Computational Rheology @IPC

Using open-source tools for aiding the Portuguese safety footwear industry

OIMUO IV - Online International Meeting for Users of OpenFOAM

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Outline

Outline

Introduction

One of the most important internationalized sector of the Portuguese industry

High value-added products

Luxury footwear

Safety

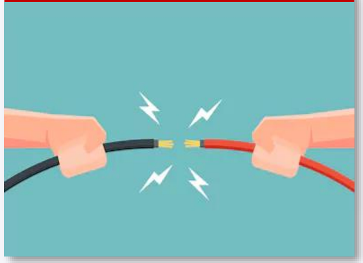
Europe market
1st: Italy (40 €)
2nd: Portugal (24 €)

China
low-cost products (6 €)
87% global production
84% global exportation

[1] APICCAPS - Portuguese Footwear, Components, Leather Goods Manufacturers' Association, "Statistical Report: Portugal," Footwear cluster 2018, 2018.

Introduction

Electrocution



Falling, crush and cut hazard

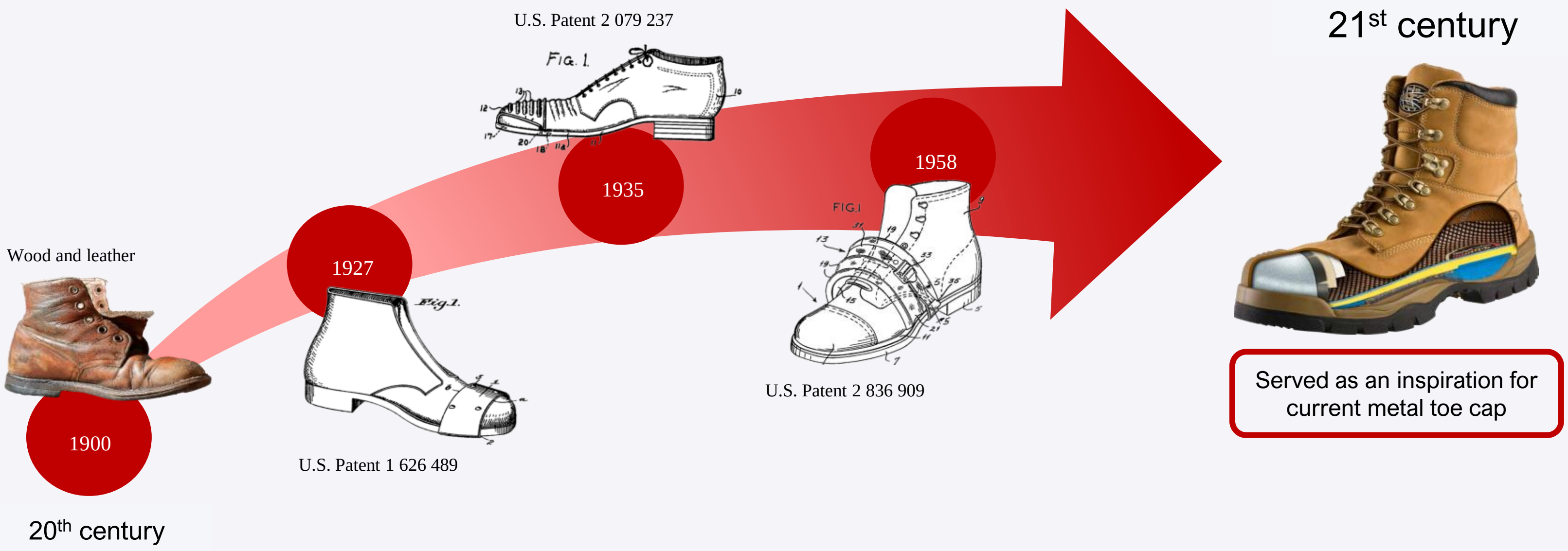
Slipping

Safety footwear are intended to protect the user from hazards at their labor place

Safety shoe

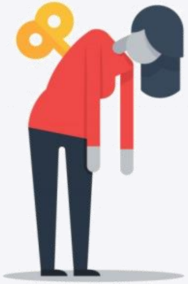
Toe cap

Introduction



Introduction

Increases human oxygen consumption.
Causes discomfort and fatigue [2, 3].



Less productivity.

Users tend to refuse the use safety shoes.

Not only safety, but
comfort and well-being are also important

[2] - S. S. Chiou, N. Turner, J. Zwiener, D. L. Weaver, and W. E. Haskell, “Effect of boot weight and sole flexibility on gait and physiological responses of firefighters in stepping over obstacles,” Human factors, vol. 54, no. 3, pp. 373–386, 2012.
[3] - M. J. Abreu, P. Mendonça, C. S. Pereira, and A. Abreu, Eds., Design of Innovative Protective Insoles for Safety Footwear. International Conference on Engineering, Technology and Innovation (ICE/ITMC): IEEE, 2017.

