Improving Mechanical Properties of Nanocomposite Coatings: Potential uses in Bone Tissue Scaffold Applications

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Introduction

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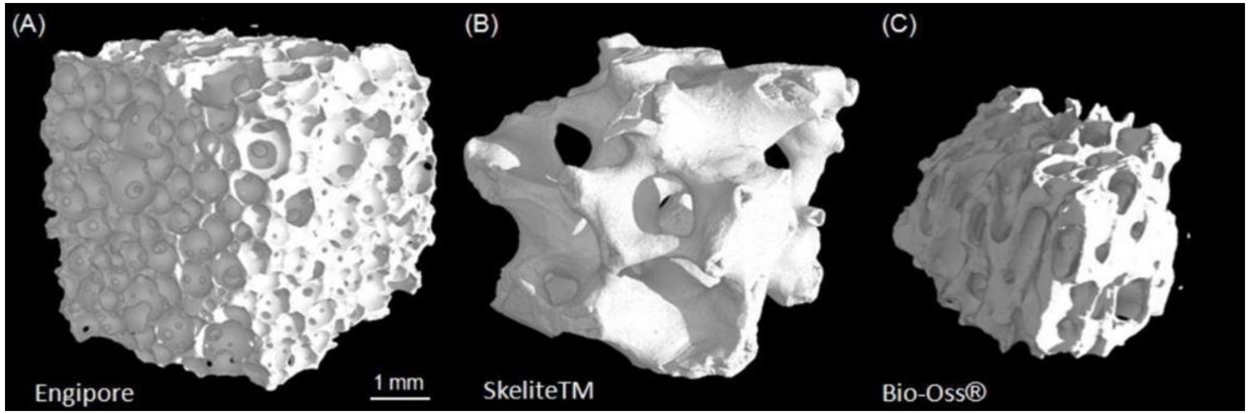
- Tissue engineering solutions are an attractive alternative to autograft treatment for bone trauma patients

- Bone tissue scaffold development has challenges:-
    - High porosity in conjunction with suitable mechanical properties



Tailor mechanical properties of bone tissue scaffolds via thin film nanocomposite coating

[Image] Alessandra Giuliani, Synchrotron Radiation and Nanotechnology for Stem Cell Research, Stem Cells in Clinic and Research, **2011**

Tunable Structure of Porous Materials

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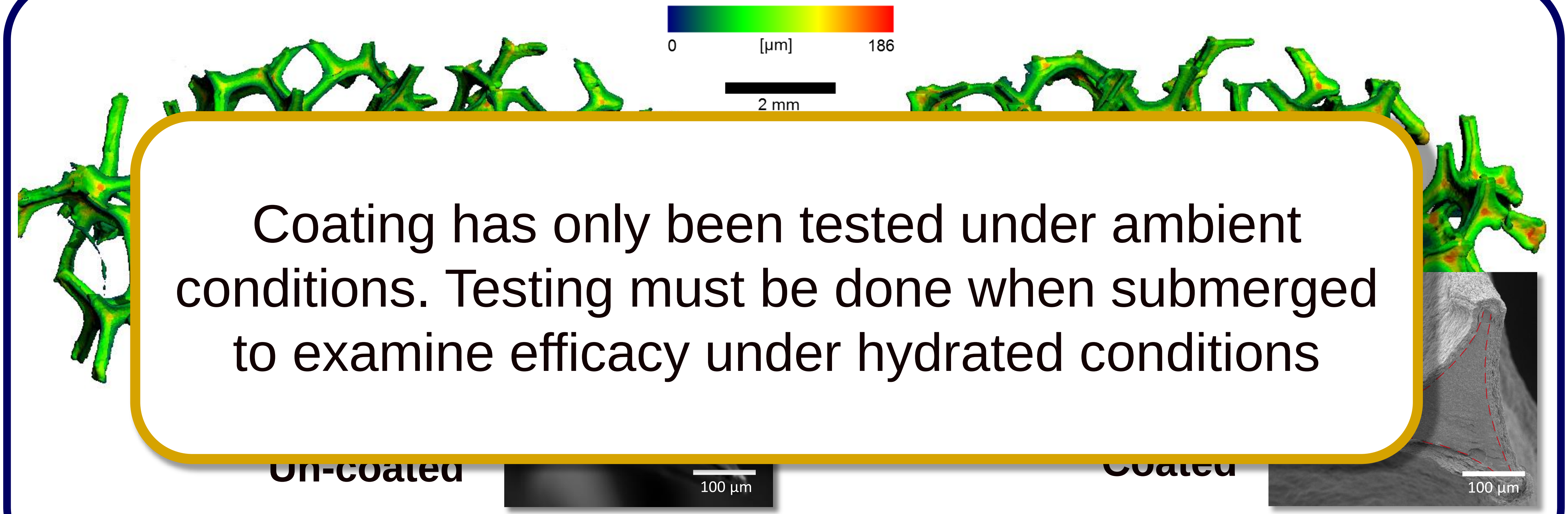


