Closing the Sim-to-Reality Gap: Thermo-Mechanical Validation of “In-Wood Decoration” Insert Molding

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Focused on simulation-to-reality correlation, turning Moldflow into smarter tooling and manufacturing decisions.

Can Moldflow reliably predict warpage in natural wood-veneer insert molding?

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- Natural wood is not a conventional engineering material
- Its anisotropy and thermal behavior complicate prediction
- Yet process decisions still depend on reliable simulation
- This work shows a practical path to improve correlation

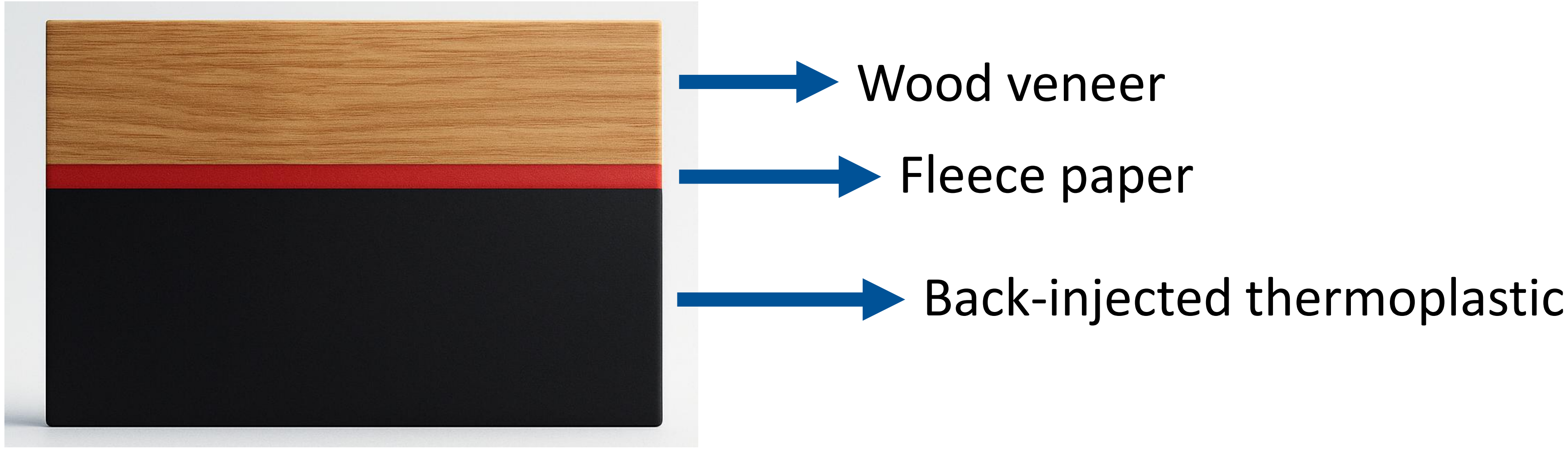
ROADMAP

1. **Background**
2. **Methodology**
3. **Validation Results**
4. **Extending Moldflow Capabilities**
5. **Learnings & Next Steps**

“A refined simulation workflow can significantly improve predictive accuracy and decision-making”

What is In-Wood Decoration?

