TA Instruments UK – 2016

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Johnson Matthey Fuel Cells

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Johnson Matthey Fuel Cells Swindon

JM Fuel Cells Ltd - a joint venture with Anglo Platinum

Started as an Anglo Platinum supported research project 1992

Swindon site established in 2002

Currently around 120 staff world wide

- Majority based at Swindon
- Research and cell test scientists located at JM technology centre (Sonning Common)
- Sales representation in EU, US, Korea & Japan

Significant Milestones

2002 – Initial technology transfer from R&D

2003 – First automotive PPAP successfully completed

2005 to 2007 – Volume manufacturing processes introduced for **Direct Methanol Fuel Cells**

2007 to 2009 – Introduction of volume manufacturing for **High Temperature** electrode manufacture (>500k parts supplied)

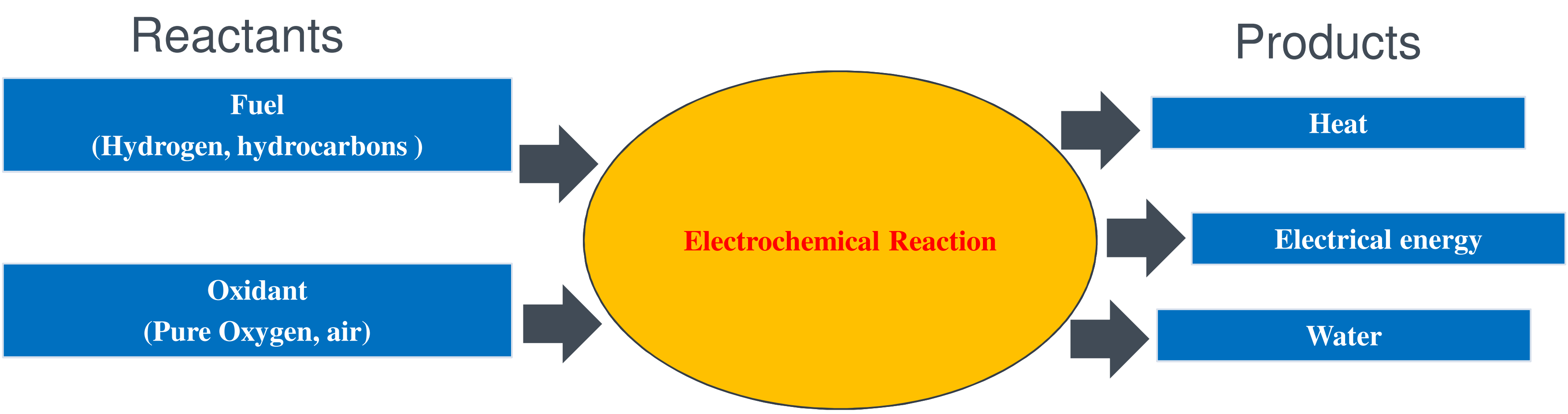
2011 – Initial **ISO9001:2008** / **ISO 14001 Certification**

2012 – Development and introduction of automated volume manufacturing processes for **Hydrogen PEM** technology

Fuel Cells

Fuel cells are devices able to **convert directly** the chemical energy of hydrogen or hydrocarbon molecules in electrical and thermal energy through electrochemical oxidation and reduction reactions.

Key feature: the single energy passage into electrical energy allow higher efficiency and performance



Fuel Cells Applications

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✓ **Charging devices.** Every hydride or methanol cartridge can contain up to 10 times more energy than a typical smartphone battery. Ideal for travelling

✓ **Back Up Power and Auxiliary Power Units.** Fuel Cell UPSs and APUs typically allow higher flexibility and scalability respect batteries; an H_2 fuel cell systems, if coupled with an electrolyser, offers also lower fuel logistic cost respect diesel generators.

✓ **Military.** The use of an additional PEM fuel cells system in submarine allow to operate in silent cruising, staying submerged for up to weeks without surfacing. The system is also vibration-free, extremely quiet and virtually undetectable.

✓ **Micro CHP power system.** Small system (700 – 1000 W) operating on natural gas and providing heat and power for residential applications. The Typical overall efficiency is 95% while the price without subsides is around 21,000 €.

Fuel Cells Applications

✓ **Stationary power plant.** Medium to large (400 kW to 1 MW) power plants providing electrical energy heat and cooling to buildings at lower energy costs, reduced emissions, 95% system efficiency and 20-year product life. Using the steam reforming process the natural gas is converted into hydrogen and send into the fuel cells for the electrochemical conversion.

✓ **Materials Handling Vehicles.** A fuel cell truck can run up to three times longer than its battery driven counterpart; by using hydrogen dispensing, truck operators can refuel their lift trucks in 3 minutes or less against 15 to 30 minutes for changing the batteries.

✓ **Transports.** Hydrogen Fuel Cell Electrical Vehicles offer a 100% pollutants free solution (the only emission in water) and comparable performance with petrol or diesel vehicles. Respect to batteries powered electric vehicles , hydrogen fuel cell vehicles can show considerably longer autonomy, up to 500 km.

Advantages/Disadvantages FCEV

- Zero CO_2 - If H_2 from electrolysis using renewable energy
- Zero criteria pollutants
- Quiet
- Good range (300 miles) and fast refuelling
- Fast to refuel – similar to ICE
- Pressurised hydrogen has much higher energy density than Li ion battery

- Currently expensive but will reduce with industrialisation and performance improvements
- Currently inadequate hydrogen refuelling network

Automotive OEM FCEV Activities

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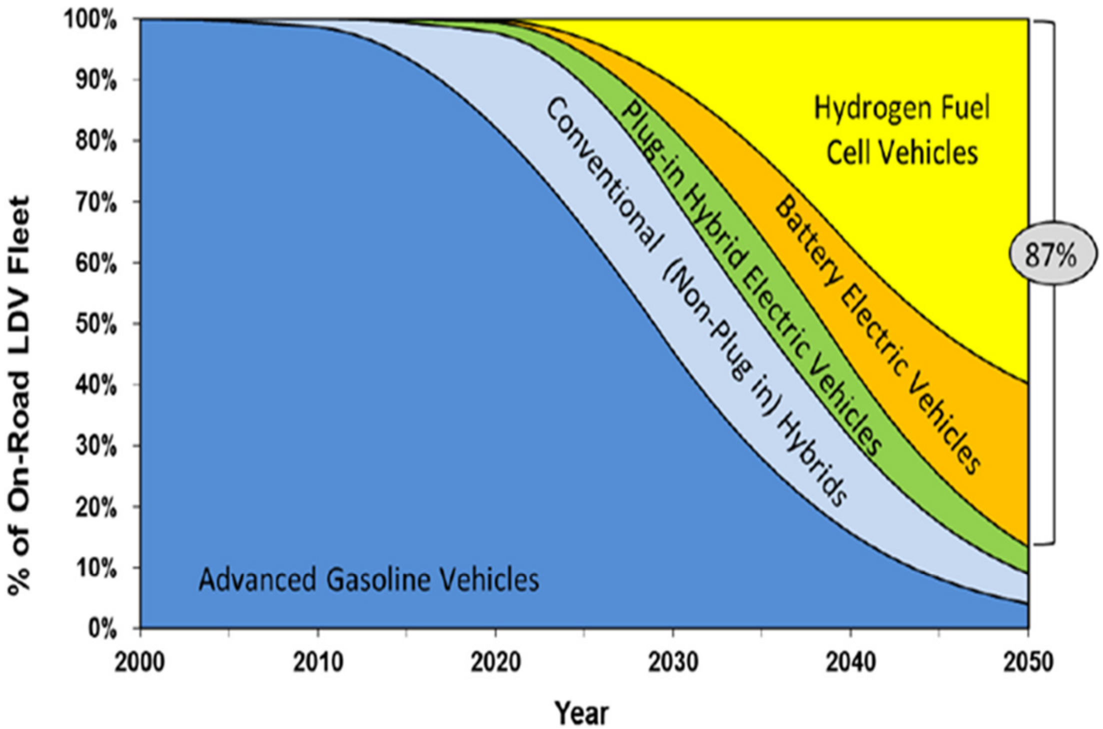
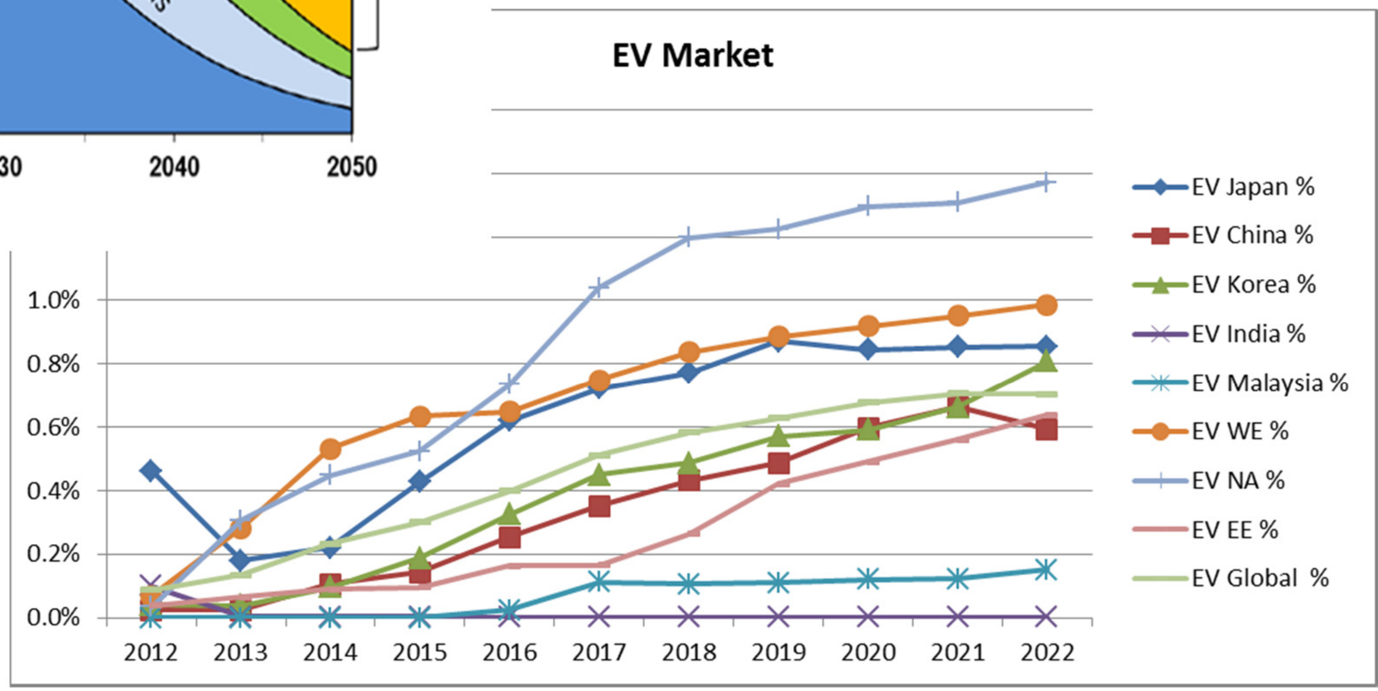
- Hyundai – launched ix35 in 2013. Produced in 100s/yr. New vehicle 2018
- Toyota – launched Mirai in 2015. Plan to produce 1000s/yr
- Honda – plan to launch new Clarity in 2017 and produce ~1000/yr
- Daimler – plan to launch vehicle 2018
- GM and Nissan early 2020s
- VW, Ford and BMW actively developing

How does this affect cars?