Coating has only been tested under ambient conditions. Testing must be done when submerged to examine efficacy under hydrated conditions

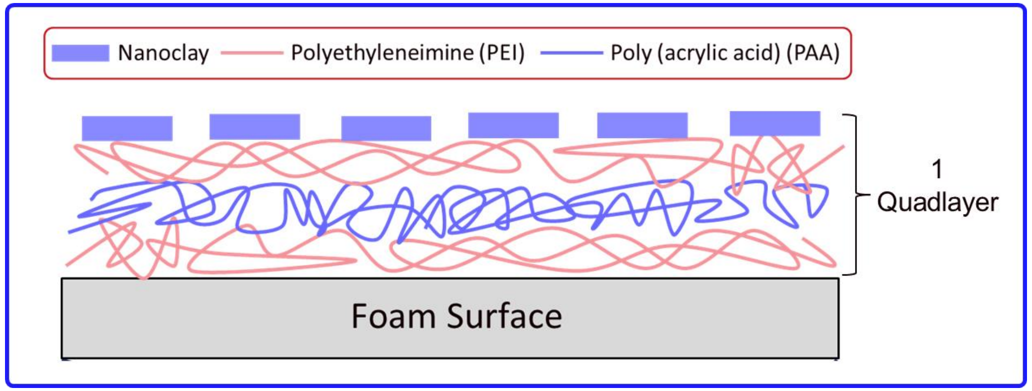
"Brick-by-brick"

Ziminska et al. ACS Appl Mater Interfaces. 2016;8(34):21968–73.

Hydrated Testing Materials and Methods

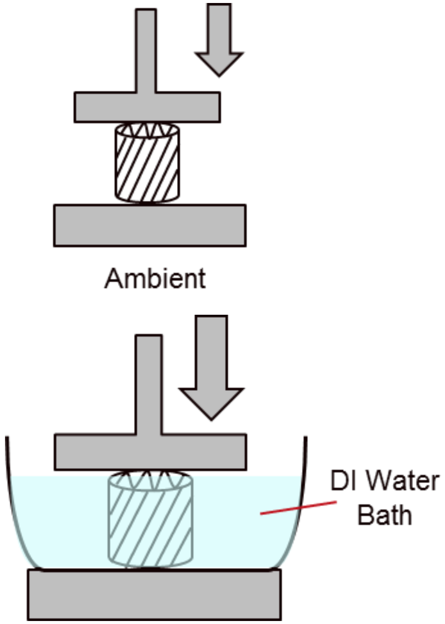
Materials

- Open cell polyurethane foam
- Coated with varying number of quadlayers of:
  - » Poly(ethyleneimine)
  - » Poly(acrylic acid)
  - » Cloisite Na^{+} nanoclay



Methods

- Tested under uniaxial compression in the elastic range at:
  - » Preload of 0.03 N
  - » Deformed to 6% of strain
  - » Crosshead speed of 2.0 mm/min
- Under ambient conditions (≈30% RH, 21 °C)
- Under DI water (100% RH, 21 °C)