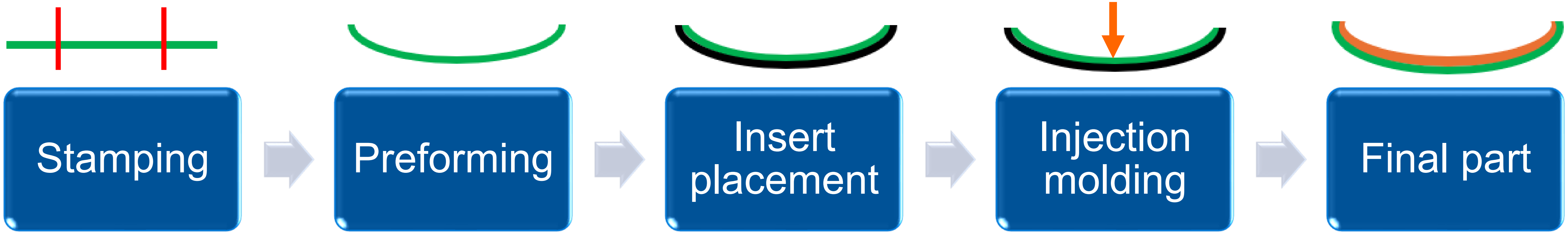
Simplified process overview



Wood veneer

Fleece paper

Back-injected thermoplastic



Stamping

Preforming

Insert placement

Injection molding

Final part

Warpage as a business problem

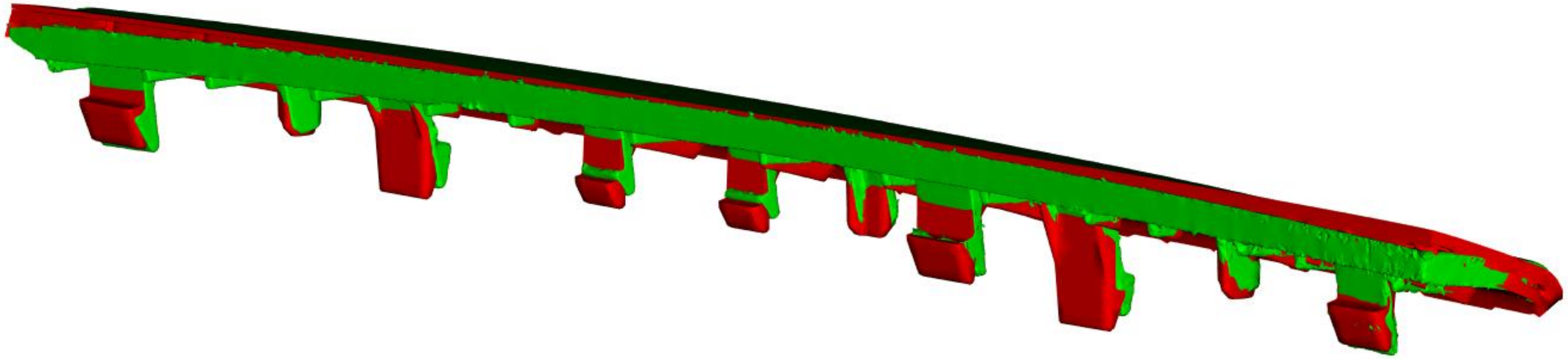
Why does it matter?

Impacts

- Scrap, rework, extra inspection, and customer risk
- Ramp-up instability and repeated process adjustments
- Hidden engineering cost and reduced process confidence

If correlation improves

- Fewer adjustments and faster process stabilization.
- Lower risk of warpage-related scrap and rework
- Better decision-making earlier in development.

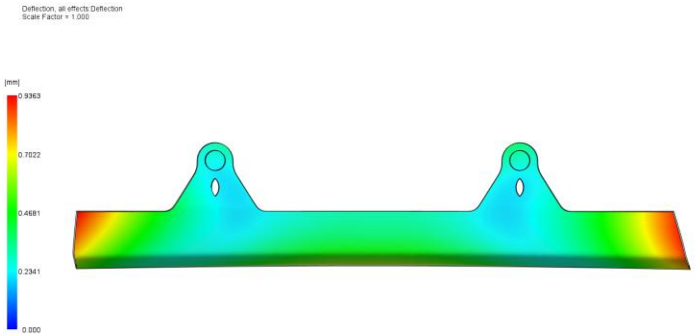


Indicative impact ranges based on engineering experience and prior project observations.

Evolution of the warpage modeling approach

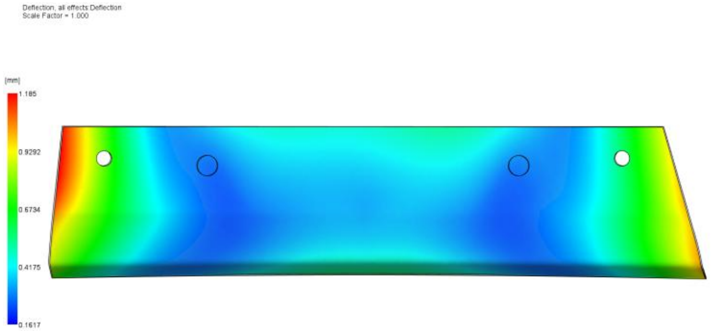
From polymer-only behavior to insert-aware prediction

Early stages



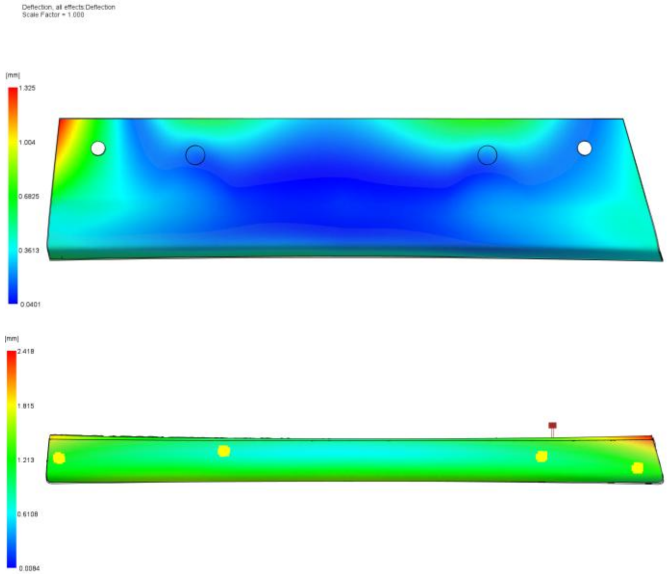
Simulation focused mainly on polymer behavior

