Crash Behaviour of Syntactic Foam-Filled Tubes for High Performance Automotive Applications

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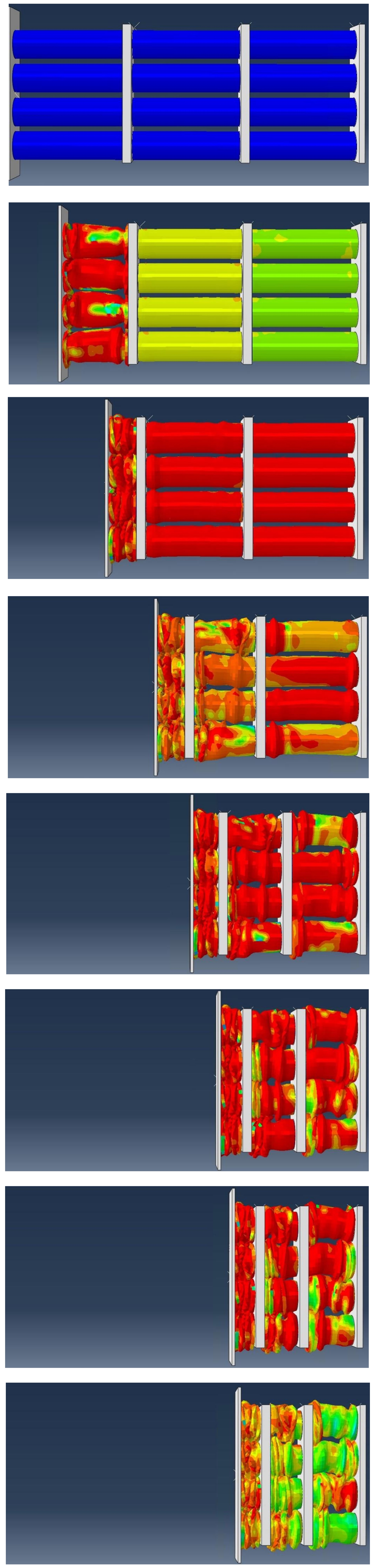


Car safety:

- Rigid **Monocoque** chassis (commercial cars) or **Survival Cell** (high performance) secures the occupant and protects them from external intrusion.
- Crash structures are needed to **dissipate energy** of crash to stop it being transferred to the occupant and **safely decelerate** the car
- **Passive systems** are responsible for the majority of energy absorption, this includes: **Crash boxes**, Bodywork (crumple zones) and door structures
- Active systems are also used including Airbags, Seatbelts and Automatic Braking
- In high performance vehicles crash structures must be able to deal with **high speeds**, whilst also having a **low mass**

A Syntactic Foam sample used during compressive testing

Syntactic Foam:

- Syntactic Foam is a **composite material** made from a base **foam** with **glass microspheres** added
- Microspheres have a diameter on the order of microns
- The **Microspheres enhance the strength of the foam** significantly
- At **high strain rates** the foam is much **stronger**, but more **brittle**
- Foams are very **good at absorbing energy** due to their ability to plastically deform to high strains under load
- Foams have significantly **lower densities** compared with the un-foamed base material
- This combination of properties means foam has a **very good Specific Energy Absorption** (SEA), making it attractive for high performance applications

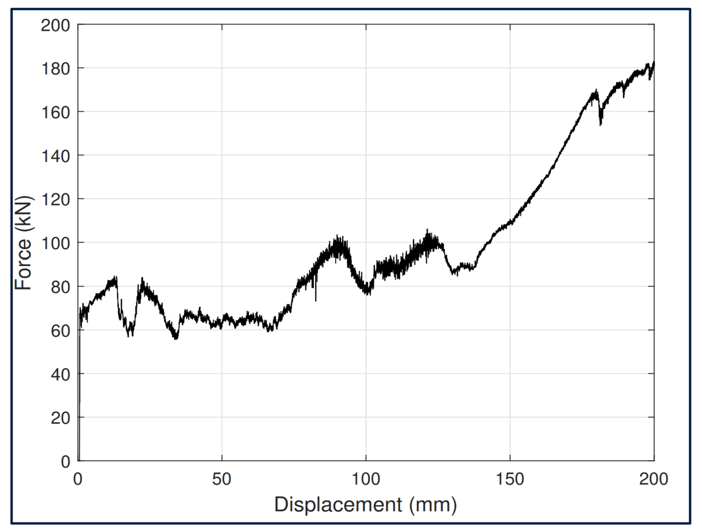
Filled Crash Tubes:

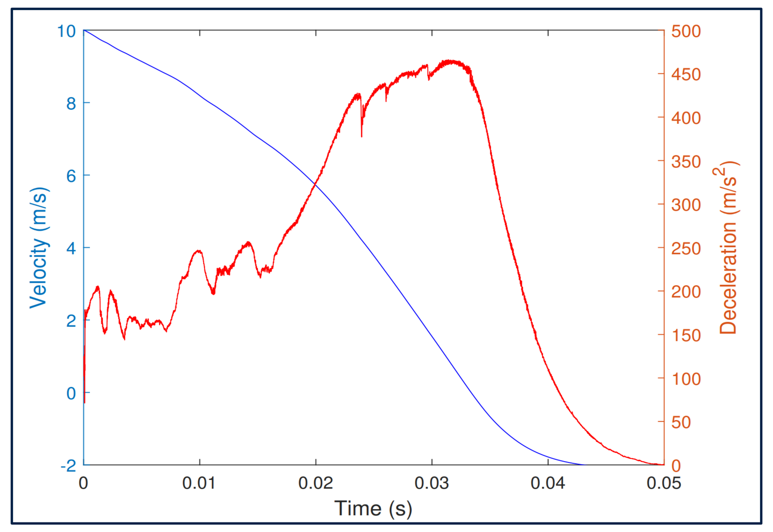
- **Aluminium Tubes** filled with **Syntactic Foam** were investigated to evaluate their performance in **compression** and a **three point bend** tests at **quasi-static** strain rates
- The foam and hollow tubes were also tested
- In compression the effect of constraining the end to allow the foam to be **fully and partially extruded** was investigated with a bespoke fixture
- The tube with the fully closed end absorbed the most energy, although the **hollow tube had the highest SEA**
- Tests were conducted at **higher strain rates**, with the foam found to have a highly rate dependent response, **enhancing the response of the filled tubes**

Compression of a 5mm length hollow tube; the tube deforms by forming two distinct 'Concertinas'

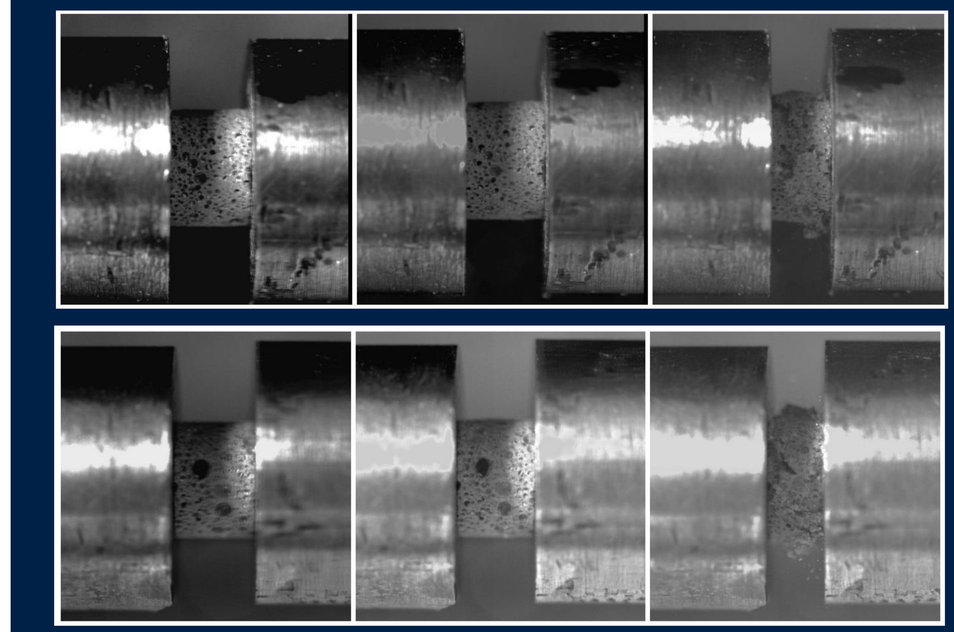
Simulation:

- A **finite element** simulation was developed in **ABAQUS Explicit**
- It was tested against the experimental results to verify it could **accurately simulate the behaviour of the materials and geometries**
- The simulation was used to investigate compression of **longer tubes** at QS and at higher strain rates more representative of crash velocities (~50 km/h)
- The effect of **combining tubes** with different end condition was investigated in both **series** and **parallel**
- Combinations of **hollow tubes and filled tubes with a closed end** were found to optimise the energy absorbed whilst keeping the mass of the structure relatively low
- The simulation was used to inform the design of a side impact structure conforming to the geometric constraints of a formula one car
- The performance was found to match that of those currently used, offering a **simpler design** at a **lower cost**, although at a slightly increased **mass**



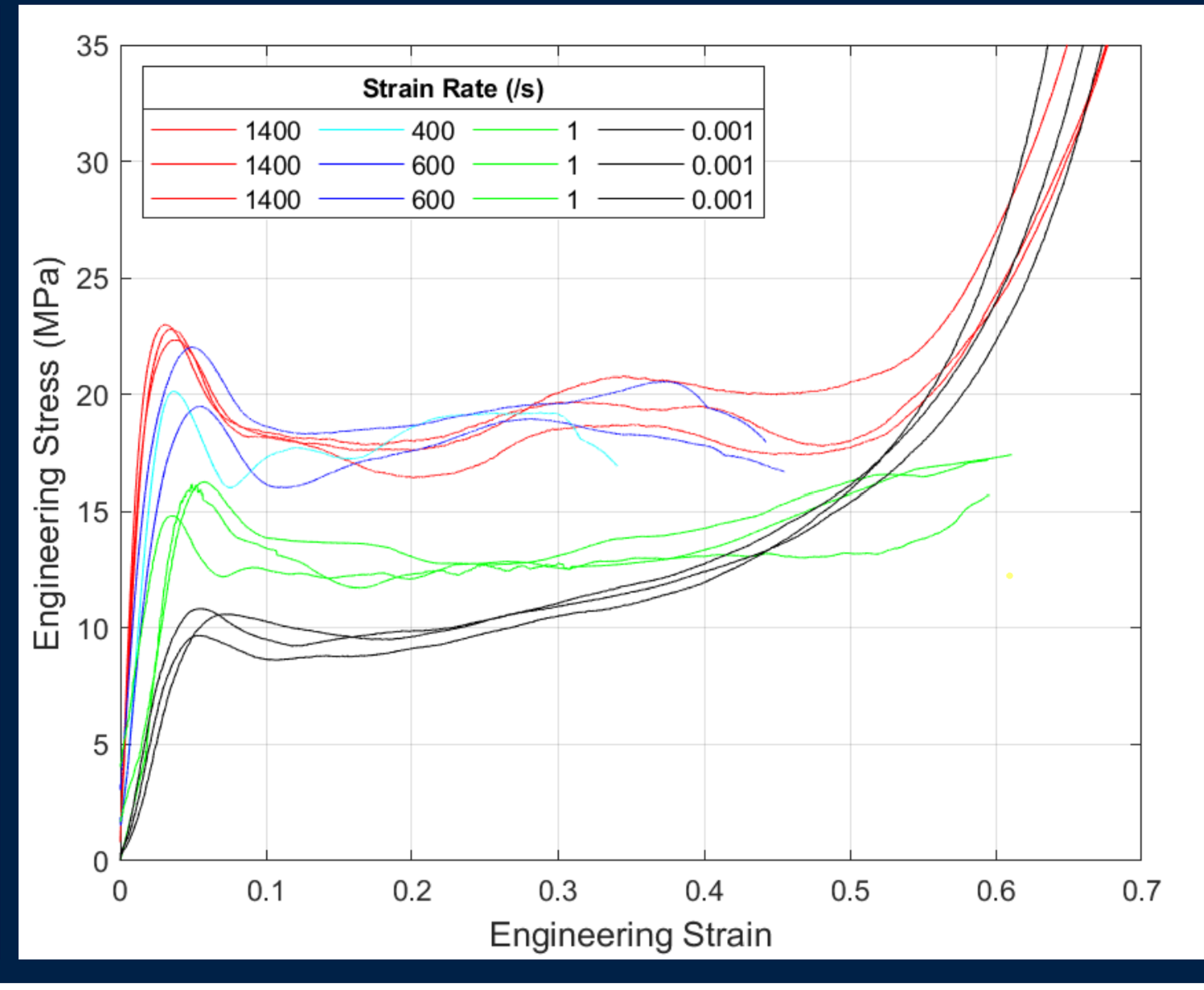


