Wrocław University of Technology

Numerical Modeling of Heterogeneous Composite Material

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Plan of presentation

- Aim of work
- Research objectives, laboratory tests
- Domain of research
- Numerical modeling of the composite
- Results, comparisons
- Conclusions

Aim of work

- Numerical modeling of the cement-based composite under various loading states
- Refining the model by including damage mechanisms
- Proposition of the algorithm for **R**epresentative **V**olume **E**lement (RVE) evaluation for different diameter of aggregate

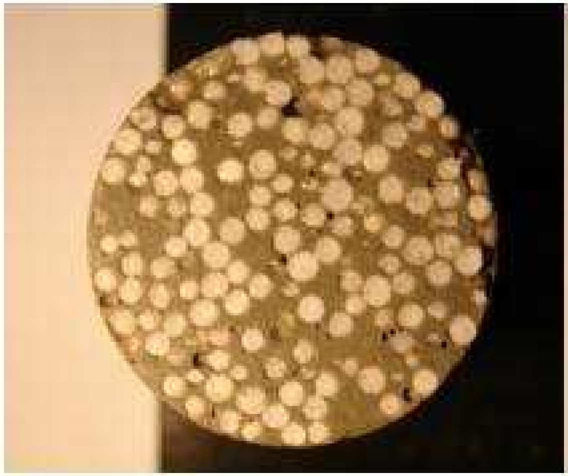
Experimental investigation (1)

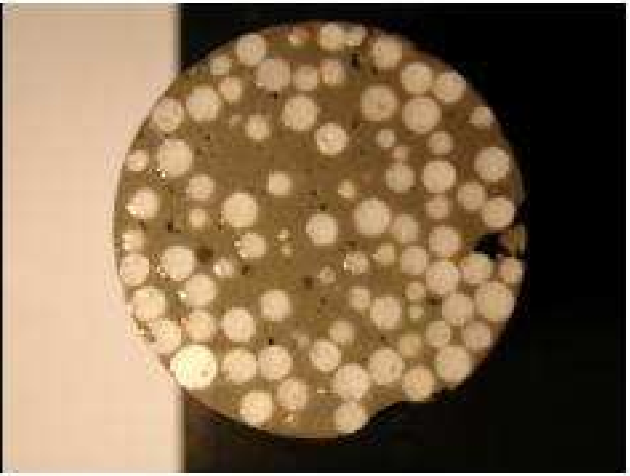
- Object of the study
  - Cement based composite with four components
- Experimental objectives
  - Study on influence of saturation degree and shrinkage effects on the basic material constants,
  - Study on effect of the biggest aggregate particle and its stiffness on material strength,
  - Study on damage mechanisms.

Experimental investigation (2)

- **Object of the study**

  Cement based composites with spherical aggregate particles with dimensions 1, 2, 4, 6 mm made of glass and polystyrene

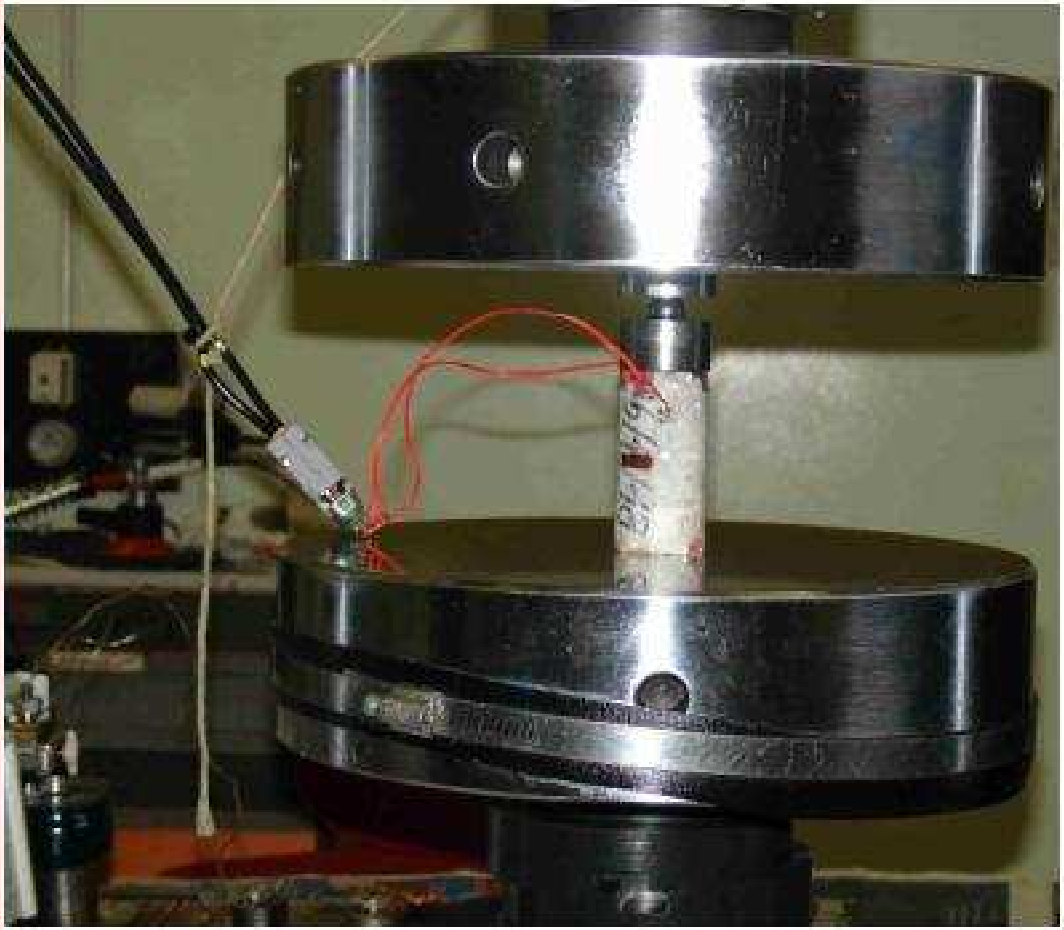


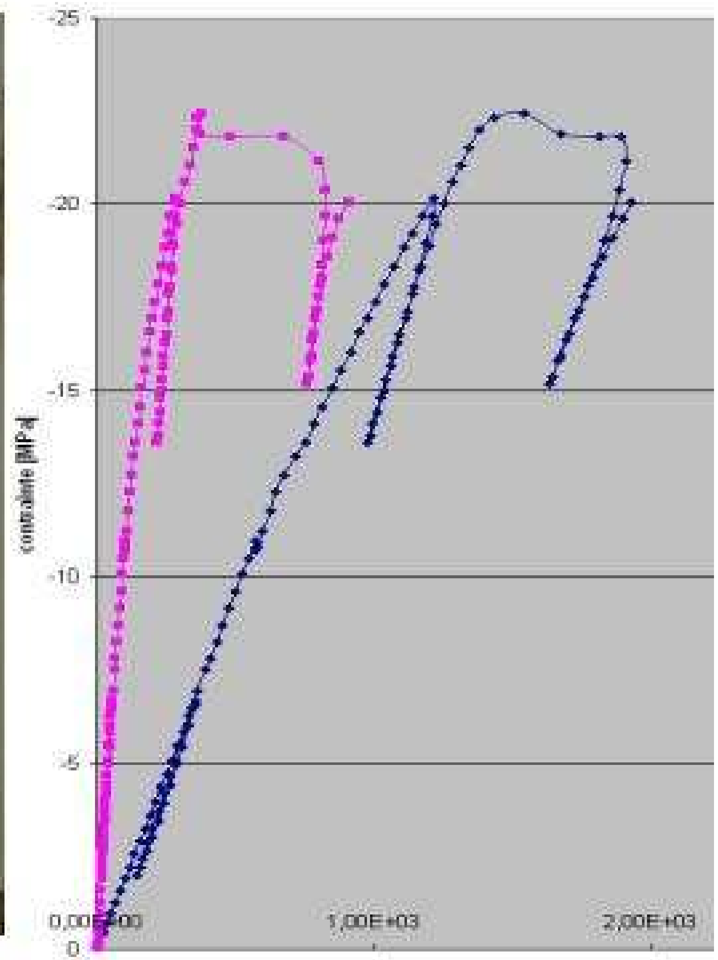


Experimental investigation (3)

- **Research objectives**
  - Water saturation degree, autogenous and drying shrinkage influence on material constants,
  - Influence of the different aggregate diameter and its stiffness on composit strenght

Experimental investigation (4)





Research domain

- Choice of constitutive models for particular components of the composite
- Comparison analysis of numerical and laboratory tests for composite model identification in macro scale
- Finite elements modeling with quasi-random distribution of components in the composite
- Analysis of damage processes

Finite element modeling (1)

1. **Assumed geometry**
   - Cylindrical sample as cuboid space Ω
   - Aggregate spheres as cubes
2. **Discrete model**
   - Space Ω divided by FE of cubicoid type - SOLID 8 Ω_e (e = 1,2,…,3456)
   - Aggregate particle modeled by 16 FE

Finite element modeling (2)

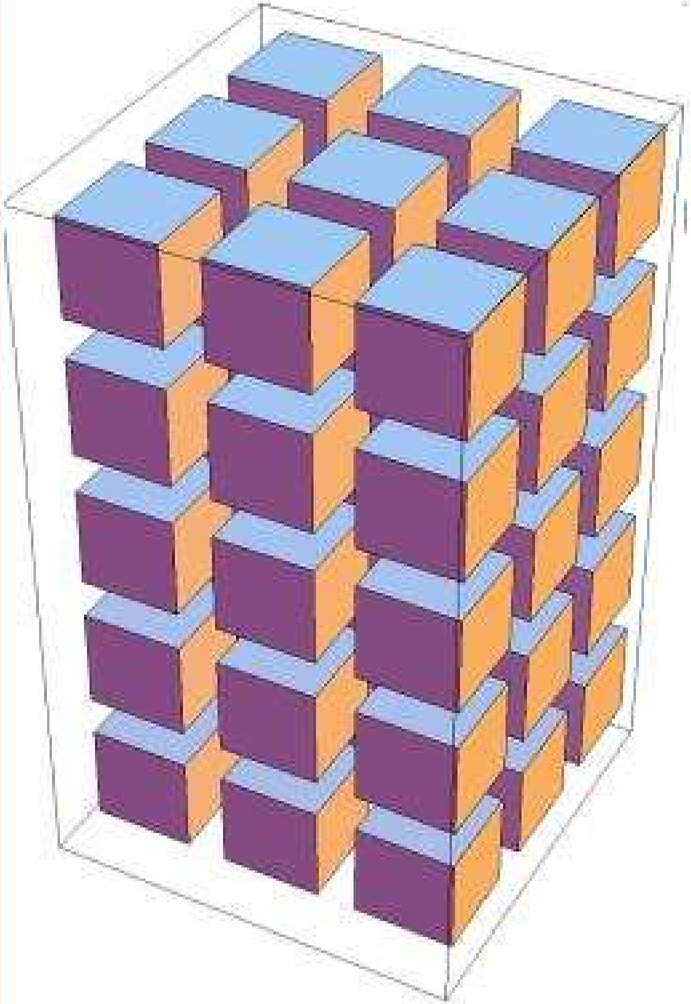
3. Constitutive models

- Aggregate - linear elastic material (E, ν)
- Cement paste - nonlinear elastic (quasi perfectly plastic) material with:
  - no damage criteria ($E(\varepsilon)$, ν)
  - damage criteria ($E(\varepsilon, d)$, ν)

4. Loading realization

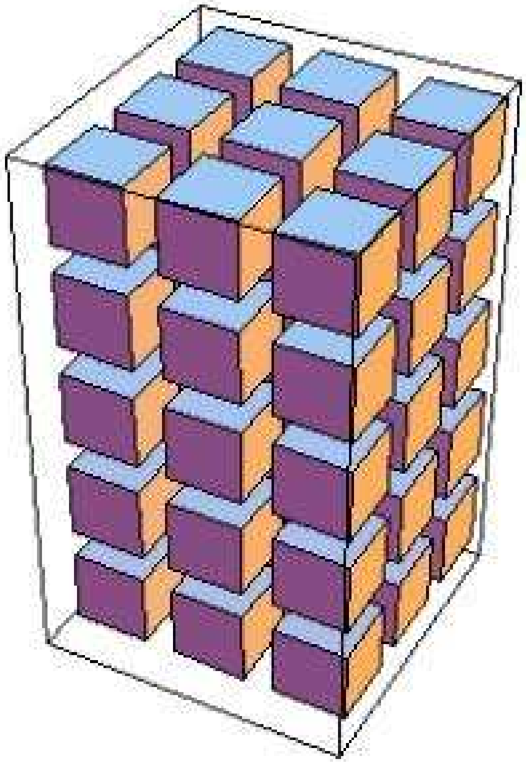
- Displacement control (incremental)
- In triaxial test additive, constant hydrostatic pressure placed on external surfaces $\partial\Omega$

Finite element modeling (3)



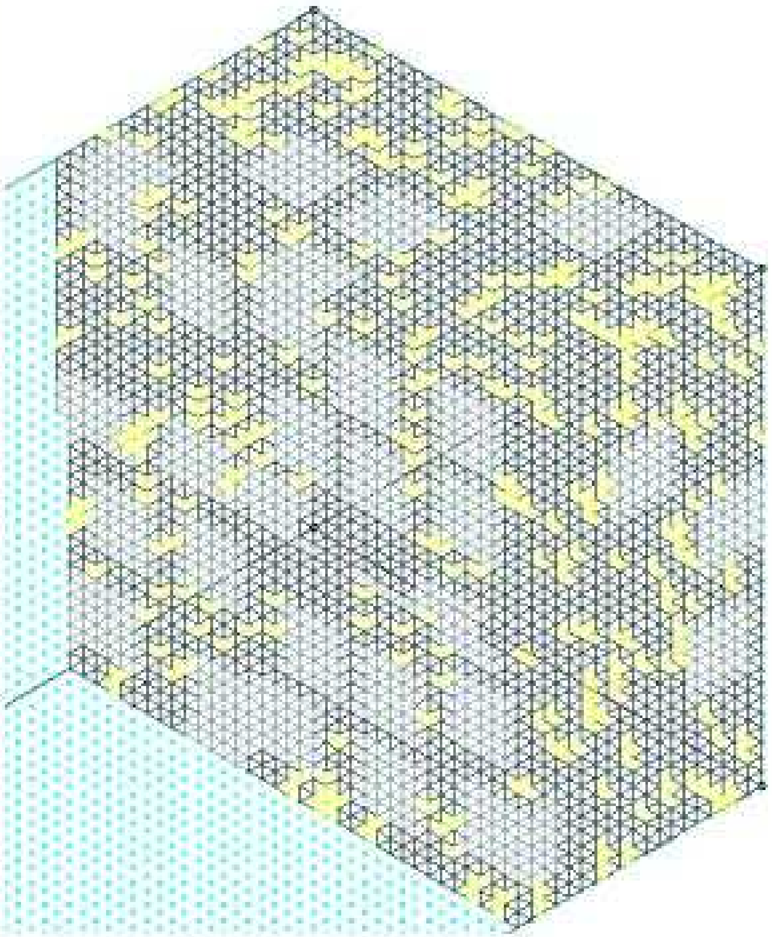
- Glass spheres assumed by cubes with the same volume but two times bigger ratio: surface/volume
- Aggregate distributed evenly with condition to obtain μ_2 = 35 % of Ω

