




Letizia **Barcellona**
PhD student

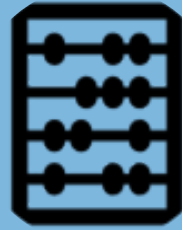
 Politecnico di Bari

 l.barcellona@phd.poliba.it

Inverse calibration of the AA5754-H22 constitutive equation at high temperature



Problem



Methodology



**Software
Integration**



**Sequential
Strategy**



**Result and
Validation**

Lightweighting:

Aluminum alloys are vital for automotive and aviation sectors.



Problem



Simulation Reliability:

Proper process design depends on accurate constitutive equations.



Hot Forming:

AA5754-H22 requires high-temperature processing for complex shapes.

Material



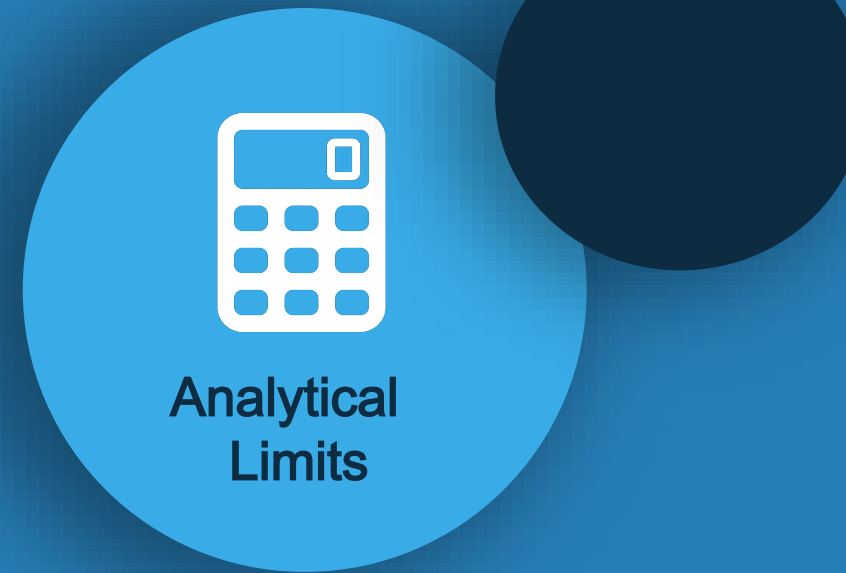
- ✓ High strength-to-weight ratio.
- ✓ Excellent corrosion resistance.
- ⚠ Hard to form at room temperature.

| Alloy | Si | Fe | Cu | Mn | Mg (min-max) | Cr | Ni | Zn | V | Ti | Other |
|-------|------|------|------|------|--------------|------|----|------|---|------|-------|
| 5754 | 0.40 | 0.40 | 0.10 | 0.50 | 2.60-3.60 | 0.30 | | 0.20 | | 0.15 | 0.05 |

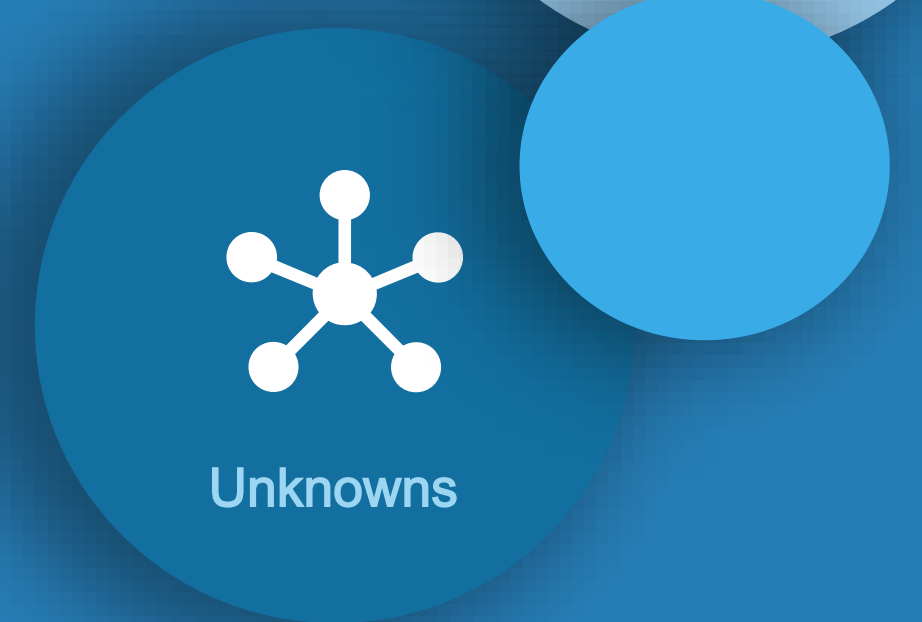
Characterization Challenges



Industrial gas forming induces biaxial stress, which uniaxial tests cannot represent accurately.



Analytical methods (e.g., Enikeev-Kruglov) fail for non-superplastic materials like AA5754-H22.



Flow stress constants depend on temperature and strain rate, requiring accurate calibration.



The material parameters are invisible to direct measurement → inverse analysis

Free Inflation Test



Imagine a balloon made of metal:
gas pressure pushes the sheet blank.



