PERSONA CIÈNCIA EMPRESA
UNIVERSITAT RAMON LLULL

SIMULATION TOOLS TO DEVELOP MATERIALS

Jornada sobre simulación en procesos de Fabricación de vidrio

Andrés-Amador García Granada, Ph.D.
Barcelona, 10 mayo 2017

CONTENTS

"All models are wrong but some are useful"
George Edward Pelham Box
18/10/1919-28/03/2013

"In 1995 I was the only one that trusted my simulation,
in 2017 everybody believe in simulation but me"
Andrés García

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1. Presentation

1.1. CV.

1.2. Examples of material characterisation for simulation.

1. Presentation

- 1.1. CV

Industrial Engineer intensification Structures ETSEIB-UPC Octubre 1996.
PFC U.Bristol residual stress in **welds** decreasing fatigue life.
PhD 2000 U.Bristol improvement of fatigue life of supersonic aircraft wings by introducing compressive **residual stresses** with **plasticity** including the study of relaxation (**creep**) at high temperature.
Simulation engineer at **EDAG** in topics such as **vibrations, rubbers, foams**,…
Simulation engineer at **SEAT** in topics such as **crash, thermal expansion, plastic injection**, … Responsible of **material data base for simulation**.
Simulation and test engineer at **AUDI** in topics such as FMVSS201U impacting against **composites, glue, glass, plastic parts**,…
Associate professor **EUETIB**.
Professor **IQS** with research projects on **plastic injection** at **nanometric** scale, **damping** of arterial pulse… and recently **glass** blowing.

1. Presentation

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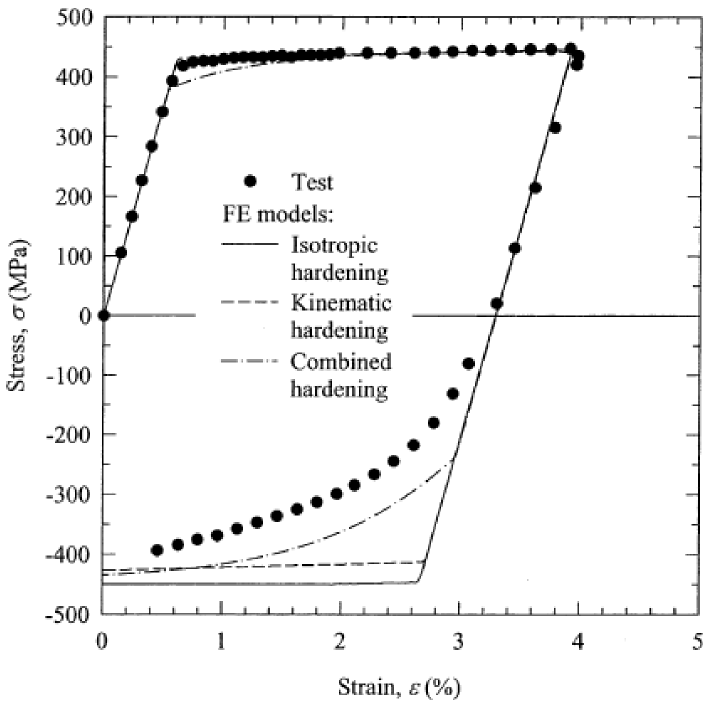
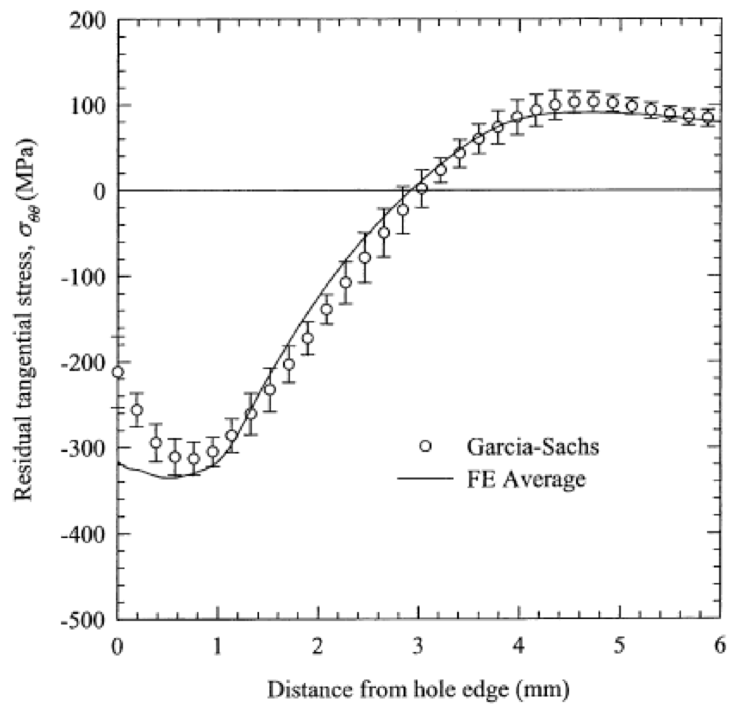
- 1.2. Example of material characterisation





Lacarac, V. D., **Garcia-Granada, A. A.,** Smith, D. J., & Pavier, M. J. (2004). Prediction of the growth rate for fatigue cracks emanating from cold expanded holes. *International Journal of Fatigue*, *26*(6), 585-595.