First key milestone



Insert materials were introduced using substitute models

My contribution



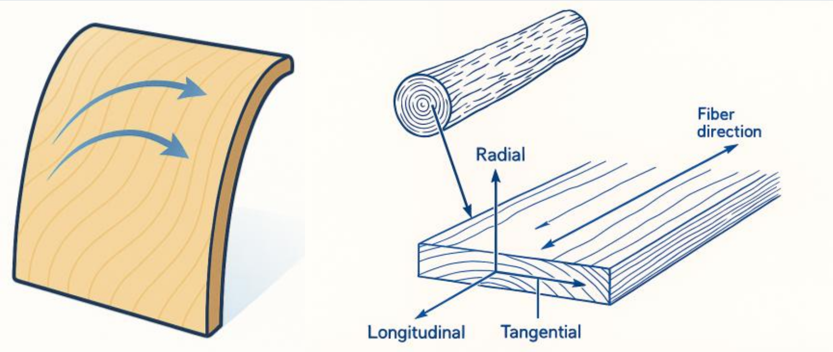
Physical investigation to calibrate orthotropic properties and extend Moldflow’s practical limits

The technical gap

Where the “standard recipe” failed

Standard Assumption	Process reality	Impact on prediction
Idealized process conditions	Real shop floor variation	Weak process correlation
Incomplete cooling assumptions	Insert, Polymer and Mold temperatures matter	Deflection is mispredicted at a first-order level.
Substitute material model	Veneer is orthotropic	Wrong shape response

Most Critical Assumptions



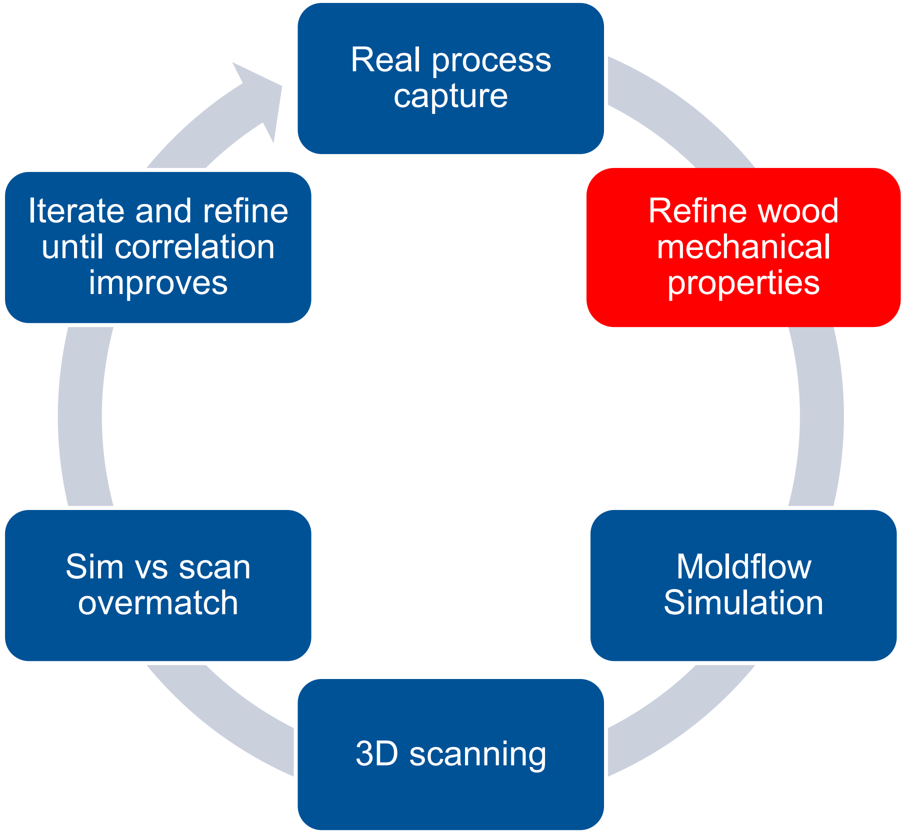
The biggest source of error was not the solver itself, but unrealistic physical assumptions.

My objective and workflow

Closing the Simulation-to-Reality Gap

Objective.

- Predict injected-part deflection with >80% coverage within ±0.10 mm
- Improve warpage control through orthotropic wood characterization
- Explore a path toward post-milling deflection prediction



