Testing Rheological and Fracture Properties of 3D-Printable Concrete in the Fluid-to-Solid Open Time Window

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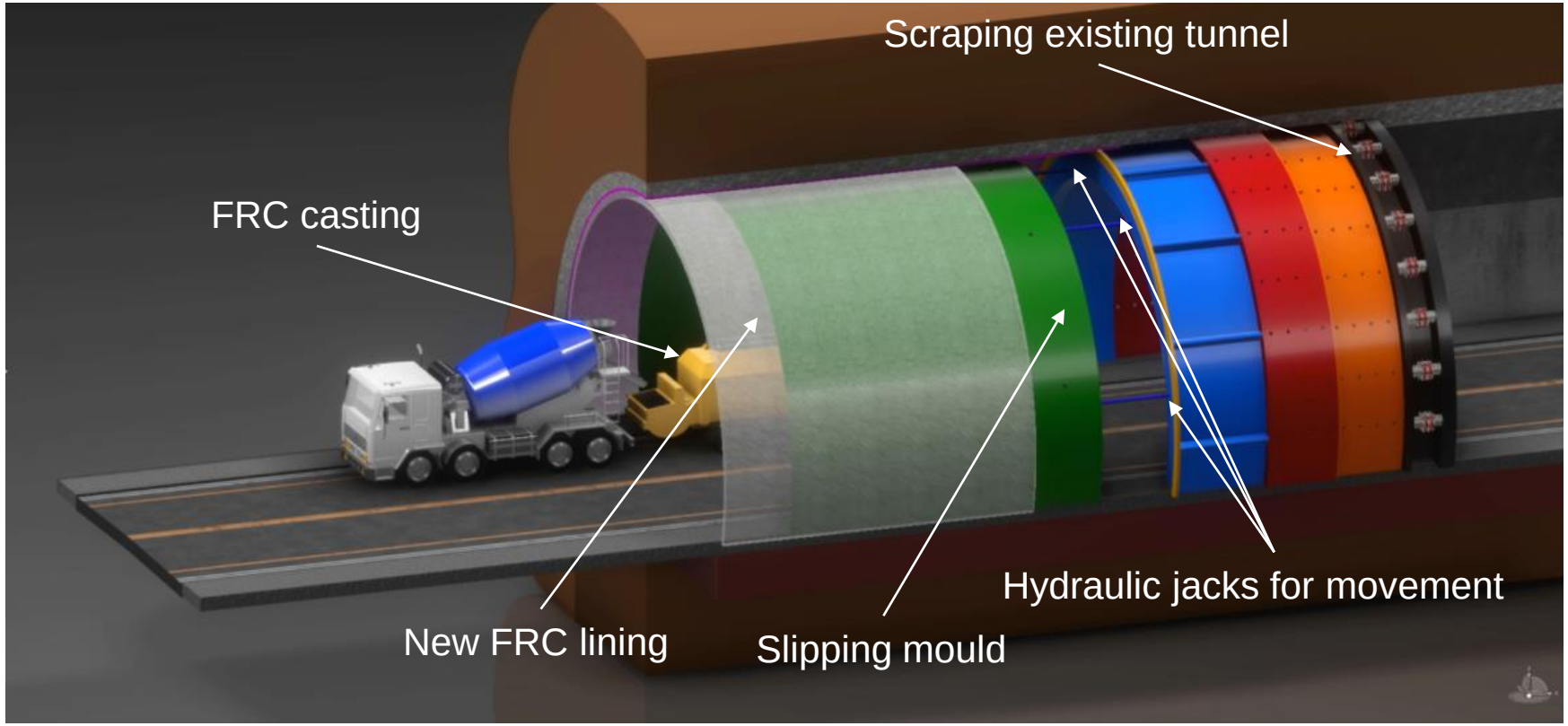
ACI Concrete Convention: Fall 2023, Boston, Massachusetts, USA

The current “tunnel issue” in Italy – Hinfra proposal



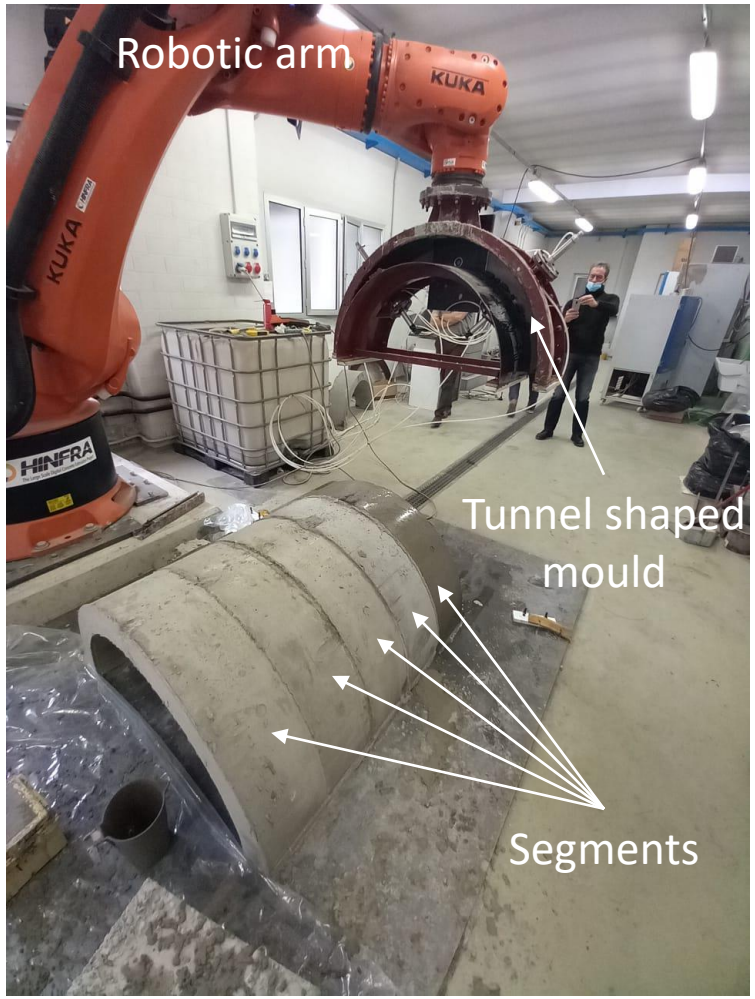
Along with the start-up company Hinfra we are developing a **slipforming** technology based on the extrusion of **tunnel** linings, representing a new **maintenance** intervention for existing tunnels (**ETLR** project).

Small Scale

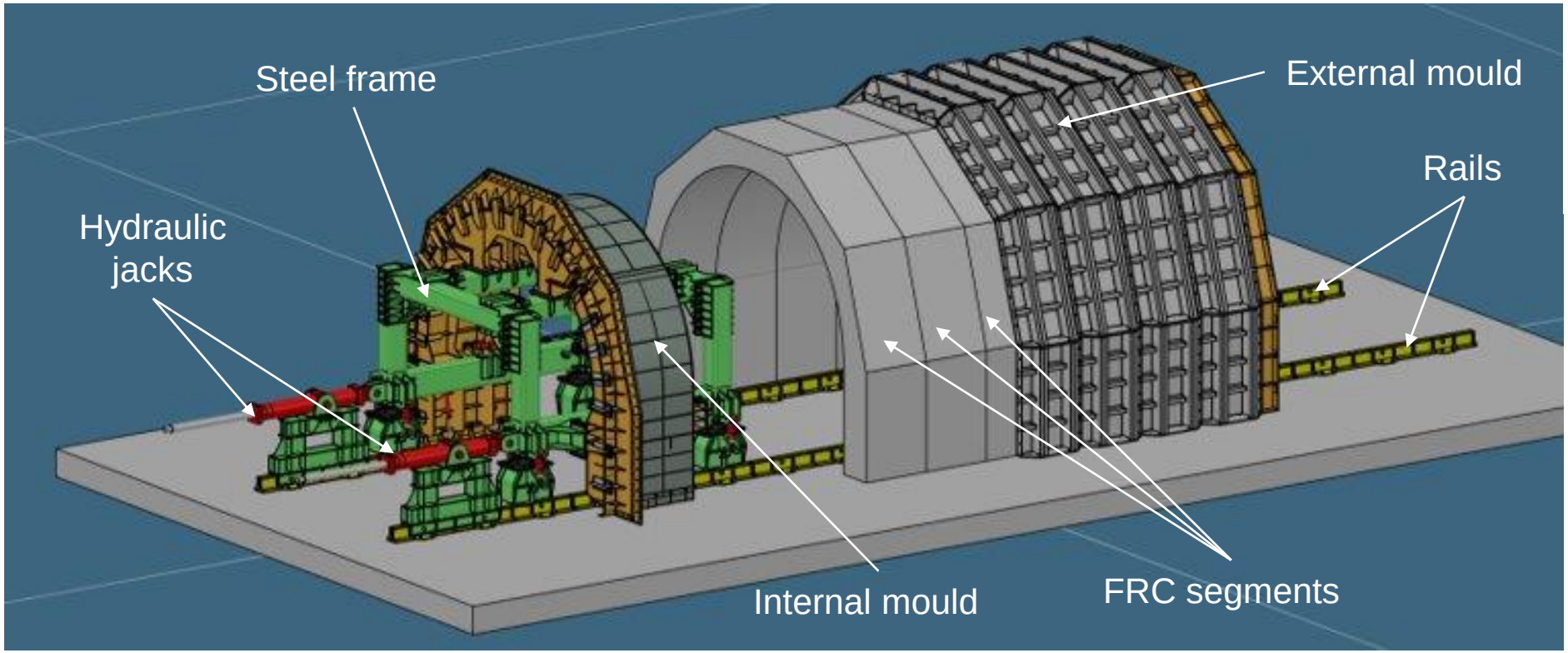
HINFRA™
The Large Scale Digital Concrete Extrusion Project

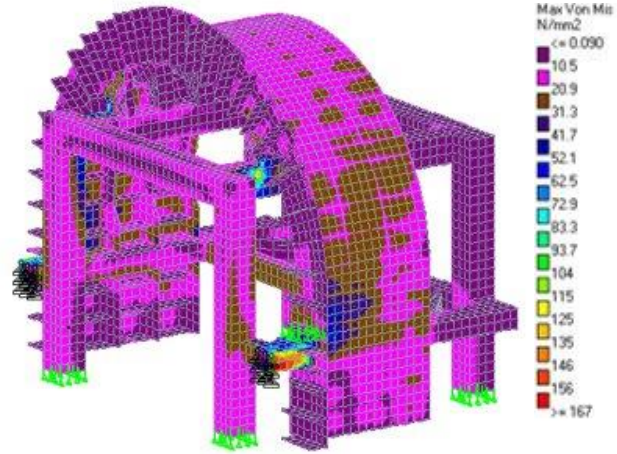
eTLR
EXTRUDED TUNNEL LINING REGENERATION

Small scale extrusions have been done by means of a **robotic arm** to validate the feasibility of the technology.



Real Scale


Steel frame
External mould
Rails
Hydraulic jacks
Internal mould
FRC segments

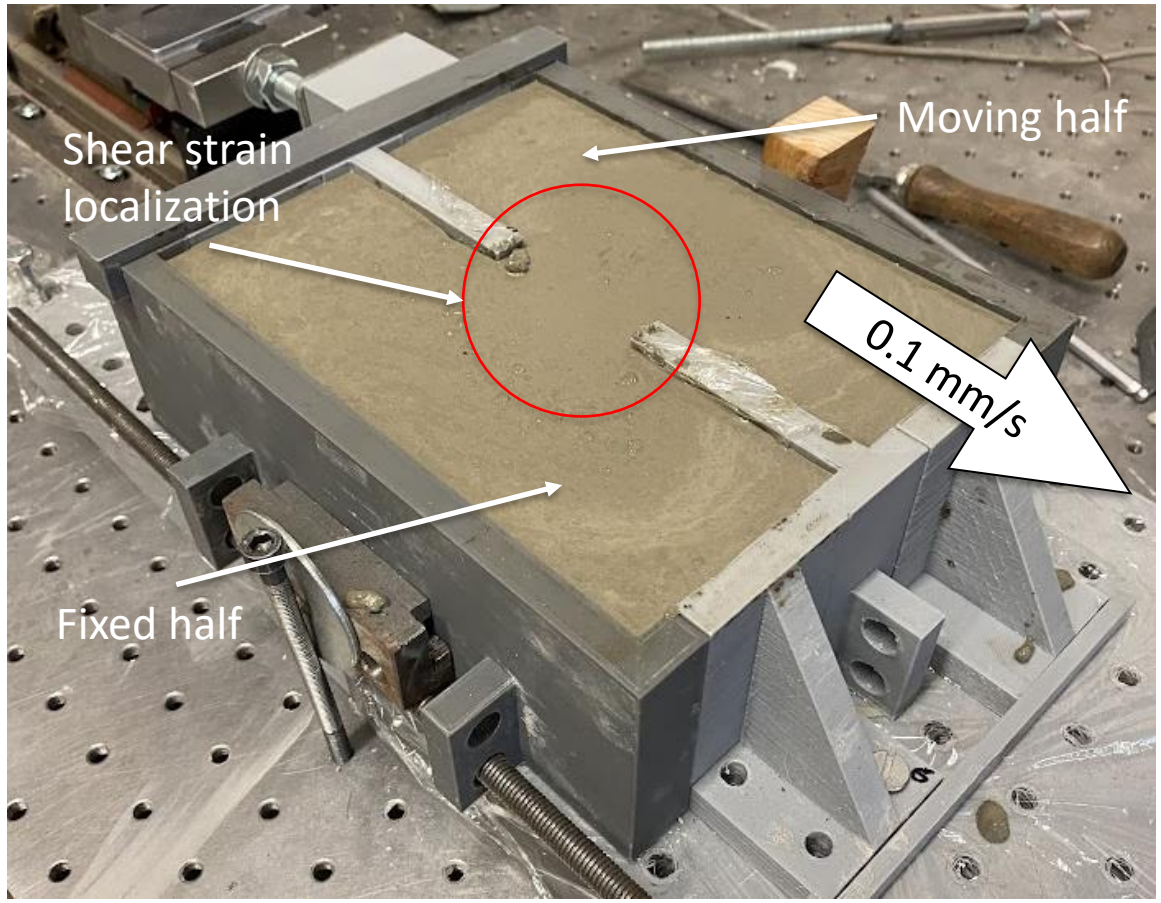

Max Von Mis
N/mm2
<= 0.090
10.5
20.9
31.3
41.7
52.1
62.5
72.9
83.3
93.7
104
115
125
135
146
156
>= 167

