The Design of a Preliminary Surrogate Model of The Human Calvarium Using a Readily Available Epoxy

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I. INTRODUCTION

Physical and computer models of the human brain continue to make advancements when characterizing the biomechanics of mild brain injuries [1-2]. In addition, we must make similar advancements with potential models of the skull since it protects the brain. The injuries endured by the skull are typically skull-fracture related and are observed in motor vehicle accidents, violent criminal behaviours, falls, or military and sporting activities [3]. A surrogate model of the skull would allow researchers to reconstruct an injury such as a skull fracture to improve protective devices without the constant need to retrieve cadaveric models. An assessment of the literature indicates that physical surrogate models of the skull are in the early stages of research and development [4]. The work published thus far has employed costly materials and/or methods to fabricate their models [4]. These include construction-based epoxy unavailable in North America [4] and 3D printing technology [4]. In this short communication, we present the preliminary design of a surrogate model of beam geometry using a readily available and affordable epoxy. We then statistically compare its fracture properties to human calvarium specimens during 4-point bending impacts. This work is the initial phase of a broader program that wishes to develop a full-scale calvarium model in future work.

II. METHODS

Surrogate Fabrication and Preparation

The material chosen to fabricate the calvarium surrogate model was *LePage Speed Set Instant Epoxy*. The epoxy set includes a double syringe applicator with a self-mixing nozzle that equally mixes the resin and hardener. To make the surrogate (Fig 1a), the epoxy mix was dispensed into a pre-made silicone mold that contained the imprint of a curved beam. The imprinted curved beam was manufactured according to the geometry reported for human calvaria [5] (Fig 1a). The surrogates were allowed to fully cure at room temperature for 2 weeks prior to experiments. Once cured, the surrogates were adhered with fibre Bragg gratings (FBGs) using cyanoacrylate to measure tensile (inner surface) and compressive (outer surface) surface strains at the center of the beam (%) - an FBG's sensitivity is 1.21 pm/ με [6].

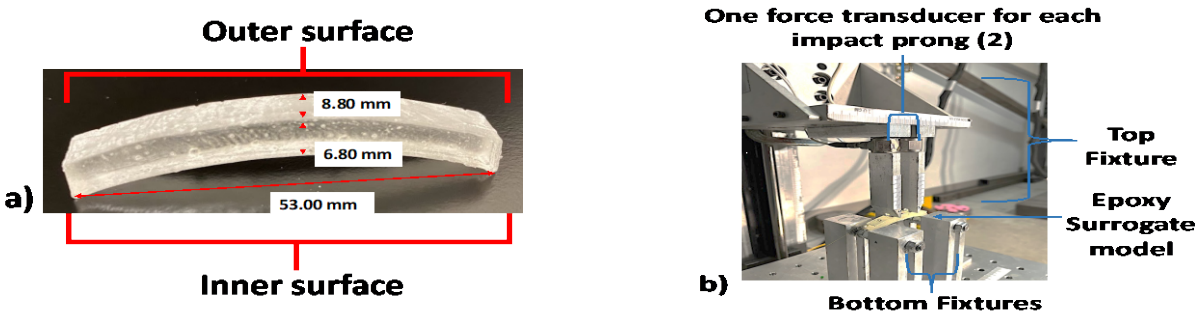

Fig 1. a) The epoxy surrogate model with an inner surface radius of curvature of 60.75 mm. b) The 4-point impact bending testing rig.

Four-Point Bending Impacts

The surrogates (n=6) were impacted in a custom-built 4-point impact bending testing rig (Fig 1b) [6]. The top impact fixture (mass: 2.62 kg) was attached to a guided linear rail while the bottom fixtures were attached to a steel base anvil. The surrogates rested freely on the bottom fixtures and were impacted on their outer surface by the top fixture's impact prongs at a velocity of 0.87 m/s. To measure force during impact, each impact prong on the top fixture was instrumented with inertially compensated force transducers (PCB model 208C05). Bending stress was calculated using the Euler Bernoulli beam theorem. Four-point bending was chosen since it yields a pure-bending scenario between the top impact prongs with minimal shearing effects.

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Human Calvaria

The fracture properties of embalmed human calvaria reported in a previous short communication by the present authors [6] were statistically compared to the surrogates using a one-way analysis of variance (SPSS).

