Effect of hydration on the mechanical behaviour of nanocomposite-coated porous bone scaffold materials

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Effect of Hydration on the Mechanical Behaviour of Nanocomposite-Coated Porous Bone Scaffold Materials

INTRODUCTION

Problem

- 2.2 Million patients undergo bone graft procedures worldwide per annum[1]
- UK cost of Autograft > £13,000 per patient[2]
- Autograft procedures cause additional trauma and complications due to extra surgery
- Allograft tissue requires de-cellularisation
- Scarcity of allograft tissue due to lack of donors

Need for synthetic bone tissue scaffolds

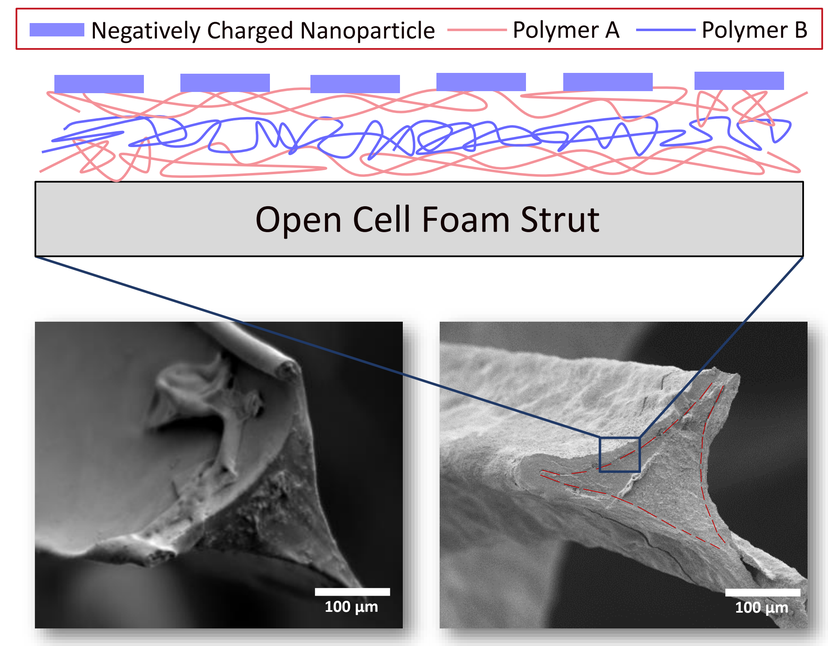
Current synthetic bone tissue scaffolds fail to meet all required biomechanical properties of host bone

↓

Nanocomposite coatings can potentially tailor biomechanical properties of scaffold materials

↓

Coatings can improve mechanical properties in ambient conditions, however they have yet to be tested under representative *in vivo* conditions



Cross-section of open cell polyurethane foam strut (a) un-coated (b) coated with 15 (PEI/PAA/PEI/Nanoclay) multilayers

1. Giannoudis et al. (2005) *Injury.* 36: S20-S27
2. Vinken et al. (2003) In: 6th EFORT Congress, Helsinki

AIM: UNDERSTAND EFFECTS OF HYDRATION ON MECHANICAL PROPERTIES OF OPEN-CELL FOAMS COATED WITH NANOCOMPOSITE THIN FILM

MATERIALS AND METHODS

- Cylindrical (12.7 x 10 mm) open cell polyurethane foam samples (45 pores per inch), were treated with 1M NaOH solution
- Foams were subjected to alternating solutions of oppositely charged species, Fig. 1, a process known as layer by layer assembly
- After deposition of 5 multilayers, samples were placed in a desiccator to dry overnight. This process was repeated until the desired thickness of coating was achieved
- Nanocomposite coated foams were mechanically tested as shown in Fig. 2

Mechanical testing under compressive loading was conducted on a Lloyd LRX frame, using a 50 N load cell, with a crosshead speed of 2 mm/min, a preload of 0.03 N and a total deflection of 0.6 mm.

