MODELLING THE THREE-POINT BENDING OF NOVEL BIOINSPIRED DENTAL CROWN COMPOSITES

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1. Background

Dental CARIES: a Global Issue

Figure 1.1. Dental hard tissue lose, a. Sound enamel, b. Initial lesion, c and d. Extensive lesion [1].

Caries is the major cause of dental hard tissue damage and teeth loss. It is an **infectious, chronic** disease that has affected **millions** of people globally [2].

- **3.2 billion** people worldwide are affected by oral disease (2019) [2].
- **22 million** adults were seen by an NHS dentist in England (2018) [3].
- **9.7 million** treatment courses in one quarter of 2018-2019 [3].
- **20%** of ceramics used as top layers fail within the first 5 years of use [4].

Current Treatment Solutions

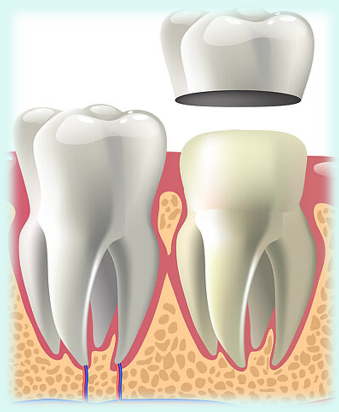

Figure 1.2. Commercial dental crown materials

Novel Dental Crown Materials Inspired by Nature

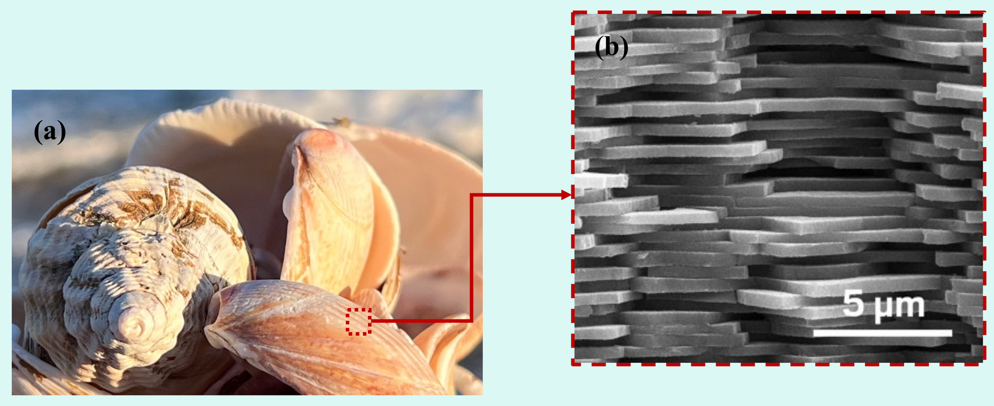

Figure 1.3 (a) Natural nacre. (b) Nacre layered structure acquired by SEM [5].

- Nature designs a perfect complex structure in living organisms on a **macro and nano-level.**
- The hierarchical structure of natural teeth is overly complex for our current manufacturing techniques.
- However, nacre (known as mother of pearl) has a simpler microstructure of **aragonite** platelets held together by **proteins** that provide good strength and fracture resistance [6].

2. Materials and Methodology

Bioinspired alumina (Al_2O_3) scaffolds were achieved by using a **cost-effective,** bi-directional freeze-casting technique. It was later densified, sintered and polymer infiltrated as described in [7].

The four different polymers used in this study are:

a) Polymethyl methacrylate (PMMA)
b) Urethane dimethacrylate/Triethylene glycol dimethacrylate (UDMA/TEGDMA)
c) Polyurethane (PU)
d) Epoxy.

