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Elastomer-ceramic Micro-composites for Armour Applications

Prof Gary Critchlow & Dr Robert Crookes

Summary of Presentation

1. Introduction:

1.1 Composite Armour & Current Challenges

1.2 Polymer-based Solutions

2. Why Bioinspired Micro-composites ?

2.1 Composite Development

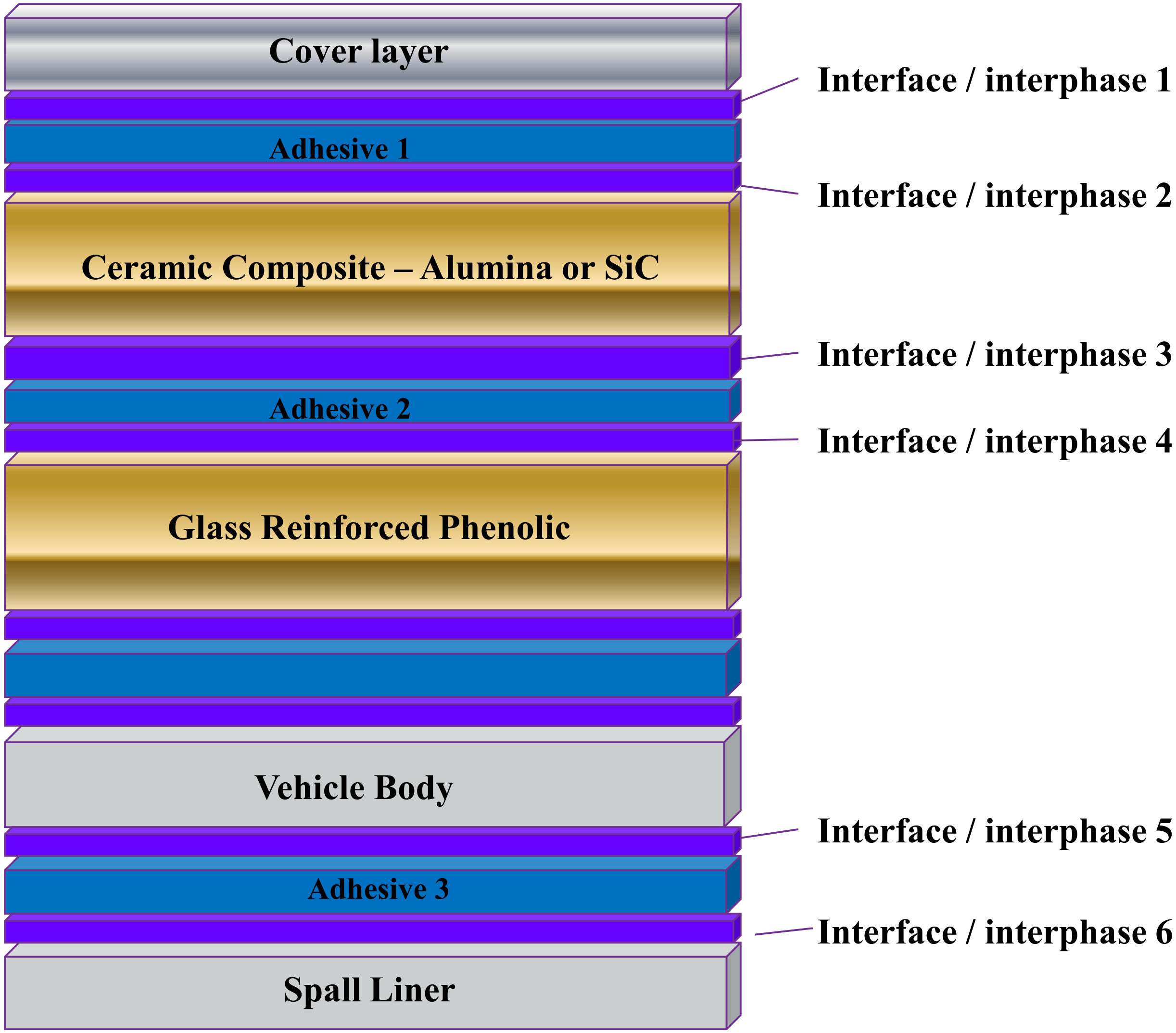
2.2 High Strain Rate Testing

2.3 Performance

3. Conclusions

1. Introduction

1.1 Composite Armour & Current Challenges



An understanding of bulk adhesive properties and interfacial properties will help optimise the use of adhesive bonding in vehicular armour.

1.2 Polymer-based Solutions: Elastomer Strike Faces

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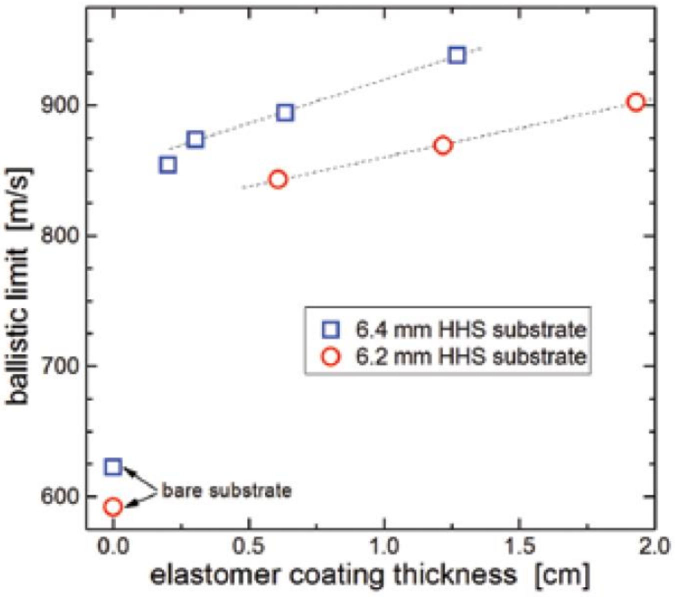
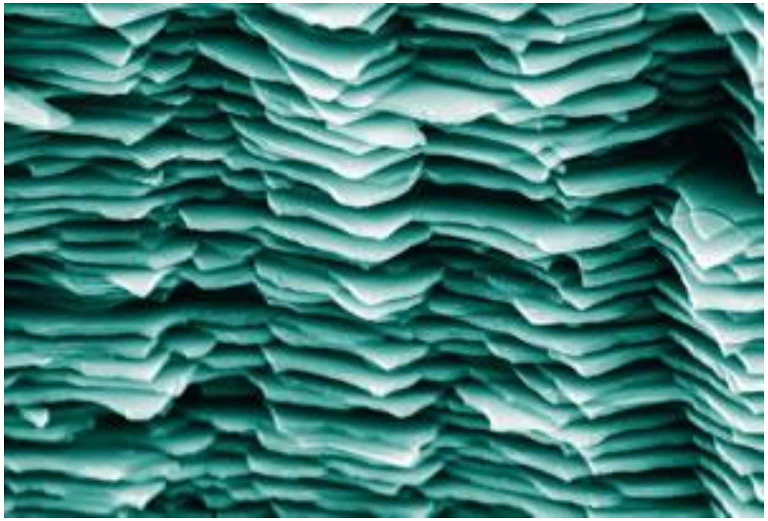
Work reported in 2010 by the US Naval research laboratory was amongst the first to explore the strike face application of elastomers.



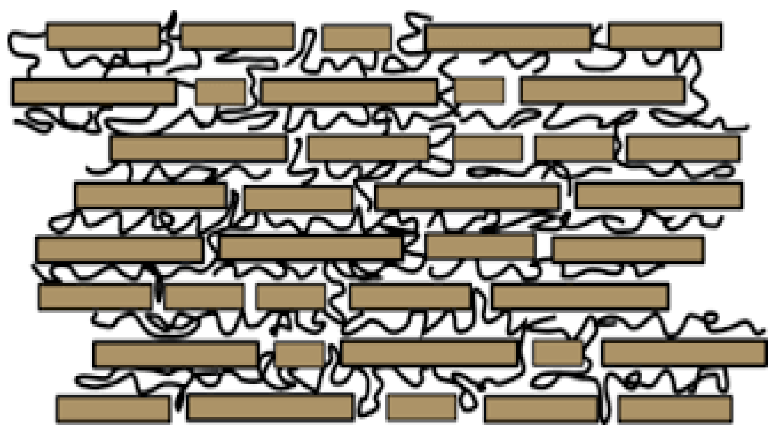
It was noted that the highest performing elastomers underwent a brittle fracture, indicating a glass transition on impact.

