Numerical and experimental study on the high strain rate deformation of tubes for perforating gun applications

IPS-16-32

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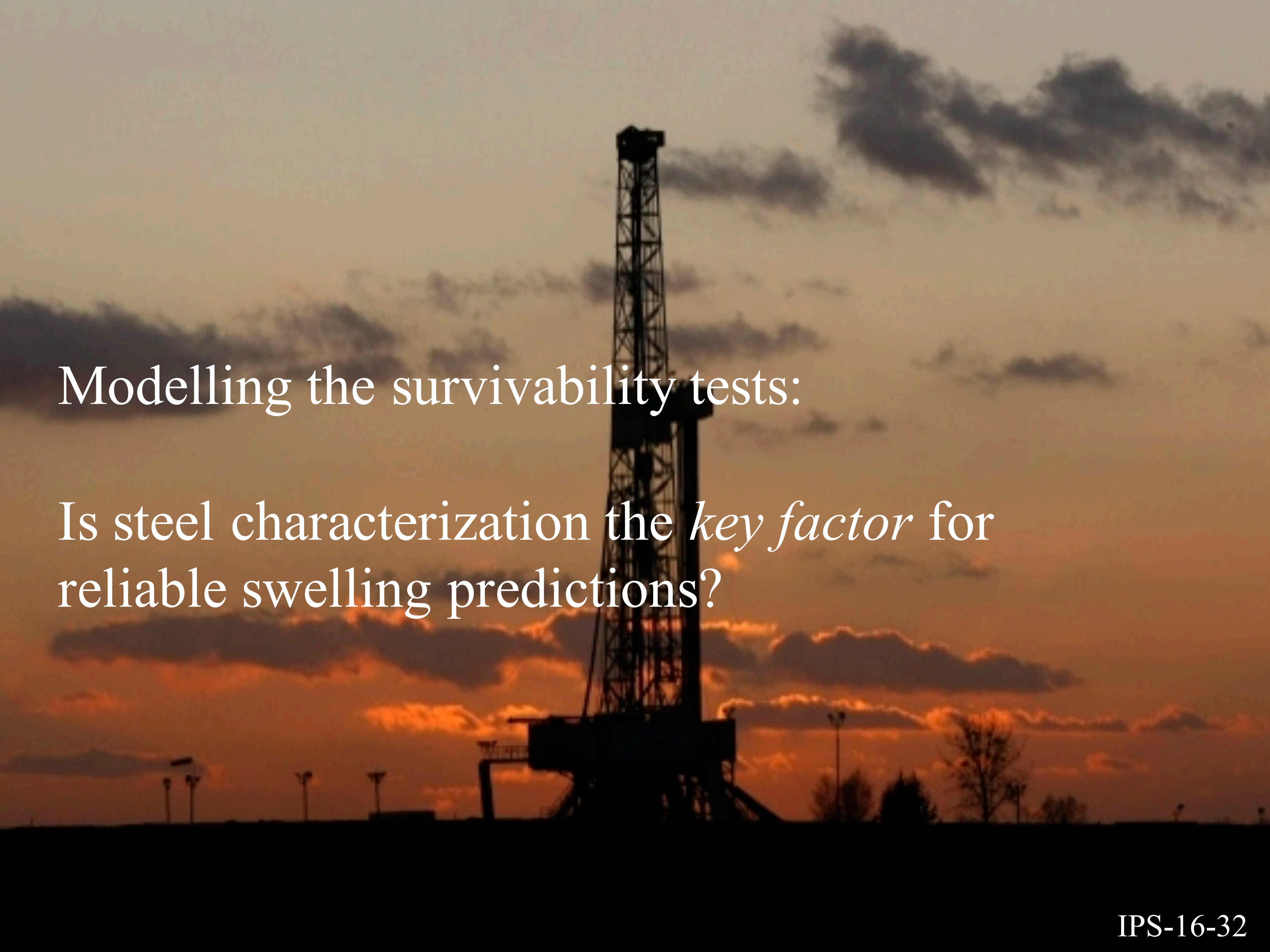
Modelling the survivability tests:
Is steel characterization the *key factor* for reliable swelling predictions?
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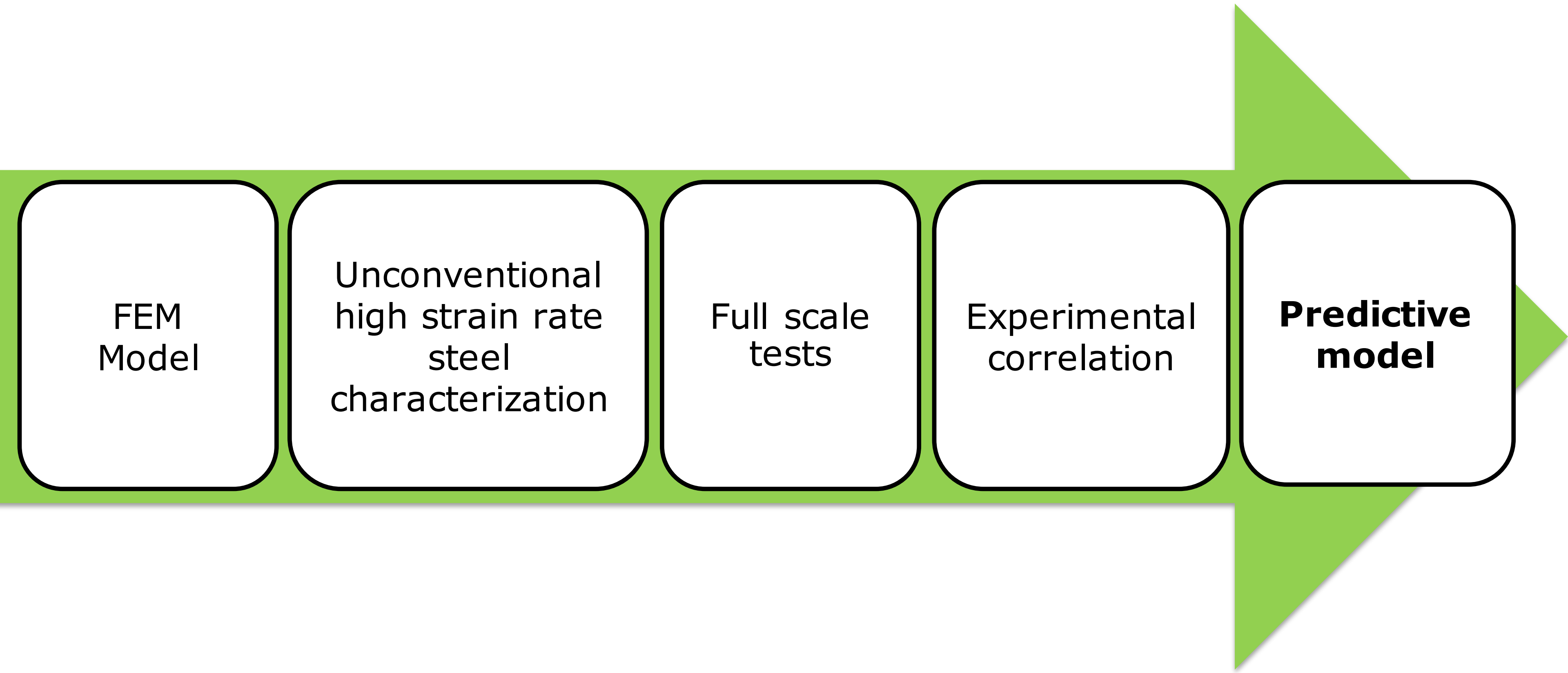
Modelling the survivability tests