Real process capture

Refine wood mechanical properties

Moldflow Simulation

3D scanning

Sim vs scan overmatch

Iterate and refine until correlation improves

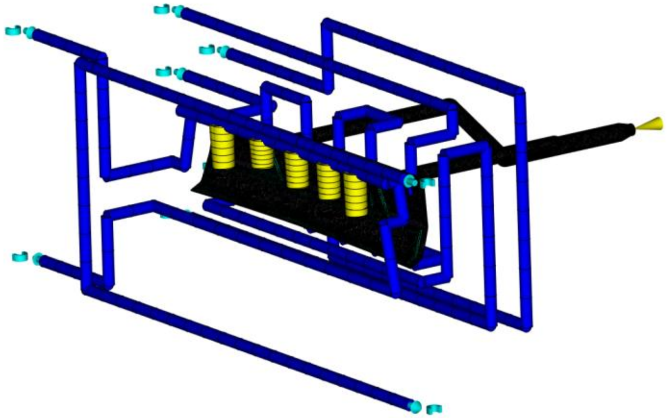
Moldflow setup

Key elements used to build a physically informed model

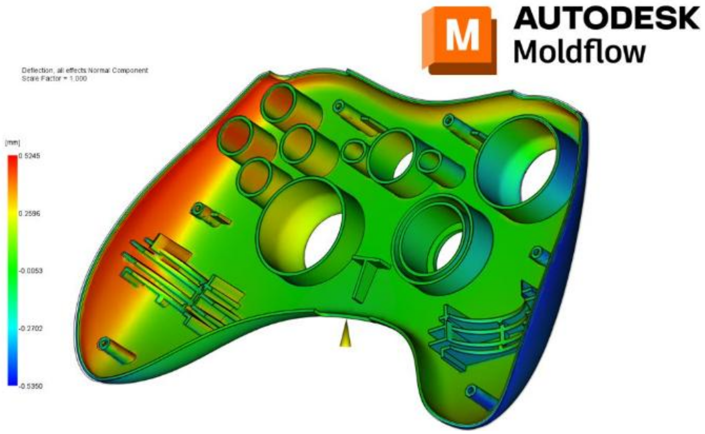
Real data

STAMP

Full model scope



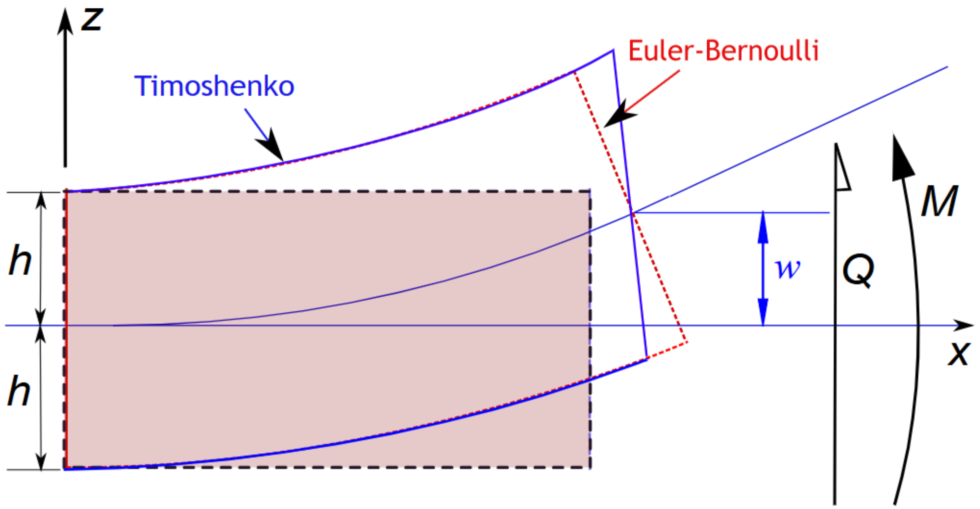
Deflection: Normal Component

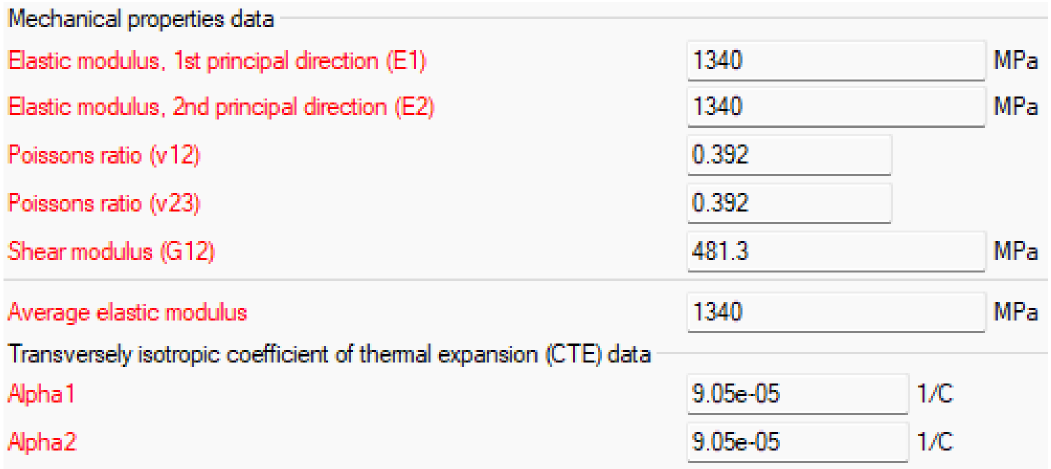


A useful setup tip is to work with *flow rate vs. ram position*, which typically provides better control and response than *ram speed*.