1. Presentation

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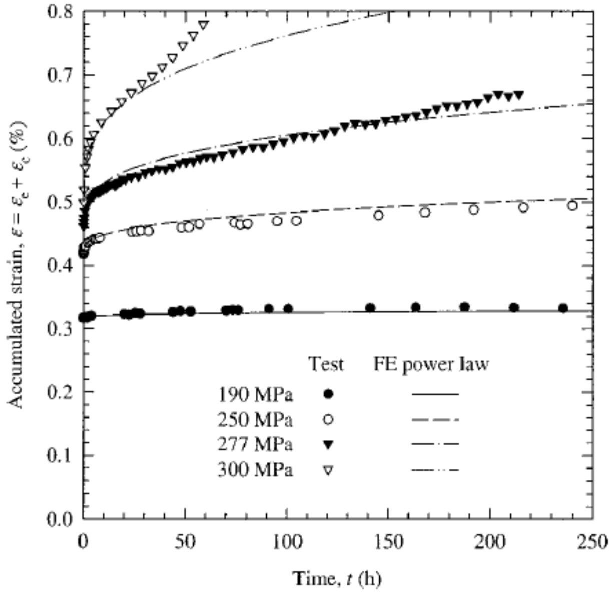

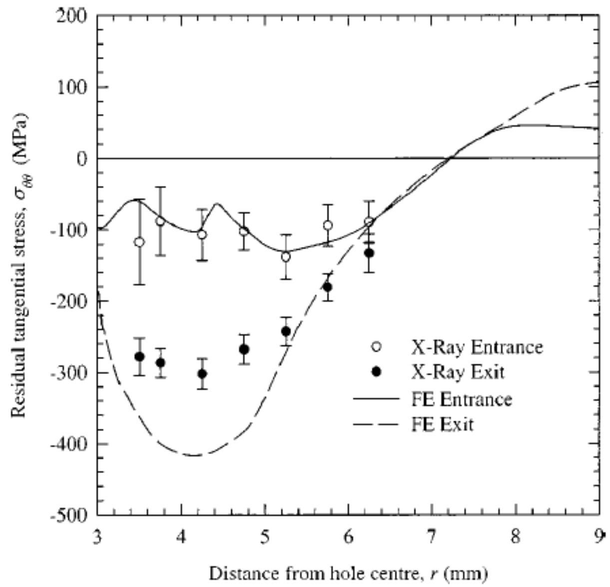

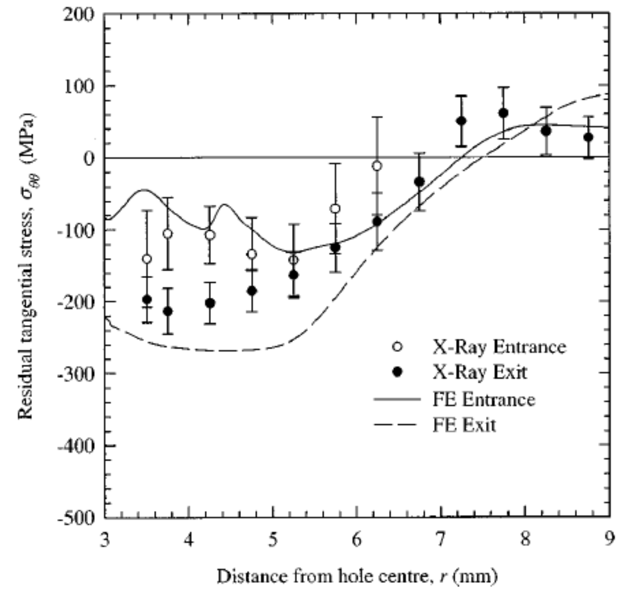

Garcia-Granada AA, Lacarac VD, Holdway PP, Smith DJ, Pavier MJ. Creep Relaxation of Residual Stresses Around Cold Expanded Holes. (2000) ASME. *J. Eng. Mater. Technol.*123(1):125-131. doi:10.1115/1.1310305.

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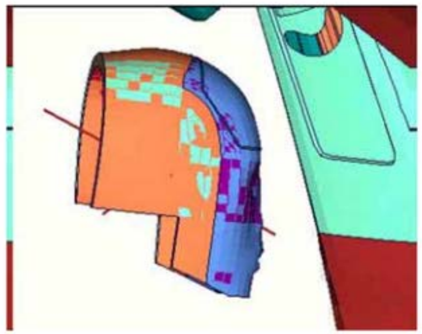
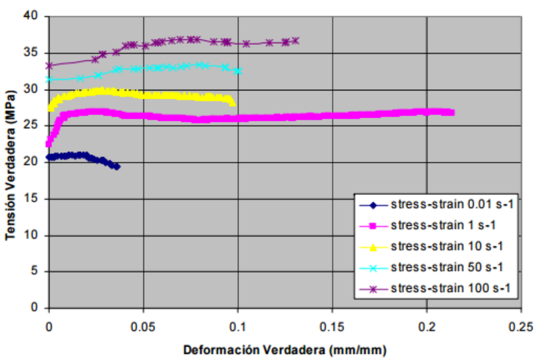
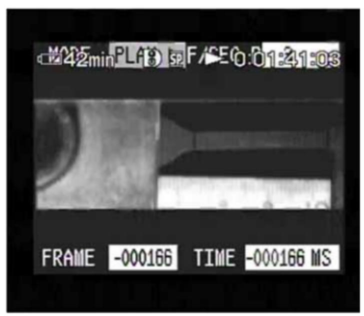
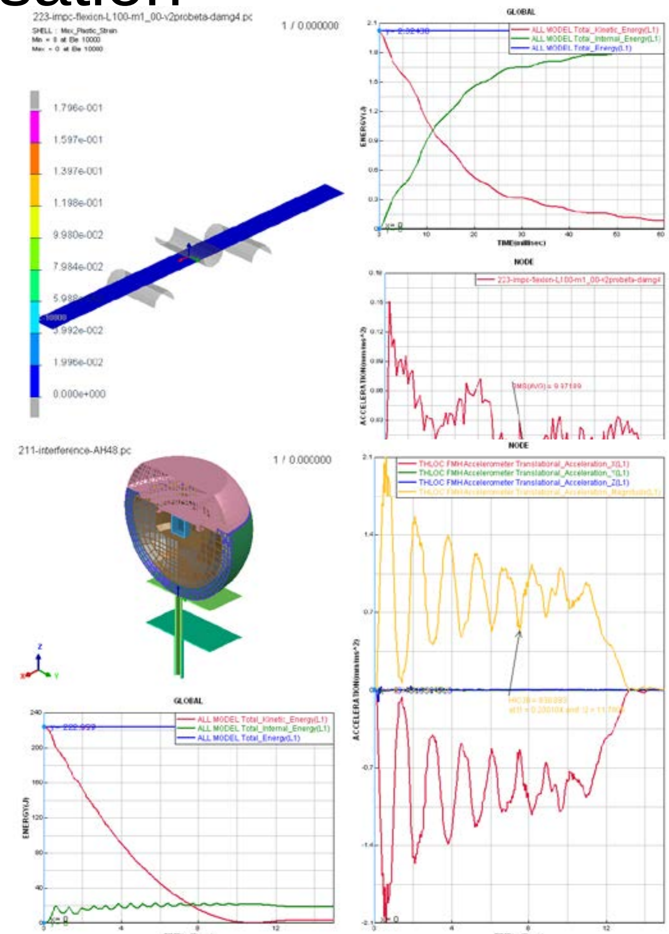
1. Presentation

