Hit the Ground Running – Wearable Sensors to Measure Foot Plantar Pressure

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Abstract

Wearable, flexible pressure sensors can identify movement patterns of the wearer and consequently predict potential injuries. In addition, foot posture and landing position are essential parameters to observe during walking and running sports activities[1,2]. This project focuses on designing and producing straightforward capacitive pressure sensors that can be fabricated and integrated into a smart insole[3]. The capacitive sensors are made from a layered structure containing fabric electrodes with a flexible dielectric layer in the centre. The suitability of the sensors for detecting foot plantar pressure has been assessed by testing the sensors using a mechanical test rig and measuring the sensor response. Furthermore, the effect of introducing micropores into the dielectric layer using two fabrication methods and the change of response corresponding to the electrodes was analyzed. The result obtained imply that the use of micropores has the potential to increase the sensitivity and response time of the sensors.

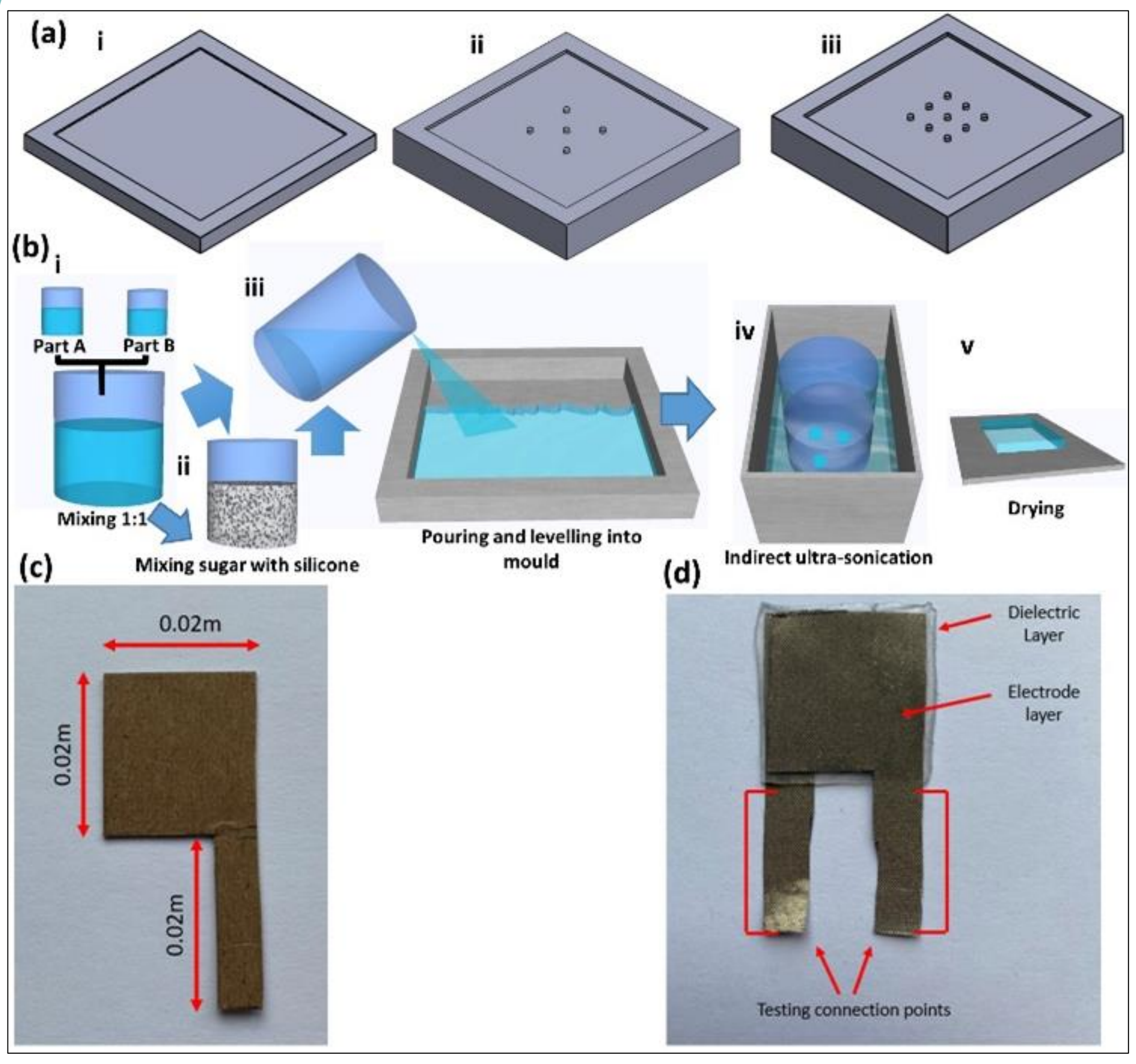

Fig. 1. Fabrication process and surface examination of sensors, (a) Moulds prepared for dielectric layer fabrication showing (i)without vertical piles, (ii) with 6 vertical piles and (iii) with 9 vertical piles (b) dielectric layer fabrication showing (i) mixing Ecoflex part A and Part B 1:1, (ii) Mixing with sugar granules, (iii) pouring into the prepared mould, (iv) indirect ultra-sonication and (v) final dielectric layer, (c) Electrode dimensions,template for fabrication (d) Fabricated capacitive pressure sensor with conductive fabric electrode layers and middle dielectric elastomer layer