Process and material requirements for the new maintenance intervention

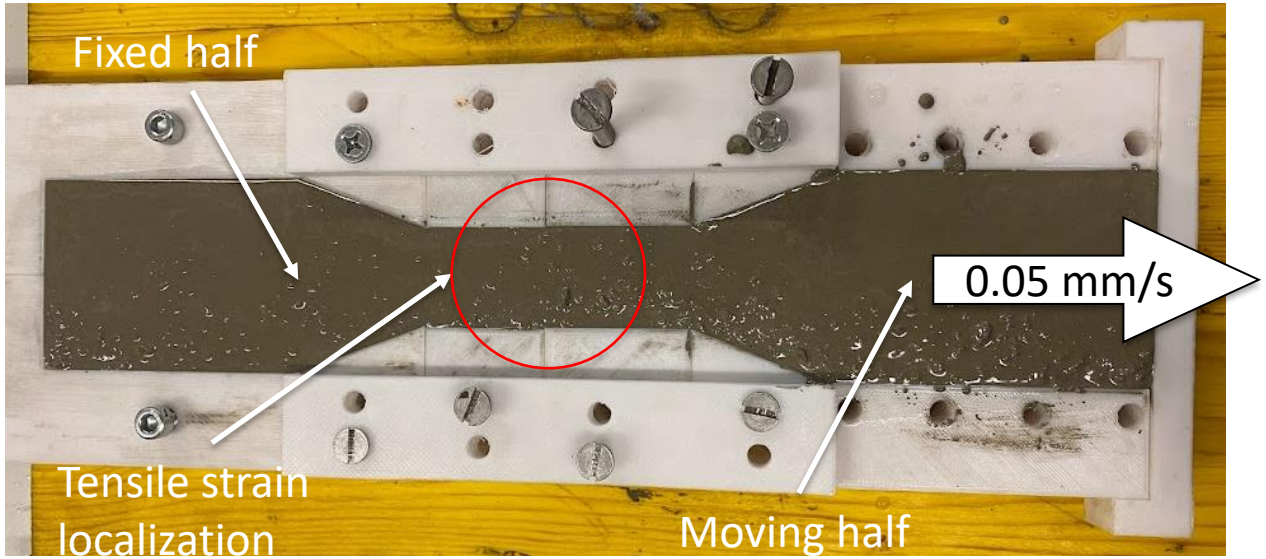
Material is **pumped** up to the key of the internal mould, from which it flows down to the bottom. As soon as the mould is filled and concrete has achieved a sufficient level of strength, the system moves, extruding **FRC** tunnel segments.

Early age – Mechanical tests

Shear box Test

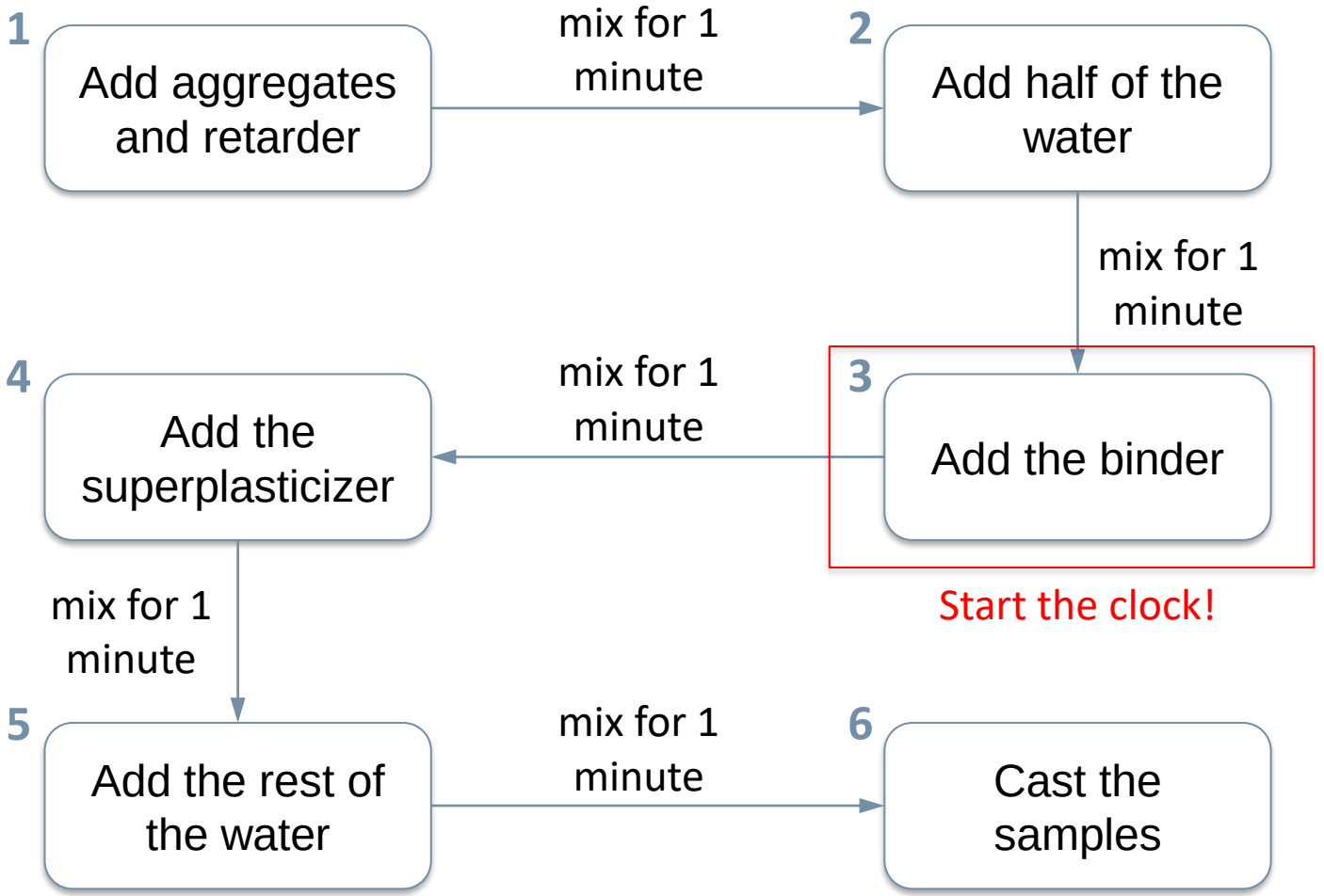


Tensile dog-bone Test



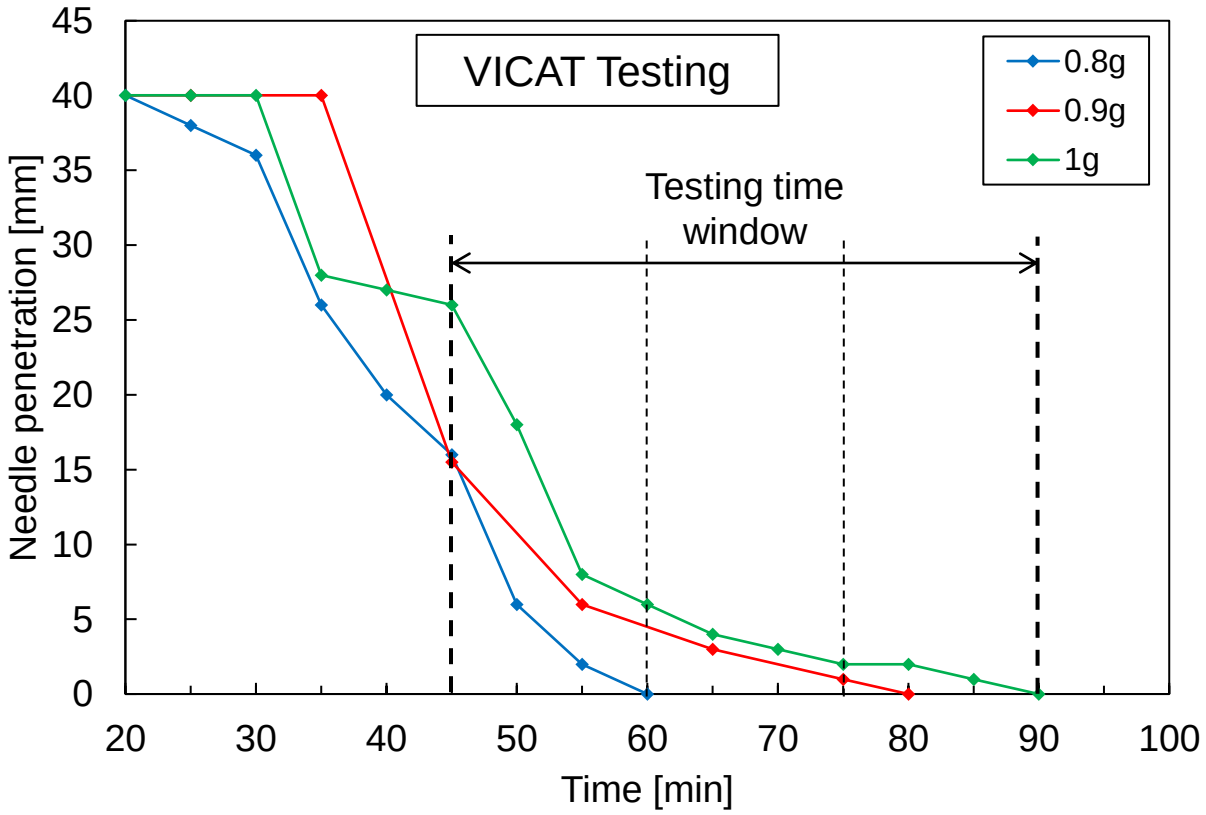
Mix design – materials and mixing process

Component	Quantity [kg/m^3]
Binder	600 (30% CSA, 70% OPC)
Aggregates	1400 ($d_{max} = 4\ mm$)
Water	210 ($w/b = 0.35$)
Superplasticizer	11.7
Retarder	0.8 0.9 1

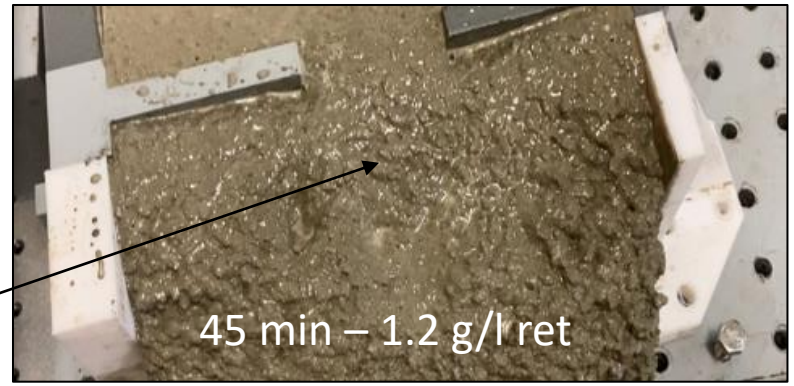


Testing Methodology – times, proportions and repetitions

Tests have been performed both for shear and tensile at **45, 60, 75 and 90 minutes** (after clock starts). All the tests have been **repeated** at least **3 times**, and the average curves are reported in the comparisons.



Too much fluid for mechanical testing



Too much stiff for early ages testing

Testing Methodology – times, proportions and repetitions

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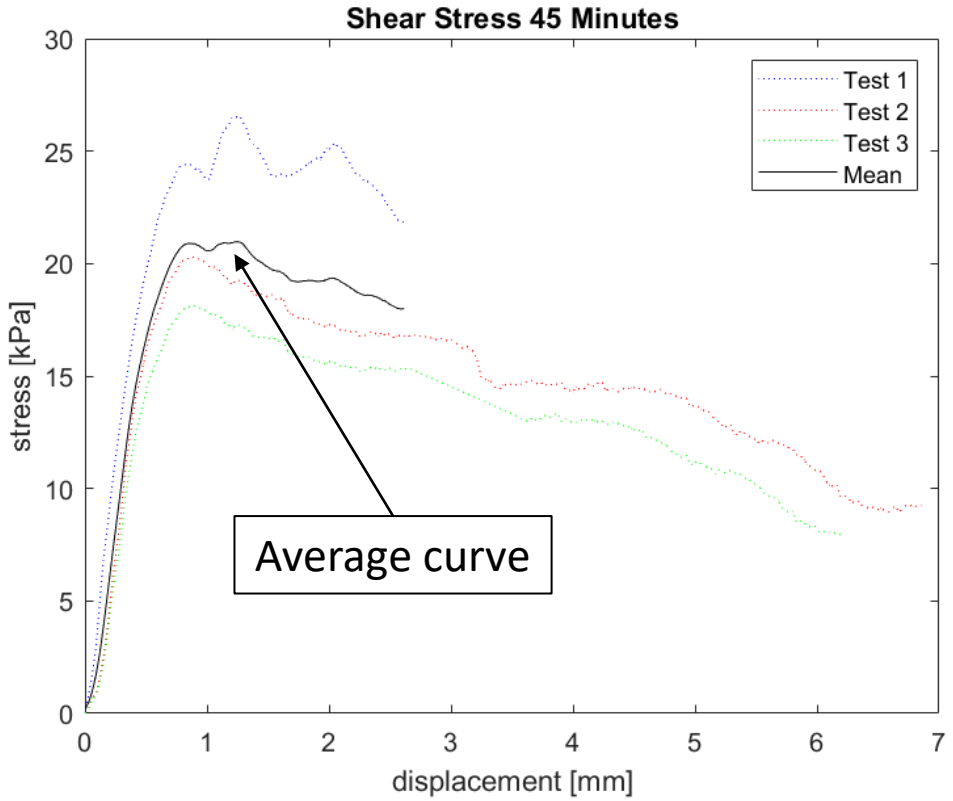

