Sporting Actions

- Although there are a great variety of sports there are a number of common actions involved
  - Propelling a projectile by an athlete or athlete-driven implement

    Golf, hockey, cricket, tennis, shot putt, javelin, squash, badminton
  - Controlling a vehicle around a track

    Skiing, skating, motorsport, snowboarding, horseracing
  - Propelling a vehicle by the athlete

    Snowboarding, toboggan, luge, cycling, rowing

General Requirements

- Conservation of momentum and energy
- Mechanical efficiency is needed
- Stiffness needs to be controlled
- Component mass needs to be minimised
- These share many similarities with aerospace so that sports equipment often ‘borrows’ materials from aerospace, e.g. Ti-based alloys and composites

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Sports Pecularities

- The use of much sports equipment involves **large strains and high strain rates**.
- The athlete is more intimately connected to the equipment and so force transfer to the human needs to be controlled
- Damping is therefore an important dynamic materials property in sports equipment
- Force reduction is important in injury reduction, but force transfer is an important feedback mechanism for athletes and so is needed for control
- These requirements are not part of the material development for aerospace applications and so it is unlikely that the structures and properties are optimised for sports equipment use

Improving Performance

- Improved performance (faster, higher, longer) comes from more efficient energy transfer
- The dynamic behaviour of materials and equipment needs to be determined
- The interaction with the athlete needs to be addressed

- Currently many sport equipement items are tested statically or quasi-statically.
- **Is this sufficient?**

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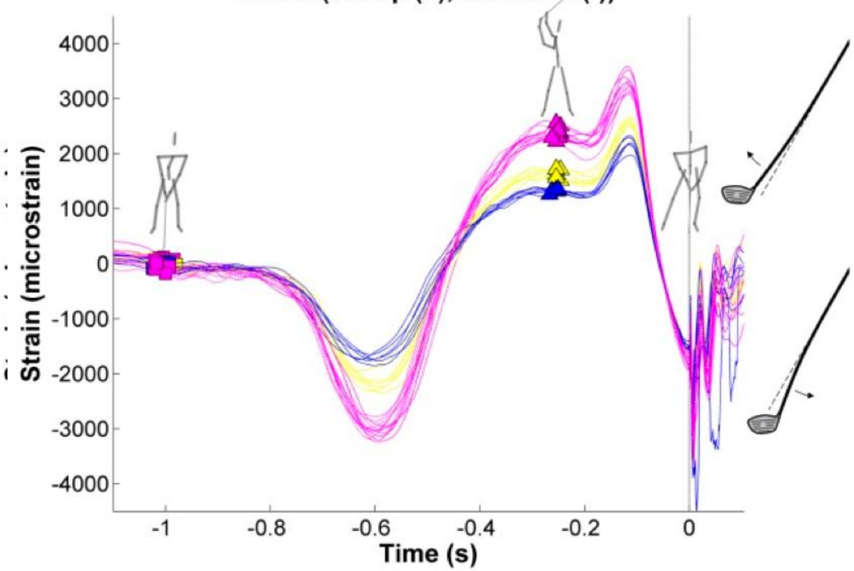
Strains and Strain Rates

- Some equipment can be strain gauged and used in sporting simulators (e.g. golf robots) or by real athletes (provided low intrusion of measuring devices)

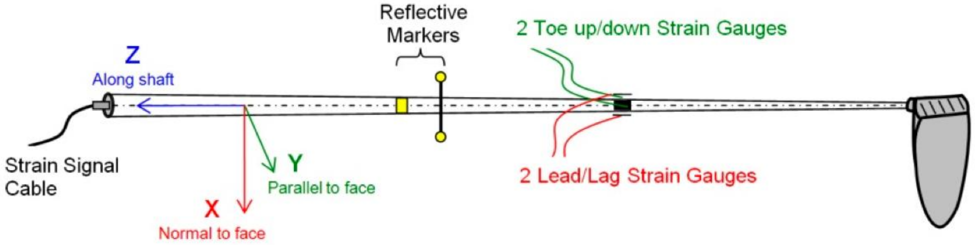


Maximum Strain rates:

Golf club shafts < 0.1 s-1

Archery Bows < 2 s-1

Ice Hockey Sticks < 8 s-1



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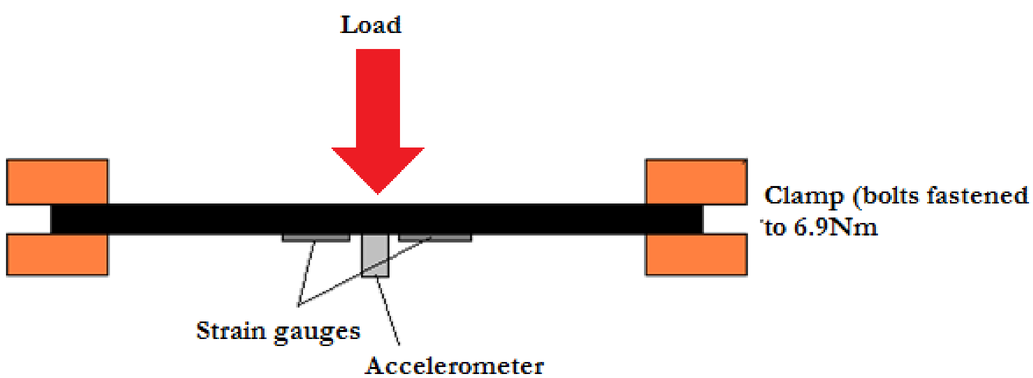
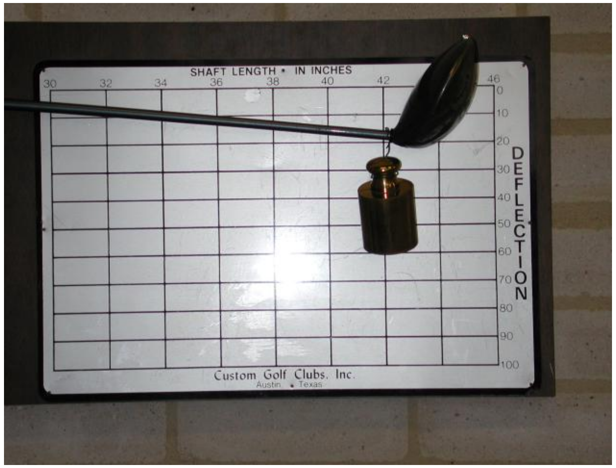
Modulus and Stiffness