- 1.2. Example of material characterisation









Garcia-Granada AA, Requerimientos técnicos de los materiales plásticos antes nuevas normativas. (2002) *Salón Motorpro. Jornada Plásticos y seguridad en el automóvil organizada por STA*.

1. Presentation

- 1.2. Example of material characterisation

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$ MTYP 101  ideal elastisch  fuer Glas
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                 0       0       0       0       0       0      1.       0
NAME GLAS -- IDEAL ELASTISCH
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                                                                 0.1        0.
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$ VW/AUDI MATERIALDATENBANK Verbundglas
$ Material fuer Windschutzscheiben
$ E-Modul 75 GPa, Fliessgrenze 10 MPa, Querkontraktion 0.22, Dichte 2.7
$ Bruchdehnung 5.0% Tangentenmodul 1.0 GPa = 1/75 E-Modul
$ (Tangentenmodul 1, 5% Bruchdehnung) => Versagen des Materials bei 60 MPa
$ Einheiten: kg, mm, msec
$ Daten von Malte Lewerenz EBK  12/00  Tel.: 76041
$ Materialdicke im 2001-Format-Input war 4.5
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
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                 0       0       0       0       0       0      1.       0
NAME Verbundglas
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        1.       0.1       0.0       0.0       0.0       0.0       0.0       0.0
       0.0       0.0       0.0       0.0       0.0       0.0
      0.05       0.0       0.0
                           0.0       0.0       0.0       0.0       0.1       0.0
      EPMX      0.05
$
```

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$              ID   MATYP              RHO     NINT    ISHG  ISTRAT   IFROZ
MATER /  8106101       1     2.55000e-06       0       2       1       0
                 0       0       0       0       0       0      1.       0
NAME GLAS -- IDEAL ELASTISCH
$          G                                                  STRAT1    STRAT2
 26.92     1.000e+19       0.0                                   0.0       0.0
$          K
      58.33

#CHK#
#                                                                 Xi
                                                               0.100
           0.0       0.0       0.0       0.0       0.0       0.0       0.0
                                                                  Q3
  .0       0.0       0.0       0.0       0.0       0.0       0.010
```

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2. Simulation studies and material properties

2.1. Problem types.

2.2. Nonlinearity.

2.3. Automatic meshing

2.4 Multiscale

2.5 Meshless problems

2. Simulation studies and material properties

- 2.1. Problem types

First we ask what we want to simulate and then we look for the material parameters required to obtain a good simulation model:

Elasticity of materials F=k*x, for example tension F=EAΔL/L, requires **E,ν**.

Rigid solid movement F=m*a, requires **ρ**.

Dynamics of deformable bodies F=k*x+c*v+m*a, ω=√k/m, requires **E,ν,ρ,ξ**.

Thermal expansion ΔL=LαΔT, requires **α**.

In this way we can evaluate the problem to be simulated and find which are the required material parameters to be obtained.

2. Simulation studies and material properties

- 2.2. Nonlinearities

We might find that our assumptions for the simulation model might be nonlinear. For example for deformation of bodies (F=k*x) we find several reasons:

Nonlinear elastic behaviour of material as for polymers, rubbers… $F=k*x^n$, require **E,ν,n**.

Nonlinear material above a yield point due to plasticity. Requires **E,ν, curve stress-strain**.

Nonlinear contacts. The stiffness of a component changes when a contact is produced against other component. Data required for both component and also for the interaction. Requires **contact penalties**.

When nonlinearities are involved the SOLVER needs to iterate to solve the equations and decide which material properties are required as a function of a previous STEP. This means hardware, software and material testing might be more complex.

2. Simulation studies and material properties

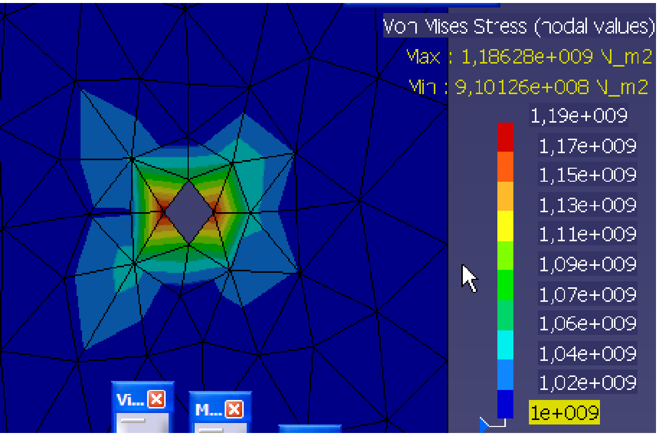
- ## 2.3. Automatic meshing

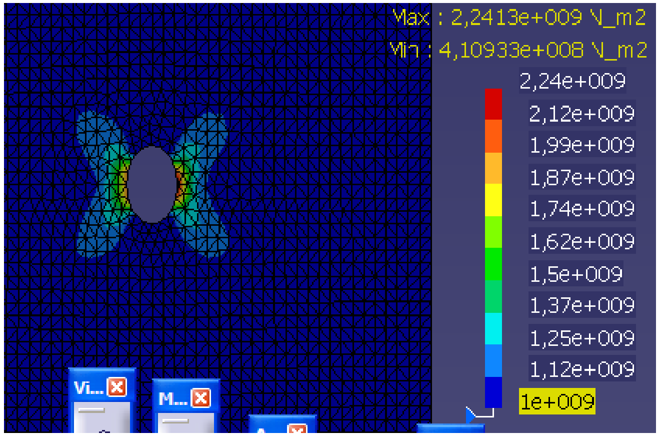
Mesh of the model is important to obtain accurate results. As an example a component with a hole is loaded in tension with 1000MPa. Around a hole we expect to have 3000MPa due to stress concentration.