2. Why Bioinspired Composites ?

Bio-inspired Composites



Nacre: hexagonal platelets of aragonite, 10–20 µm wide and 0.5 µm thick separated by sheets of organic matrix composed of elastic biopolymers.



Composite Development

Alumina fillers of various shapes and sizes were melt mixed at various %vol in polyisobutylene (PIB).

Alumina	Diameter µm	Thickness µm	Aspect ratio
Al_2O_3 powder	10	10	1
PWA 20	19.5	3.12	6
Alusion®	12.7	0.35	35

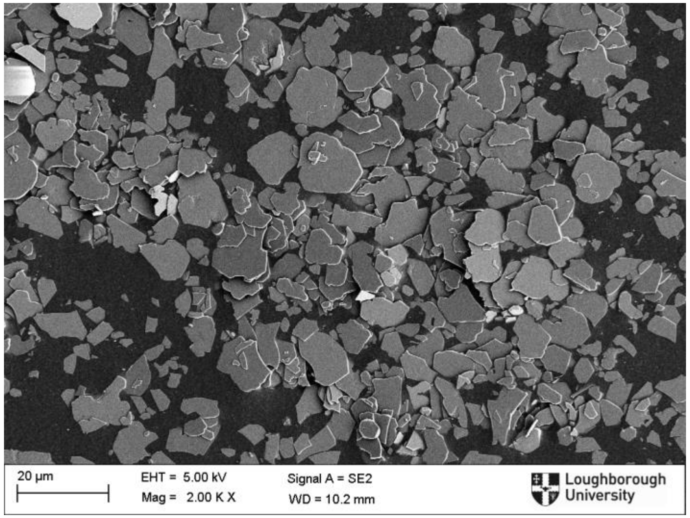
Developed using a solvent casting process from toluene - alumina.

Surface modifiers added.

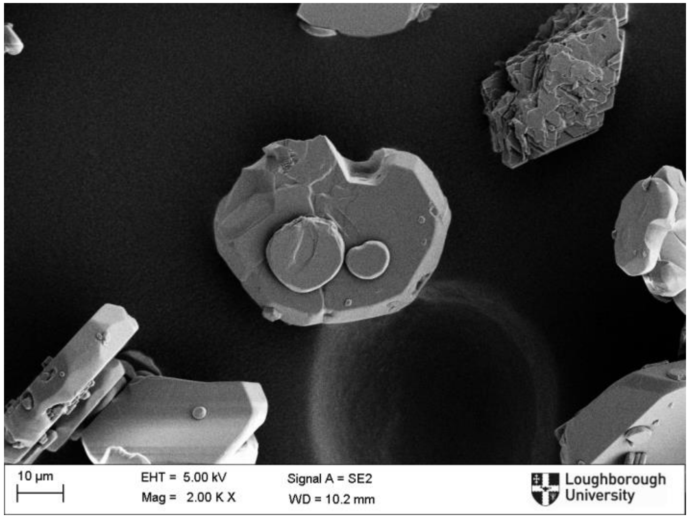
Polymer added.

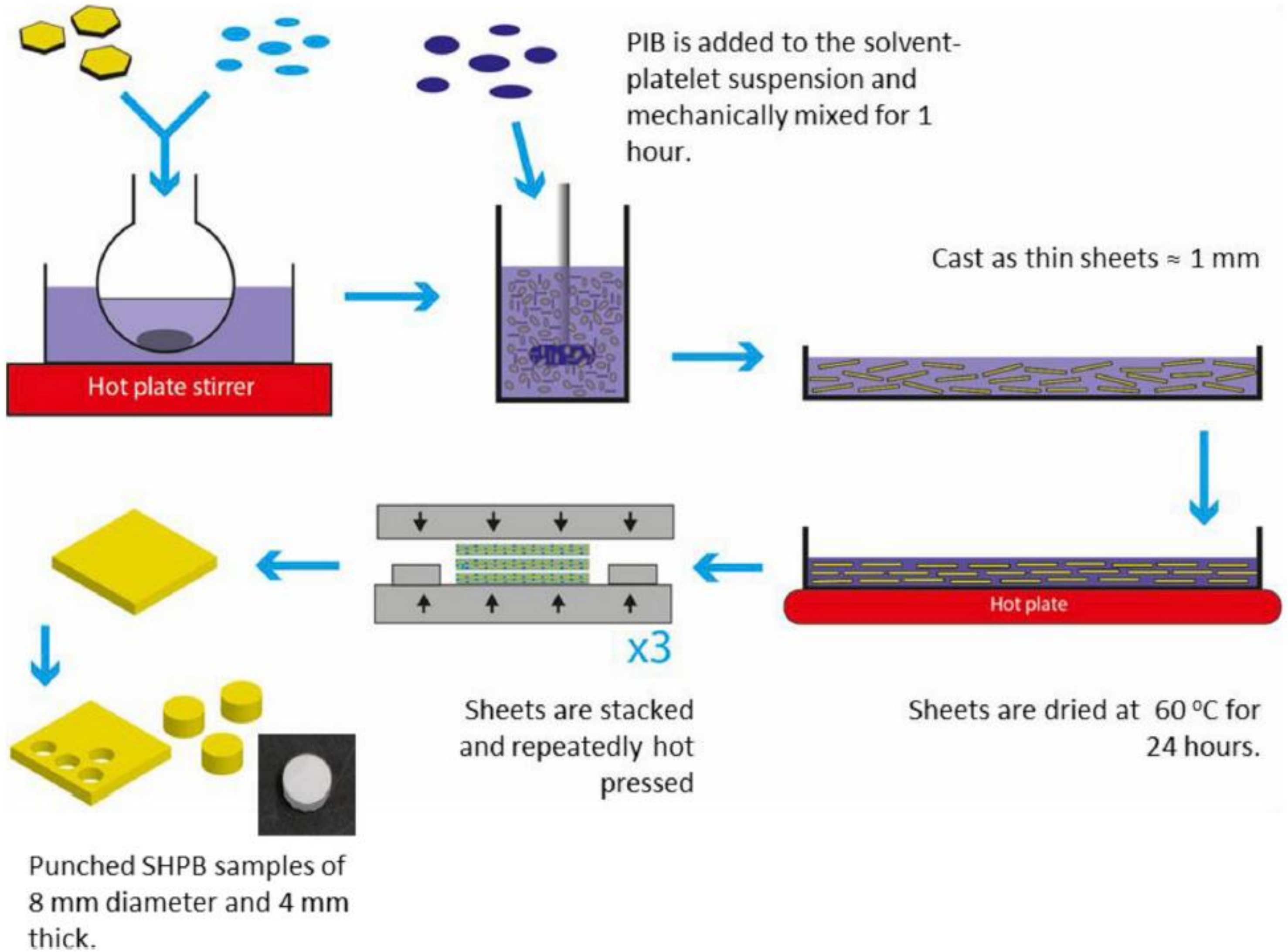
Manufactured using a scalable melt mixing process.