- Efficient energy transfer (and aerodynamics) requires high stiffness and so high specific modulus materials
- Most modulus / stiffness measurements are quasi-static, but dynamic values are needed for sporting applications





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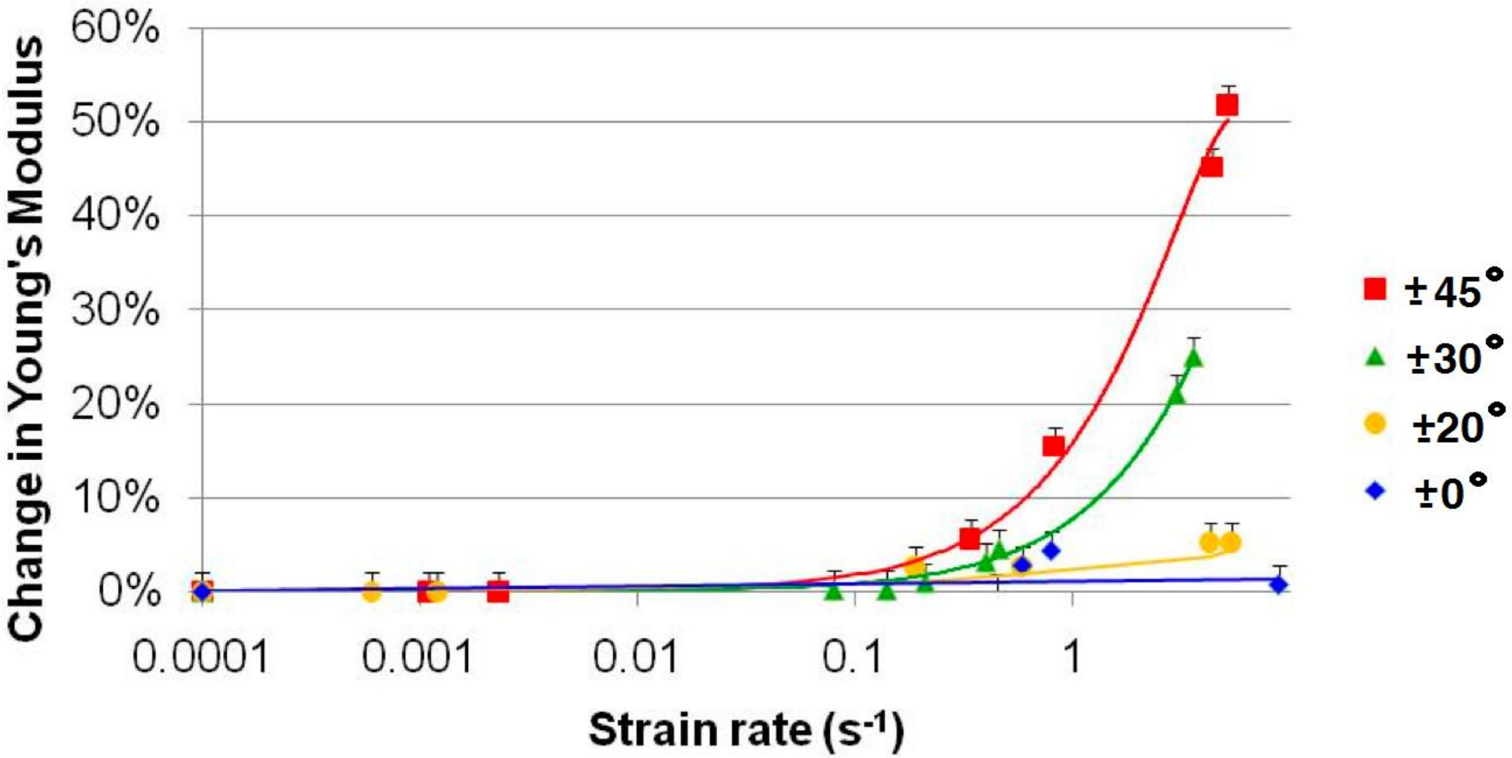
Modulus and Stiffness

- Impact testing can then identify the strain rate range for which the modulus of composites become rate-dependent