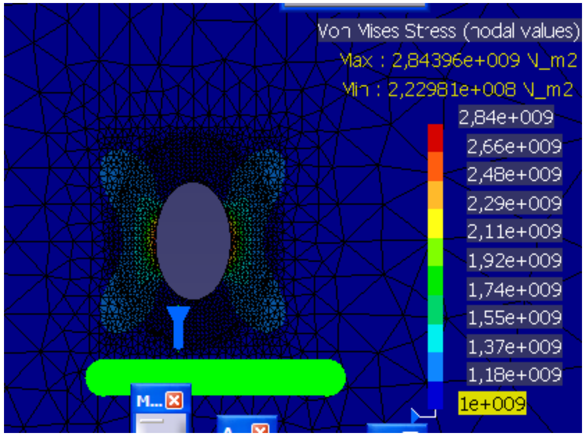
If we remesh with fine mesh everywhere improves slightly with long calculation times.

If we remesh locally we go closer to the desired solution with low CPU time .

¿What are 3000MPa? ¿Which material can stand such value?



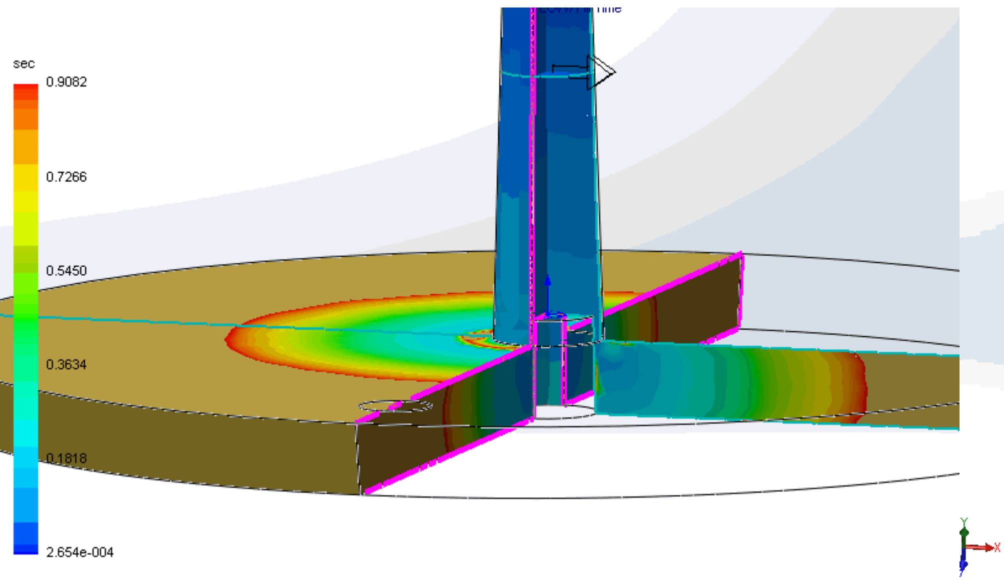


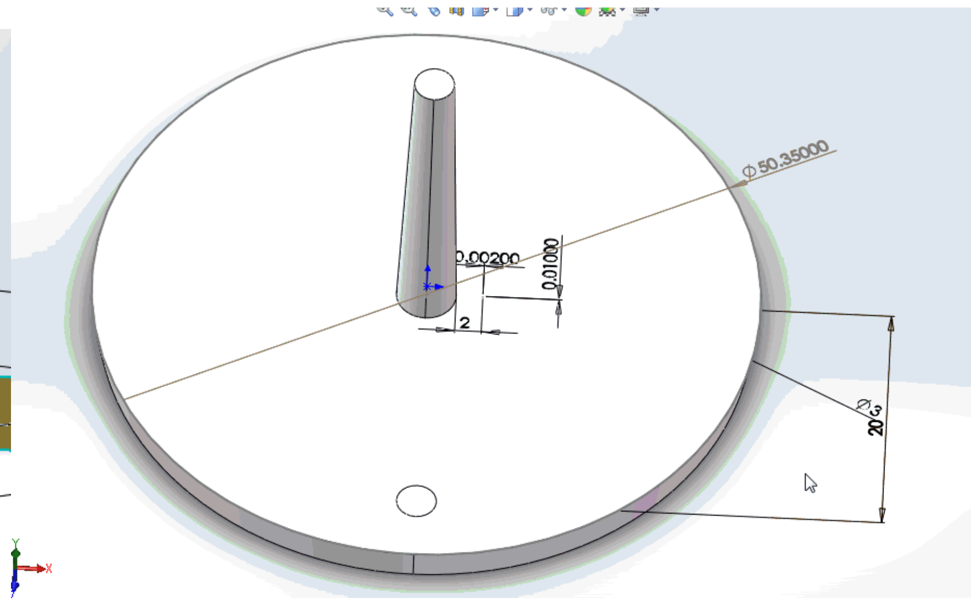


2. Simulation studies and material properties

- ## 2.4. Multiscale

We need to identify if the problem to be solved occurs on a mm scale or in a lower scale such as μm or even nm. If we want to study problems on different scales in just one model we might find wrong results due to excesive mesh transitions.
For such cases it is possible to use sub-modelling techniques where simulations on the mm scale are used as boundary conditions for simulations on the nm scale.