Alusion ®



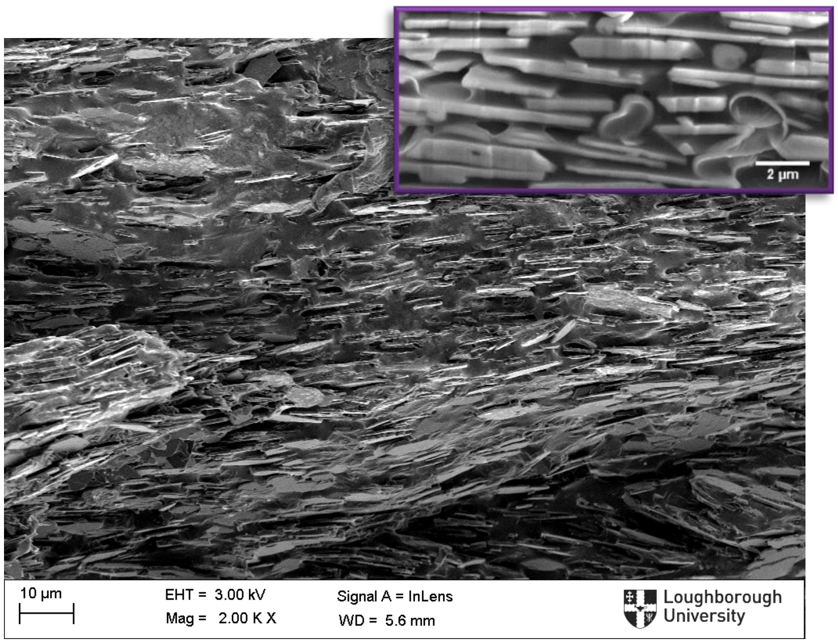
PWA 20



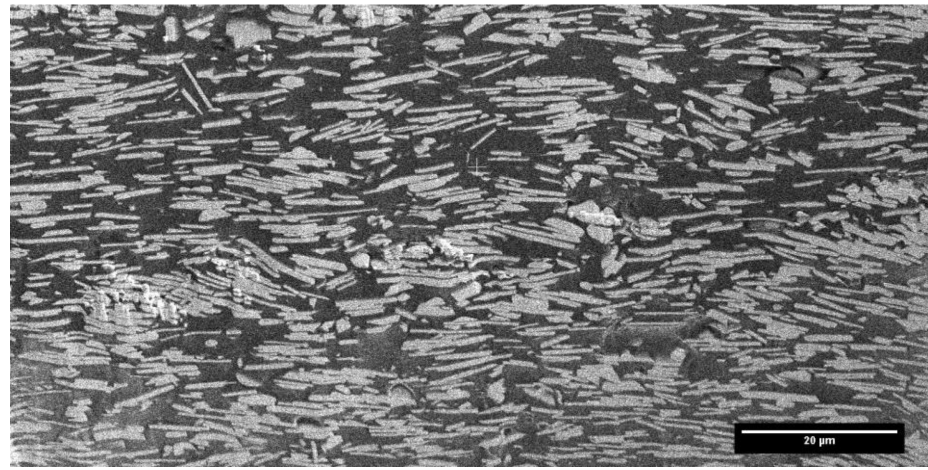

PIB is added to the solvent-platelet suspension and mechanically mixed for 1 hour.
Hot plate stirrer
Cast as thin sheets ≈ 1 mm
Hot plate
x3
Sheets are stacked and repeatedly hot pressed
Sheets are dried at 60 ºC for 24 hours.
Punched SHPB samples of 8 mm diameter and 4 mm thick.

- Alumina platelet reinforced elastomeric composite with highly aligned platelets up to 40 %vol.

Gallium ion FIB section



Fracture face of 40 %vol platelet composite



Massive P-FIB section through 30 %vol platelet composite

2.2: High Strain Rate Testing

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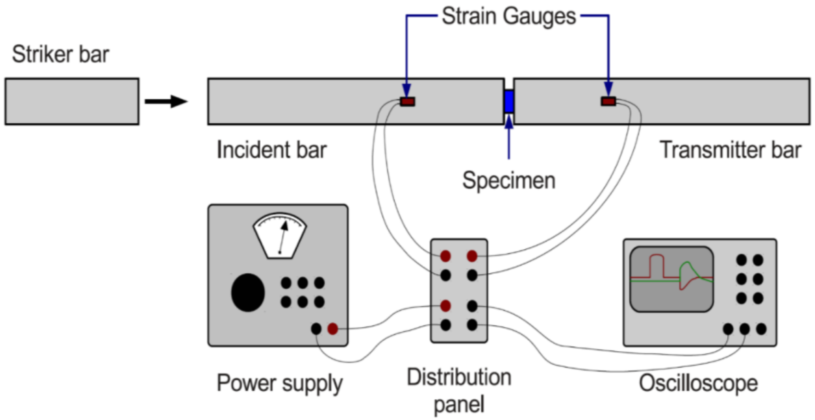
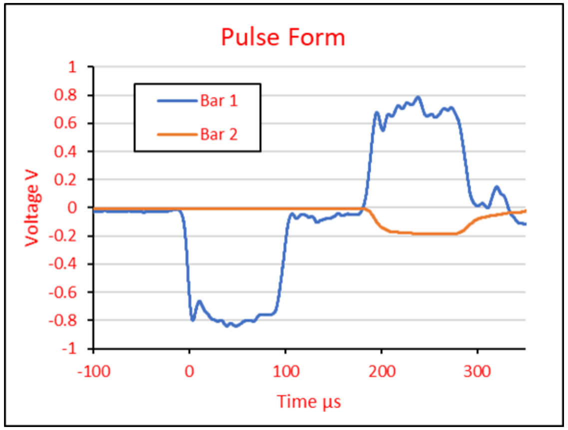
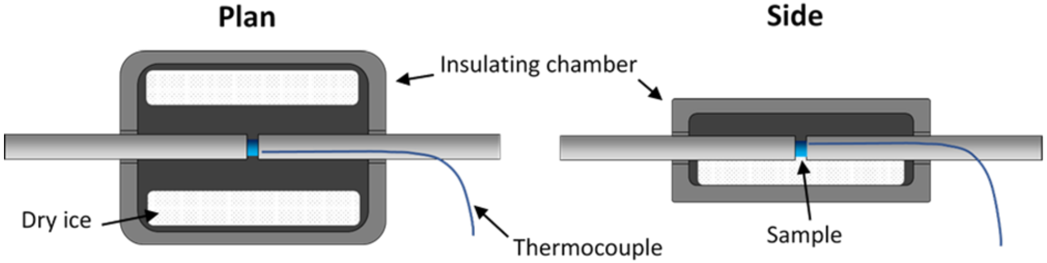
Split Hopkinson Pressure Bar testing can be used to determine high rate deformation properties of materials.

Here we use low temperature SHPB to simulate higher strain rates. This is based on the well established time-temperature equivalence theory.





Low temperature set-up



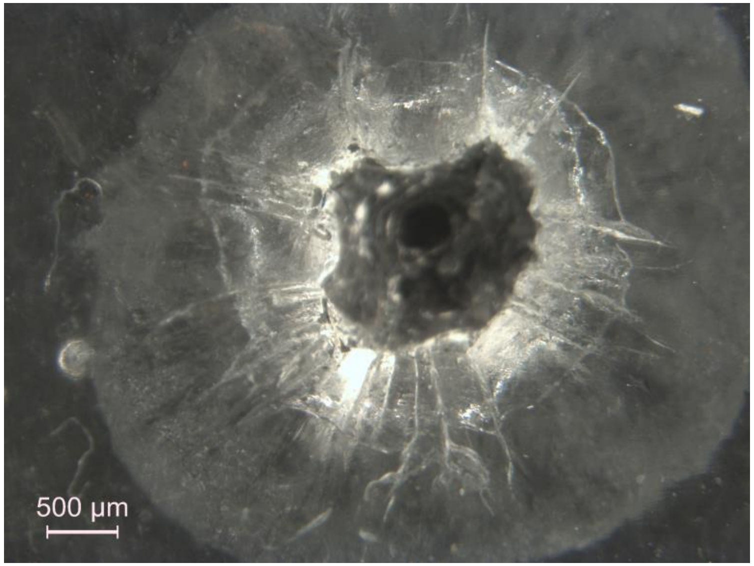
Also:

Impact experiments with velocities up to ~950 $m.s^{-1}$.

2.3: Performance: Butyl Rubber and Polyisobutylene

- Some soft elastomeric polymers such as PIB and IIR undergo a hard, brittle, state change when impacted at ballistic rates.