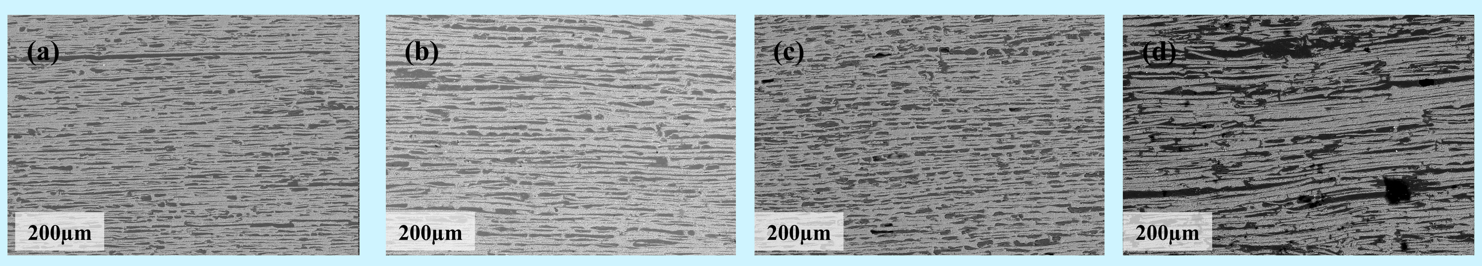

Figure 2.1 The microstructure SEM images of Al_2O_3 composites with different polymer phases. (a) Al_2O_3/PMMA, (b) Al_2O_3/UDMA-TEGDMA, (c) Al_2O_3/PU and (d) Al_2O_3/epoxy.

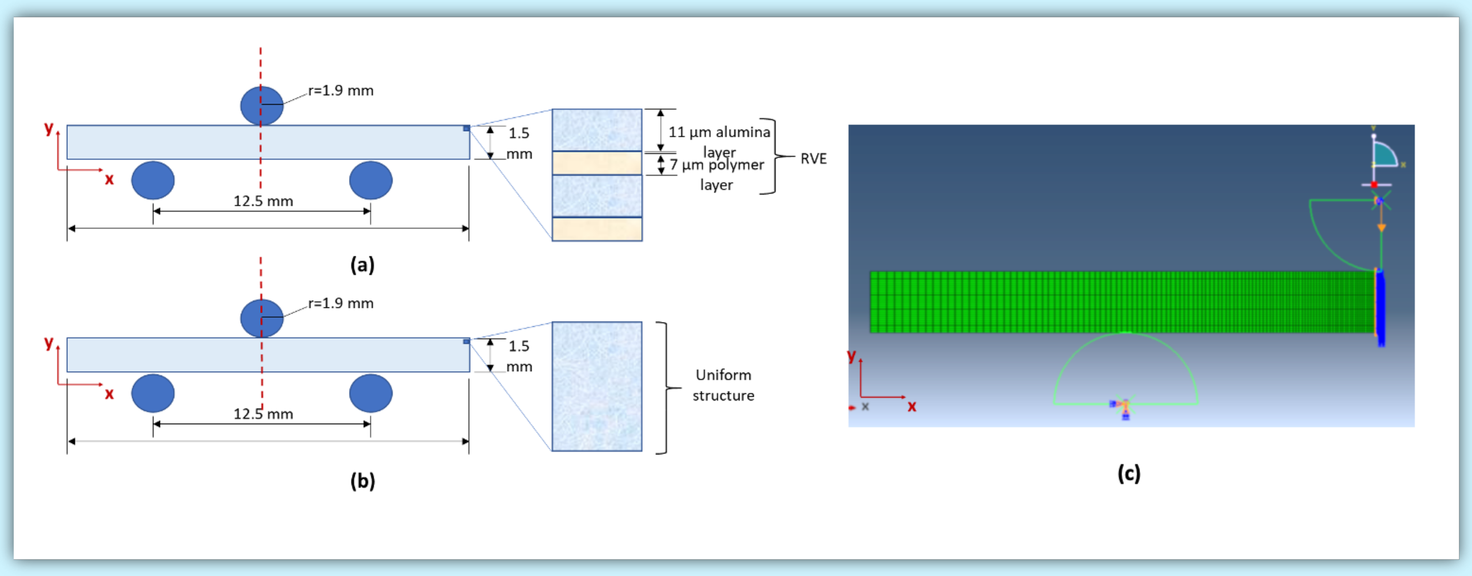

Figure 2.2 A schematic diagram of the three-point bending test. (a) The geometry equivalent uniform structure model, (b) Bioinspired multi-layer structure, (c) 2D axisymmetric three-point bending boundary conditions used in FEM.

The FEM simulations were carried out using the commercial finite element software, ABAQUS® (version 6.4.2, 2018). Two types of models were proposed using the same finite element framework:

i) Bioinspired multi-layer model
ii) Equivalent uniform structure model, without a layered architecture, to compare the stress distributions in the four composites.

