Improved Material Modelling for Destructive Re-entry Assessments

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Objectives

- Three Separate Areas of Interest

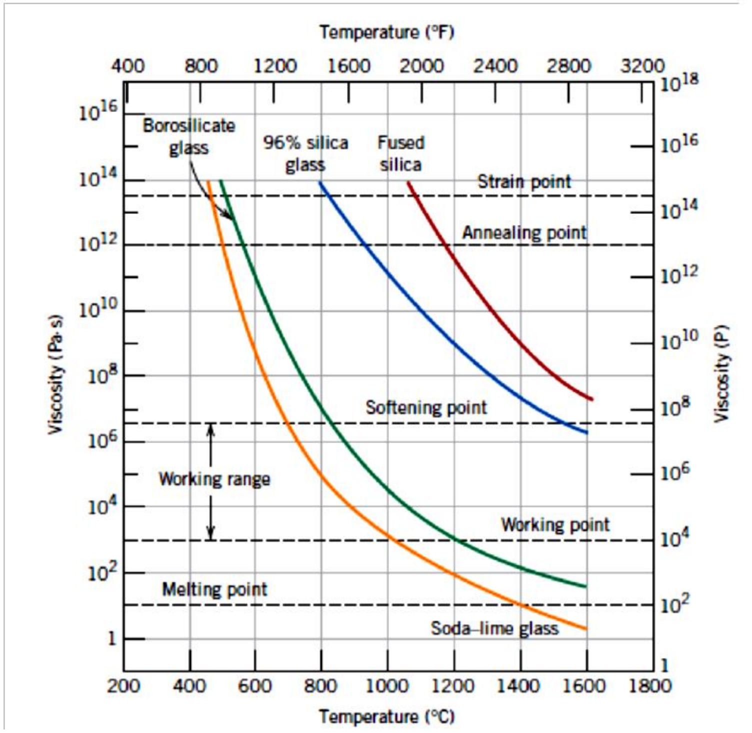
- Glass Modelling
  - Specific investigation of fused silica and Zerodur
  - Development of ‘glass’ model for destructive re-entry tools

- Ejecta Interaction
  - Does the impact of aluminium on hot titanium/steel surfaces enhance demise?
  - Splashes seen on recovered tanks

- Bipod Demisability and Design-for-Demise
  - Critical part of optical payloads
  - Often titanium or CFRP, so can provide casualty risk

Glass Materials

- How do Glass Materials Demise?
  - Glasses do not have melting point
  - Reduction in viscosity with increasing temperature
    - Different profiles for different glasses
  - Hypothesis: shear failure when hot
- Characterisation of Zerodur, Fused Silica
  - Basic properites (OGI)
  - Temperature-viscosity curve (SHU)
  - State-of-melt Testing (SHU)
- Testing of Materials
  - Confirm (or deny) shear failure
  - Consolidate modelling approach
- Construct/Verify Models
  - Data from testing
  - CNES data on Zerodur



Glass Material Demise Modelling

- Glasses generally modelled as equivalent metals
  - DAS, DEBRISK known models

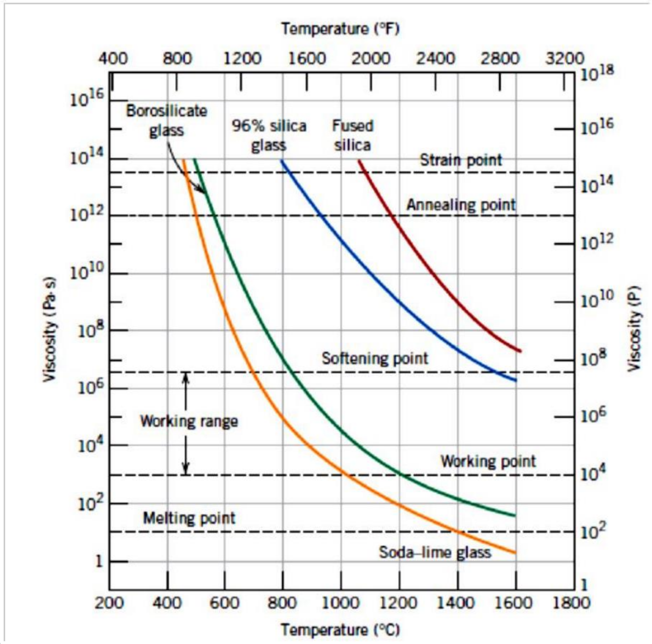
Property	DAS-Fibreglass	DAS-Zerodur	DEBRISK-Glass	DEBRISK-Zerodur
Density (kg/m^3)	1840	2530	3500	2530
Melt Temperature (K)	1200	1424	1473	1430
Specific Heat (J/kgK)	1047	842→1645	1000	N/A
Latent Heat (J/kg)	232	250000	250000	N/A
Emissivity	1	1	0.92	0.45 (thin) 0.85 (thick)