Introduction

SAFETY TOE CAP

METALLIC

- Oldest solutions (steel or aluminum);
- Present in most safety shoes;
- Stamping, casting or injection.

✗ Heavy (~35% total shoe weight);
✗ Electrically conductive;
✗ Permanent deformation;
✗ Inconvenience in security checkpoints.

NON-METALLIC

- New trend
- **Thermoplastic** or thermoset
- Injection or compression molding

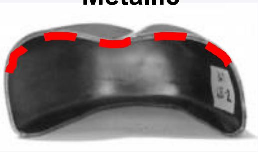
✓ Lighter (less 40% weight);
✓ Good electrical isolator;
✓ Recovers from deformation.

ISO 20345

Impact of **200 J**

Compression up to **15 kN**

Metallic



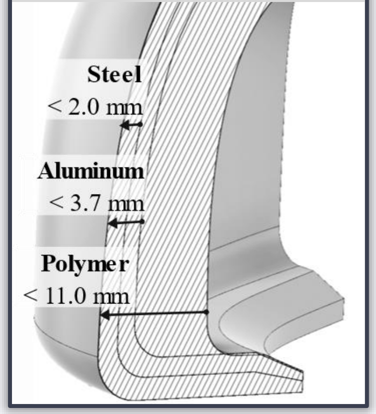
Permanent deformation

Non-metallic

Partial recovery

Airports - metal detectors

Toe cap thickness comparison



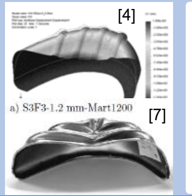
Requires higher volume concept

Causes aesthetic and design problems

Introduction

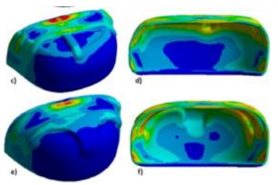
Metalic solutions

- Substitution of regular steel with stronger steel;
- Local hardening zones;
- Accounts for safety footwear requirements;
- Weight saving up to 50%.



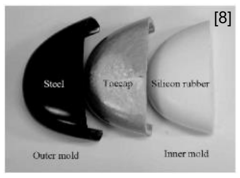
[4] [7]


[5,6]

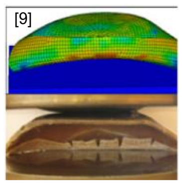


Polymer solutions

- Mostly thermosets with impregnated fibers (glass, aramid, carbon);
- Were not tested under safety footwear standard conditions (impact below 100 J, compression up to 10 kN).



[8]


[9]


[10]

Simulation

Commercial software →

ANSYS LS-Dyna solver;
ANSYS explicit dynamics;
SolidWorks Simulation;

ABAQUS Standard;
ABAQUS Explicit.

To expensive for small companies.

[4] S. Costa, N. Peixinho, and J. P. Mendonça, “Design and Testing of a New Metallic Solution for Toecap Component on Safety Footwear,” Applied Mechanics and Materials, 44-47, pp. 1460–1464, 2011.
[5] S. L. Costa, J. P. Mendonça, and N. Peixinho, “Numerical Simulation of Quasi-Static Compression Behavior of the Toe Cap Component for Safety Footwear,” International Journal of Computer Theory and Engineering, vol. 6, no. 4, pp. 285–291, 2014.
[6] S. L. Costa, J. V. Silva, N. Peixinho, and J. P. Mendonça, “Advanced Metallic Solution for Toe Cap Component,” Proceedings of the ASME 2013 International Mechanical Engineering Congress and Exposition, pp. 1–9, 2013.
[7] N. Peixinho, S. Costa, and J. Mendonça, “Impact Behaviour of Safety Shoe High Strength Steel Parts,” Engineering Transactions, vol. 66, no. 2, pp. 175–185, 2018.
[8] S. M. Lee, T. S. Lim, and D. G. Lee, “Damage tolerance of composite toecap,” *Composite Structures*, vol. 67, no. 2, pp. 167–174, 2005.
[9] C. C. Yang, M. Duhovic, R. J. T. Lin, and D. Bhattacharyya, “Finite element modelling and analysis of composites toecaps,” *IOP Conference Series: Materials Science and Engineering*, vol. 4, pp. 1–6, 2009.
[10] S. Erden and M. Ertekin, “Mechanical Evaluation of a Composite Overshoe Protector,” *TEKSTIL VE KONFEKSIYON*, vol. 27, pp. 414–420, 2017.