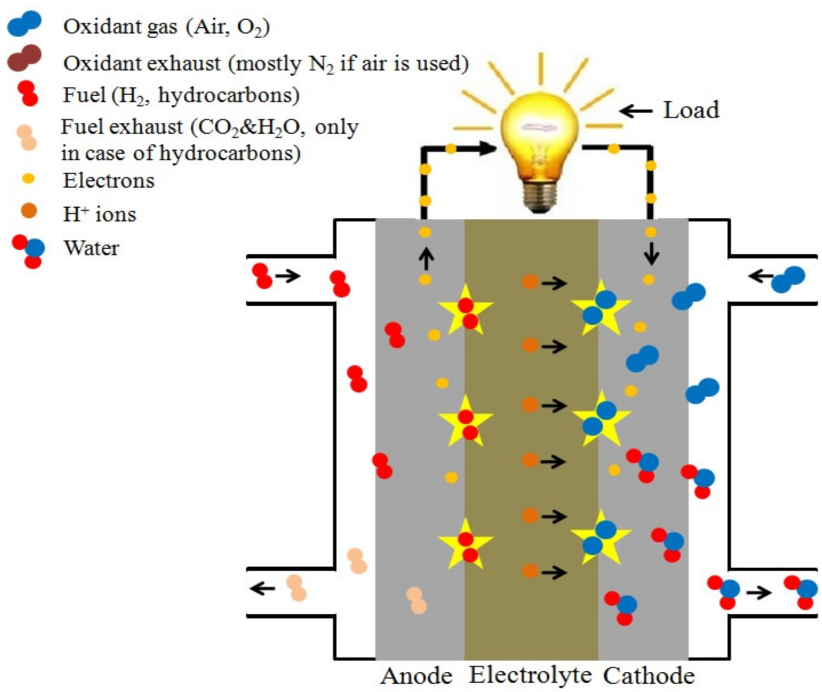


- This is the car fleet on the road
  - Means no new ICE from 2040
  - Growth of new Electric Vehicle sales from 0 to 100% in next 25 years

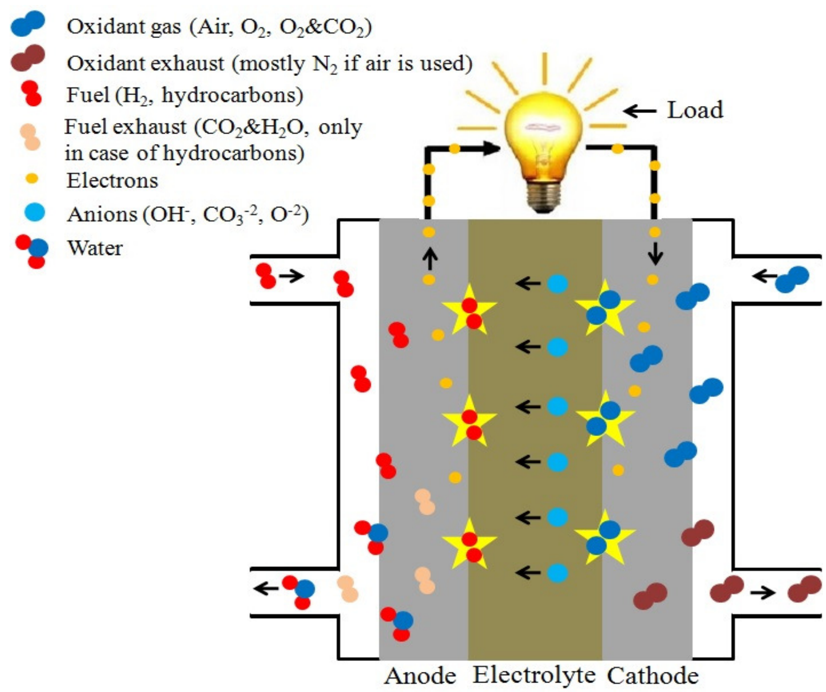


How Fuel Cells Work

- The fuel reacts at the anode generating electrons trough an oxidation reaction
- The electrons flows into the external circuit providing electrical power
- At the cathode the electrons and the oxidant are recombined with a reduction reaction
- The oxidation reaction and the reduction reaction are fed by cations (positive ions) or anions (negative ions) flowing trough the electrolyte



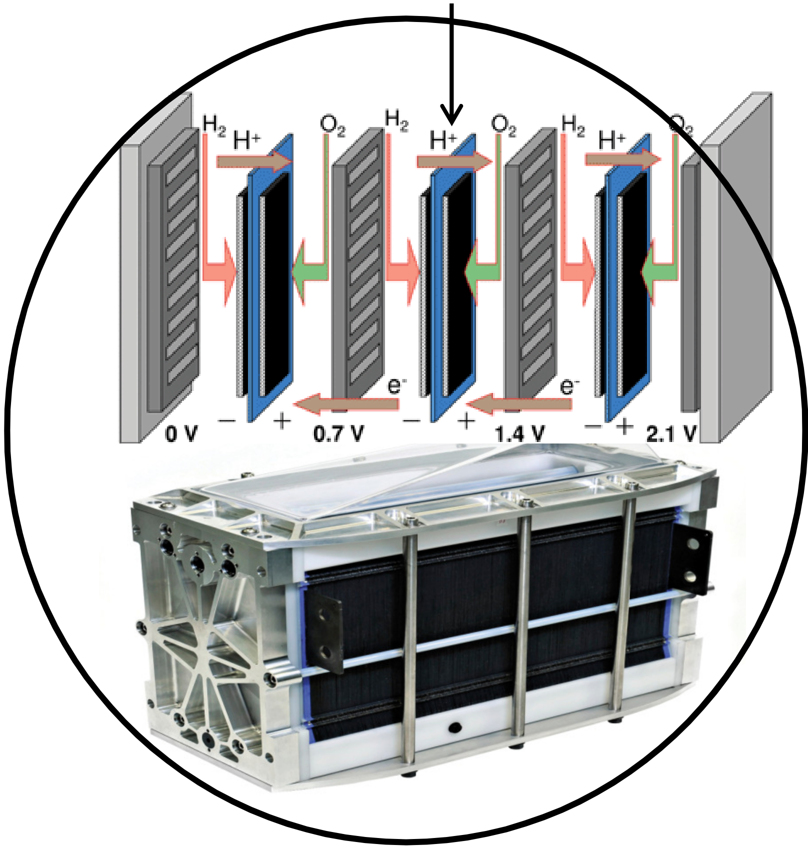
Acid electrolyte → H^+ (cation) flow



Alkaline electrolyte → anions flow

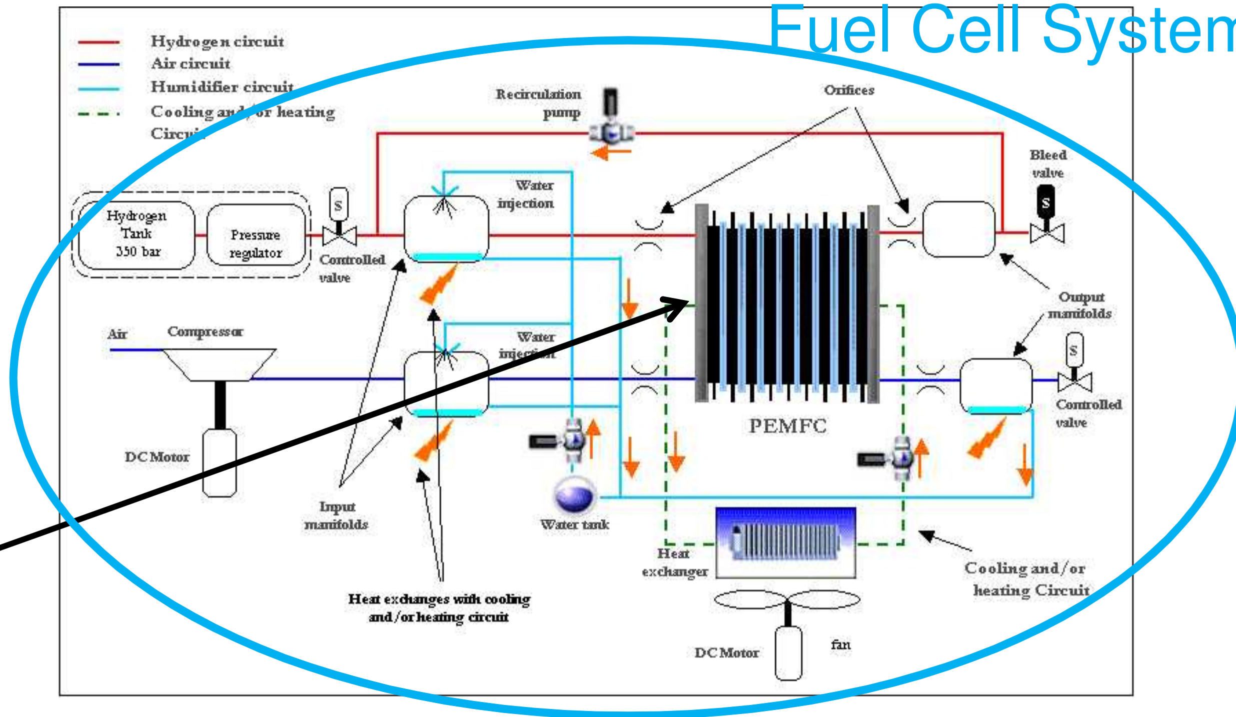
Fuel Cells System

Single Fuel Cell



Fuel Cell Stack

Fuel Cell System



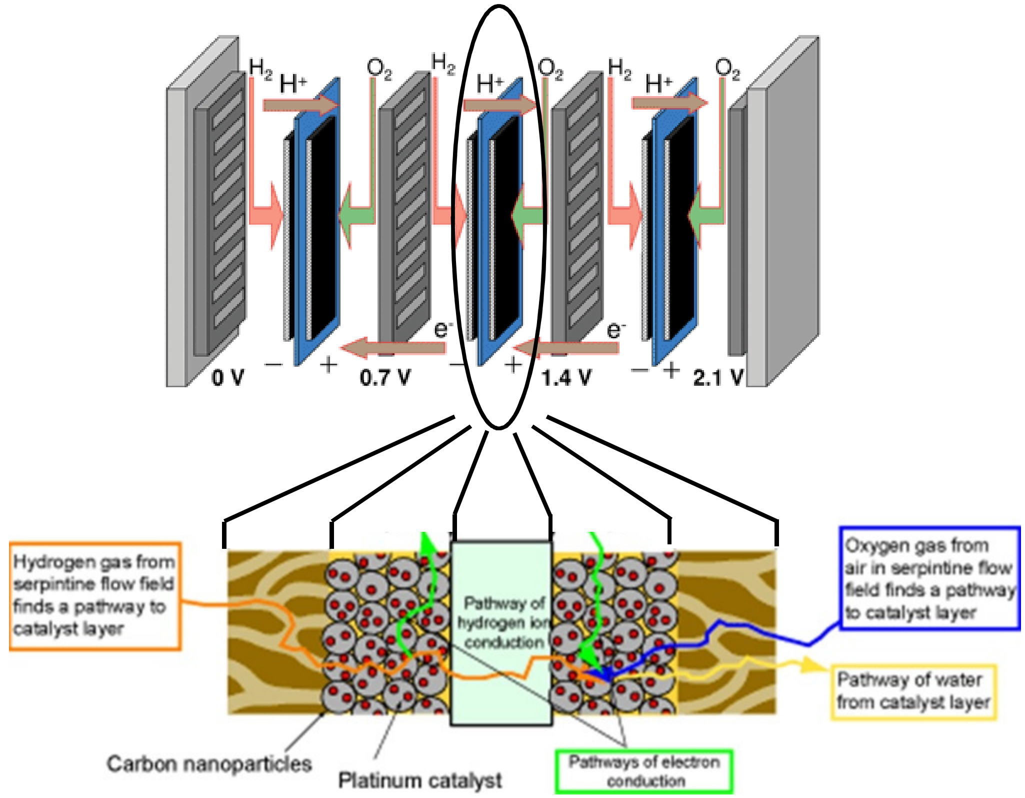
Johnson Matthey Fuel Cells Products

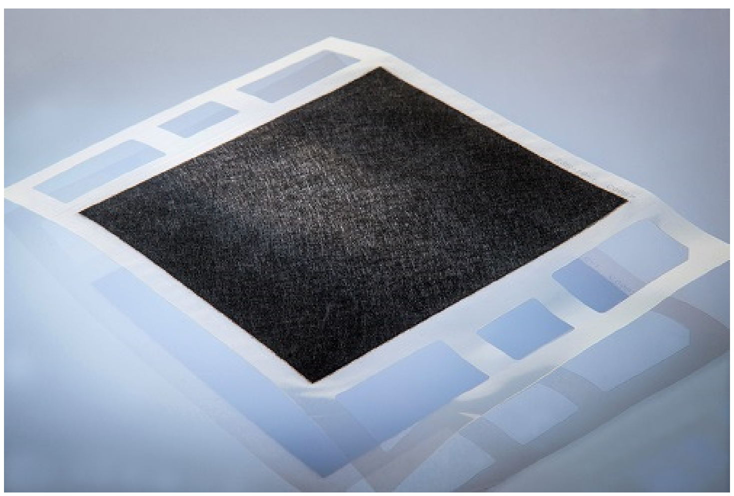
JM's key product is the MEA
(membrane electrode assembly)

A sandwich of:

- two sheets of carbon paper
- two catalyst layers
- a plastic membrane
- a sealing and supporting plastic film

Making good MEAs requires skills in materials science, chemistry, catalysis, mechanical design and manufacturing





Proton Exchange Membrane (PEM)

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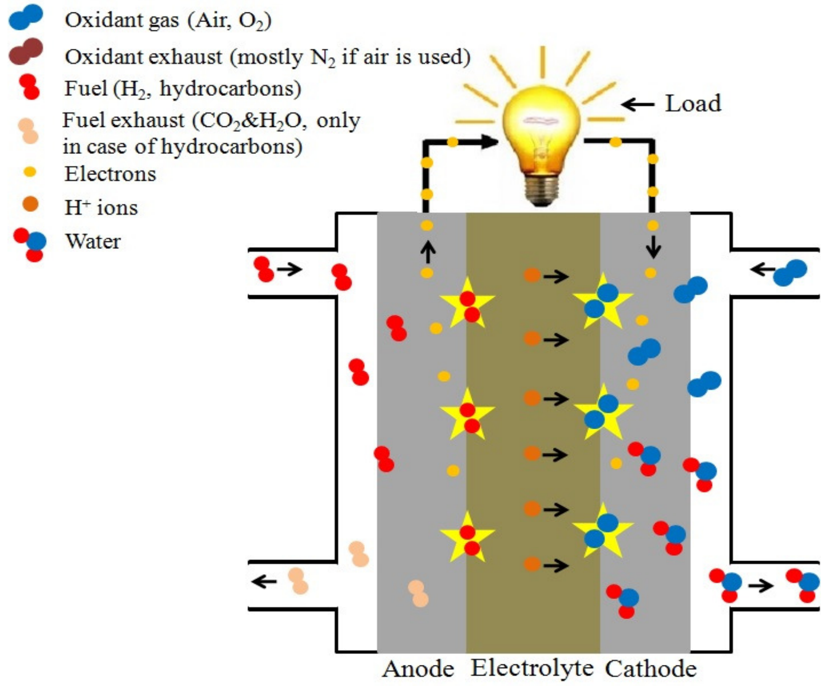
Properties:

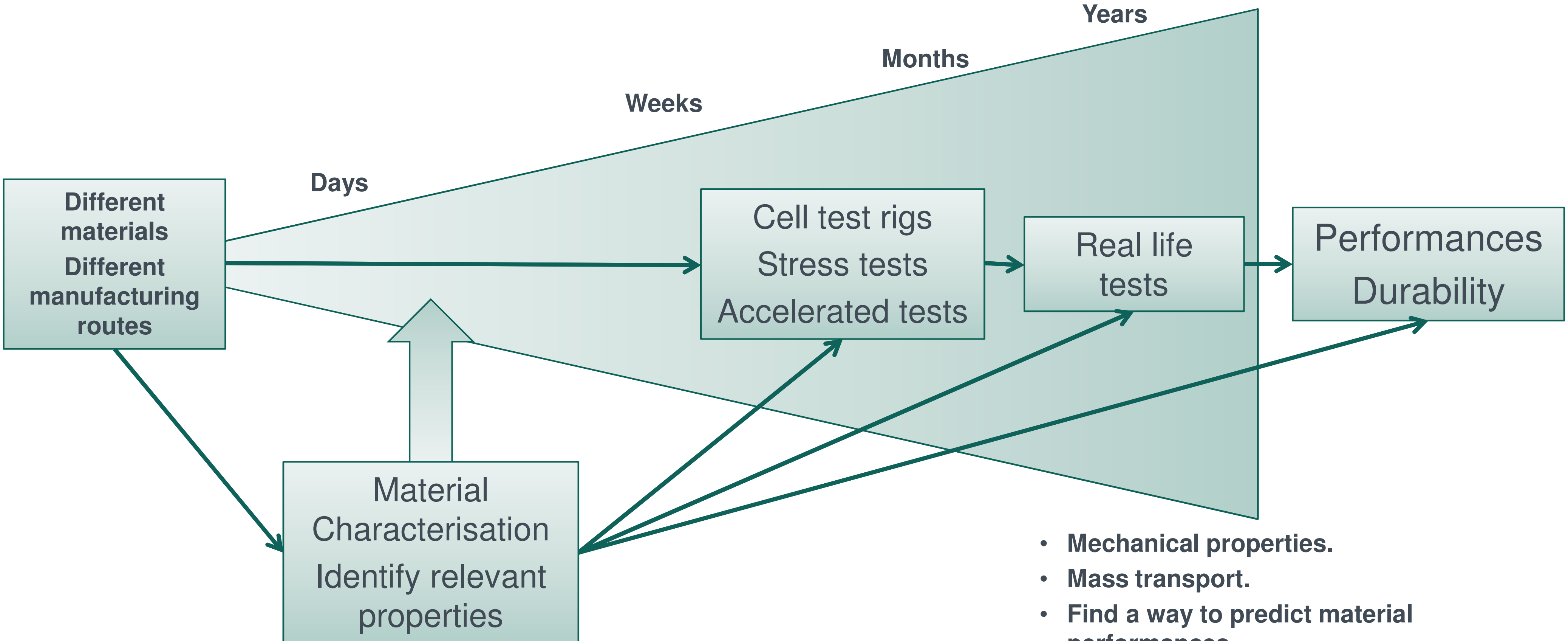
- High proton conductivity
- High water transport
- Electrically insulator
- Gas impermeable
- Durable, mechanical, thermal and chemical stability
- Thin



Non-stationary conditions:

- Change in temperature
- Change in humidity, from dry to fully hydrated conditions
- Change in dimensions as effect of hydration, internal stress

The missing link

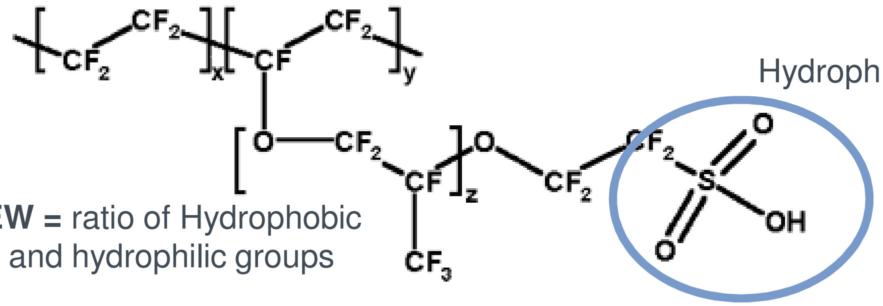


- Mechanical properties.
- Mass transport.
- Find a way to predict material performances.

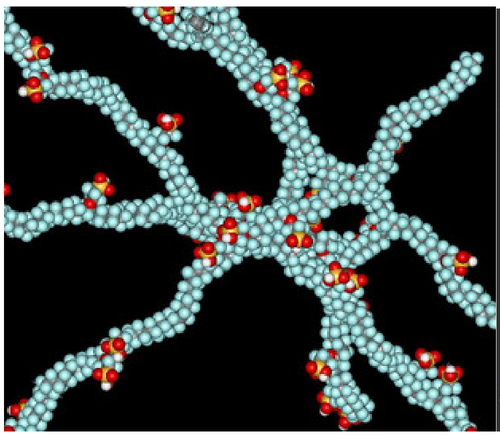
- Performances.
- Durability.

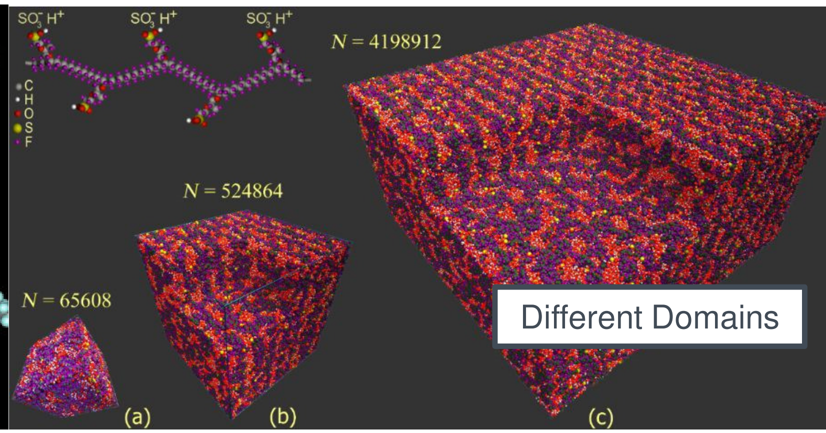
PEM Structure

PTFE Hydrophobic backbone
Mechanical properties

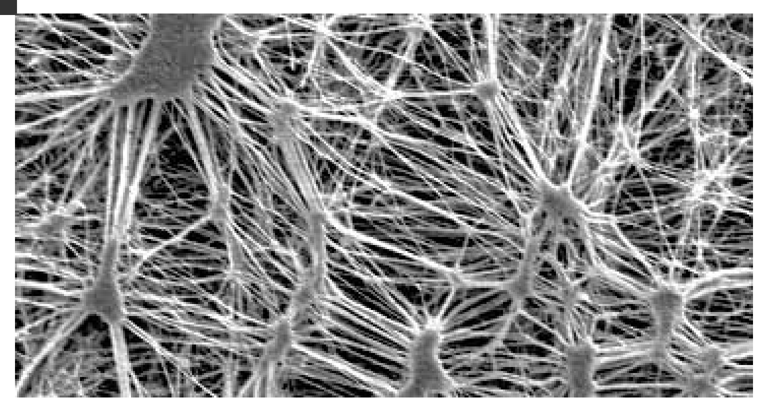


EW = ratio of Hydrophobic and hydrophilic groups





Reinforcement Material to improve the mechanical properties



Dynamic Mechanical Analysis

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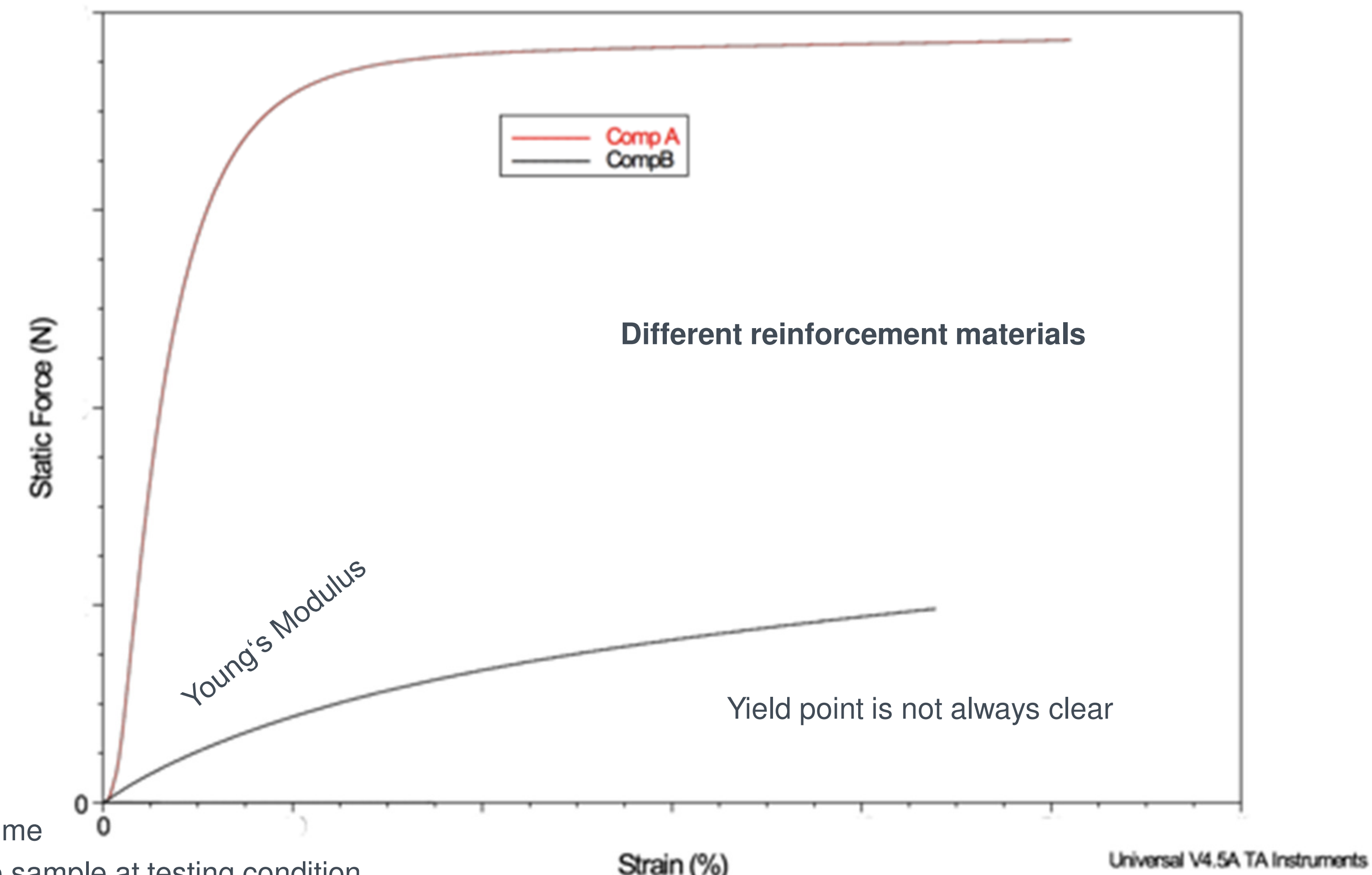
- Operational conditions (T, RH)
- Material Conditioning time

- Stress vs strain curves
- Introduction of Modulated investigation

- PEM, Reinforcement Modulus
- Swelling

PEM

- **Stress vs Strain at hot and wet condition.**
- **Operational conditions**

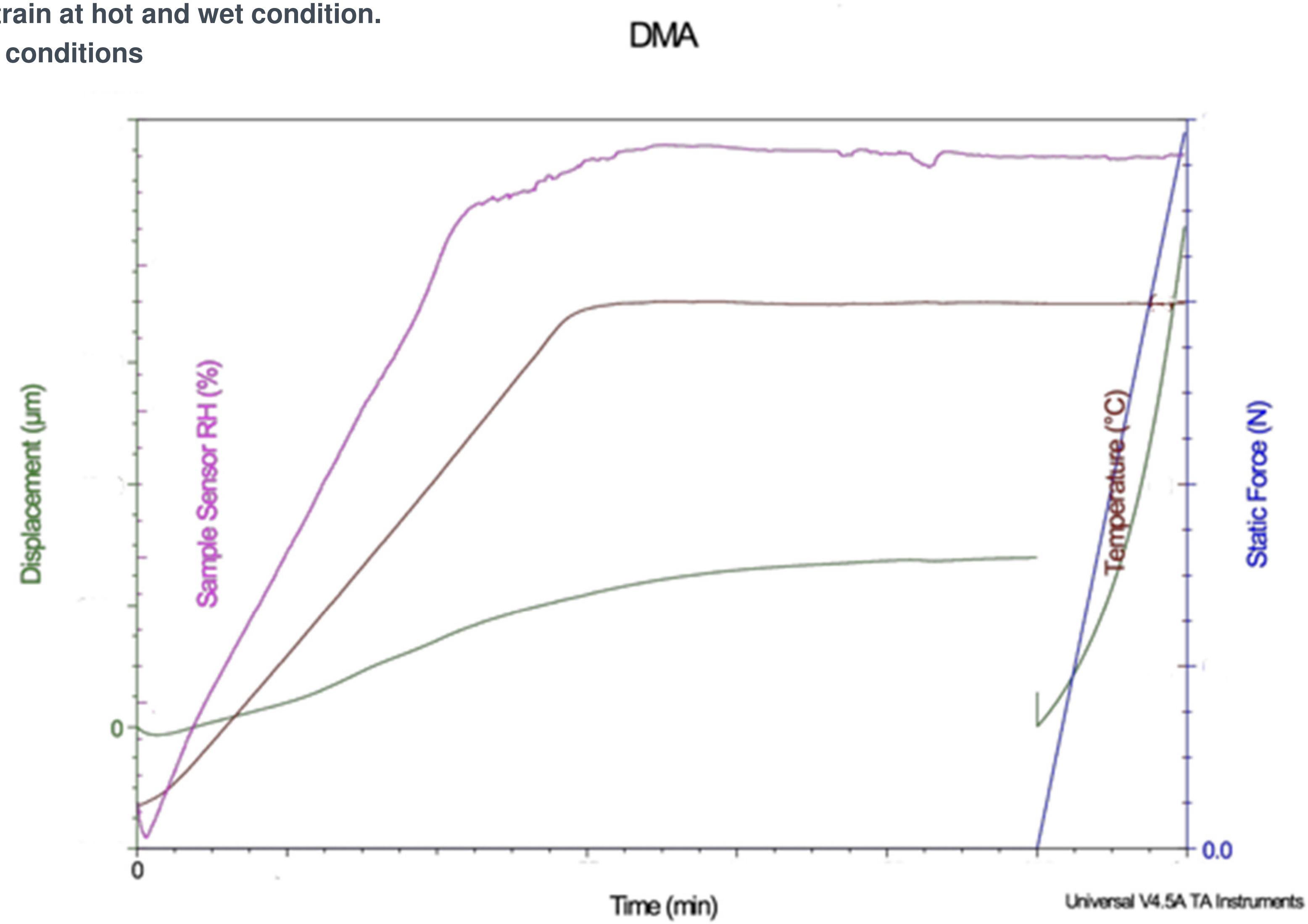


Conditioning time

Equilibrate the sample at testing condition.