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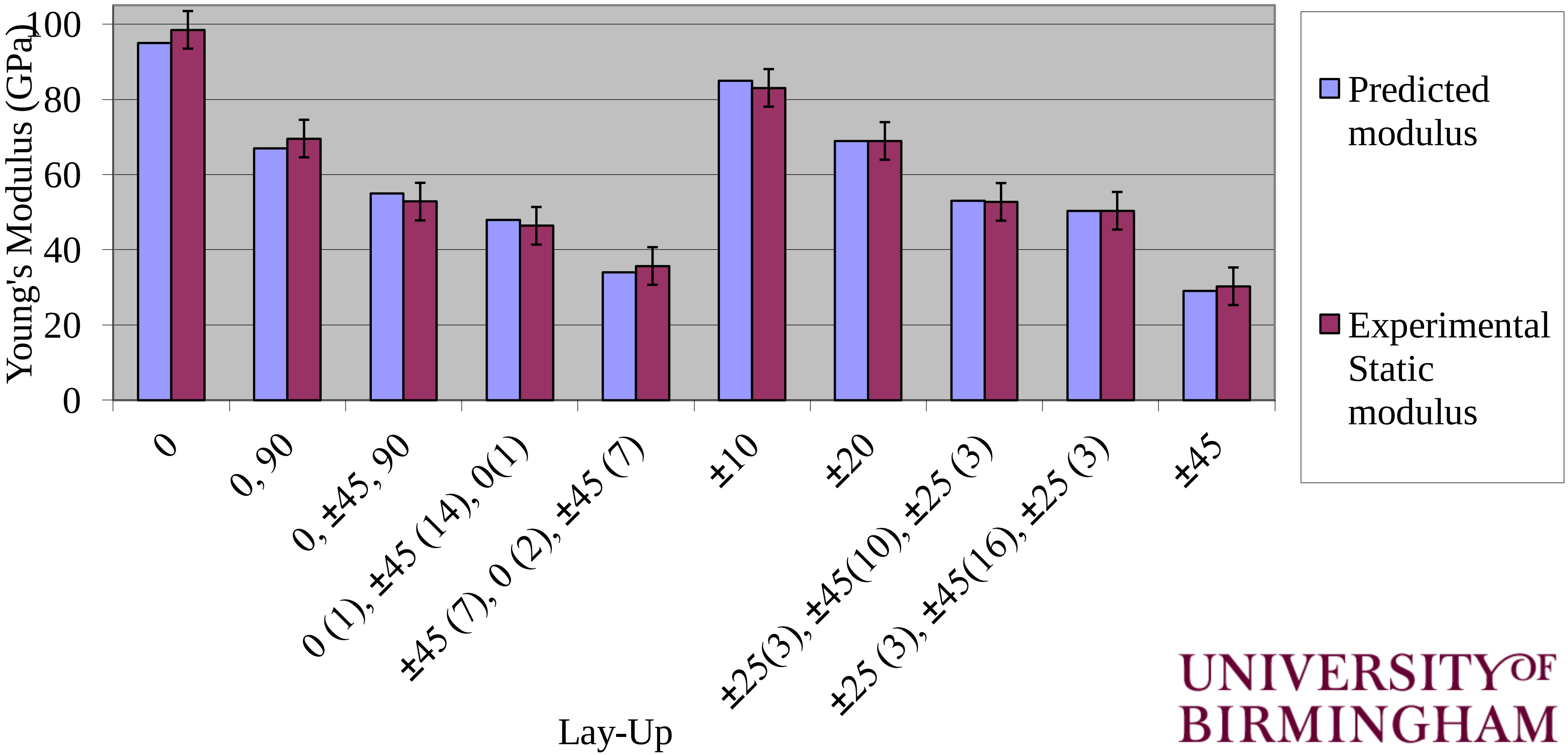
Modulus and Stiffness

- For many sports quasi-static modulus / stiffness measurements are sufficient and these can be designed through appropriate laminate stacking design codes



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Damping

- The strong interaction between athlete and equipment for handles and shafts means that damping to control forces transmitted to the athlete is necessary

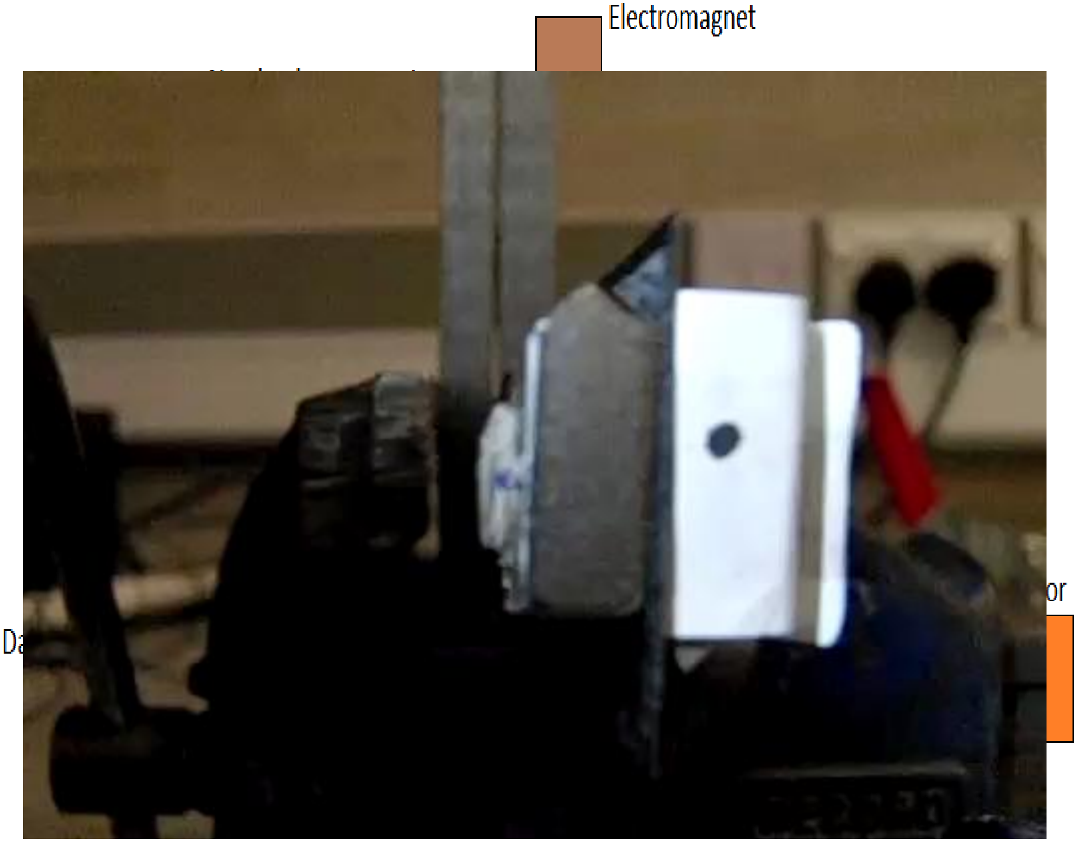
- Excess force transfer can lead to short- or long-term injury, e.g. tennis elbow.

