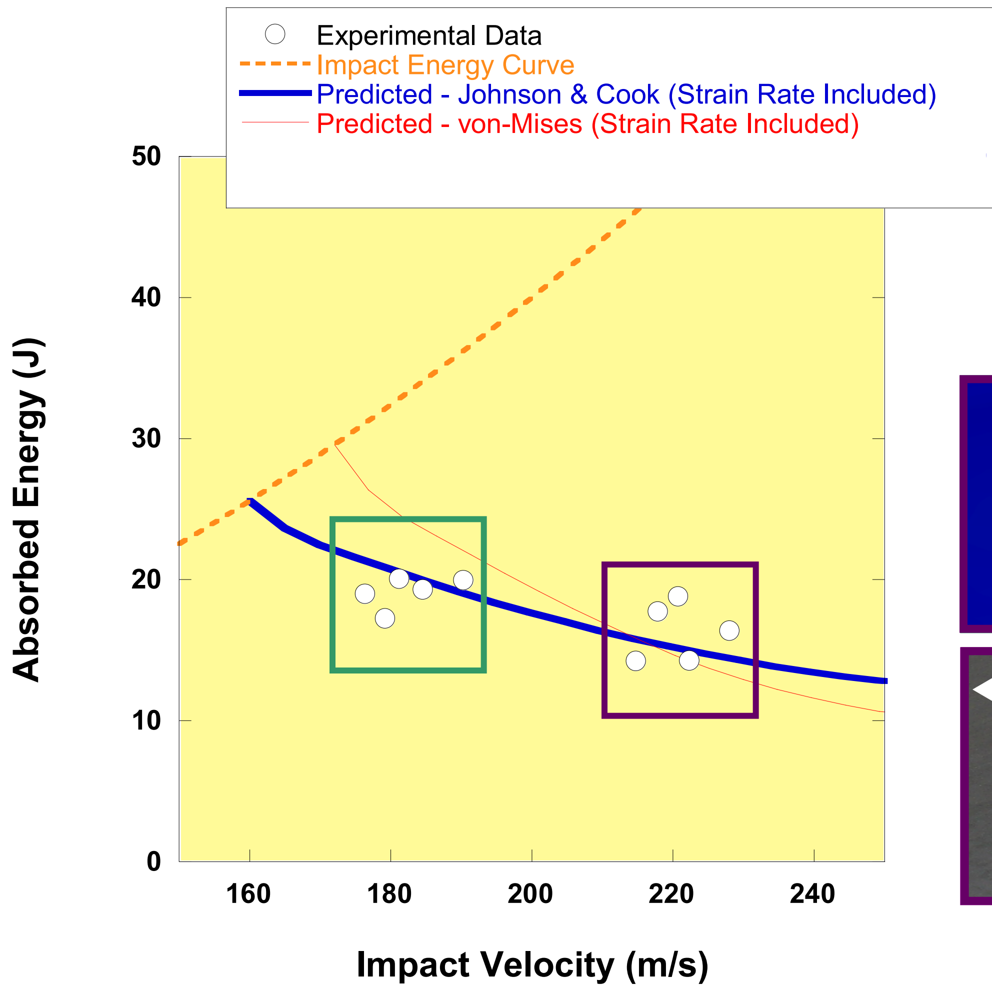
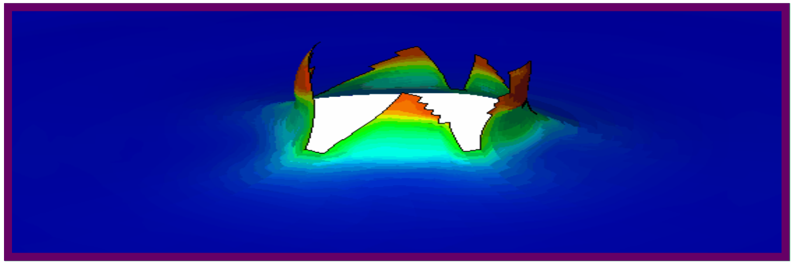
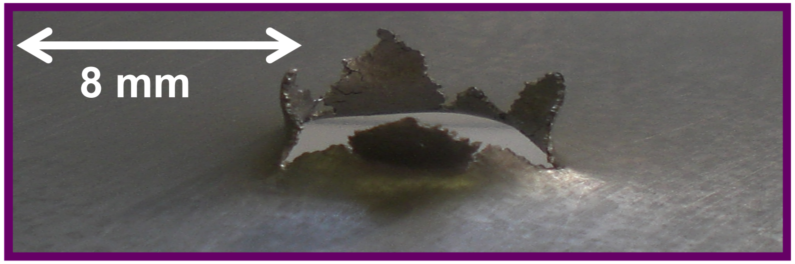




Low Velocity Regime





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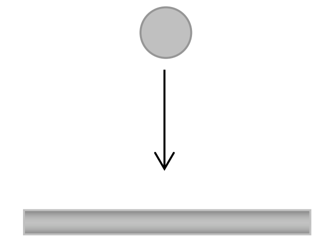
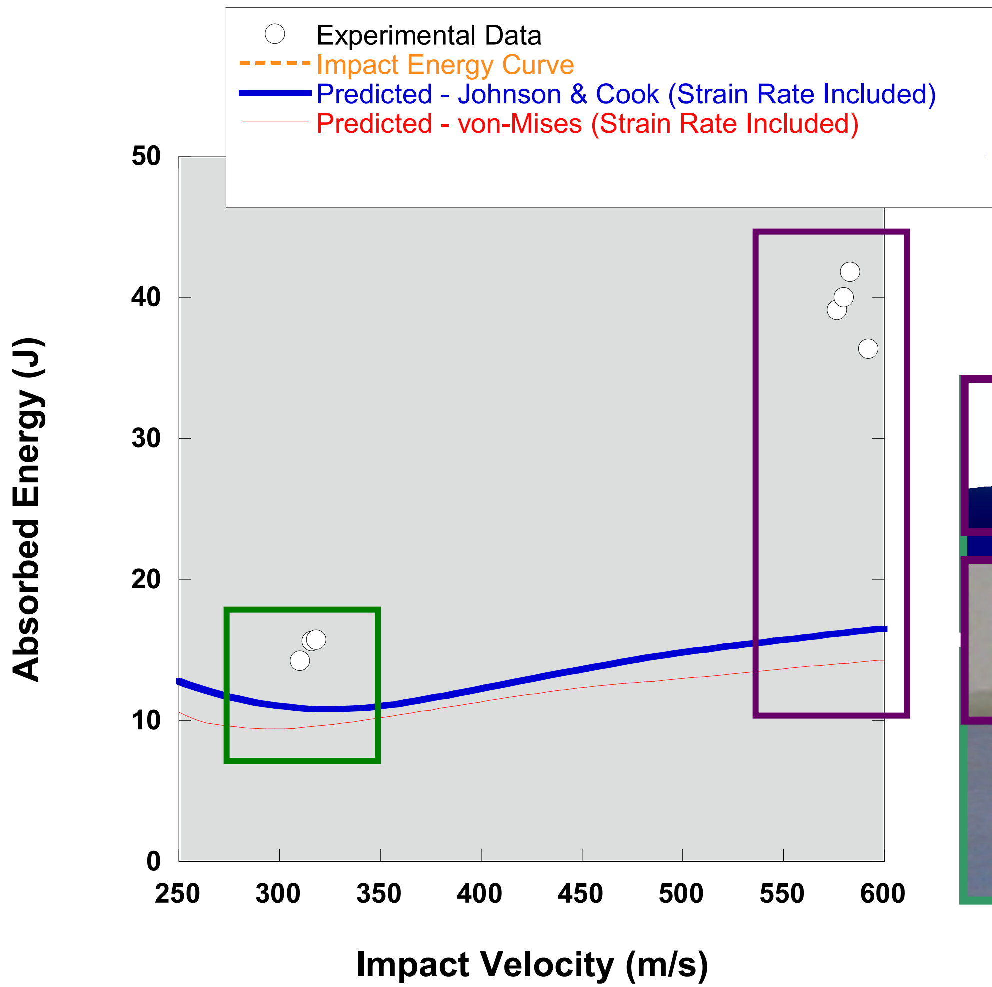
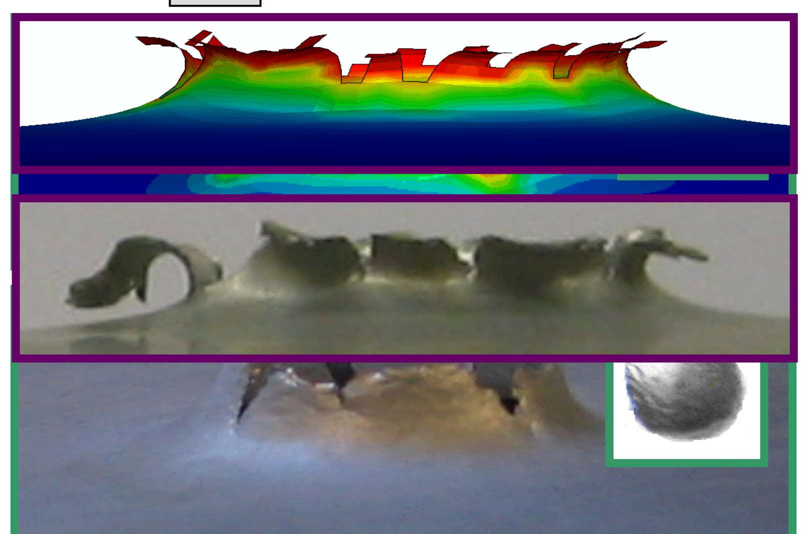
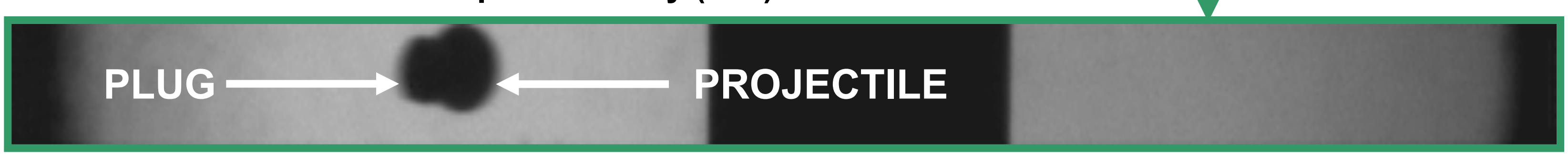