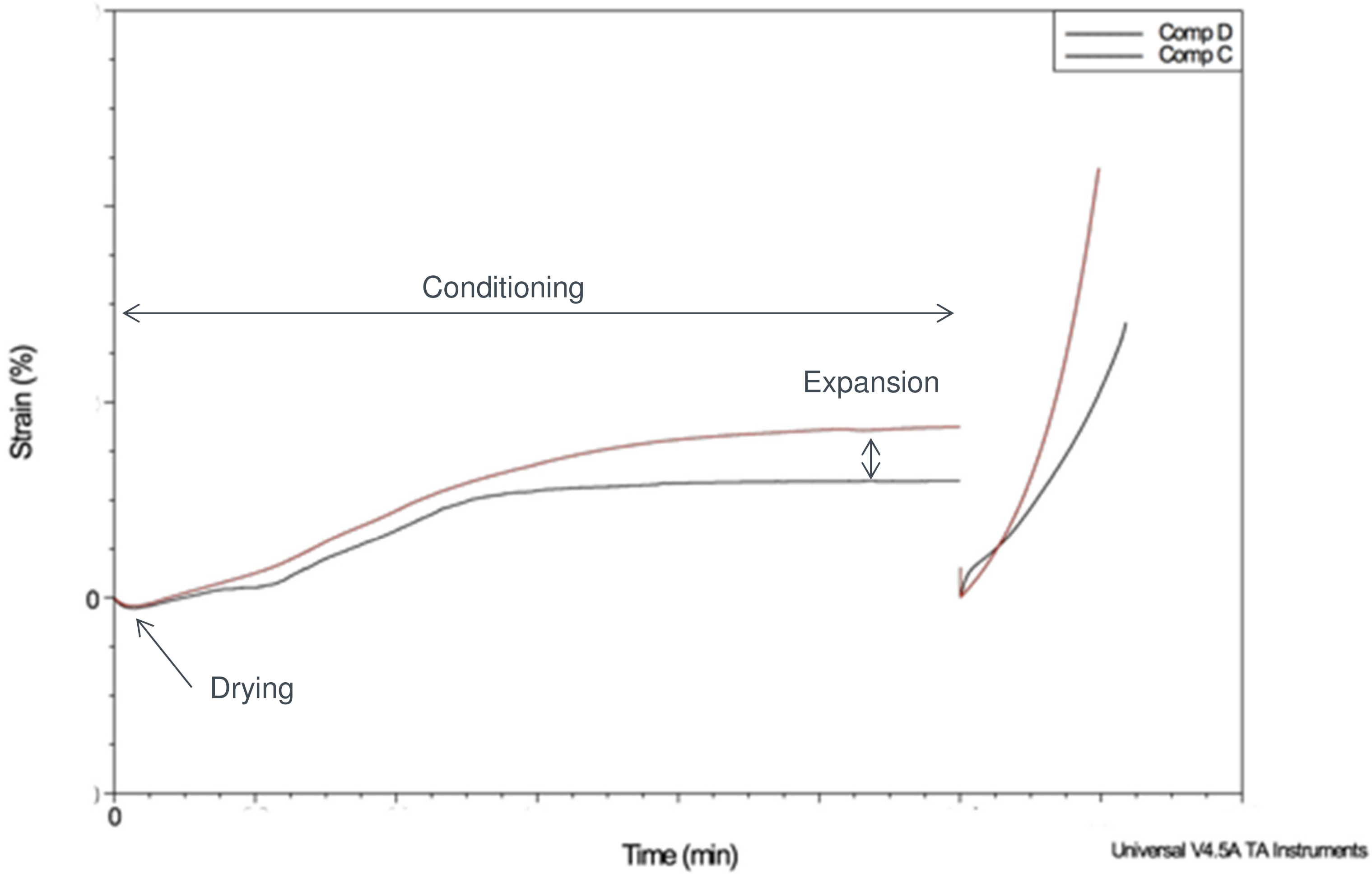
PEM

- **Stress vs Strain at hot and wet condition.**
- **Operational conditions**



PEM

- **Stress vs Strain at hot and wet condition.**
- **Operational conditions**



PEM

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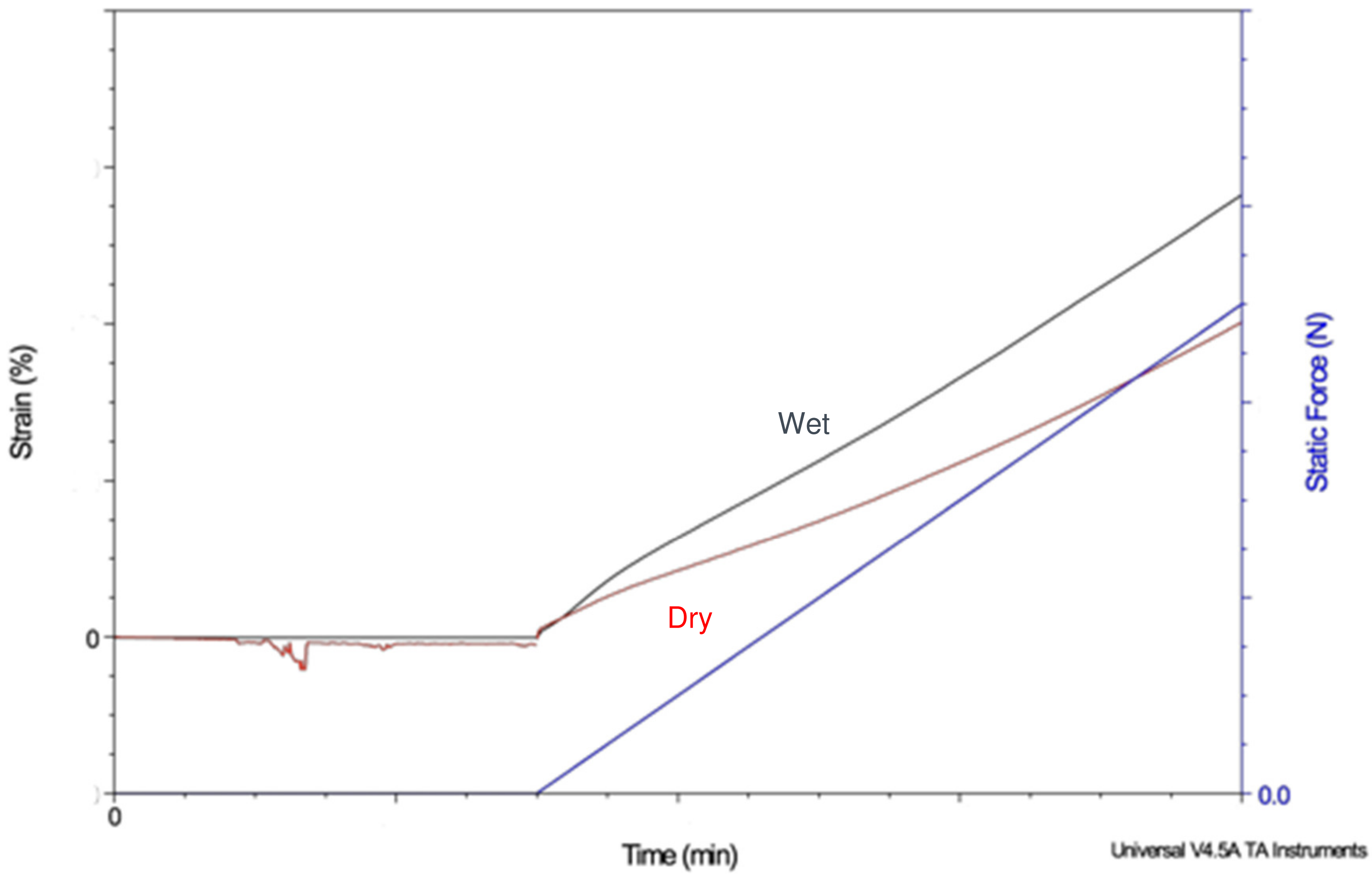
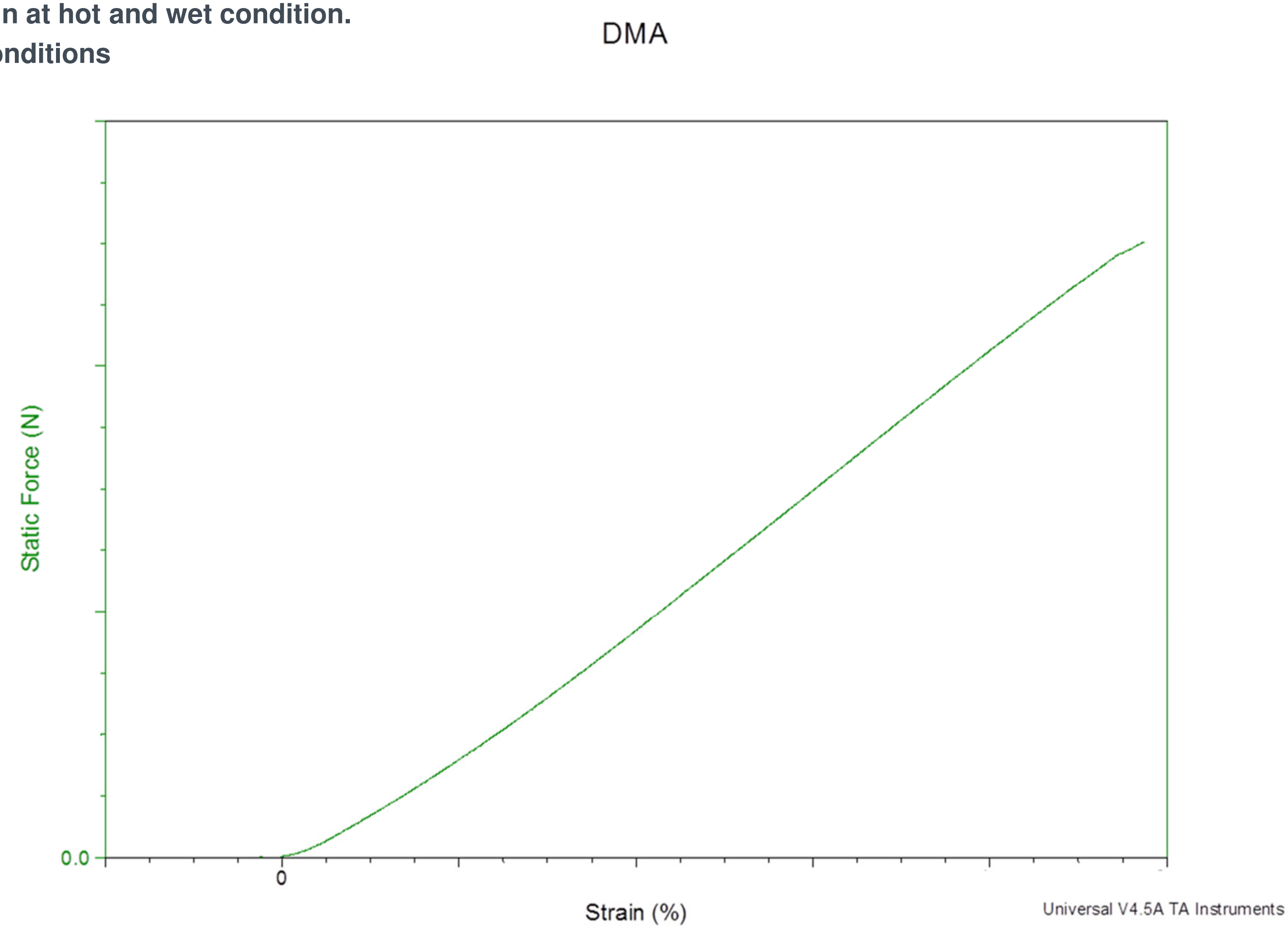