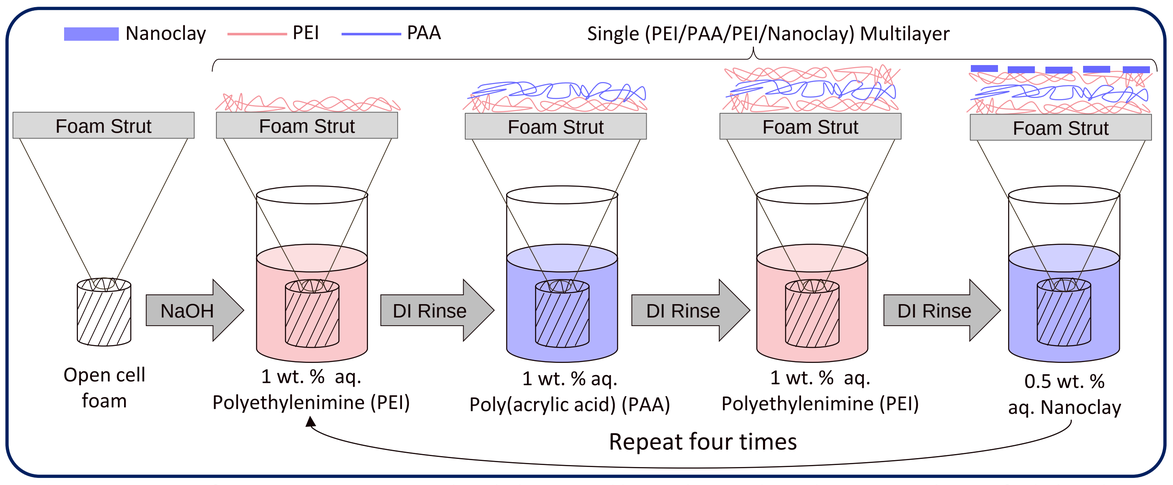


Figure 1. Deposition of a nanocomposite coating via layer by layer assembly. Samples are subjected to aqueous solutions of polyelectrolytes and a charged nanoclay for the deposition of a single multilayer and repeated until a 5 multilayer coating has been deposited.

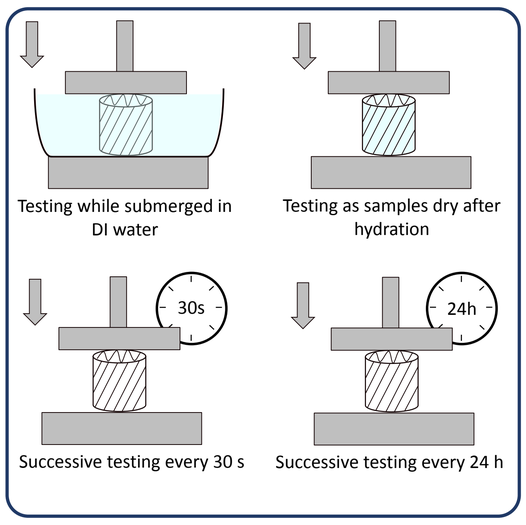
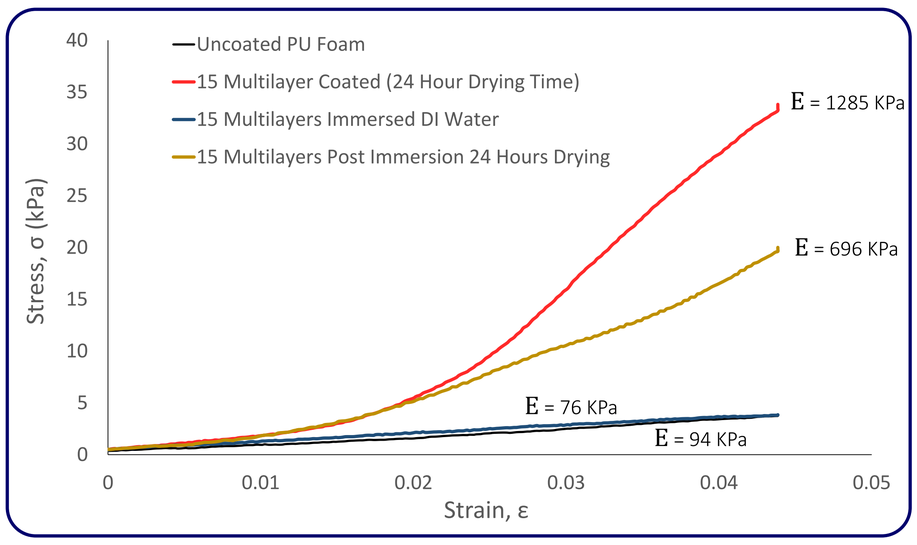
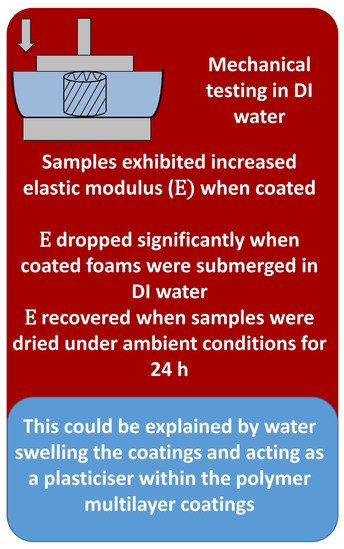


Figure 2. Compressive mechanical conditions of nanocomposite coated open cell foams.