III. INITIAL FINDINGS

The differences in fracture force, fracture bending moment, and fracture stress between the epoxy-based surrogate and calvaria were not great enough to be statistically significant (p>0.05) (Fig 2). The surrogates' surface fracture strains were statistically significantly greater (p<0.05) compared to the calvaria (Fig 2).

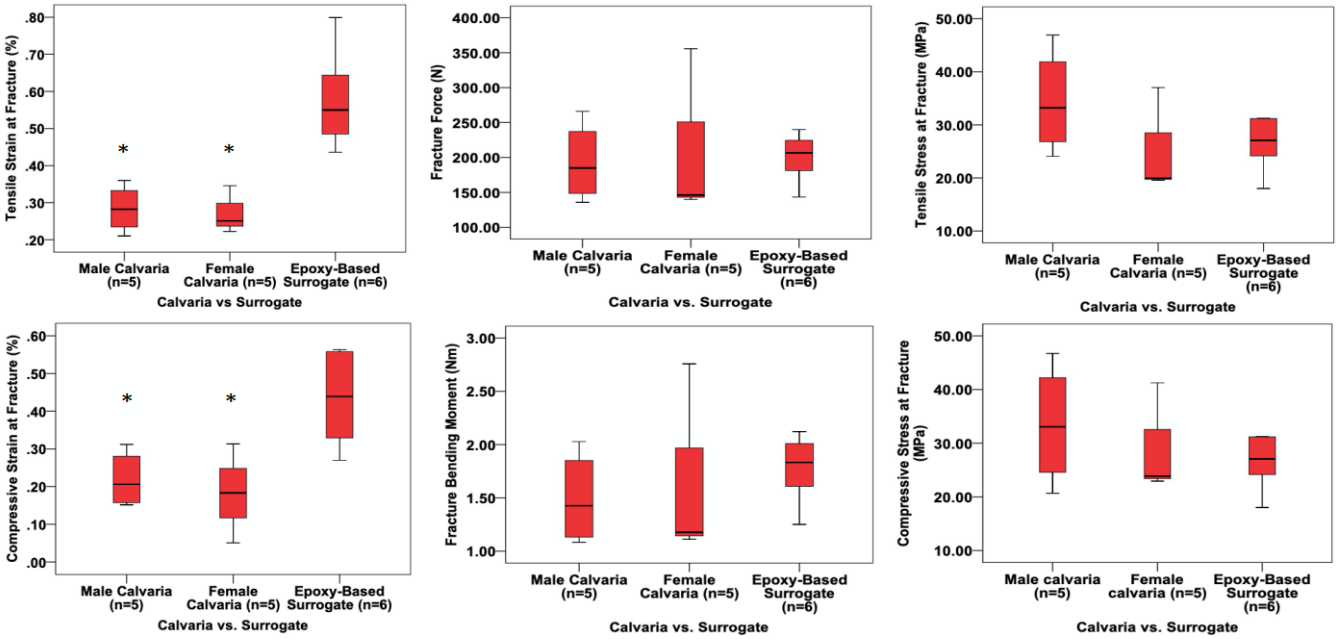

Fig 2. Fracture properties of the calvaria (n=10) and the surrogates (n=6) displayed as boxplots. * Indicates a statistically significant difference compared to the surrogates (p<0.05).

IV. DISCUSSION

Preliminary calvarium surrogate models were fabricated using a readily available commercial epoxy. Our early findings suggest that the epoxy used in this work may be a prospective material when constructing a calvarium surrogate. This was revealed by observing no significant differences in fracture force, fracture bending moment, and fracture stress between the surrogates and calvaria. A previous study that used Masterflow 622 epoxy, a construction-based epoxy, had a greater 3-point flexural mean stress (59.84 MPa) [4] compared to this study's epoxy (26.45 MPa) and the calvaria (29.13 MPa). The next steps of this work would require increasing the brittleness of the surrogates, or in other words, reducing their fracture strain values as our findings had implicated significant differences compared to calvaria. Potential ways to reduce the strain values are to integrate with the epoxy a secondary material with brittle-like behaviour such as glass or ceramic, though their cost and accessibility are undetermined. In addition, we intend to develop strategies to reduce bubbles formed in the surrogate (Fig 1a) as this can potentially weaken the structure for some surrogates and influence the variation in fracture properties as more tests are carried out.

V. ACKNOWLEDGEMENTS

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