- This brittle fracturing has been correlated to increased ballistic resistance. This occurs when these polymers are backed by hard materials such as steel.



Dynamic Materials Analysis

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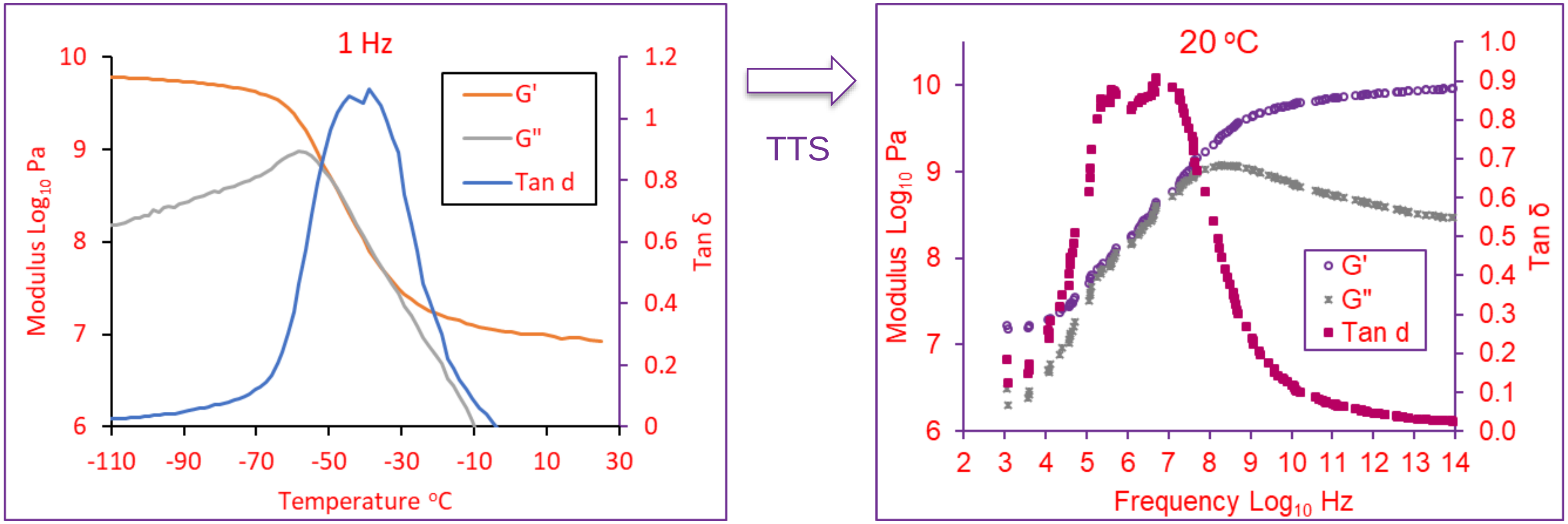
- Performed at 1, 10 and 100 Hz
- Temperature ramp from -110 to 30 ^{o}C.
- Fitted to the William-Landel-Ferry equation to determine a shift factor (α_r) that allows us to equate temperature to strain rate.



SHPB: High Strain Rate & Low Temperature behaviour of PIB and IIR.

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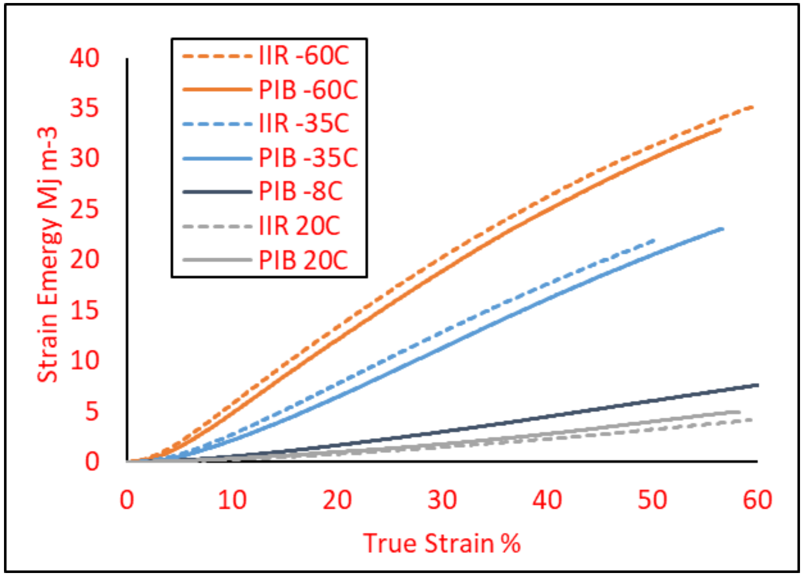
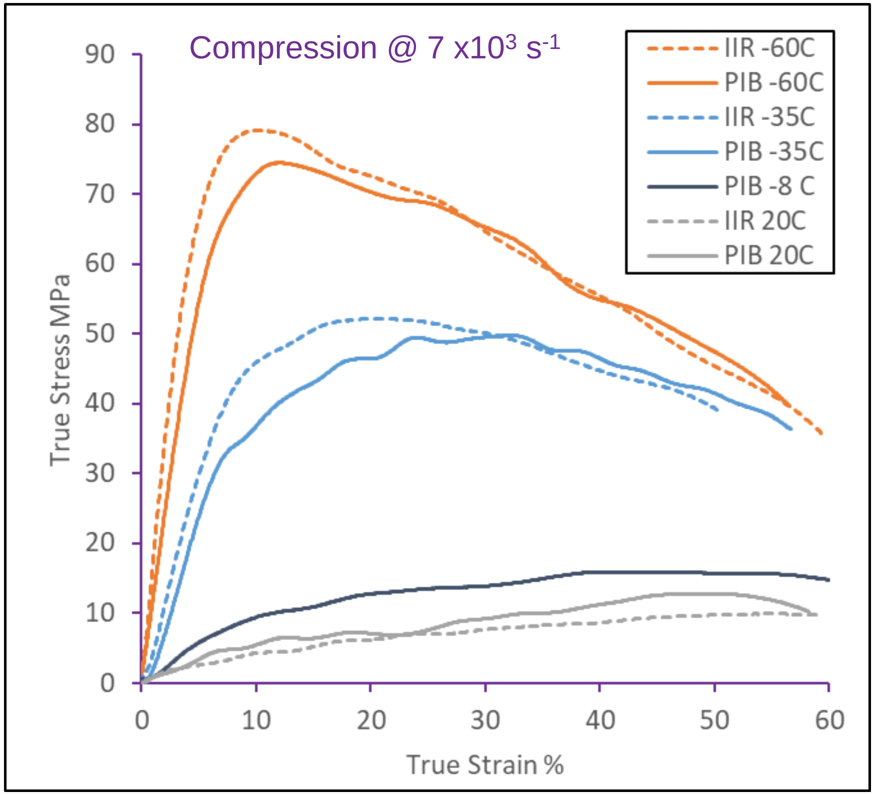
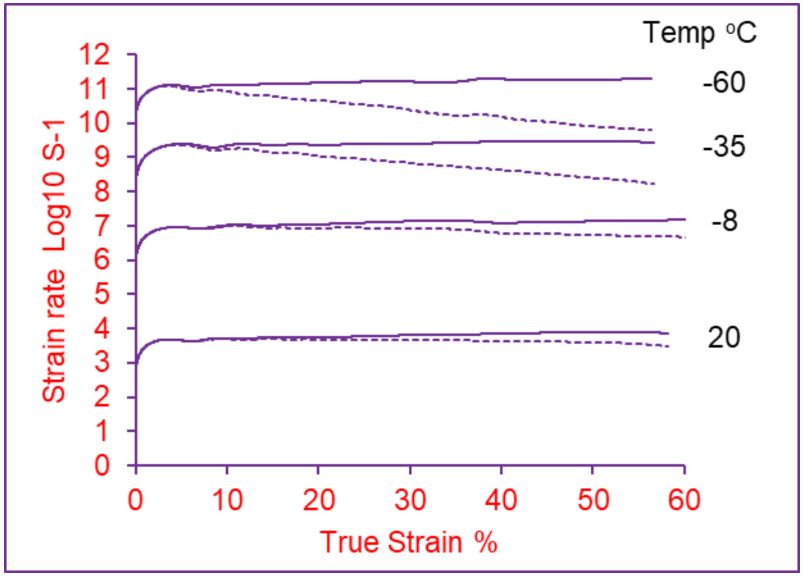
- SHPB tests down to a temperature of -60 ^{o}C.
- Large increase in modulus, strength and strain energy from -8 to -35 ^{o}C.
- All samples underwent total elastic recovery.
- Using DMA master curves we can estimate an equivalent 20^{o}C strain rate as high as 10^{11} s^{-1}.