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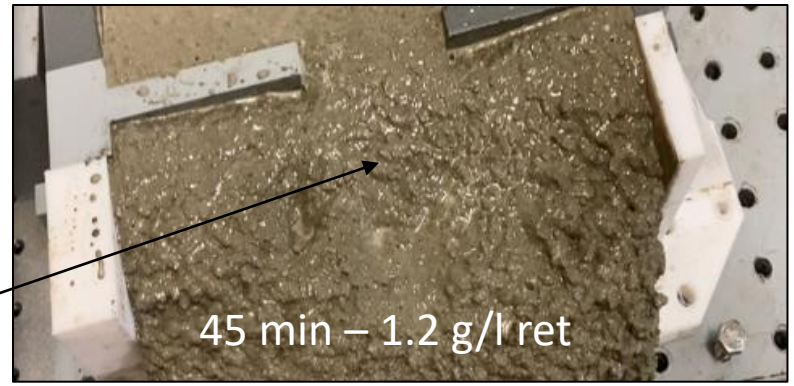
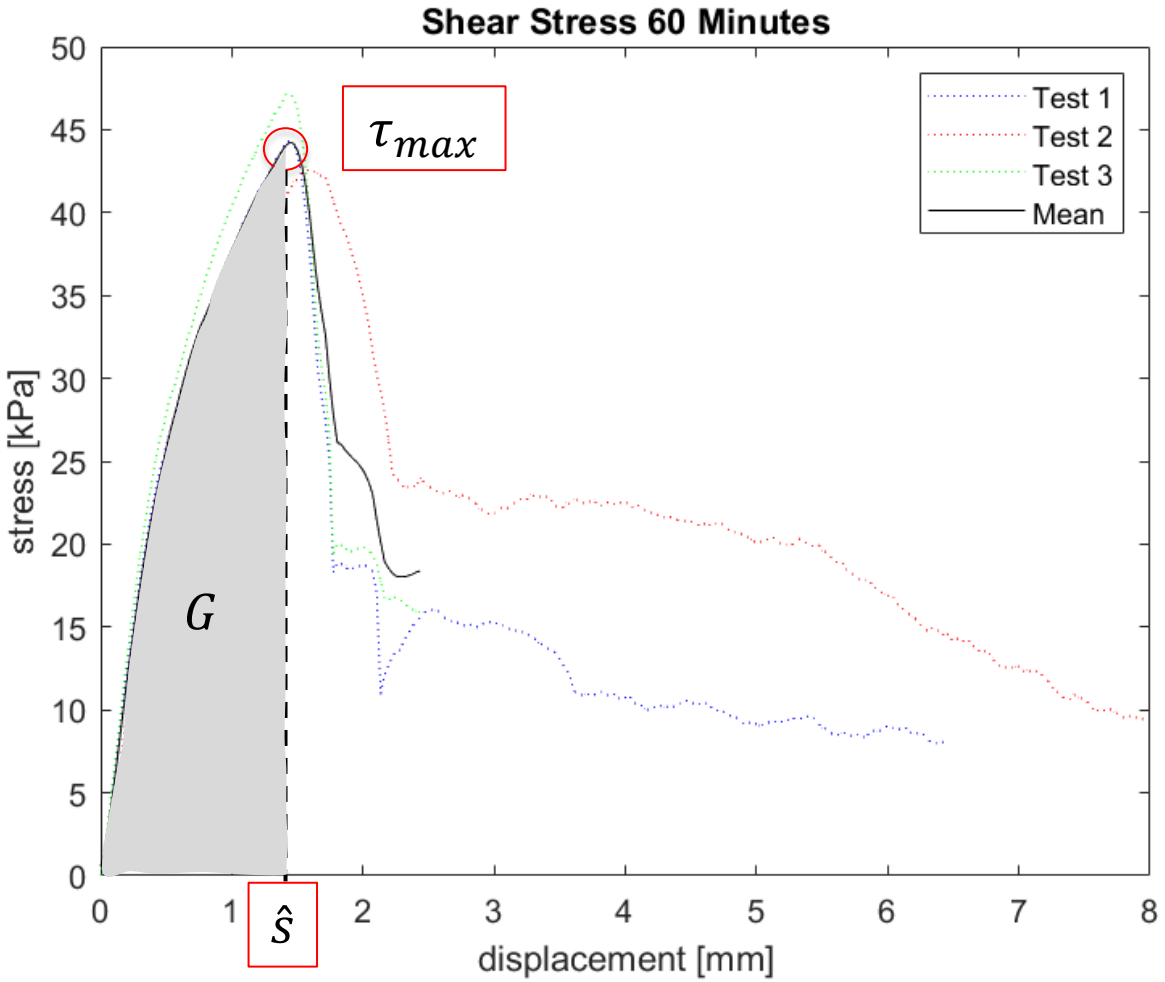


Too much stiff for early ages testing

Shear Tests – peak stress and stored energy



Peak stress:

$$\tau_{max} = \max\{\tau(s)\}$$

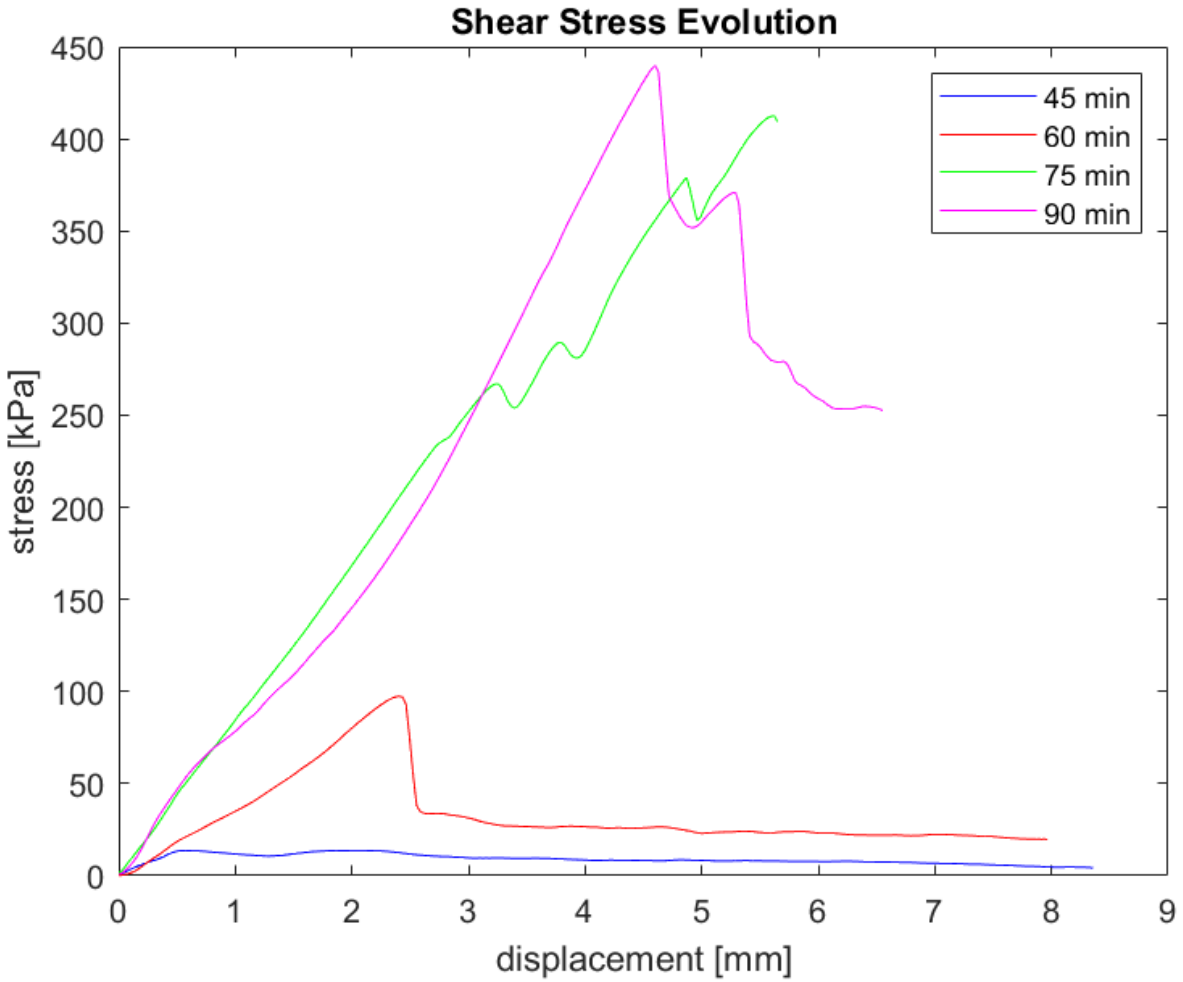
Stored energy:

$$G = \int_0^{\hat{s}} \tau(s)ds$$

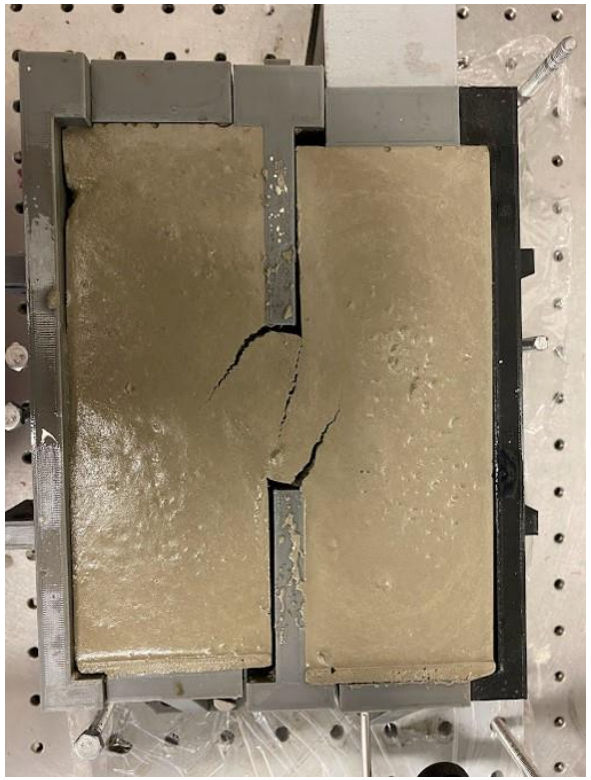
Stored energy per unit displacement:

$$g = {}^{G}/_{\hat{s}}$$

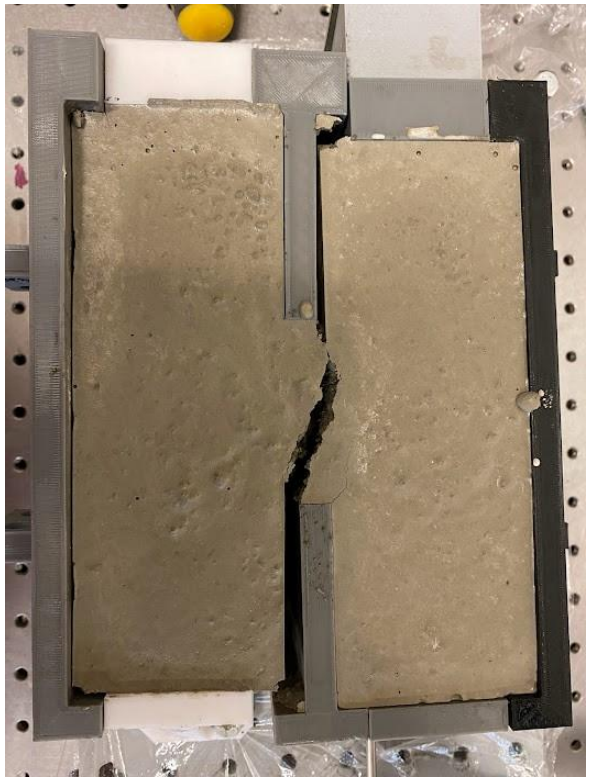
Shear Tests – results, retarder 0.8 g/l



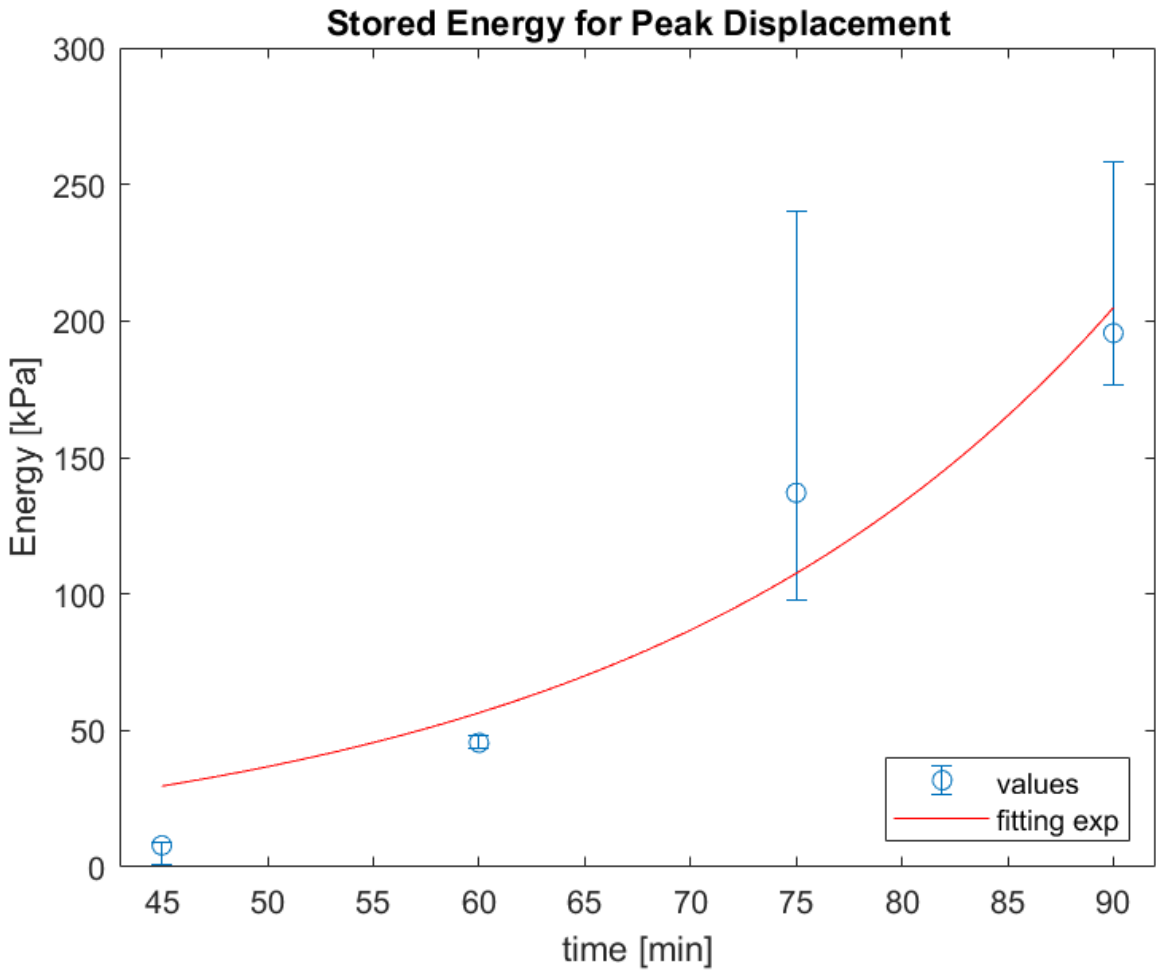
45 minutes

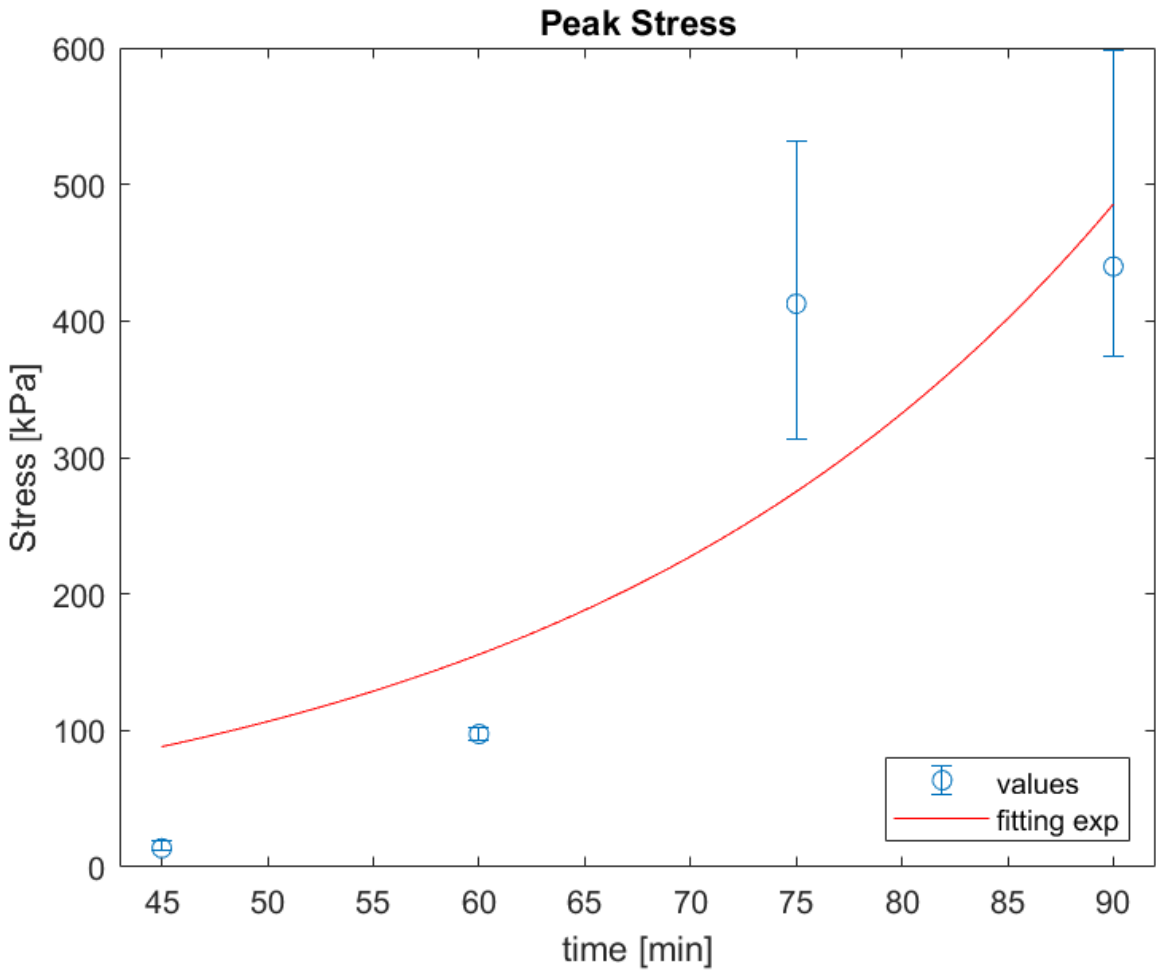


60 minutes



Shear Tests – effect of retarder (0.8 – 0.9 – 1 g/l)





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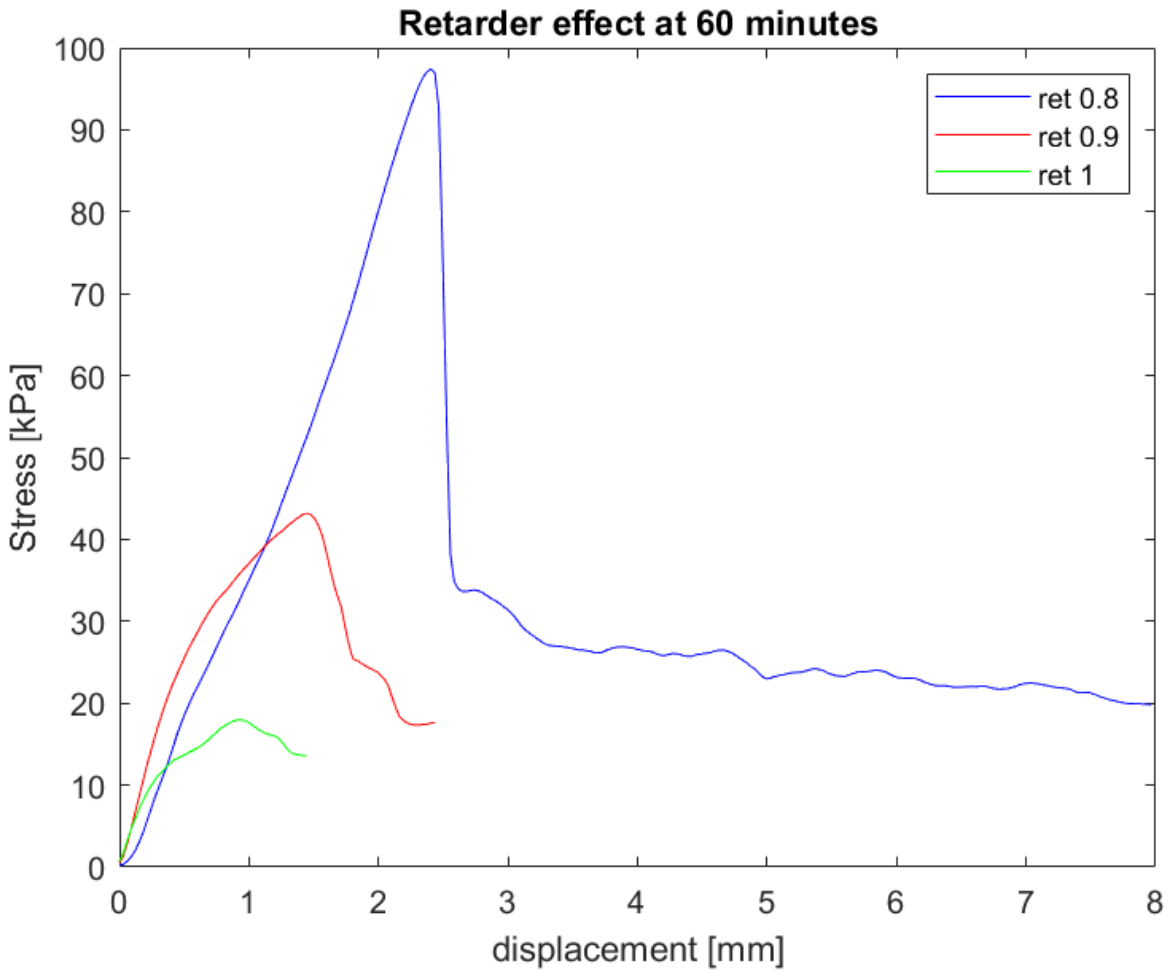