Wood insert characterization

The key lever to improve results





Mechanical properties data		
Elastic modulus, 1st principal direction (E1)	1340	MPa
Elastic modulus, 2nd principal direction (E2)	1340	MPa
Poissons ratio (v12)	0.392	
Poissons ratio (v23)	0.392	
Shear modulus (G12)	481.3	MPa
Average elastic modulus	1340	MPa
Transversely isotropic coefficient of thermal expansion (CTE) data		
Alpha1	9.05e-05	1/C
Alpha2	9.05e-05	1/C

“Illustrative interface view”

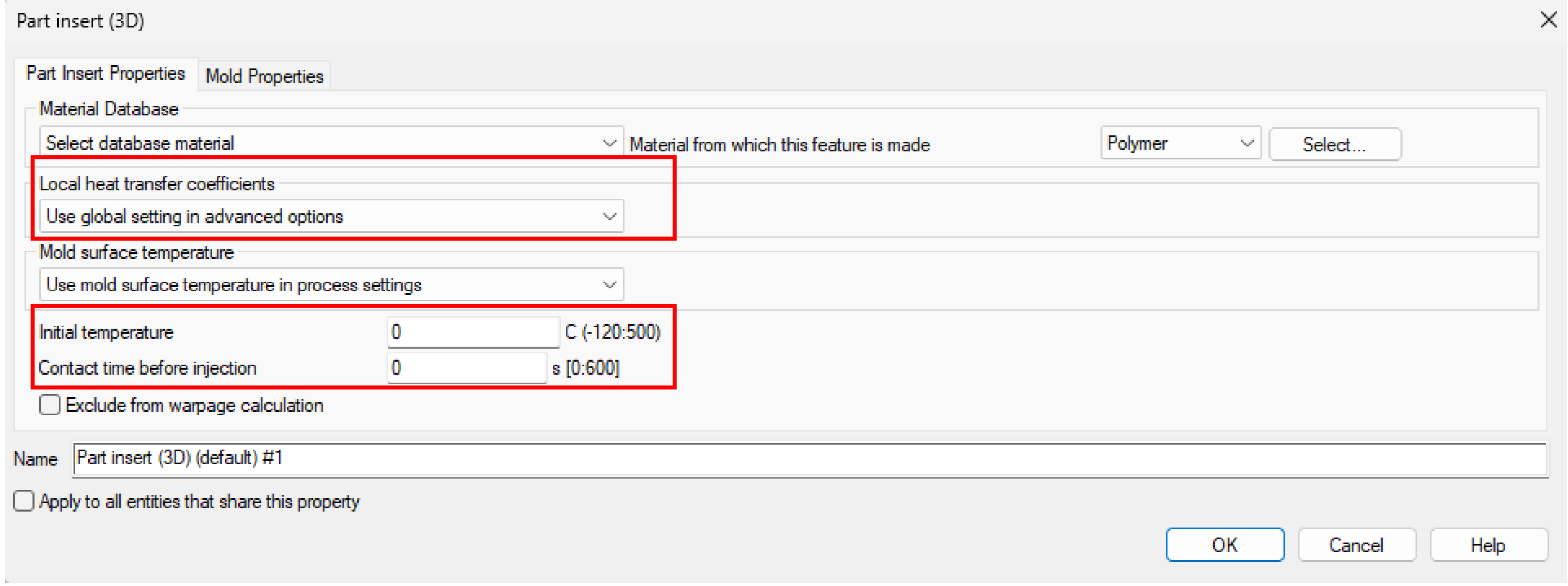
Wood is not a “generic solid”—it requires orthotropic mechanical properties:

- Axis 1 (along the grain) = higher stiffness, lower thermal expansion.
- Axis 2 (across the grain) = lower stiffness, higher thermal expansion.

This directional behavior strongly affects warpage shape

Wood insert characterization

Thermal conditions also matter



Part insert (3D)

Part Insert Properties | Mold Properties

Material Database: Select database material — Material from which this feature is made: Polymer

Local heat transfer coefficients: Use global setting in advanced options

Mold surface temperature: Use mold surface temperature in process settings

Initial temperature: 0 C (-120:500)

Contact time before injection: 0 s [0:600]