  - Significant variation in models
- SAMj models matched from shear based models
  - Large latent heats required in order to capture data
  - More conservative than the other models

Property	SAMj-Fused Silica	SAMj-Zerodur
Density (kg/m^3)	2200	2530
Melt Temperature (K)	2600	1558
Specific Heat (J/kgK)	746→1300	746→1300
Latent Heat (J/kg)	10000000	4000000
Emissivity	0.8	0.8

Glass Material Demise Modelling

- Viscosity-shear Model
  - Based on understanding of hot outer layer
  - Material shear
  - Zerodur test picture suggests this type of mechanism
- Different Behaviour for Different Glasses
  - Create exponential viscosity-temperature curve
  - Use HBI model for internal temperature gradient
  - Decide how much material can shear
    - Arbitrary selection of 1000Pa.s
  - Consider Rayleigh-Taylor instability
    - Fixed surface tension of 0.3N/m used
    - Gives mass loss timescale
    - Scale mass which can shear by timescale
  - Assume sheared mass does not re-solidify
- Only known 'non-equivalent' model

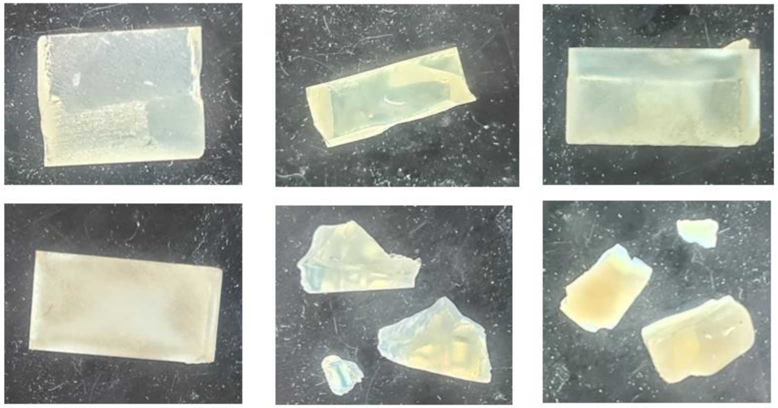


Glass Materials

- State-of-Melt Testing
  - Experiments performed
    - Zerodur exposed to high temperatures for different timescales
      - 600K – 1750K for 20s-600s in fixed temperature furnace
      - Little observed for short timescales
      - Some crystallisation on quenching
      - Internal stresses cause cracking on quenching