Outline

Goals

1. Characterize thermoplastic toe caps to obtain the material properties;
2. Simulate standardized mechanical quality testes performed at the industry level;
3. Compare the results.

Outline

Methodology

Characterization

Structural analysis	*InfraRed spectroscopy*
Morphology analysis	***S**canning **E**lectron **M**icroscopy*
Thermal analysis	***D**ifferential **S**canning **C**alorimetry*
Mechanical analysis	*Quasi-static test, 50 mm/min*

Computational workflow

OpenFOAM

solids4FOAM toolbox

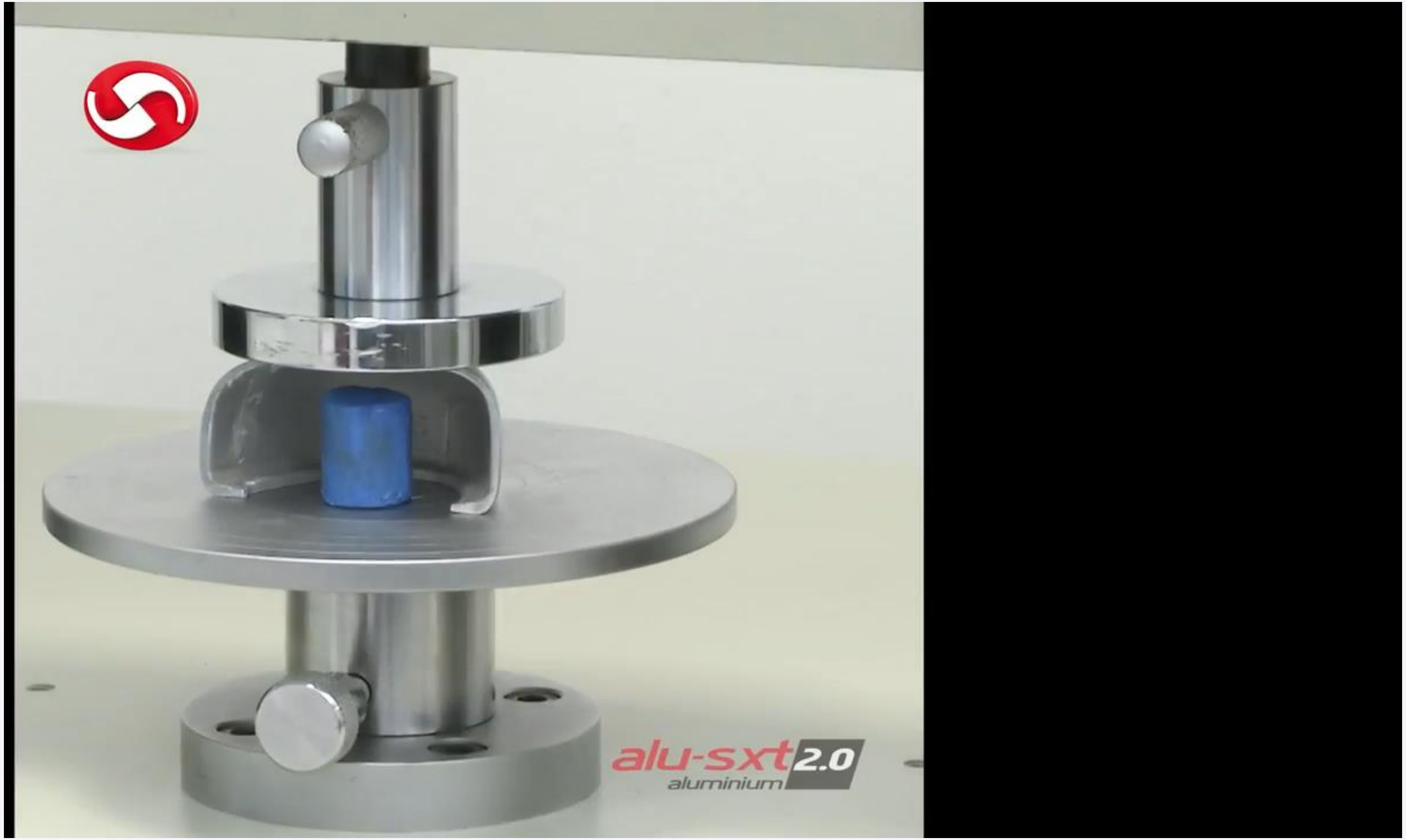
Compression test setup