FEM Model → Unconventional high strain rate steel characterization → Full scale tests → Experimental correlation → Predictive model

Need for a tool able to predict the swelling of the gun carrier

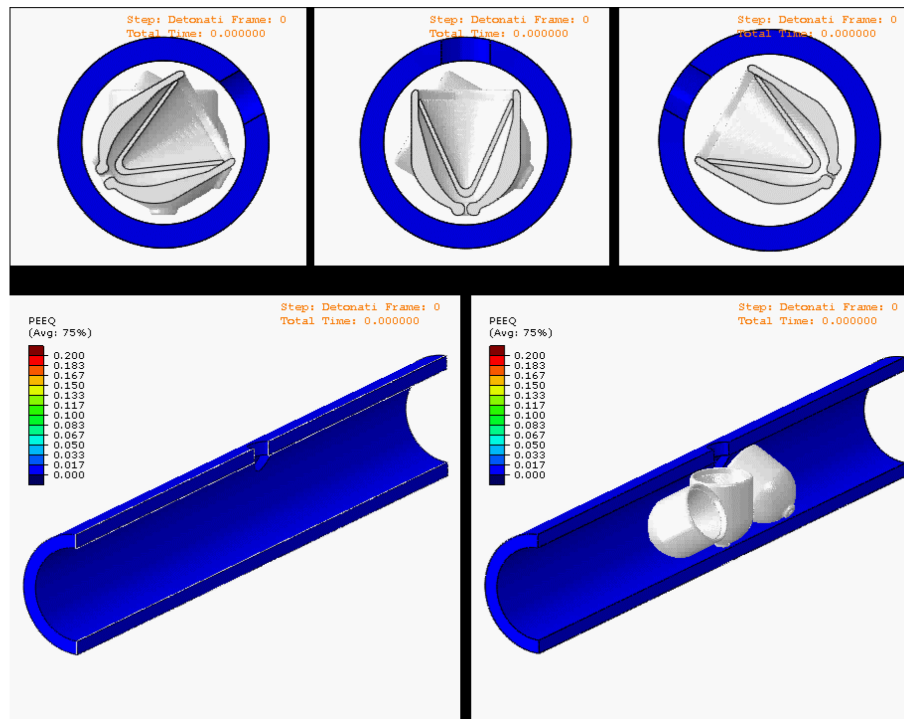
3D model of a gun carrier with 3 shaped charges

Each section modelled as follow:

1. **Steel gun carrier**: Johnson-Cook (J-C) plasticity model, obtained from experimental tests at high strain rates;

2. **SC: casing** and **liner**: J-C material/damage model*;

3. **Explosive**: Jones-Wilkins-Lee (JWL) equation of state*.