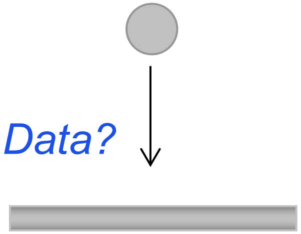
High Velocity Regime

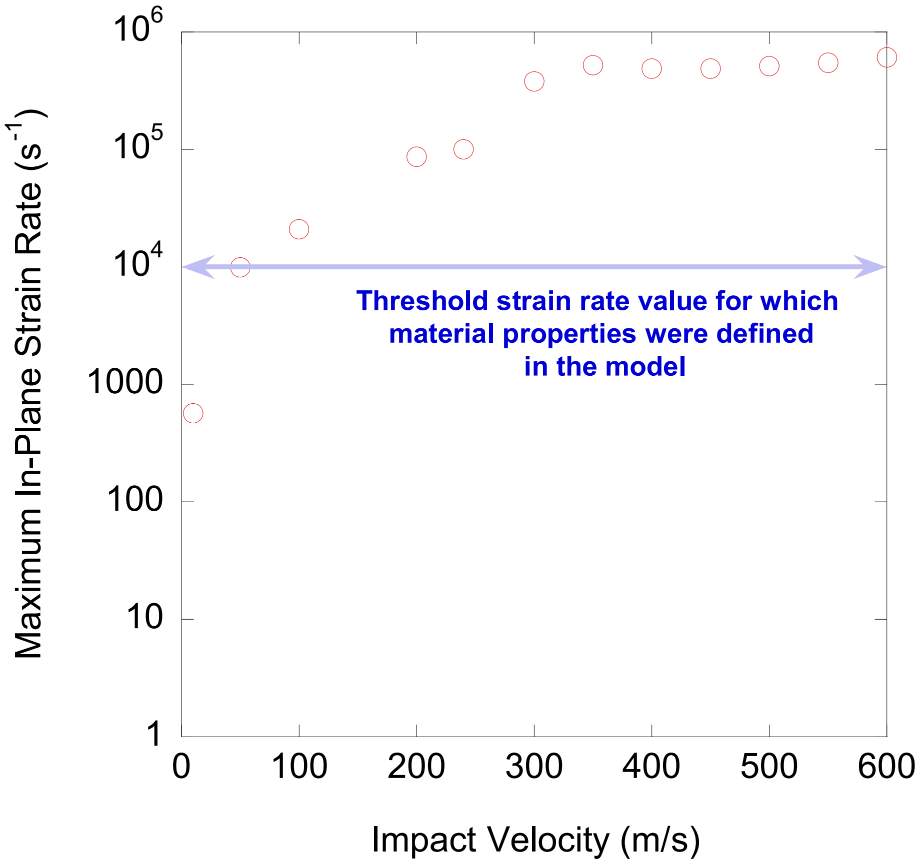




➤ Single Faceplates – Experiments and Predictions

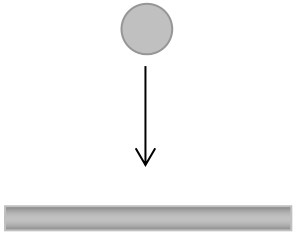
➤ Inadequate Strain Rate-Dependent Material Property Data?



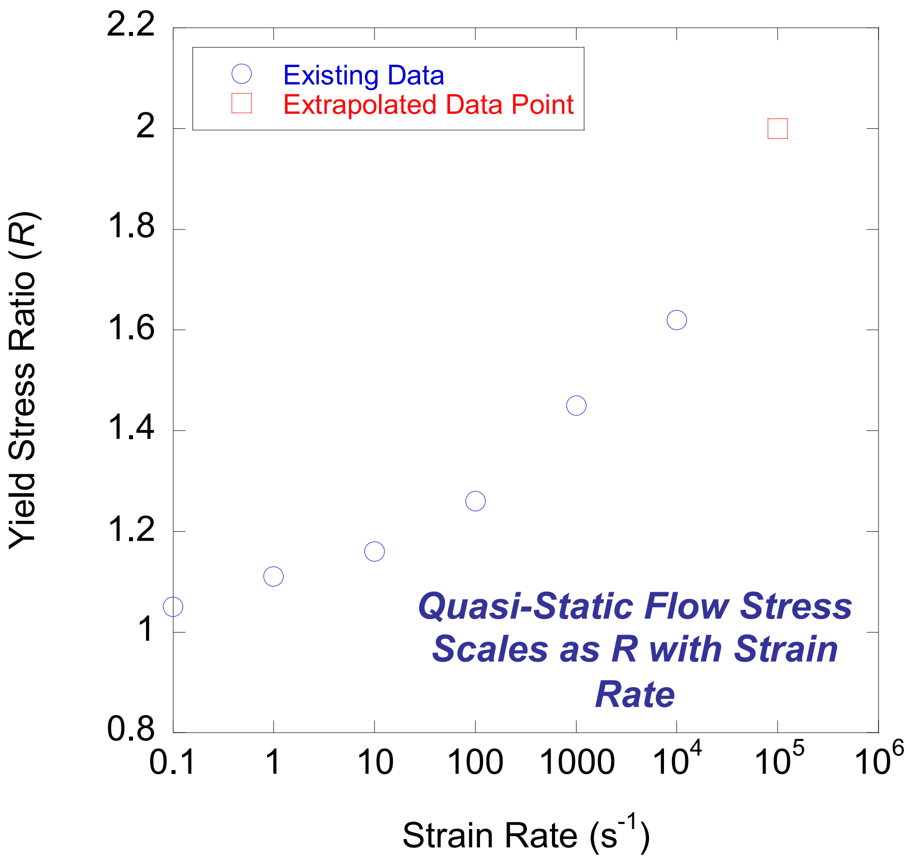


➢ Single Faceplates – Experiments and Predictions

➢ High Strain Rate Material Behaviour



von-Mises Plasticity
Hardening Behaviour – Yield Stress Ratio



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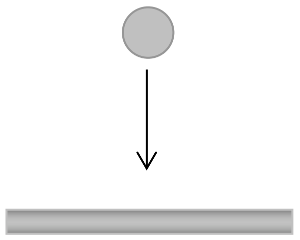

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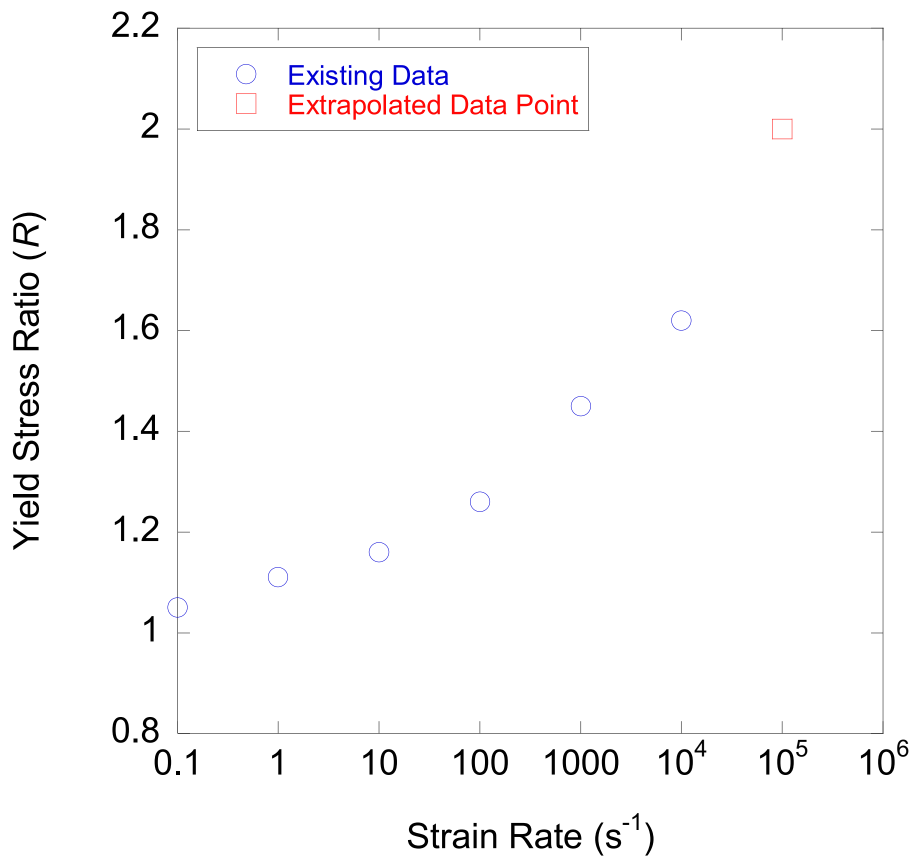