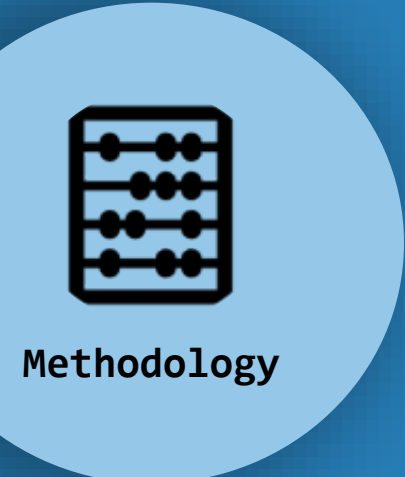
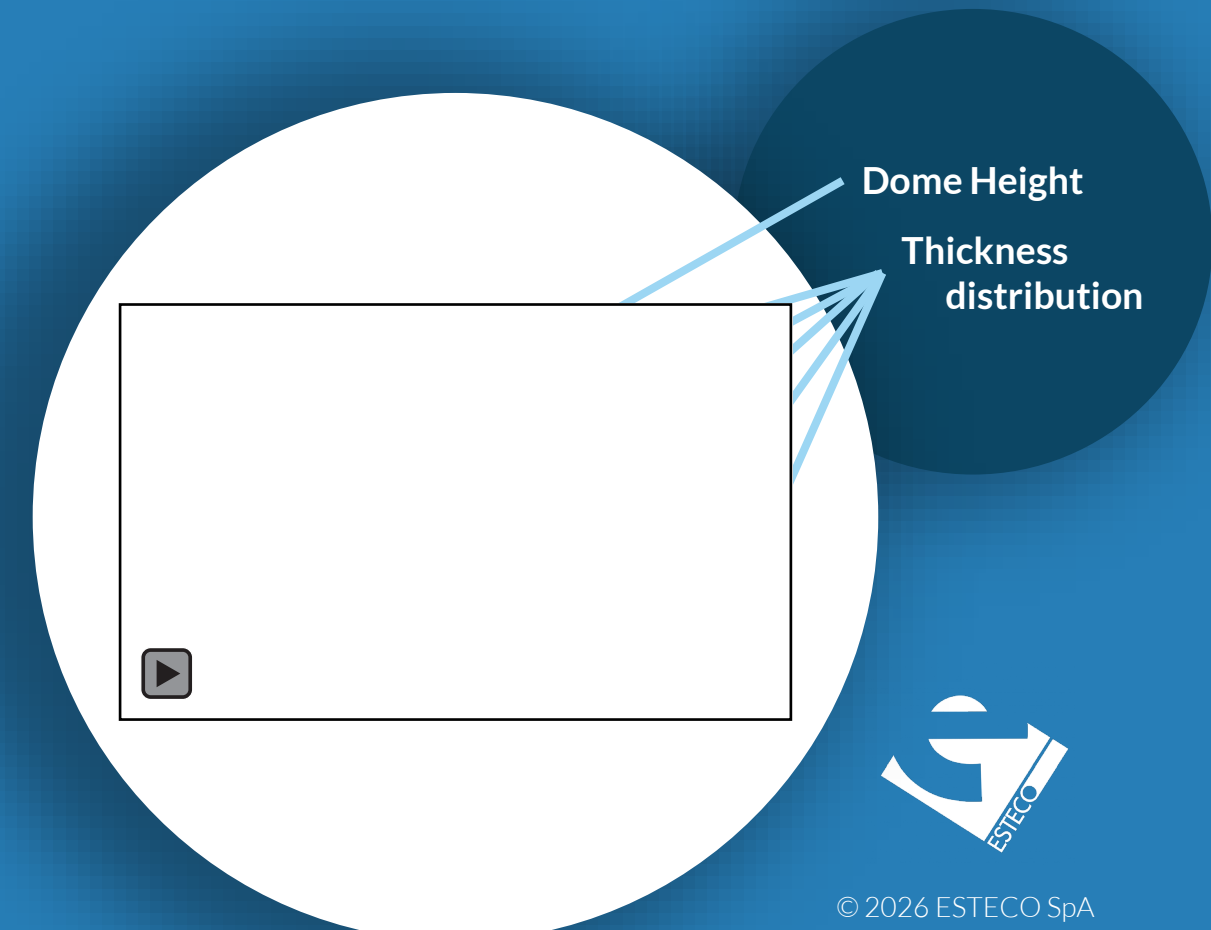
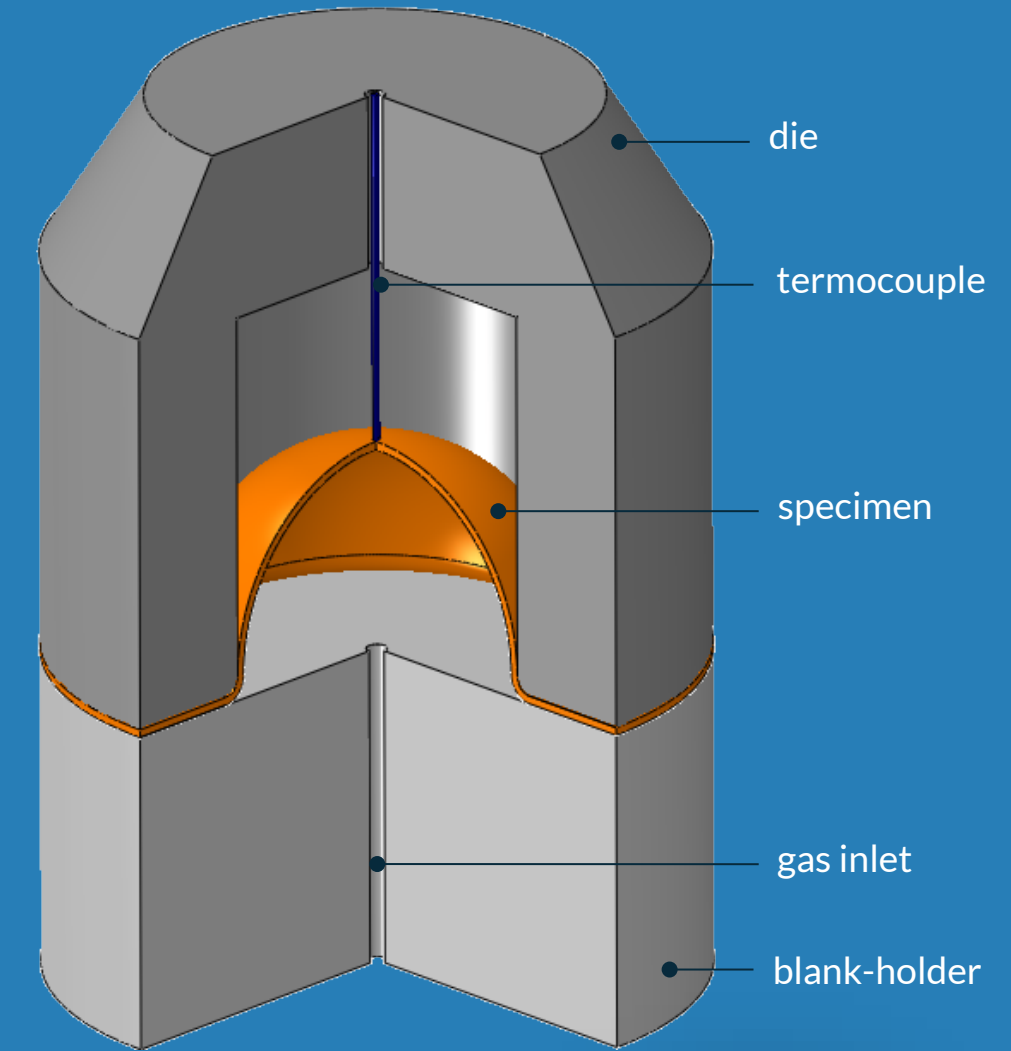
We track **Dome Height** over time.
We measure **Final Thickness** distribution.

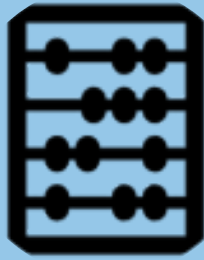


Our goal is to find the mathematical "recipe" that explains why it deforms exactly this way.



Experimental tests were conducted at four constant pressure levels (0.5, 0.6, 0.7, and 0.8 MPa) at 400°C.





Methodology

Backofen Model: Input



$$\sigma = C \cdot \dot{\epsilon}^m$$

The model relates equivalent stress to strain rate through two key constants:

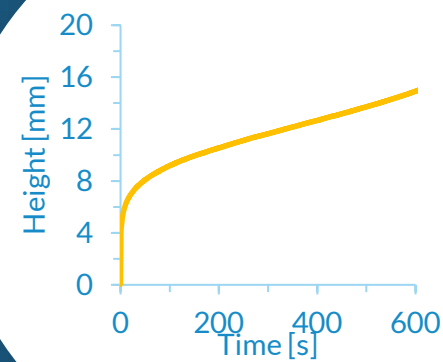
m: Strain rate sensitivity index (influences thinning behavior).