Finite element modeling (4)



- Homogenous distribution is later randomized with the following conditions:
  - particles can move in each of the principal directions, until they are blocked by another particle
  - probability that for one of each principal directions aggregate keeps its position is 50%; probability it moves right and left is evenly 25%

Finite element modeling (5)



- Empty spaces, which left after aggregate distribution, are filled with cement paste, water and voids.
- For the present numerical modeling, water and voids are 'hidden' in constitutive model of cement paste

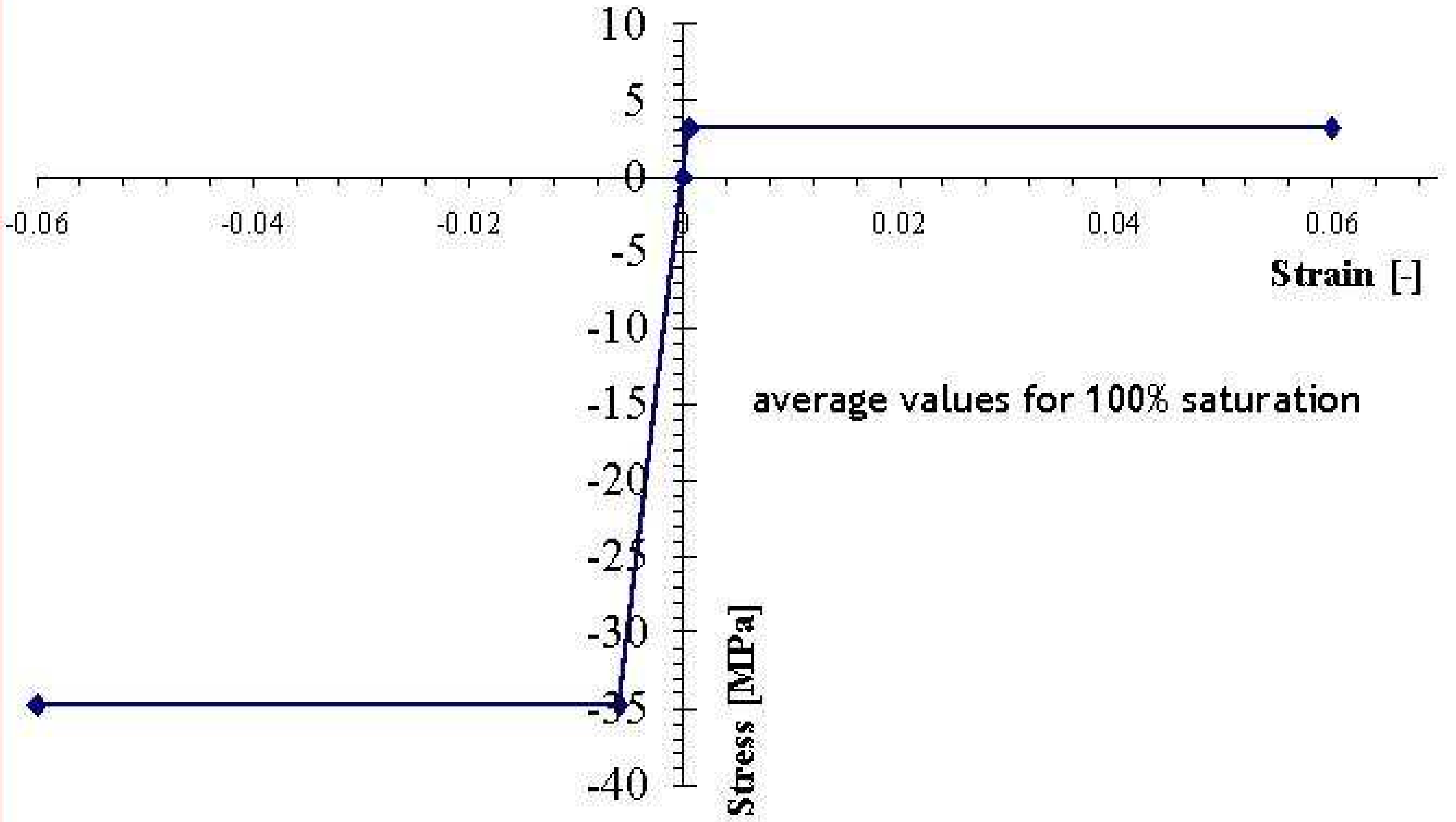
Material description

- Uniaxial and triaxial tests evaluated in laboratory - information about basic elasto-plastic parameters of elasto-plastic model
- An individual constitutive models are assumed for each of the components
- For the first approach all of the contacts between the particles are stiff.

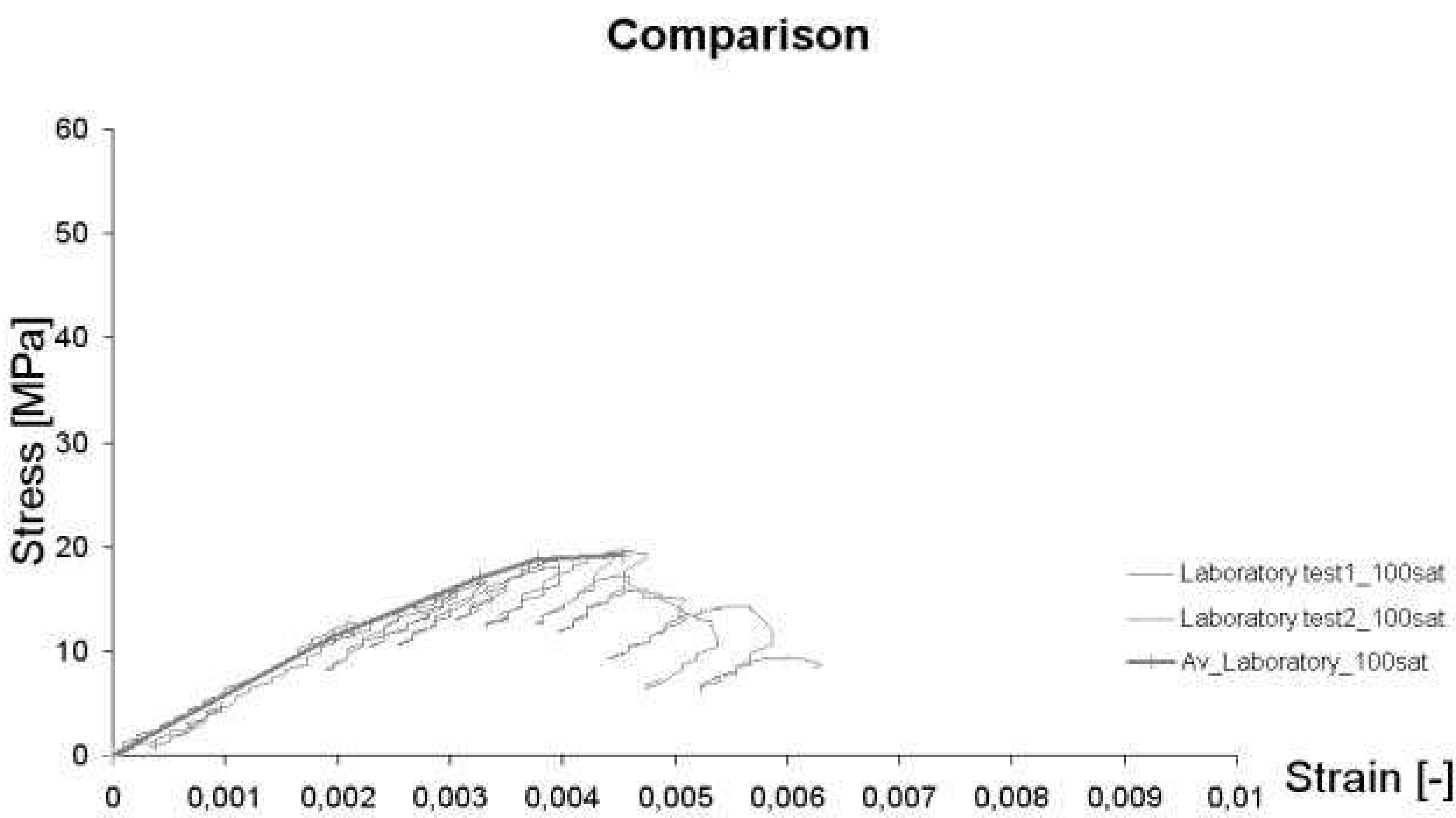
Constitutive models of components

- Glass aggregate
  - Linear elastic body with Young modulus E = 77 GPa
  - Poissons ratio ν = 0.1
- Cement paste
  - Model parameters are assumed on the base of the laboratory tests
  - Laboratory tests were performed for four degrees water saturation: 0% , 33%, 66%, 100%