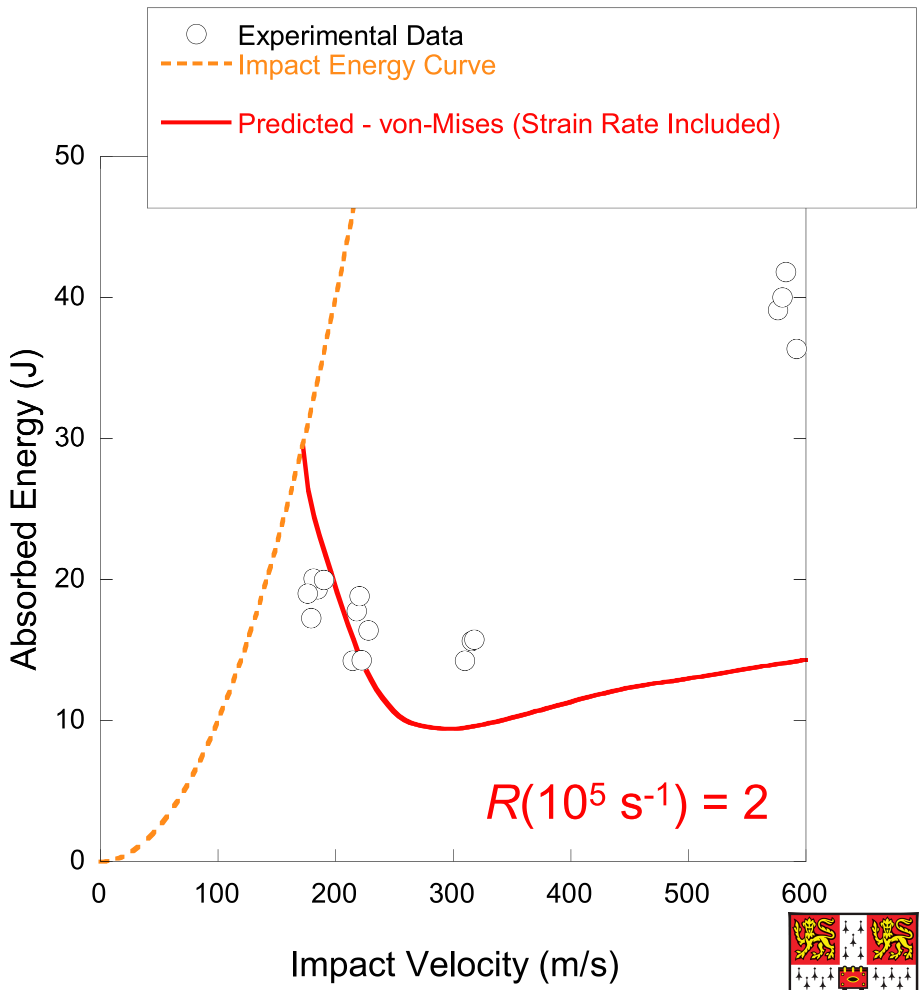

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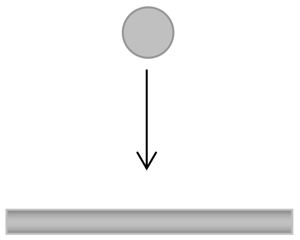

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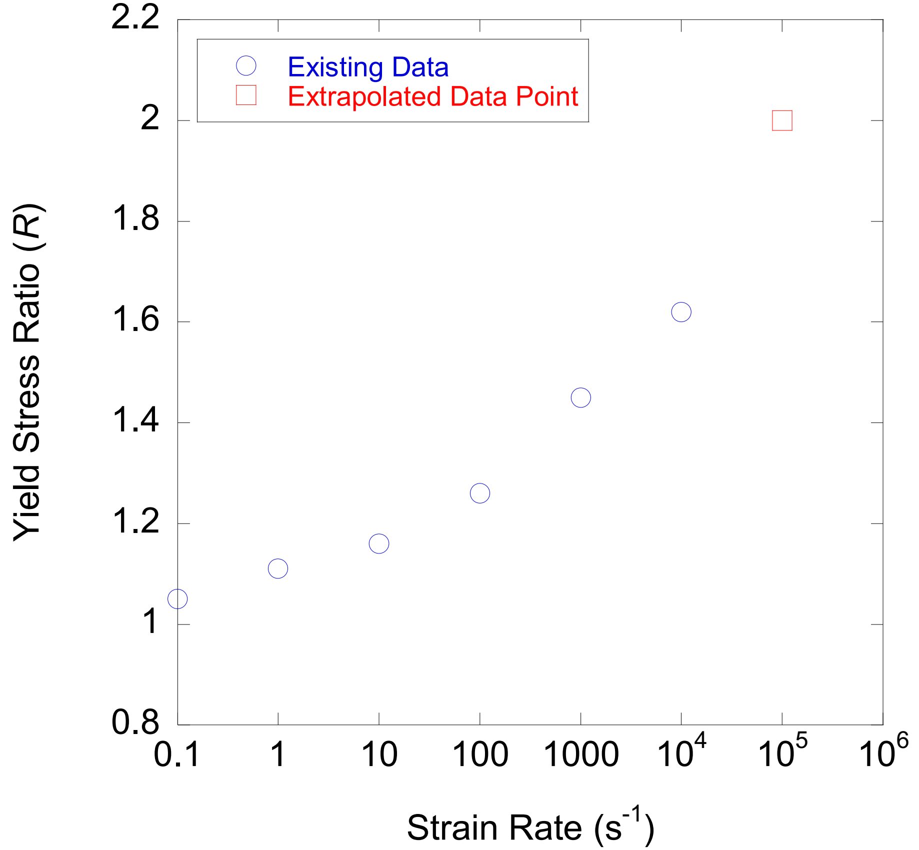

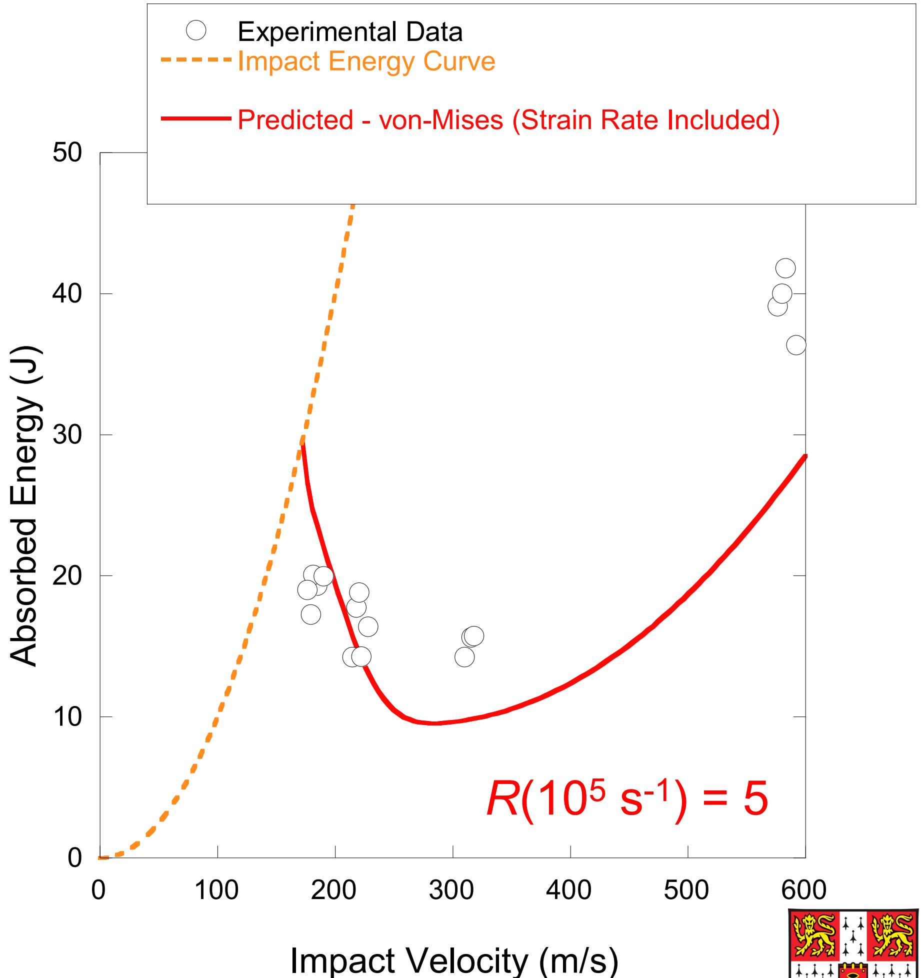

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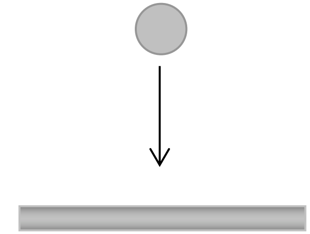
➢ *High Strain Rate Material Behaviour*



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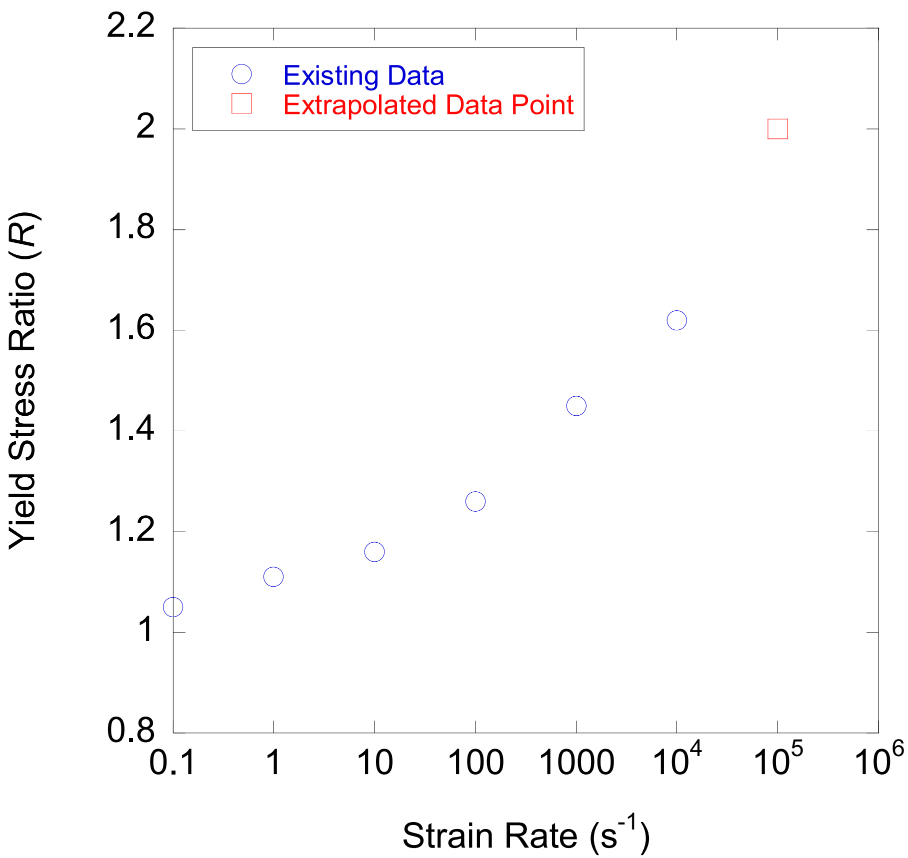