RESULTS AND DISCUSSION



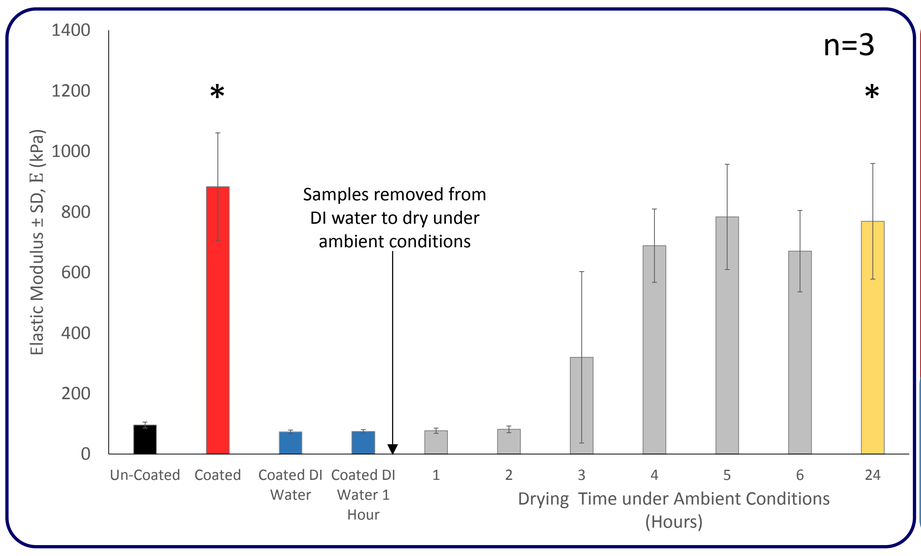


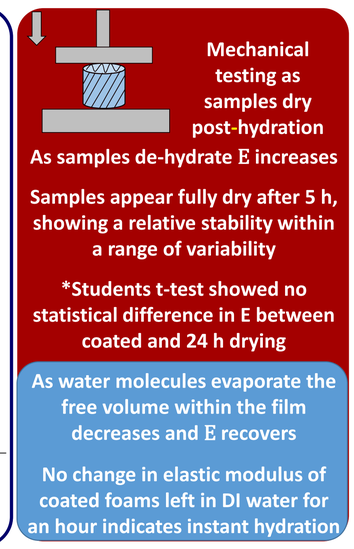
Mechanical testing in DI water

Samples exhibited increased elastic modulus (E) when coated

E dropped significantly when coated foams were submerged in DI water
E recovered when samples were dried under ambient conditions for 24 h

This could be explained by water swelling the coatings and acting as a plasticiser within the polymer multilayer coatings





Mechanical testing as samples dry post-hydration

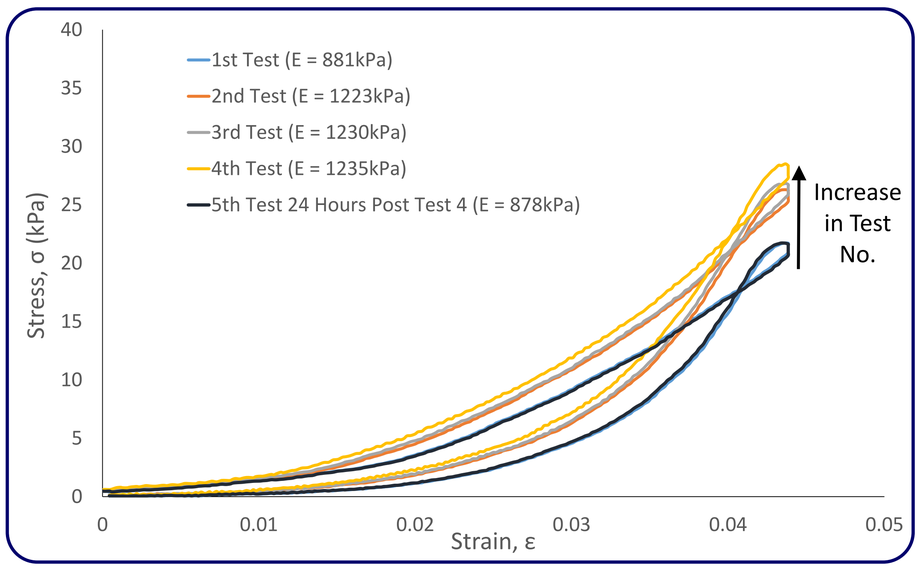
As samples de-hydrate E increases

Samples appear fully dry after 5 h, showing a relative stability within a range of variability