☐ Exclude from warpage calculation

Name: Part insert (3D) (default) #1

☐ Apply to all entities that share this property

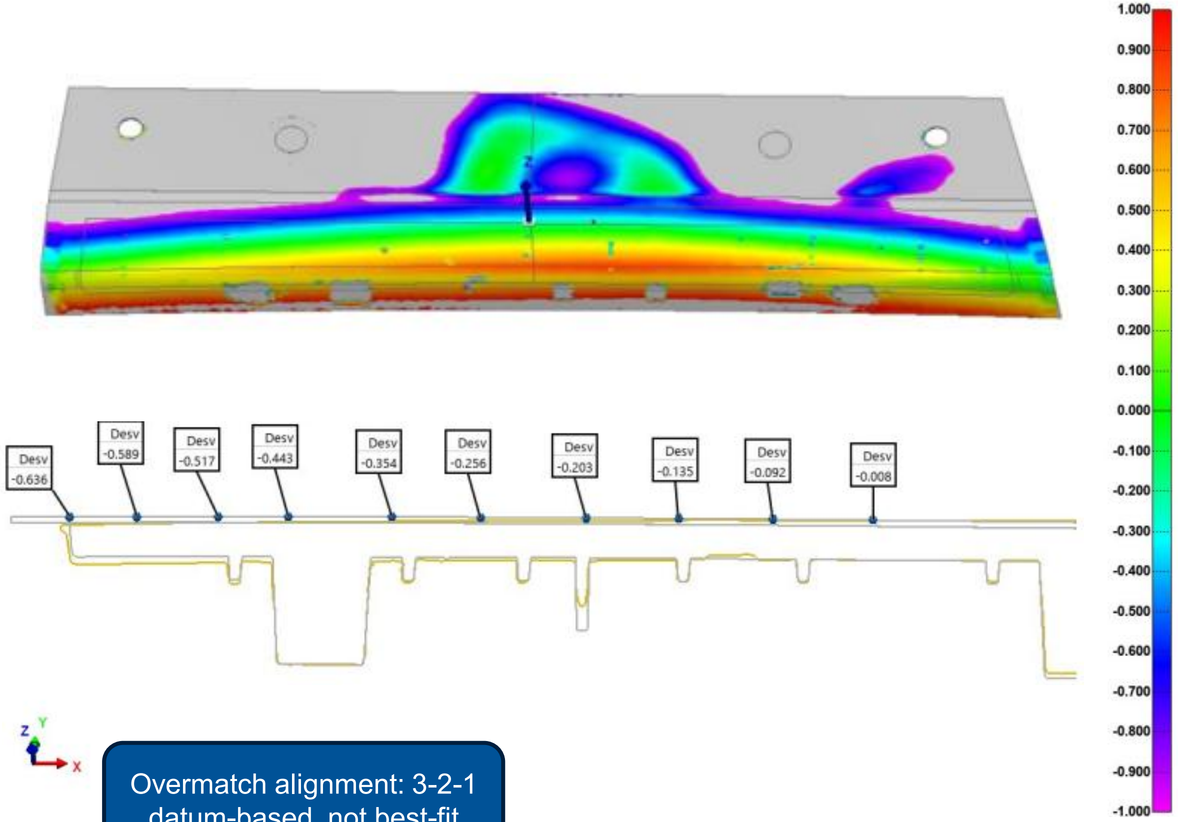
The temperature difference between insert and polymer until freezing affects warpage development

- ➢ Insert initial temperature and contact time before injection are relevant inputs
- ➢ The effective heat transfer coefficient can be adjusted to better reflect real thermal interaction.

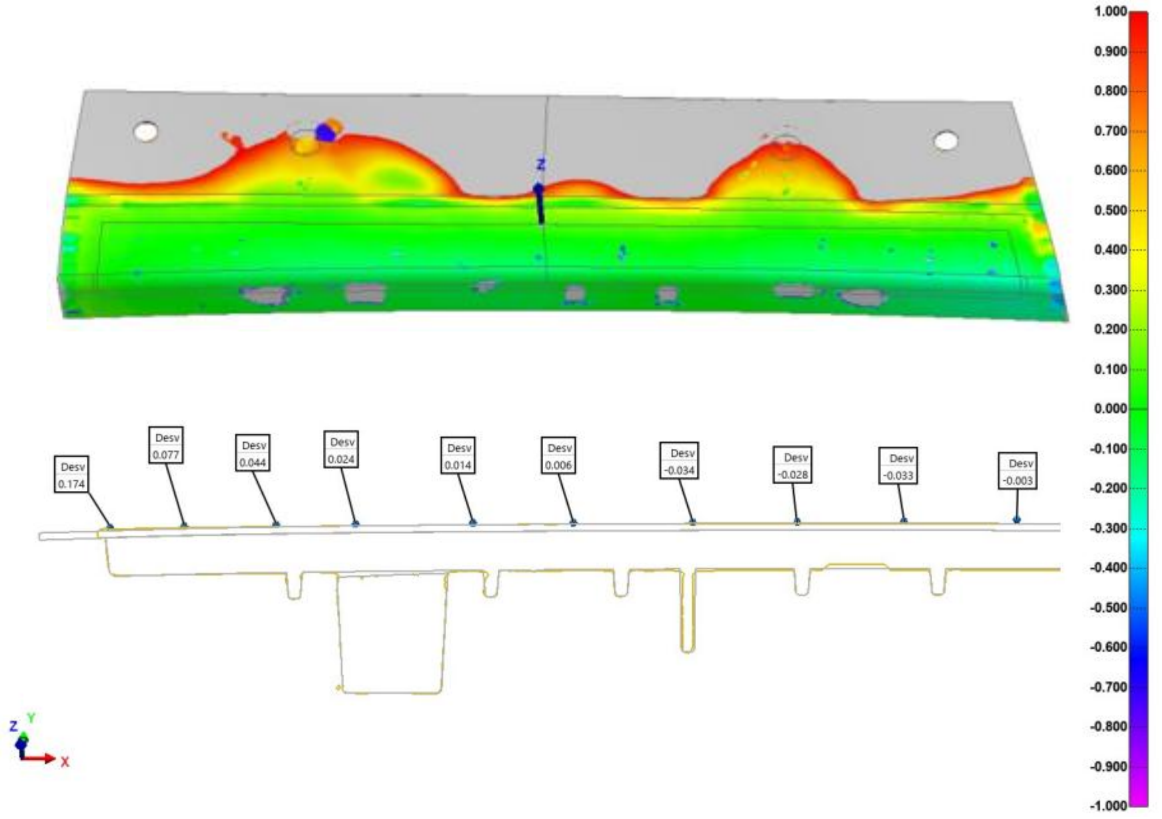
Validation: shape correlation before vs. after calibration

Scan-to-Simulation Comparison (Overmatch): Measured Mesh vs Deflected CAD

Before: without adjustments.