C: Strength coefficient (defines flow stress level).

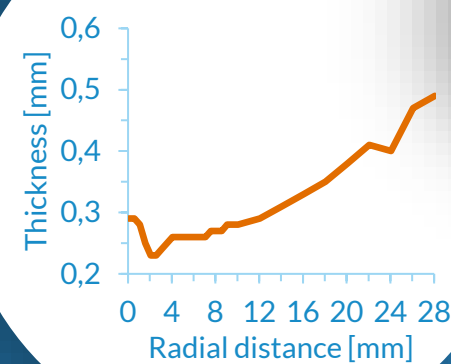
Target Data: Output



Methodology



Time evolution: Dome height growth during expansion, extracted through a thermocouple.



Final thickness profile: Post-forming thickness distribution and radial shape. Data extracted at a 0.5 mm pitch using scanner acquisition.

Inverse Analysis



Methodology



The FE Model

We build a virtual Abaqus model of the test. We set the parameters (C, m).



The Error Estimation

Does the virtual data match the real one? Yes or no?
The **Error** is our answer.



The Loop

Let modeFRONTIER change the parameters and the design characterize by the smallest error is identified.

Double step optimization



Sequential Strategy

1 Step

Focus on m

Target: Thickness Distribution.

Since thinning is governed by m , it is optimized first while keeping C constant (150 MPa·s^m).
Range [0.10-0.35]

2 Step

Focus on C

Target: Dome Height Evolution.

Using the optimal m , the coefficient C is identified to match the time response
Range [10-300]

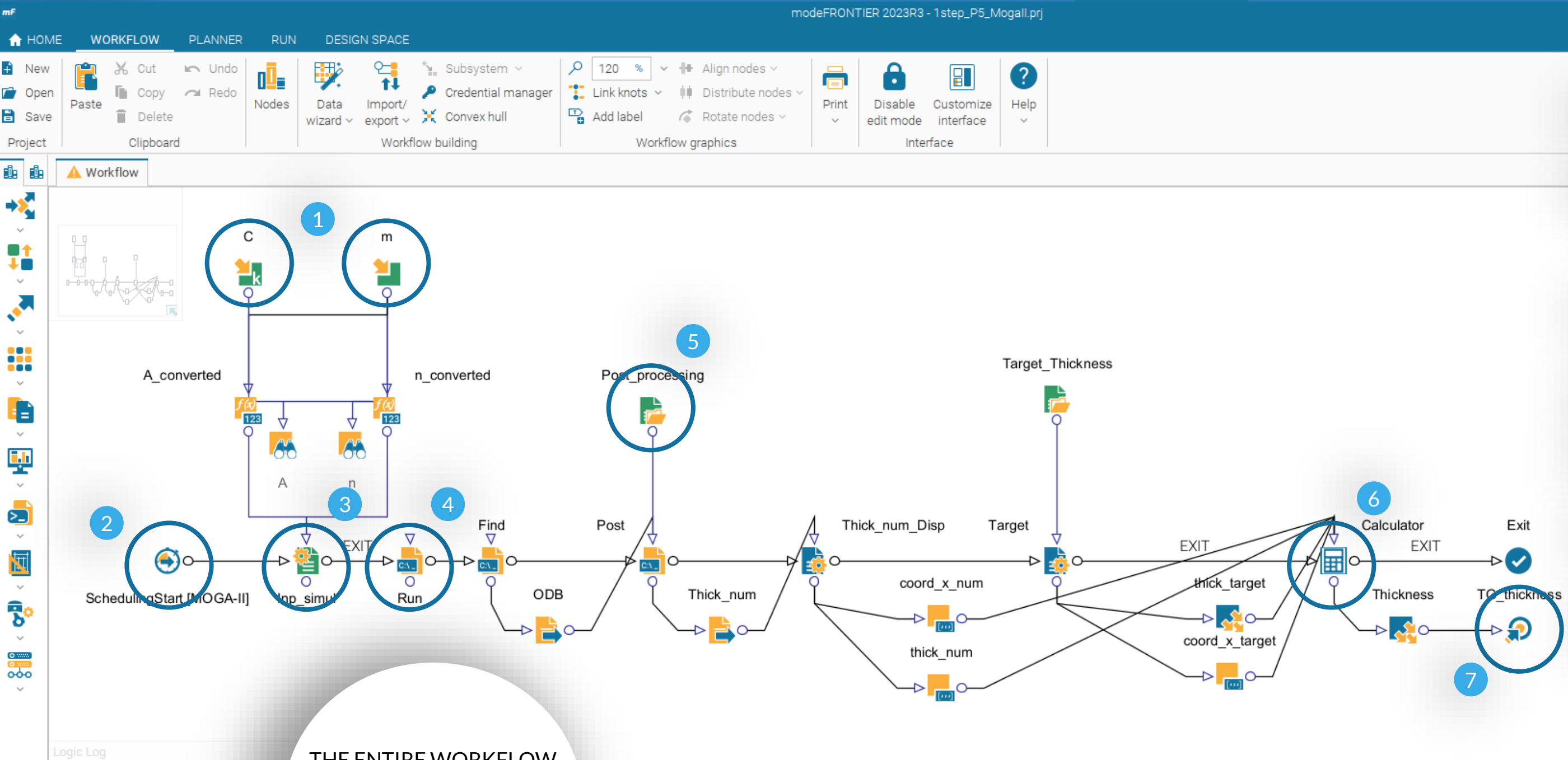
Why a double-step?

It was intentionally chosen to separate the parameters as a function of their dependence on experimental data. The *double-step* approach ensures full control over each objective by isolating parameter m as the main driver for thickness convergence and C as the driver for the final shape geometry

Software
Integration

Workflow

mode^mFRONTIER



AUTOMATION STRATEGY

- 1 **Input Variable Node:** C and m parameters.
- 2 **DoE/Algorithm:** DoE Sobol (50 design); MOGA-II, 20 generations (Selection, Crossover, Mutation).
- 3 **Input File:** Update the input variables
- 4 **DOS Node:** Start Abaqus CAE solver.
- 5 **Python Node:** Script to extract the output data.
- 6 **Calculator Node:** Interpolation of the numerical and target data.
- 7 **Objective Node:** Calculation of the difference between numerical curve and target.

THE ENTIRE WORKFLOW
IS **AUTONOMOUS**,
RUNNING FROM INITIAL
DOE TO THE OPTIMAL SET.



Genetic Algorithm

- **Uniform Space-Filling:** Ensures an unbiased distribution of initial parameters across the defined range.
- **Limited Overlapping:** Eliminates clustering and sampling gaps, providing a superior baseline compared to random DoE.
- **Computational Efficiency:** Optimal balance between information density and FEA solving time.