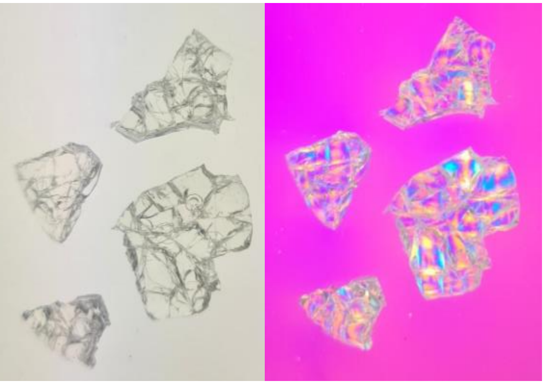
1400 K

1750 K



20 s 40 s 60 s

Glass Materials



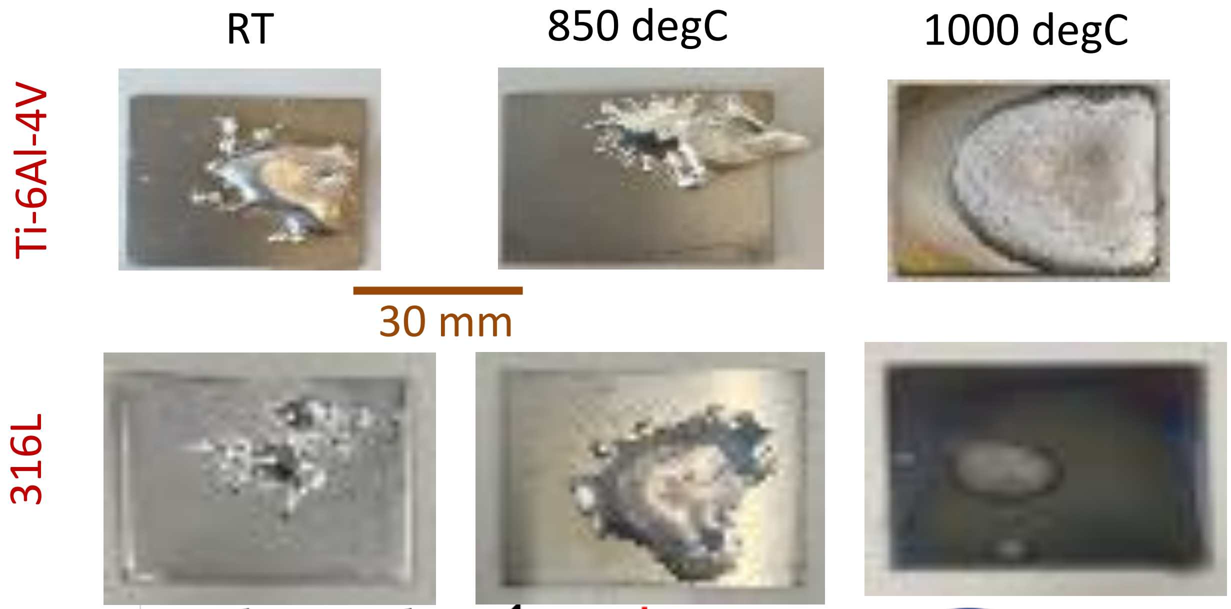
- State-of-Melt Testing
  - Longer term exposure
    - Ensures that temperature of interest reached
    - 1400K – fully crystallised on quenching
    - 1750K – appears glassy, high internal stresses
    - No bubbling observed
      - Possibly a low pressure effect
      - Cavitation?
  - Further post-test analysis to be performed
    - Observe levels of phase separation, crystallisation and cracking
    - Microscopy, X-ray diffraction

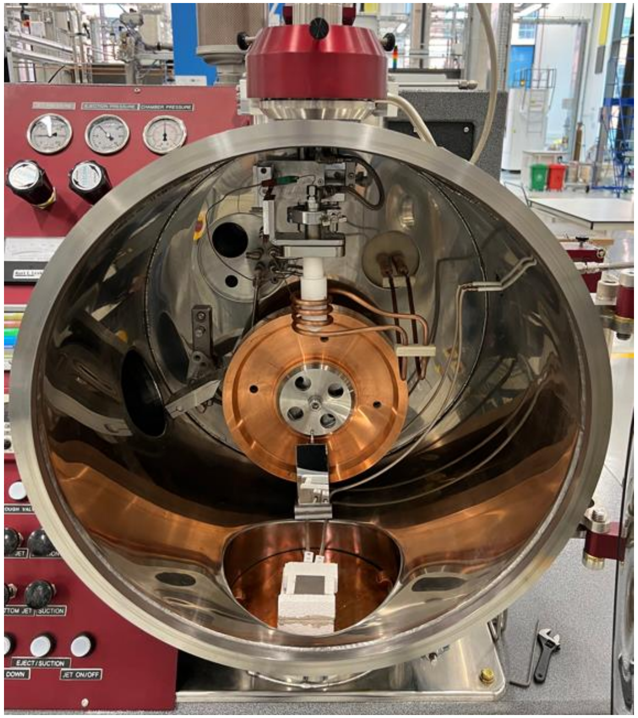
Ejecta Reactions (FGE)