DMA of Composites

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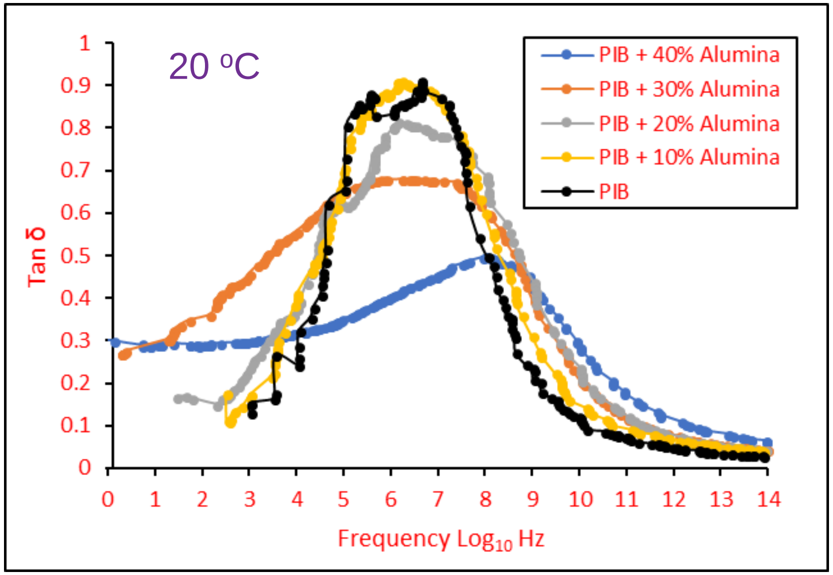
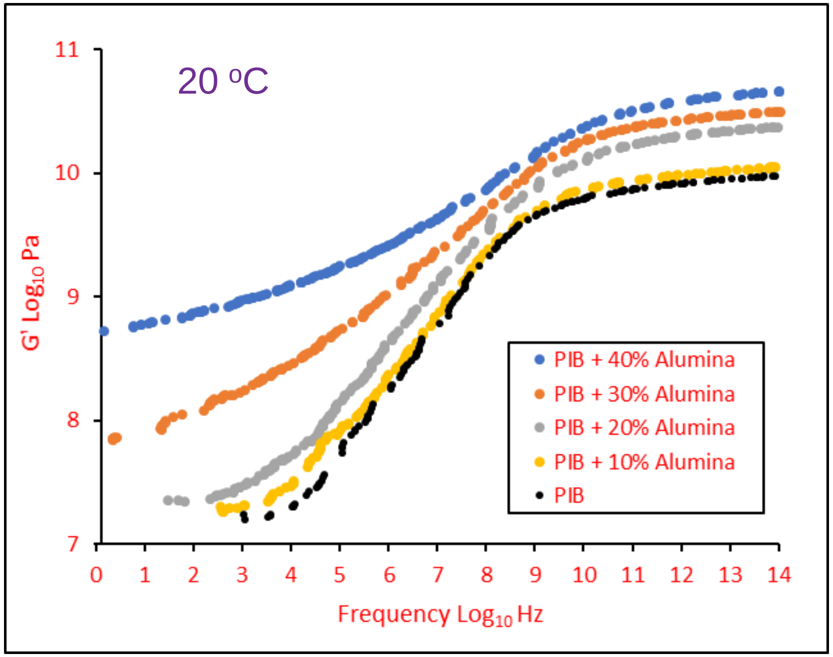
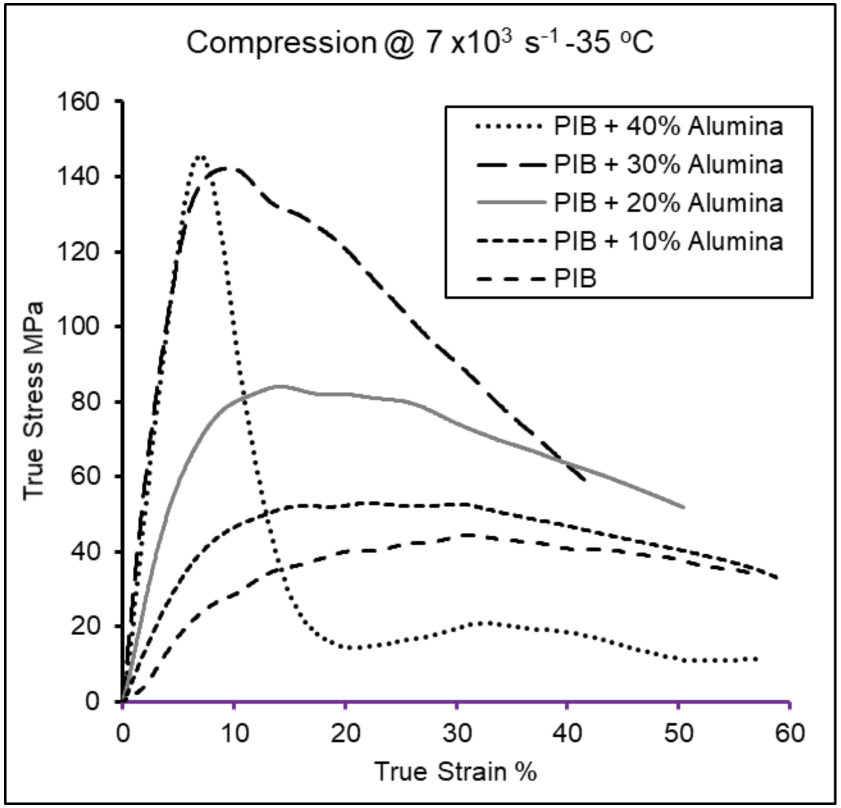
- Huge increases in storage and loss modulus.
- A broadening of tan δ but a reduction in peak height.
- Reinforcing effect of platelets changes with strain rate.

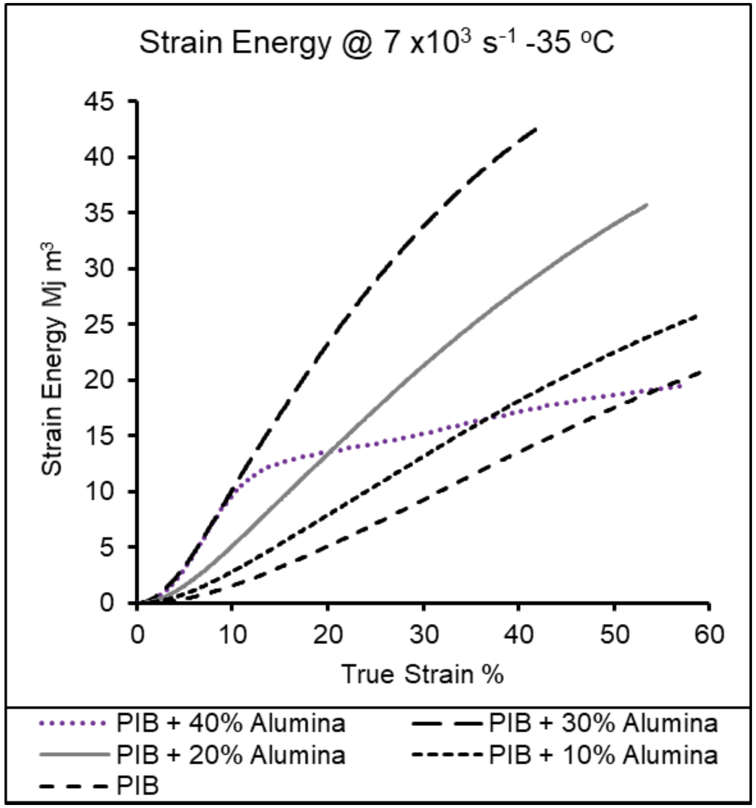




SHPB Properties of Composites

- 40 %vol showed early failure with reduced strain energy absorption
- 30 %vol showed same ultimate strength but increased toughness with only 15% plastic strain on release.
- Same strength as some polycarbonates but with greater hysteresis across the T_g