- **Electrode materials:** A woven conductive fabric (70% polyester, 16% copper and 14% nickel) & knitted conductive fabric (83% nylon and 17% silver)
- **Dielectric material:** Ecoflex 00-30 elastomer Part A and B (1:1 ratio).
- **Insulating layers:** Developed sensors were kept inside Chitosan based insulating layer and sealed well to prevent from atmospheric interference. (Figure 1, Table 1)

- **Sensor fabrication**

Three aluminium moulds were created to fabricate the dielectric layer of the sensors(0.041 m × 0.041 m × 800 µm). One mould was created with uniform depth of 800 µm without any microstructures present. Two moulds were created with vertical columns to include pores in the dielectric layer (Fig. 1a).

Porosity using Microcrystals - A second approach was investigated to introduce porosity within the dielectric, using microcrystals (sugar) that could be dissolved after curing. 20 g of Ecoflex 00-30 solution was mixed with 5 g of caster sugar. Once the solution was homogenous, it was poured into the mould with no holes and kept in 70 ^{0}C oven for 2 hours

TABLE I. Fabricated sample categorization (W- Woven, K- knitted).

	Type 1		Type 2		Type 3		Type 4	
Dielectric Layer	Non-structured dielectric layer		5 micropores		9 micropores		Micropores generated from caster sugar	
Electrode layer	W	K	W	K	W	K	W	K
Sensor code	1.1	1.2	2.1	2.2	3.1	3.2	4.1	4.2