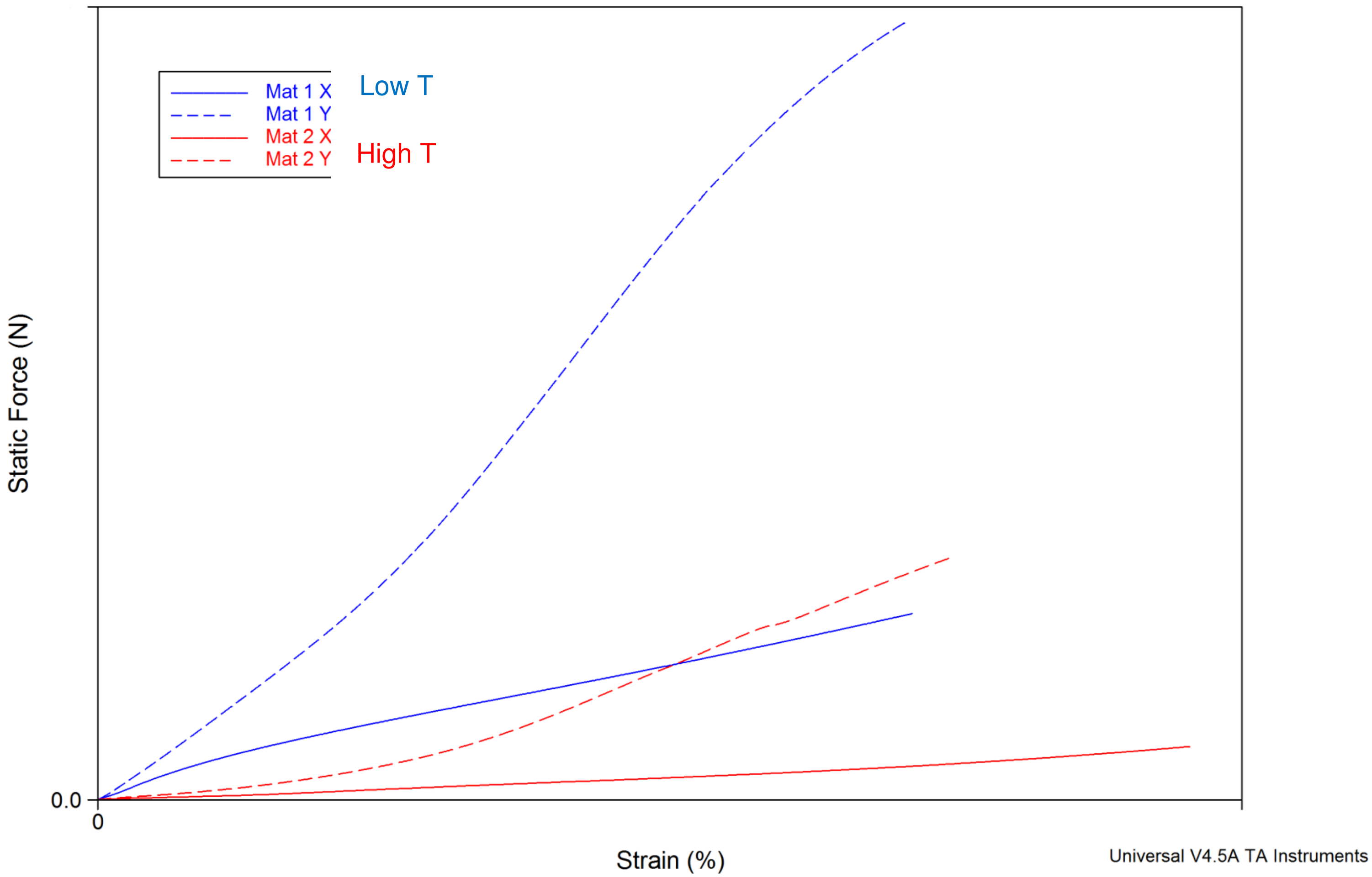
Reinforcement

- **Stress vs Strain at hot and wet condition.**
- **Operational conditions**



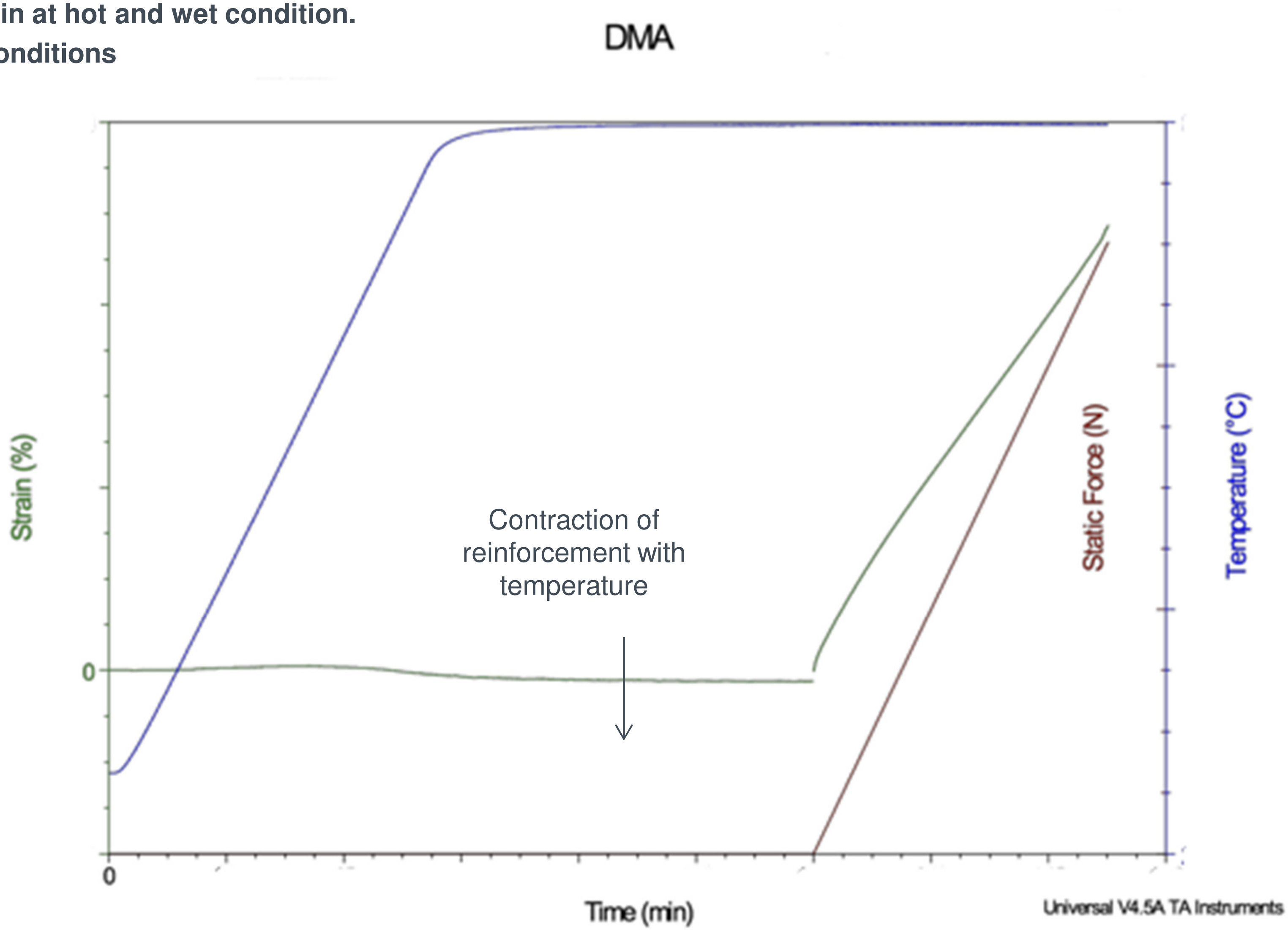
Reinforcement

Completely different behaviour of the material, we are above the TG.
Another important property we need to take into account is the anisotropy of the material.