Effect of Structure

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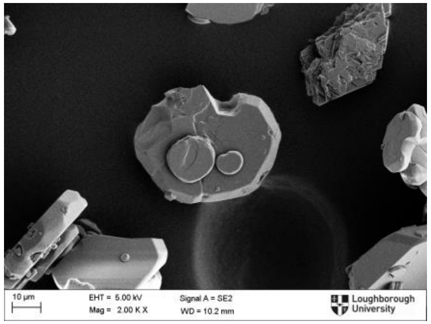

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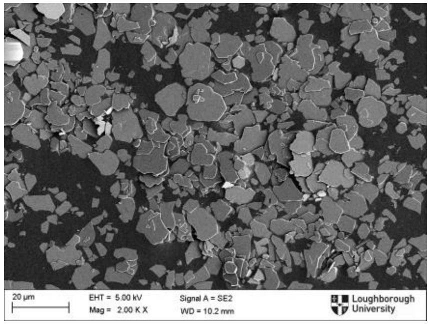

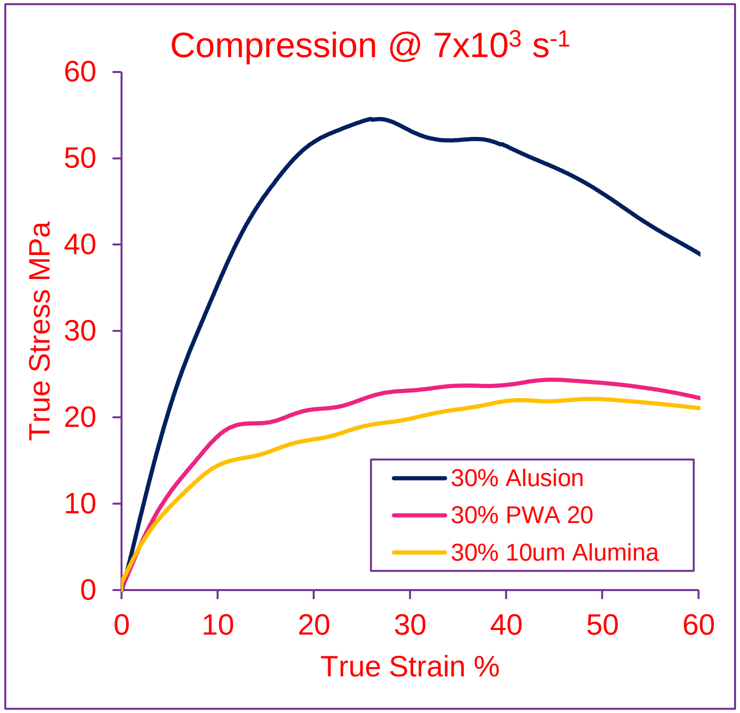

High Rate Glass Transition Properties

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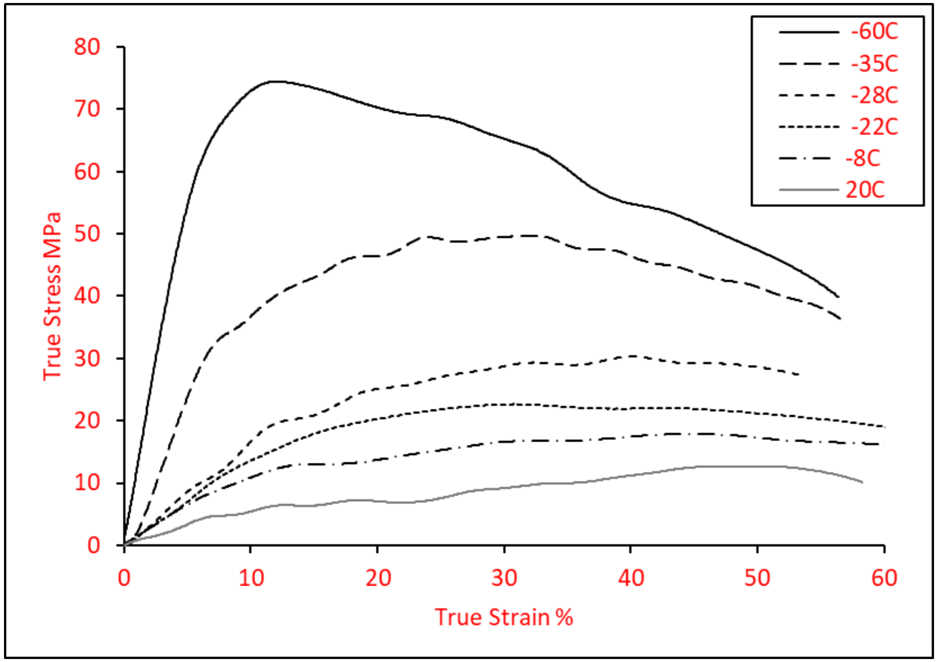
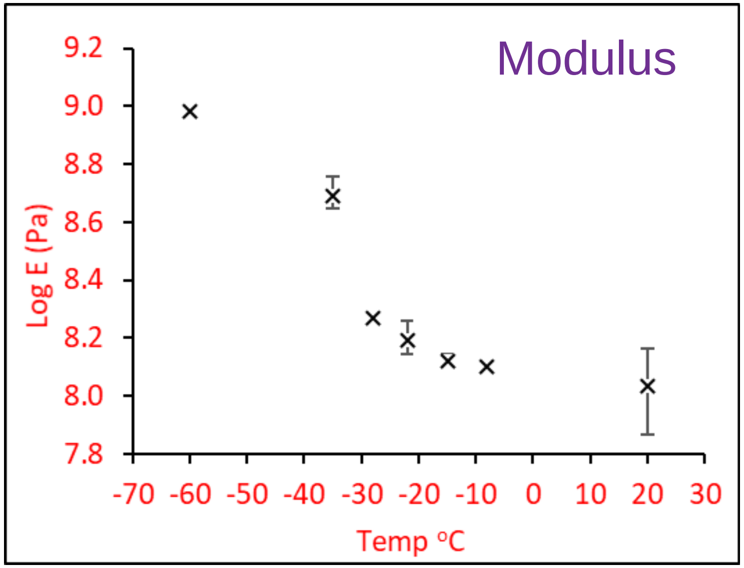
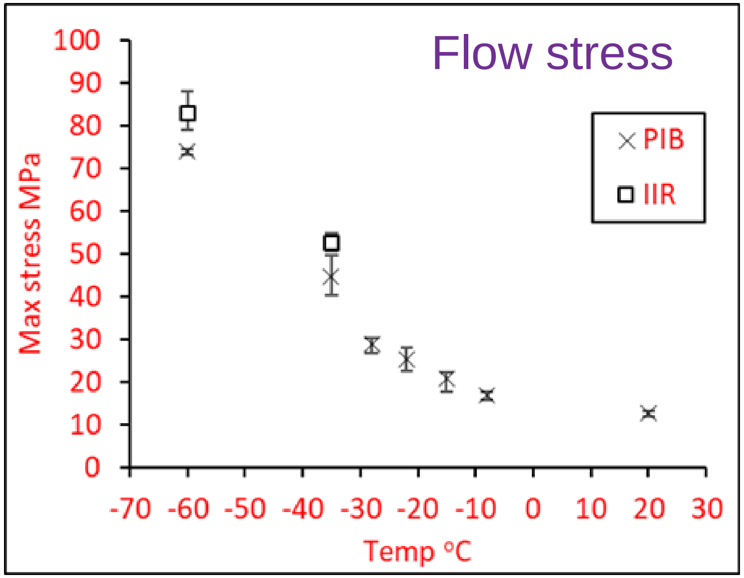
Low temperature SHPB of polyisobutylene clearly identified a glass transition at ≈ -30 ºC. This corresponds to a sharp increase in modulus and strength.