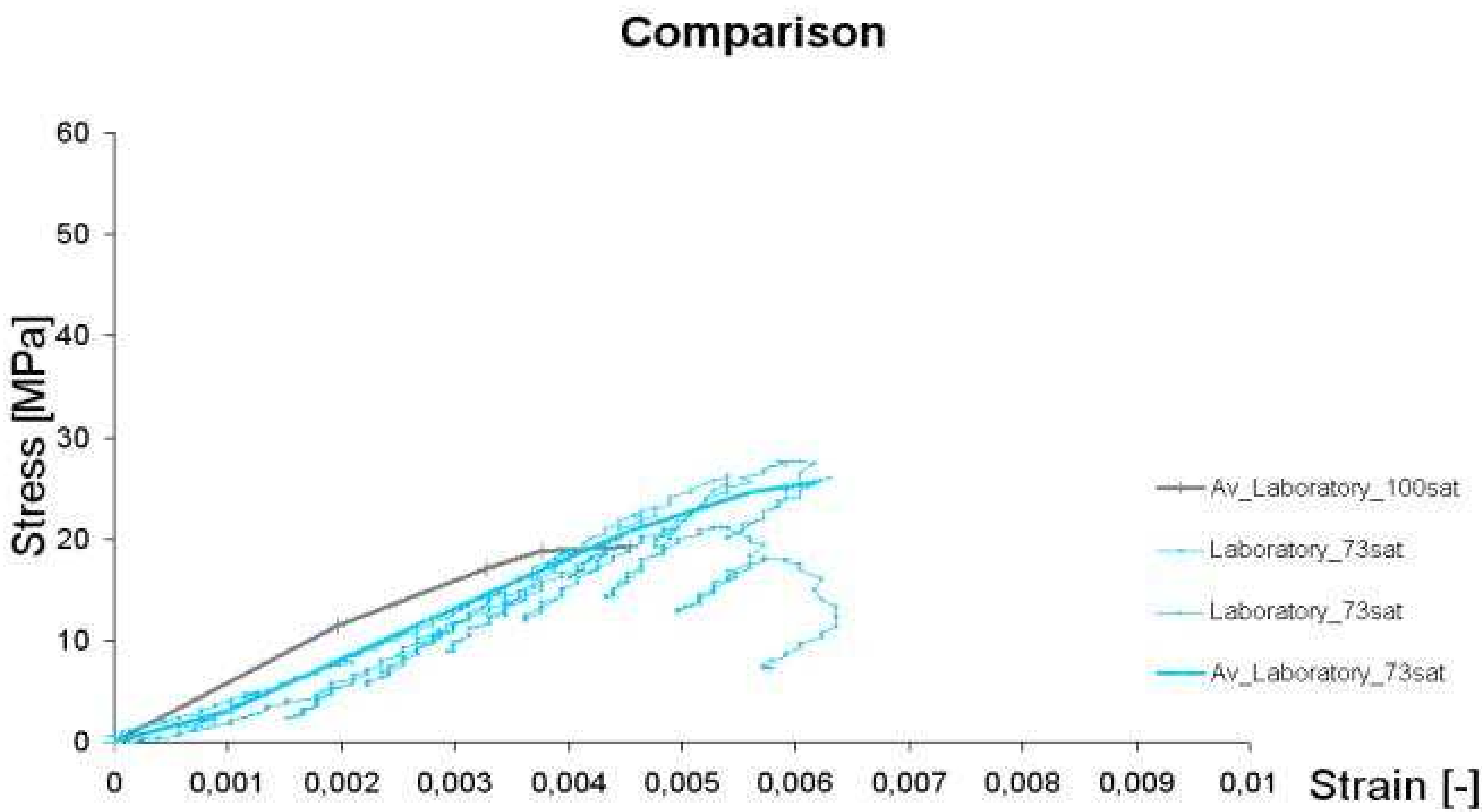
Constitutive model of the cement paste



Uniaxial compression laboratory test



Uniaxial compression laboratory test



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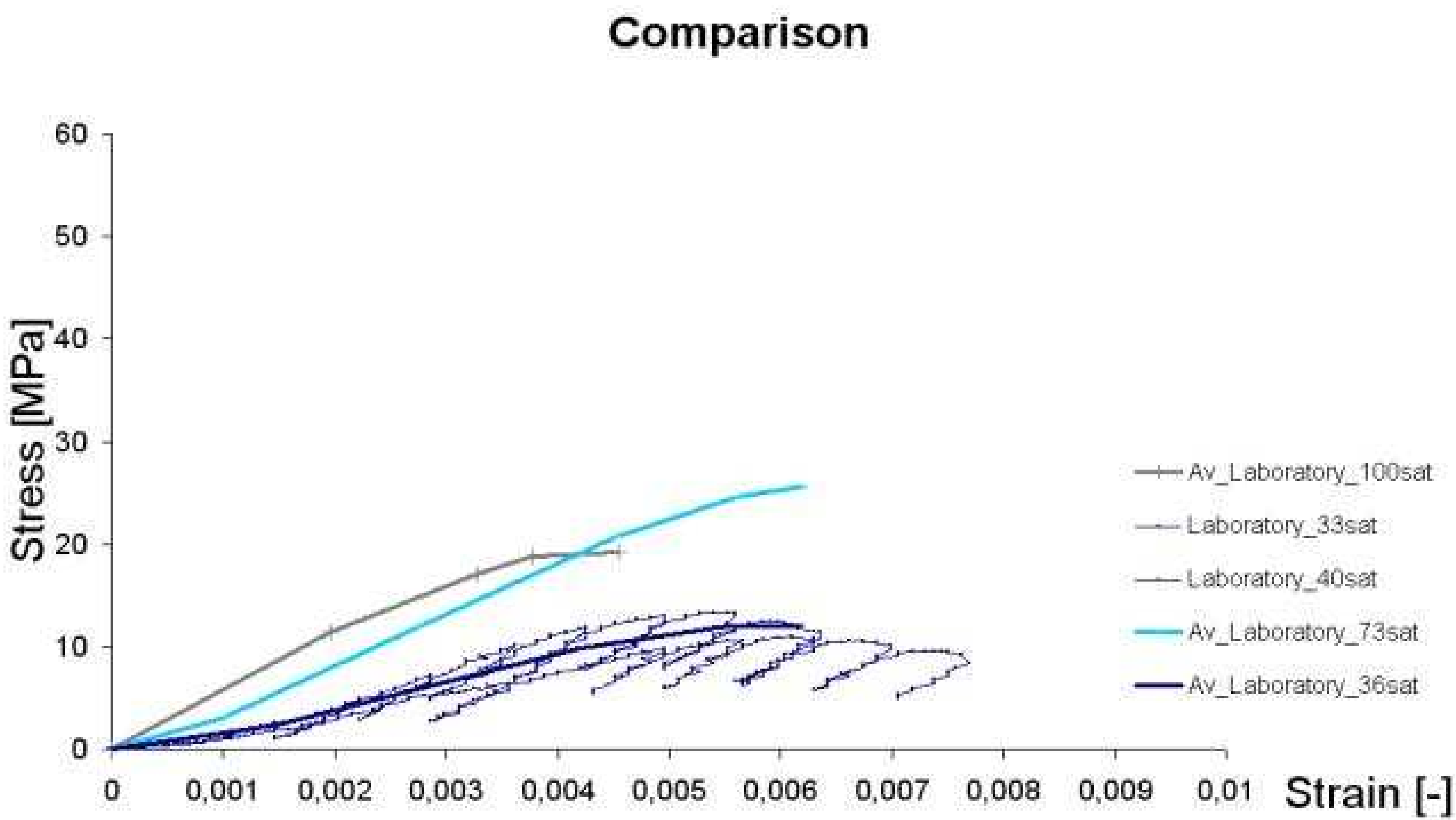

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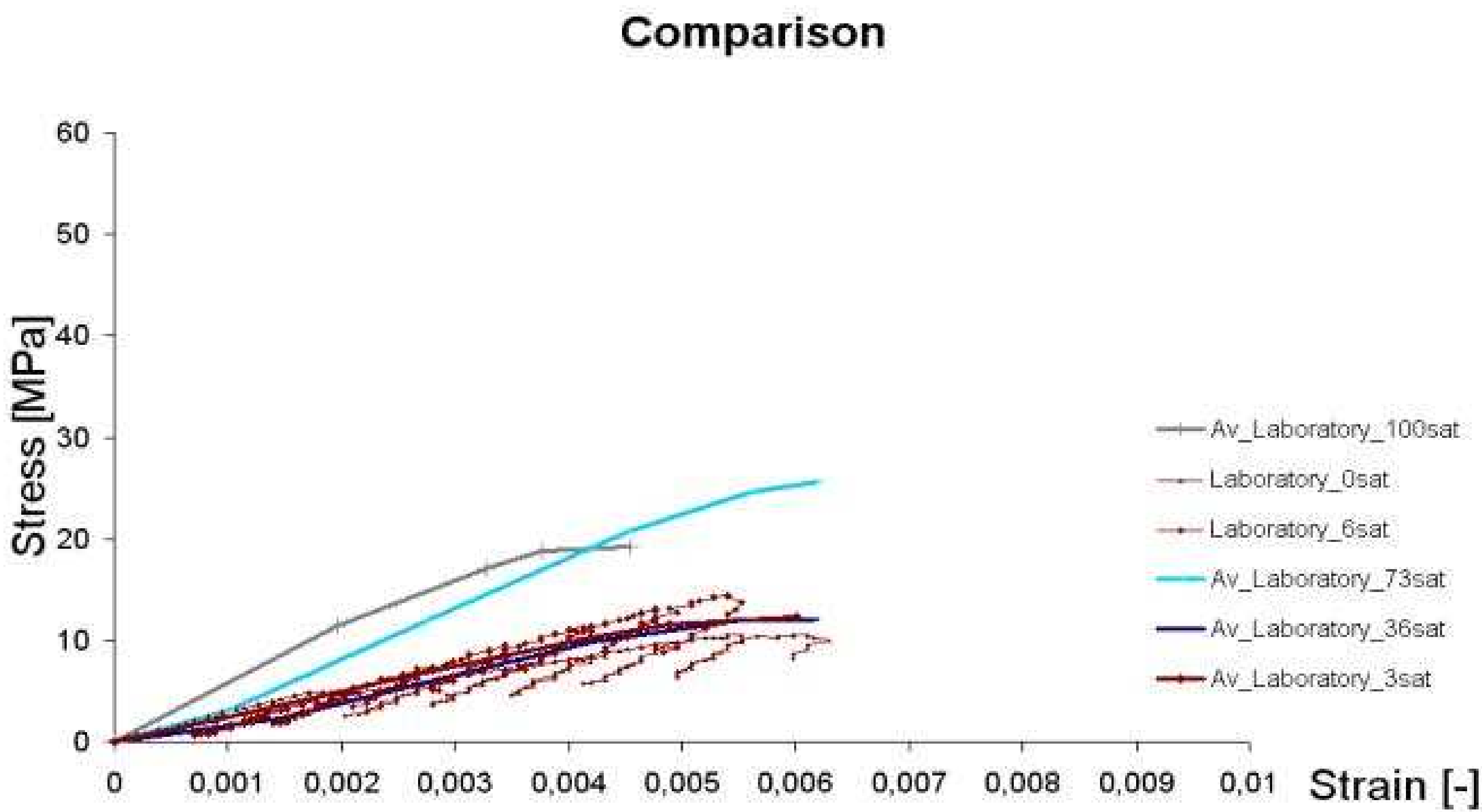

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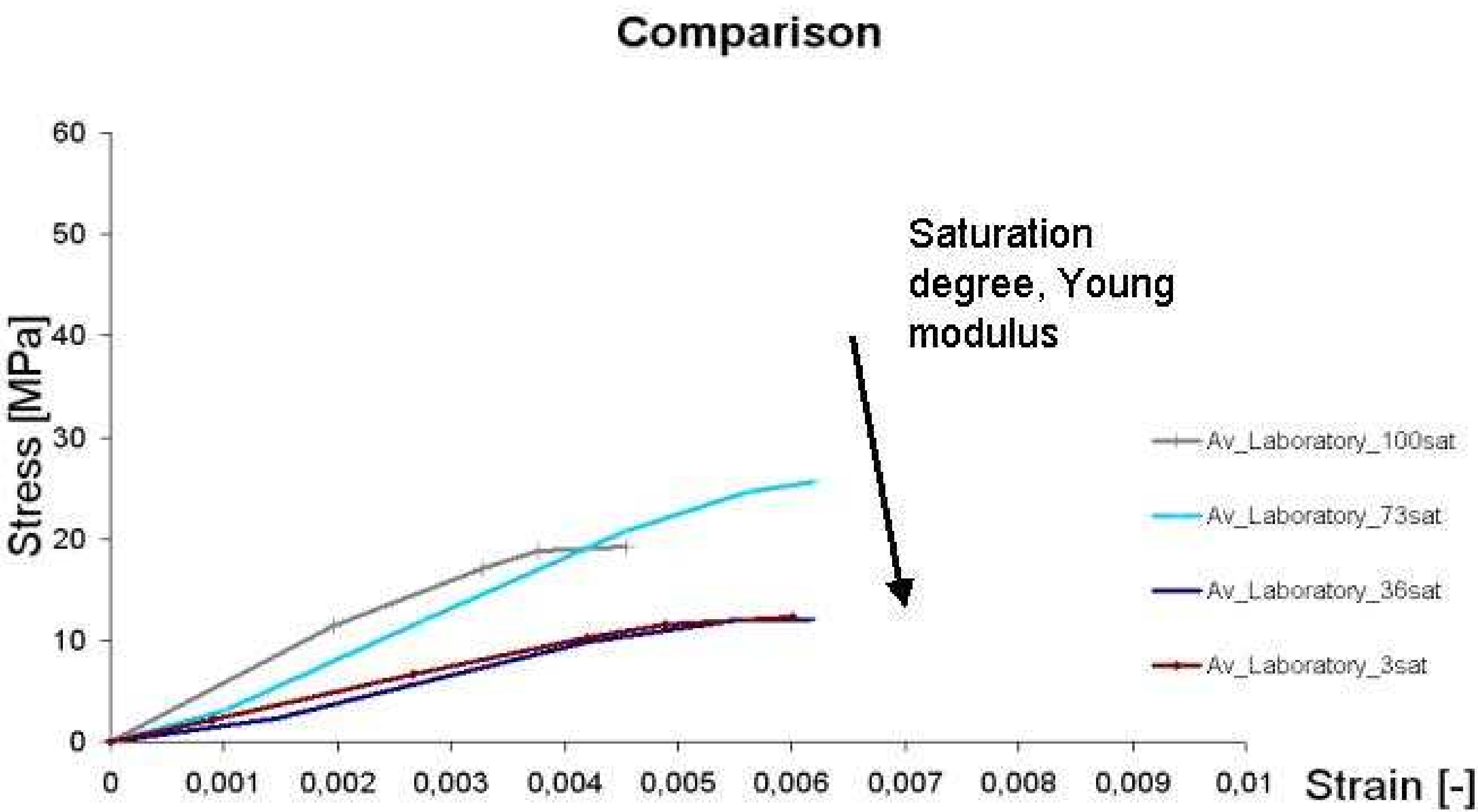
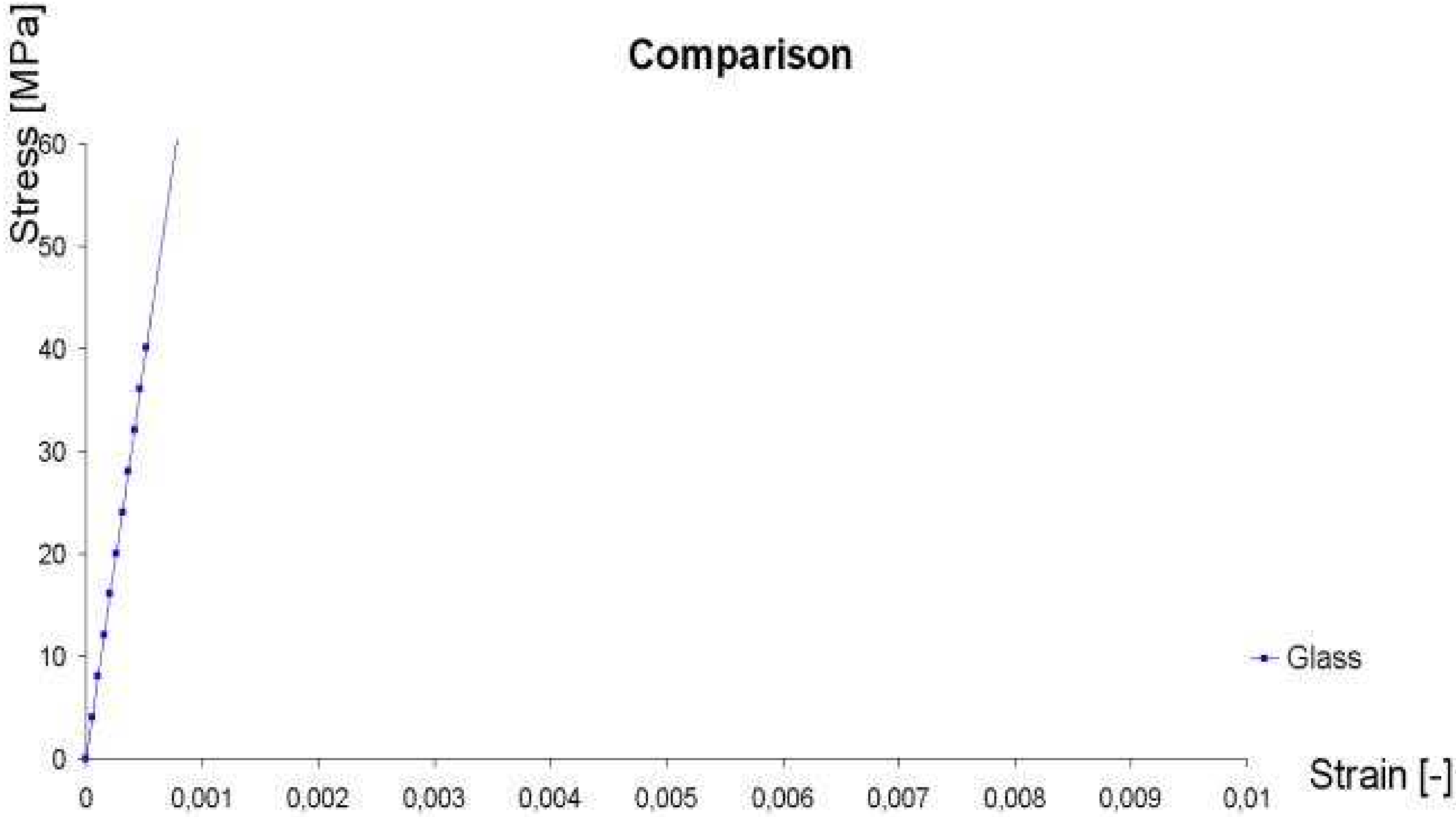