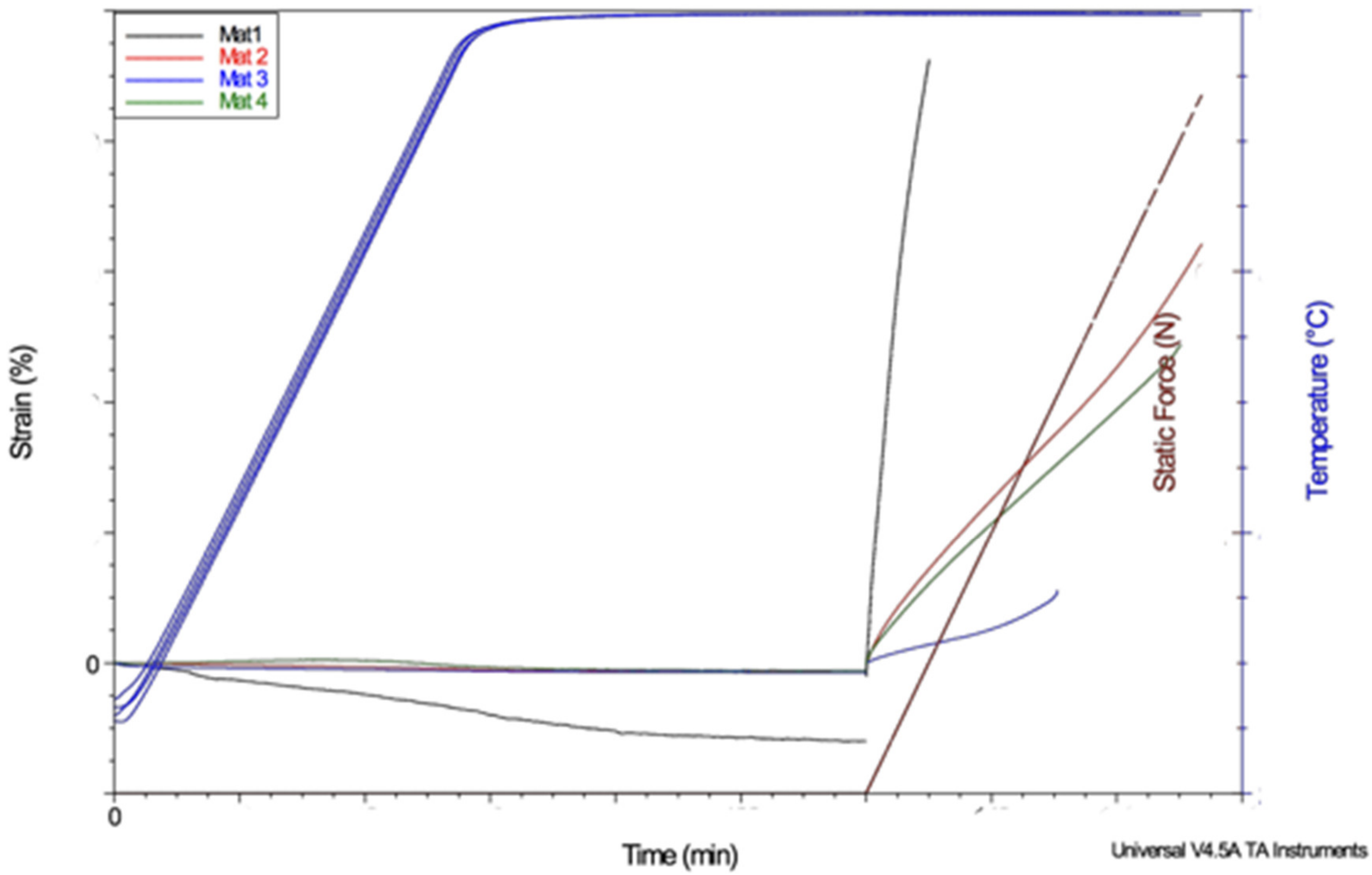


Reinforcement

- **Stress vs Strain at hot and wet condition.**
- **Operational conditions**



Reinforcement



Reinforcement

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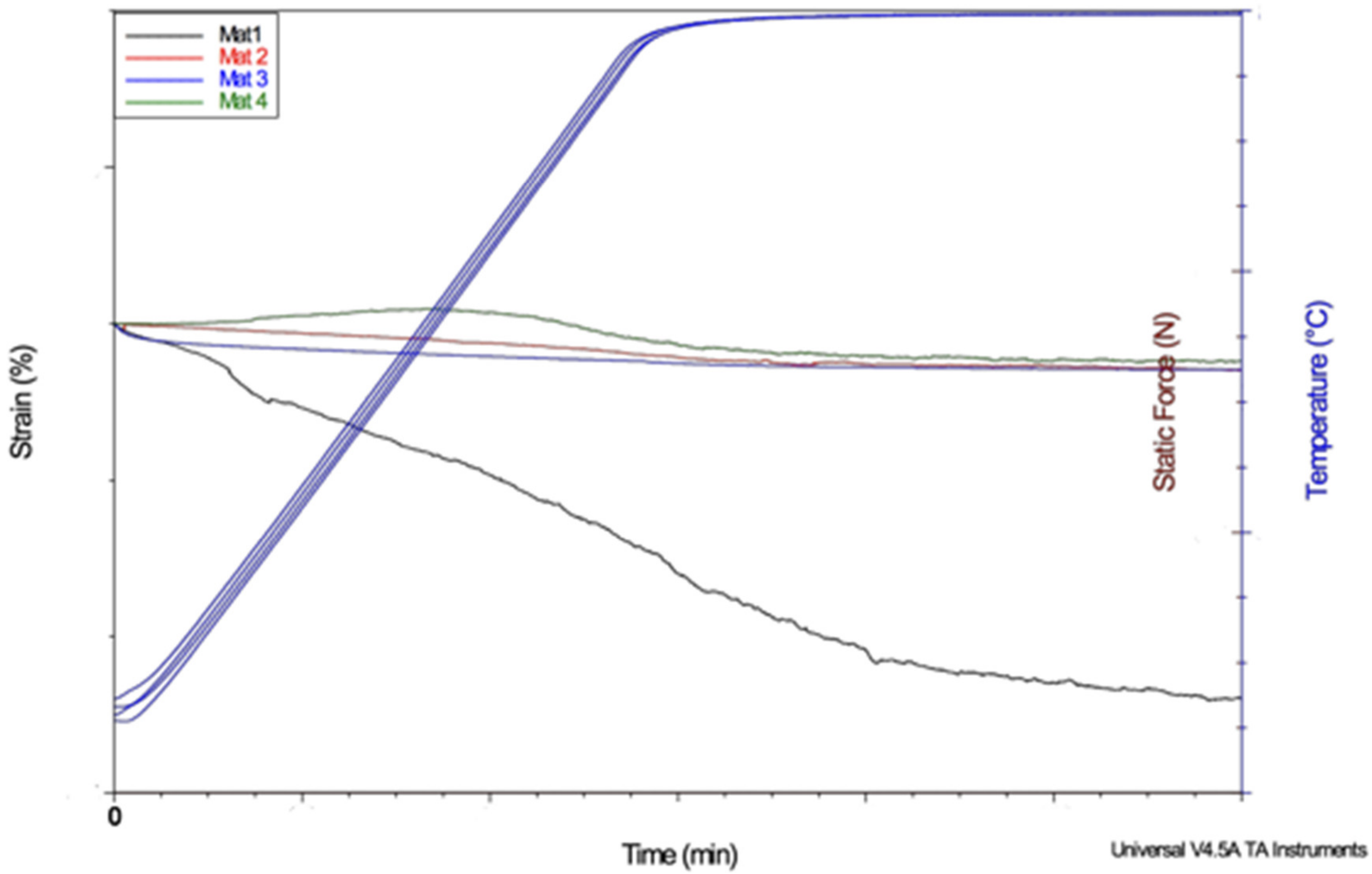

DMA PEM

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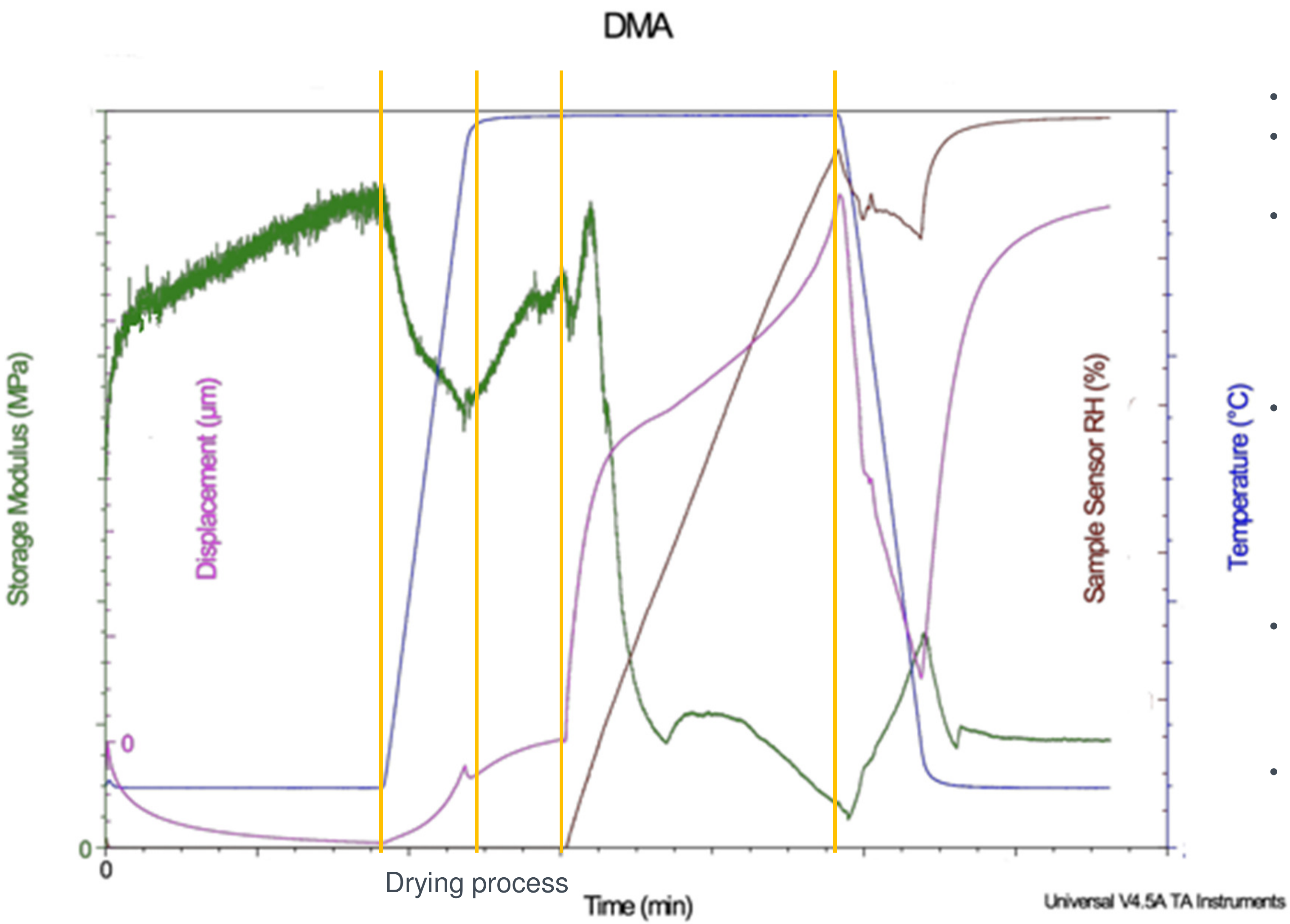
Constant frequency



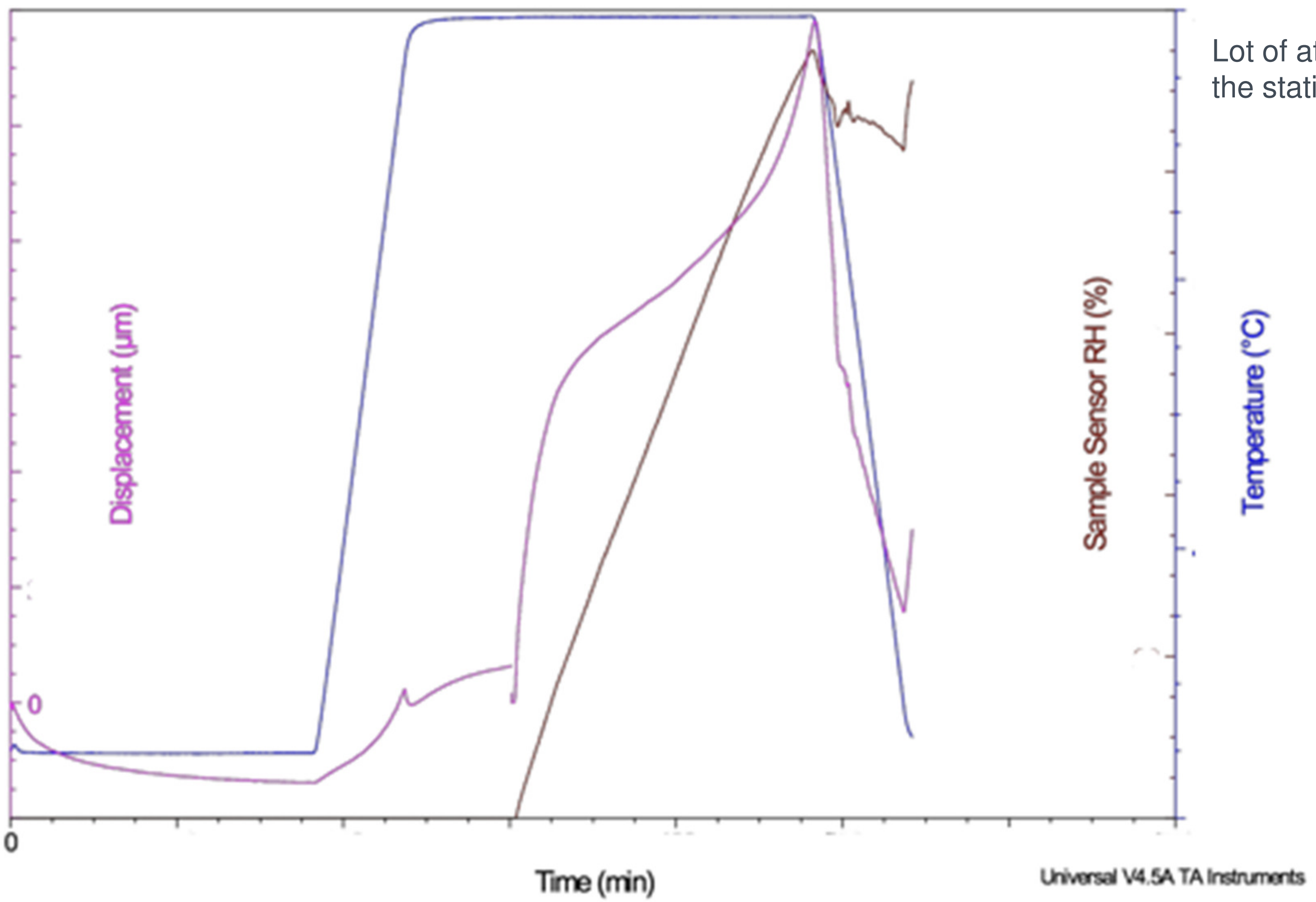
- Composite material
- Different domains

- Drying process
  - contraction of the ionomer
  - contraction of the Reinforcement

- Temperature increases
  - Decrease of storage modulus
  - PTFE characteristic and previous contraction of the reinforcement
- Temperature increases
  - Increase of the of the Storage modulus driven by the initial expansion
- RH increases
  - Drop of storage modulus with water uptake

Ensure the test is set up properly

Non modulated experiment

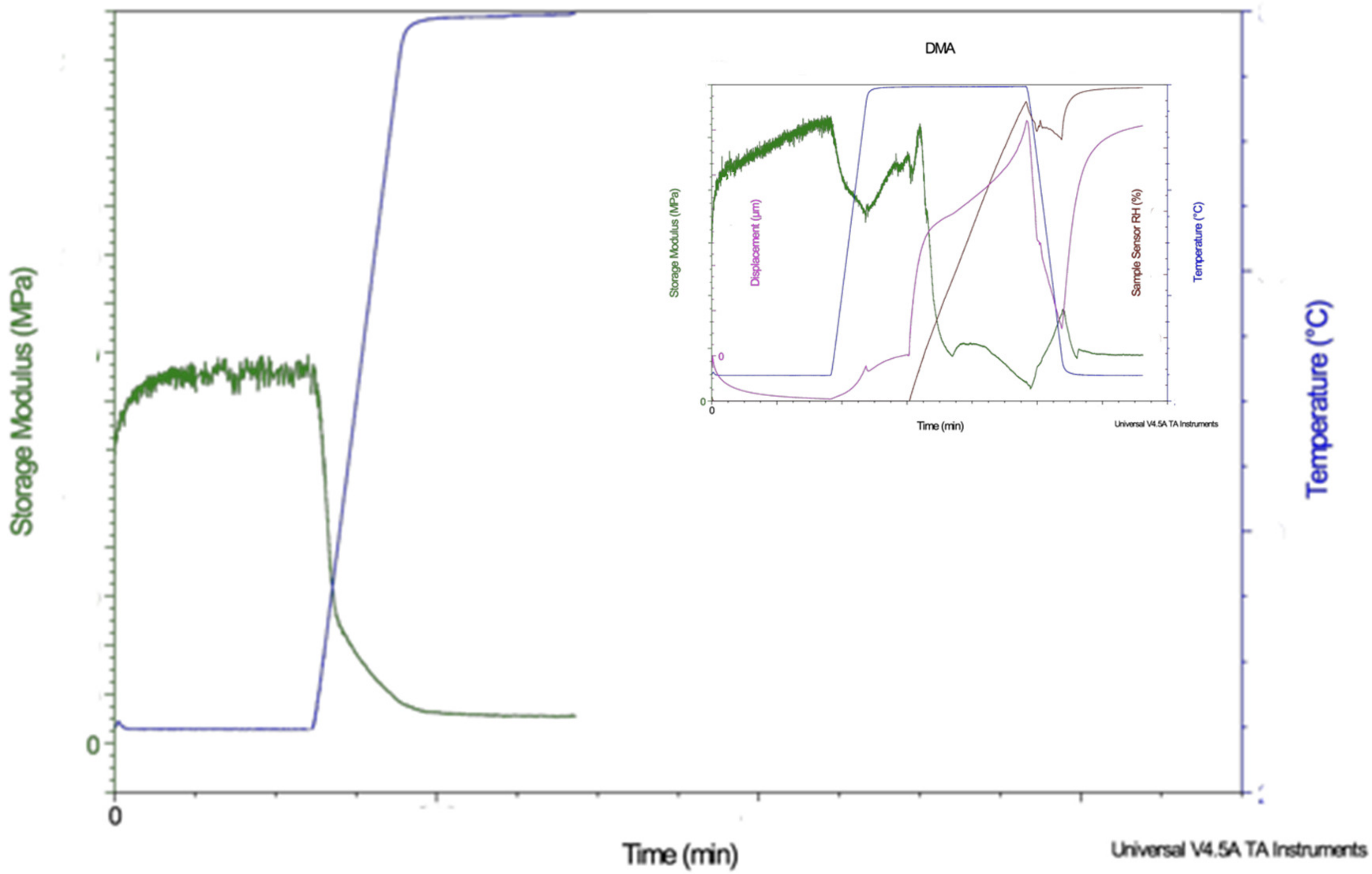


Lot of attention to the static force

Reinforcement

DMA

The reinforcement tend contracts and loose storage modulus with temperature



DMA

- Set up a set of tests suitable for the relevant properties.
- Test at operational conditions
- Evaluation of the different components of the PEM
- We are working to expand the database of materials used both in the lab tests and cell testing to ensure a strong correlation.