Sobol DoE

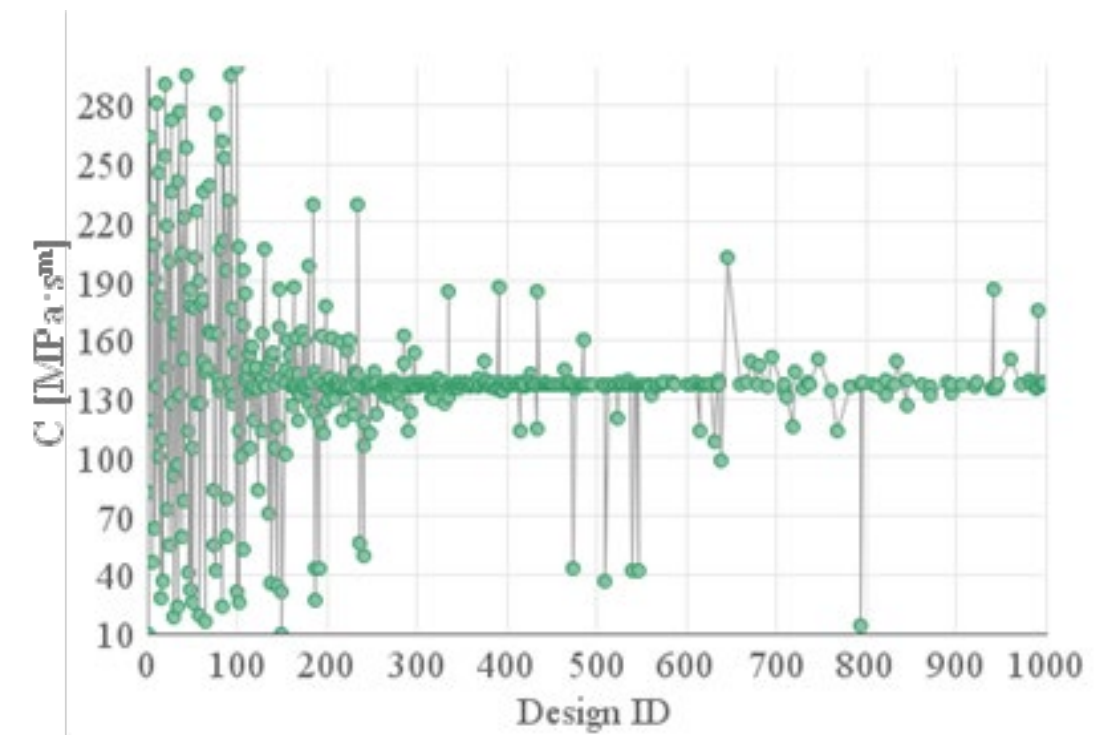
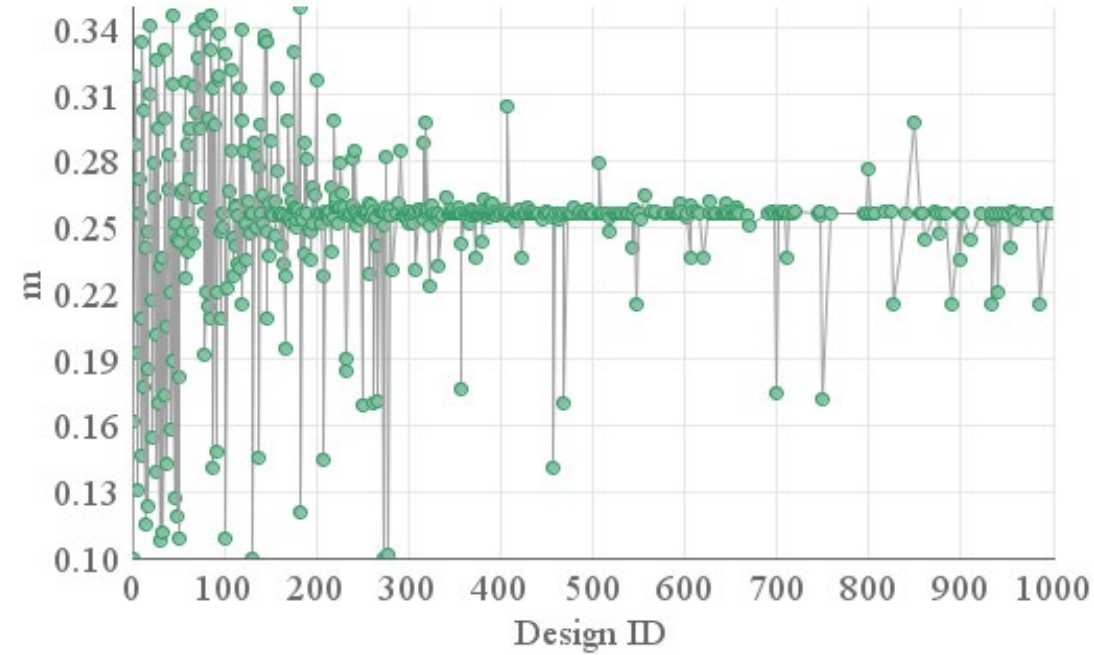
MOGA-II
(Multi-Objective
Genetic Algorithm)

- **Precision in Inverse Problems:** Superior handling of non-linear correlations between C and m .
- **Multi-Search Elitism:** Preserves optimal candidate sets across generations, preventing premature convergence.
- **Global Exploration:** Efficiently explores the design space, avoiding entrapment in local minima.



