3D printing with silicone elastomer for biomedical applications

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Statement of purpose: Silicone is an attractive elastomeric material which has been widely used for biomedical applications, i.e., medical devices[1]. In a traditional industrial manufacturing process, silicone products are often fabricated using a specialized injection moulding technique. However, injection moulding with a very complex design is not ideal solution for small-volume production due to the high upfront cost of molds. 3D printing technology can be an attractive alternative for low volume direct fabrication of silicone products, especially customized in patient-specific medical devices, in order to negate the need for expensive moulds and quickly fabricate complex 3D geometries[2].

The fabrication of silicone-based soft and elastic parts by 3D printing is challenging. Due to the high viscosity and long curing times, it is difficult to 3D print parts with sub-millimetre dimensions; Besides, the resultant 3D-printed PDMS-based elastomeric object may not have sufficient mechanical properties for functional use. How to 3D print the parts with great resolution and tunable mechanical properties remains a major challenge to be solved. In this study, we developed a family of novel photocurable PDMS-based resins for DLP or SLA printing. The printed parts have tunable mechanical properties and fast photo-curing rate. Moreover, this approach allowed for 3D printing of PDMS-based objects with complex microarchitecture, high resolution, excellent surface finishing and low cytotoxicity.

Methods: UV LED DLP Stereolithography: An Asiga Freeform PRO2™ printer was used to produce stereolithography prints. The printer was fitted with high-power UV 385 nm LED; Mechanical property test: The mechanical tensile-stress tests and cyclic tensile test were performed using INSTRON-5566 with a 100 N load cell based on ASTM D638 standard using type V specimen samples. Cyclic compression tests were performed on INSTRON-5566 with a 5 kN load cell using 3D printed cylindrical samples 13 mm in diameter and 6.3 mm high.

Results: In this study we introduced hydrogen bonding into the silicone polymer, which greatly increased the interaction forces between polymer chains, thus improved the printability, mechanical properties and its miscibility with conductive polymer polyaniline (PANI). We further studied the formulation of the silicone resin, ensuring that the resin could still be flowable and maintain viscosity as low as possible for SLA and DLP printing.

Our resin has faster UV crosslinking rate compared with plain PDMS without hydrogen bonding groups. Meanwhile, the resin can also be cured under blue light, and the printed parts exhibited high cell viability, thus were shown to be non-cytotoxic via MTS assay, which suggests that the silicone resin has great potential for various medical applications.

The mechanical properties of cured silicone could be well tuned. The tensile strength varied from 0.2MPa to 4MPa, while the maximum strain of our resin reached up to 1000%, which is higher than reported photo-cured 3D printable elastomers and the existing commercially available thermally cured silicone elastomers. Besides, the printed parts also exhibited great compressive properties. It could bear 90% of compression strain, correspondingly 2000N load force, and completely recover to its original shape after 10 cycles of successive tests.

Our resin demonstrated excellent printability for complex structures, i.e., human heart model with irregular shape, hollow structure and wall thickness of 0.2mm. Interestingly, the silicone printed part also has good conductivity by adding certain ratio of conductive polymer PANI into the resin formulation. Moreover, it has strong adhesive strength to biological tissues, which has potential for use as conductive tissue adhesive/patch.

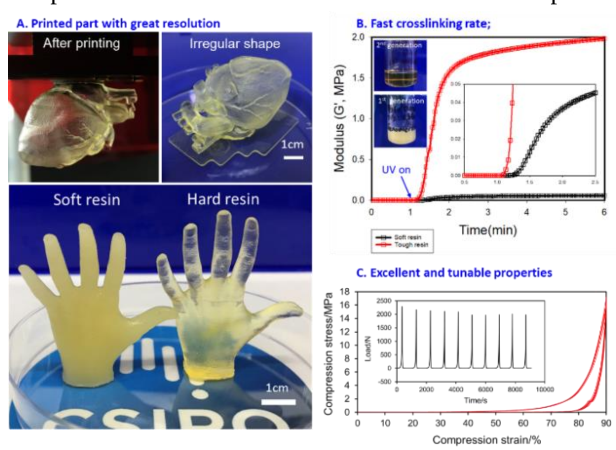

Figure 1. A). printed parts; B). fast photo-crosslinking rate and C). compressive property of CSIRO resin

Conclusions: Novel crosslinkable silicone-based resins were developed in this study to enable and improve the fast silicone 3D printing. A wide range of complex geometries with tunable mechanical properties were rapidly printed using these silicone-based resins. The silicone resin has good conductivity by adding polyaniline and has potential to be used as condutive tissue patch/adhesive.

References: 1. Jeong, S. H.; Zhang, S.; Hjorth, K.; Hilborn, J.; Wu, Z., Adv Mater 2016, 28, 5830-6.
2. Bhattacharjee, N.; Parra-Cabrera, C.; Kim, Y. T.; Kuo, A. P.; Folch, A., Adv Mater 2018, 30, e1800001.