- Under damping can lead to large oscillations of the equipment (during a swing for example).

- Excess damping leads to removal of a feedback loop to the athlete

- Viscoelasticity can be effective in providing damping, e.g. shoe foams, running track surfaces, but this is **strain and strain rate dependent**

Damping Characterisation



•Each panel was clamped at cantilever length of 50 mm.

•Each panel was fitted with a Kyowa uniaxial strain gauge (type KFG) to monitor the oscillation

•Using the signal generator the panel was forced to oscillate through a swept sine frequency.

•This was passed through a Fast Fourier Transform (FFT) where the damping and fundamental bending frequency was calculated.

•Strain and strain rate was altered by changing the magnitude of the oscillation

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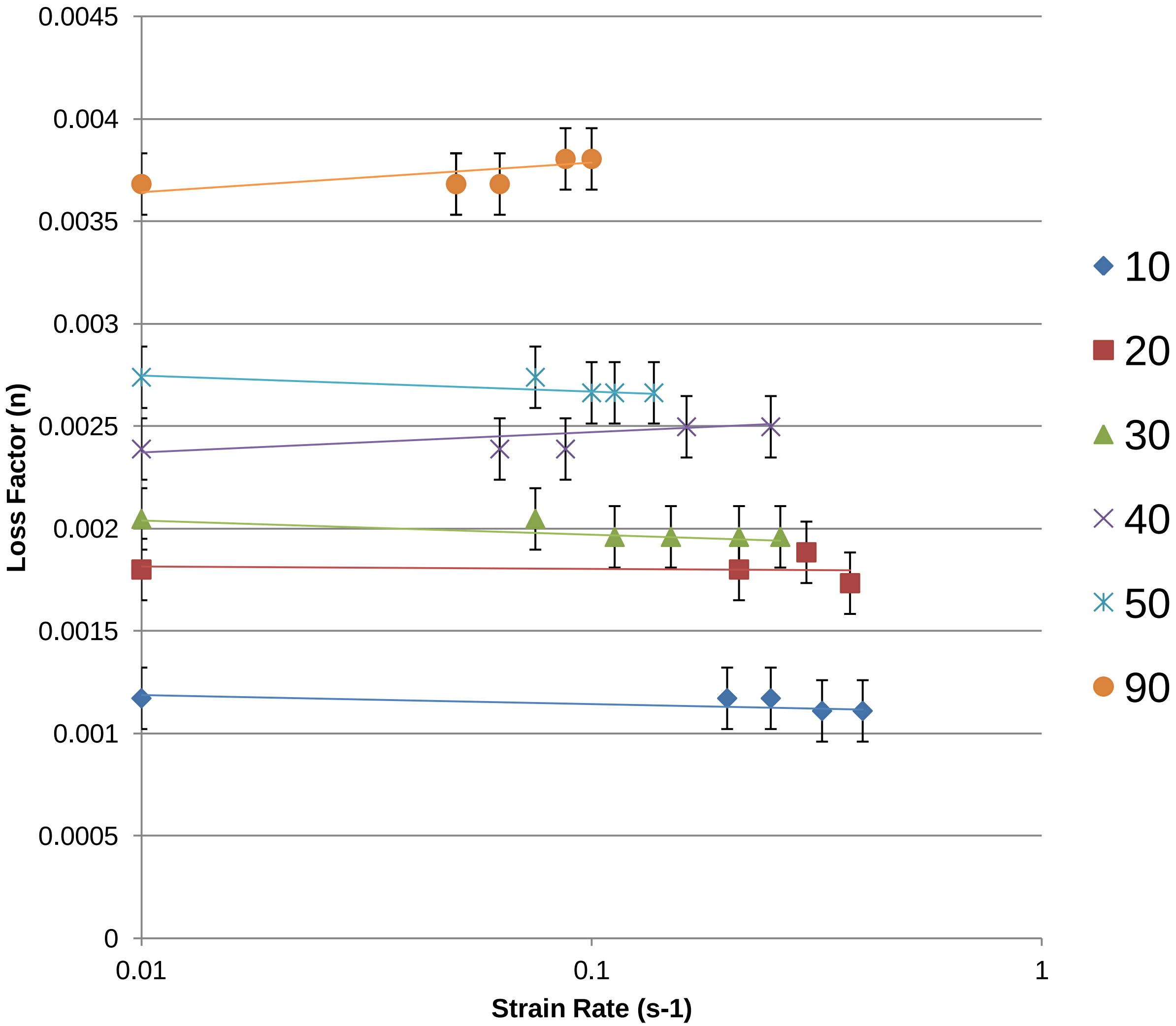
Strain Rate Sensitivity on Damping



- Strain rates in golf typically fall under 0.2 s^{-1} (Slater and Betzler, 2009)
- No noticeable change in damping can be seen in the range applicable to golf.
- This agrees with Slater and Betzler (2009), where no change in stiffness was noticed through the same range.