Coated Foams Hydrated Testing

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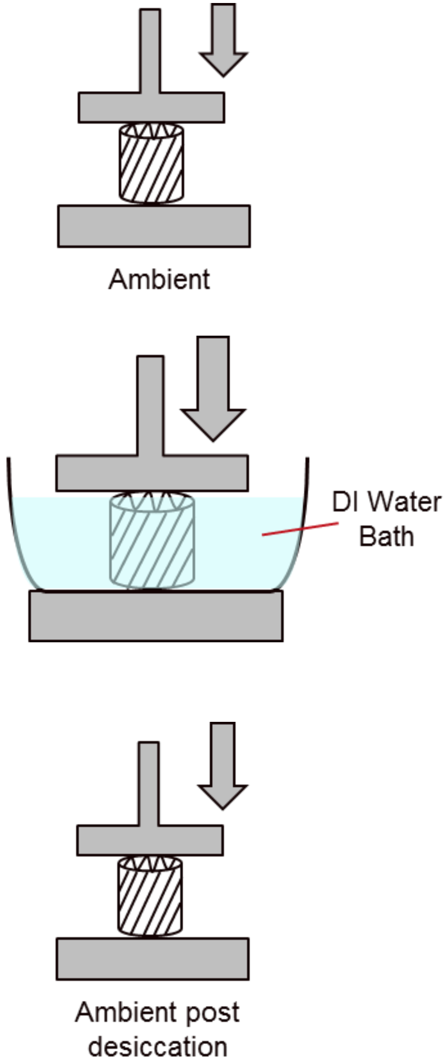
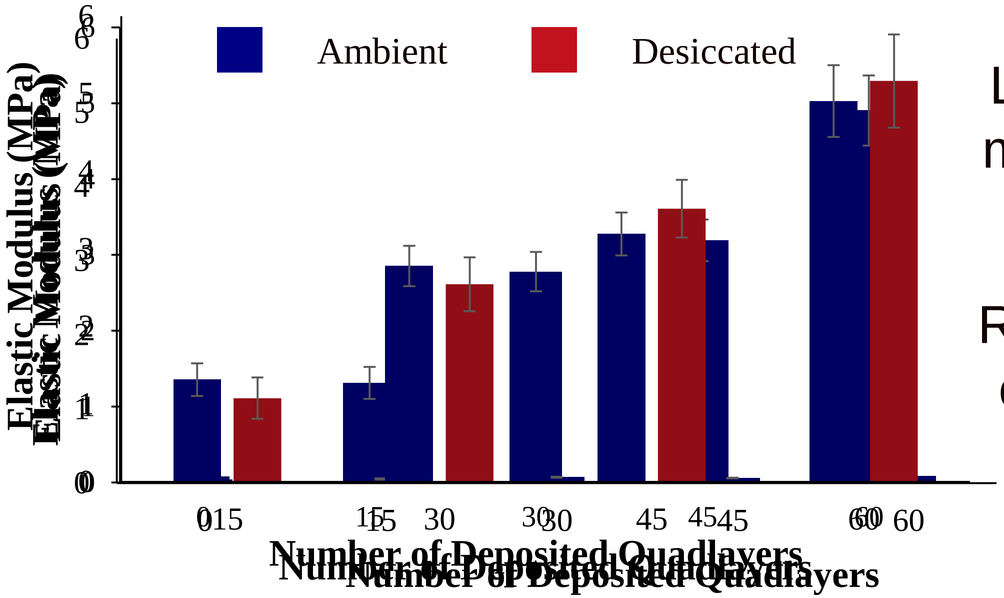


(n=5)

	Average Elastic Modulus (MPa) ± SD			
Quadlayers	Ambient	In Water	In Water 1 Hour	Desiccated
0	0.08 ± 0.00	0.05 ± 0.00	0.05 ± 0.01	0.10 ± 0.01
15	1.31 ± 0.21	0.06 ± 0.01	0.06 ± 0.01	1.08 ± 0.27
30	2.78 ± 0.26	0.08 ± 0.01	0.08 ± 0.01	2.54 ± 0.35
45	3.19 ± 0.28	0.07 ± 0.01	0.07 ± 0.00	3.52 ± 0.37
60	4.9 ± 0.46	0.10 ± 0.01	0.09 ± 0.01	5.17 ± 0.60



