Synthesis and additive manufacture of piezoelectric ceramic scaffolds for tissue and neural regeneration

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Project Background

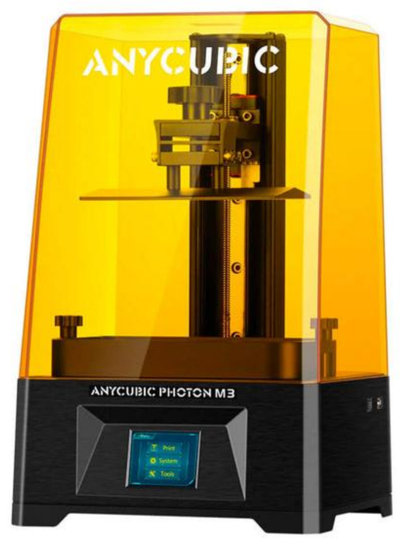
Spinal cord injuries cause irreversible tissue and neural damage, leading to long-term disabilities. While electrical stimulation has emerged as a promising tool for promoting neural regeneration, its clinical application is hindered by wired implant scaffolds and external power sources. Piezoelectric materials offer an alternative wireless solution – however, thus far, most are Pb based and not suitable for bio application.

This project demonstrates the feasibility of additively manufacturing complex shaped piezoelectric porous structures, specifically potassium-sodium-niobates (KNN), by using Digital Light Processing (DLP), suitable for bioimplant application. This poster highlights the outcomes of comprehensive synthesis and characterisation of the produced feedstock material for DLP.

Valeo C+CSC cervical interbody fusion device [1] (Arts, Wolfs and Corbin, 2013)

Research (Results + Discussion)

The first step for the project was to synthesise KNN near the morphotropic phase boundary (MPB) by conventional solid state ceramic processing. $K_{0.5}N_{0.5}NbO_3$ was selected as a lead-free piezoelectric material due to its very good piezoelectric properties, high Curie temperature, biocompatibility and existence of MPB.



DLP 3D printer

Following the synthesis of KNN, high-density sintered pellets were produced at temperatures ranging from 1100°C to 1150°C for the characterization of material composition, morphology, and piezoelectric properties **(Figures 1 – 4)**.