Constant displacement of 0.7 mm applied on the top pin and 2D 4-node bilinear plane strain quadrilateral elements (CPE4R) were used to simulate the model.

3. Results and Discussion

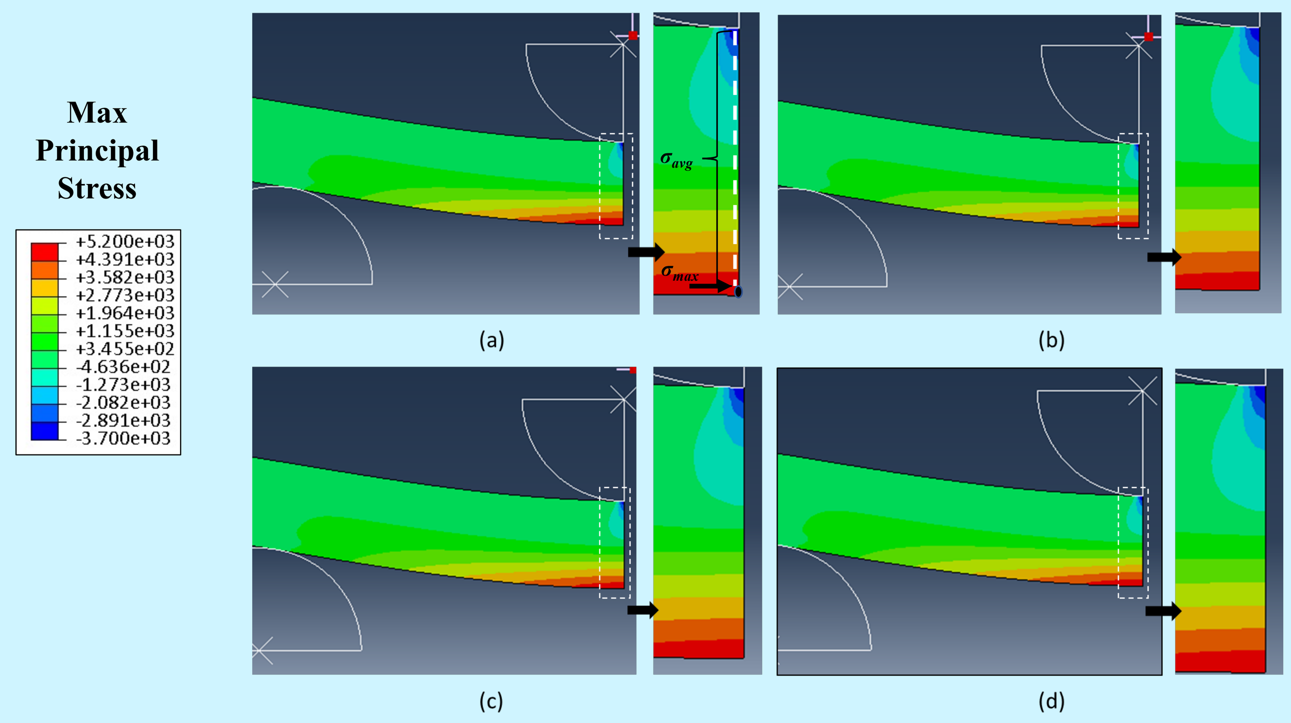

Figure 3.1 Principal stress distribution in equivalent uniform structure models of Al_2O_3 composites. The central region of the model magnified to show the stress concentration area. (a) Al_2O_3/PMMA, (b) Al_2O_3/UDMA-TEGDMA, (c) PU, (d) Al_2O_3/epoxy. The scale bar is in MPa. With insert image of high magnification of stress concentrated area.

The average stress (σ_{avg}) value was calculated from the central line nodes under the top pin. According to the statistical analysis, there was a statistically significant difference in σ_{avg} between equivalent uniform structure models and bioinspired multi-layer models ($p \leq 0.05$).