Result and
Validation

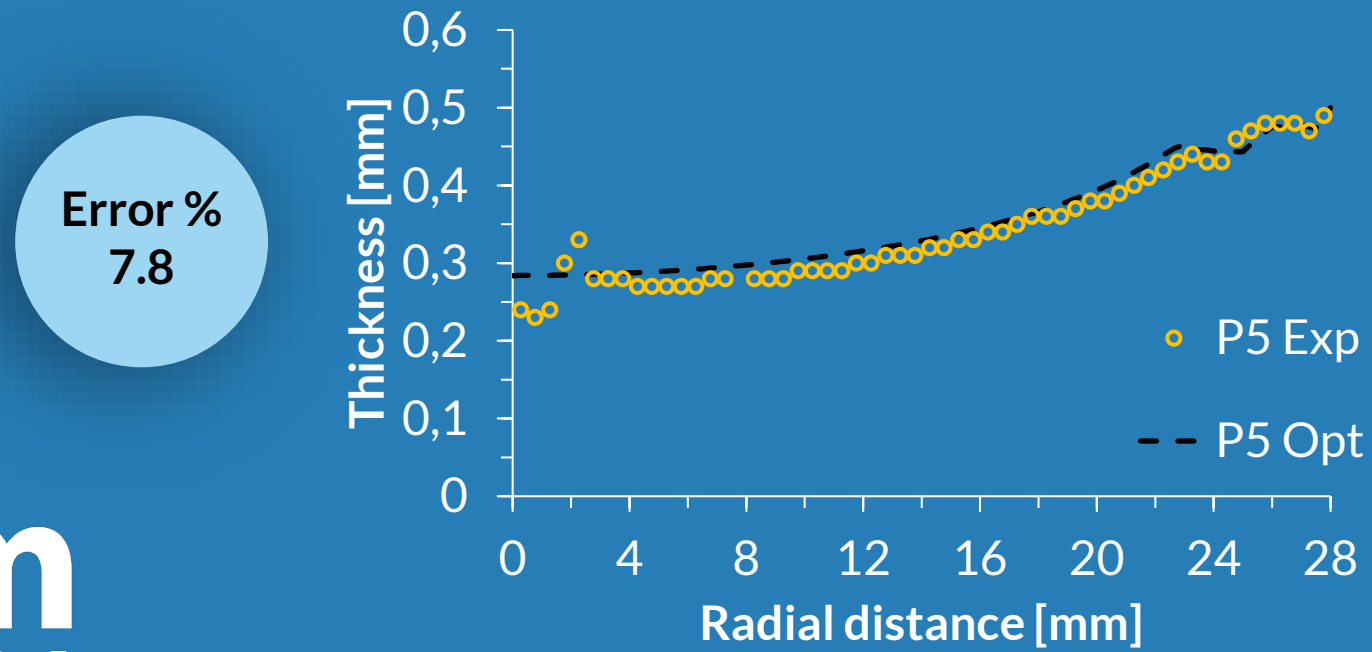
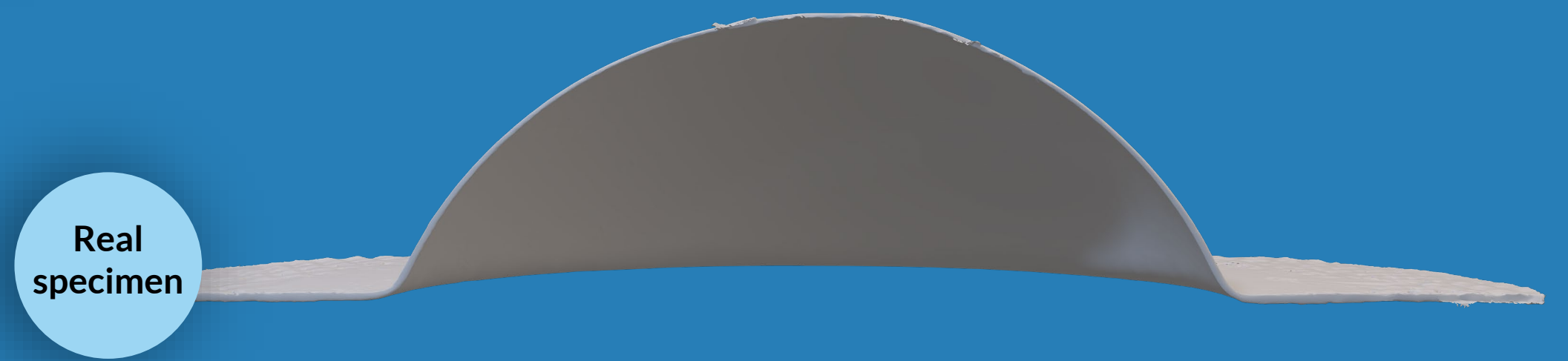
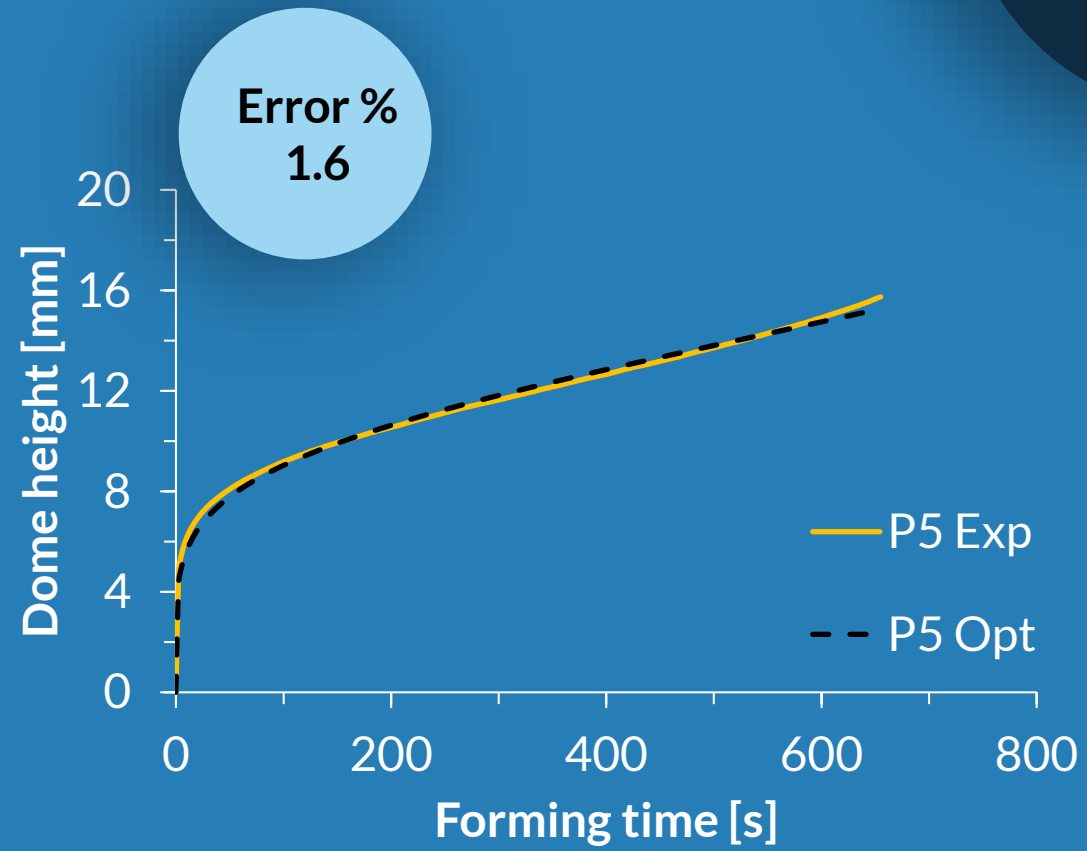
Identified Parameters



| ID | Pressione [MPa] | C [MPa·s ^m] | m |
|----|-----------------|-------------------------|-------|
| P5 | 0.5 | 141.6 | 0.256 |
| P6 | 0.6 | 137.8 | 0.257 |
| P8 | 0.8 | 140.5 | 0.264 |

Limited variation (~3%) indicates high methodology accuracy across different loading regimes, confirming parameter consistency.