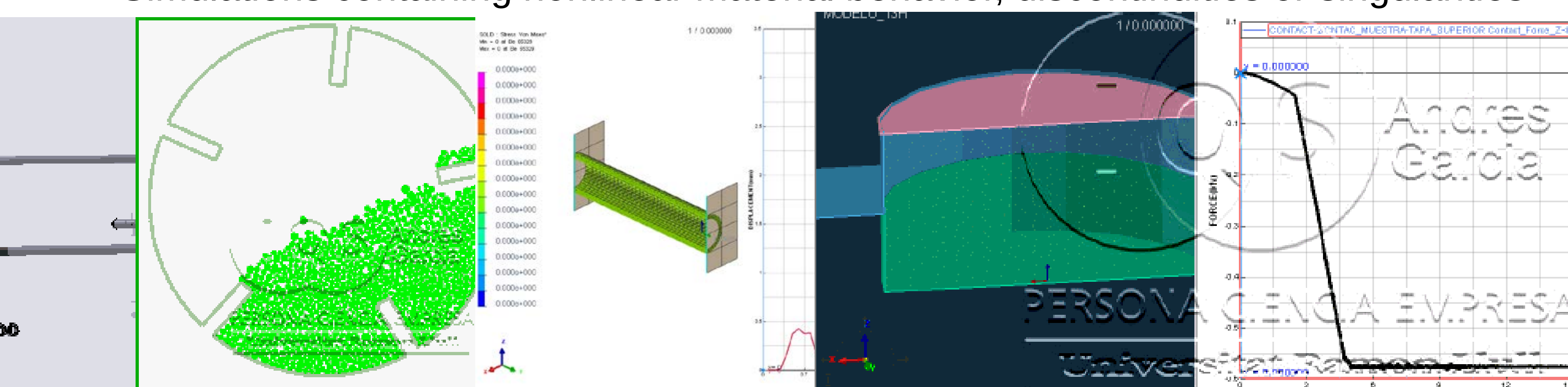


2. Simulation studies and material properties

- 2.5. Meshless solutions

For problems where the geometry is changed completely during the simulations there are several techniques that avoid excessive element deformation. Meshfree methods are intended to remedy these problems and are also useful for:

- Simulations where creating a useful mesh from the geometry of a complex 3D object may be especially difficult or require human assistance
- Simulations where nodes may be created or destroyed, such as in cracking simulations
- Simulations where the problem geometry may move out of alignment with a fixed mesh, such as in bending simulations
- Simulations containing nonlinear material behavior, discontinuities or singularities



3. Influence of fabrication process in material properties

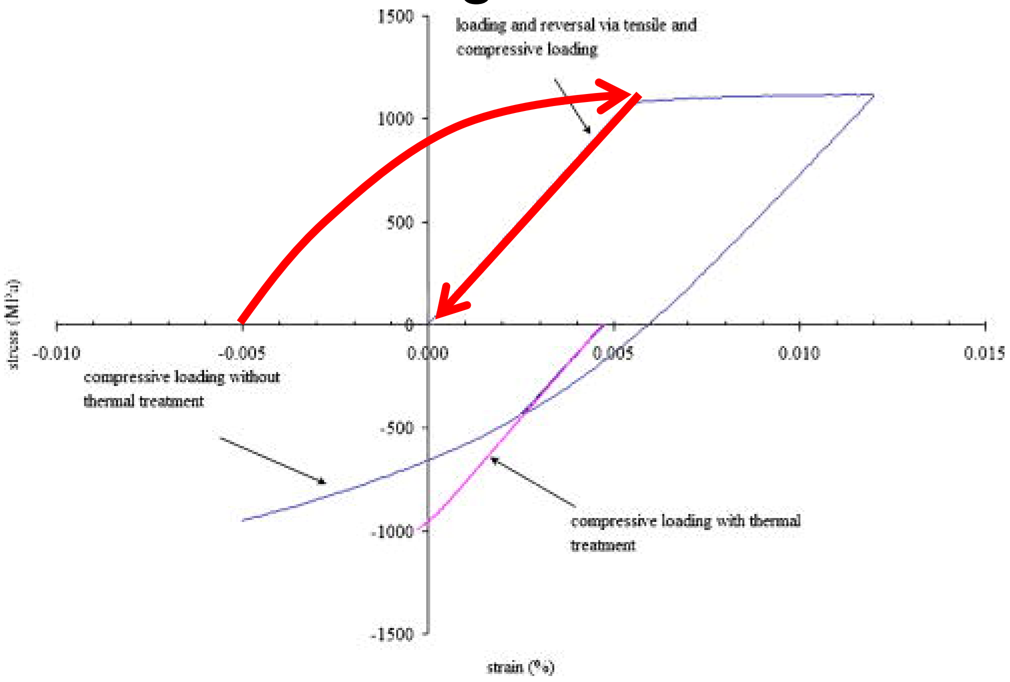
3.1. Bauschinger effect.