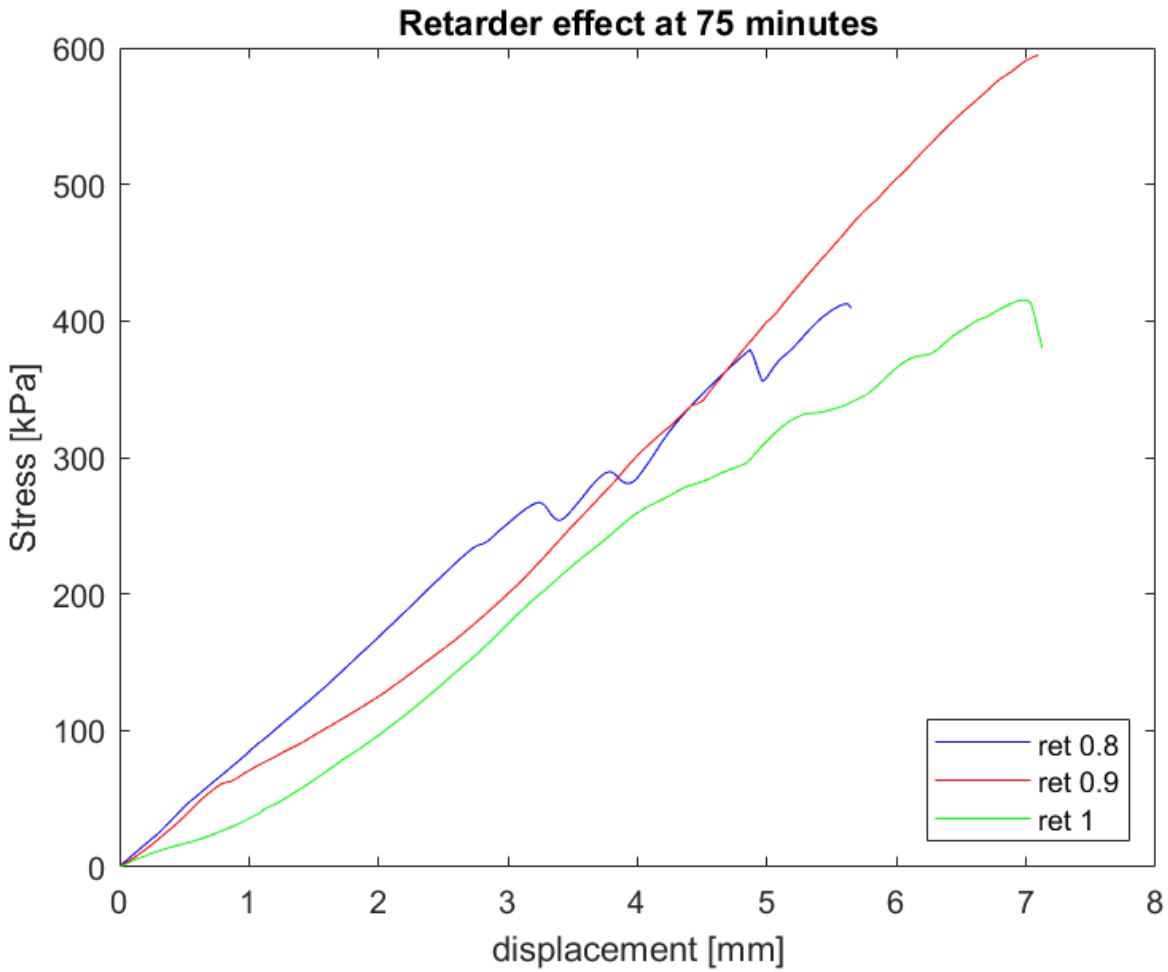

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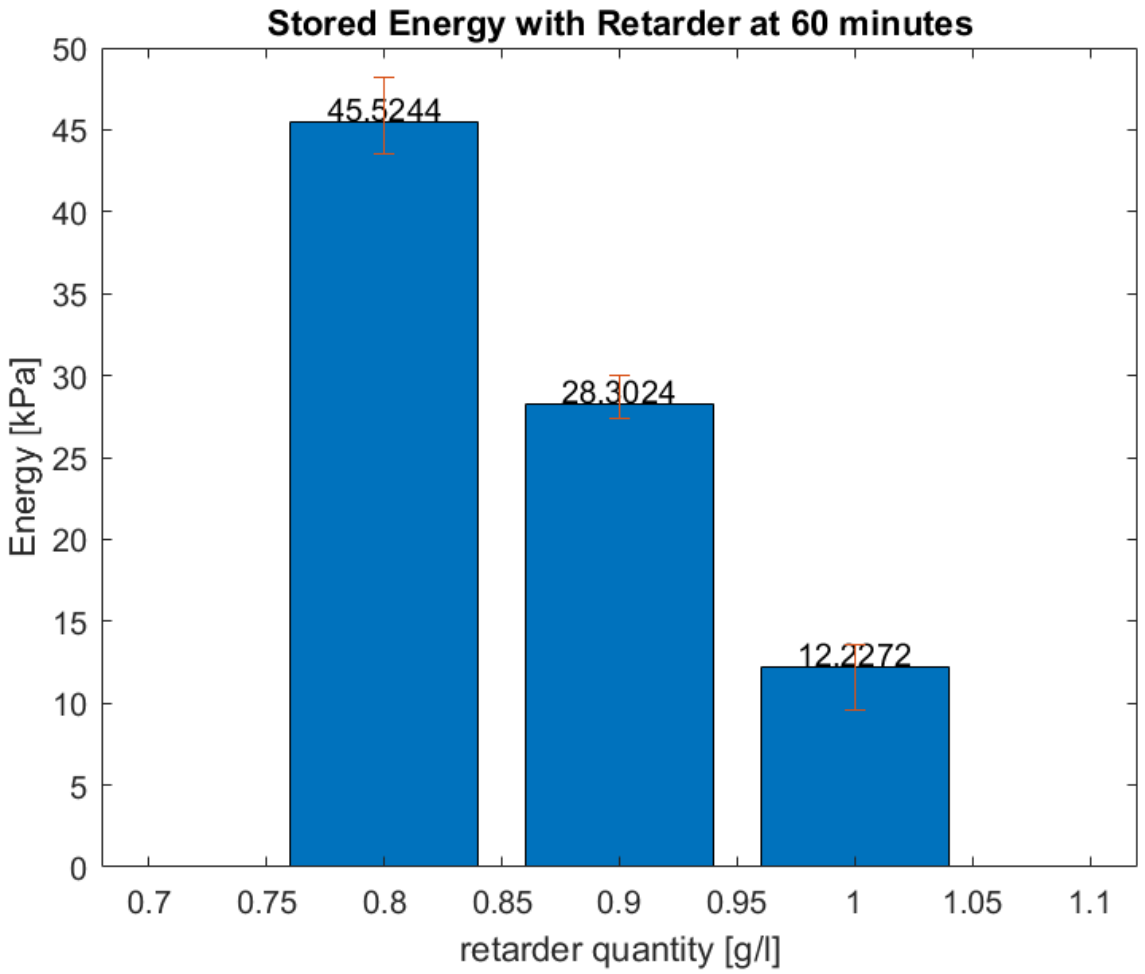

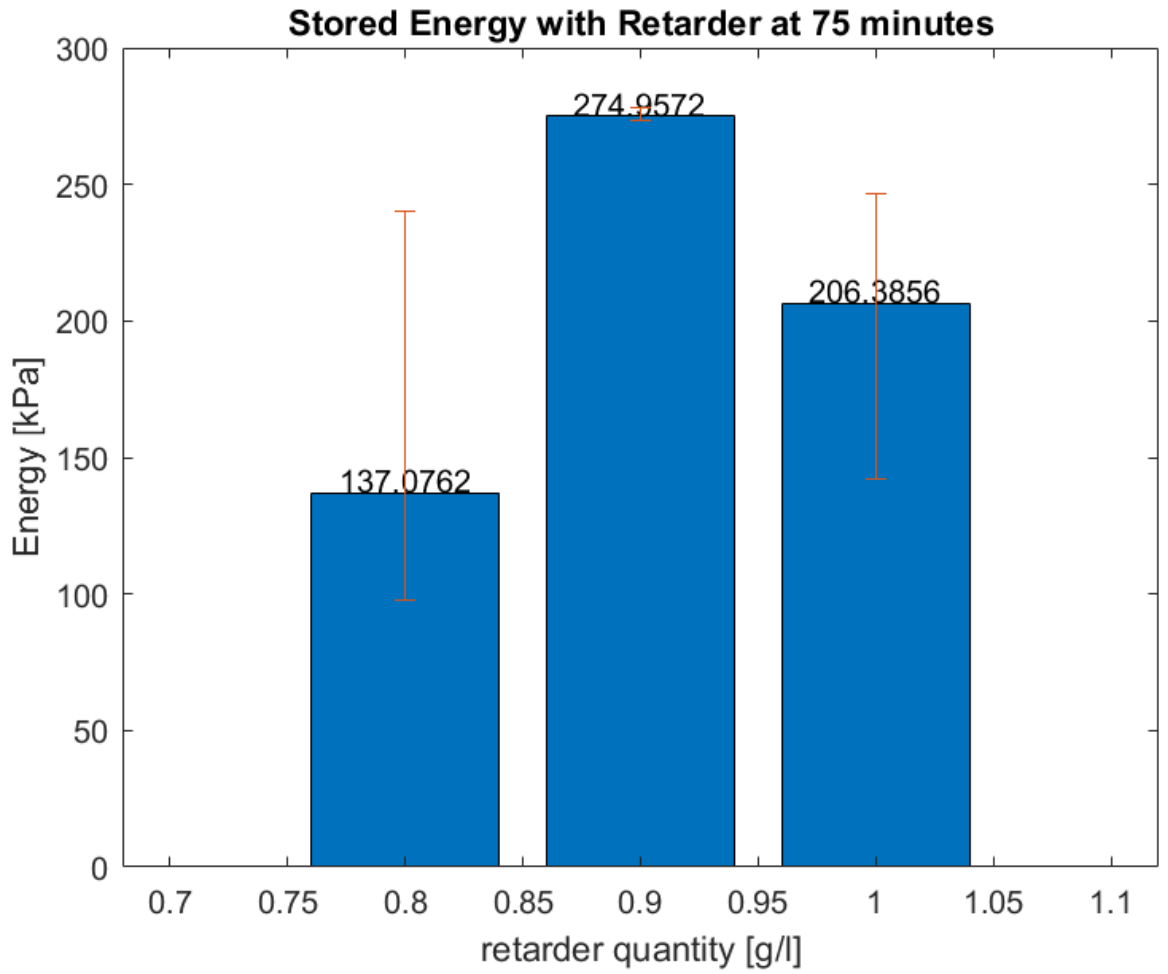

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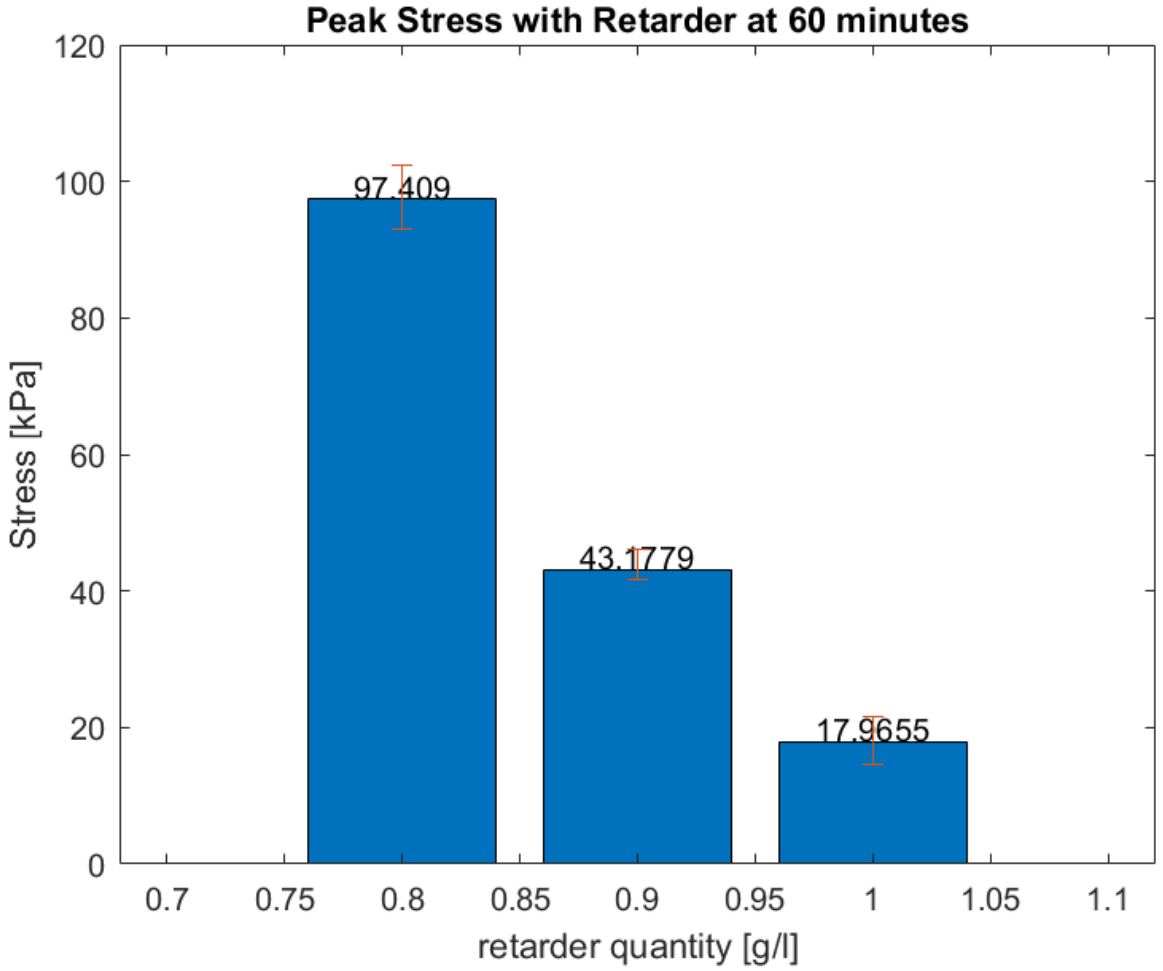
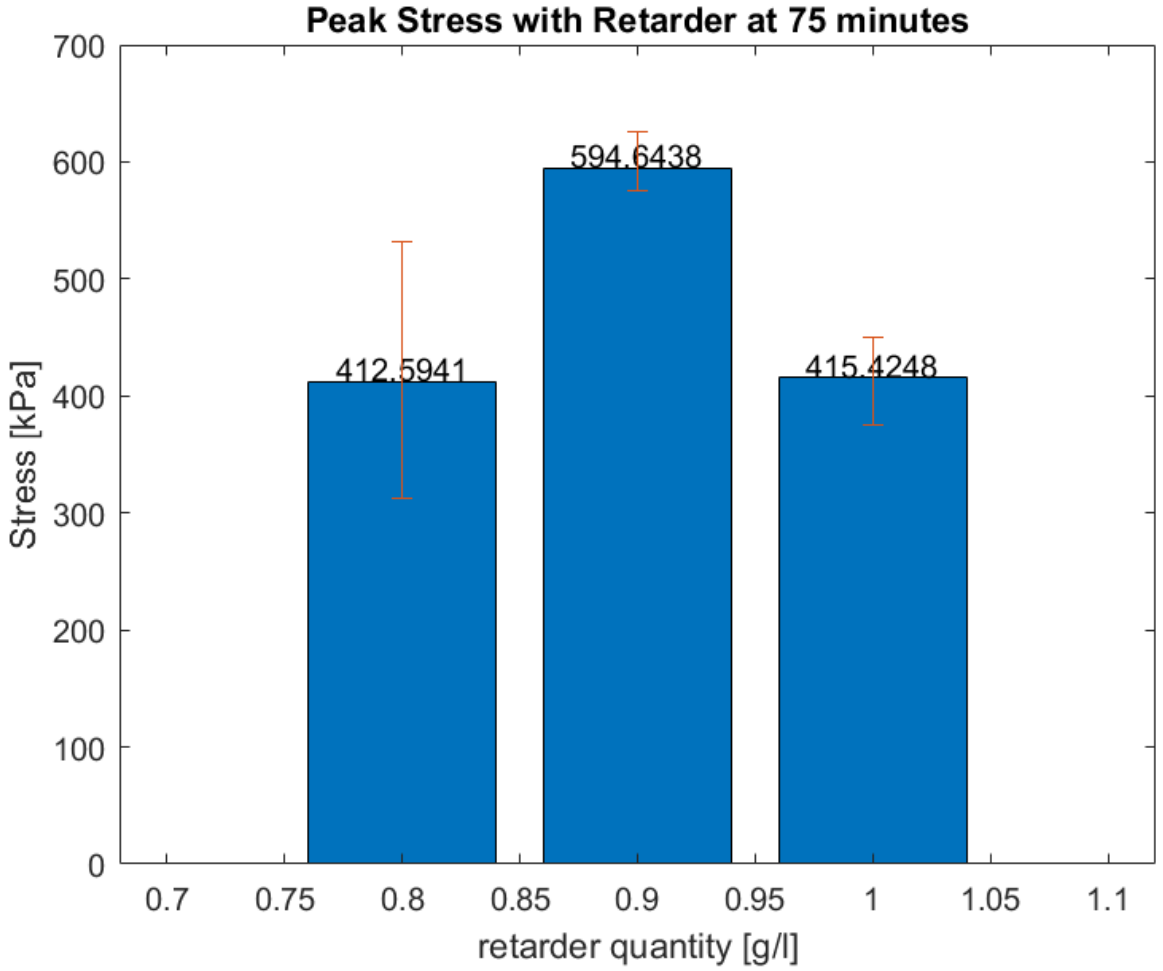
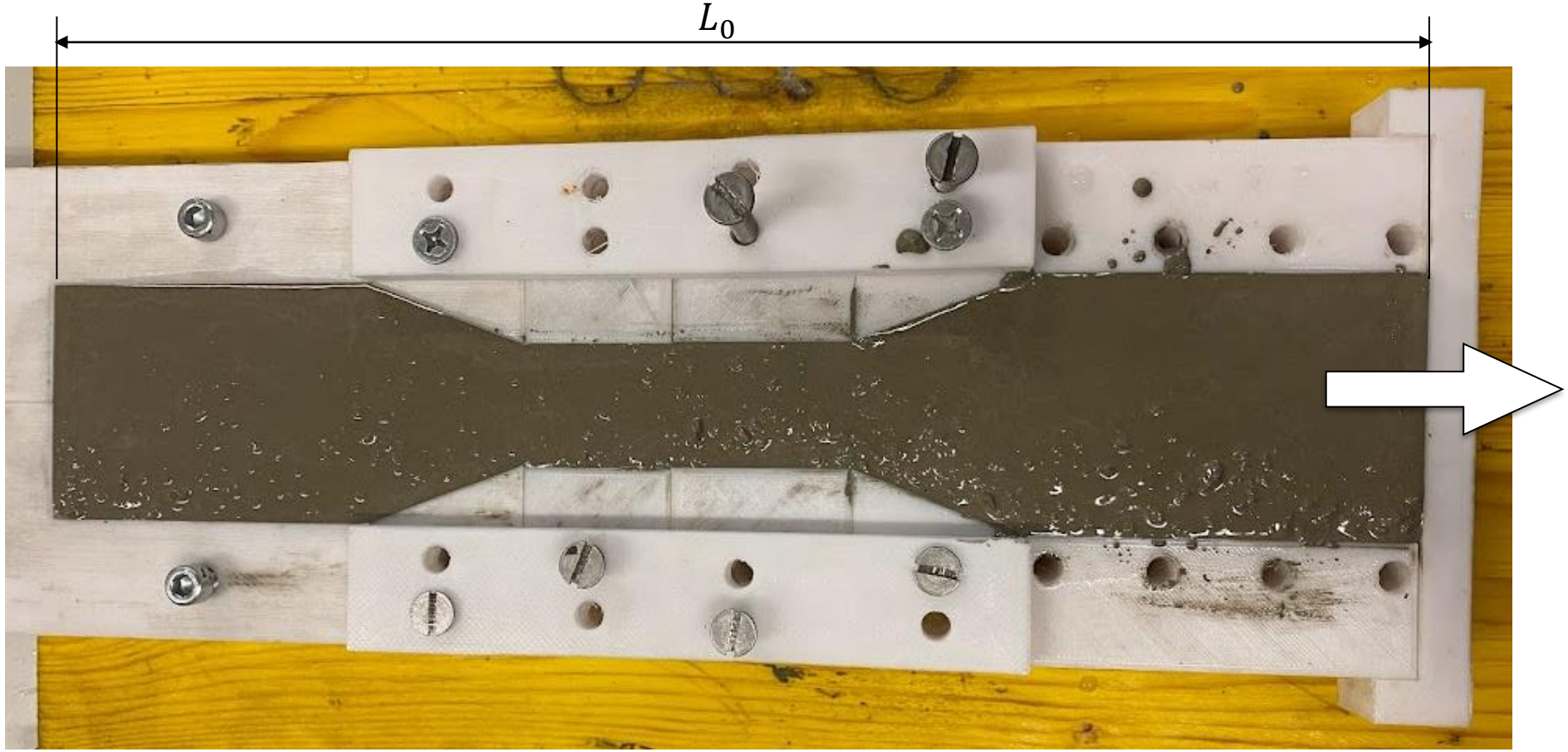