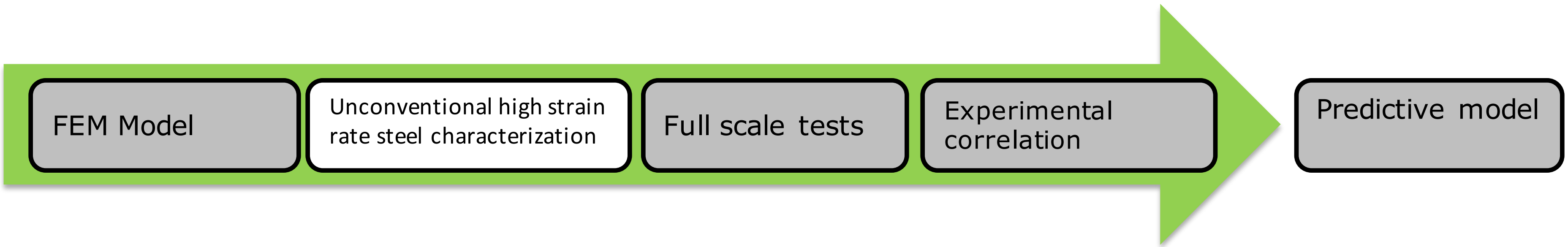


Sequential detonation of 3 charges (5 ms delay)

Swelling predicted as permanent plastic deformation on the steel carrier

*literature data

More info



Need for experimental high strain rate tests for proper steel characterization

Tests methodology: Split Hopkinson bar test (SHBT)

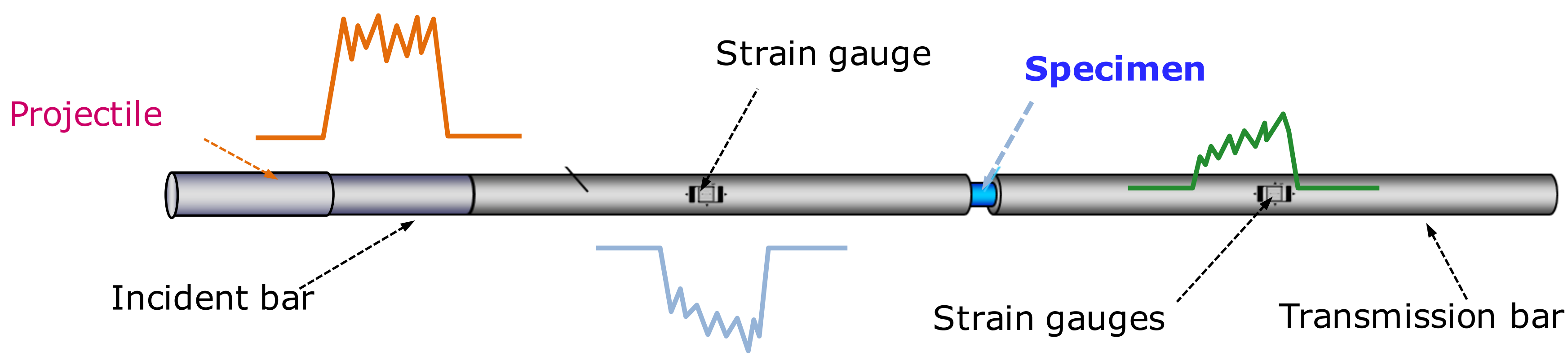
The projectile hits the incident bar generating a compressive wave train

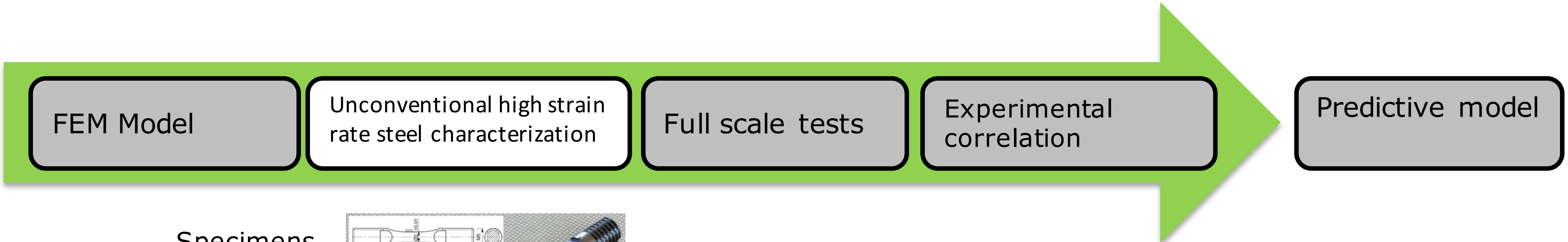
The wave train is propagated at the speed of sound