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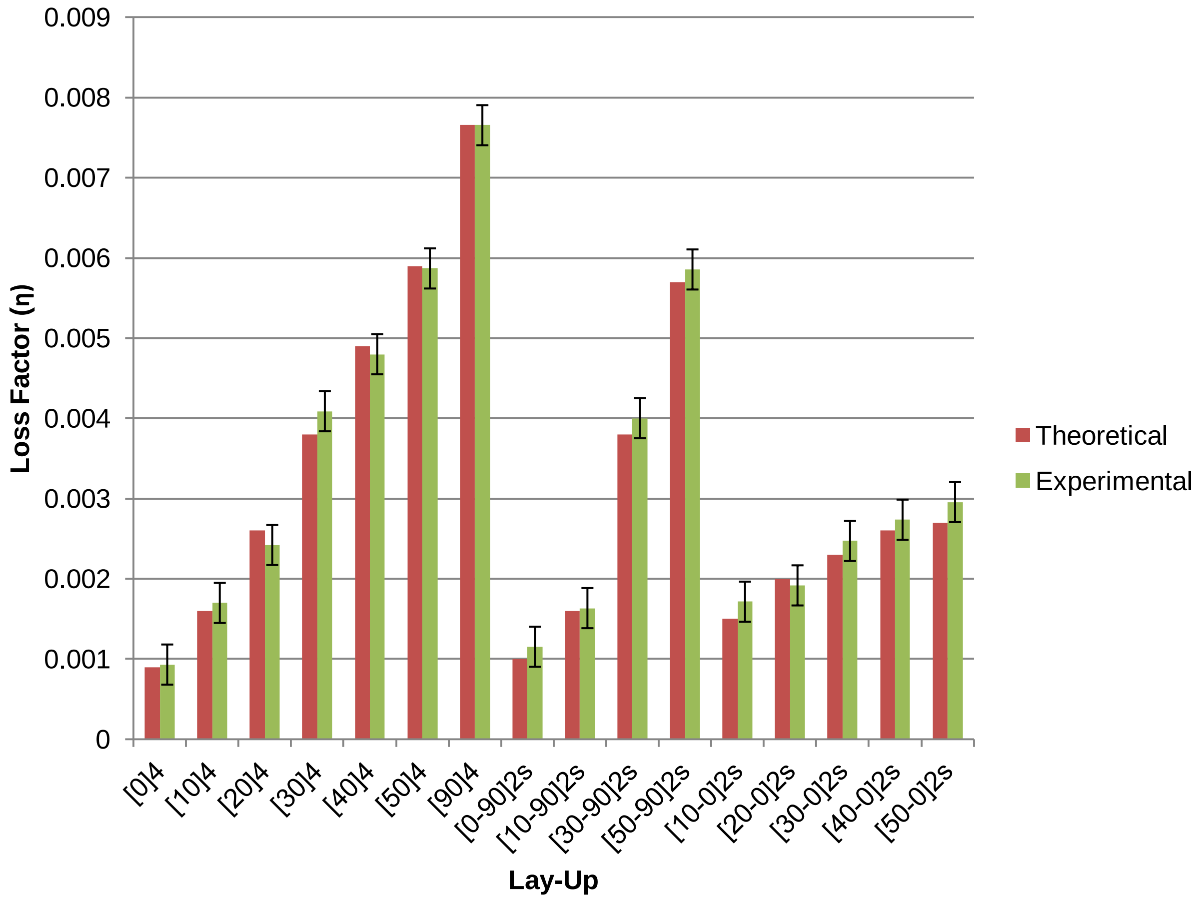
Damping Modelling



- Theoretical based on 0 and 90° panels.
- Good agreement between theoretical and experimental.
- Only 4 ply panels were tested however CLT is only valid for thin laminates so model may fail for much thicker laminates