The response of the Side Impact Structure during a simulation of the axial compression test: the **Force-Displacement**, **Velocity-Time** and **Deceleration-Time** curves are shown above and the response at **intervals of 0.005 s** is shown on the left



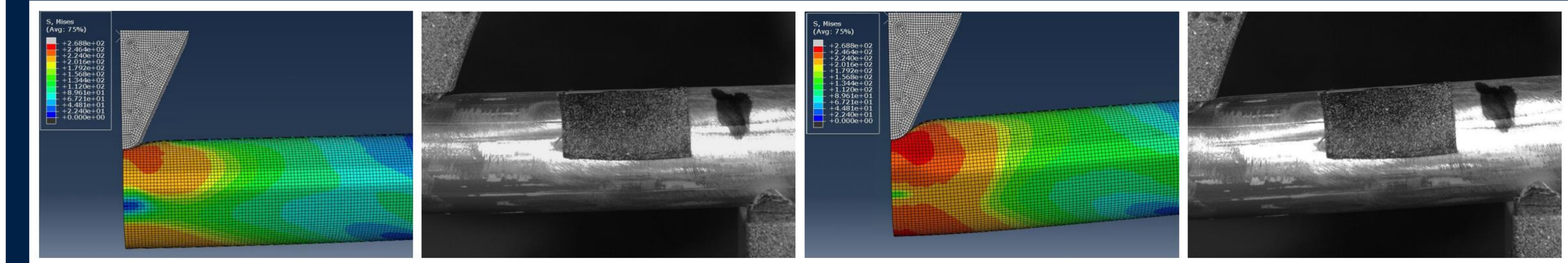
High Rate Testing:

- To better understand the behaviour of the foam it was tested in axial compression at four strain rates
- For **Quasi-Static** tests a **Zwick Z250** was used
- For Tests at **1/s**, an **Instron** Hydraulic machine was used
- A **Split Hopkinson Pressure Bar** was used to load the foam at very high strain rates of **400-1400/s**
- The foam was highly rate dependent, with its **strength doubling** at the **very high strain rates** (see right)
- The foam was, however, increasingly **brittle** with **increasing strain rate** (see right, the upper picture is at 600/s and the lower at 1400/s)
- The **densification strain** of the foam was found to be around **50%**, however at higher rates the foam fractured before this
- At high strain rates, the foam must be confined to carry load