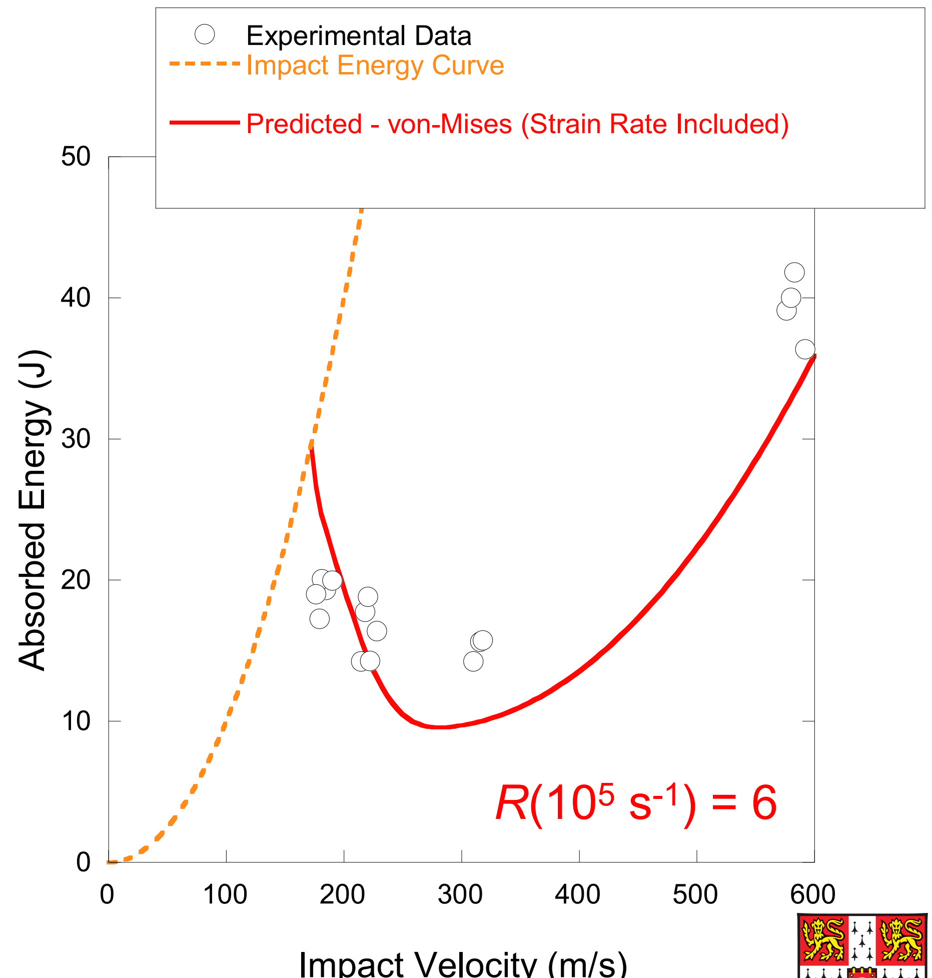

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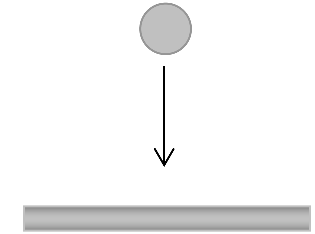

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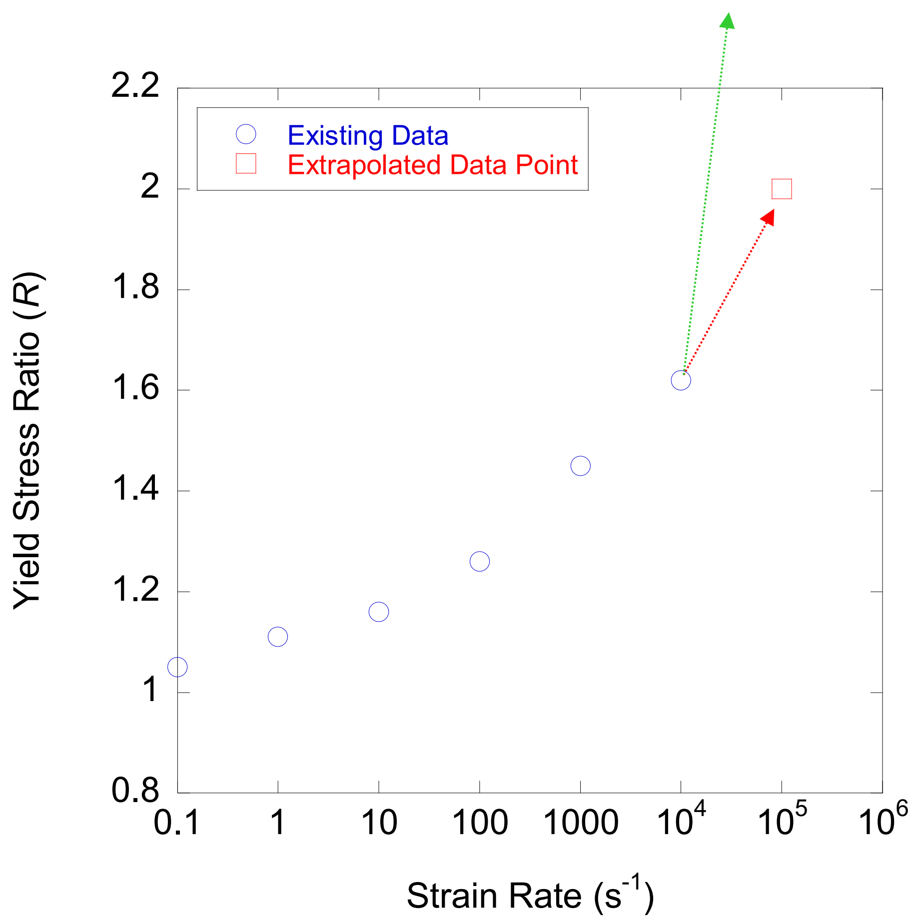