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Free-body Measurement

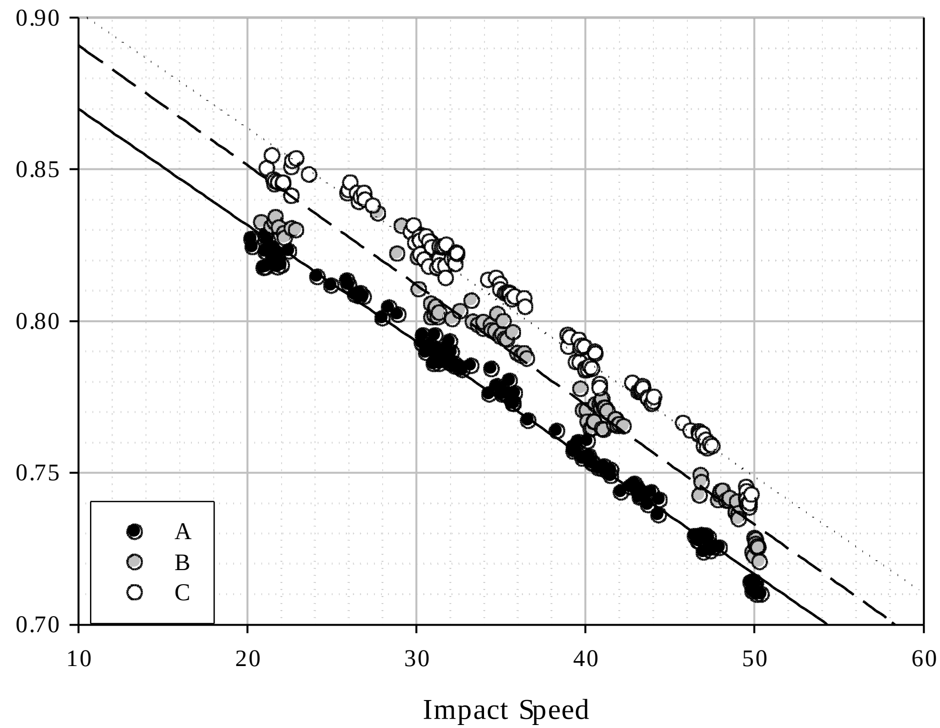
- Golf shafts along with bats and rackets are amenable to instrumentation using gauges and accelerometers
- The dynamic behaviour of balls is more difficult to quantify
- Many balls are characterised by coefficient of restitution measurements by recording speeds prior to and after impacts with rigid or semi-rigid targets
- This gives a measure of the ball performance, but does not indicate how that performance is achieved

Free-body Measurement

- CoR gives overall effects, e.g. the decrease in ball CoR with increasing inbound speed

- Increased strain rate would increase the stiffness, reducing hysteresis and therefore increasing CoR.

- An increase in strain leads to greater hysteresis and therefore and decrease in CoR. Showing strain the more dominant feature.



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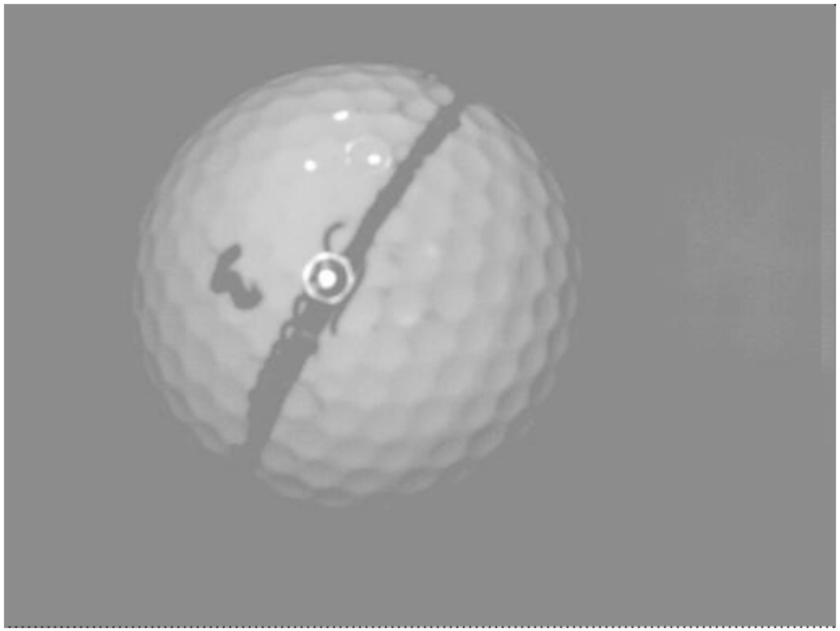
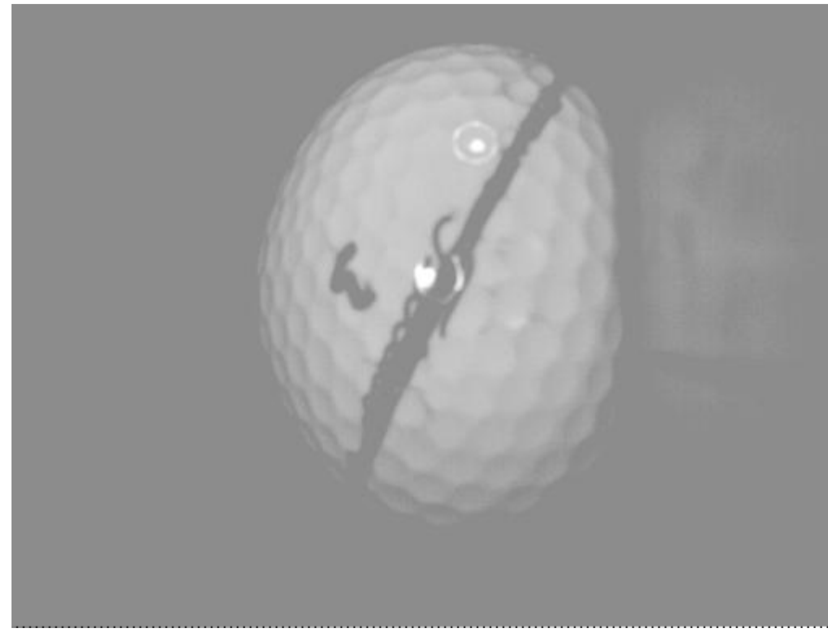
Free-body Measurement

- Whilst targets can be instrumented to give forces during impact and contact times the ball deformation needs to be measured in a non-contact manner