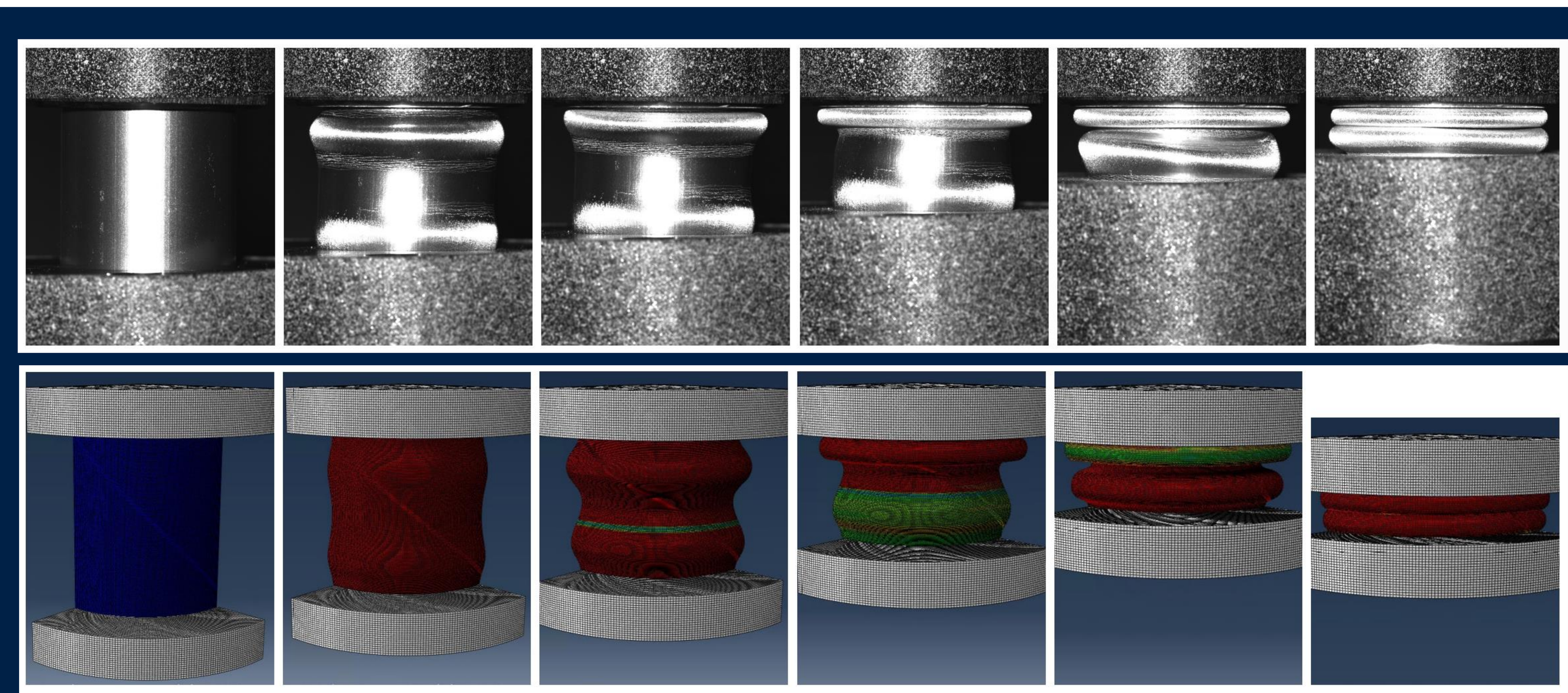
Finite Element Modelling:

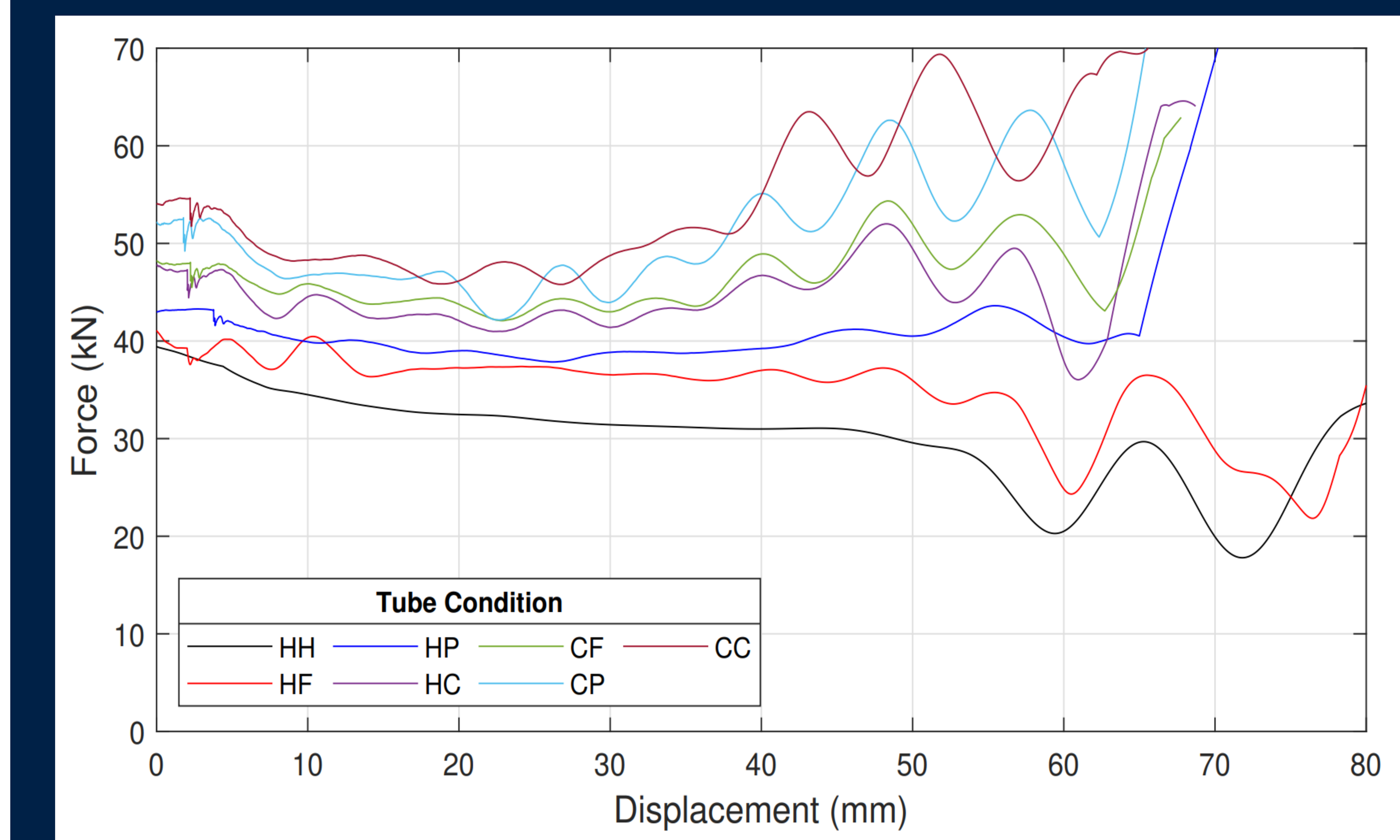
- The behaviour of the **foam** was simulated with a '**crushable foam**' model calibrated to the test data
- The **Aluminium** was simulated with the **default plasticity model** and test data from a research paper
- The models were found to simulate the response of the tubes well and accurately predict the energy involved, however the deformation was often idealised when compared with the experiments (see below)



Series and Parallel Tubes:

- As the crash tubes become longer for practical applications, they become at risk of deforming with **diamonds or buckling**, both of which require **less energy to deform than concertinas,** so forcing concertinas is desirable
- A longer tube can be split into shorter lengths joined in series, combinations of two 100mm tubes were tested at a crusher speed of 50km/h
- If a hollow tube was used with a filled tube, the hollow tube would deform before the filled tube deformed, but two filled tubes would deform simultaneously
- The best combination for **Specific Energy Absorption** was a hollow tube and a filled tube with a closed end (**HC**) (bottom left)
- Two 100mm tubes were tested in various combinations in parallel at 50km/h, which forced the tubes to deform with the same number of concertinas
- The **HC combination was found to be optimal for SEA** in parallel
- The Force-Displacement results are shown below, the notations H, F, P and C refer to hollow, full extrusion, partial extrusion and closed end respectively





The graph to the left shows a that the combination of two shorter hollow tubes is better than one longer tube, in this configuration more total concertinas are formed which requires more energy.