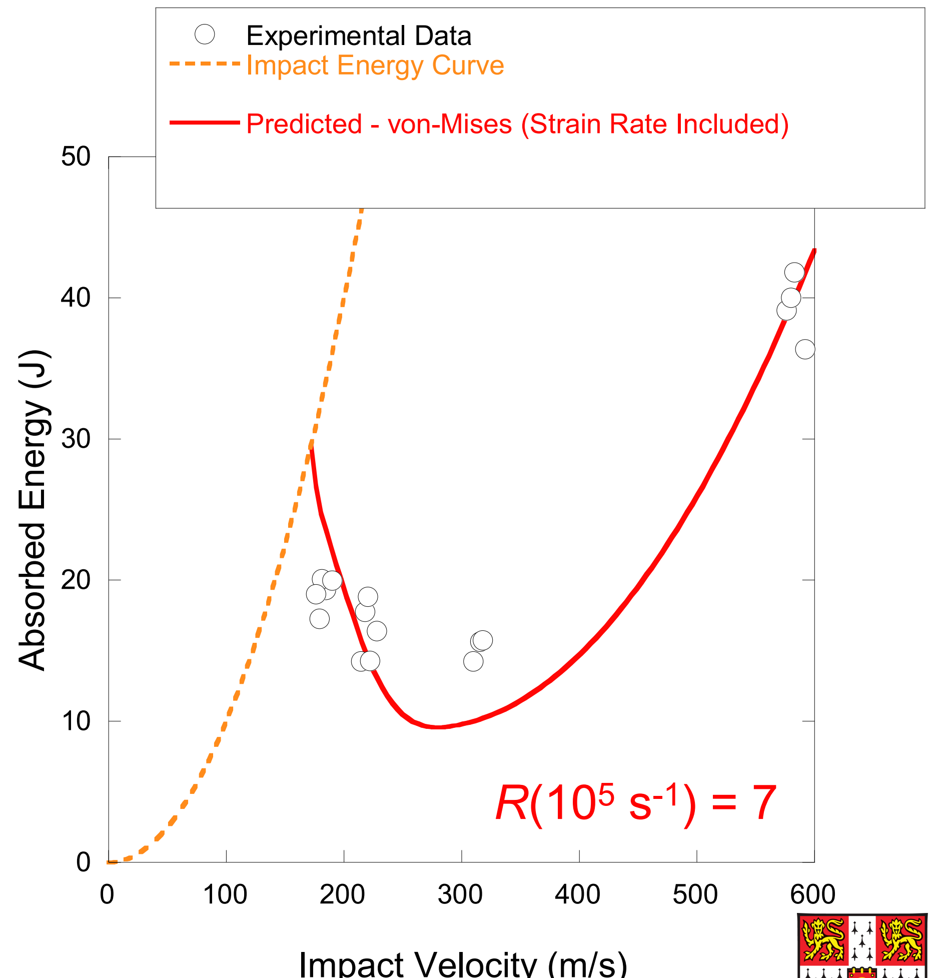

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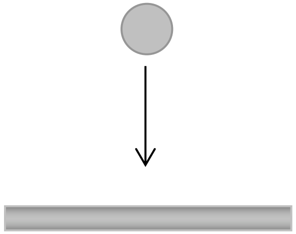
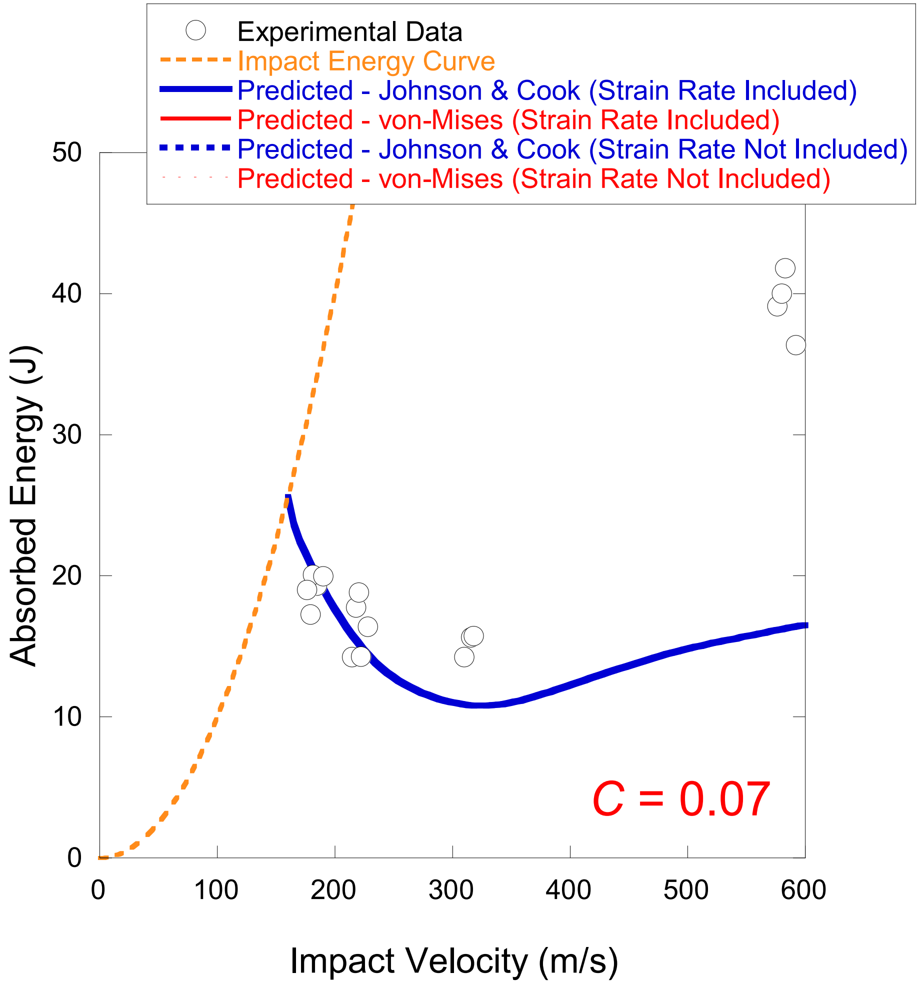


Johnson & Cook Plasticity
Hardening Behaviour – Hardening Constant (*C*)



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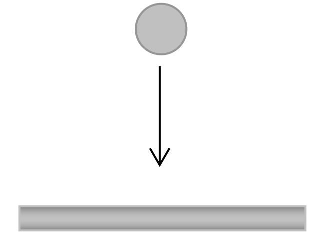

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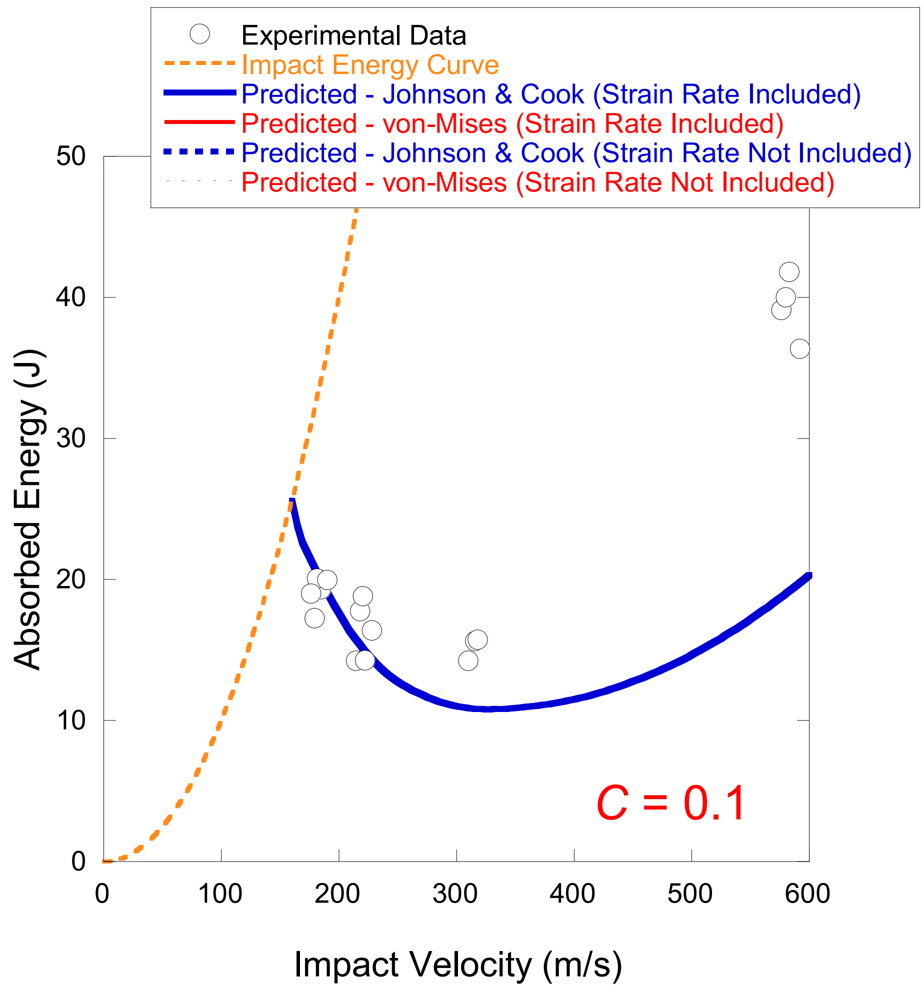
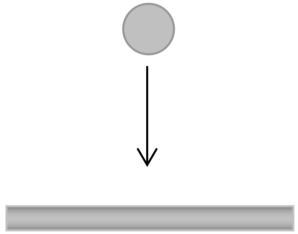


- *Single Faceplates – Experiments and Predictions*
  - *High Strain Rate Material Behaviour*



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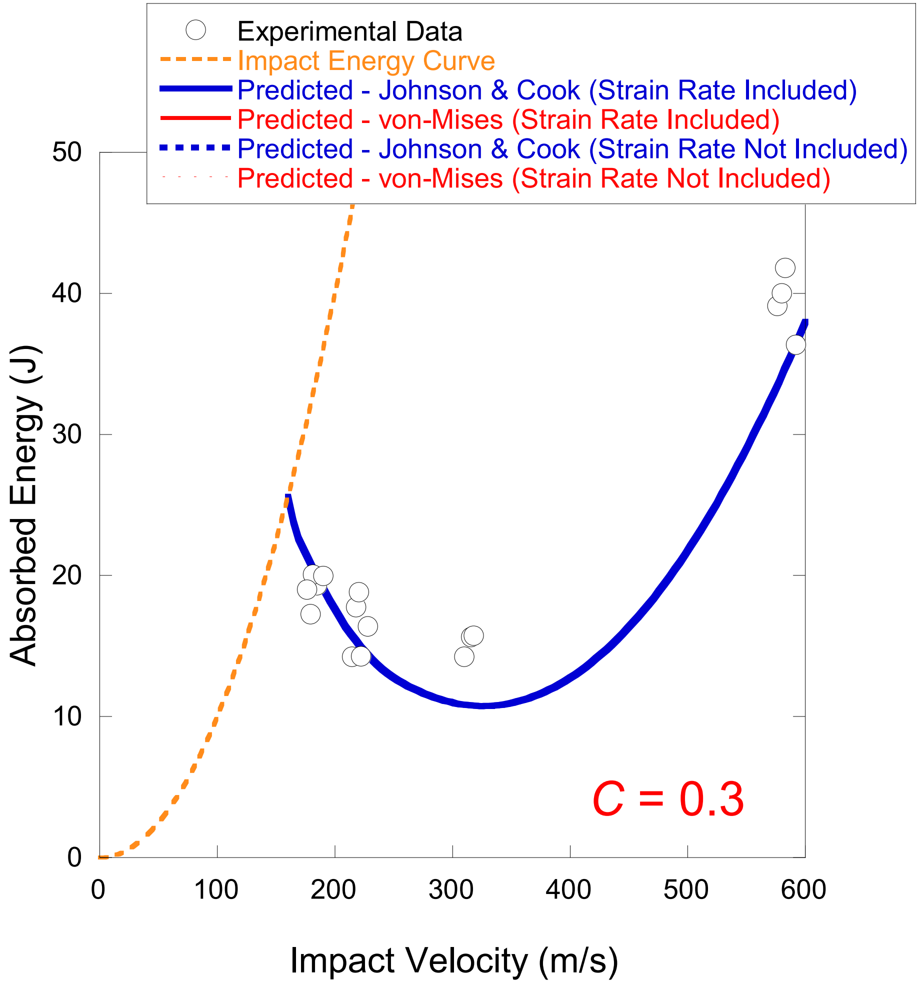