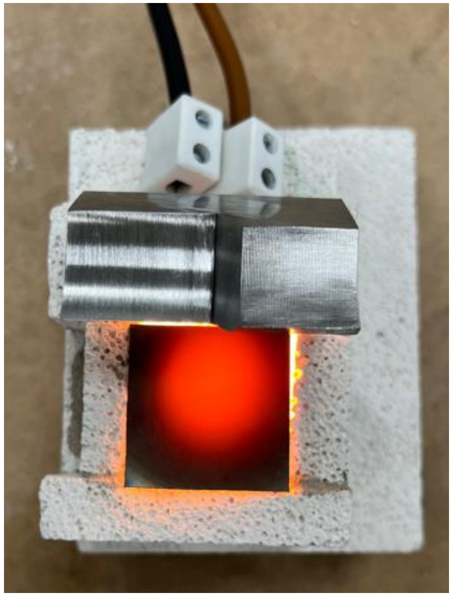
- Demise Assistance to High Temperature Materials
  - Molten aluminium splash on steel/titanium
  - Exothermic reactions possible
    - Literature suggests that thermite (metal-metal oxide) reactions are unlikely
    - Literature suggests that intermetallic reactions may need thinner structures
- Two Stages of Testing
  - Laboratory tests
    - Basic metallurgical reactions
    - Devise sensible wind tunnel tests
  - Wind tunnel testing
    - Can we see effect in representative conditions?
- Model Derivation
  - Realistic possibility is that this is not an effective demise mechanism

Ejecta Reactions

- Laboratory Testing (University of Sheffield)
  - Arcast melt spinner
  - Molten aluminium dropped
  - Heated titanium plate
    - Furnace designed to heat plates
  - Tests complete
  - No clear reactions observed

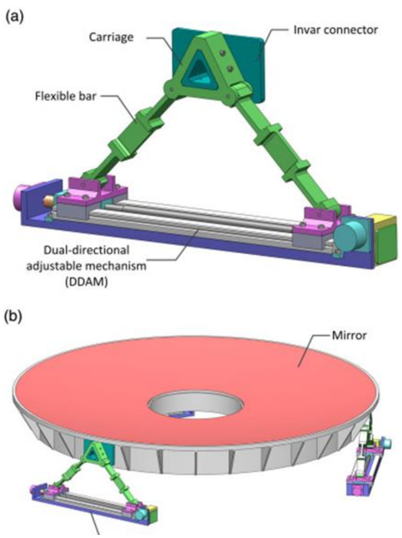


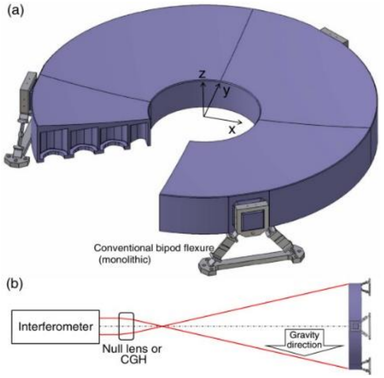


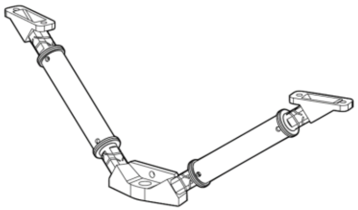


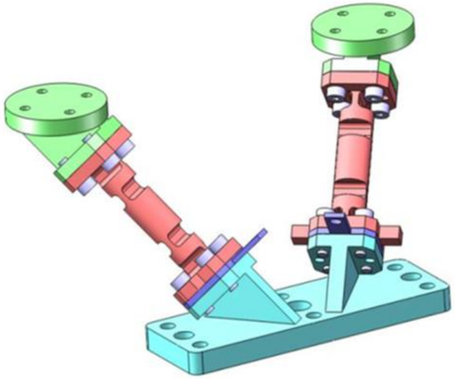
Bipods

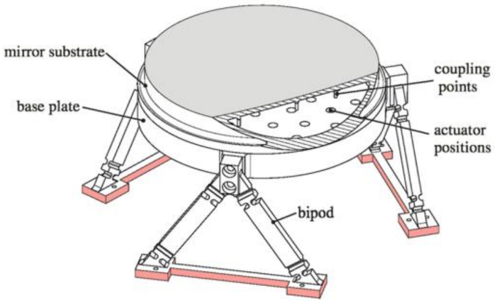
- Support Optical Payloads
  - And other things…
- Often Low Demisability
  - Titanium, CFRP, Invar
  - Huge variety
- Test Nominal Bipod
  - ‘Standard’ design, titanium
- Design ‘Demisable’ Bipod
  - Lightweighting
  - 3D printing (flow paths?)
  - Test and assess
- Modelling