Core Deformation





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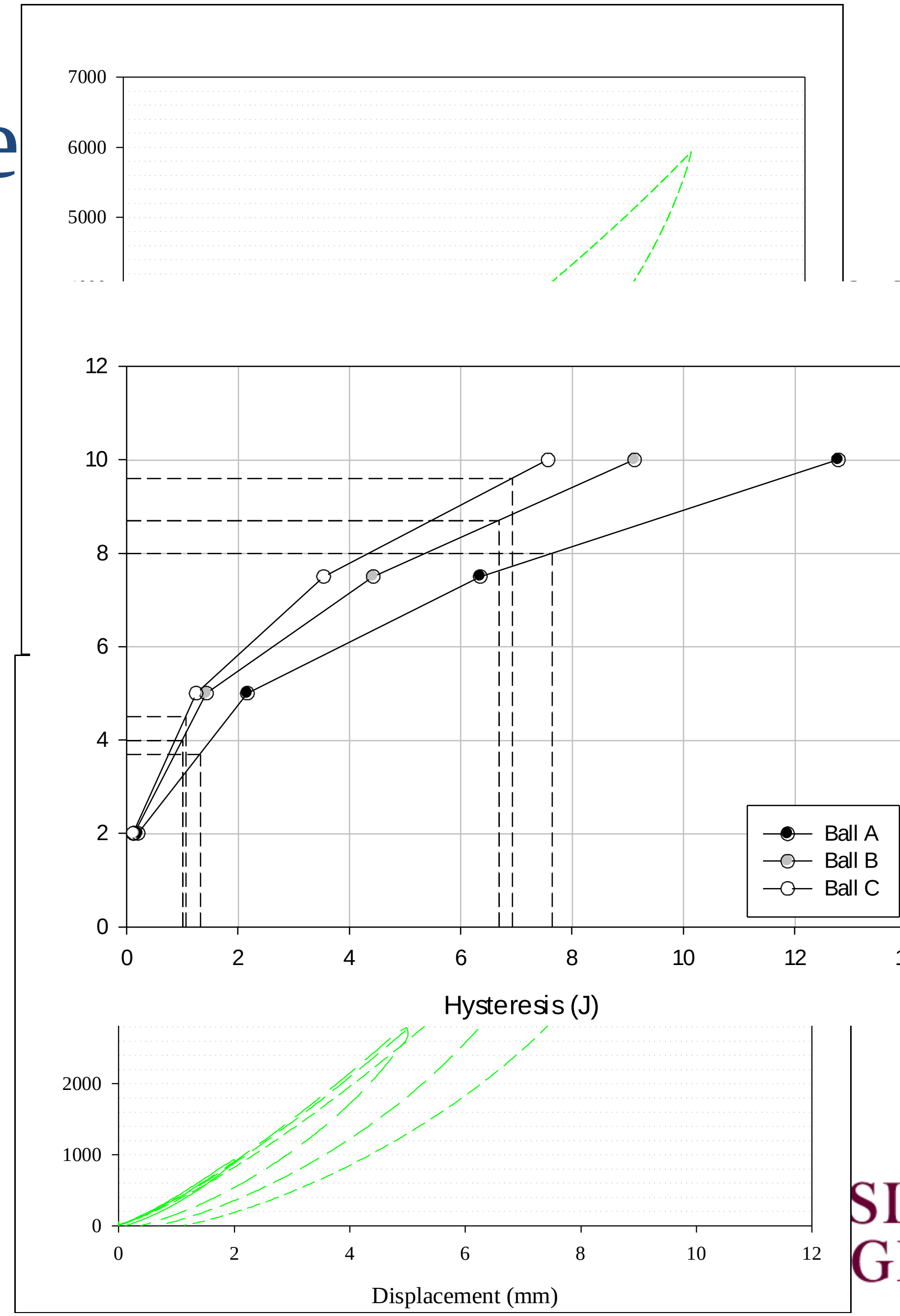
Material Choice

- Compression test balls, cores and constituent materials
- Same deformation as impact, but at range of slow strain rate (2 mm/s)
- Measure energy losses
- Predict ball performance based on component part properties
- Use as basis of FE modelling