It is partly reflected

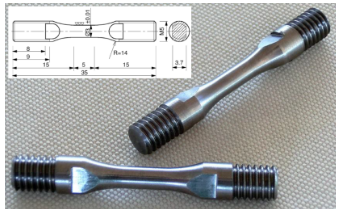
- Partly crosses the specimen and reaches the transmission bars

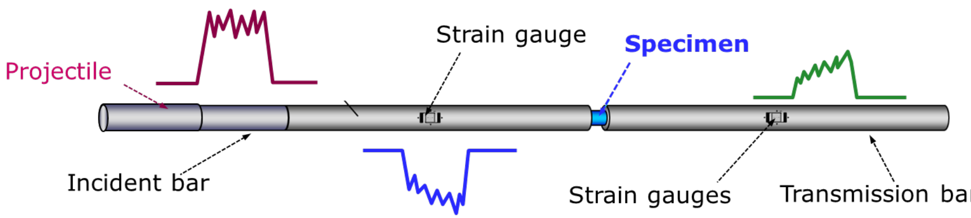
The reflected and transmitted waves are used for reconstruction based on the two signals the dynamic mechanical characteristic is obtained.

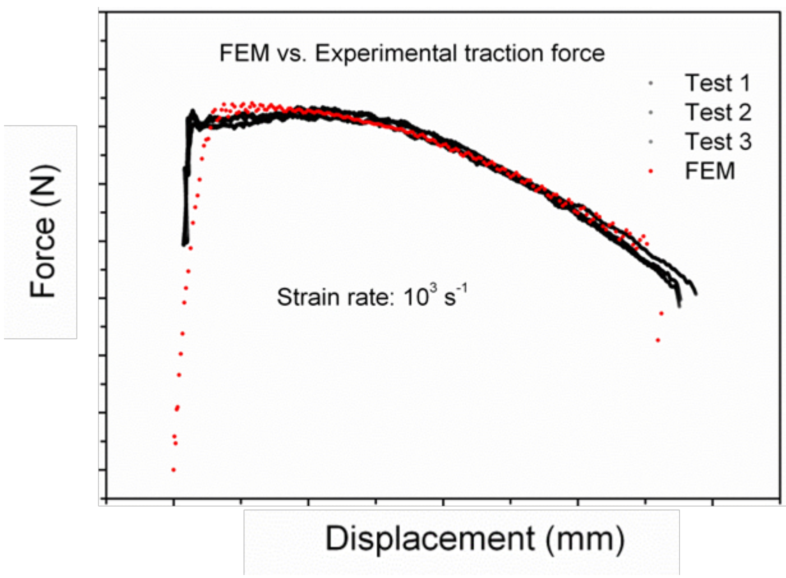




Specimens machined from Perf Gun Carrier Material



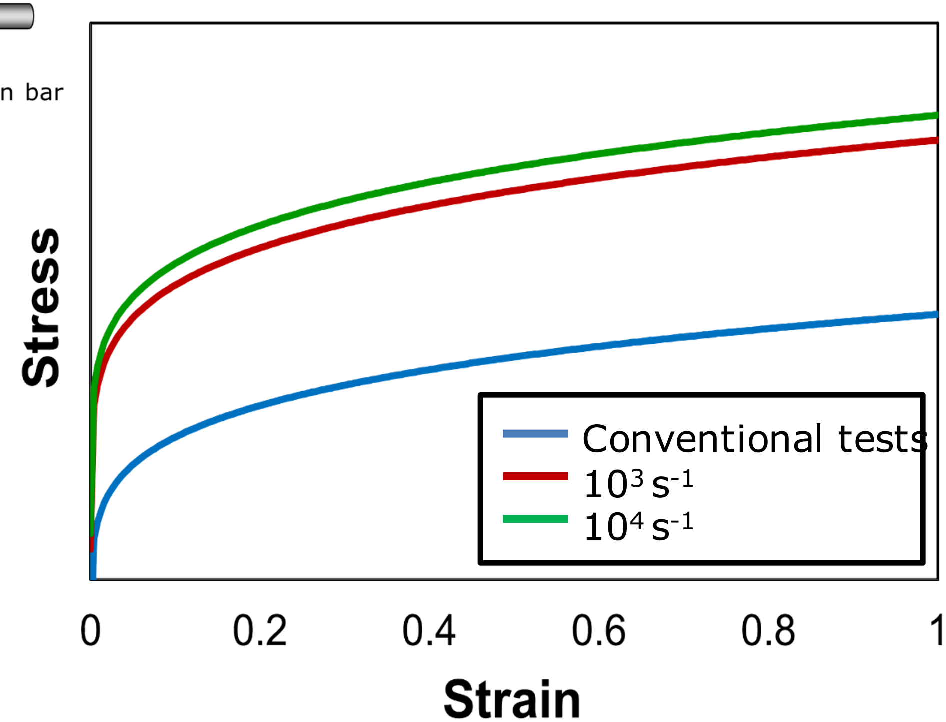




Johnson-Cook (J-C) constitutive model

Stress = (Plasticity)(Log. of strain rate)(Temperature)