After: with adjustments.



Overmatch alignment: 3-2-1 datum-based, not best-fit

Validation: shape correlation before vs. after calibration

Metrics Used for Correlation

Static Metric	Before	After
N (measure points)	20	20
Average (mm)	−0.2916	**−0.0003**
Standard Deviation (mm)	0.2312	**0.0835**
RMSE (mm)	0.3686	**0.0814**
MAE (mm)	0.2997	**0.0455**
Min / Max (mm)	−0.722 / 0.071	**−0.290 / 0.174**

Calibration significantly reduced bias and improved correlation quality.

Tolerance	Before	After
✓ **±0.8 mm:**	100%	100%
✓ **±0.5 mm:**	75%	100%
✓ **±0.2 mm:**	35%	95%
✓ **±0.1 mm:**	25%	90%

The results show a major performance jump when applying the calibrated mechanical properties:

Coverage within ±0.10 mm improves from 25% to 90%.

Post-milling (predicting deflection after cutting)

New conditions = new deflection

Why post-milling deflection changes:

1. Fixturing and datuming strategy.
2. Mechanical and thermal effects during cutting.
3. Wood–polymer interaction.
4. **Removal of molding-support material.**
5. Time and environment effects.

If material removal is the dominant driver, a practical approximation path becomes possible.

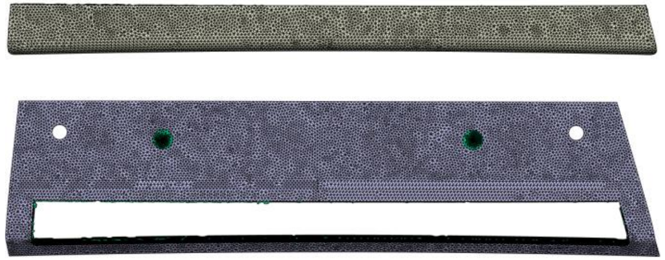
Post-milling (predicting deflection after cutting)