Loss of mechanical properties major challenge for application in biomaterials

Coating transitions from stiff material to material as flexible as polyurethane foam

Recovery from soft to stiff state could be utilised for actuation outside of biomaterials

Mechanism of Mechanical Property Loss

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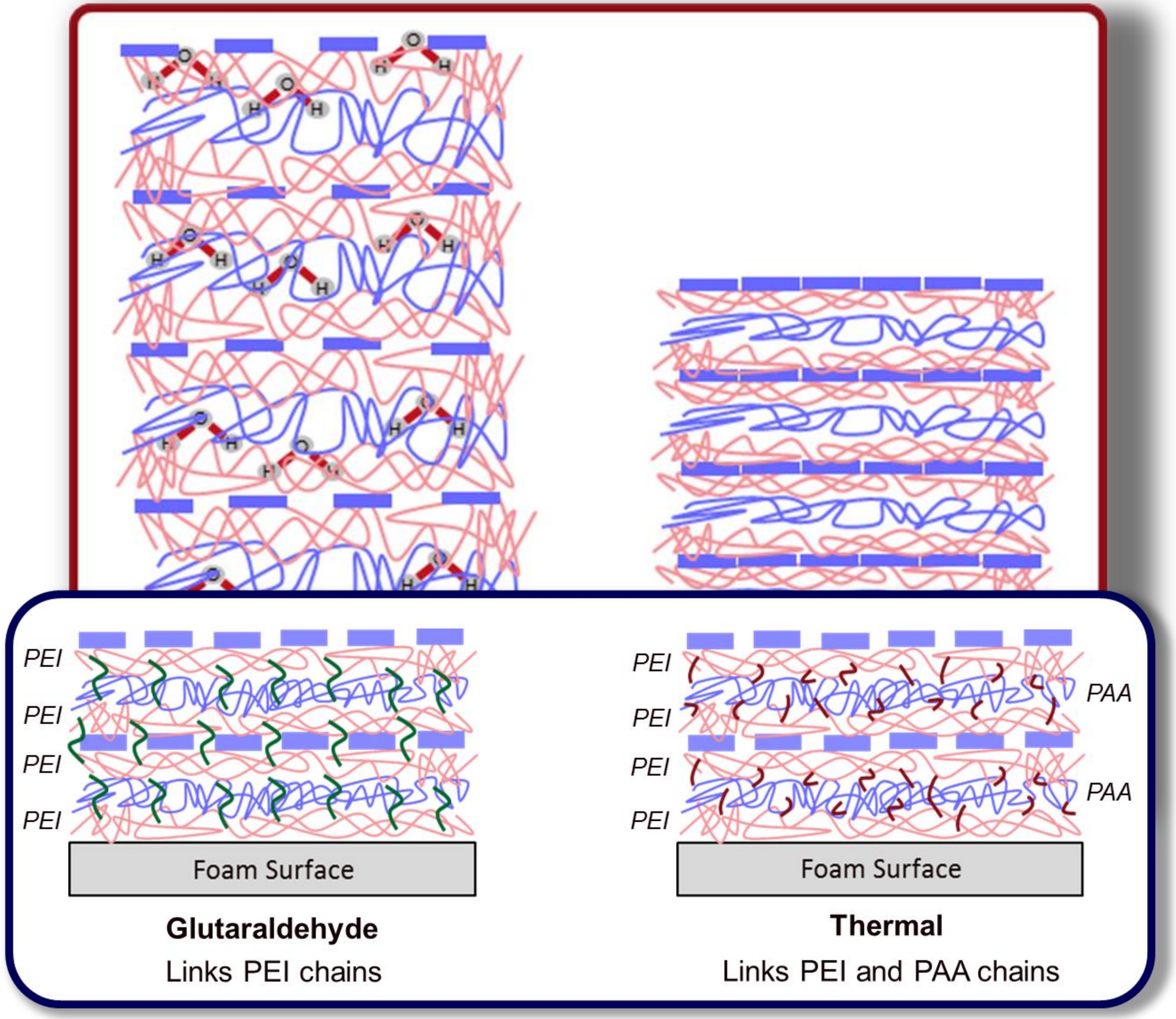
Water Distribution in Multilayers of Weak Polyelectrolytes[1]

Proposed Solution:



[1] Tanchek et al. Langmuir. 2006;22(11):5137–43.