Validation:

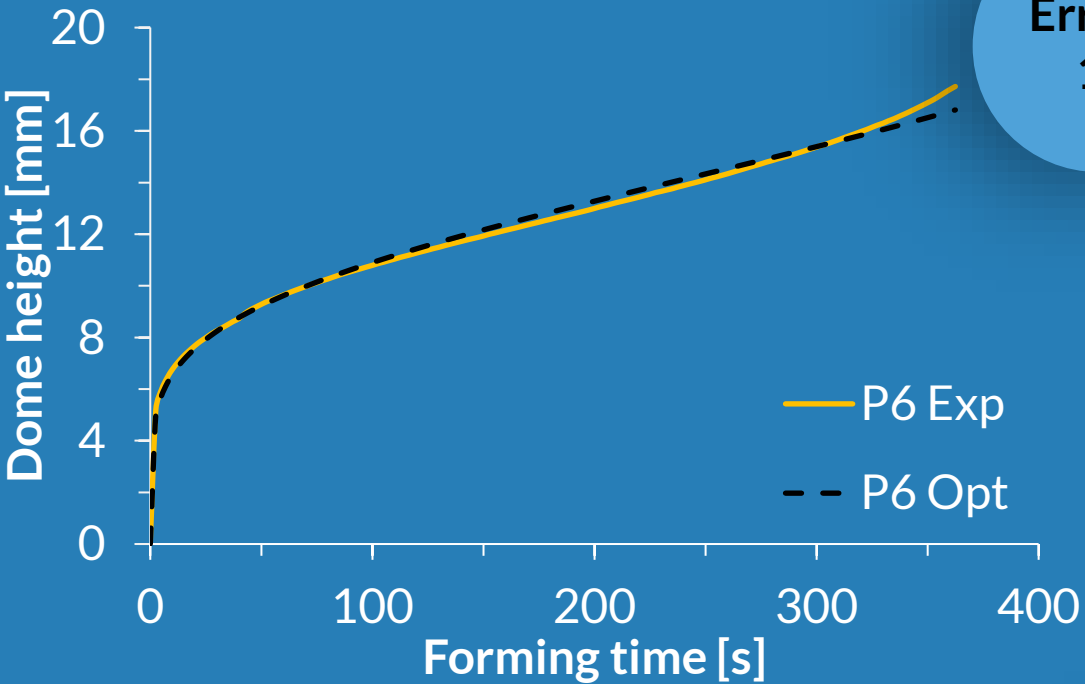


Validation:

P6 CASE
COMPARISON

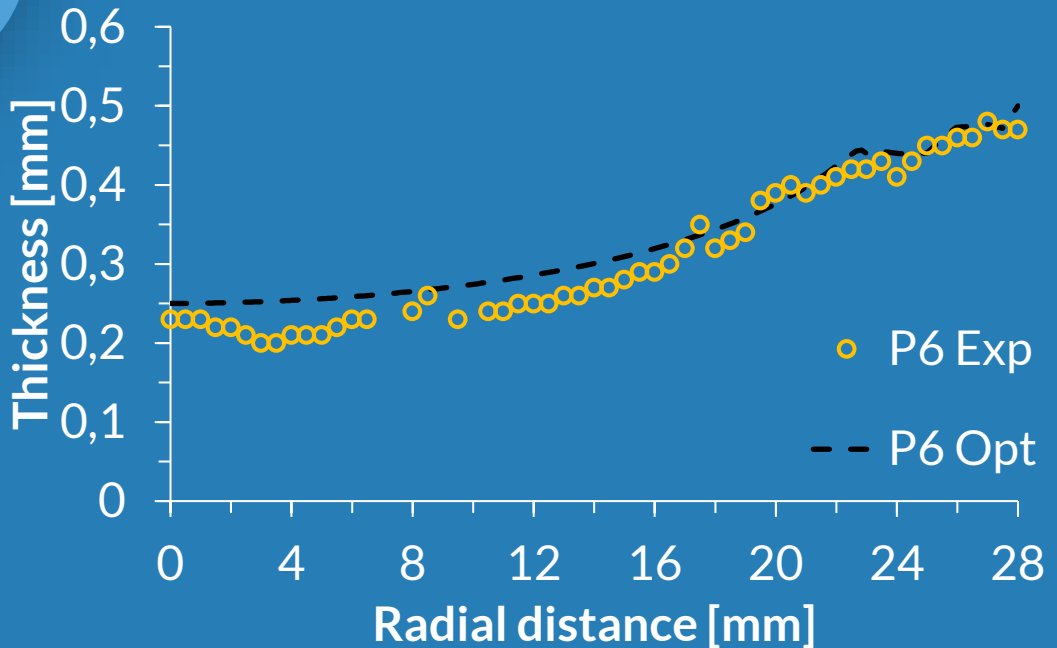


Result and
Validation

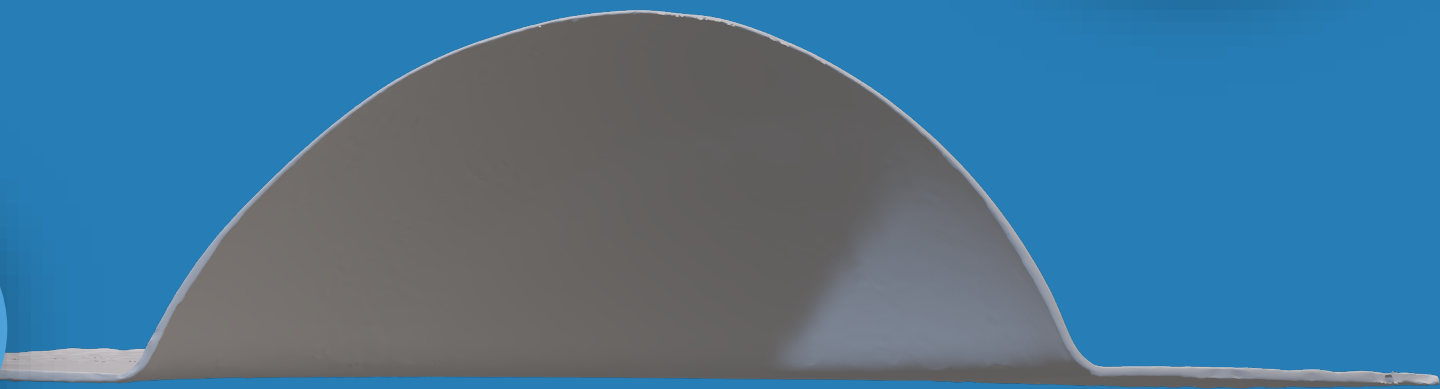


Error %
1.5

Error %
7.5



Real
specimen



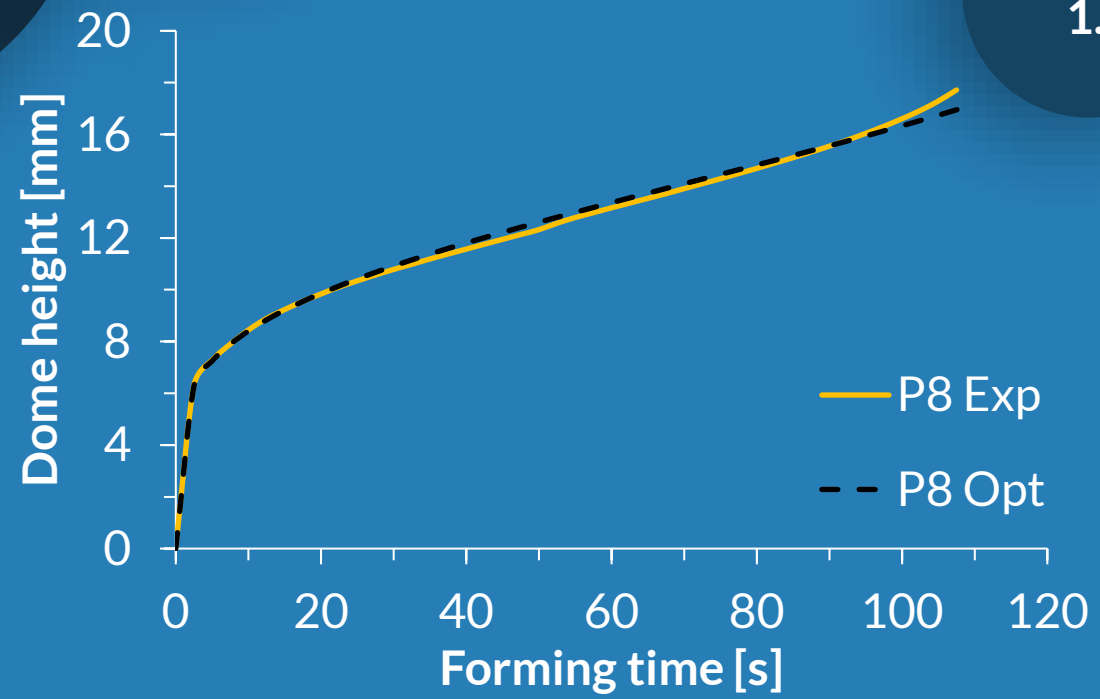
Best
design



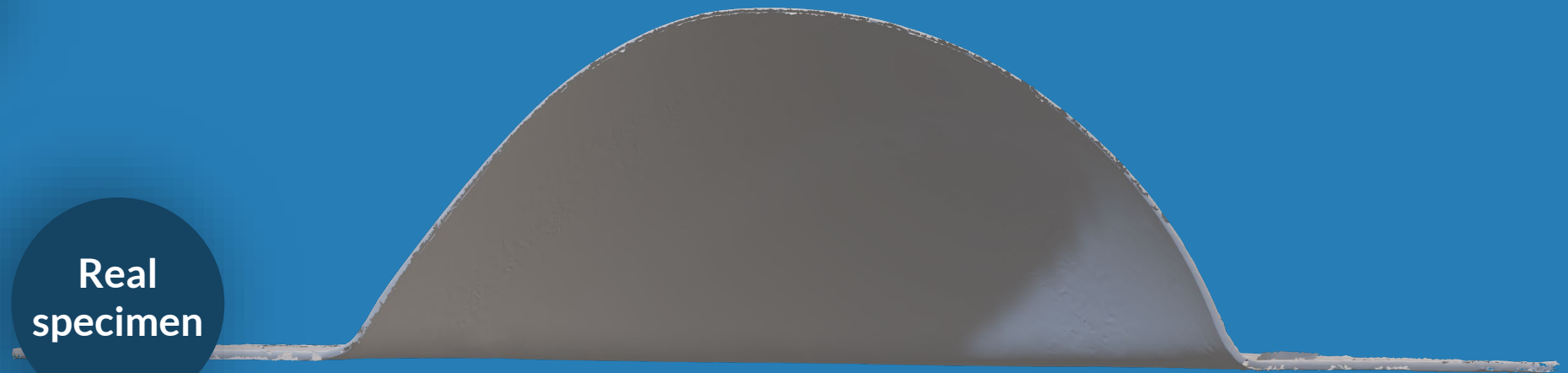
P8 CASE
COMPARISON

Validation:

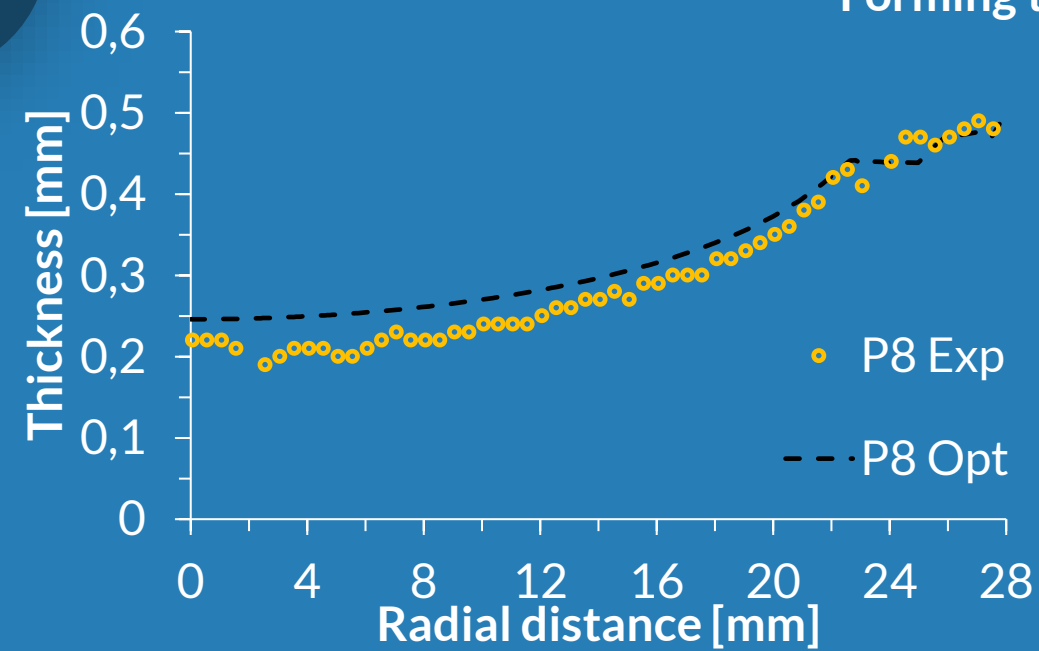
Result and
Validation



Error %
1.3



Error %
8.9

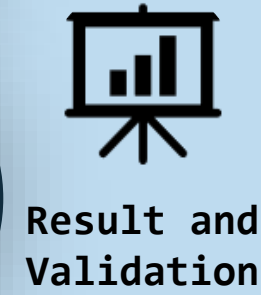


Best
design



Validation:

P7 CASE



Result and Validation



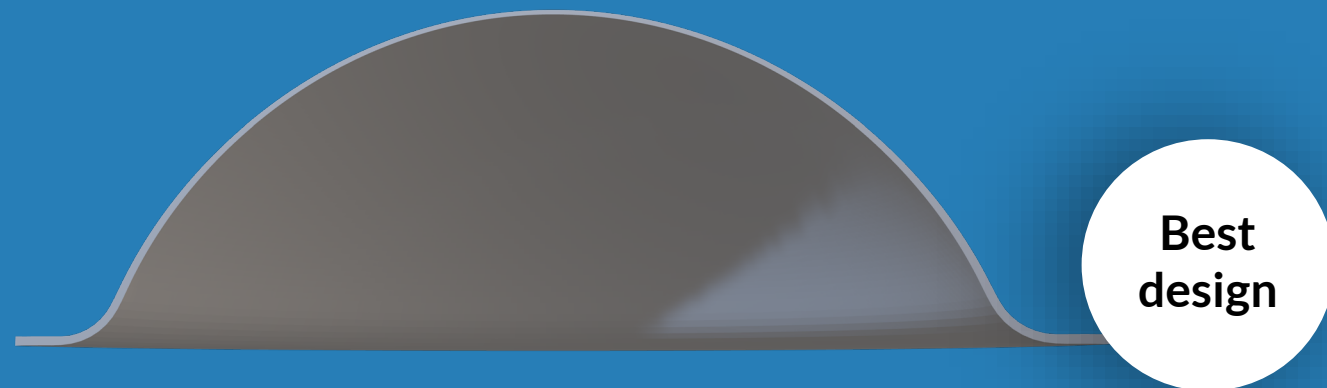
Predictive Interpolation

Constants for P7 were estimated using a **second-order polynomial function** (parabolic fit) based on P5, P6, and P8 results.