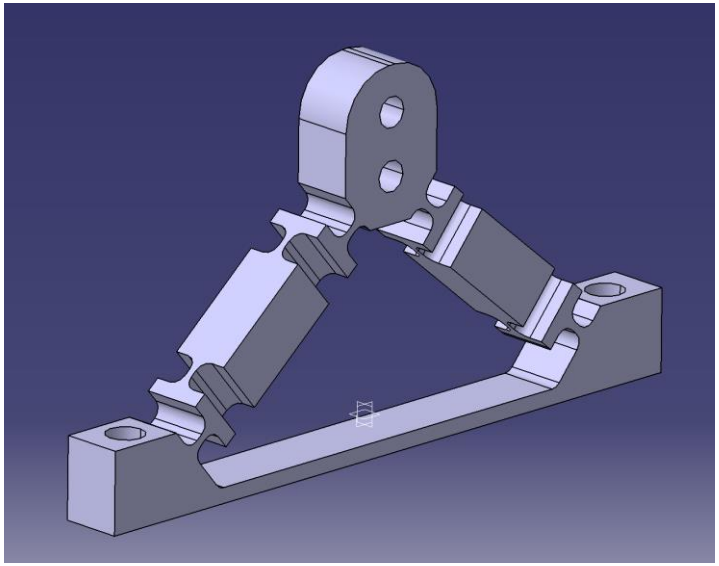


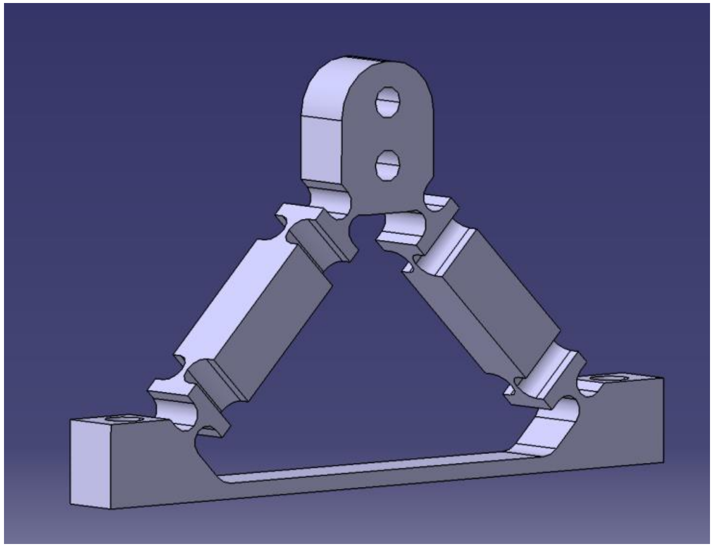




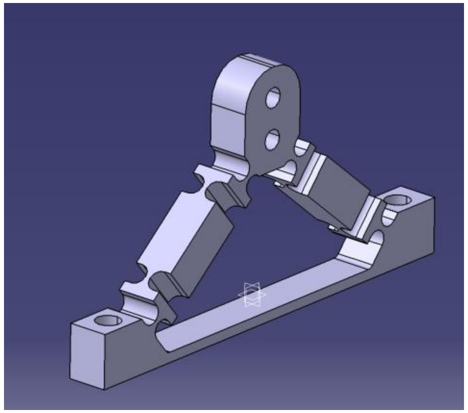
Bipod Investigation

- Strawman Bipod Designed (UCL)
  - 22g
- Designed to Support 8kg
  - Design load 50 g
  - 3.5 kN per 3 frames
- Single solid A-frame
  - 1175 N (Y, out of plane)
    - 154 Mpa
  - 1761 N (X in plane)
    - 235 Mpa
  - Stiffness of the suspension
    - holding a rigid mass
  - Out of plane 495 Hz
  - In plane 412 Hz
- Sized for Wind Tunnel Test





Wind Tunnel Testing (L2K, DLR)



- Campaign 1 Test Planning in Progress
  - Bipod designed
    - 3D printed
    - Thin structures of high interest – fragmentation?
  - Glass sample design
    - Zerodur samples 50mm diameter / square
      - Stagnation and shear tests
    - Fused silica samples ordered
      - Rods to be tested (3mm, 6mm, 10mm)
  - Ejecta testing
    - Heat titanium plate close to melt
    - Place aluminium object in flow in front of plate
    - Splash from molten aluminium on to plate
    - See what happens!
- Testing is very soon…

Conclusions

- Three Key Areas of Investigation

- Glasses
  - Characterisation testing in progress
  - No bubbling of Zerodur at high temperature at atmospheric conditions
- Ejecta
  - No evidence of a real effect from literature or laboratory tests
  - To assess in wind tunnel
- Bipods
  - Thin structures are of interest for demisability (or fragmentation…)
  - How to design for demise?

- Much to learn from upcoming test campaign