A, B, n — C, ε_0 — m

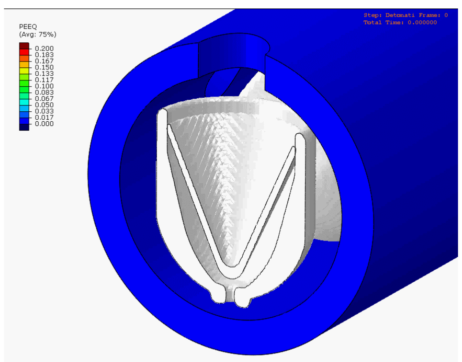


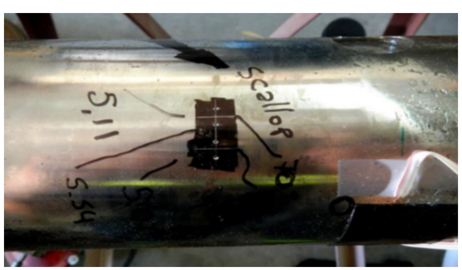
In order to calibrate the J-C model's parameters, FEM inverse analysis onto the experimental curves up to a discrepancy within about 5% have been carried out.

- FEM Model
- Unconventional high strain rate steel characterization
- Full scale tests
- Experimental correlation
- Predictive model

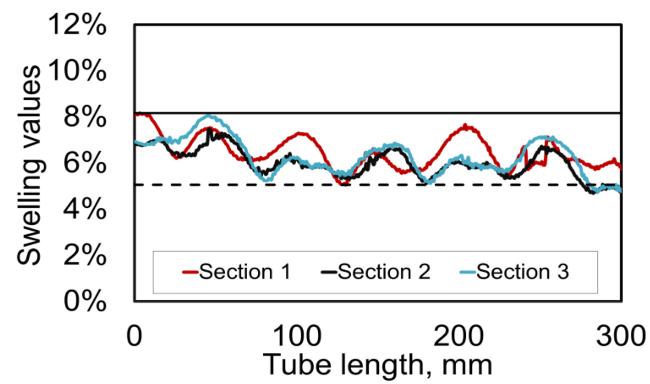
Need for experimental measurements of **local** strain deformation and **overall** swelling

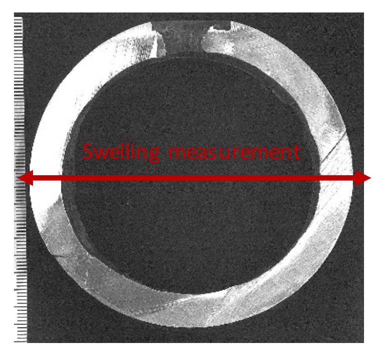
Local strain deformation measurement at the max. impact angle determined by FEM model