Impact test setup

Outline

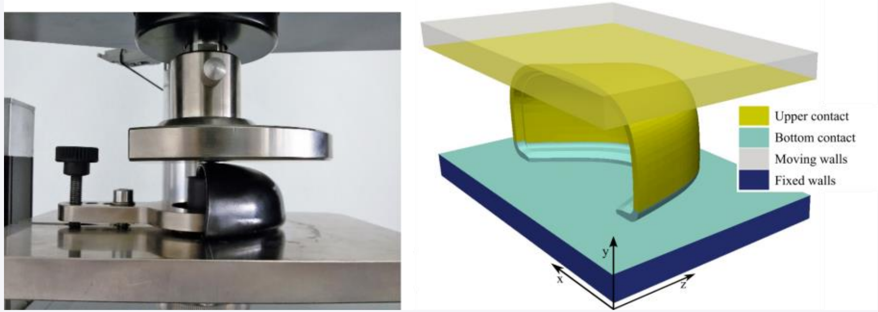
Modeling

Source: https://www.youtube.com/watch?v=seR6FdSRrQo

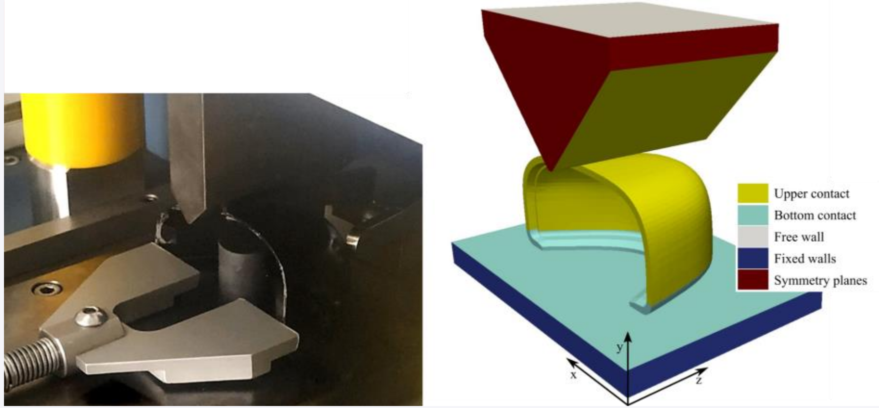


Modeling

Compression test, up to 15 kN



Impact test, 200 J



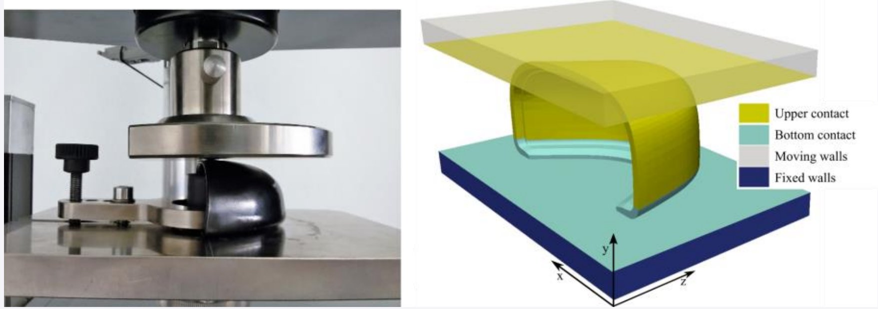
For simulation purposes:

- ✓ Moving top plane at 5 mm/min;
- ✓ Stop when top plane reaches 15 kN.

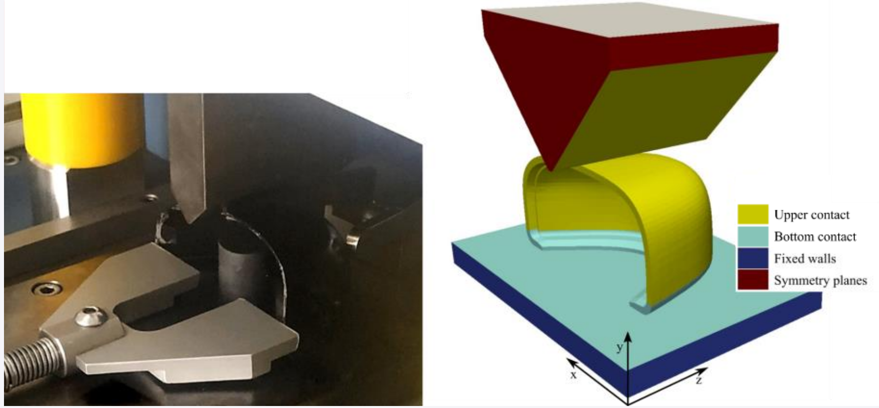
- ✓ Simulation starts with an initial velocity of the striker, corresponding to an impact energy of 200 J;
- ✓ Striker velocity reaches 0 m/s.