Tensile Tests – displacement into strain

Tensile dog-bone Test



Measurement:

ΔL, displacement

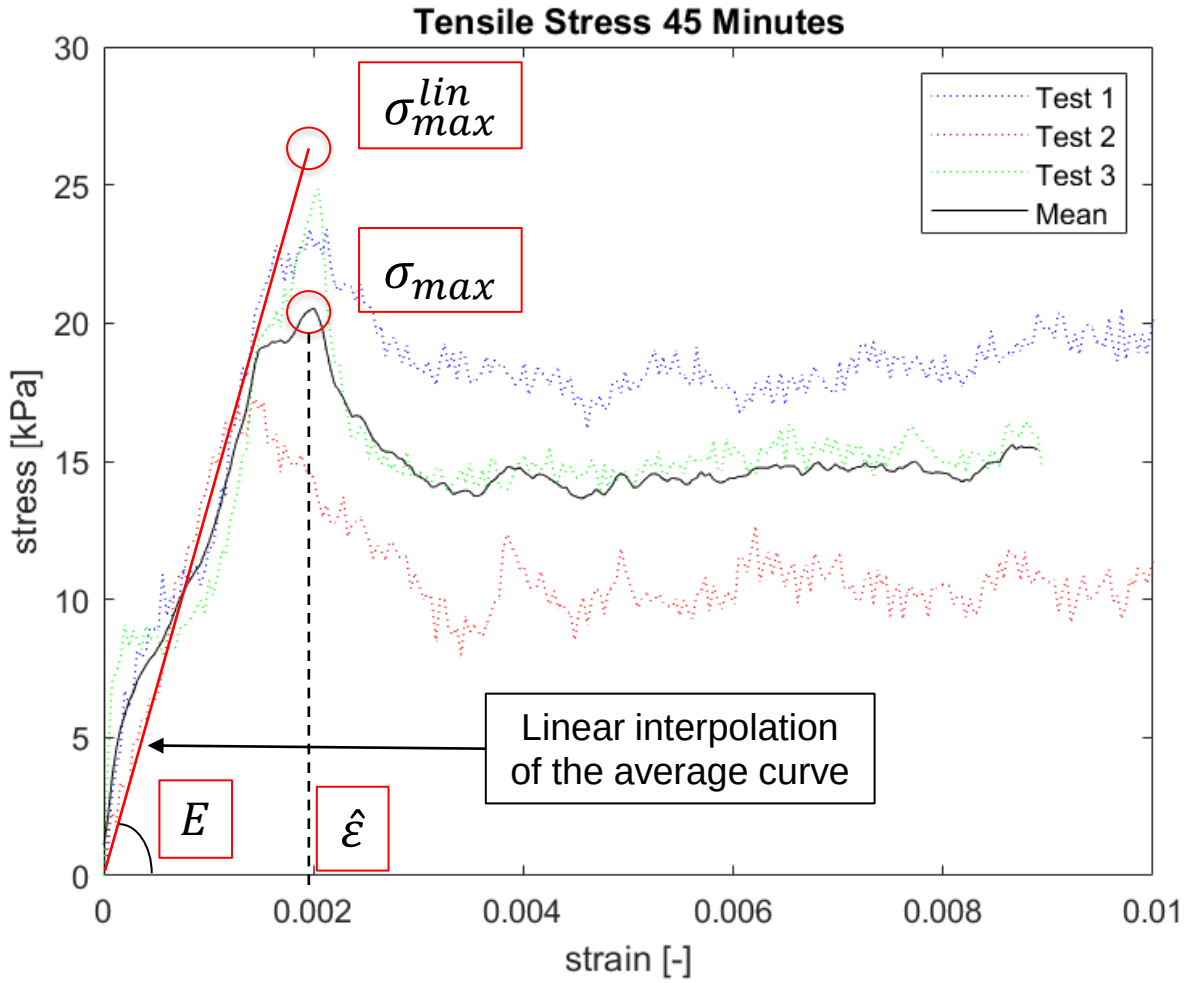
Geometry:

L_0, length

Strain:

$\varepsilon = {}^{\Delta L}/_{L_0}$

Tensile Tests – peak stress and Young's modulus



Peak stress:

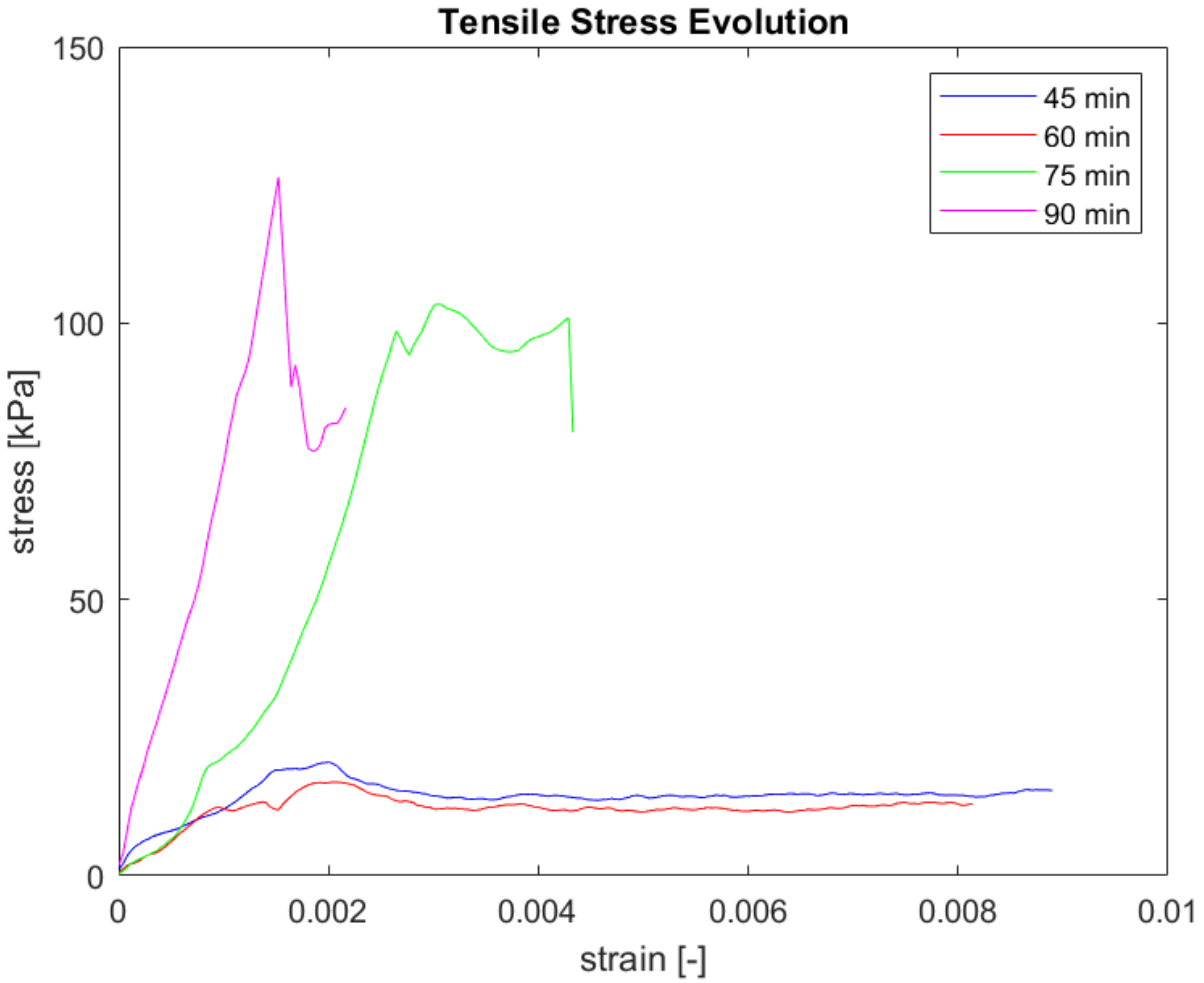
$$\sigma_{max} = \max\{\sigma(\varepsilon)\}$$

Young's modulus:

Linear interpolation in {0, $\hat{\varepsilon}$} interval of displacement.

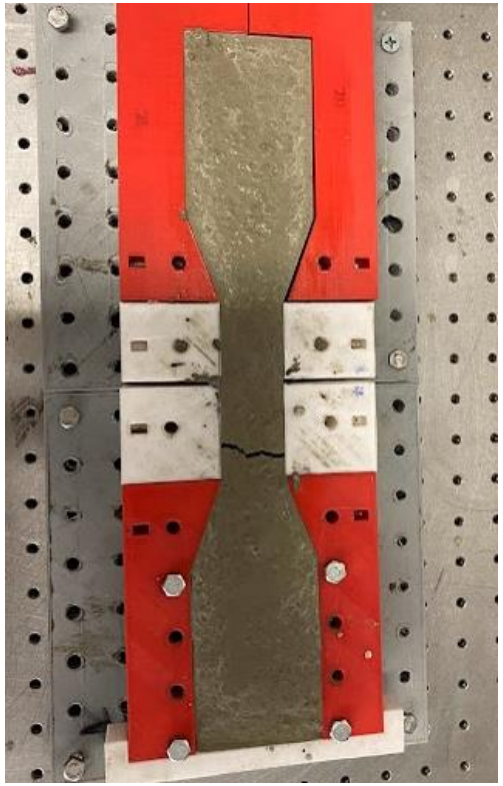
$$E = {}^{\sigma_{max}^{lin}} / _{\hat{\varepsilon}}$$