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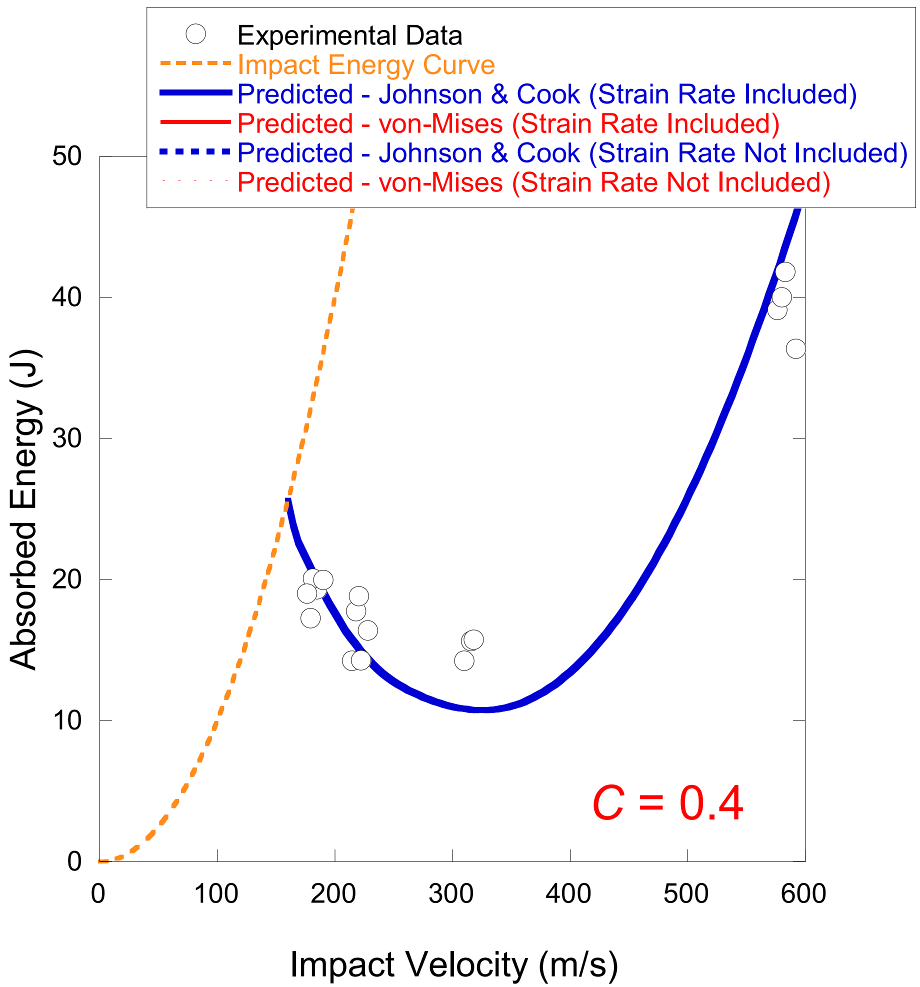

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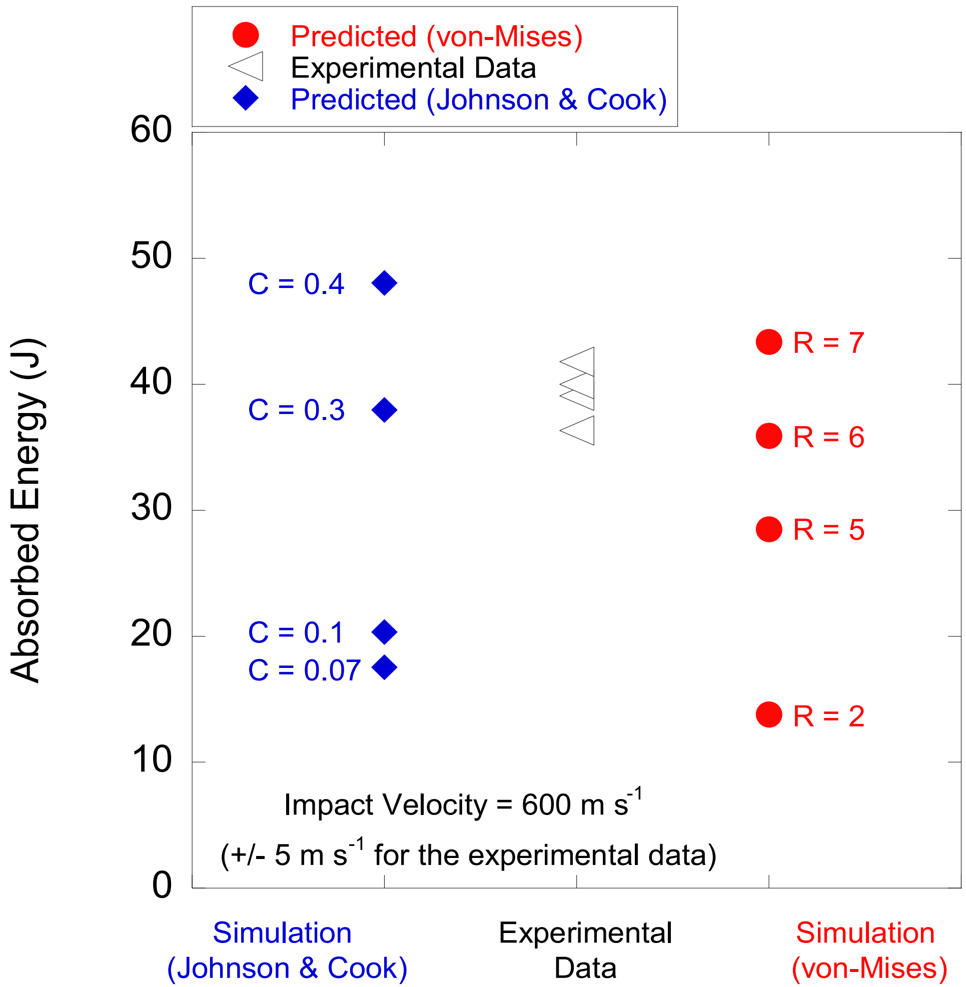
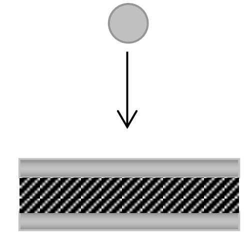
➢ High Strain Rate Material Behaviour



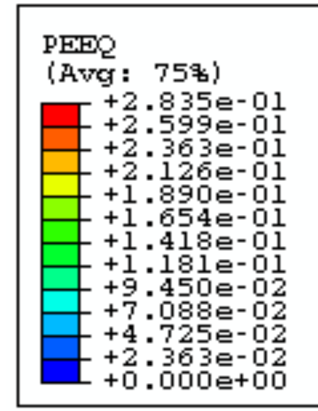
- *Dislocation Drag?*
- *Deformation Twinning?*
- *Martensitic Transformations?*

➢ Sandwich Panels – Experiments and Predictions

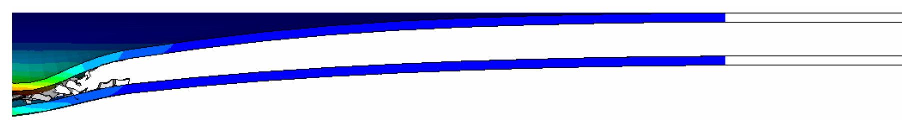
➢ Low Velocity Impact (<200 m/s)