Computational modeling



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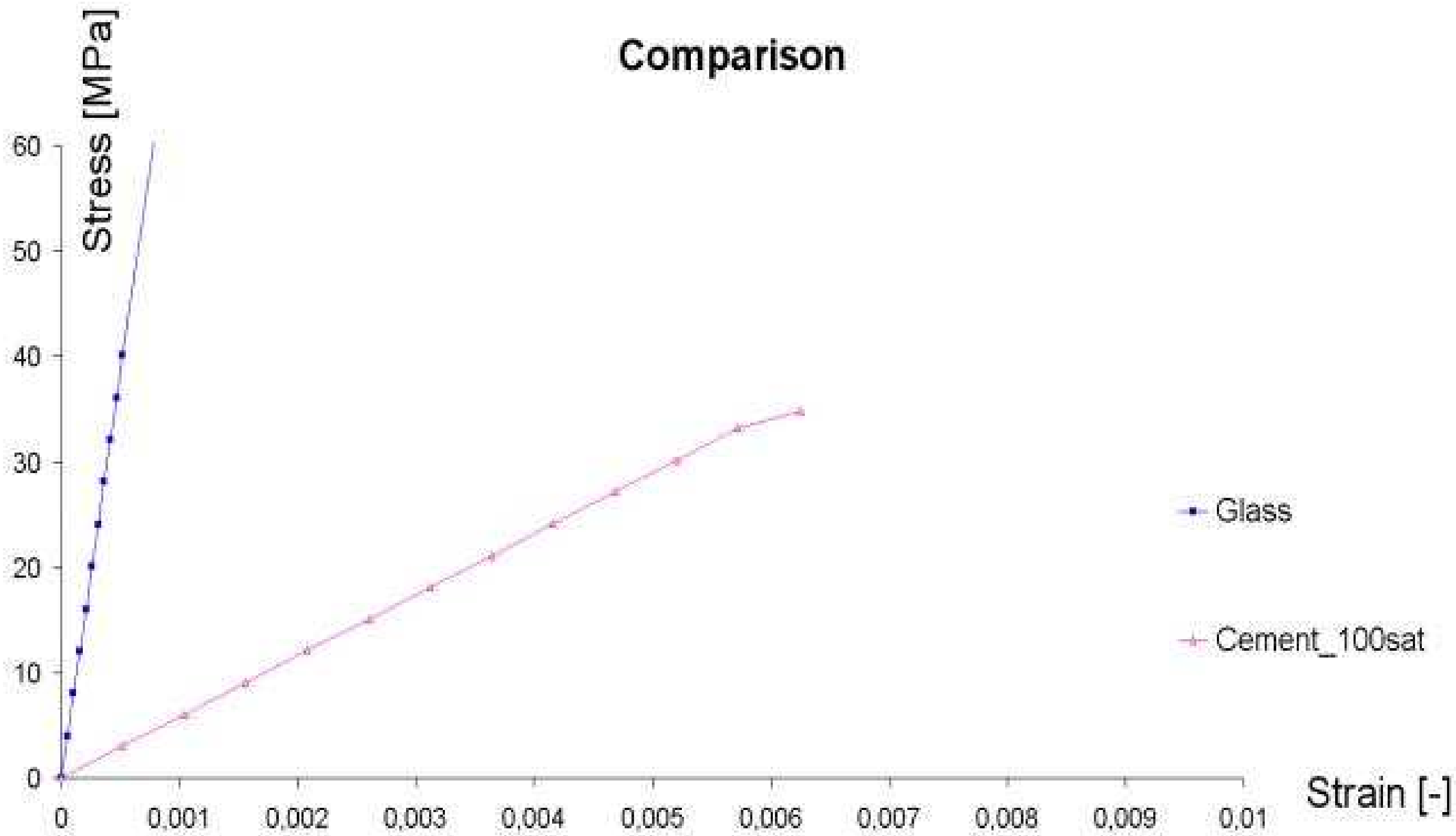

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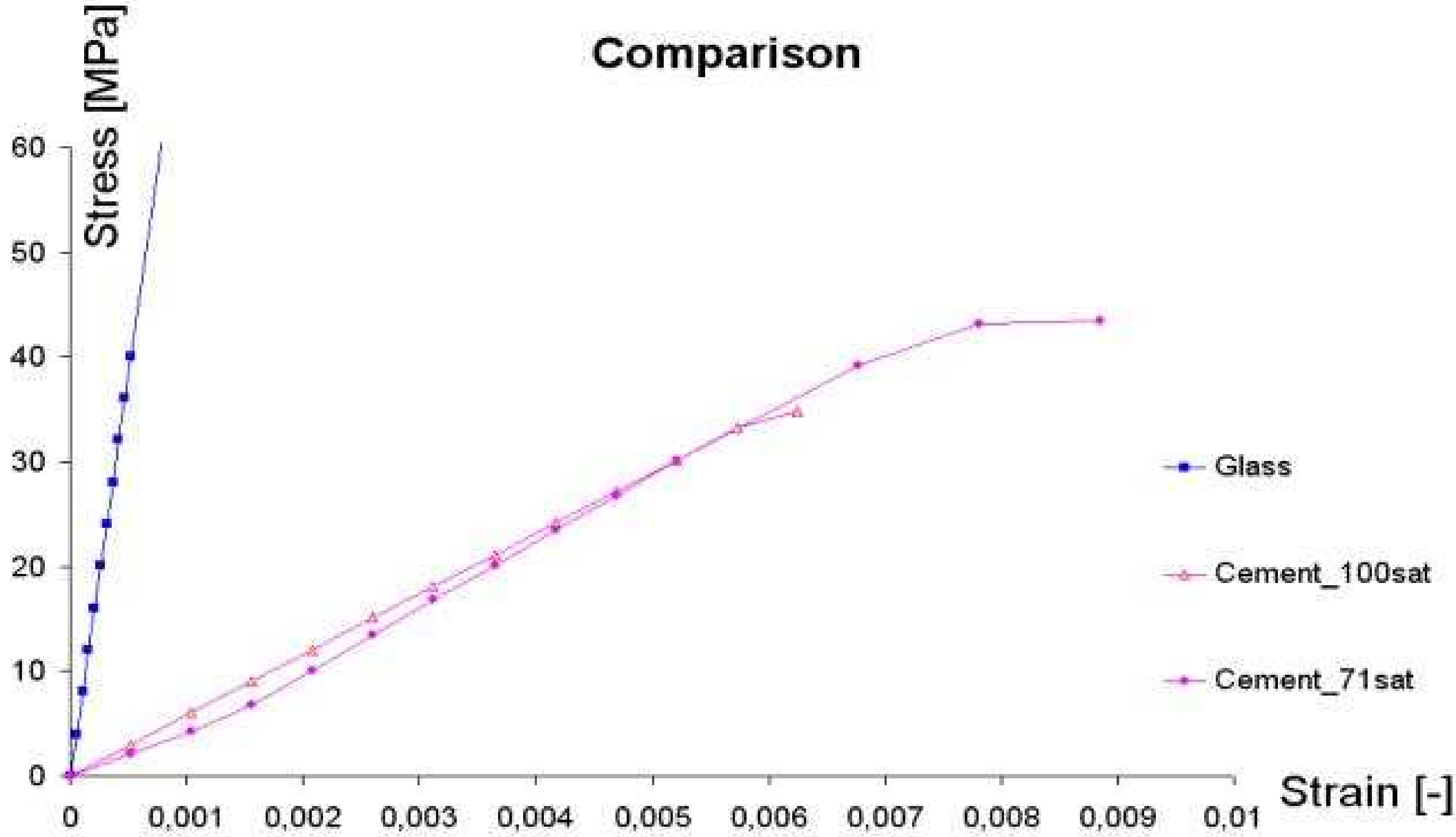

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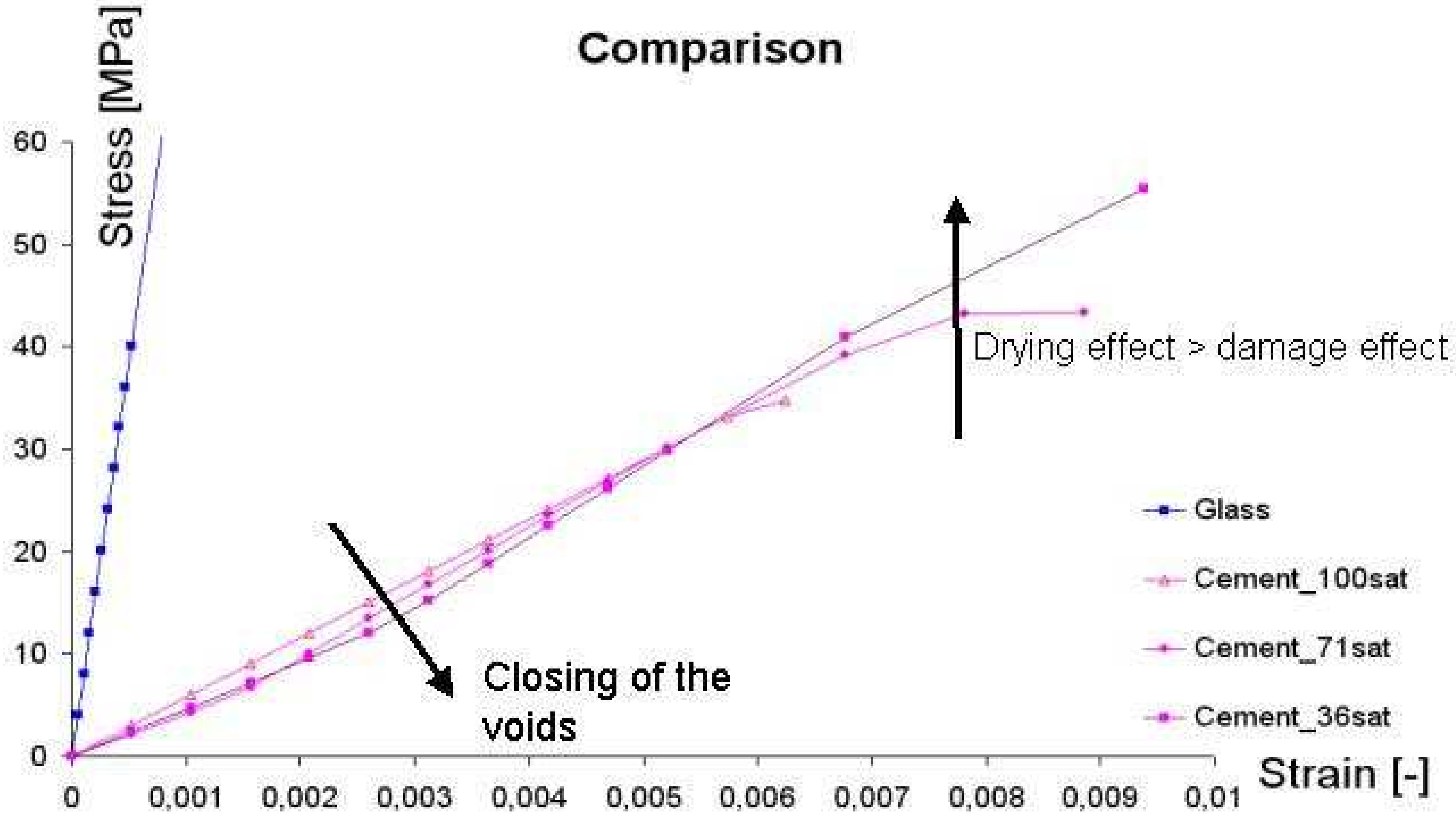