Modeling

Compression test, up to 15 kN



Impact test, 200 J



Patch	*Boundary*	
Upper contact	type	solidContact;
	frictionCoeff	0.3;
Bottom contact		
Moving walls	type	fixedDisplacement;
	displacementSeries	{5mm/min}
	value	uniform (0 0 0);
Fixed walls	type	fixedDisplacement;
	value	uniform (0 0 0);

Upper contact	type	solidContact;
	frictionCoeff	0.3;
Bottom contact		
Fixed walls	type	fixedDisplacement;
	value	uniform (0 0 0);
Symmetry planes	type	solidSymmetry

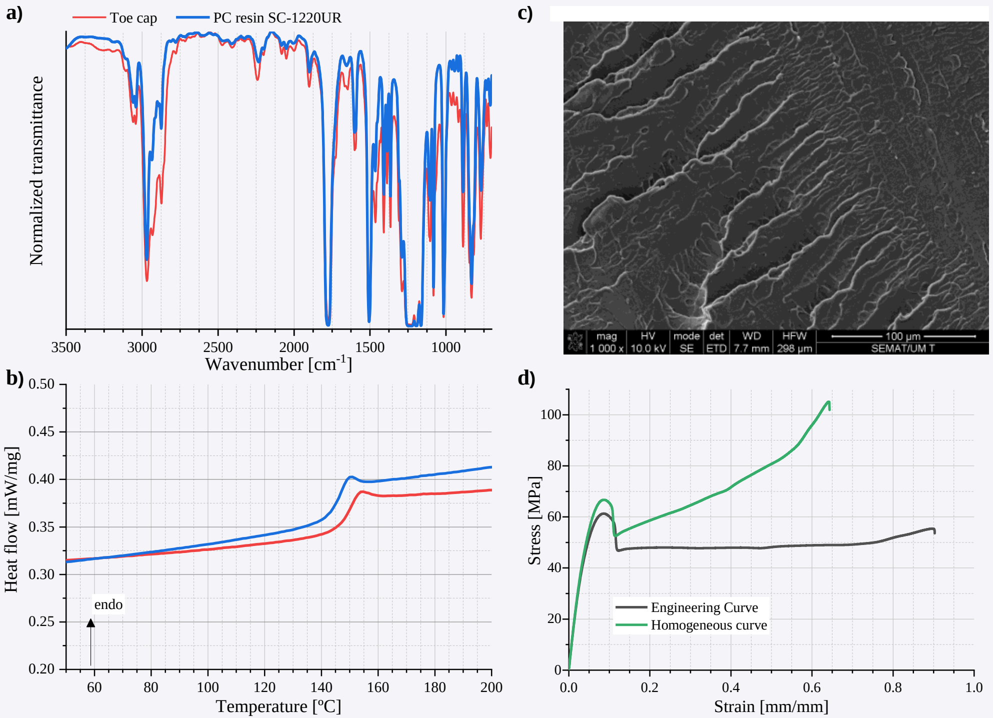
*initial velocity defined with *setFields*

Outline

- Introduction / Context
- Goals
- Methodology
- Modeling
- Results
- Conclusions and Future Work