3.2. Residual stress.

3.3. Injection parameters.

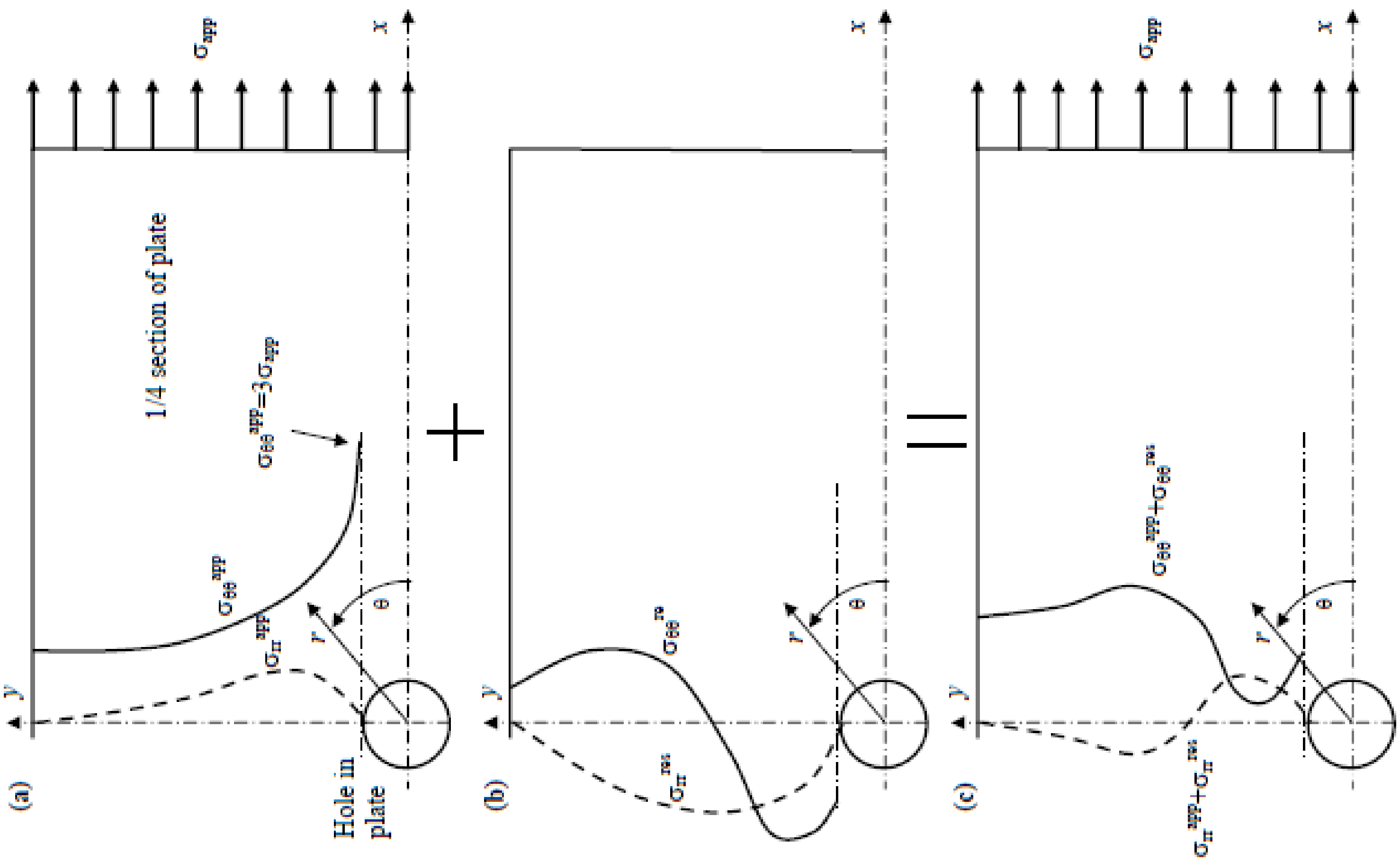
3. Influence of fabrication process in material properties

- 3.1. Bauschinguer effect



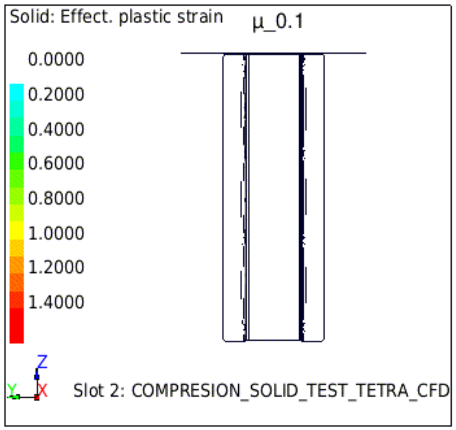
3. Influence of fabrication process in material properties

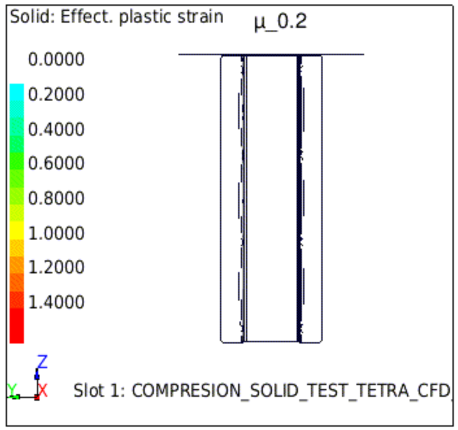
- 3.2. Residual stress

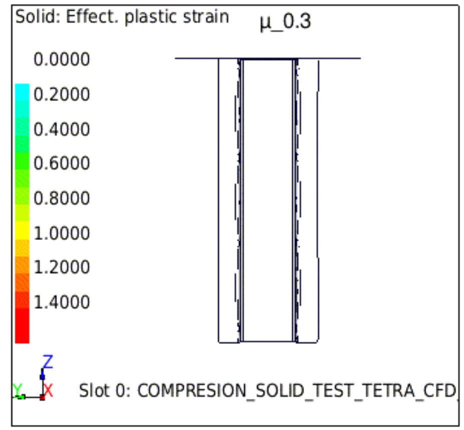


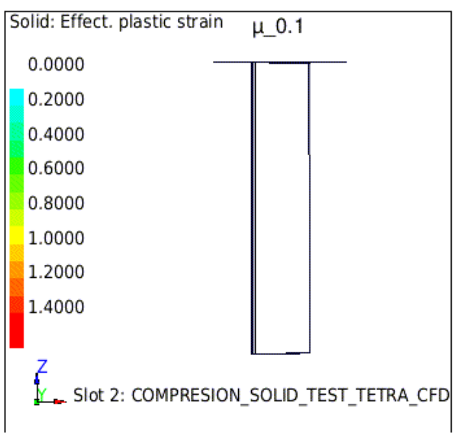
3. Influence of fabrication process in material properties