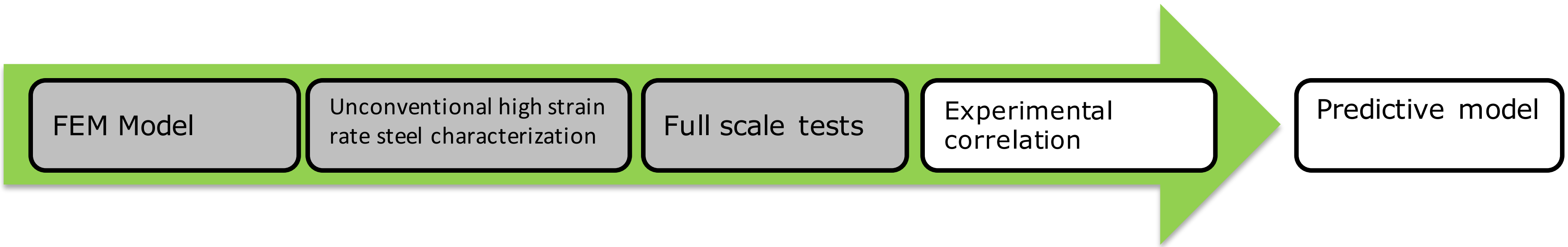


Overall swelling measurement sections

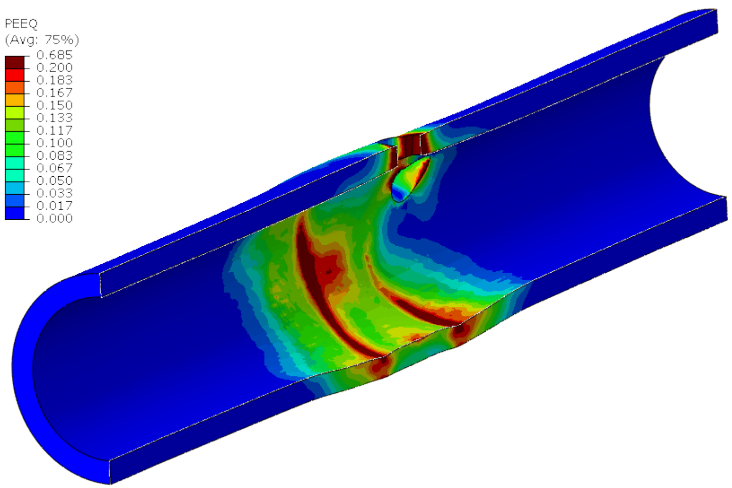


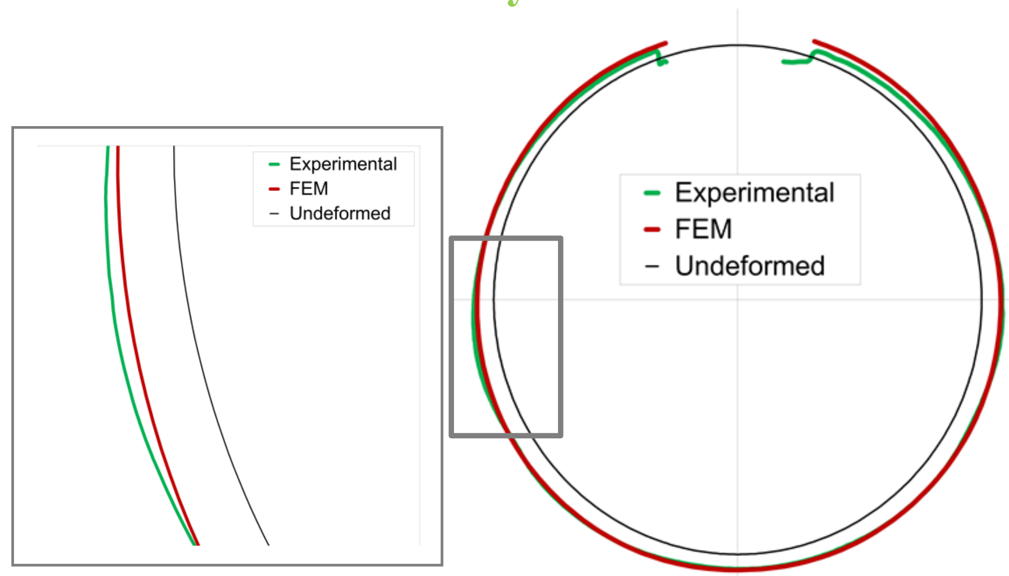


More info



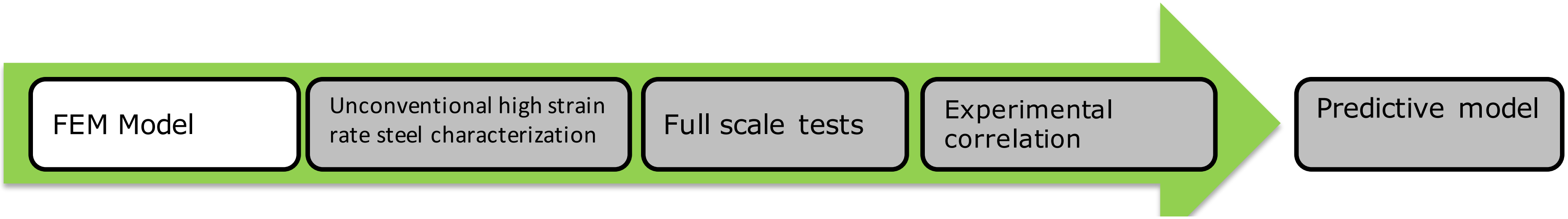
Local and overall post mortem deformation vs numerical analysis results





	Measurement Position	Experimental value	FEM value
Overall swelling	Location with max. value	8.3%	8.0%
Local deformation	70°	10.3 %	10.2 %
	55°	5.1 %	6.5 %