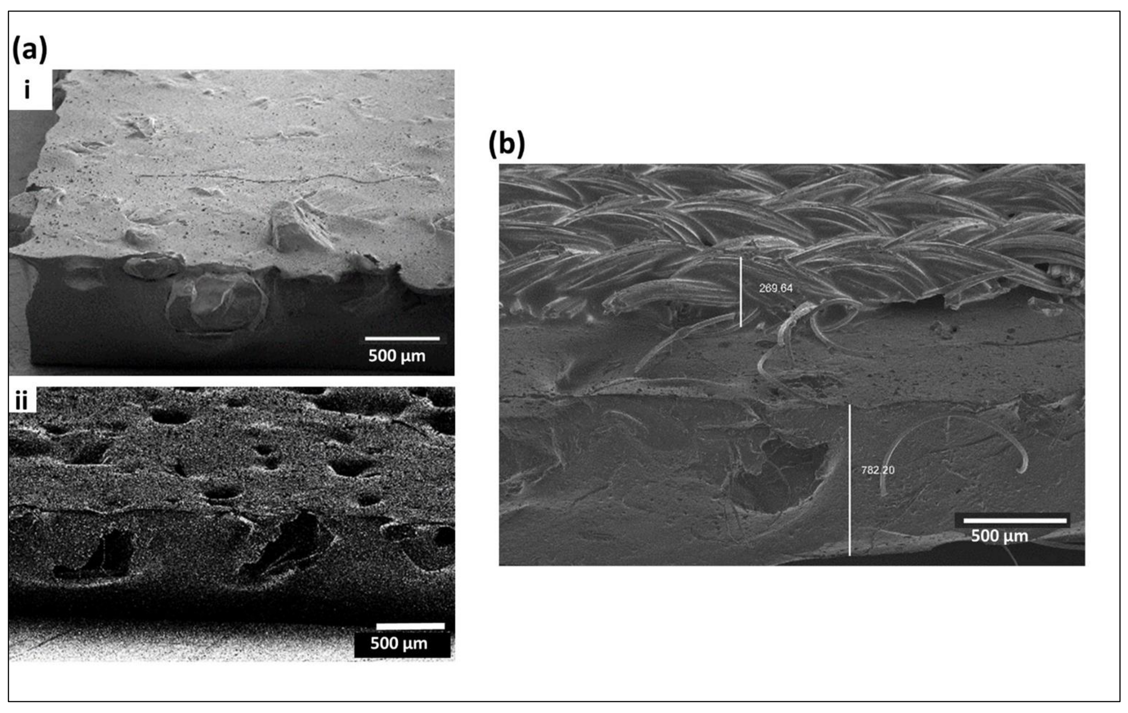

Fig. 2: (a) SEM images of sugar granular mixed dielectric sample (i) before and (ii) after washing, (b) SEM of fabricated sensor

From the SEM image the thickness of the dielectric layer was measured as 780.729 µm. The measurements of the pocket created from the sugar granules displayed on the side of the dielectric layer was 521.265 x 255.178 µm

Keysight U1701B handheld capacitance meter and the Univert CellScale Machine were used to test the fabricated capacitive pressure sensors (Figure 3). Using the CellScale machine, stretch magnitude was changed between 2 %, 3 % and 4 % displacement (Figure 4).

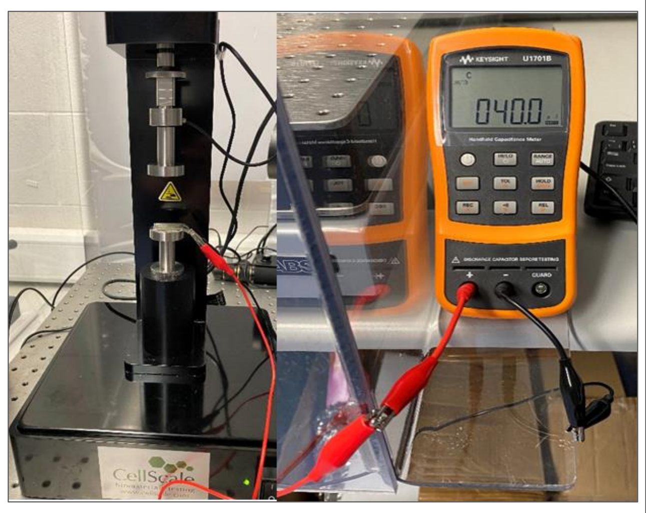

Fig. 3. Mechanical rig for measuring sensor performance. Cell Scale machine (left), Keysight handheld capacitance meter (right)