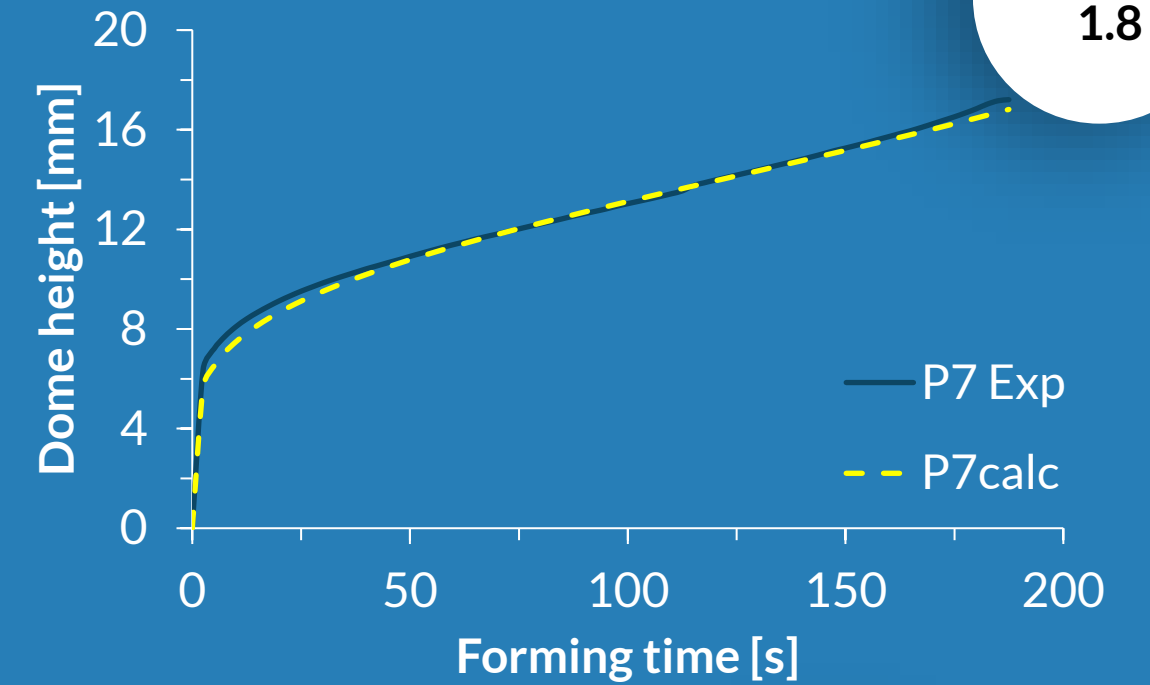
| ID | Pressione [MPa] | C [MPa·s ^m] | m |
|--------|-----------------|---------------------------|-------|
| P7calc | 0.7 | 137.5 | 0.259 |



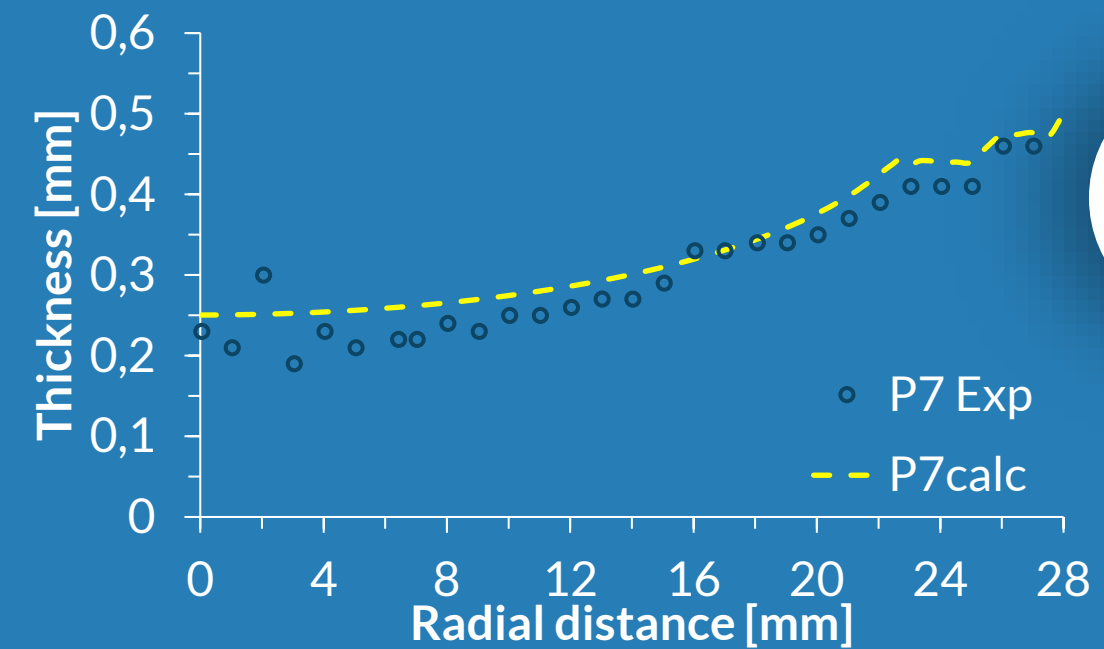
Real specimen



Best design



Error %
1.8



Error %
10

Conclusions



Accurate Calibration

The Sequential Double-Step procedure effectively decouples m and C , ensuring physical consistency.

Integrating **Abaqus + modeFRONTIER** created a reliable results for AA5754-H22 gas forming applications at 400°C.



High Predictive Capability

The identified parameters of the three case demonstrate the accuracy of the two step inverse approach. This accuracy is confirmed by the limited errors of the intermediate P7 condition whose values were calculated from a second order polynomial function.



Flexibility of the proposed methodology

We can apply this workflow also for different materials starting from experimental data.

um
2026

Questions?
THANK YOU FOR YOUR ATTENTION

esteco.com



Letizia Barcellona
PhD student

 Politecnico di Bari

 l.barcellona@phd.poliba.it