***Students t-test showed no statistical difference in E between coated and 24 h drying**

As water molecules evaporate the free volume within the film decreases and E recovers

No change in elastic modulus of coated foams left in DI water for an hour indicates instant hydration



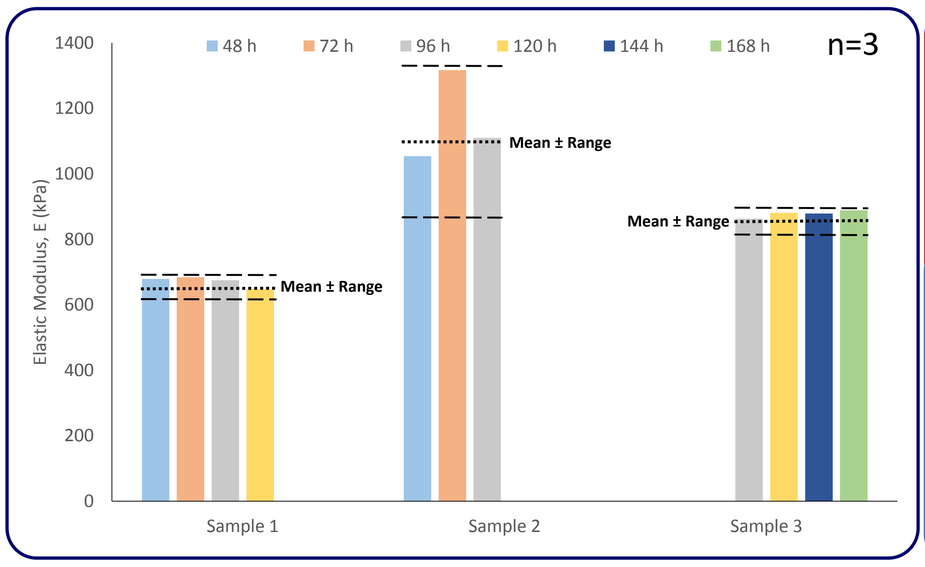
Successive mechanical testing every 30 s

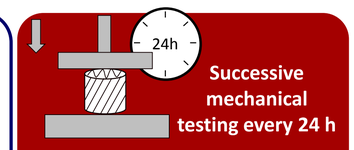
Upon repeated mechanical testing samples exhibited an increase in E

After 24 h the sample relaxed and the E returned to the initial value before testing

Increase in mechanical properties upon cyclic loading is characteristic of a viscoelastic effect

Effect of increased E is reversible therefore, permanent changes to material structure is not likely





Successive mechanical testing every 24 h

Variation within 5.5% of mean, except sample 2 at 72 h

Repeated mechanical testing over extended period of time does not statistically influence the elastic modulus

Range of variation in samples could be due to sample variation

Significant increase at 72 h could be due to temperature and relative humidity within the lab

FUTURE WORK

Future work will focus on the implementation of methods to reduce the effect of hydration upon nanocomposite coatings to achieve tailored biomechanical properties under representative *in vivo* conditions. One such mitigation technique, as illustrated in Fig. 3, would be the deposition of layers to prevent diffusion of water molecules in the coating.

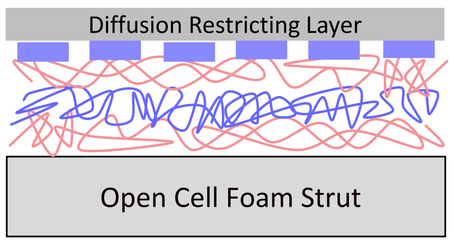


Figure 3. Implementation of diffusion restrictive "capping layer"

CONCLUSIONS

- Mechanical properties of coated foams decreased in DI water due to plasticising effect
- Coated foams appear to be hydrated almost immediately upon submersion
- Mechanical properties recover as coated foams dry
- Coated foams show a notable viscoelastic effect when tested in immediate succession
- After 48 hours drying, coated foams show little variation (typically within ± 5.5% of the mean) indicating effects of successive loading is reversible

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