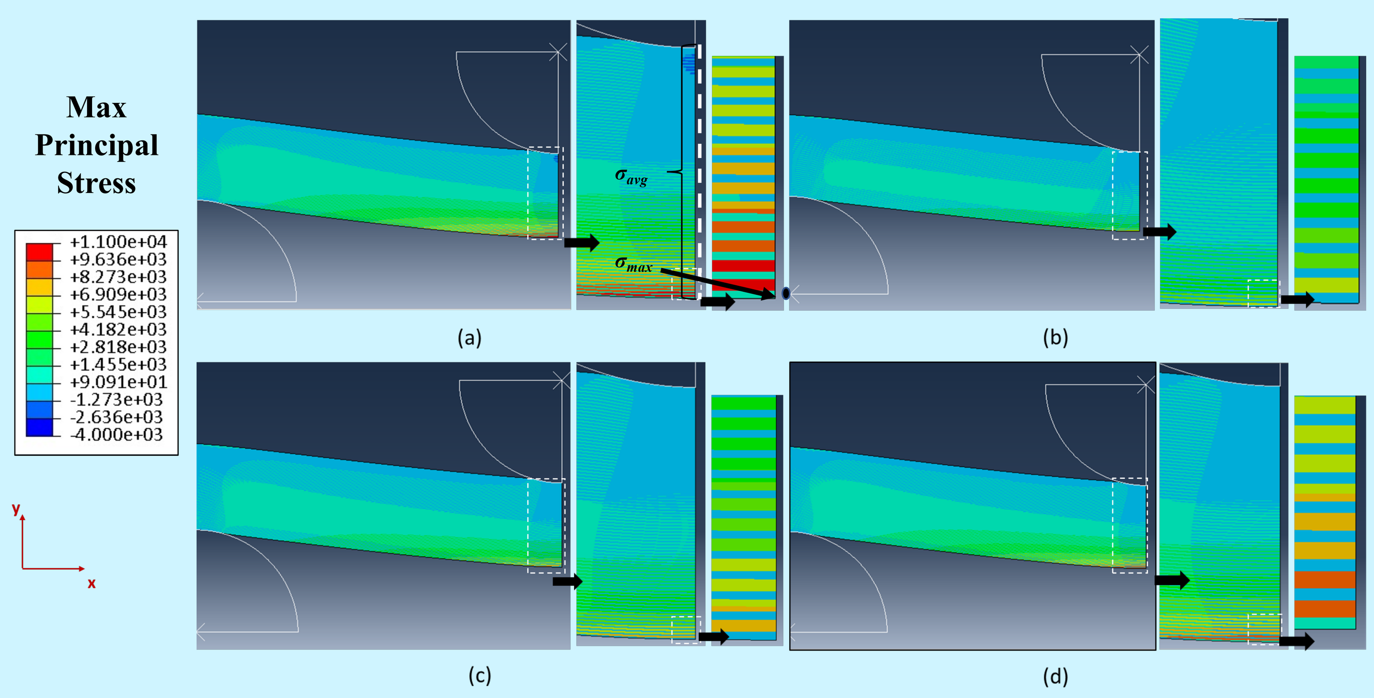

Figure 3.2 Principal stress distribution in bioinspired multi-layer structure models of alumina-based composites. The central region of the model magnified to show the stress concentration area. (a) Al_2O_3/PMMA, (b) Al_2O_3/UDMA-TEGDMA, (c) PU, (d) Al_2O_3/epoxy. The scale bar is in MPa.

In each model, the differences between polymer components' σ_{avg} is minimal in equivalent uniform structure models, whereas it is significantly higher in bioinspired multi-layer models ($p \leq 0.05$).

The Al_2O_3/PMMA composites displayed higher σ_{avg} than Al_2O_3/UDMA-TEGDMA and Al_2O_3/PU composites ($p \leq 0.05$). However, a statistically significant difference was not found between the σ_{avg} of the Al_2O_3/PMMA and Al_2O_3/epoxy compositres ($p \leq 0.05$).

4. Conclusion and Future Work

The present study focused on stress distributions in bioinspired multi-layer Al_2O_3 composites and compared them with an equivalent uniform structure model using 2D FEM modelling. The σ_{avg} in multi-layer models is lower than that of the equivalent uniform structure models.

In addition, polymer associated differences were identified in σ_{avg}. This modelling technique requires less computational memory along with faster convergence, meaning it can be beneficial in optimising polymer composition for further 3D modelling to investigate tri-axial stress state. Thus, it will develop better understanding on the mechanical performance of a novel, bioinspired, Al_2O_3 based dental crown material.

Acknowledgements

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