Crosslinking of Coating Design Outline

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Two-level factorial design of experiments (DoE) to investigate crosslinking effect

Inputs:

• Glutaraldehyde molarity (M)	0.00 - 2.50	M
• Glutaraldehyde time (mins)	30 - 300	mins
• Thermal treatment temperature (°C)	0 or 120	°C
• Thermal treatment time (mins)	60 - 1500	mins
• Crosslink treatment interval	5 or 30	quadlayers

Outputs:

- Ambient elastic modulus (kPa)
- Hydrated elastic modulus (kPa)
- Coating thickness (µm)

Crosslinked Coated Foams Hydrated Testing

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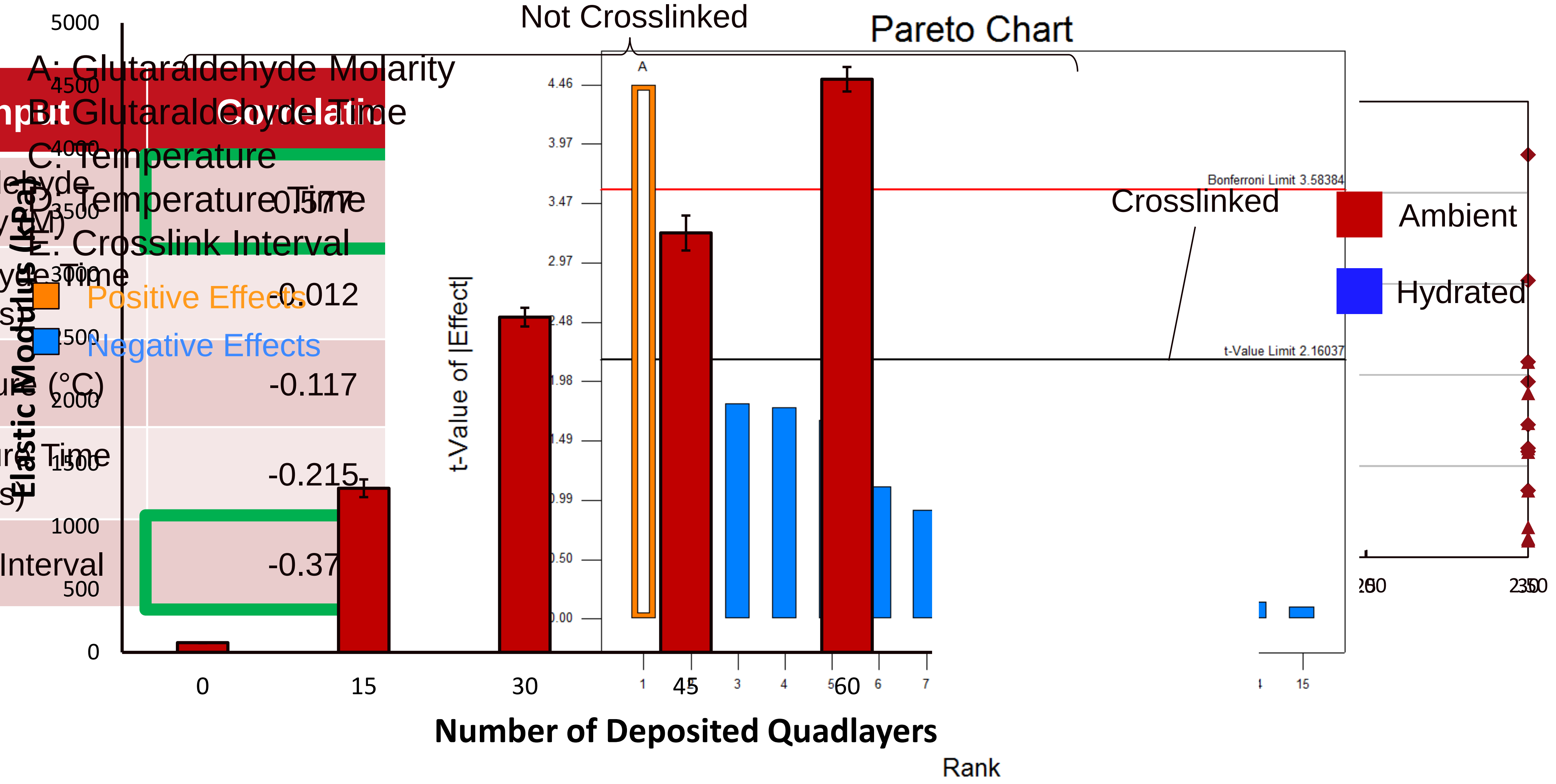
DOE Input	
Glutaraldehyde Molarity (M)	0.577
Glutaraldehyde Time (mins)	-0.012
Temperature (°C)	-0.117
Temperature Time (mins)	-0.215
Crosslink Interval	-0.37