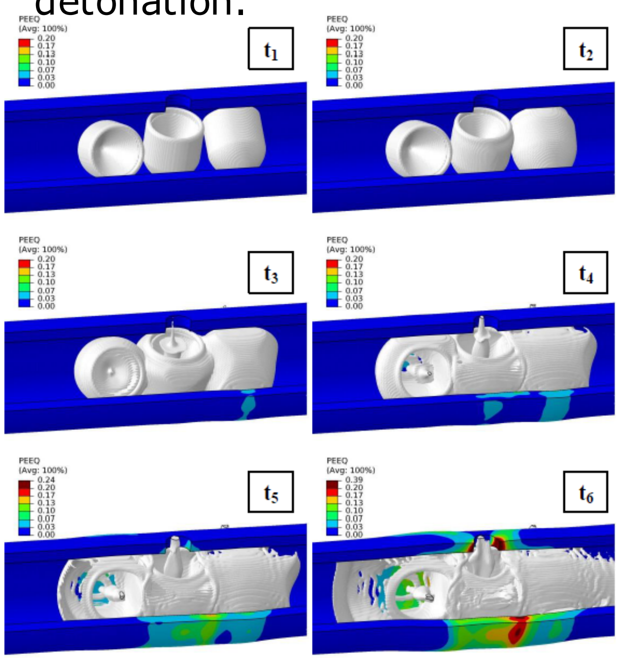
More details

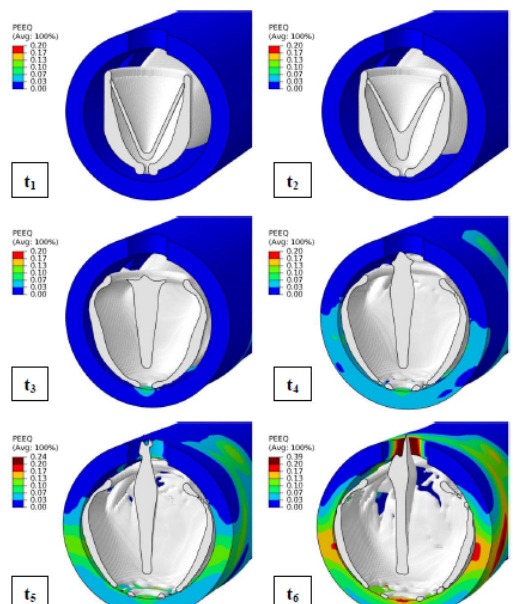


To be able to take into account variables such as large deformations, mechanical impacts, fracture mechanics in solids and material thermal softening a coupled Eulerian-Lagrangian FE model has been developed.

Each section modelled as follow:

1. **Gun carrier:** Lagrangian technique (good accuracy of the strain field and accurate damage criterion implementation).
2. **SC:** Eulerian technique (by means of volume fraction tool implemented in Abaqus/CAE) is a suitable for very high deformation experienced during the detonation.





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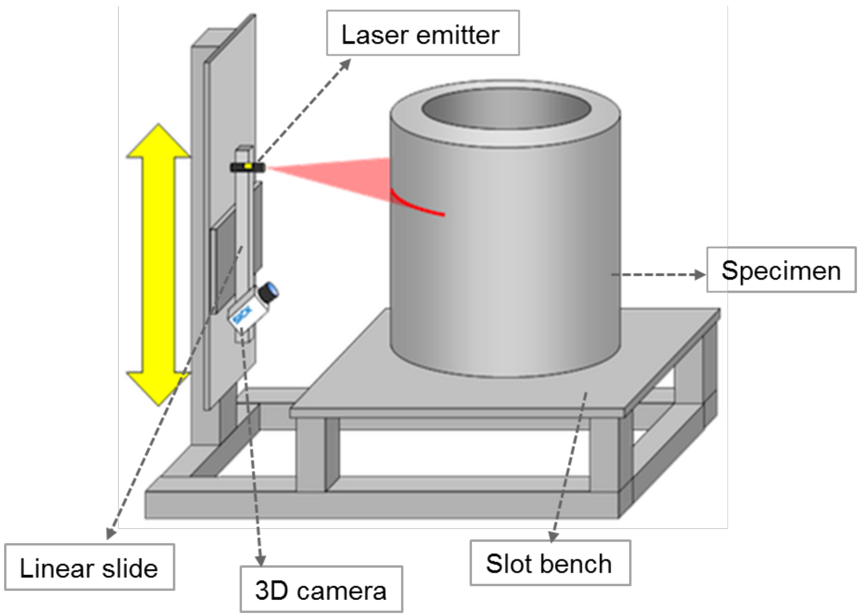
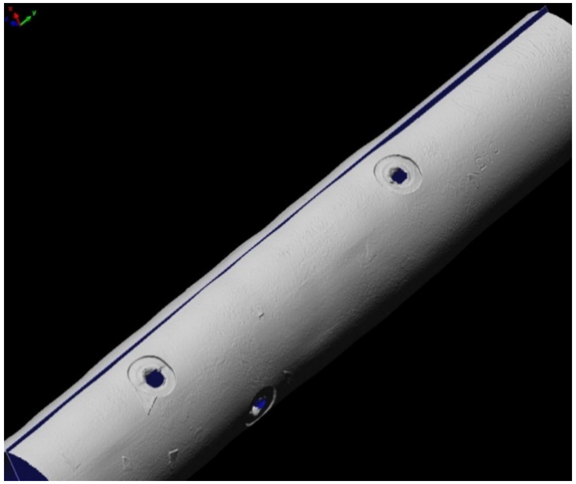
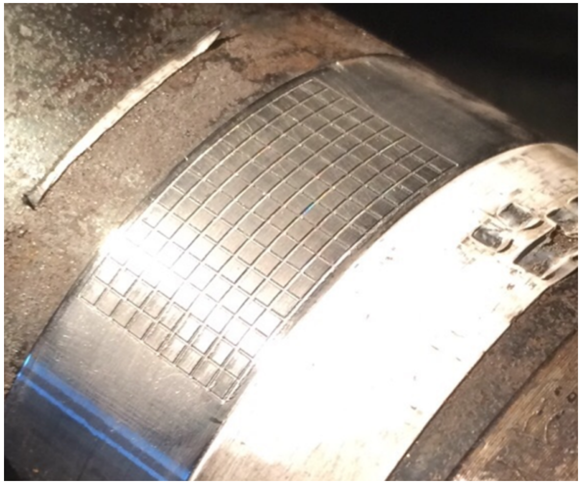
Swelling measurements 3D Laser scan