mm/s

m/s

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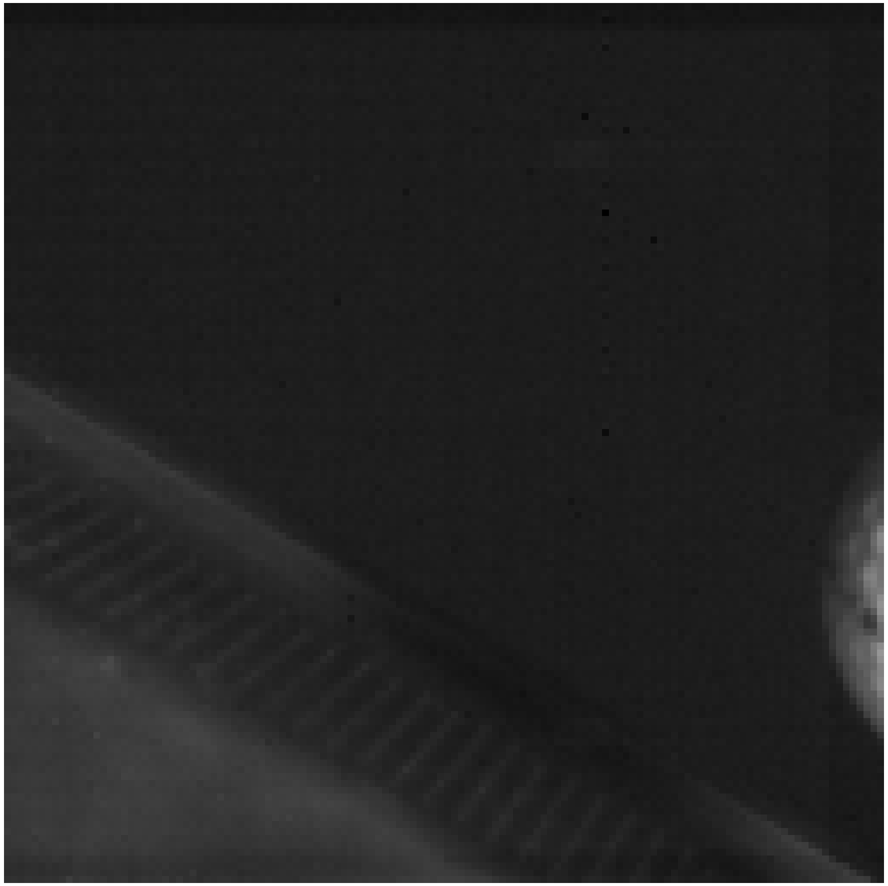
Normal / Oblique Impact

- The approach above is very successful for normal impact, and carries through to other sports, e.g. hockey

- However this is only part of the answer as most shots involve oblique where significant rates of back spin are generated



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Normal / Oblique Impact

- To address this the strains in different parts of the ball are needed, i.e. large deformation in the cover to give interaction with grooves and large core deformation to generate contact area

- Large core deformation should result in large viscoelastic energy losses

- In this aspect the strain rate is also important, not on loading, but on unloading

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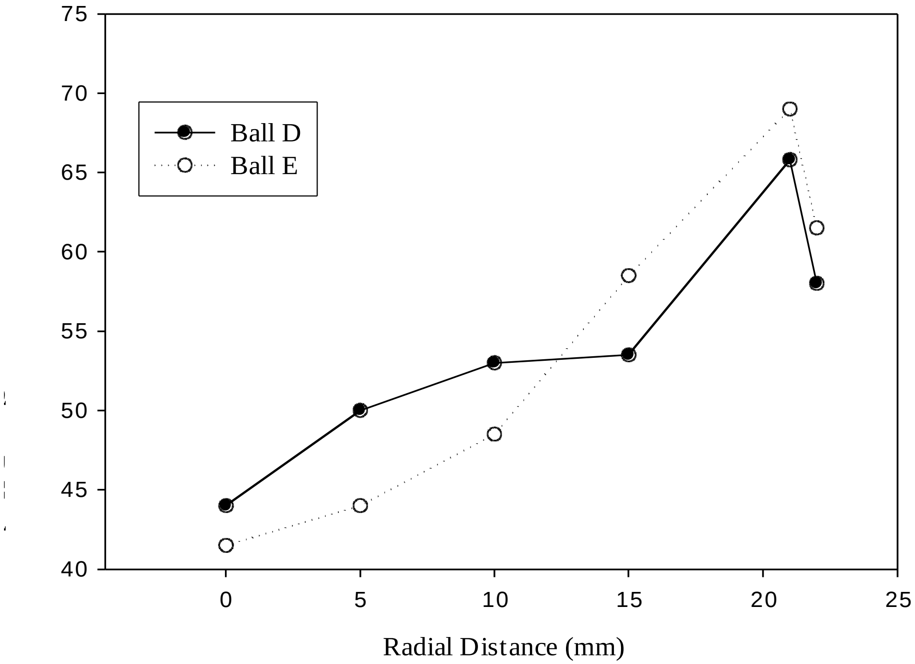
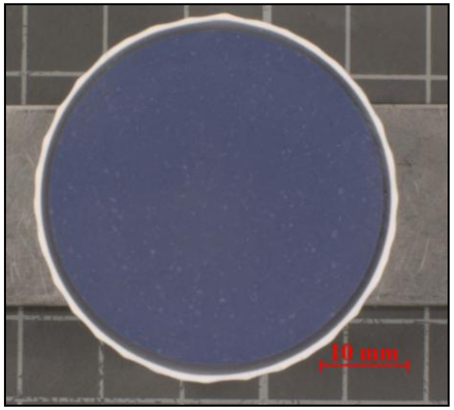
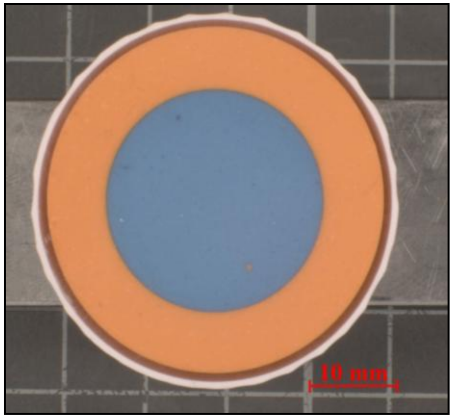
Use of Hard Mantle



- Harder mantles deform more elastically - force soft core to recover faster than normal
- Reduces viscous part of deformation unloading





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Conclusions

- Sports equipment performance can be improved provided that the mechanism behind the action can be determined

- Accurate strain and strain rate determination is needed in order to characterise the equipment and component materials under sports-specific conditions.

- Static testing for equipment fabricated from composites/polymers maybe be sufficient. Some application dynamic testing is required.