Compression stress/strain curves from 20 to -60 ºC at a strain rate of 6000 s^{-1}





Time-Temperature Superpositioning

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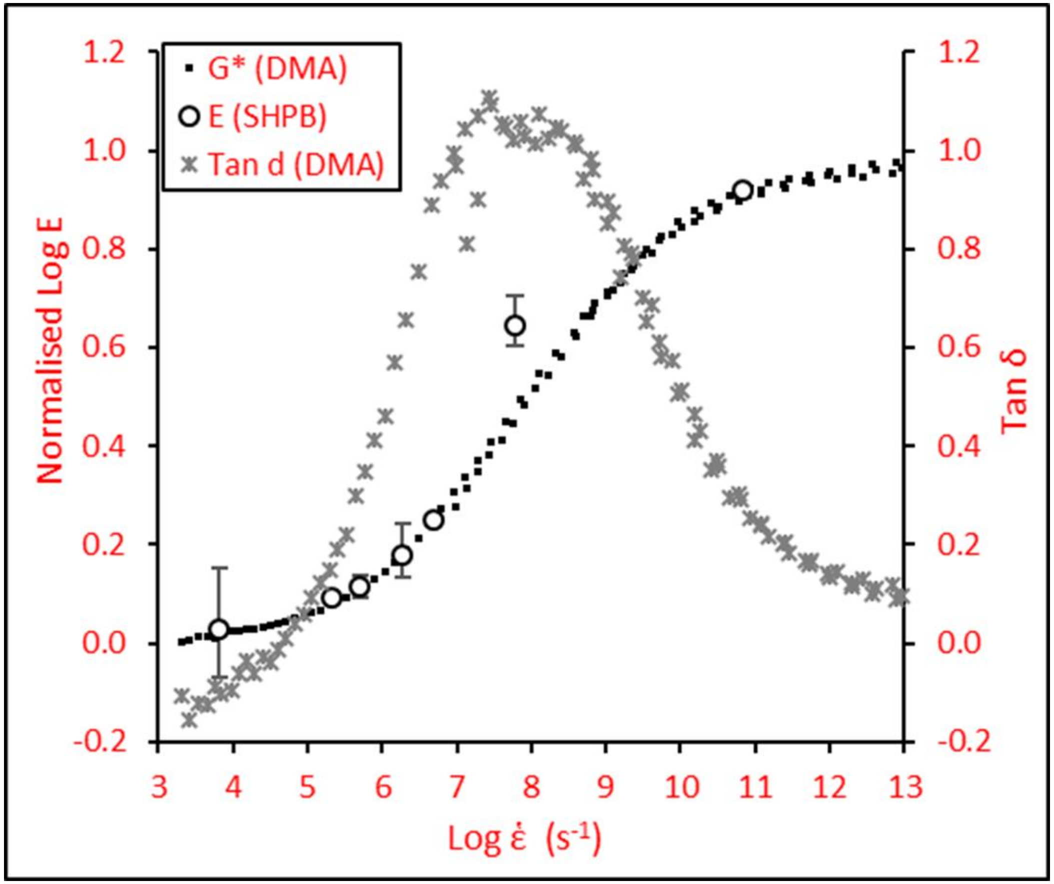
Williams-Landel-Ferry TTS can be performed on both DMA and SHPB to generate a strain rate dependant master curve at 20 ºC.

The master curve indicates only a slight transition at ballistic rates.

However, this is the response of the polymer without radial confinement.

What happens if we take into account pressure effects?



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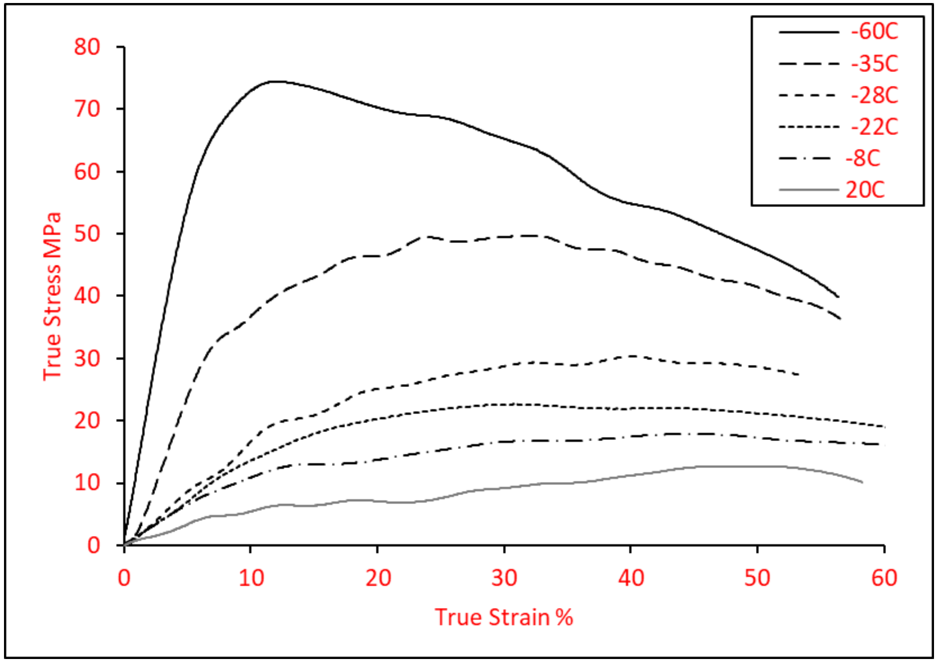

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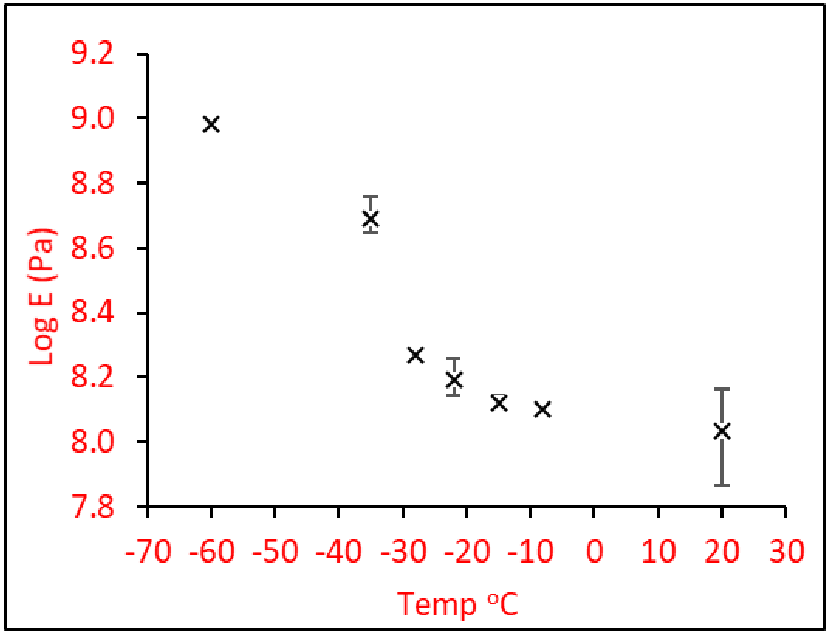
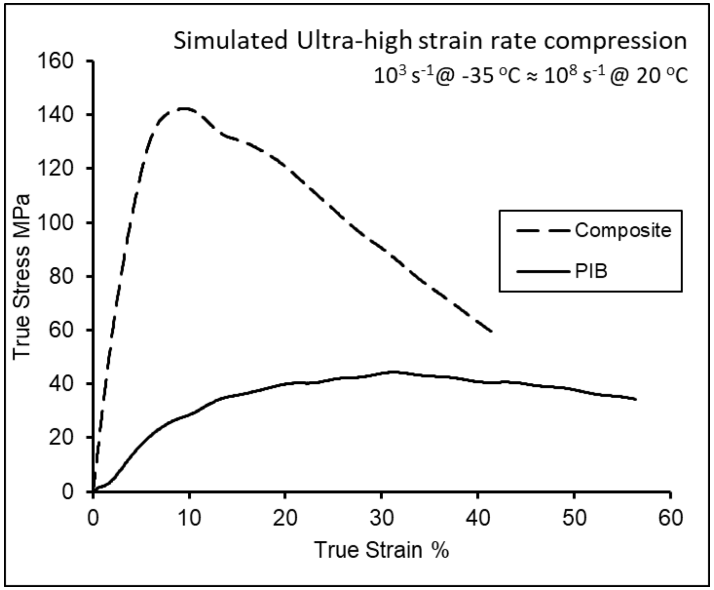