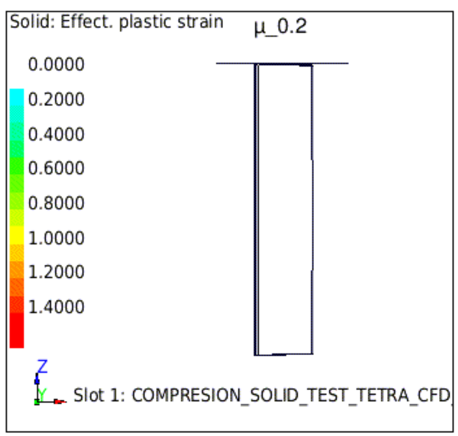
- 3.3. Injection parameters

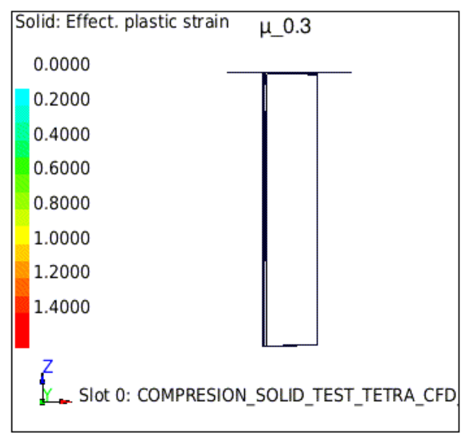












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4. Examples in glass

4.1. Stiffness.

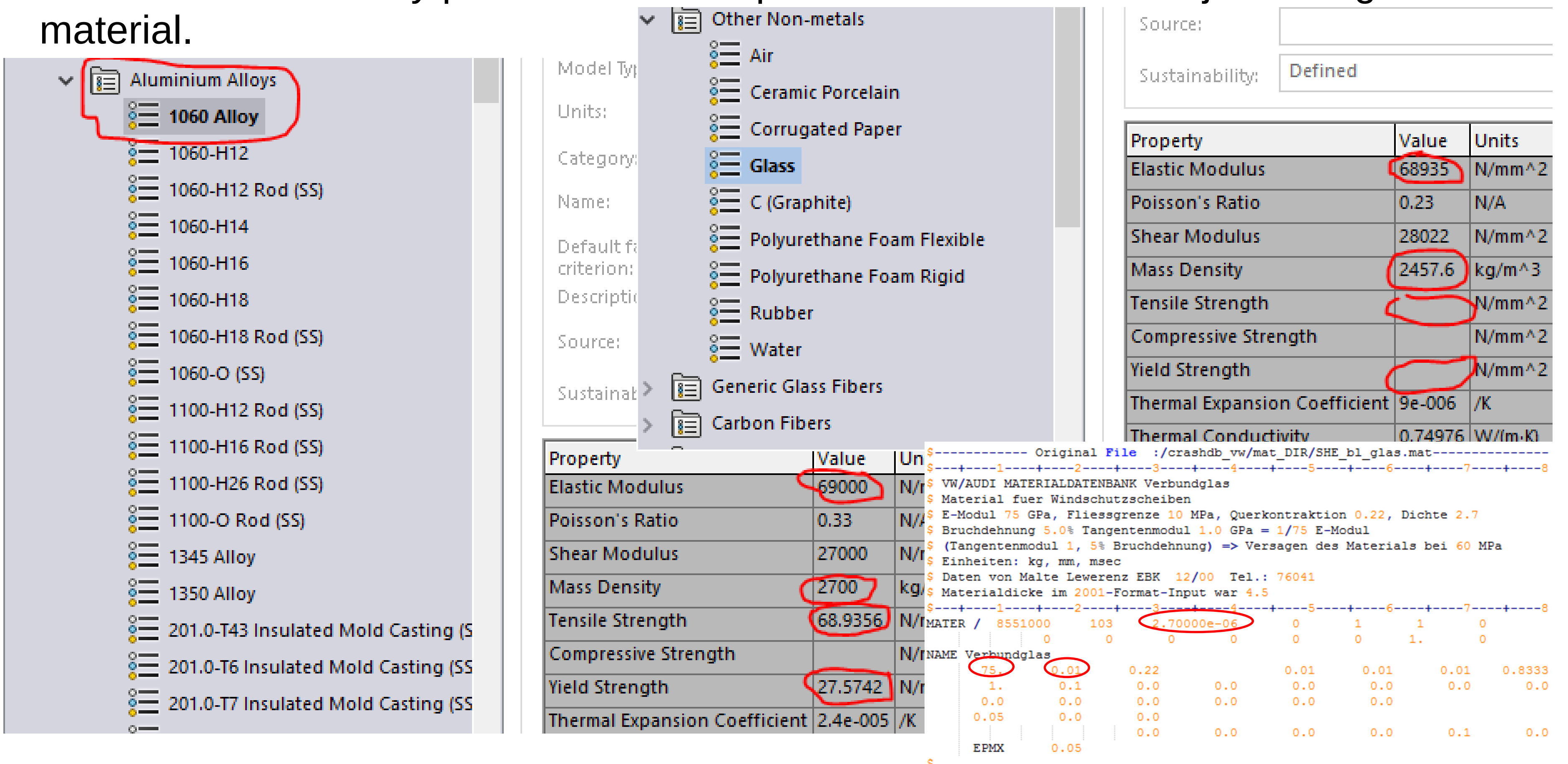
4.2. Fracture.

4.3. Forming.

4. Examples in glass

- 4.1. Stiffness

Glass is usually compared to aluminium. For example if use SolidWorks we can do simulations with many parameters and options for aluminium and just one glass material.