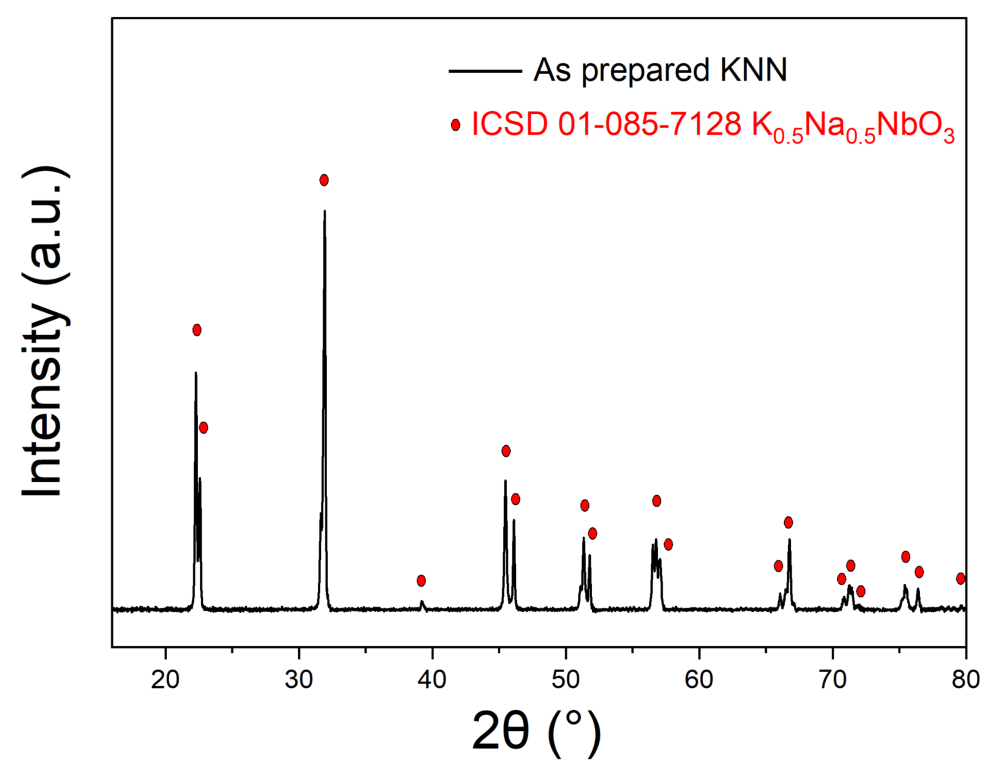


Figure 1: XRD pattern of KNN synthesise post calcination

XRD of powder confirms the synthesis of single phase $K_{0.5}N_{0.5}NbO_3$. The obtained XRD is compared to a reference pattern from ICSD.

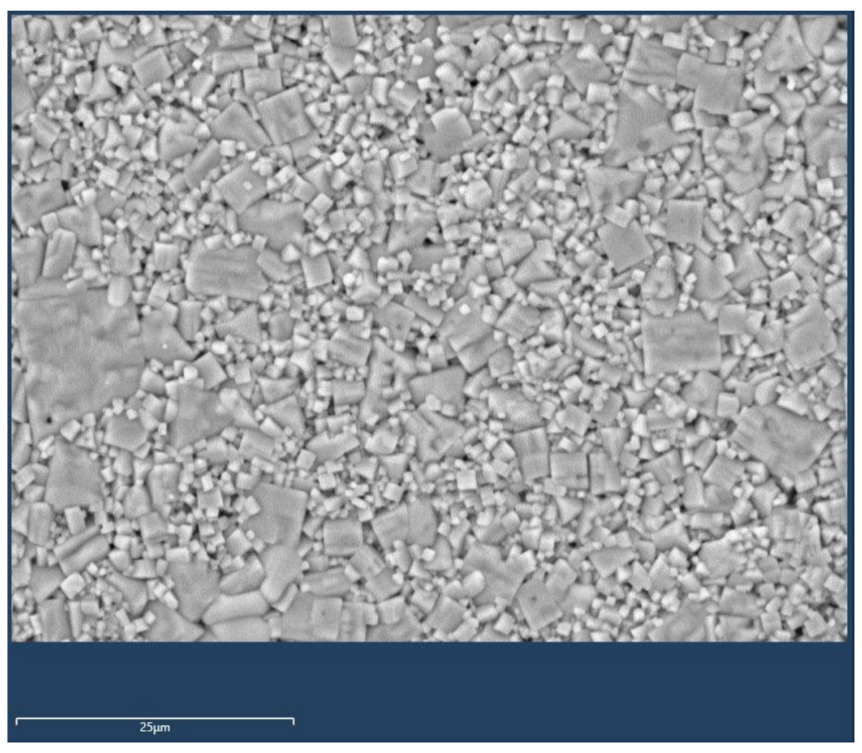


Figure 2: SEM of pellet sintered at 1100°C

SEM image of unpolished pellet shows the high density 4.30 g/cm^3, limited porosity and grain size of the pellet.