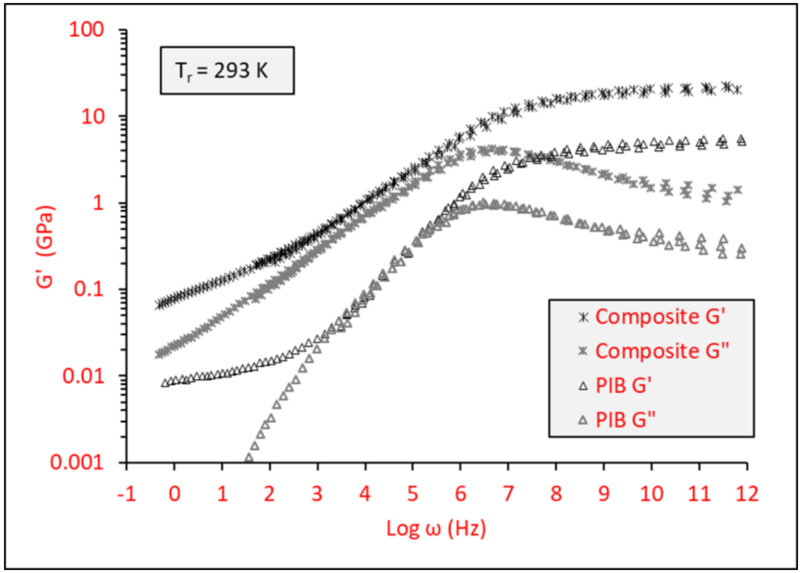
Modulus

Dramatically increased modulus, strength and strain energy over the unfilled polymer.

High strain deformation at simulated ultra-high strain rates.

Ballistic testing showed an 80% damage reduction to Armox 440 with a 2 mm thick strike face





Ballistic Performance

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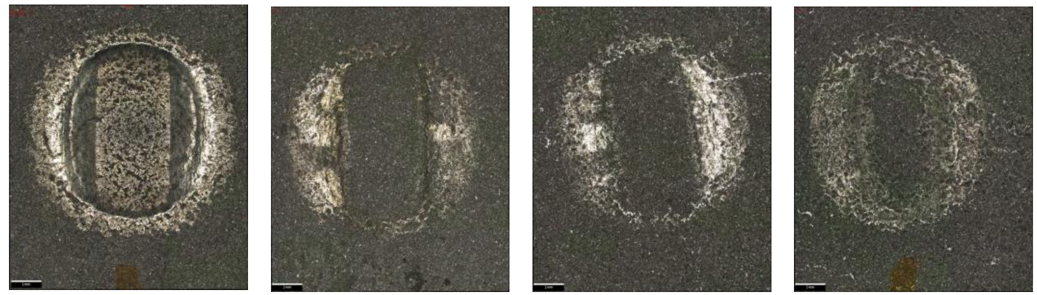
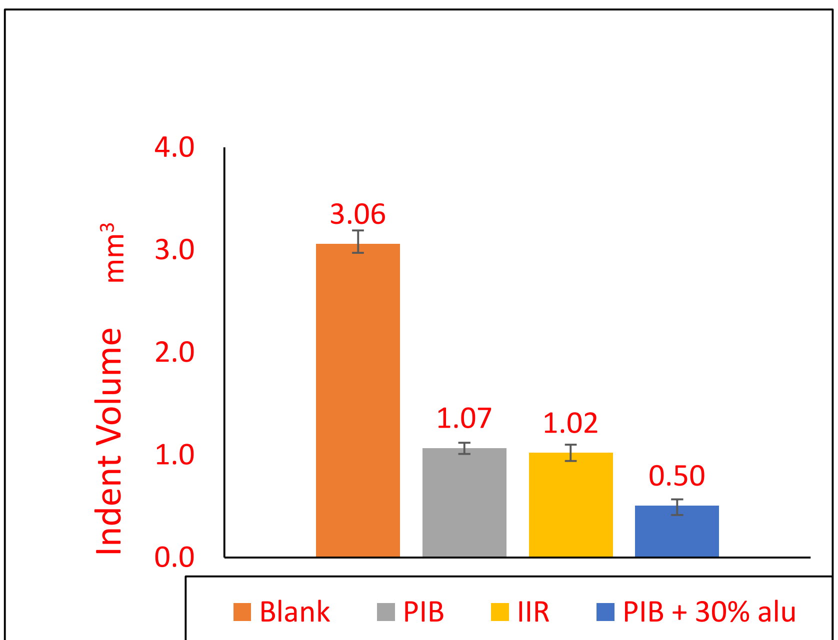
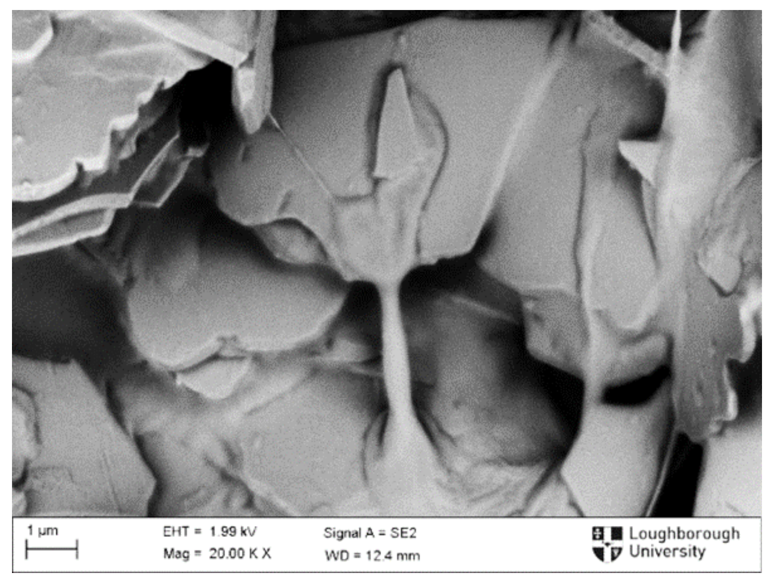
- 5 mm diameter 1.1g steel fragment simulating projectile.
- Projectile velocity of **320 ms^{-1}**(716 mph)
- **2 mm** of elastomer/composite backed by 5 mm Armox 440 steel plate.

Blank PIB IIR PIB + 30% alumina platelet





Importantly: visible reduction in indent severity



3. Conclusions

Key Properties

- Flexible, mouldable, rubber layer.
- High damping properties to dissipate shock waves.
- Dramatically hardens on ballistic rate impact whilst remaining ductile. Leading to large kinetic energy dissipation through deformation, platelet movement and shockwave dissipation.
- 12% increase in strain energy per unit mass over the unfilled polymer.

Next Steps

- Direct performance comparison with industry standard GRP strike faces
- Formulation optimisation
- Environmental durability testing