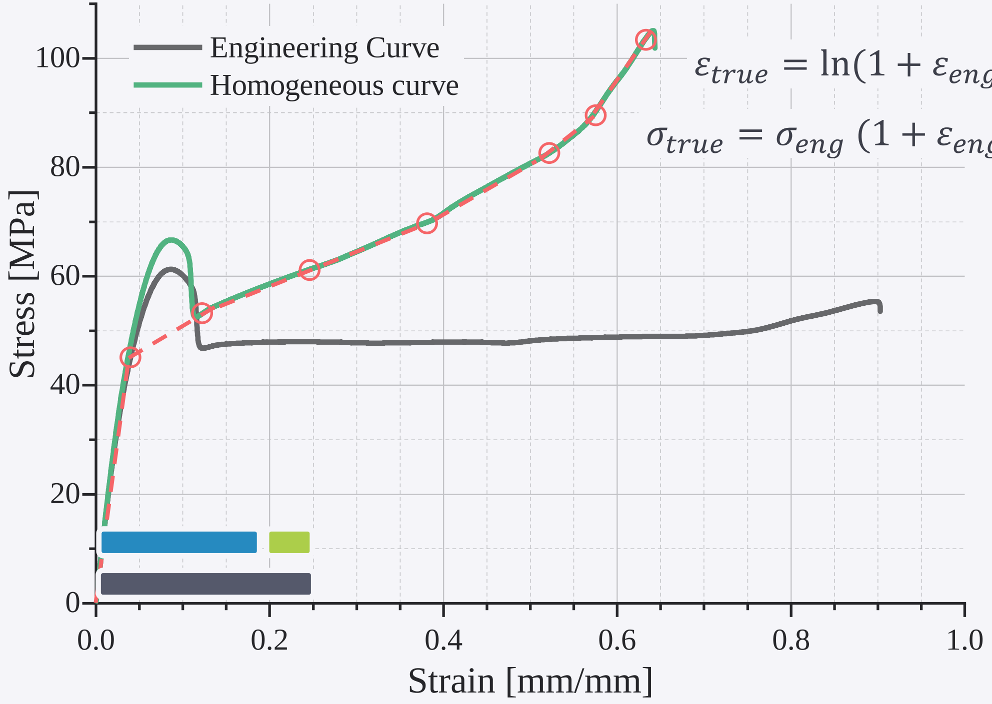
Results

Material characterization



Results

Material characterization



$$\varepsilon_{true} = \ln(1 + \varepsilon_{eng})$$

$$\sigma_{true} = \sigma_{eng}\,(1 + \varepsilon_{eng})$$

	Toe cap	Plate/striker	
Elastic Modulus	2.3	200	*GPa*
Poisson ratio	0.3	0.3	-
Density	1 200	7 850	*kg/m³*

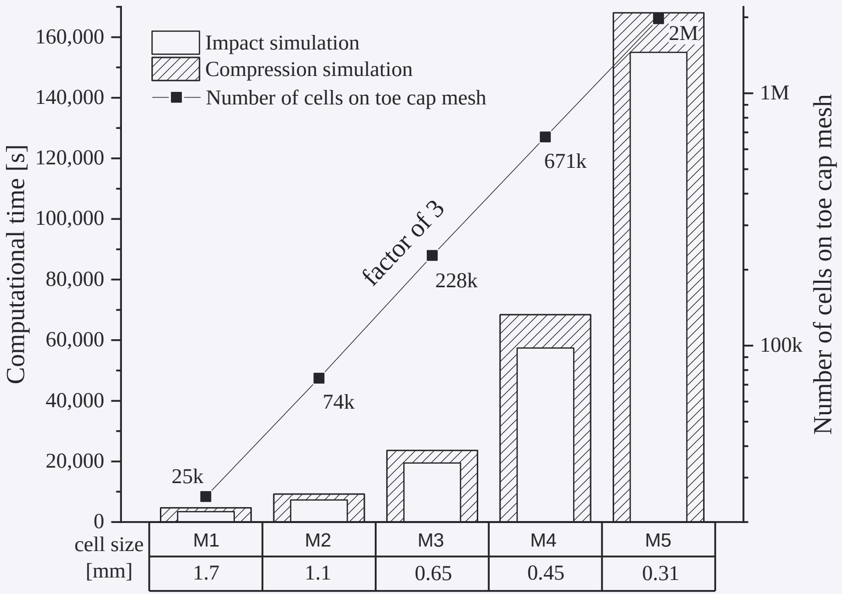
Mechanical model: Neo-hookean

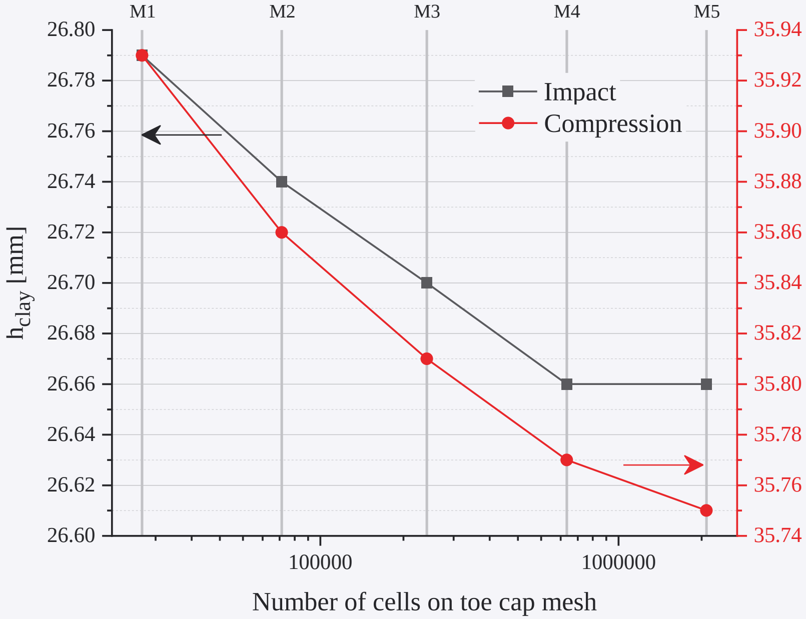
$$\varepsilon_{elastic} = \frac{\sigma_{true}}{E}$$