Property	Value	Un
Elastic Modulus	69000	N/r
Poisson's Ratio	0.33	N/A
Shear Modulus	27000	N/r
Mass Density	2700	kg/
Tensile Strength	68.9356	N/r
Compressive Strength		N/r
Yield Strength	27.5742	N/r
Thermal Expansion Coefficient	2.4e-005	/K

Property	Value	Units
Elastic Modulus	68935	N/mm^2
Poisson's Ratio	0.23	N/A
Shear Modulus	28022	N/mm^2
Mass Density	2457.6	kg/m^3
Tensile Strength		N/mm^2
Compressive Strength		N/mm^2
Yield Strength		N/mm^2
Thermal Expansion Coefficient	9e-006	/K
Thermal Conductivity	0.74976	W/(m·K)

```
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$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$ VW/AUDI MATERIALDATENBANK Verbundglas
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NAME Verbundglas
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        1.       0.1       0.0       0.0       0.0       0.0       0.0       0.0
       0.0       0.0       0.0       0.0       0.0       0.0
      0.05       0.0       0.0
                           0.0       0.0       0.0       0.0       0.1       0.0
      EPMX      0.05
$
```

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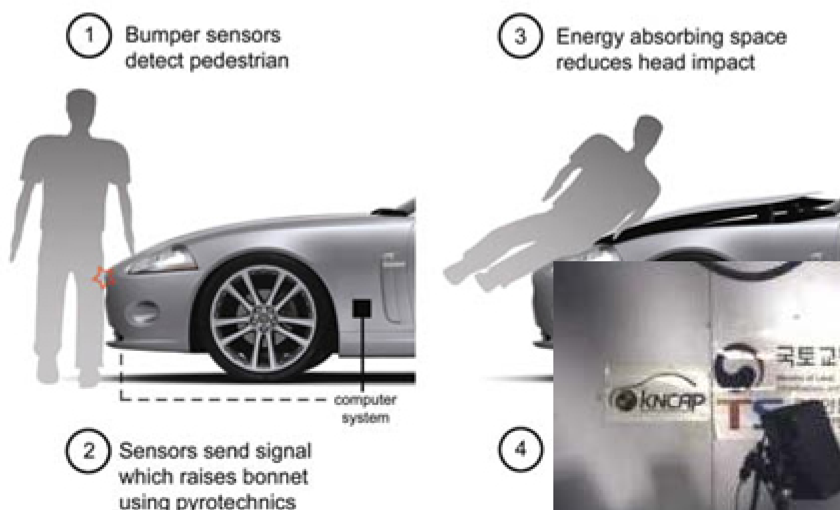
4. Examples in glass

- ## 4.2. Fracture

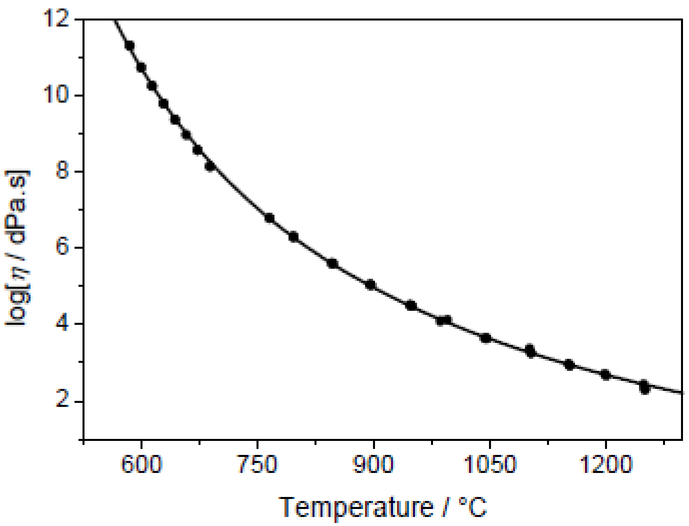
Tempering and residual stresses in glass might affect their behaviour for crash analysis.

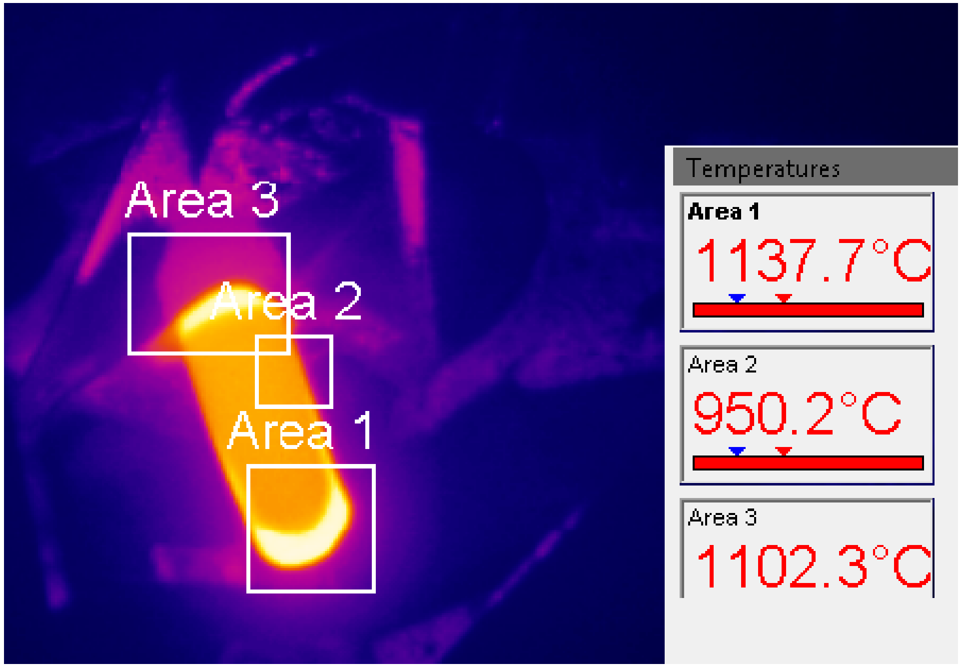


4. Examples in glass

- 4.3. Forming

Glass forming is related to viscosity as a function of temperature. With less temperature more viscosity and we need more time to form or more pressure.





SUMMARY

- First ask what are the physics and the best model to approximate your problem to a useful result.
- Investigate if your assumption is realistic as for example assume a linear model or constant temperature model.
- Decide if normative test such as tensile test is good enough to obtain material data.
- Explore validation simulations to check that manufacturing process parameters such as cooling are included in the capability of your simulations.

IQS

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