All simulations conducted here have used the Johnson & Cook Plasticity Algorithm



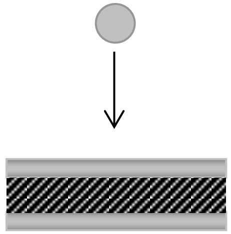
100 m/s

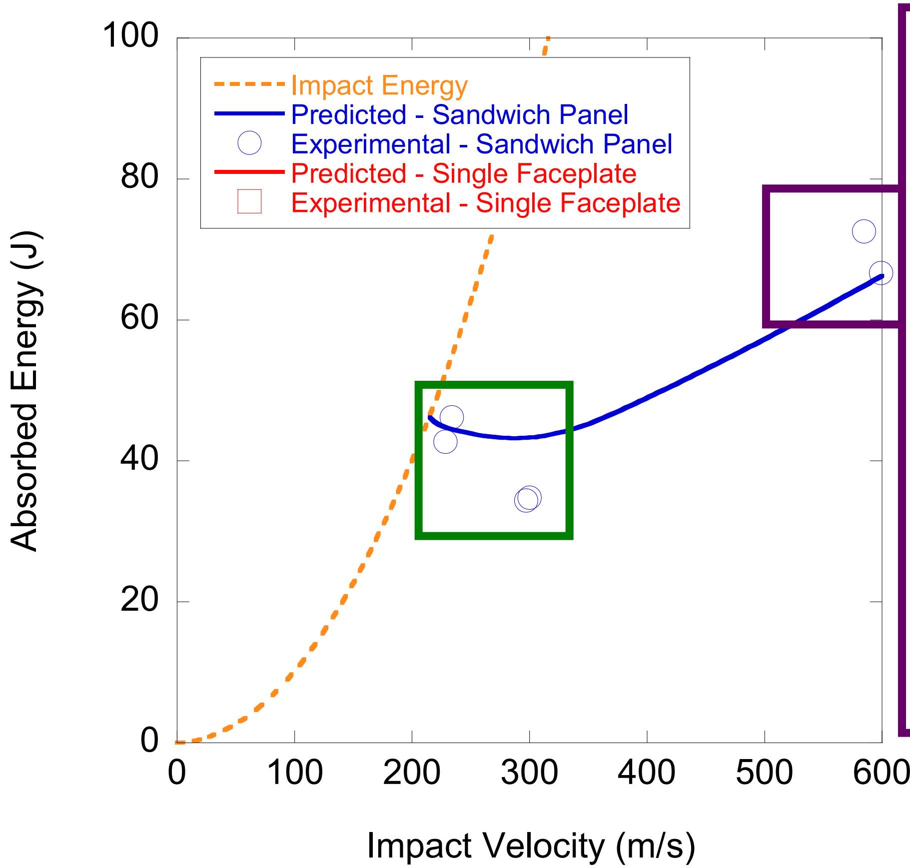


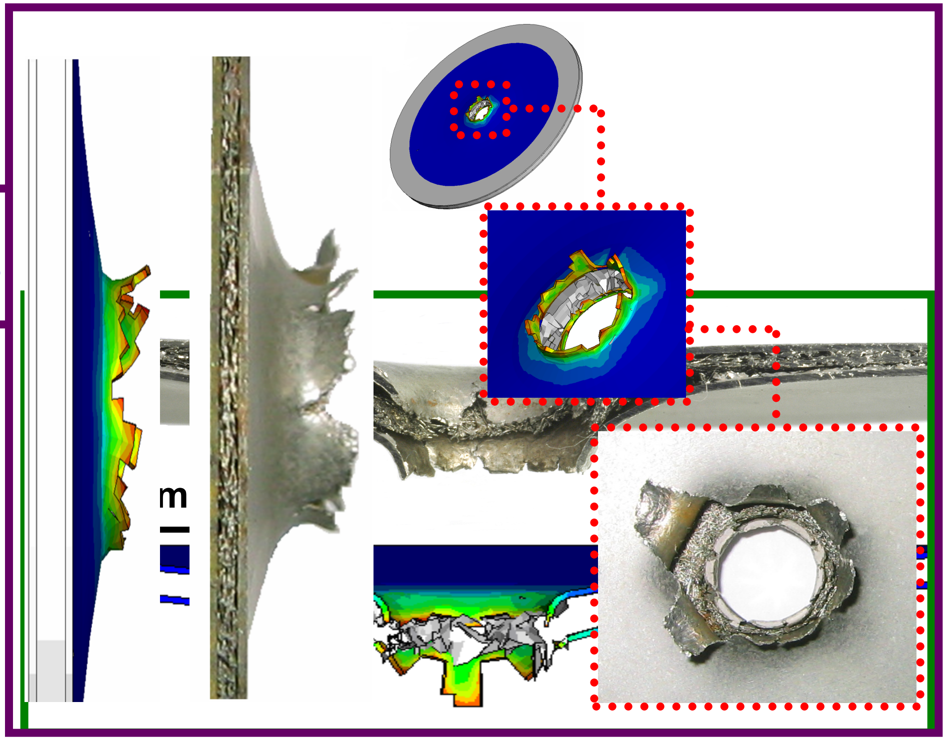
103 m/s

➢ Sandwich Panels – Experiments and Predictions

➢ High Velocity Impact (>200 m/s)

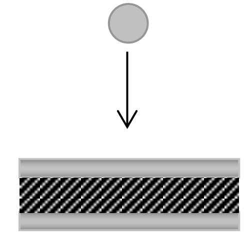


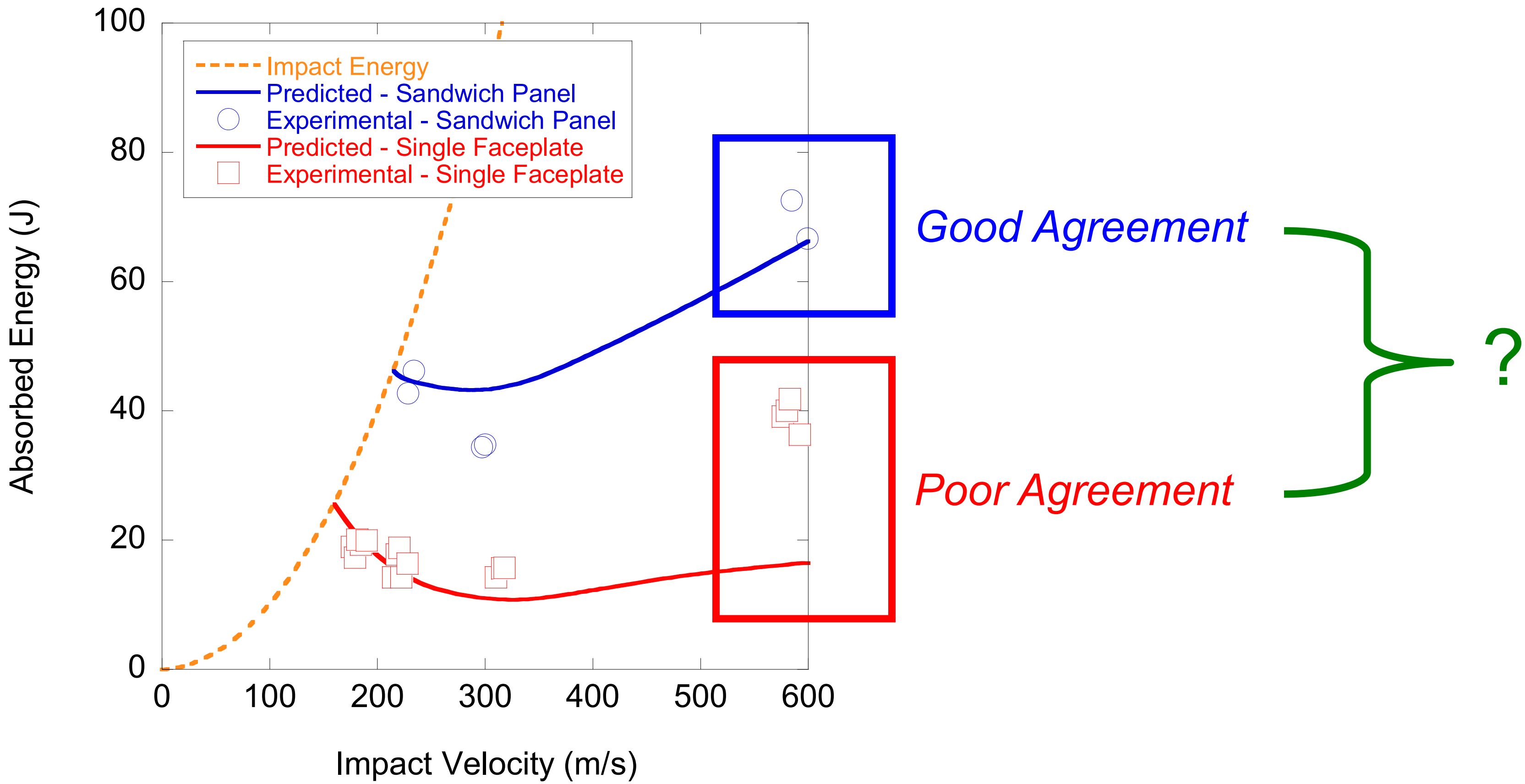




➢ Sandwich Panels – Experiments and Predictions

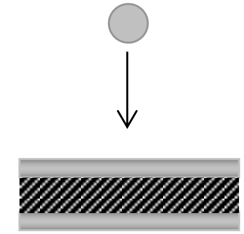
➢ High Velocity Impact (>200 m/s)

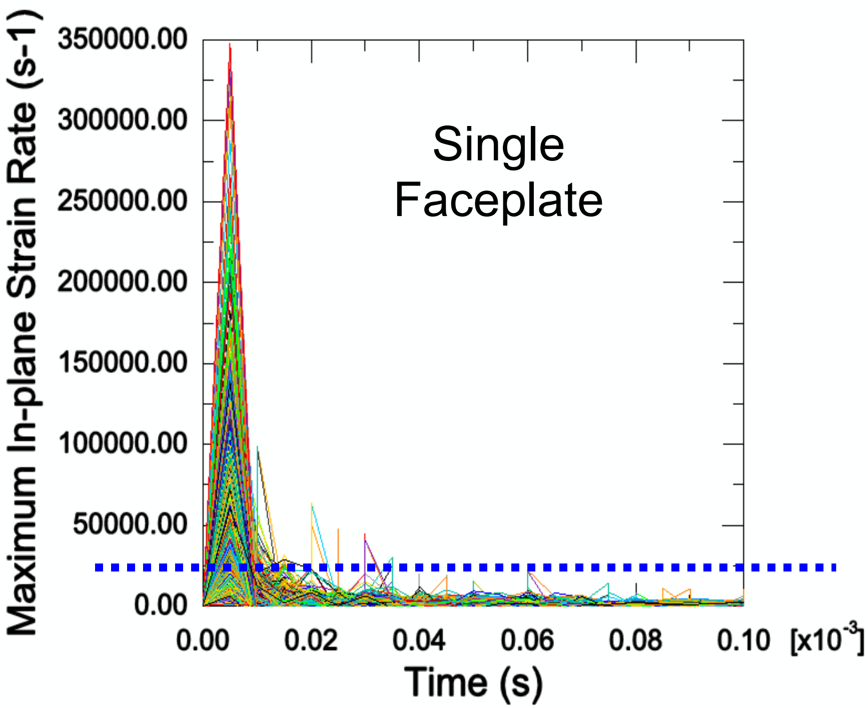


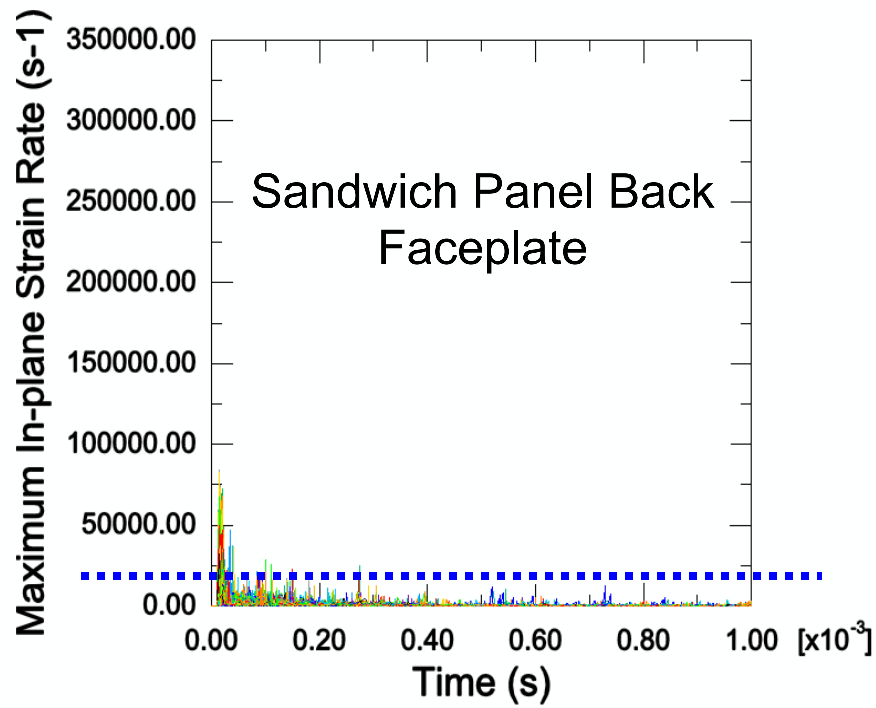


➢ Sandwich Panels – Experiments and Predictions

➢ High Velocity Impact (>200 m/s)