$$\varepsilon_{plastic} = \varepsilon_{total} - \varepsilon_{elastic}$$

Results

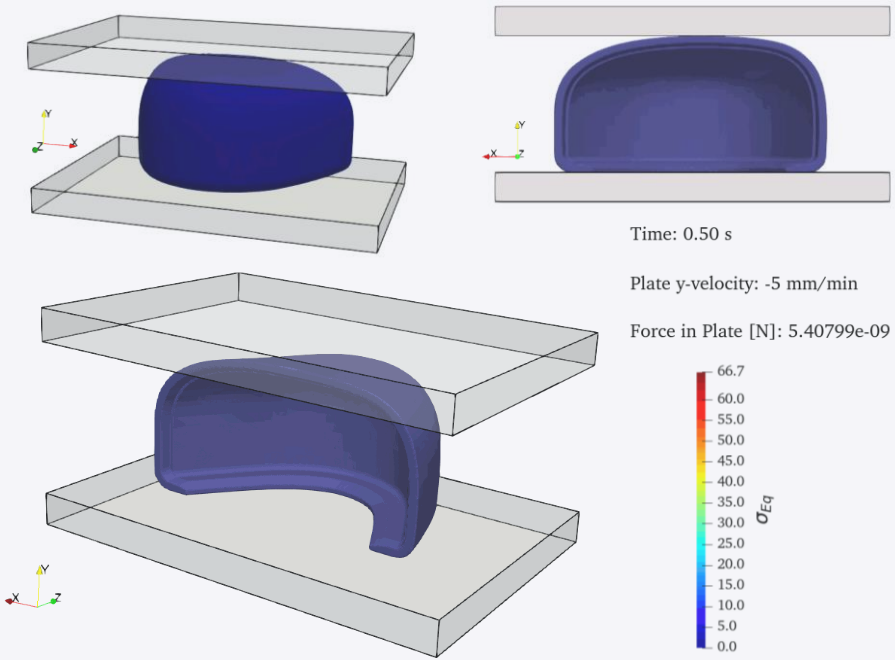
Mesh sensitivity analysis

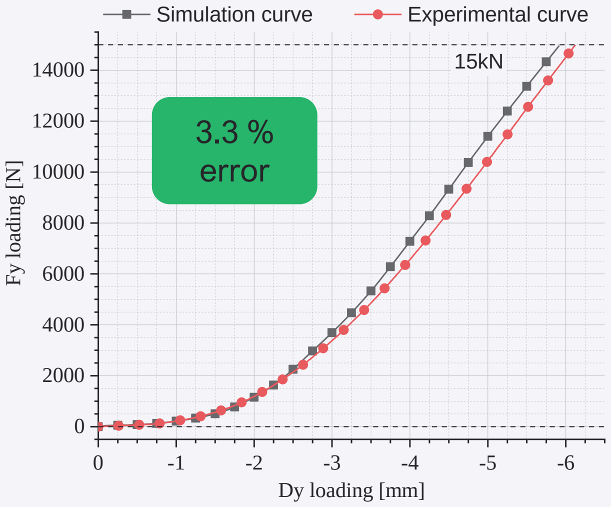




Results

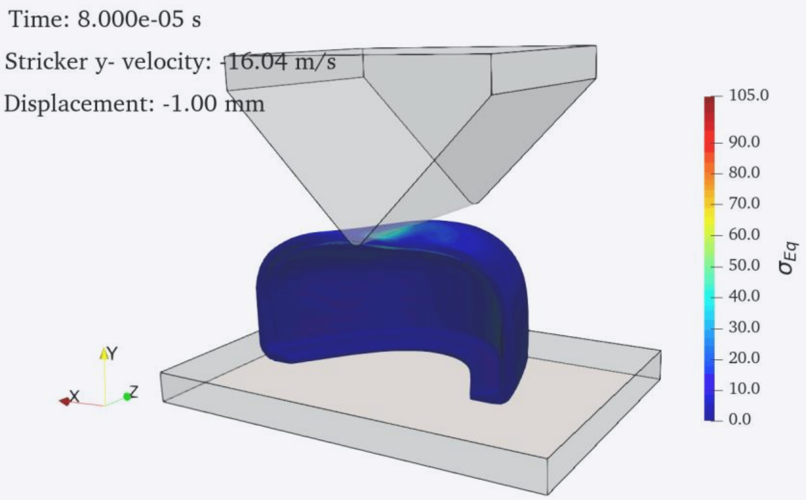
Compression

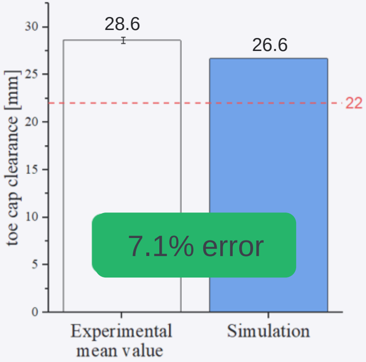




Results

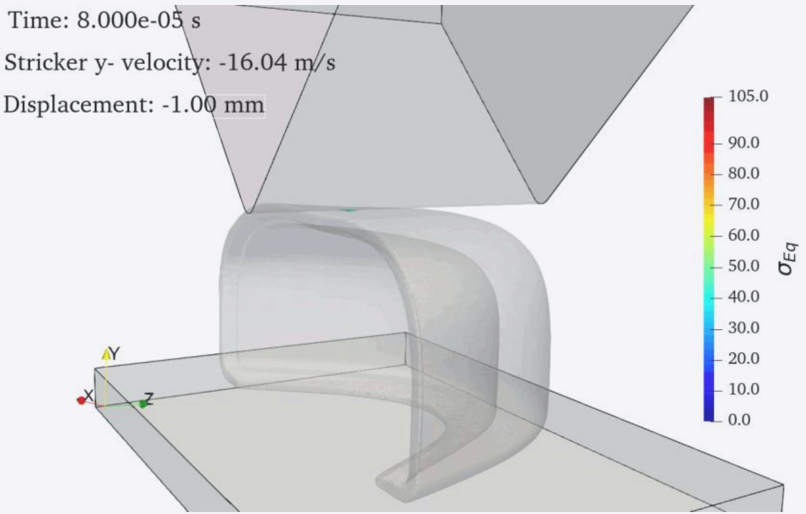
Impact

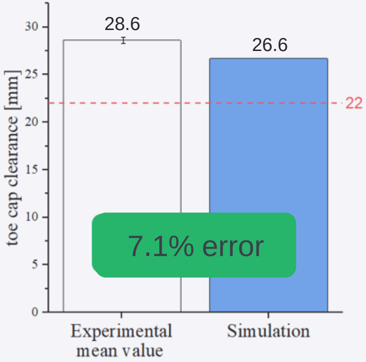




Results

Impact

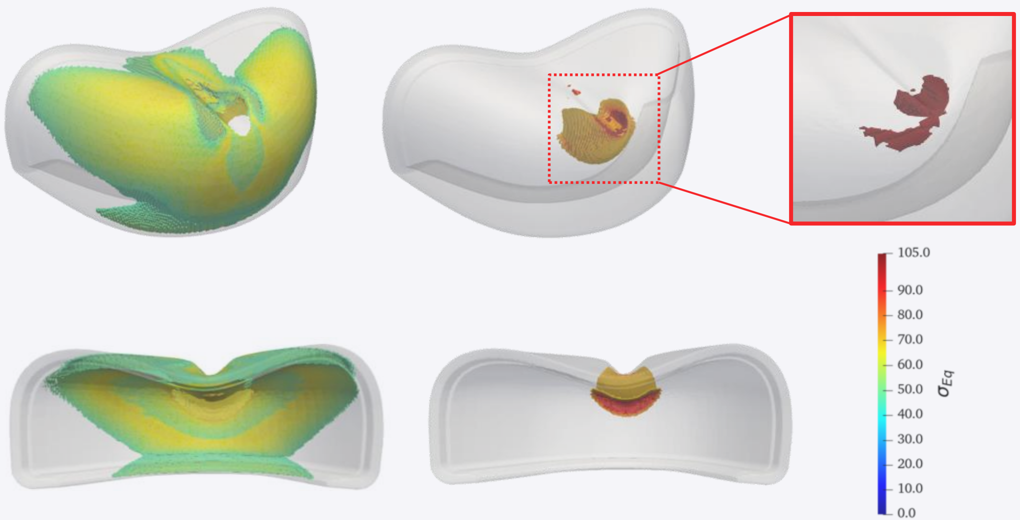




Results

Impact

45 – 70 MPa	70 – 100 MPa	100 – 105 MPa



- ✓ The critical region is the impact location;
- ✓ A few cells reach the maximum stress of the material curve.

Outline

Conclusions and Future Work

Main conclusions

1. The toe cap thermoplastic material was identified to be a neat polycarbonate, and its tensile behaviour was characterized in quasi-static tests.
2. Standard industry mechanical quality tests were modeled with *solids4Foam*, a toolbox for FSI analysis withing the OpenFOAM® framework.
3. The obtained results were very promissing, showing that *solids4Foam* and OpenFOAM can be a valuable tool for CAE in the footwear industry.

As future work

- To explore new design concepts with:
  - Mechanical model for post-yield behaviour of polymer materials
  - Lighter weight and “Breathable” solutions
  - Improved Thermal Comfort
  - Hybrid designs (multi-materials)

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Thank you for your attention