Workflow

Select and identify the final geometry and machined features

Exclude trimmed regions from warpage calculation

Approximate fixture constraints and datums



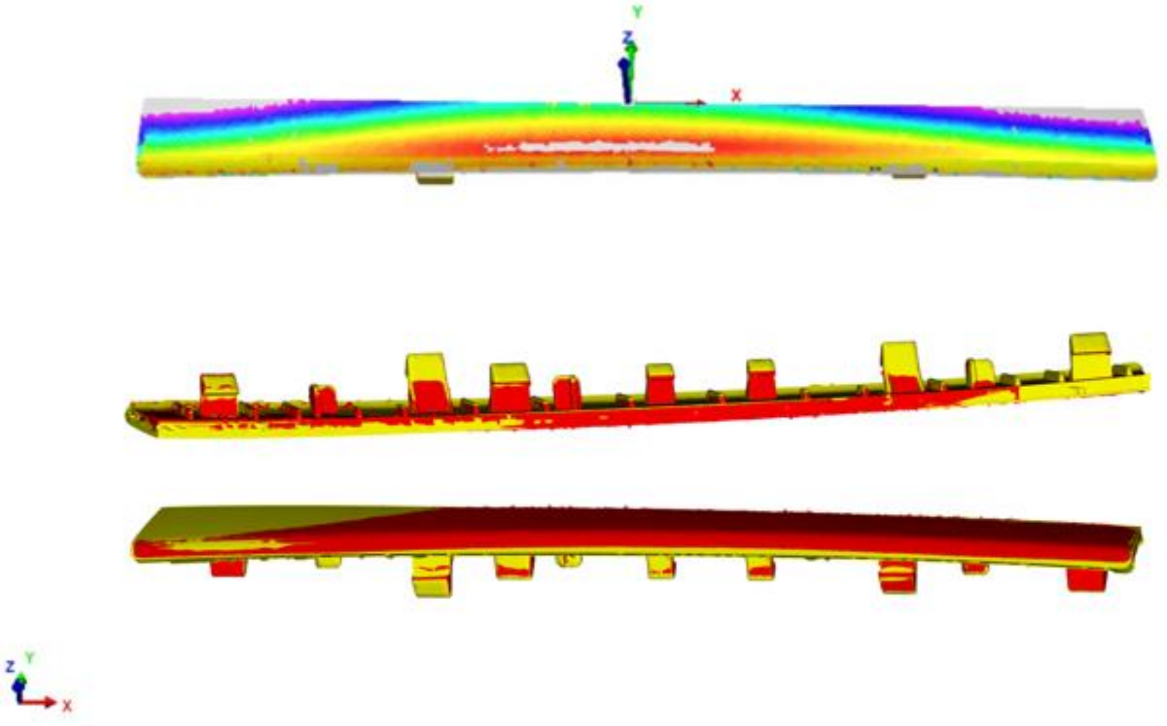
☑ Exclude from warpage calculation

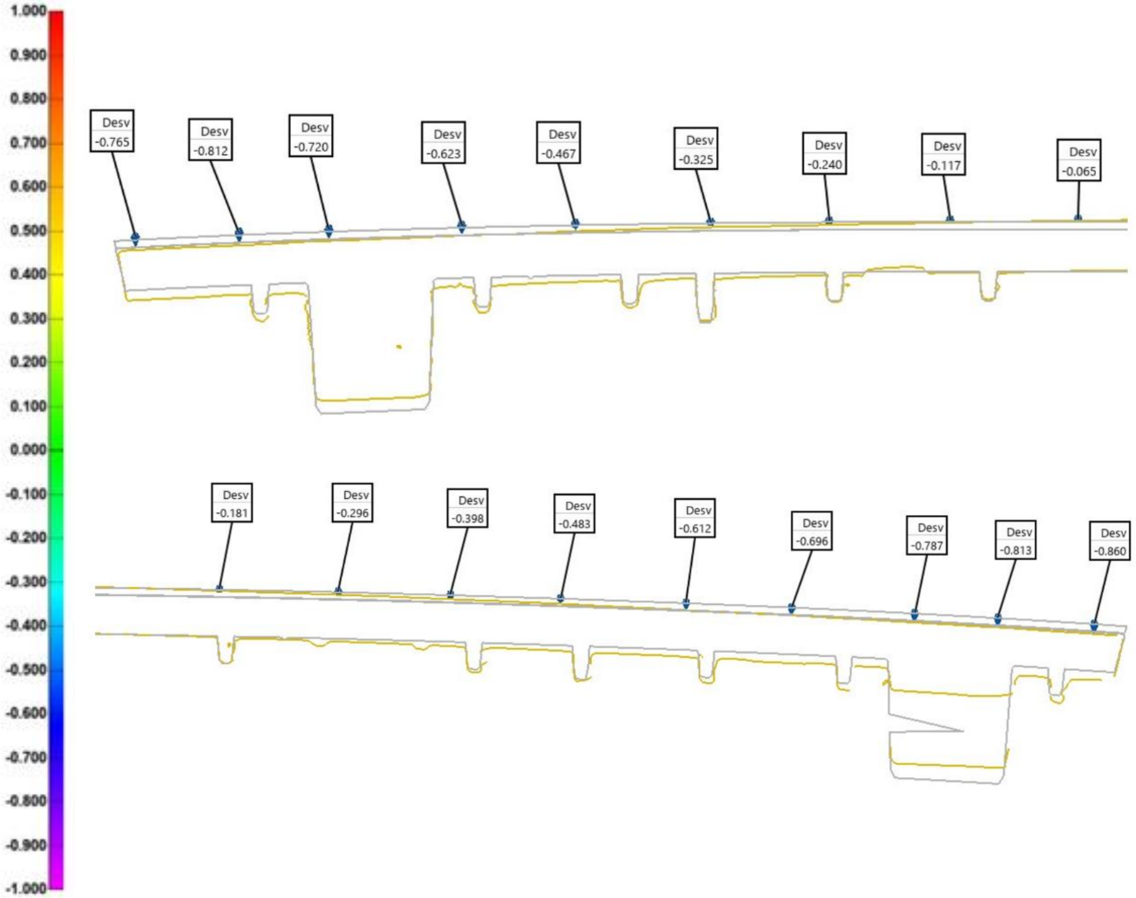
Re-running the analysis under post-milling conditions produces a different and more realistic deflection state.

Post-milling validation: first approximation

Scan-to-Simulation Comparison (Overmatch): Measured Mesh vs Deflected CAD

Overmatch alignment: 3-2-1 datum-based, not best-fit





Post-milling validation: first approximation

Metrics Used for Correlation

Static Metric	After
N (measure points)	18
Average (mm)	**−0.514**
Standard Deviation (mm)	**0.263**
RMSE (mm)	**0.574**
MAE (mm)	**0.514**
Min / Max (mm)	**−0.860 / 0.065**

Tolerance	After
✓ **±1.0 mm:**	100%
✓ **±0.8 mm:**	83.3%
✓ **±0.5 mm:**	50.0%
✓ **±0.2 mm:**	16.7%
✓ **±0.1 mm:**	5.6%

- **First quantified** post-milling approximation in our workflow.
- 100% of points within **±1.0 mm** and 50% already within **±0.5 mm.**
- A systematic bias remains, creating a clear calibration path for the next iteration.

Lessons learned and next steps

How we scale the method beyond one program—while closing the remaining gaps

Lessons learned

- Capture real process data, not only nominal settings.
- Use early sim-vs-scan comparison to accelerate tuning.
- Treat natural inserts with directional properties, not generic substitutes.

Limits and Next Steps

- Address humidity and grain-orientation effects.
- Build a more robust wood-material database.
- Extend the method to other inserts.
- Couple post-milling prediction with fixture/process data.

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THANK YOU

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