Tensile Tests – results, retarder 0.8 g/l



60 minutes

90 minutes



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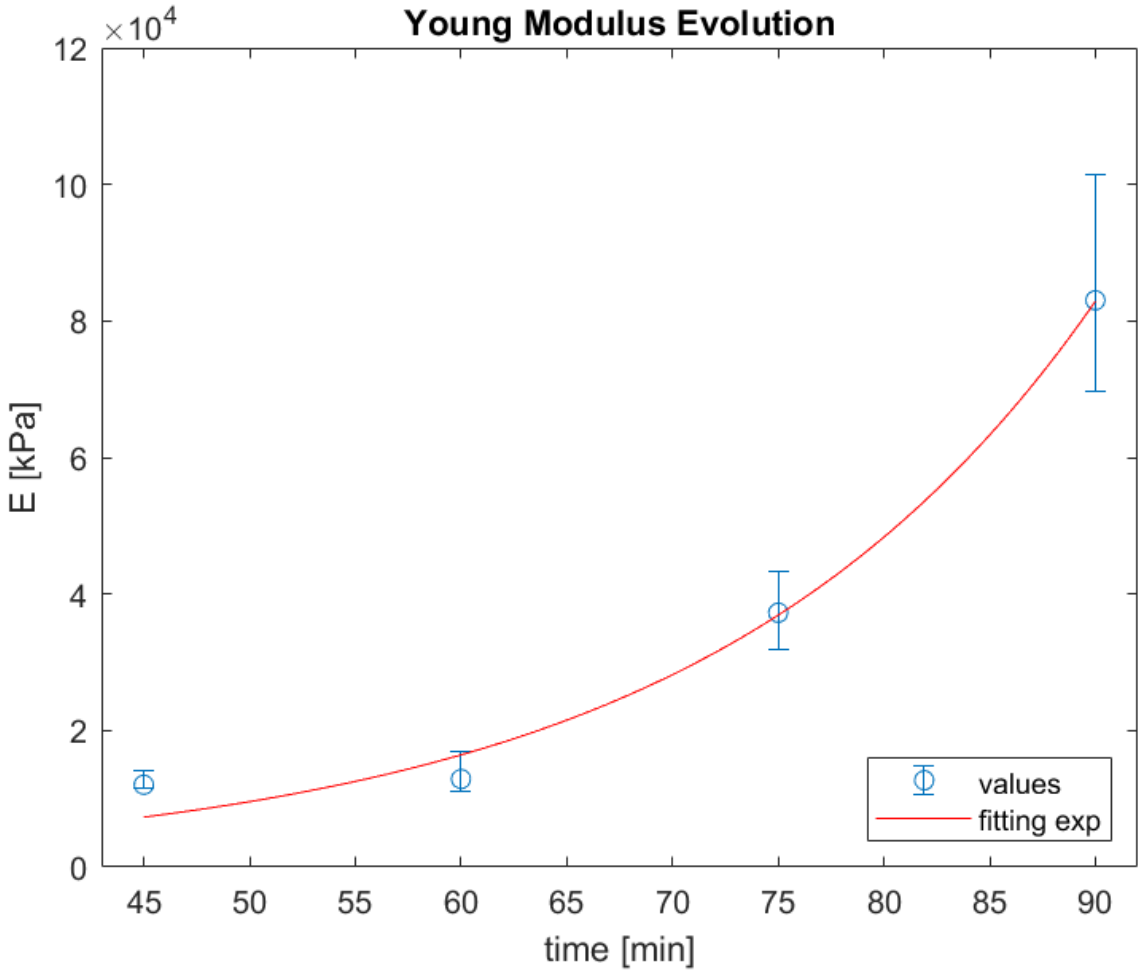

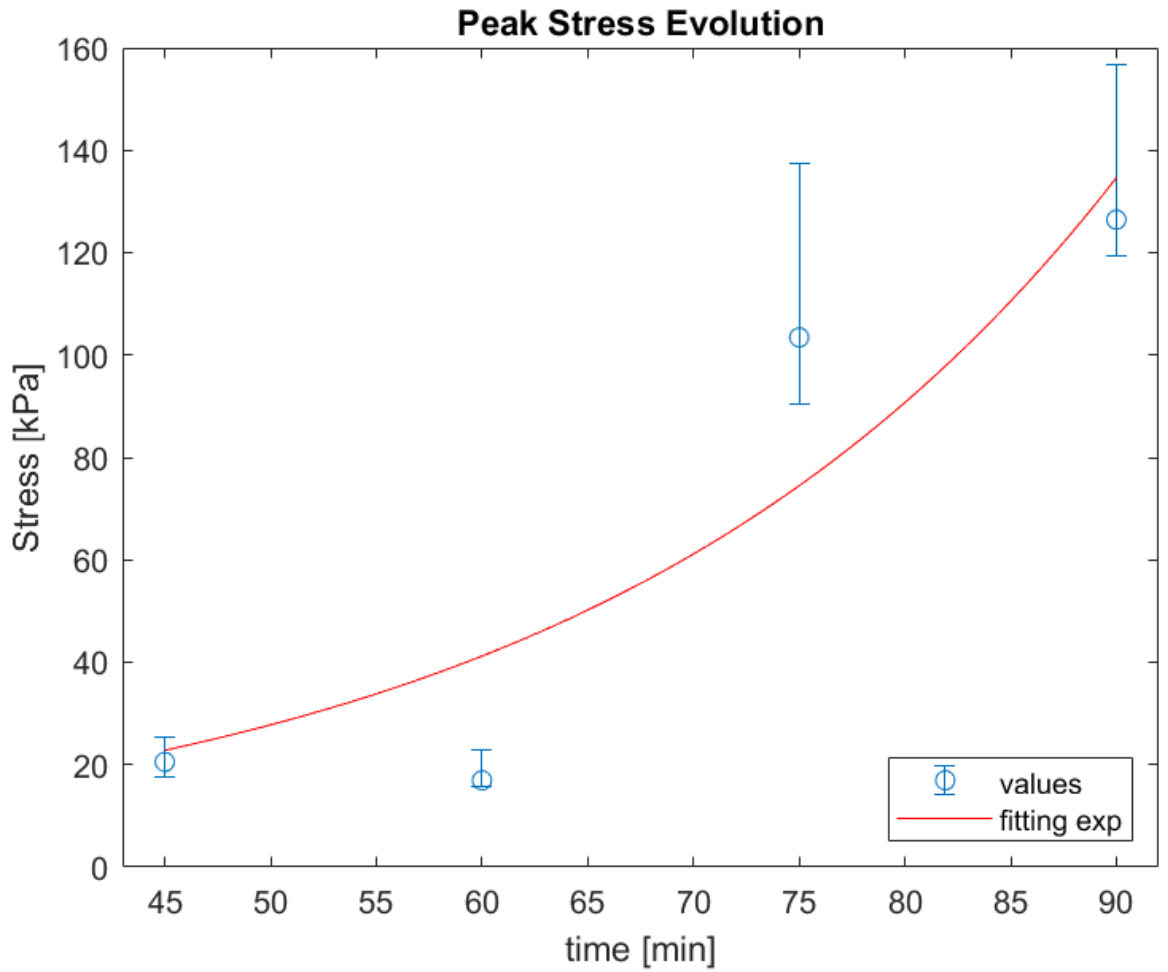

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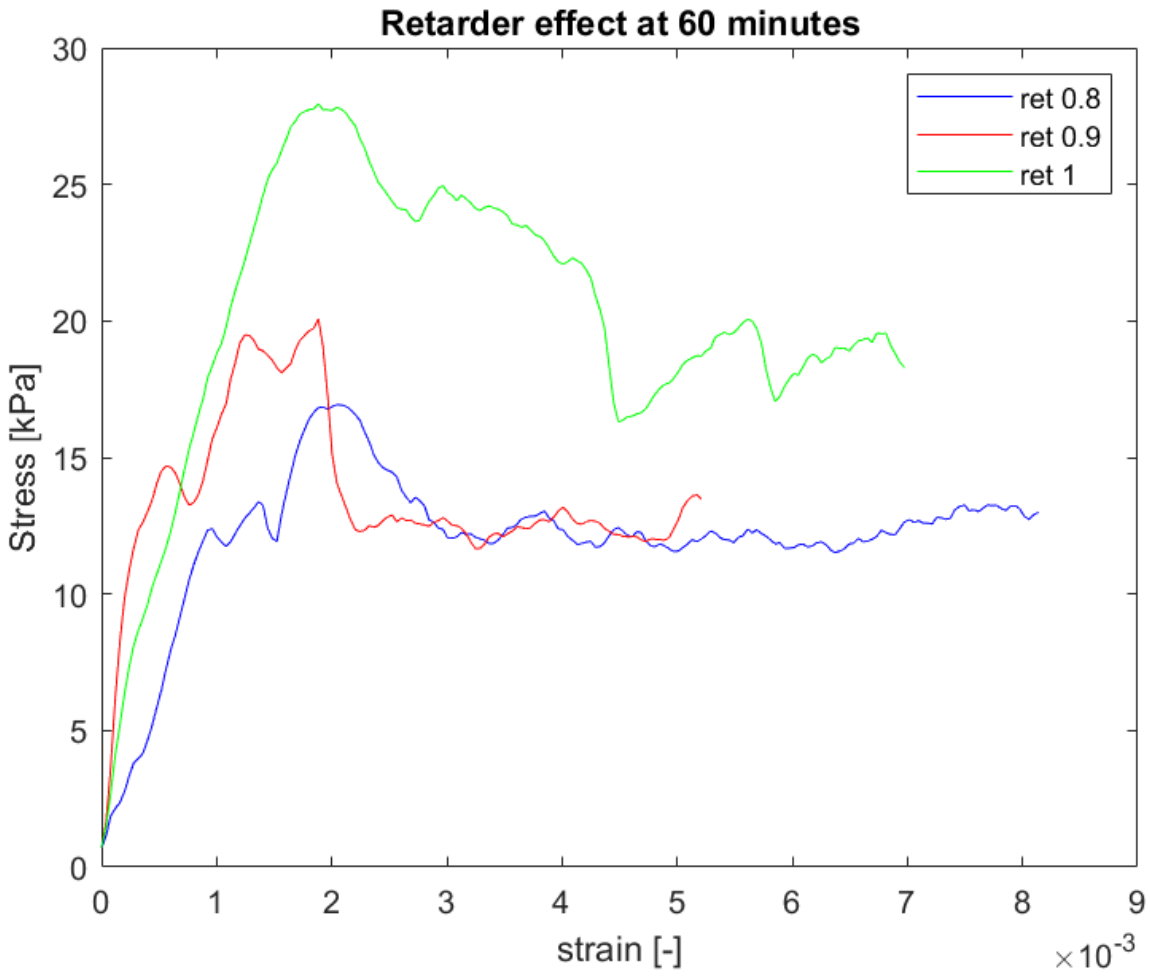