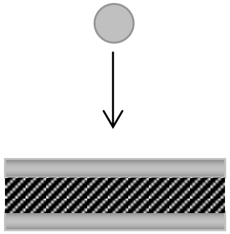


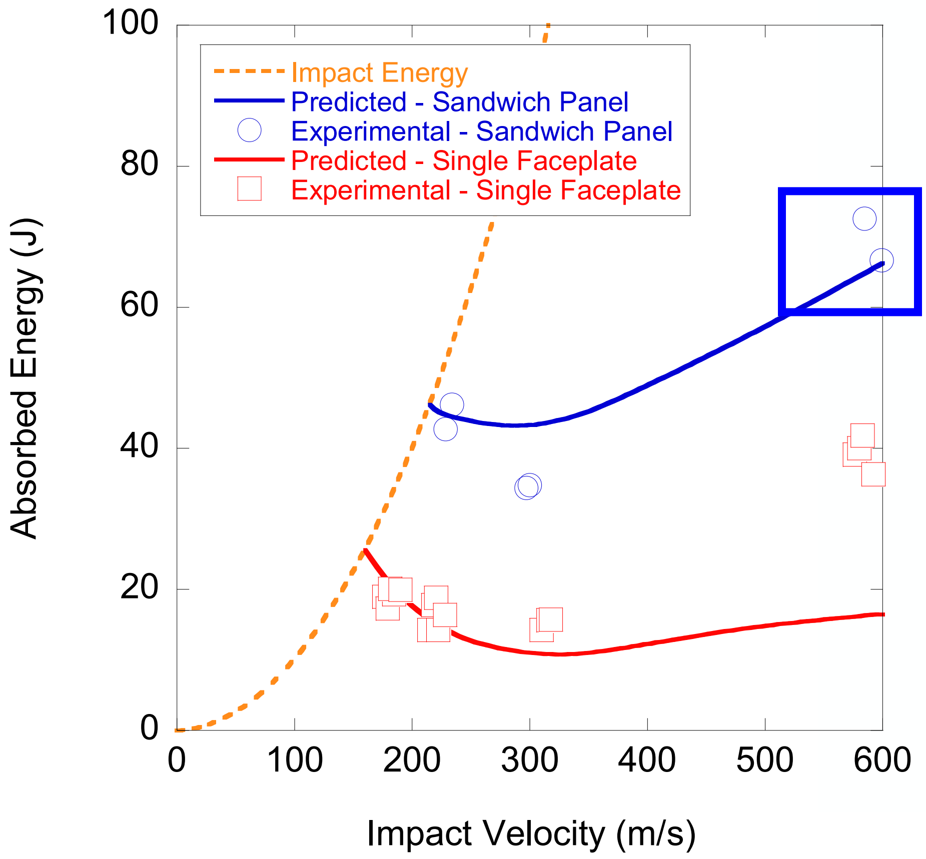


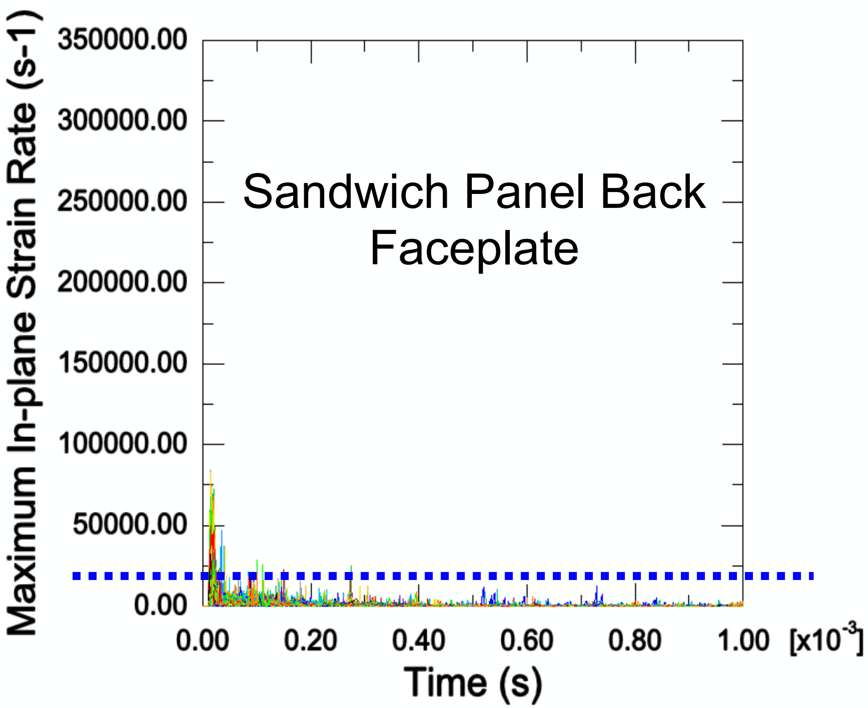


➢ Sandwich Panels – Experiments and Predictions

➢ High Velocity Impact (>200 m/s)

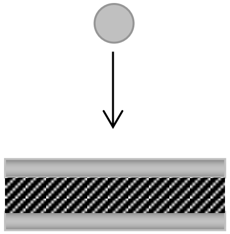




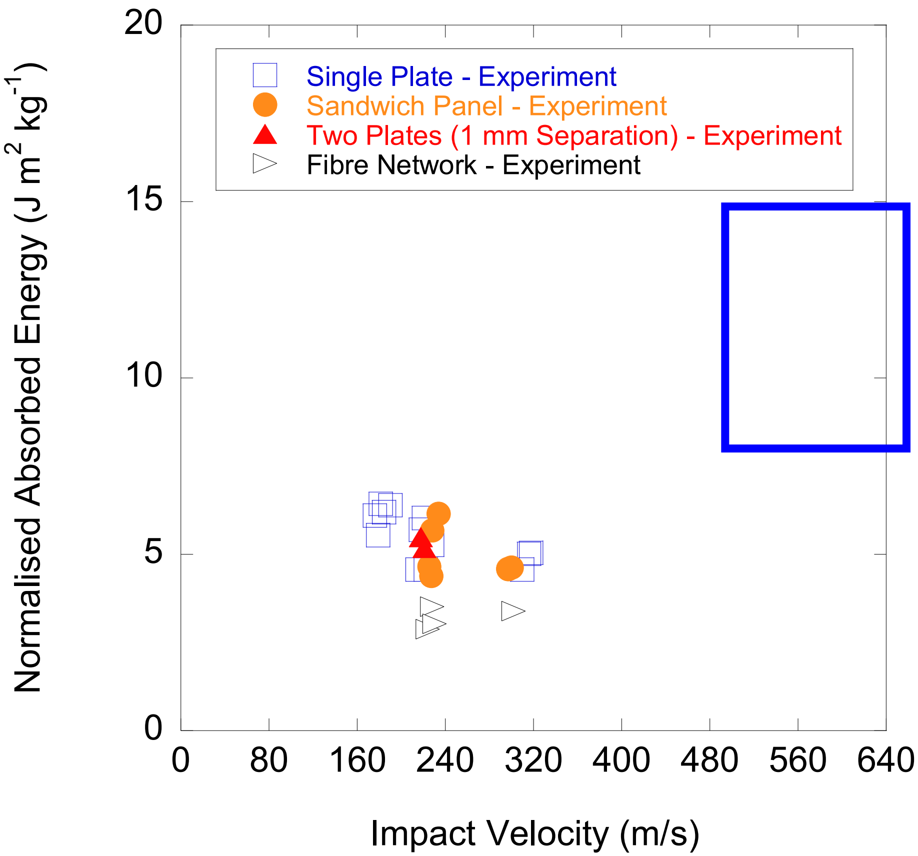


➢ Sandwich Panels – Experiments and Predictions

➢ Specific Absorbed Energy



Consider the Specific Absorbed Energy (Normalised by Areal Density)



Single Plate is Superior (in terms of specific absorbed energy)

- *The core compressibility (and plastic work) helps to reduce the projectile speed to a value which is conducive to low strain rates in the rear sandwich panel faceplate. In this manner, the favourable strain rate-hardening characteristics of the stainless steel faceplate (which are significantly enhanced at very high strain rates) are not exploited.*

➢ *Conclusions*

- ***A lightweight sandwich panel with a metallic fibre core has been fabricated***
  - Can be handled in a manner similar to that of monolithic sheet
  - Can be resistance welded
  - Is comparatively cheap

- ***The core architecture can be characterised using x-ray microtomography***
  - Architectural data can be used to predict elastic (and yield stress) mechanical properties – Clyne & Markaki Model

- ***The capacity of the sandwich panels to absorb energy when struck (at normal incidence) by spherical projectiles has been investigated***
  - When normalised by areal density, the sandwich panels are no more effective at absorbing energy than a single faceplate (at low and intermediate projectile velocities)
  - At high projectile velocities, single faceplates absorb more energy (on a weight-for-weight basis) than the sandwich panels due to plastic compression of the core which mitigates the favourable (energy absorption) strain rate-hardening characteristics of the faceplate material

➢ *Conclusions*

- ***A sandwich panel finite element model has been developed***
  - The faceplates were modelled as elastic-plastic solids with a strain rate-dependent, critical plastic strain failure criterion
  - The core material was modelled as an anisotropic crushable continuum with a quadratic shear stress failure criterion (VUMAT sub-routine – Zhou and Louca)
  - Predictions and experimental data are in close agreement
- ***The predictive FE capability must now be utilised to optimise the core material***
  - *Exploit rate-hardening characteristics of the faceplate material*
  - *Improve the energy-absorbing performance of the core material*

  Simultaneously