DVs

- **Durability is correlated to the water uptake (EW, Reinf, …)**
- **Performances are correlated to the water uptake (EW, …)**

- **Next step: investigation of water uptake**
  - **Total water uptake**
  - **Water uptake kinetics**

PEM

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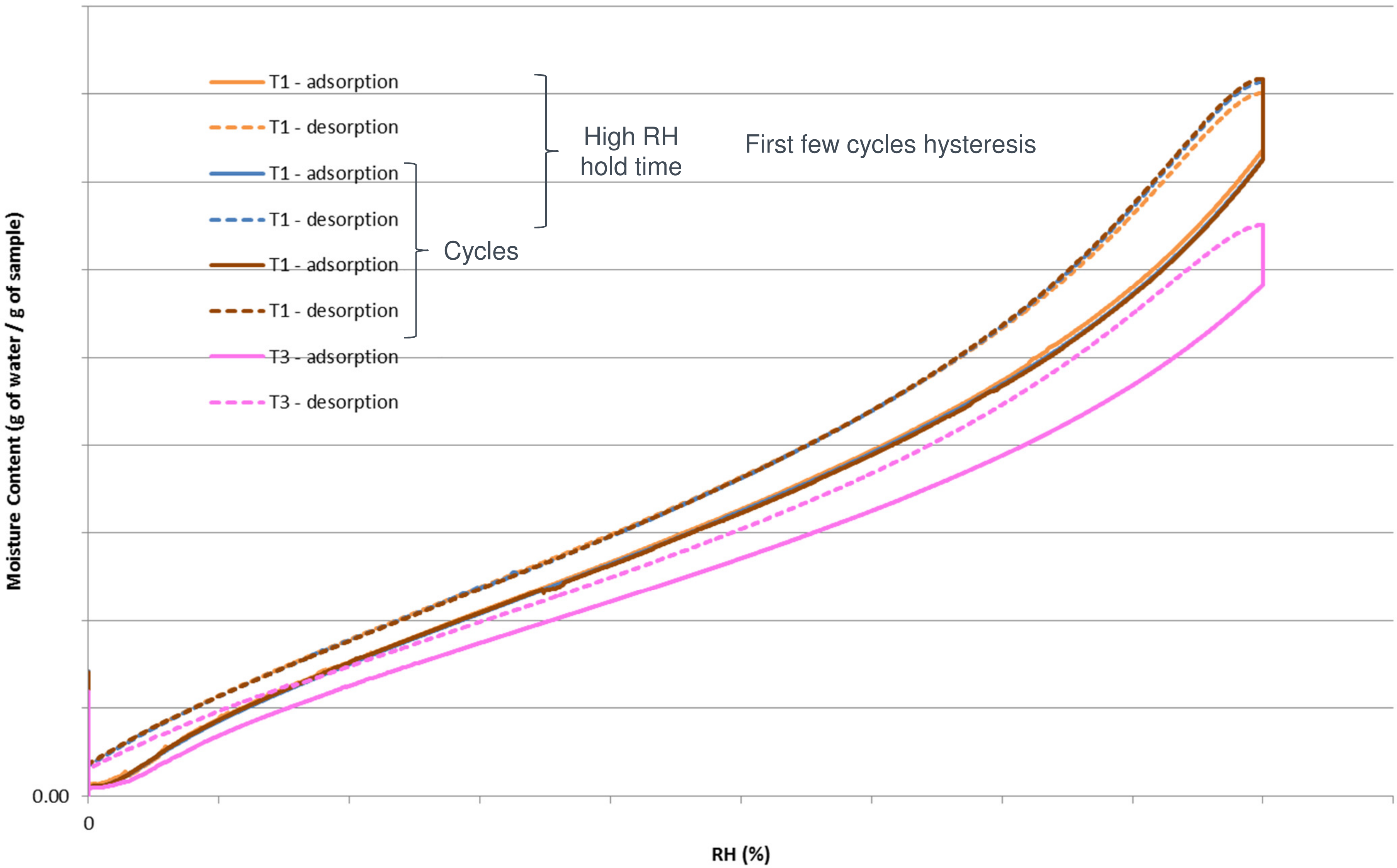

PEM

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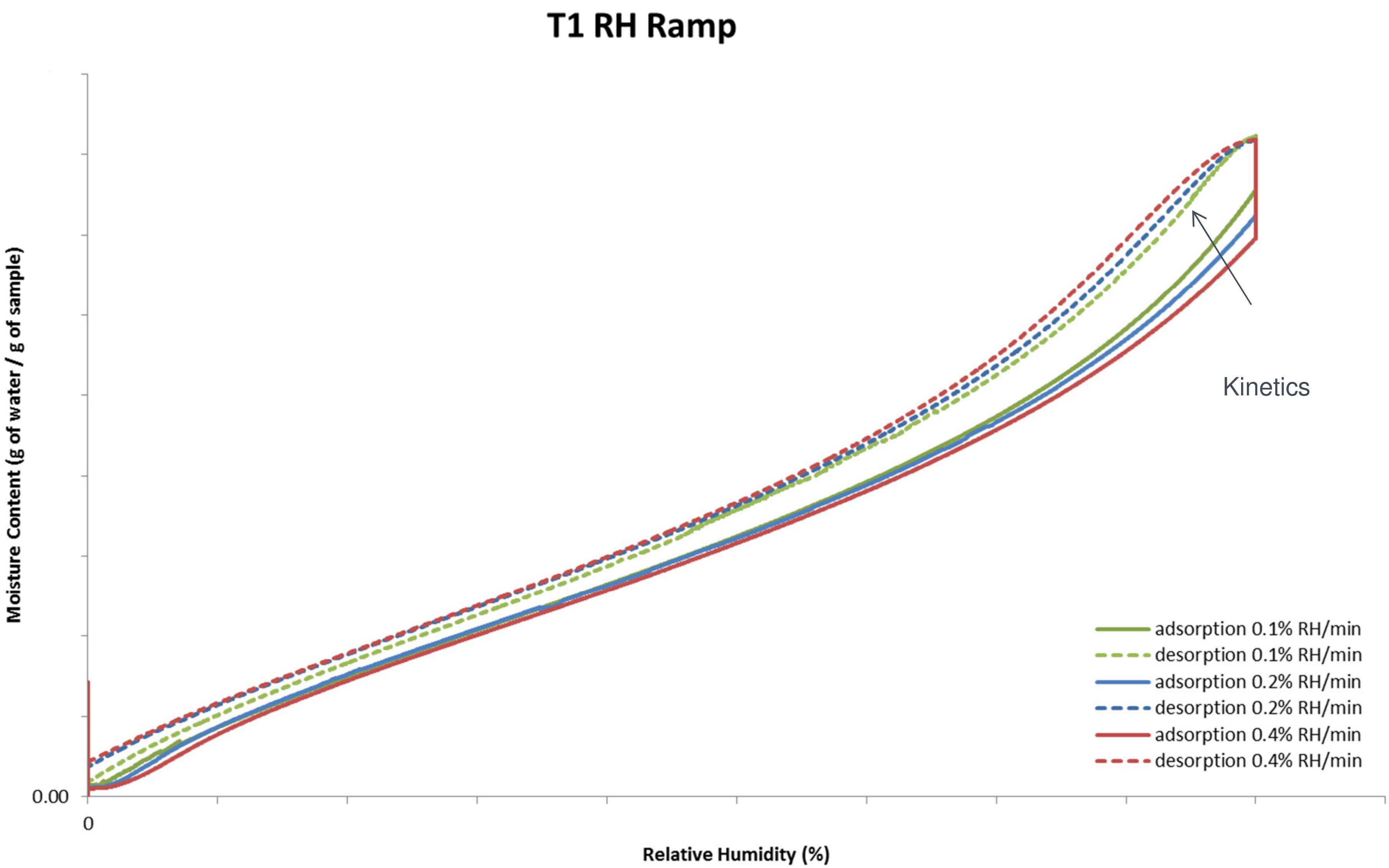
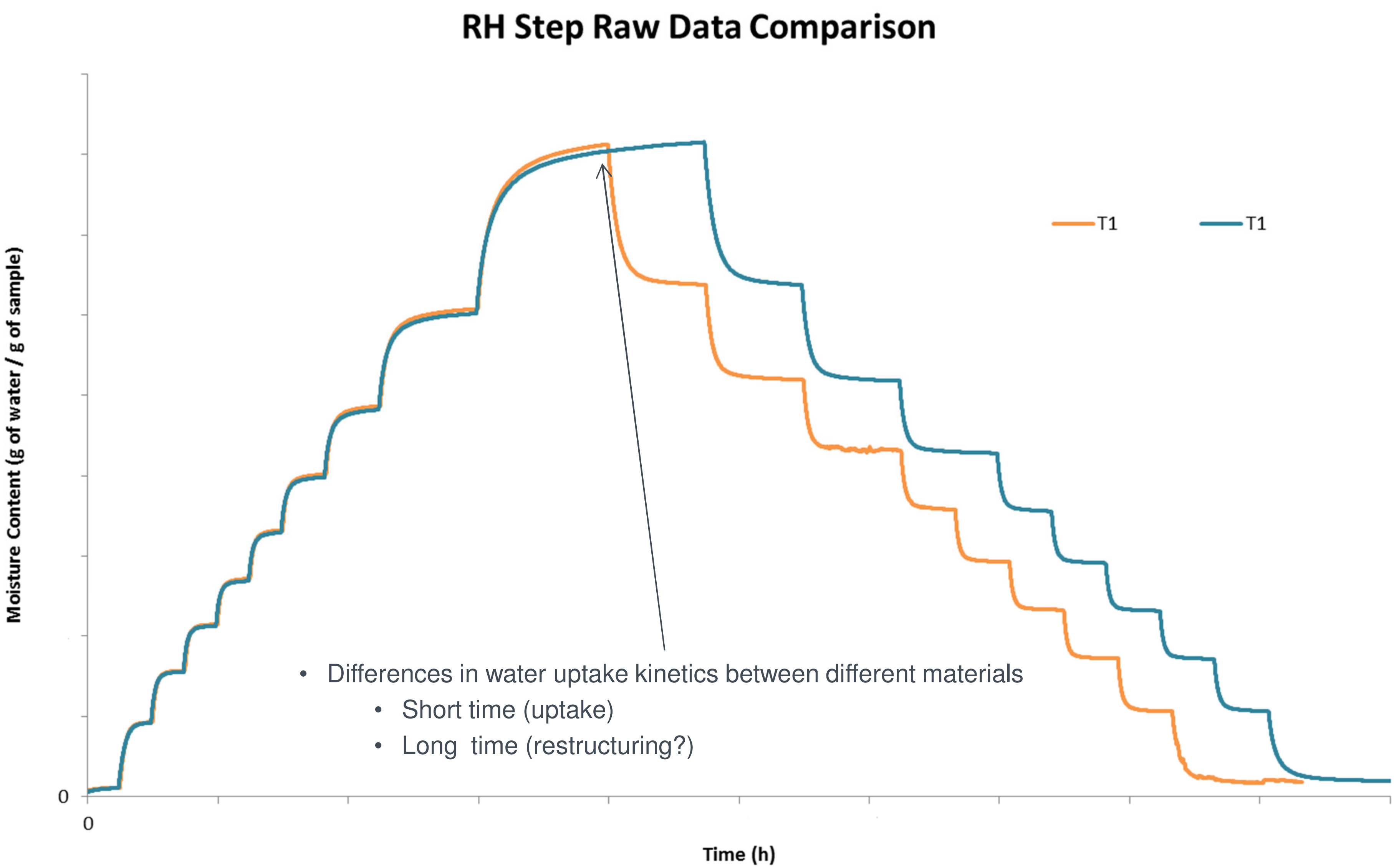
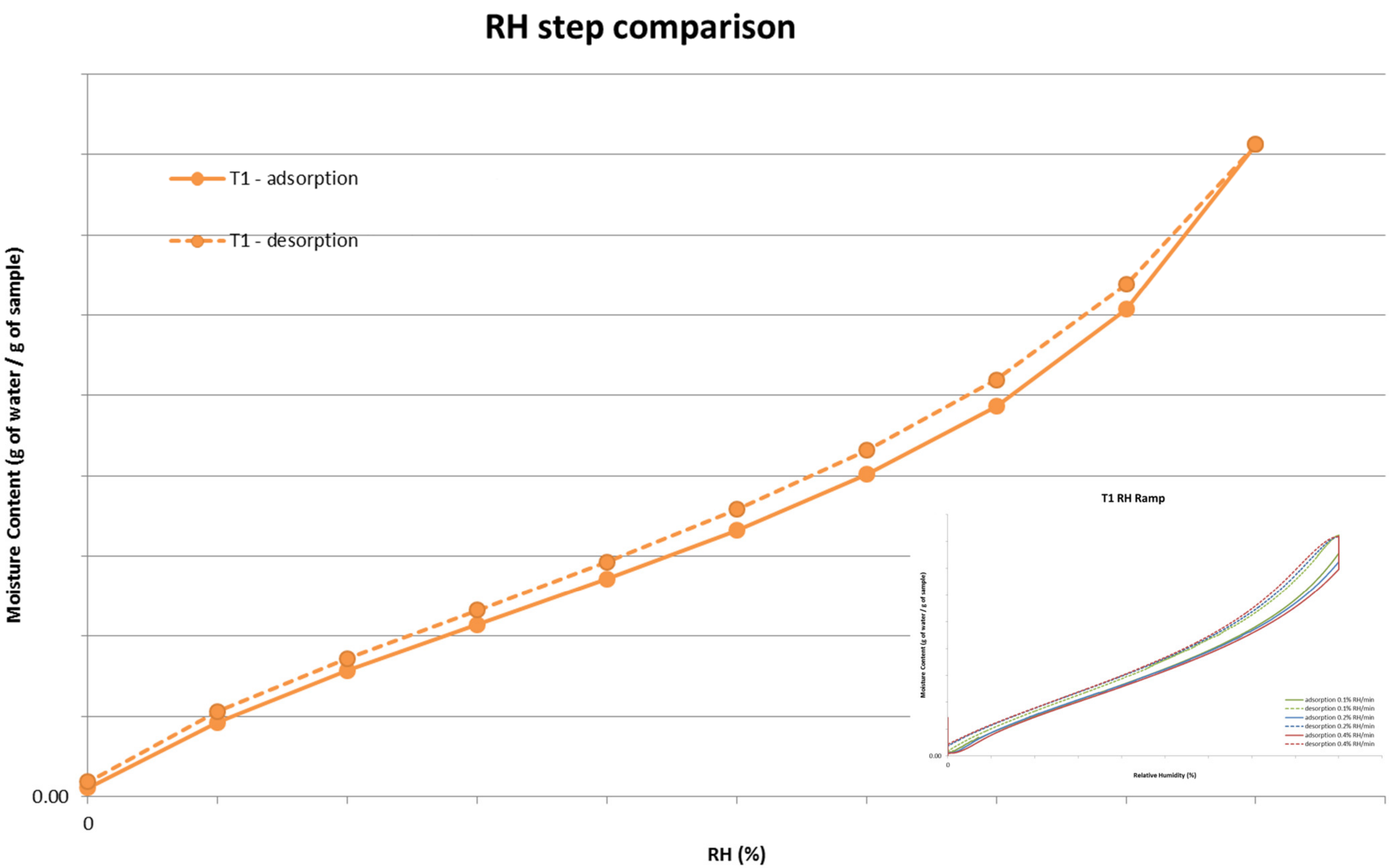