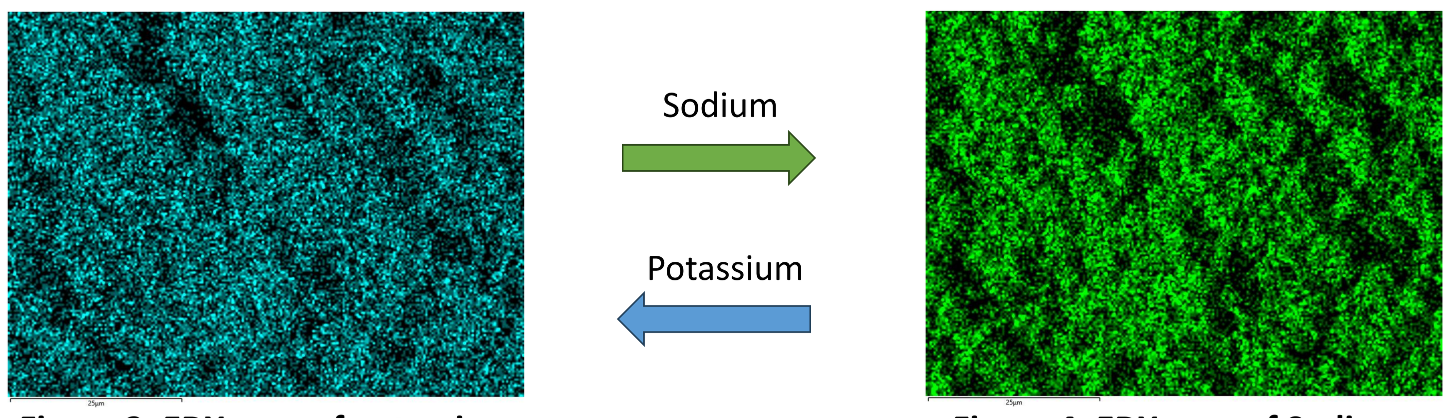


Figure 3: EDX map of potassium

Figure 4: EDX map of Sodium

EDX images (**Figures 3 – 4**) of pellet surface shows homogenous mixing of the potassium and sodium constituents

Research (continued…)

The hysteresis loop obtained (**Figure 4**) displays the polarization behavior, indicating the presence of a strong ferroelectric phase. The ceramic's remnant polarization and coercive field can be inferred from the graph at the x and y intercepts.

	d_{33}	P_r (μC/cm^2)	E_c (kV/cm)
KNN	63.2	17.54	9.1
Literature	80 [2]	11.4 [3]	8.5 [3]