Conclusions

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- Mechanical contribution of (PEI/PAA/PEI/Nanoclay) coating is negligible upon submersion in DI water
- Mechanical properties of coating fully recover to match elastic modulus under ambient conditions, after desiccation
- Effects of hydration on coating analogous with **water plasticisation** as described by Tanchak et al.[1]
- Chemical crosslinking of primary amine groups between PEI layers is the main factor for retention of mechanical properties when hydrated
  - Effect of thermal temperature
  - Effect of thermal time
  - Effect of glutaraldehyde time

  } Not significant

  - Effect of glutaraldehyde molarity
  - Crosslink point

  Significant
- Crosslinking improved retention of elastic modulus in water by up to 45%, further improvements expected after DoE optimisation

[1] Tanchek et al. Langmuir. 2006;22(11):5137–43.

Future Work

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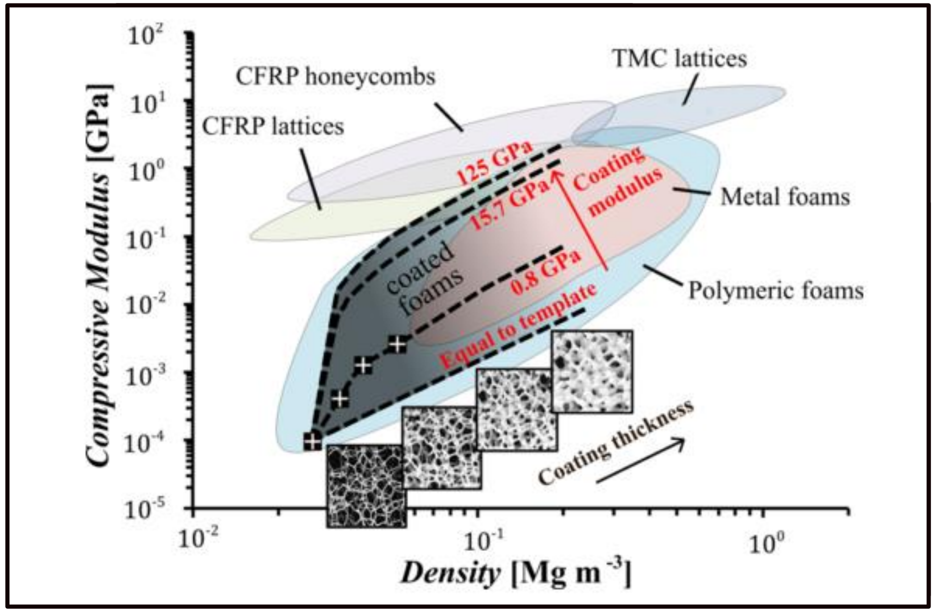
- Optimised crosslinking experiment based on DoE analysis
  - » Confirmation and validation of DoE analysis
  - » Confirmation of crosslinking activity
- Compile results alongside Ziminska et al. Ashby-Gibson model adaptation
  - » Predict potential hydrated elastic modulus



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