Technical data used for the present analysis:

- Focus depth < 0,1 mm;
- Scan rate of 100 mm/s for a longitudinal resolution of 0,1 mm.

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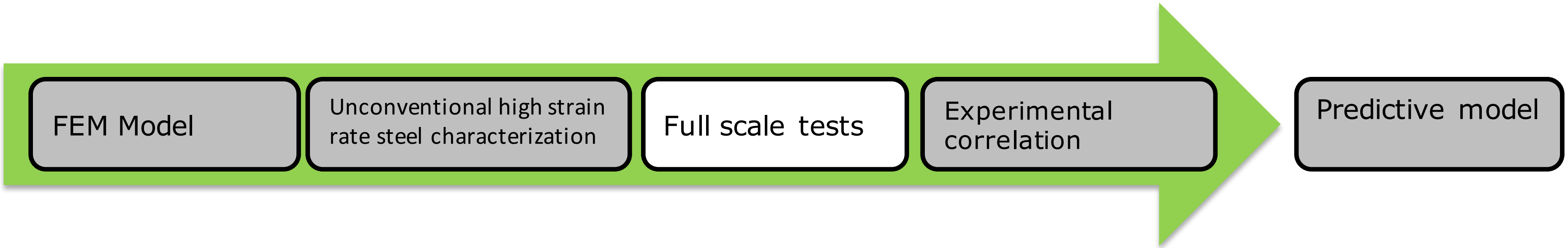
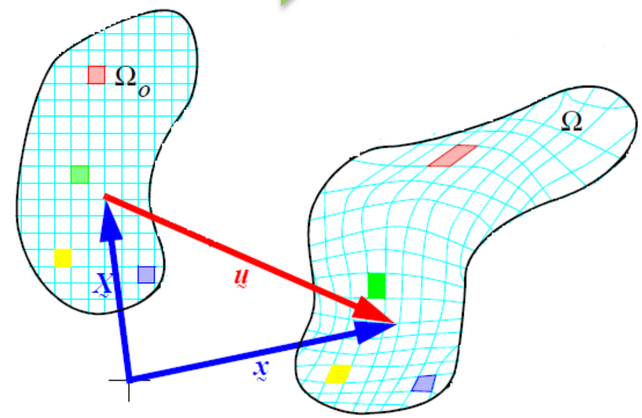
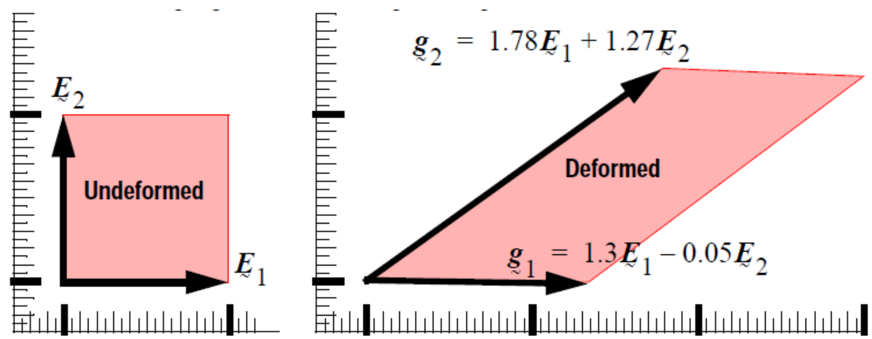


Strain estimation by surface displacement measurement

A technique able to measure the maximum plastic strain in the metal (i.e. it is a complementary measure w.r.t. the strain gauges one) consists in laser embossing a grid on the polished surface of the tube at the area of interest (**1**). After the test, the local displacement is measured using a laser scanning (**2**). The outcome is the deformation gradient tensor ***F*** (**3**).

From ***F*** it is possible to calculate the strain field to be compared with FEM.





$$[F] = \begin{bmatrix} 1.3 & 1.78 \\ -0.05 & 1.27 \end{bmatrix}$$

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Thanks for your attention