PEM



- Differences in water uptake kinetics between different materials
    - Short time (uptake)
    - Long time (restructuring?)

DVs



RH step comparison
T1 - adsorption
T1 - desorption
Moisture Content (g of water / g of sample)
0.00
0
RH (%)
T1 RH Ramp
Moisture Content (g of water / g of sample)
adsorption 0.1% RH/min
desorption 0.1% RH/min
adsorption 0.2% RH/min
desorption 0.2% RH/min
adsorption 0.4% RH/min
desorption 0.4% RH/min
0.00
0
Relative Humidity (%)

Jump analysis validation

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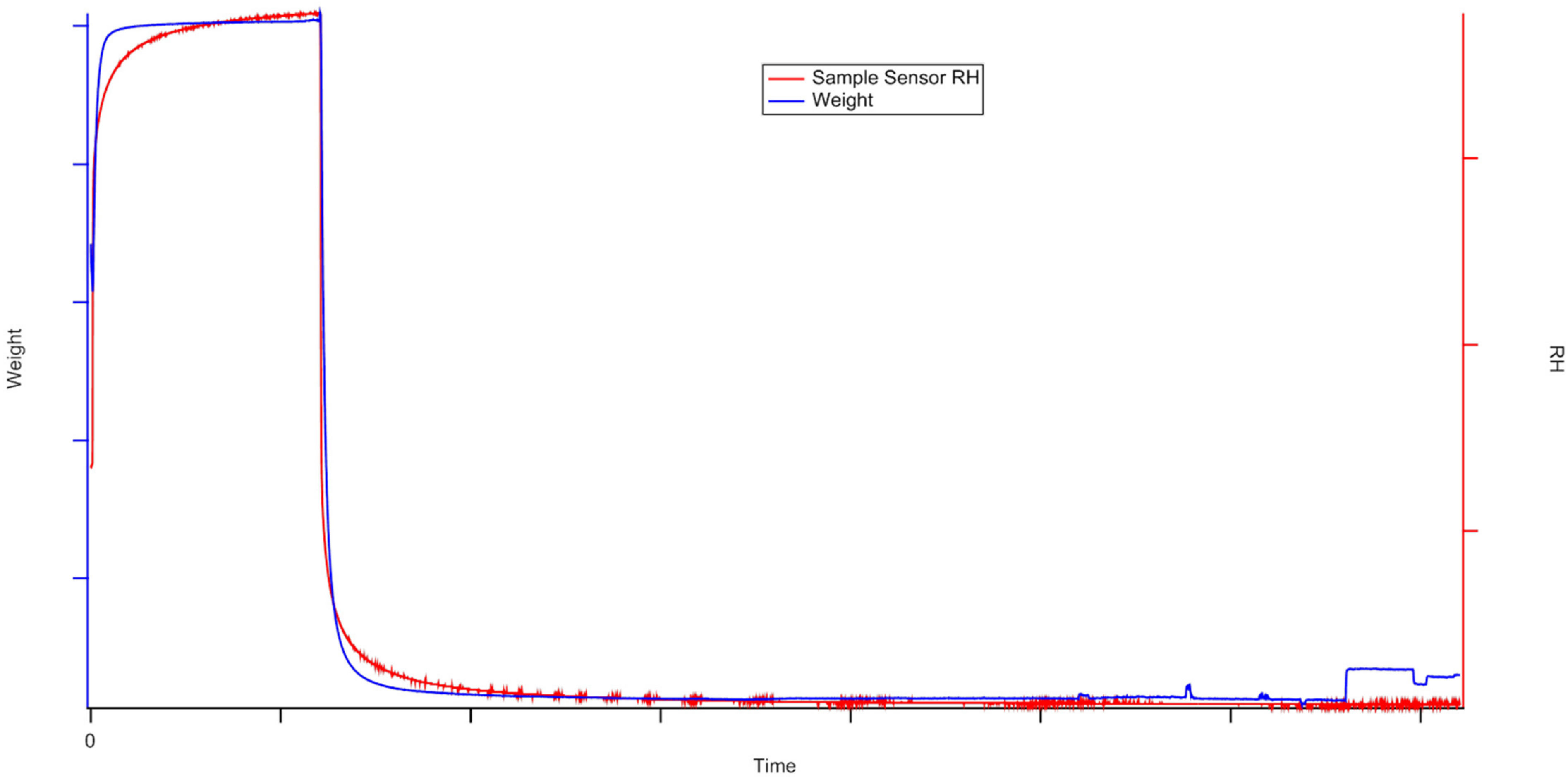
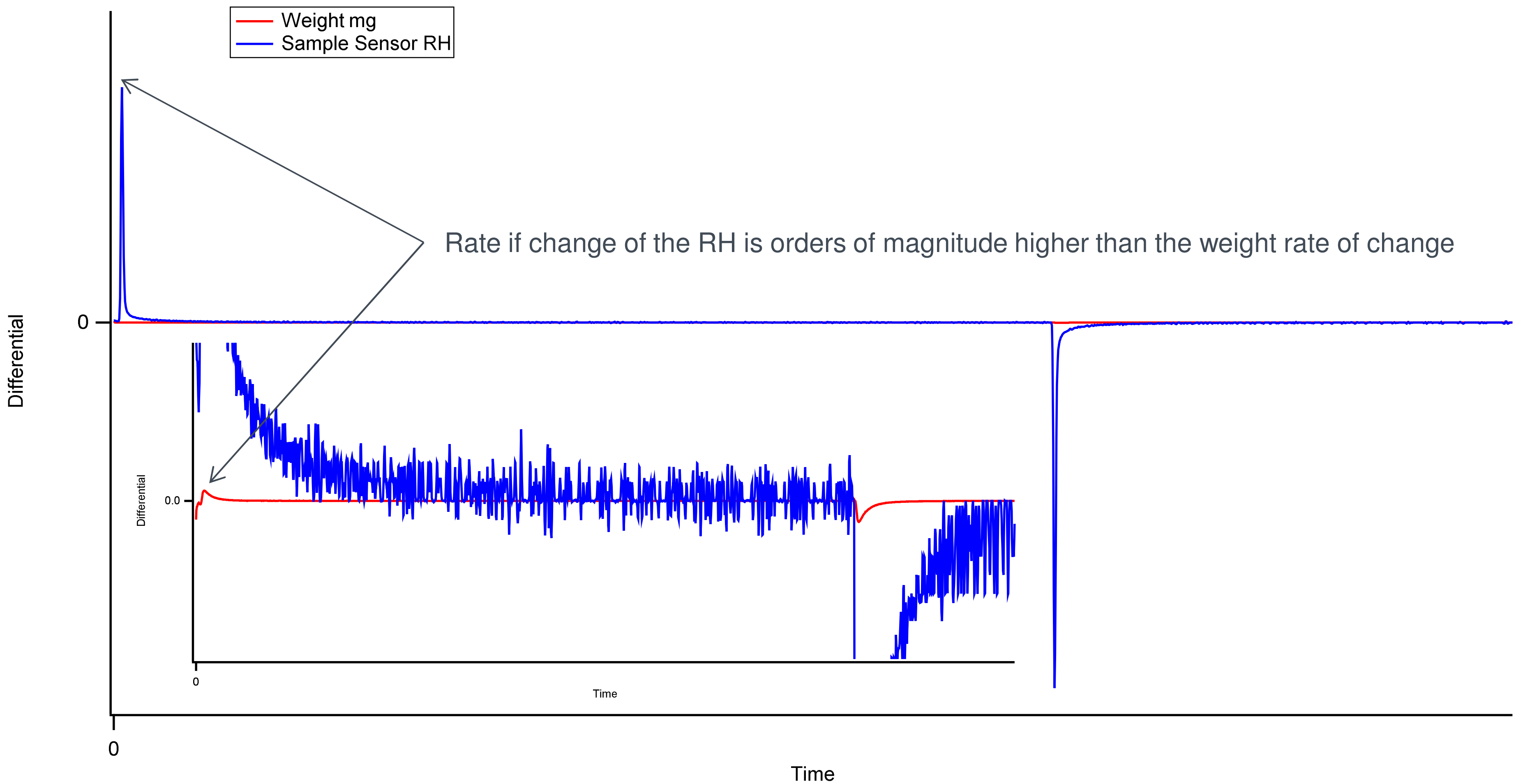
Drying investigation



Rate of change



DVs

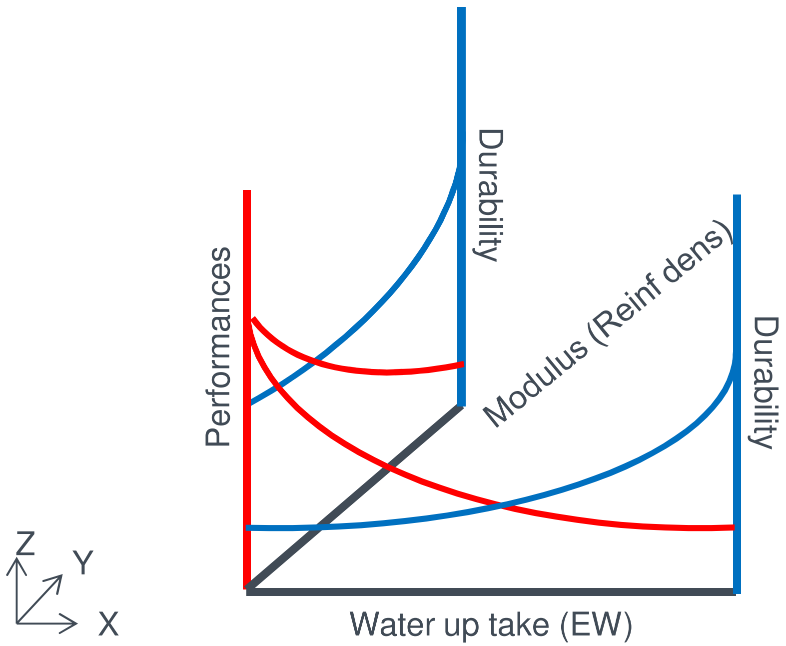
- Water uptake kinetics
- Total water uptake
- Restructuring kinetics

- Correlation between water uptake and mechanical properties
- External correlation between water uptake and performances
- Response time to change in conditions

DMA DVs Finals remarks

- Material properties and cell testing correlation
  - Initial expansion and Young's modulus with the durability
  - Water uptake with mass transport, performances

- New tools to evaluate different materials, the different components and finally how to predict trends of durability and performances



Thank you for listening

And

Q&A time