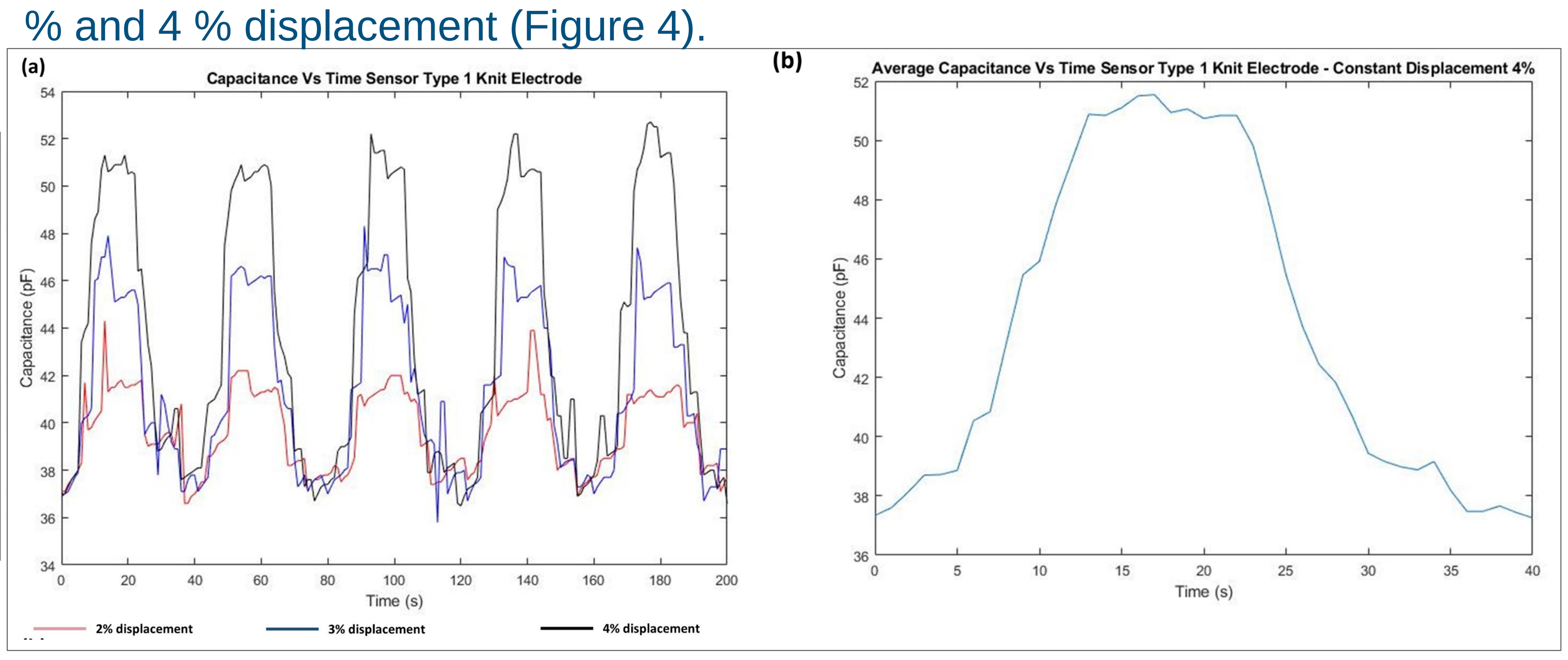

Fig. 4. Capacity performance of sensor type 1.1 as an example (a) time vs capacity for 2 %, 3 % and 4 % for 5 cylces and (b) 4 % 1 cycle

Sensors made with vertical pore structures and woven conductive layers have provided a linear relationship over capacity and displacement.

Experimental results (Figure 5) indicate that woven electrodes have low linear values and the knit electrode has a high standard deviation for all three constant displacements. Sensors made with the sugar granule microporous technique show moderate sensitivity with high linearity, which gives promising results for further investigations.

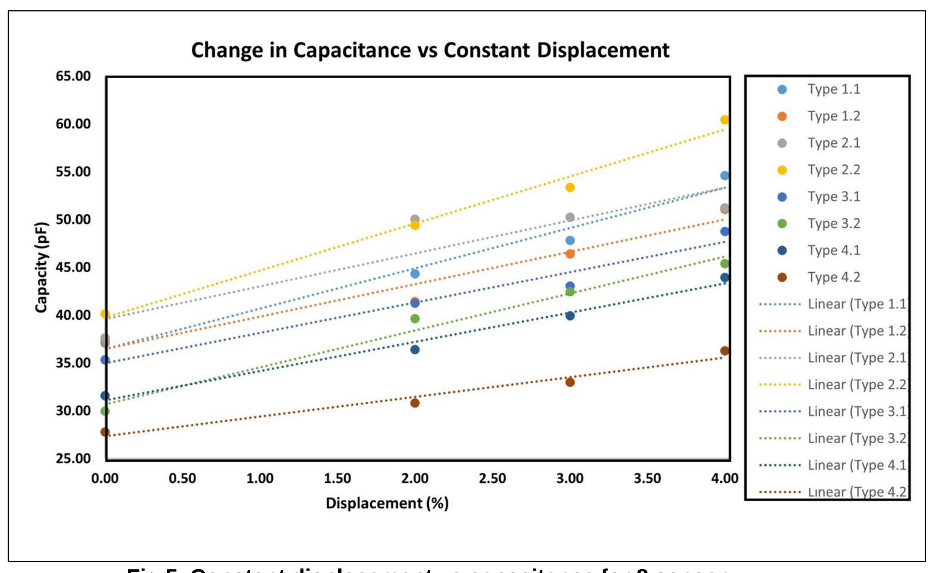

Fig 5. Constant displacement vs capacitance for 8 sensor

Based on the limitations of the measurement techniques observed in this study, a more sensitive LCR meter and high frequency, high force linear actuation system would be needed to allow an accurate comparison between the different approaches for fabricated capacitive pressure sensors

Conclusion

This work presents the development of a capacitance based flexible pressure sensor using textile-based materials. Two methods of adapting the properties of the dielectric layer were tested by increasing the porosity of this layer. Porosity of the layer was confirmed using SEM imaging. The results obtained imply that sensitivity and response time can be improved by implementing microporous structures to the dielectric layer. Further modifications are needed to investigate different levels of porosity, and a test-bed is required, to measure the sensor response during simulated human movements for further validation.

References

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Funders

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