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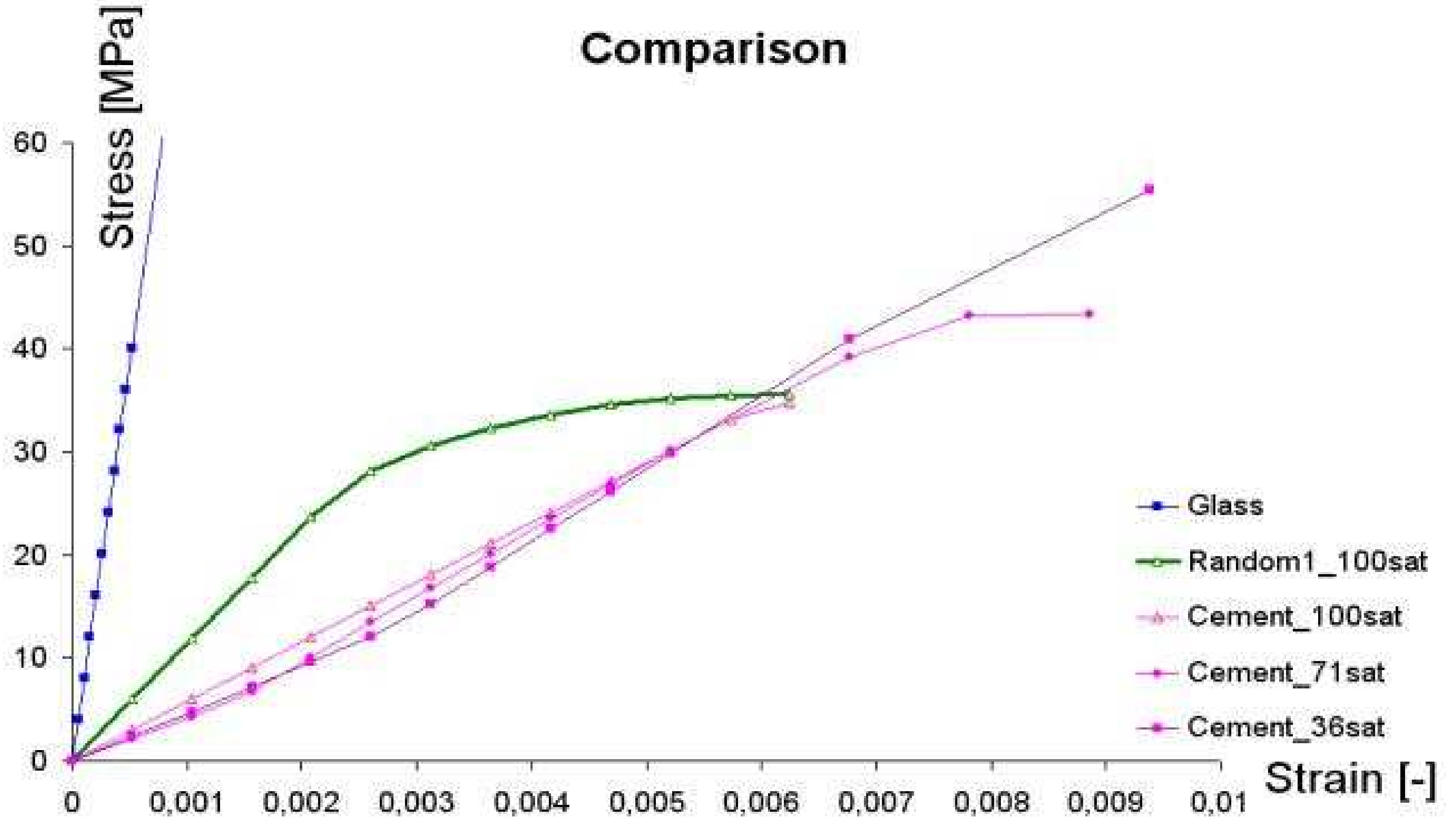
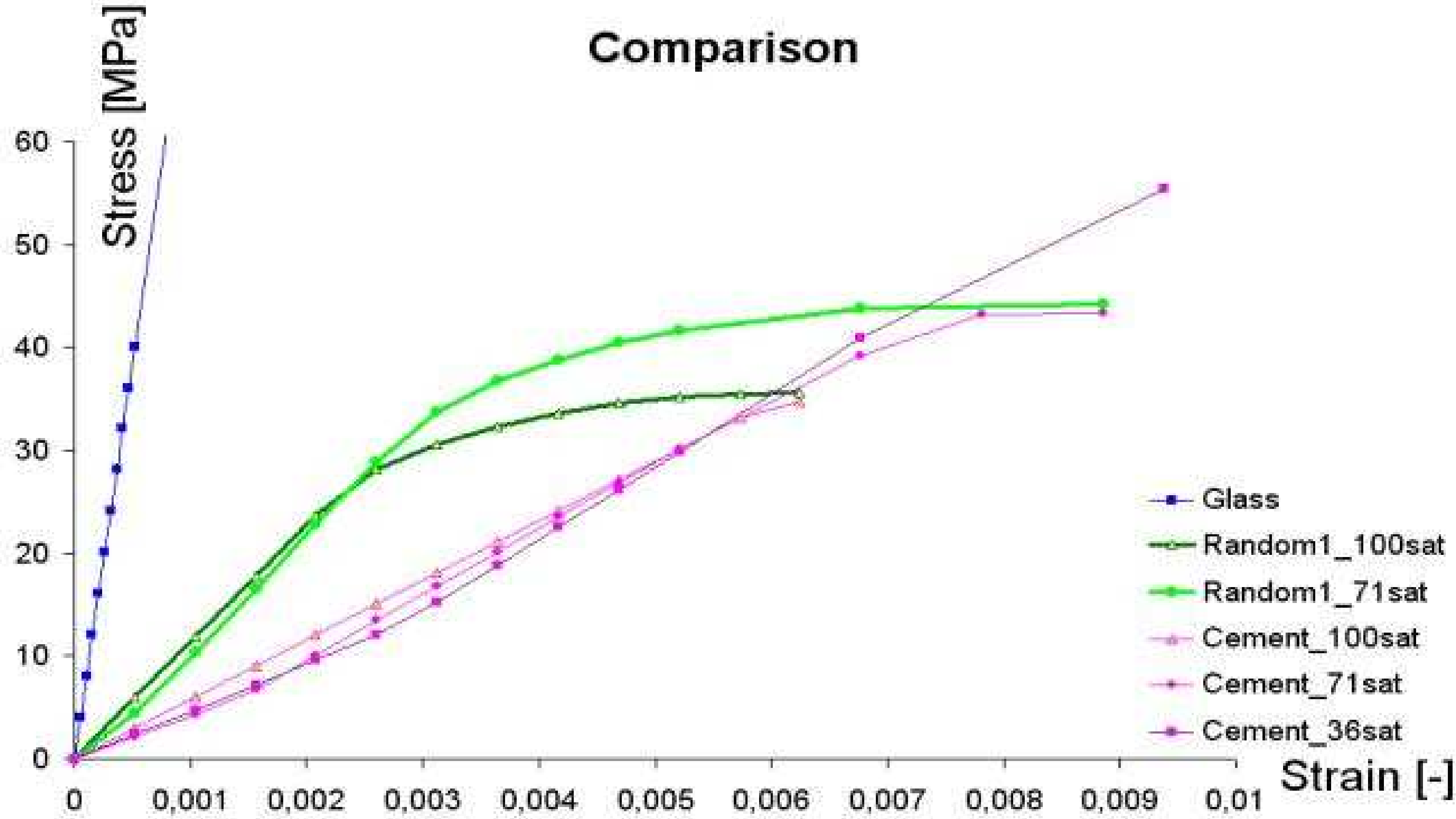
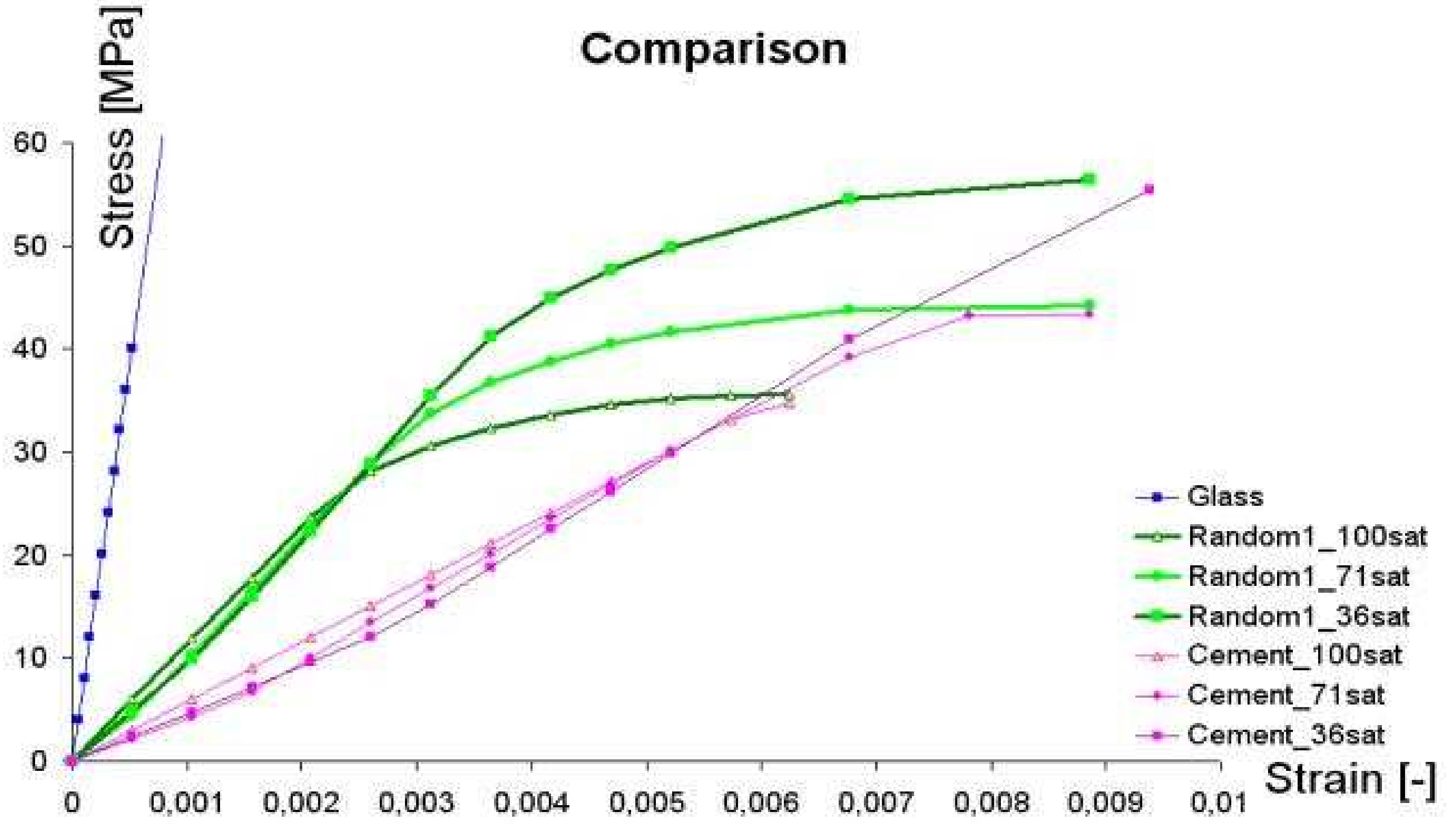


Computational modeling



Computational modeling



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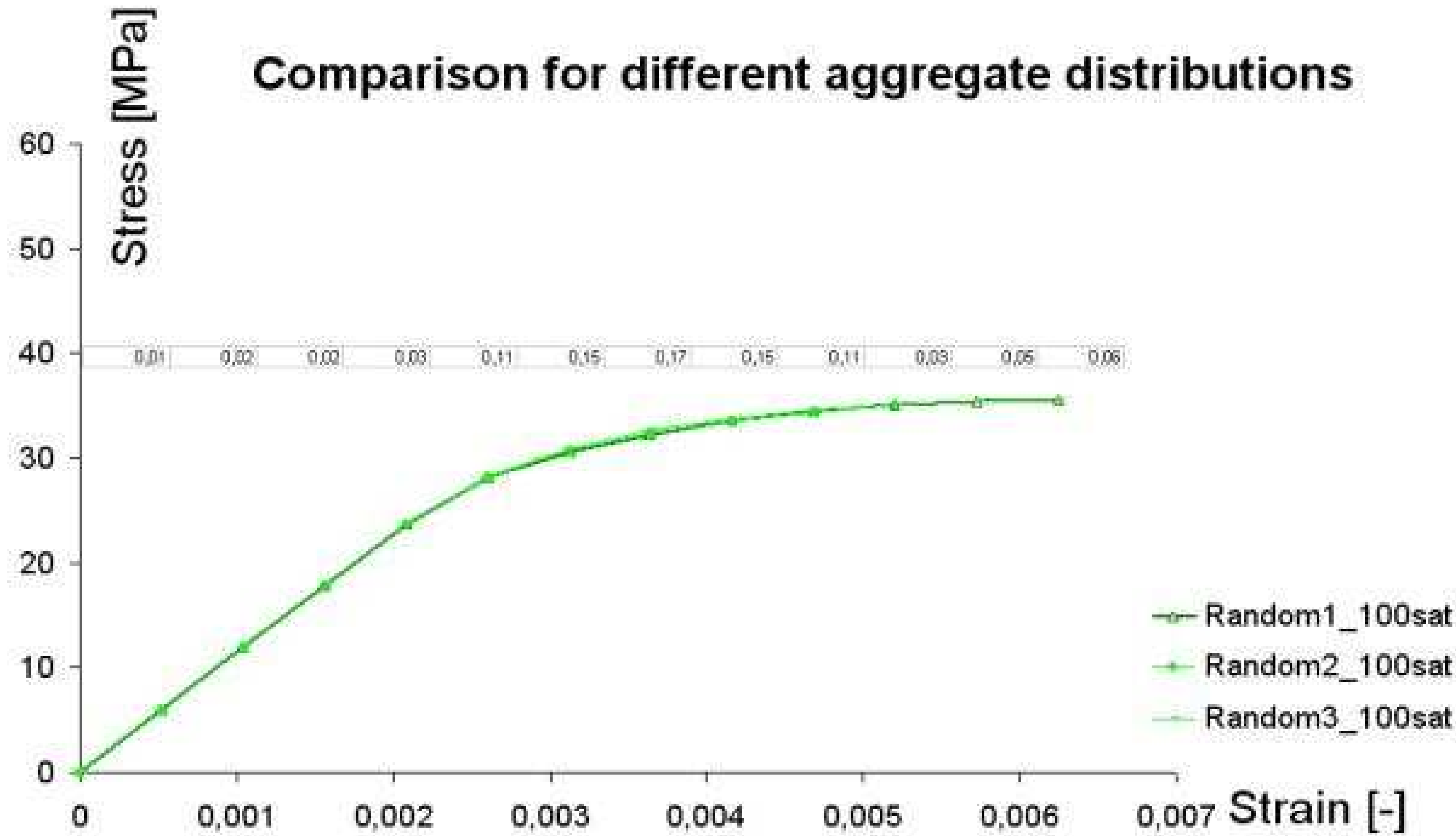
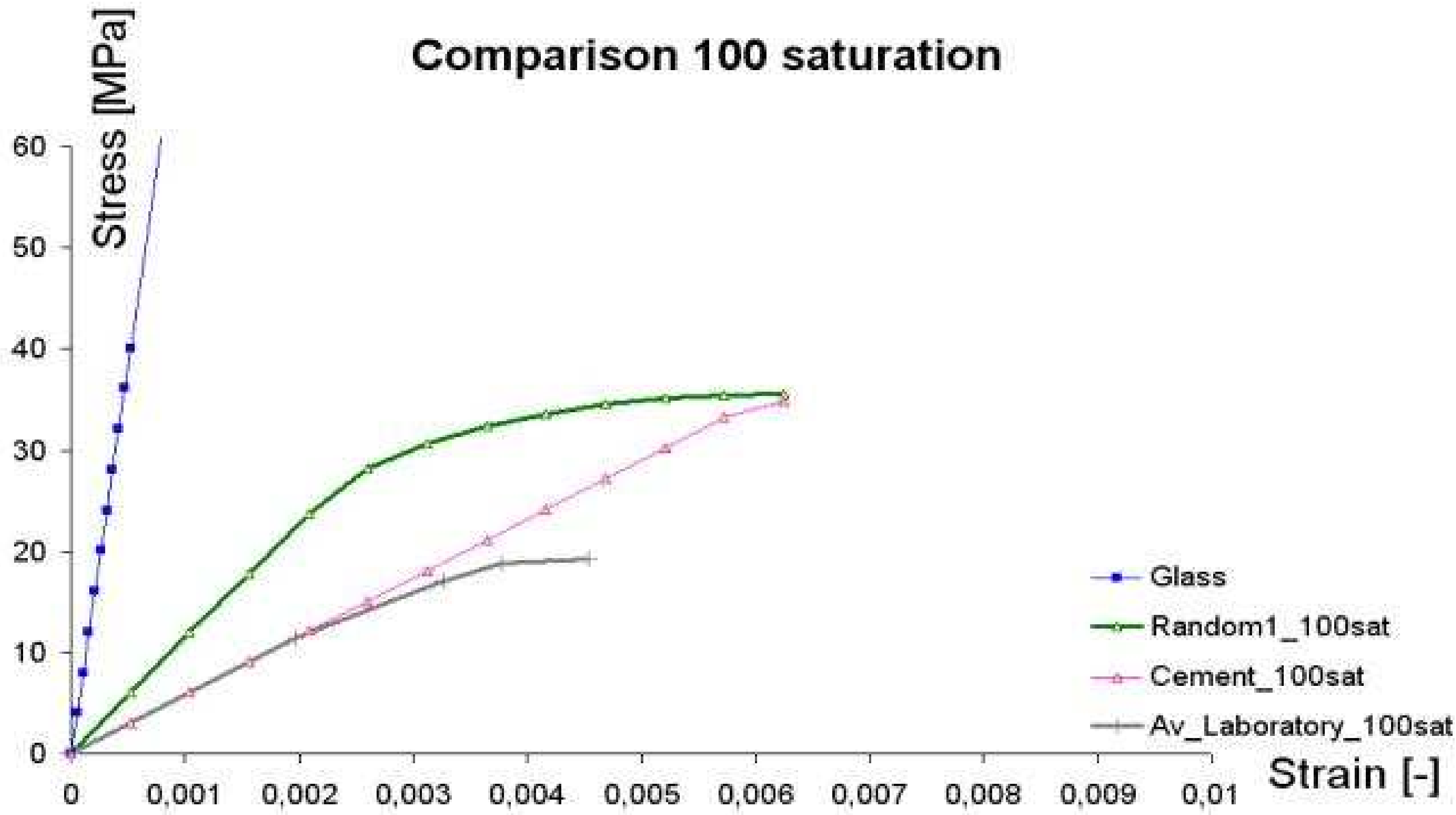
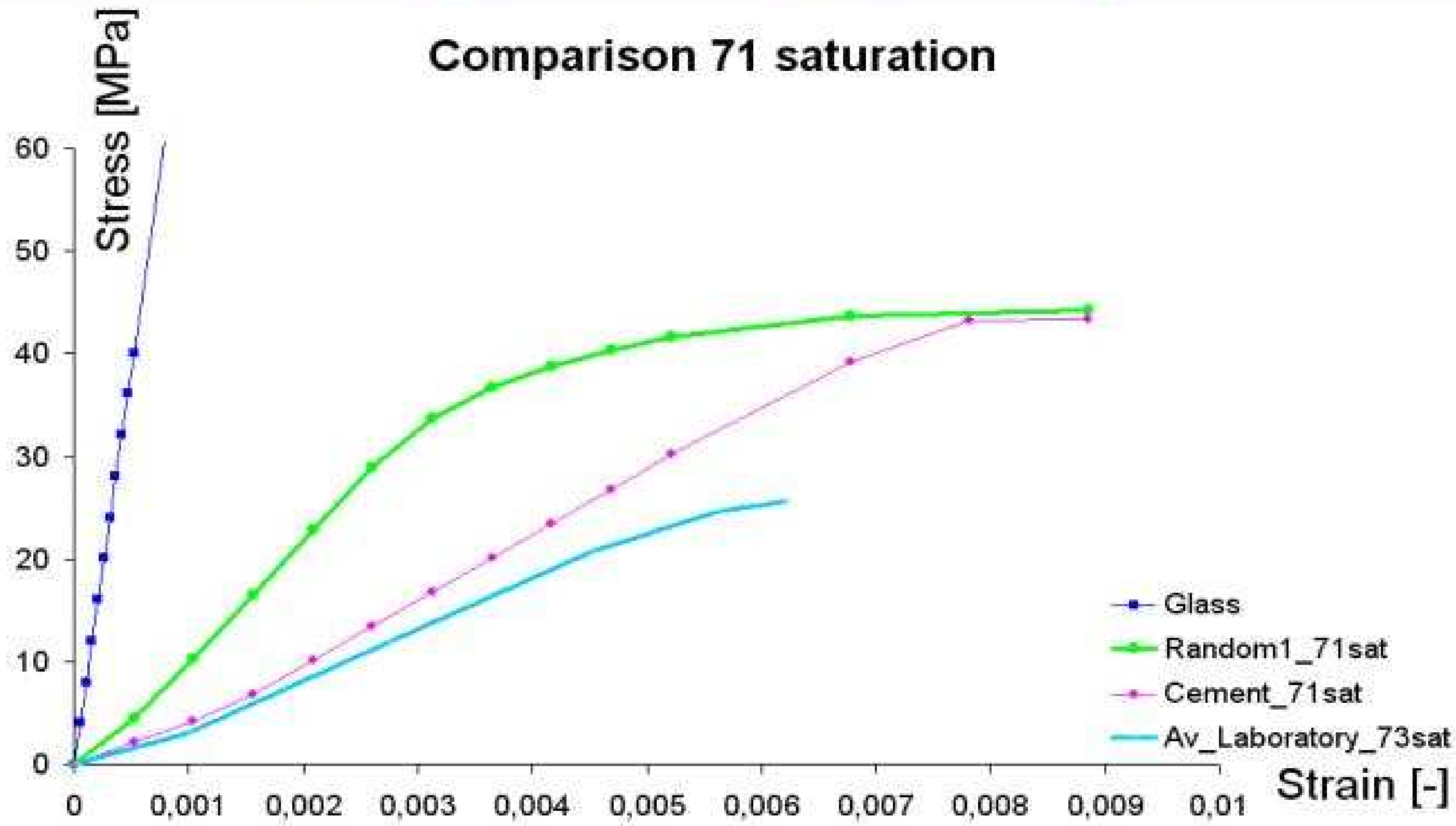