Table 1: Key piezoelectric values of synthesised KNN compared to literature

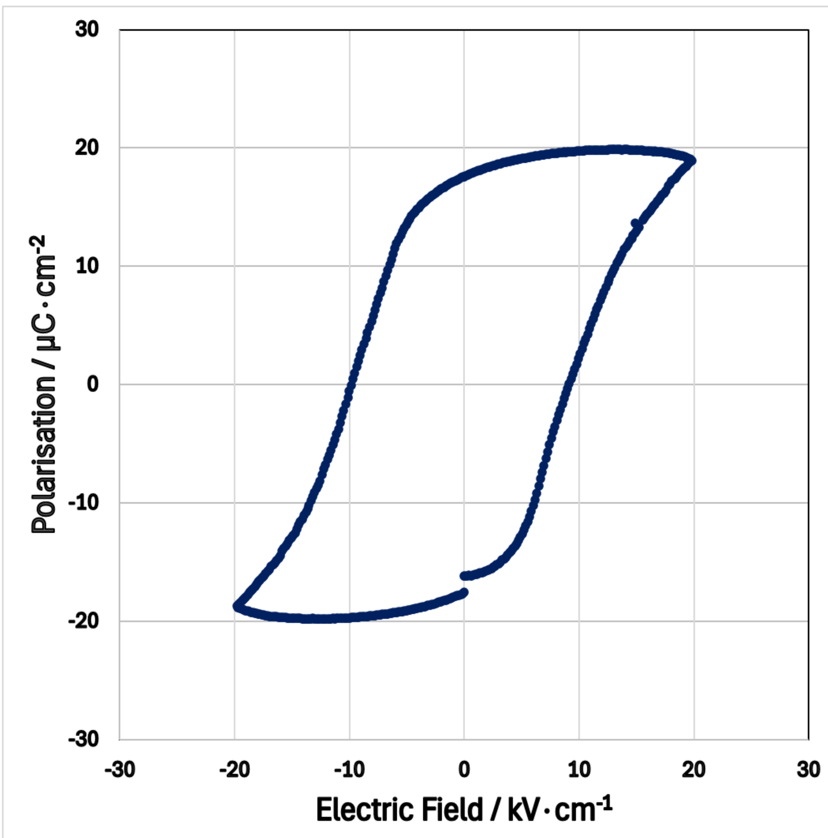


Figure 4: P-E hysteresis loop

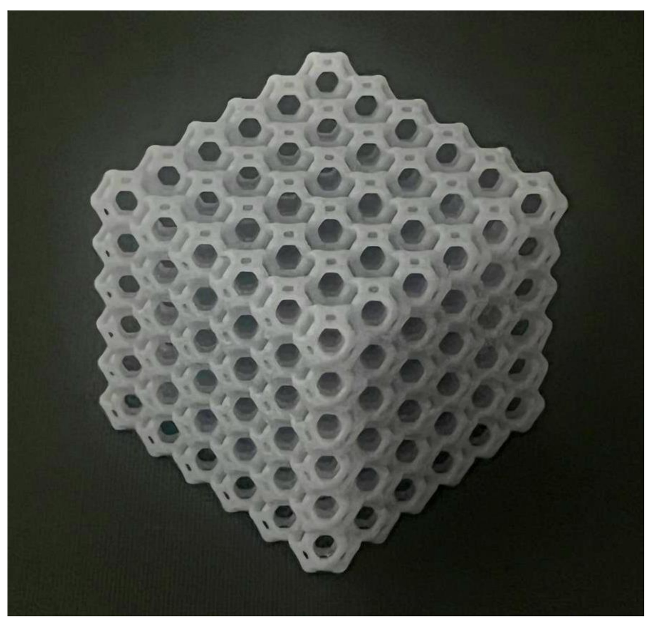


Figure 5: Kelvin TPMS structure

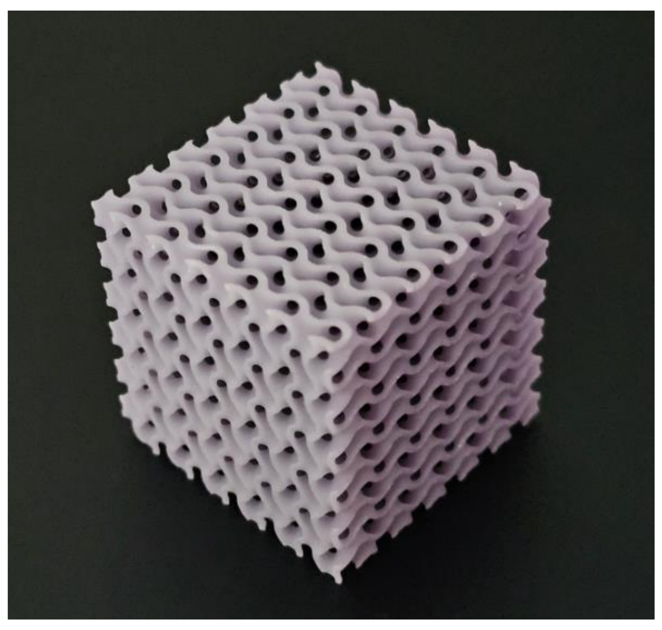


Figure 6: Gyroid TPMS structure

Example TPMS structures, as seen in **Figures 5 – 6**, have been manufactured using commercial resin. These structures will be used for the manufacture of KNN porous scaffolds. The ceramic 3D printing will continue in the final quarter of the project.

Constituents	Material
Photocurable resin	1,6-hexanediol diacrylate and 1,1,1-trimethylopropane triacrylate
Dispersant	DISPERSEBYK-111
Photoinitiator	Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide
Ceramic Powder	KNN (~40-45 Vol%)

Table 2: material constituents for 3D resin printing

Conclusion

Solid solution KNN was successfully manufactured with sintered parts achieving 95% theoretical density and high ferroelectric properties (d_{33} = 63.2; **Table 1**). Ceramic printing is underway as suitable ink constituents (dispersant, binder system, photo initiator, oligomers) for 3 printing KNN have been identified **(Table 2)**.

References

[1] Arts, M.P., Wolfs, J.F. and Corbin, T.P. (2013). The CASCADE trial: effectiveness of ceramic versus PEEK cages for anterior cervical discectomy with interbody fusion; protocol of a blinded randomized controlled trial. *BMC Musculoskeletal Disorders*, 14(1). doi:https://doi.org/10.1186/1471-2474-14-244.
[2] Zhengfa *et al.* (2011) *Grain growth and piezoelectric property of KNN-based lead-free ceramics*, *Current Applied Physics*. Available at: https://www.sciencedirect.com/science/article/pii/S1567173911002252
[3] Vendrell, X., García, J.E., Bril, X., Ochoa, D.A., Mestres, L. and Dezanneau, G. (2015). Improving the functional properties of (K0.5Na0.5)NbO3 piezoceramics by acceptor doping. *Journal of the European Ceramic Society*, [online] 35(1), pp.125–130. doi:https://doi.org/10.1016/j.jeurceramsoc.2014.08.033.