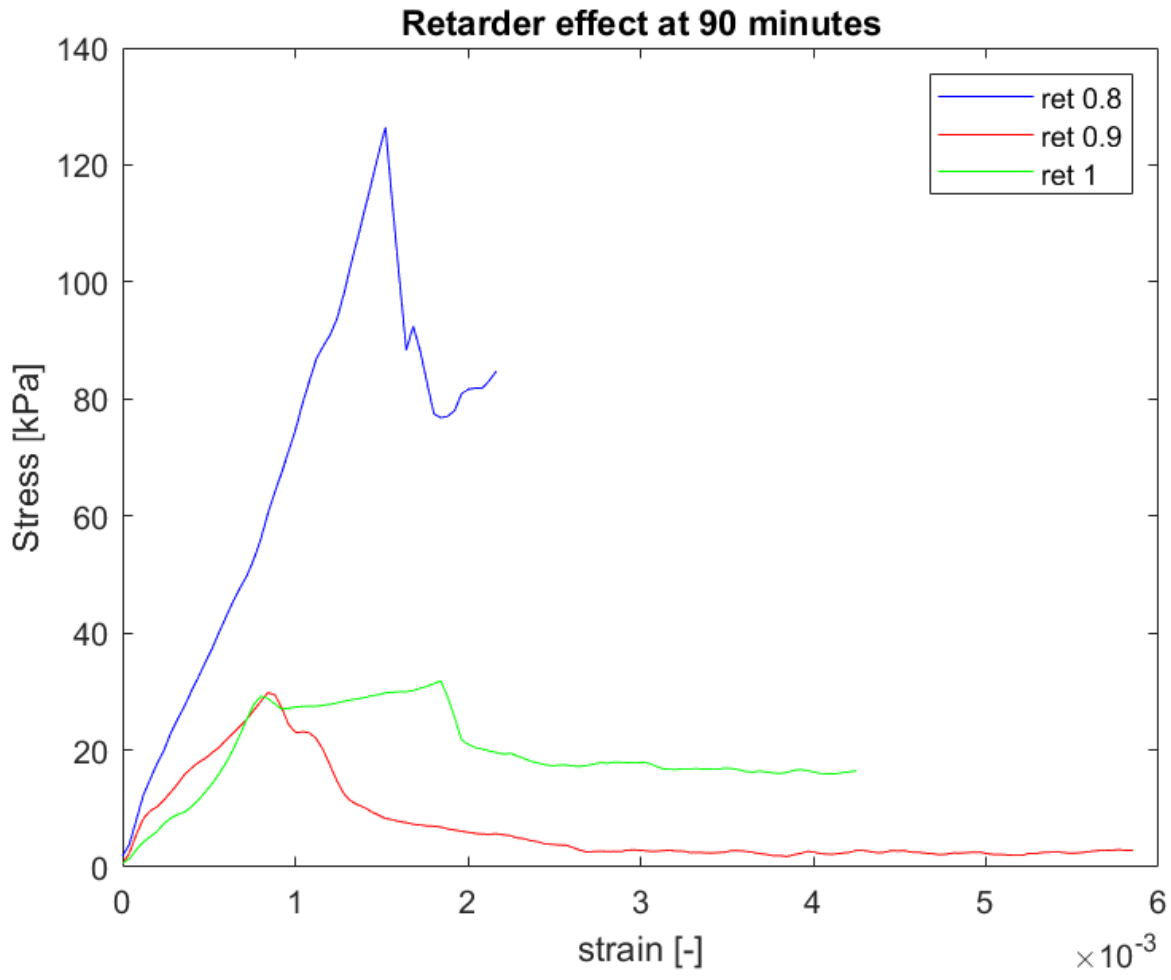

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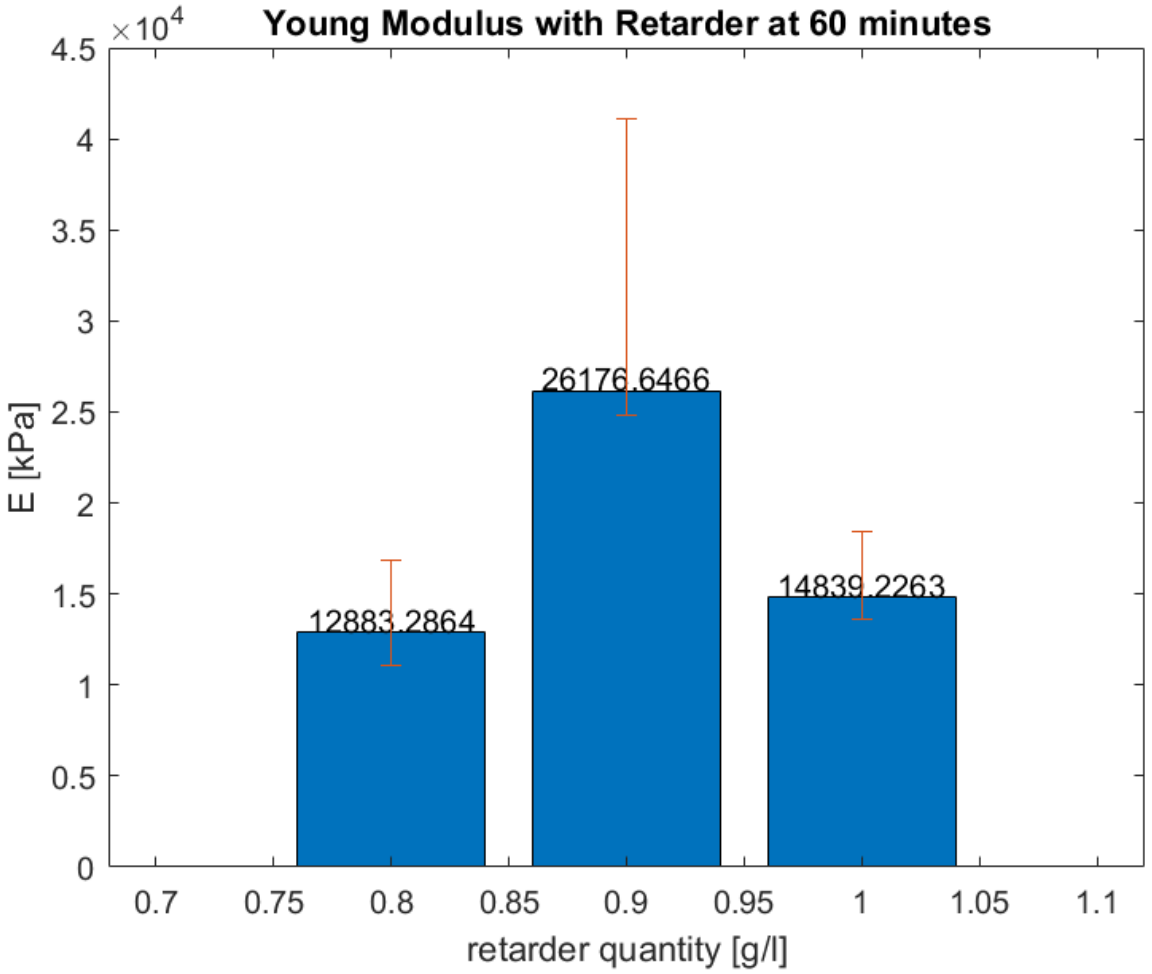

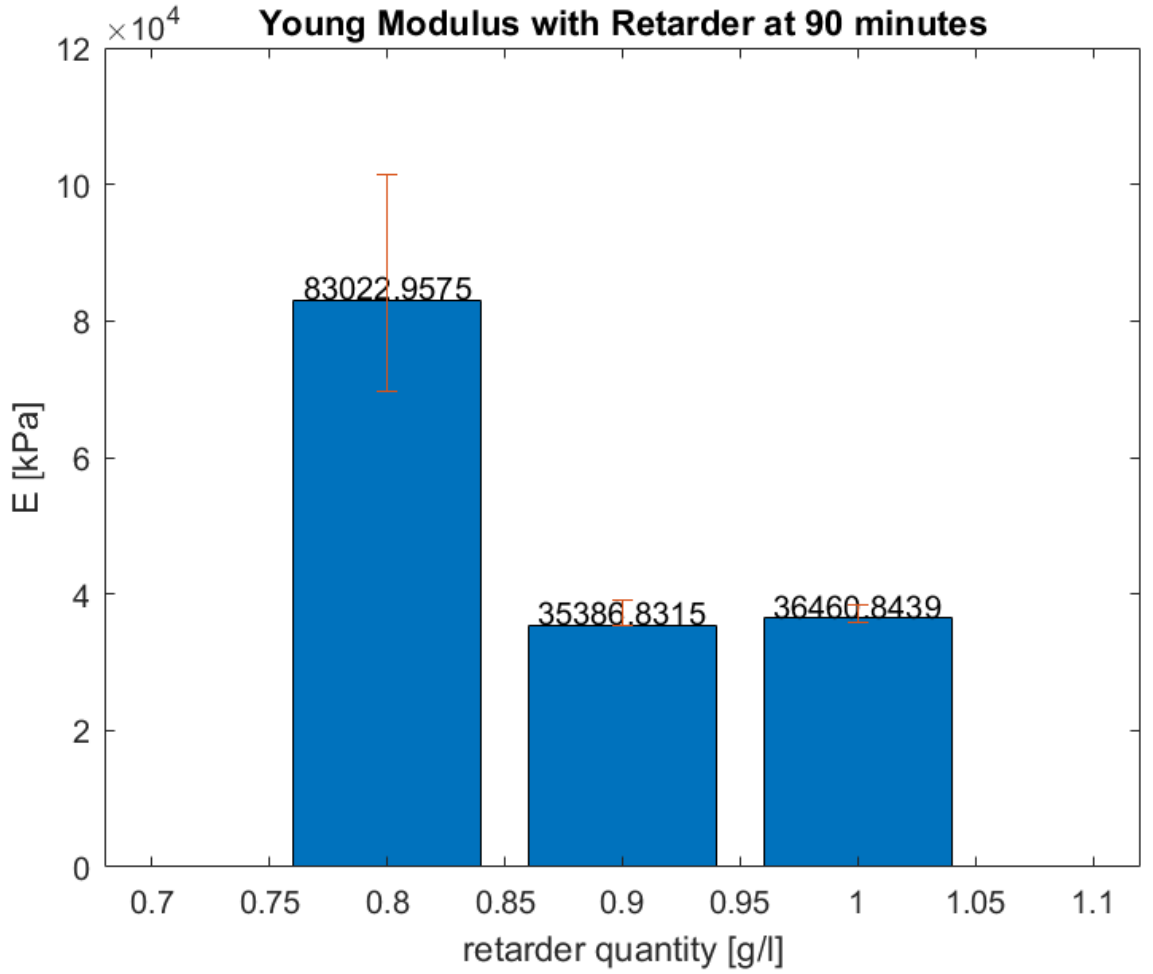

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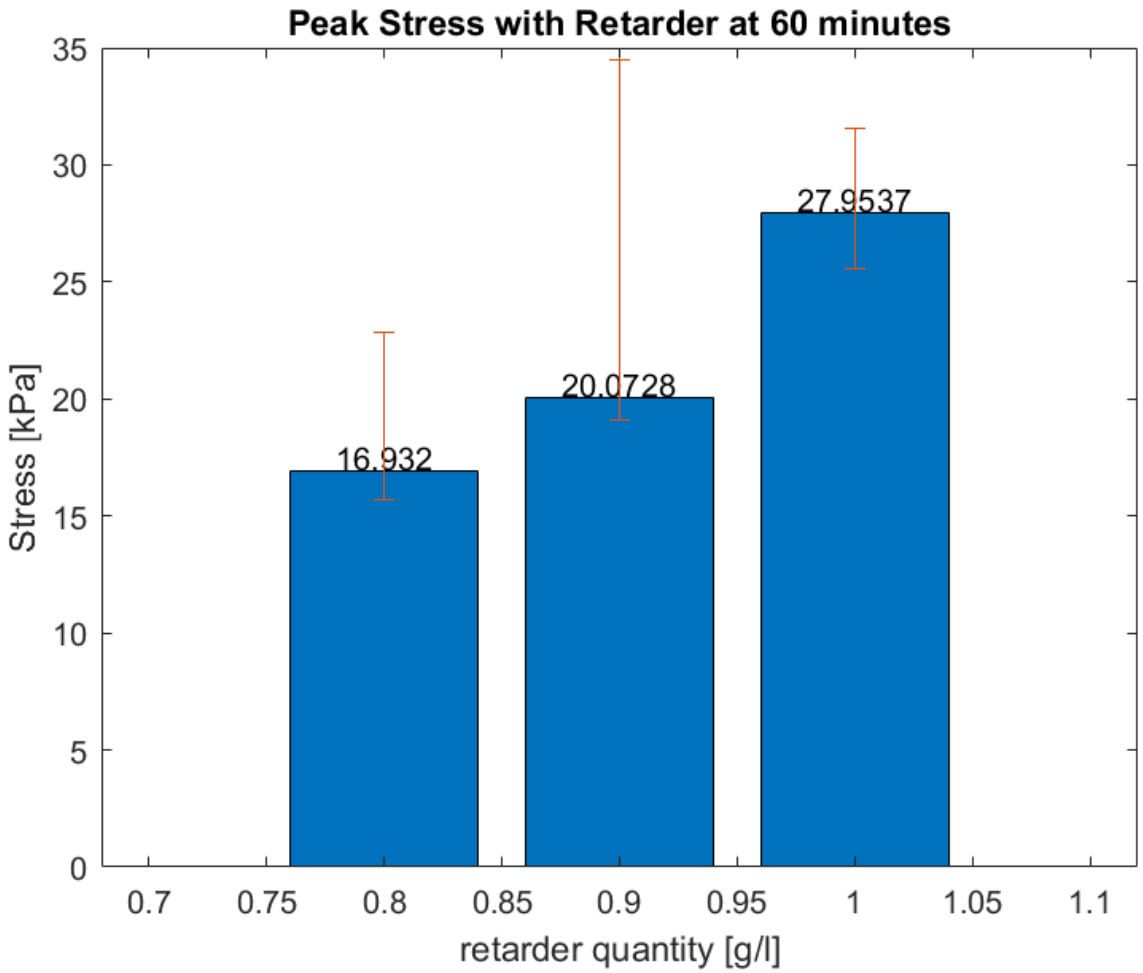

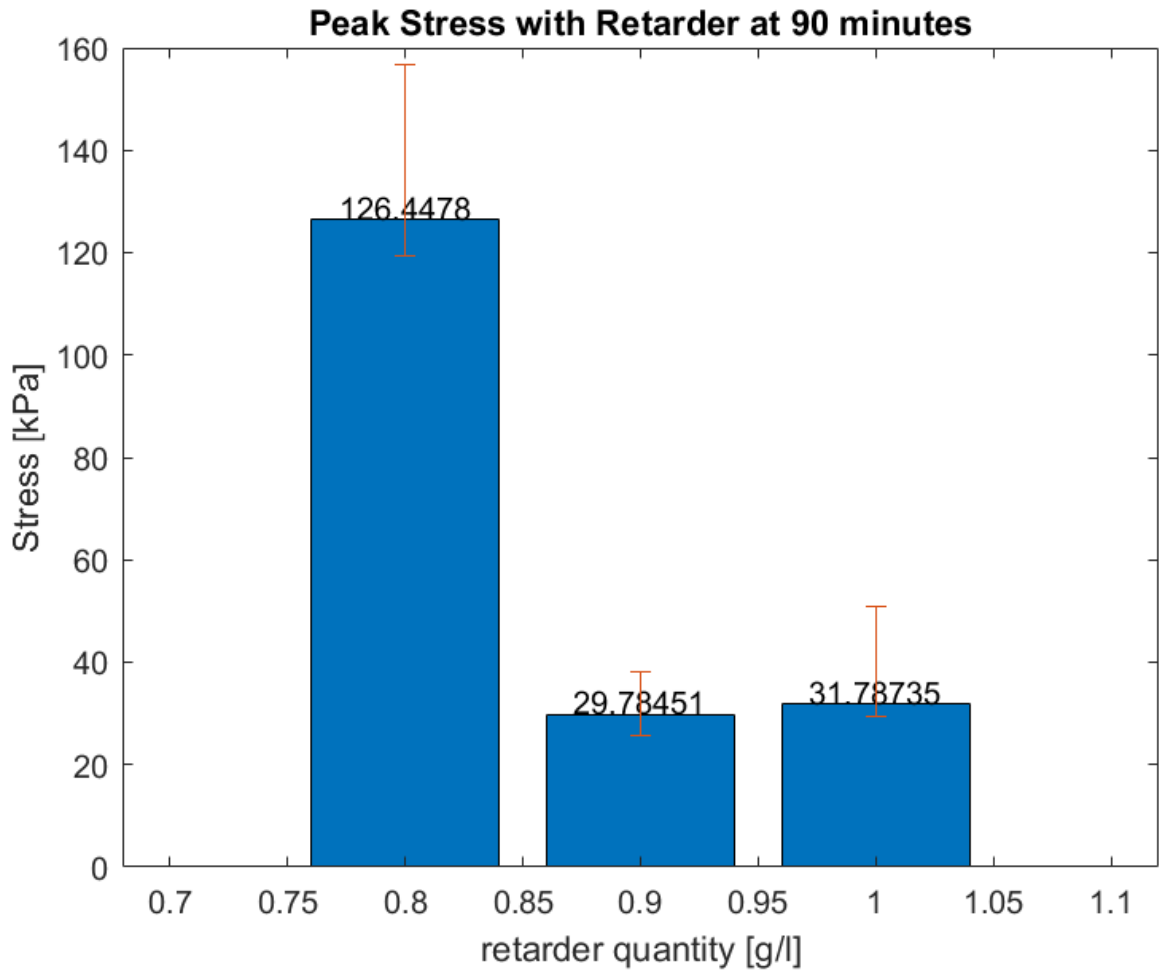

Conclusions

- A new testing methodology, consisting of **shear box** and **tensile dog-bone** moulds, has been introduced with the aim of studying the **intermediate state** of concrete, between fresh and solid state, by measuring shear and tensile strengths;
- Thanks to these tests is possible to study the **plastic state** of the material, that has great interest for advanced construction applications;
- An **exponential increment** of the **strengths** along time has been observed both for the shear and tensile tests;
- Varying the quantity of **retarder,** the plastic time window of the material can be adjusted. The higher the value of the retarder, the more delayed is the setting time of the material as well as the **plastic time window**;
- The increment of the **shear strength** is **faster** than the tensile strength. This is due to the **compressive** strength that contributes to the shear failure of the samples;
- From the **shear** tests, after **75 minutes** the retarder has **no** longer any **effect**;
- From the **tensile** tests, retarder has still an **effect** at **90 minutes**.

Thank you for the attention!

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PON RICERCA E INNOVAZIONE 2014 - 2020

HINFRA™ The Large Scale Digital Concrete Extrusion Project