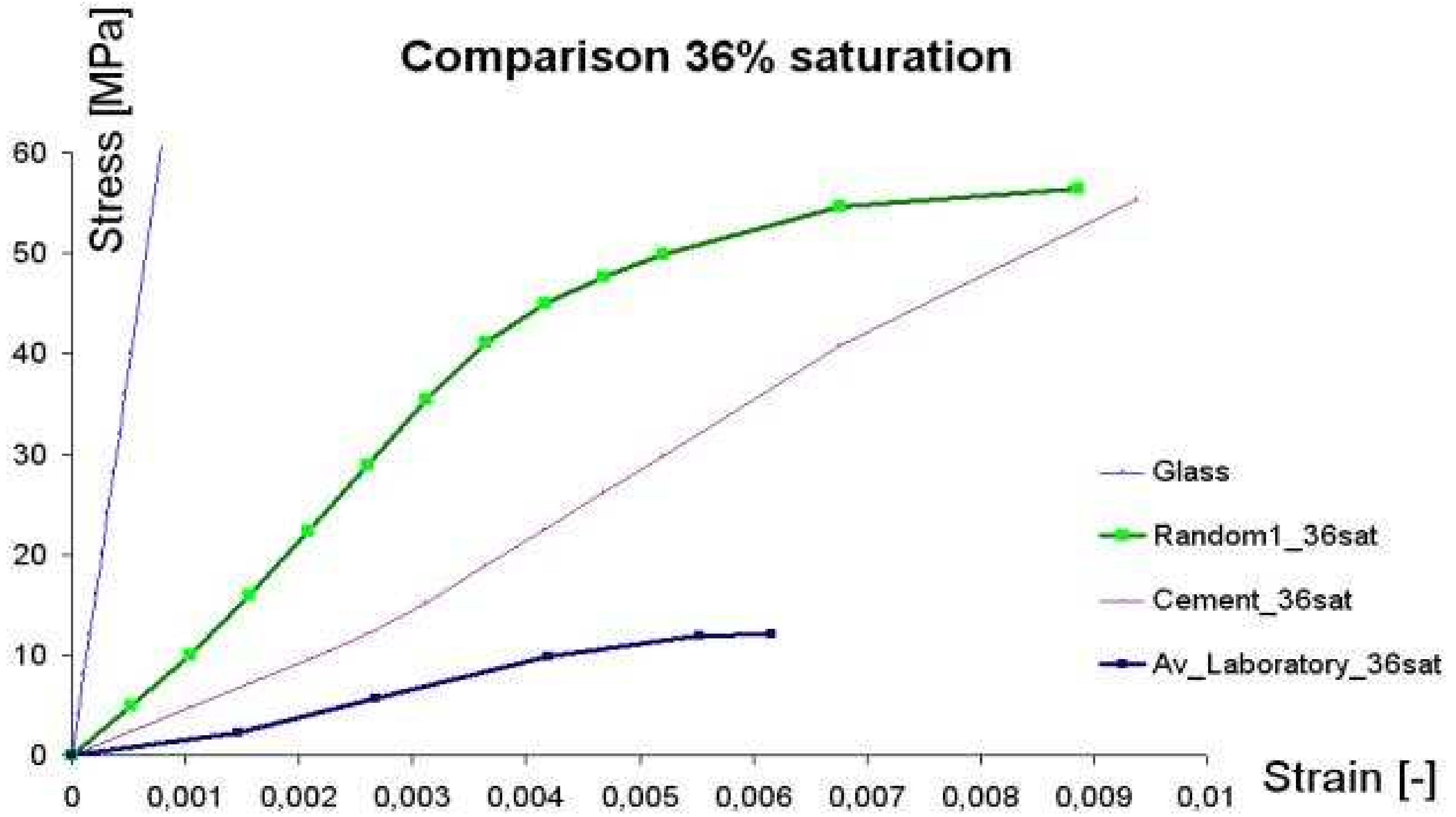
Uniaxial compression laboratory test and computational modeling



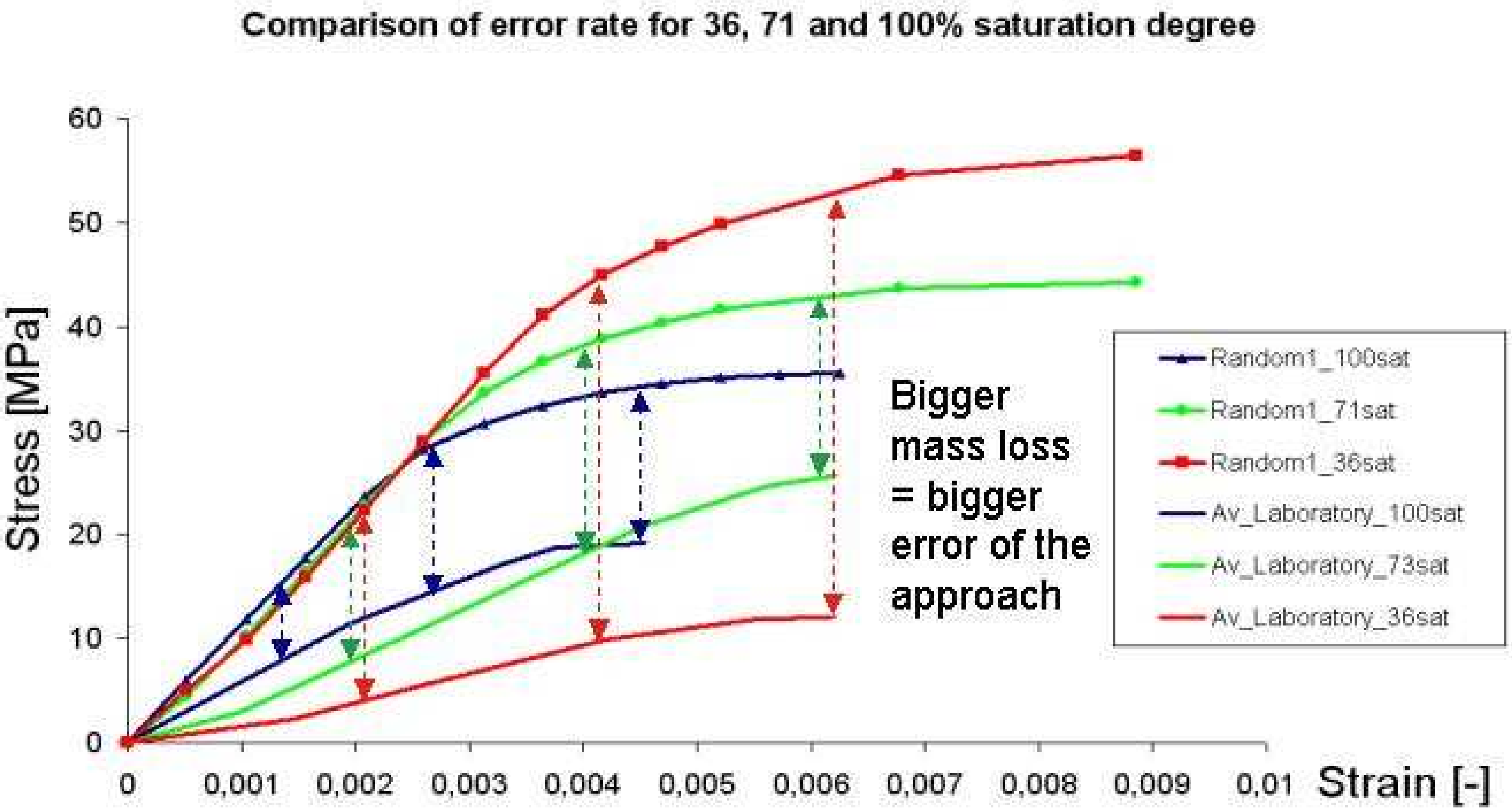
Uniaxial compression laboratory test and computational modeling



