Encapsulation of Novec7000 in Thin Alginate Capsules for On-Demand Activation in Pneumatic Phase-Change Soft Robotic Systems

Rayan A. M. Basodan[1,2], Jack Keddie[1], Byoungyoul Park[2], and Hyun-Joong Chung[1]
[1] Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Canada.
[2] Quantum and Nanotechnologies Research Centre, National Research Council of Canada, Edmonton, Canada.
Email: Chung3@ualberta.ca

INTRODUCTION

This work demonstrates a simple and accessible method for encapsulating the volatile liquid Novec 7000 within thin-walled alginate capsules for use in pneumatic phase-change soft actuators. Traditional pneumatic soft robots often rely on external pressure sources, limiting mobility. Pneumatic phase-change soft actuators utilise volatile liquids for untethered operation, but they can be sensitive to environmental temperatures and face challenges in containing volatile liquids during fabrication.

To address this, a novel technique was developed to encapsulate Novec7000, an inert fluid with a boiling point of 34 °C, inside small 3–4 mm alginate capsules with wall thicknesses ranging from 5–10 μm for long term containment and on demand release of the volatile liquid.

MATERIALS AND METHODS

Capsules are formed by injecting Novec7000 into partially gelled sodium alginate droplets undergoing ionic crosslinking in a calcium chloride bath. As the alginate crosslinks from the surface inwards the Novec7000 is spontaneously encapsulated for long term containment. Subsequent drying of the alginate shrinks the hydrogel into a thin shell which can be activated on demand to release the volatile liquid. This encapsulation method requires minimal equipment and expertise, making it widely accessible.

RESULTS AND DISCUSSION

These capsules of Novec7000 contained in dry thin alginate shells can be triggered either mechanically or thermally. On-demand activation and release of Novec7000 allows for precise control over when actuation in pneumatic phase-change soft actuators occurs. Mechanical compression activation tests showed that rupture occurs at forces ranging around 2 to 6 N, with lower forces required at faster compression rates due to the viscoelastic behaviour of the liquid-filled capsules. Thermal activation experiments revealed that the activation time decreased significantly with increasing temperature, but it eventually occurs at any temperature above the volatile liquid's boiling point of 34 °C.

(Fig 1) Shows illustrations and pictures of the Novec7000 within thin-walled alginate capsules' preparation process and activation mechanisms.

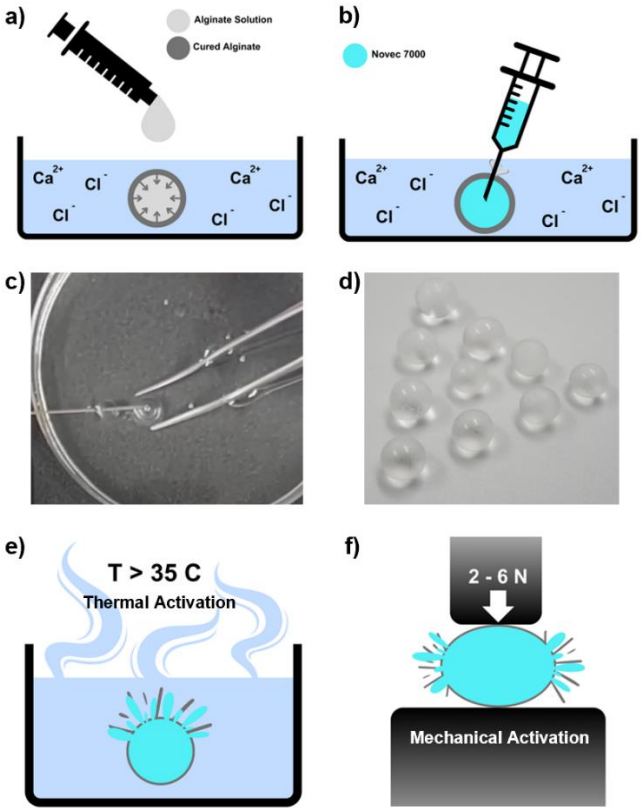

Fig 1 : Schematic illustration of the Novec7000 in alginate capsules preparation and activation. (a) Preparation method of the capsules where sodium alginate droplets are immersed in a $CaCl_2$ salt bath and a crosslinked alginate shell as allowed to form. (b) Continued preparation of the capsules where Novec7000 is injected into the alginate hydrogel shell. (c) Picture of Novec7000 being injected into a crosslinking alginate shell. (d) Picture of prepared capsules of Novec7000 within dry thin alginate shells. (e) Thermal activation of the capsules. (f) Mechanical activation of the capsules.

CONCLUSIONS

This study presents a straightforward and accessible approach to encapsulating Novec7000 within thin alginate capsules, enabling long-term containment and on-demand release of volatile liquids for pneumatic phase-change soft actuators. The capsules' dual activation modes—mechanical and thermal—offer flexible and precise control over actuation timing. Mechanical tests demonstrated reliable activation at low forces, while thermal activation showed responsiveness above the liquid's boiling point, with faster activation at higher temperatures. This encapsulation strategy overcomes key challenges in untethered pneumatic soft robotics by protecting volatile liquids during fabrication and operation.