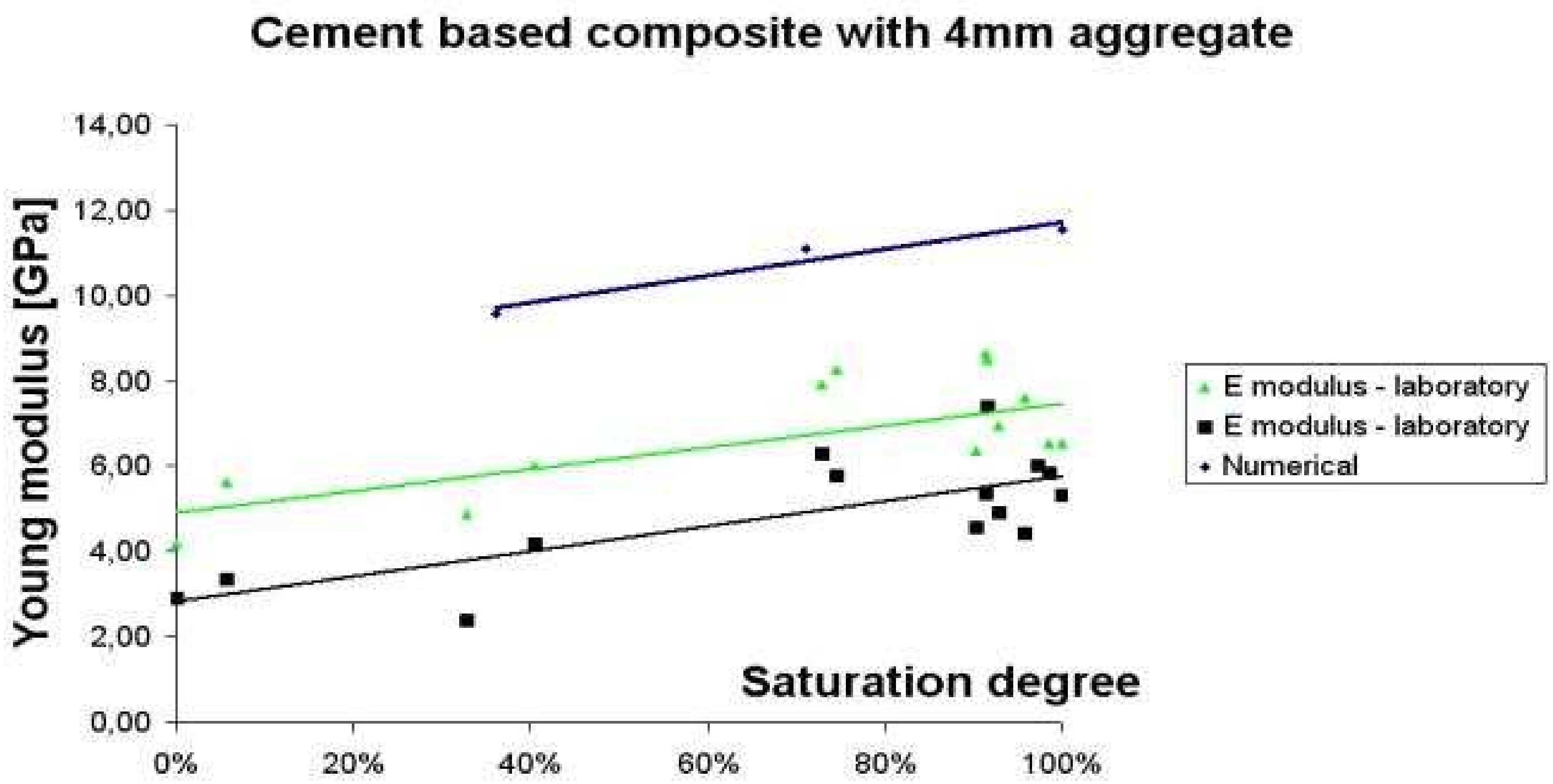
Uniaxial compression laboratory test and computational modeling



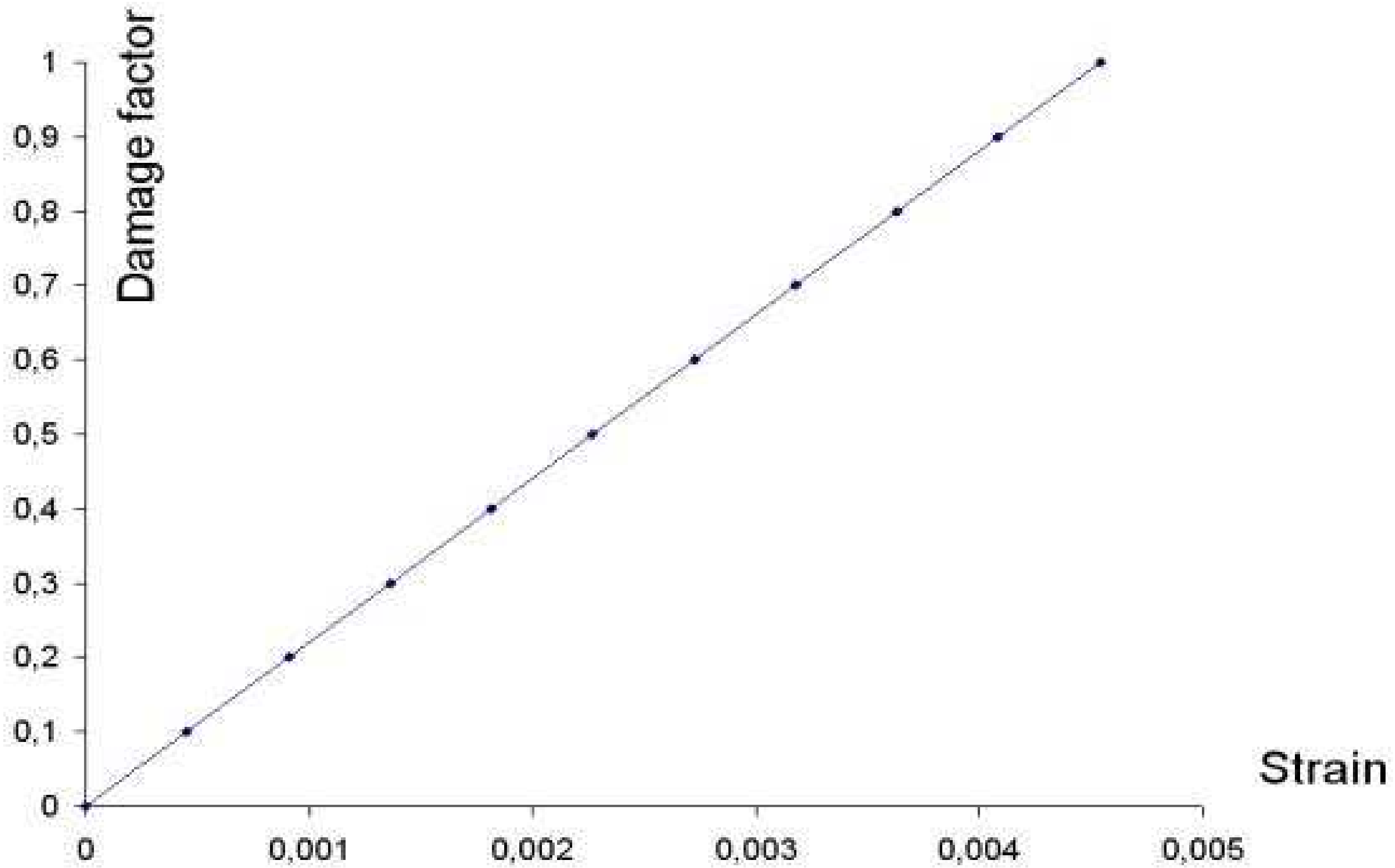
Uniaxial compression laboratory test and computational modeling



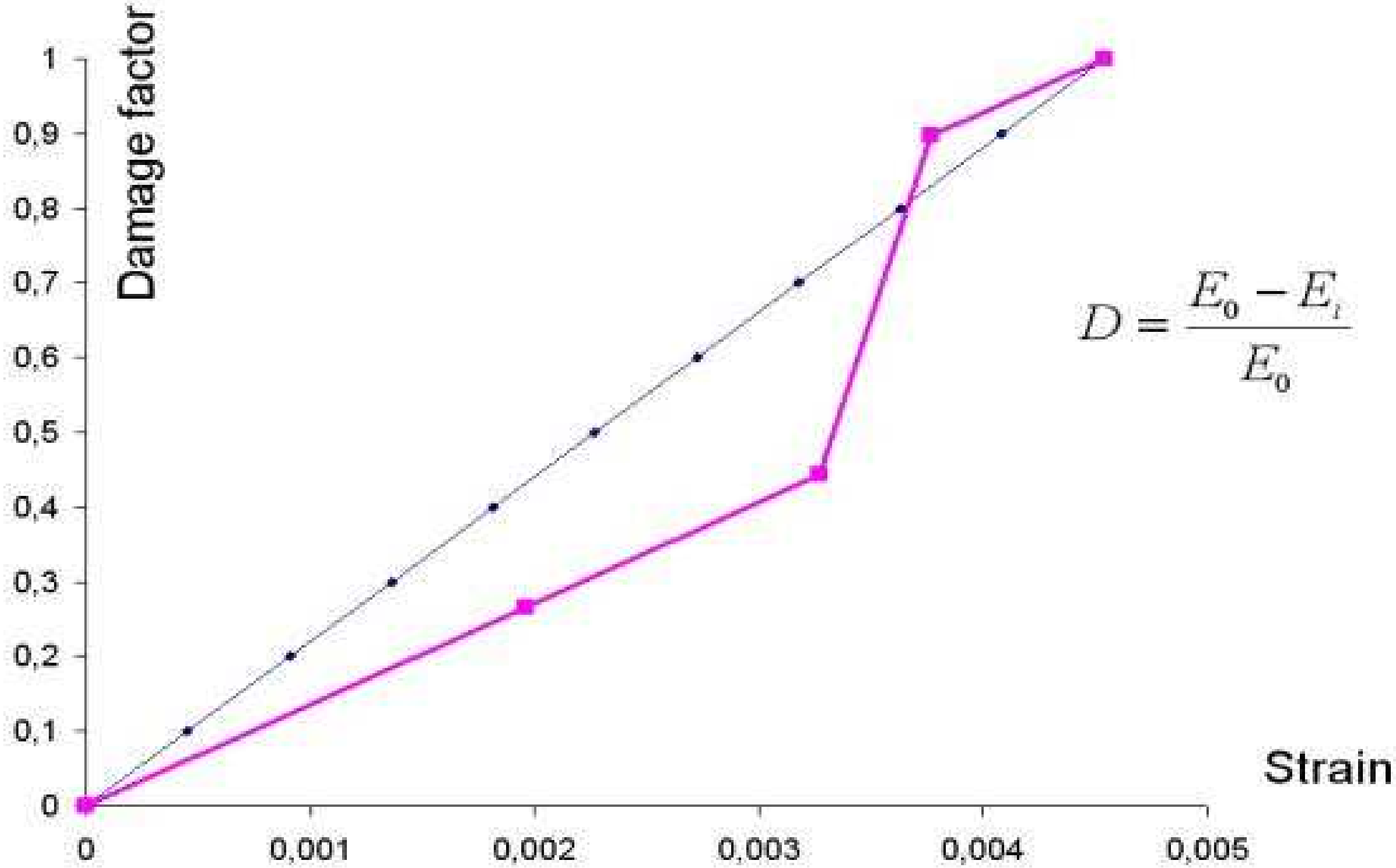
Young modulus in laboratory tests and numerical tests as function of saturation degree



Damage modeling, basic approach

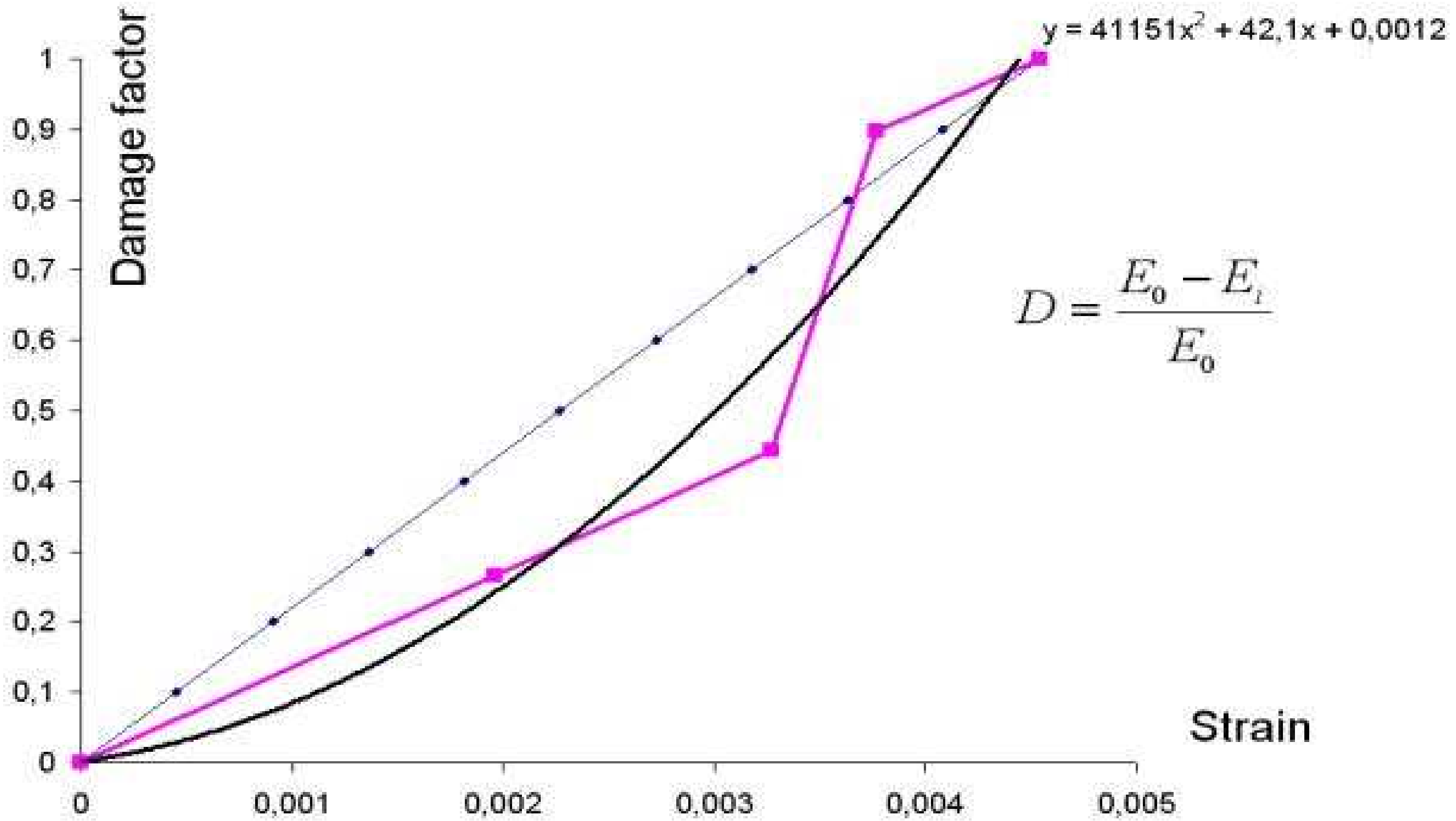


Damage modeling, basic approach



$$D = \frac{E_0 - E_i}{E_0}$$

Damage modeling, basic approach



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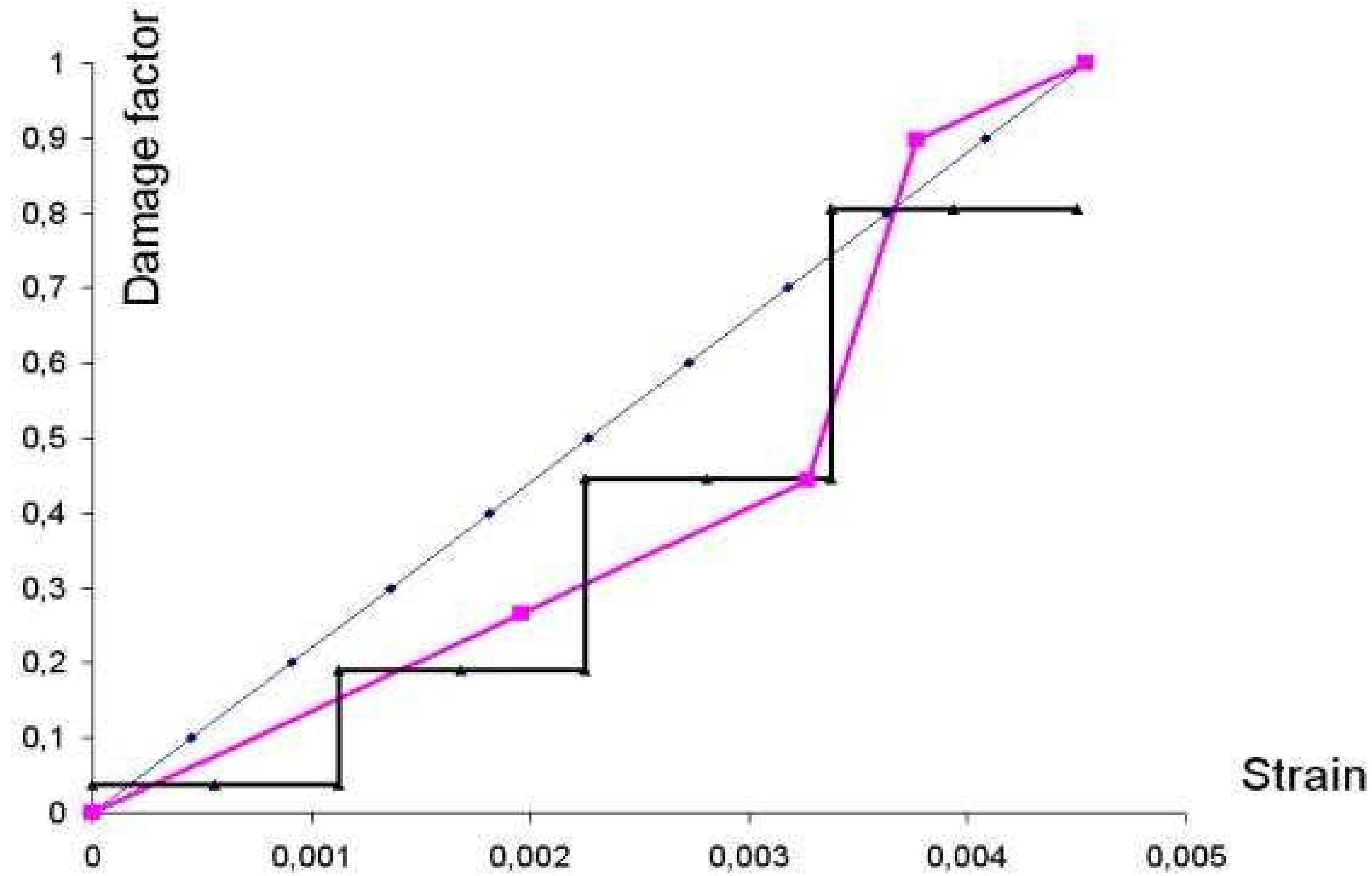
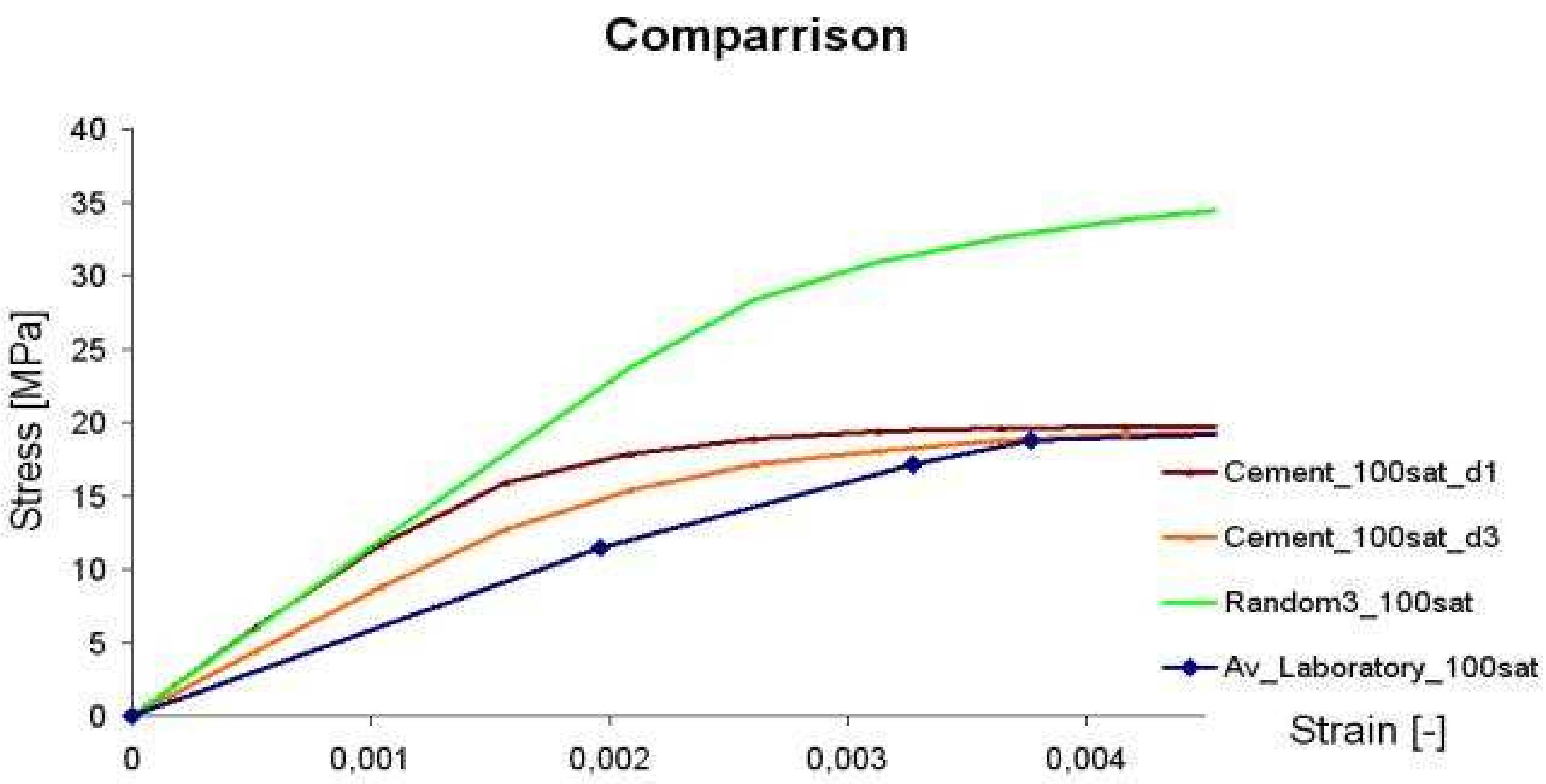


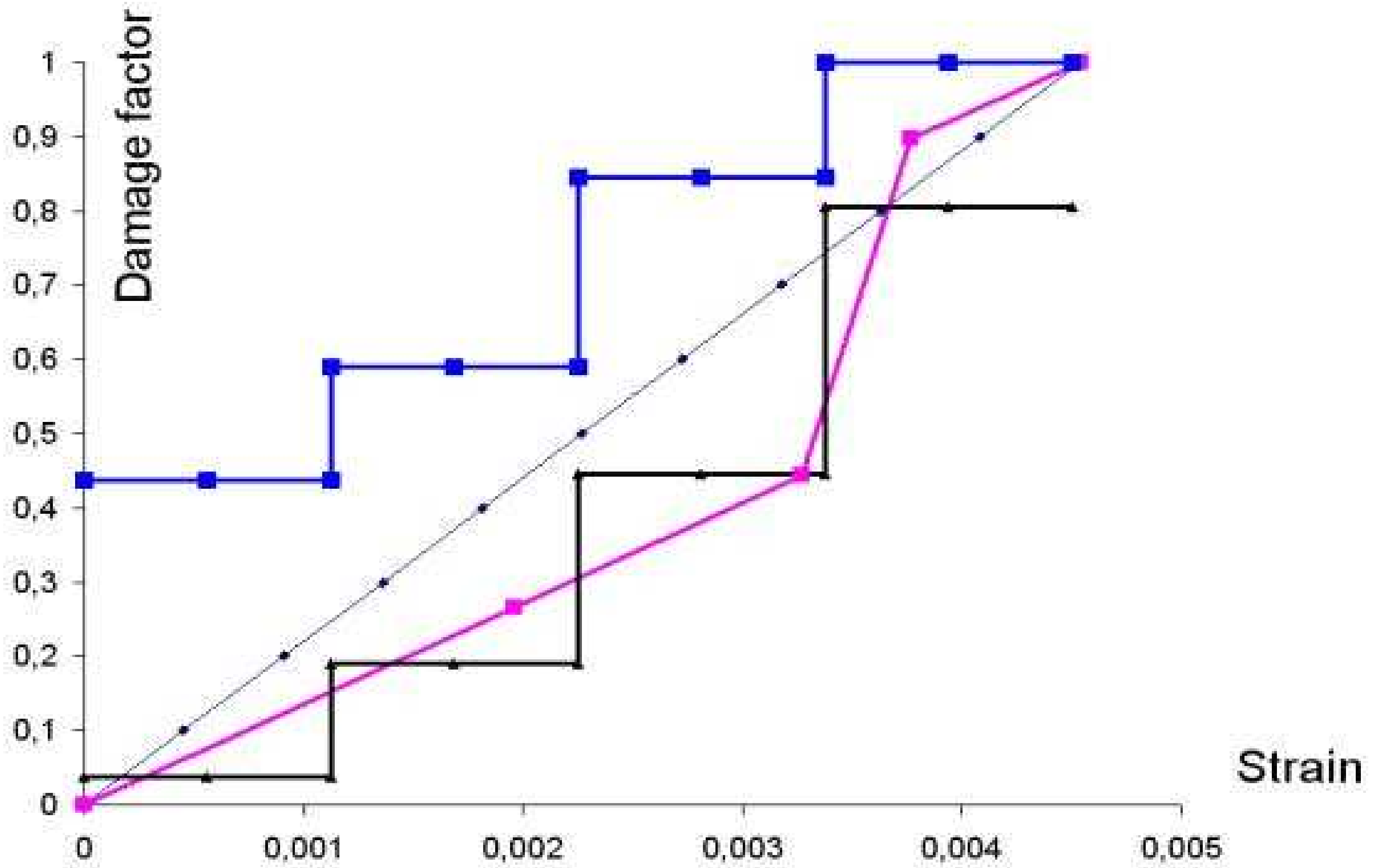
Damage modeling, basic approach



Damage mechanisms

D =	D – temperature gradient	D – autogenous shrinkage	D – drying shrinkage
100% saturation	*	*	-
66% saturation	*	**	*
33% saturation	*	**	**
0% saturation	*	**	***

Damage modeling, basic approach



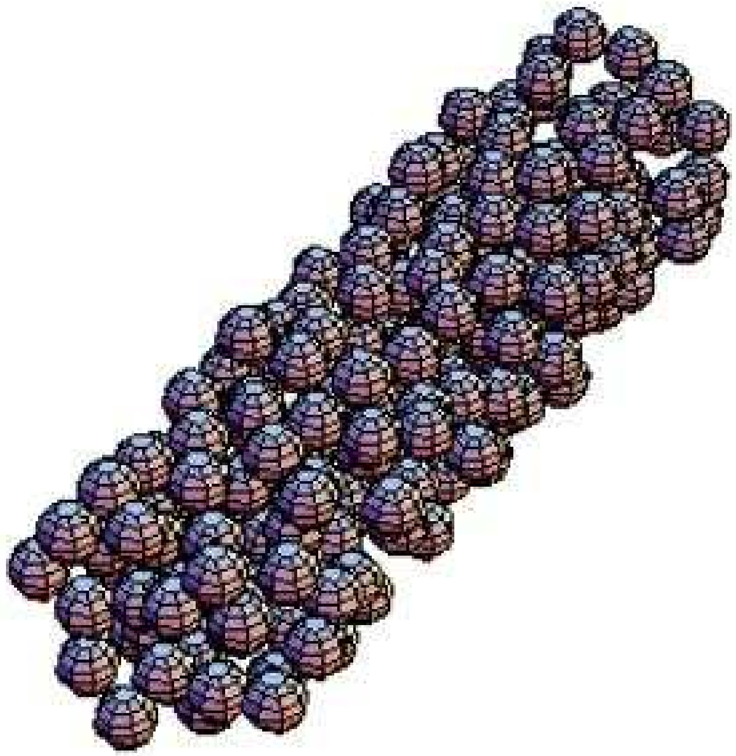
Conclusions

- Cement paste continuous model should take under consideration saturation degree influence:
  - Direct saturation degree implementation (Coussy 95, …)
  - Non direct implementation by C and ϕ
- Presented algorithm of composite numerical modeling allows an objective description of laboratory tests
- Modeling in meso level is more effective then macroscopic modeling and gives possibility to take under consideration more physical mechanisms present during different loading states
- Considerable difficulties appear in modeling of composites with cement paste matrices. They are due to nonlinear mechanical effects like: autogenous shrinkage, shrinkage under drying and finally general damage of the material

Conclusions

- **Simplification of aggregate and sample shape should be omitted**
- **For random distribution of aggregate we further use modified Metropolis algorithm (S.Torquato 2004)**
- **How modified?**

  2d model of random distribution of circles inside square is extended by authors to random distribution of spheres inside cylinder



Another possibilities of the method usage, further research goals

1. Prediction of composite macroscopic reactions in the whole range of mechanical and non mechanical (saturation degree change) loading conditions as a supplement for laboratory tests or even it's replacement
2. Estimation of RV for a particular composite. Evaluation of correction parameters, if RV is to small for the case, so the results can be valuable for the further projection of material macroscopic response

Thank you for your attention