IN-SITU STUDY OF THE FRACTURE BEHAVIOUR OF BIOINSPIRED ALUMINA-BASED COMPOSITES WITH DIFFERENT COMPLIANT POLYMER PHASES

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General Introduction

A dental crown is a cover or cap that is used to replace part of a damage tooth to restore its normal size, shape, and mechanical function. Due to their natural-looking aesthetics, all-ceramic crowns have become the most preferable choice.

There are a range of biocompatible ceramics used in dentistry, such as alumina and especially yttria-stabilised zirconia, which is favoured for its high fracture toughness, compared to other dental ceramics. However, most of those ceramics are much stiffer and harder than human teeth which can lead to excessive wear of opposing teeth. This drawback could be overcome by forming ceramic-polymer composites with a nature inspired microstructure, such as the laminated structure found in nacre, that can produce a less stiff material with high fracture toughness. To obtain optimised performance characteristics, a suitable material combination needs to be identified.

This study used in-situ mechanical microscopy using scanning electron microscopy (SEM) fracture toughness testing to assess and compare the fracture toughness behaviours of nacre-like alumina-based composites with different polymer phases.

Experimental Methods

A previous study found that 60% alumina fractions provided good flexural strength and fracture toughness properties. Therefore, this ceramic fraction was used in this study. Blocks of 60% alumina composite material were manufactured by using a bi-directional freeze casting technique to create a lamellar ceramic scaffold that was later densified, sintered, and polymer infiltrated. The polymers used in this study were Polymethylmethacrylate (PMMA), Urethane dimethacrylate (UDMA), Polyurethane (PU), and Epoxy. Single-edge bend specimens, 25×5×2.5 mm in dimension (L×W×B), were then sectioned from the manufactured blocks, using a low-speed diamond saw. In accordance to the ASTM E1820 testing standard, the samples were pre-notched to provide an initial crack length of approximately half of the sample width, using a slow-speed saw. The notch was then sharpened by repeatedly passing a razor blade, irrigated with 1 μm diamond suspension, across the notch tip.

Three-point bending tests were performed using a Deben Microtest, with a 150 N loadcell, inside a Tescan MIRA II SEM. Tests consisted of elastic-compliance and monotonic loading methods with constant displacement rates of 100 μm/min and 20 μm/min, respectively. Fracture toughness and R-curve behaviour were determined using non-linear elastic fracture mechanics as outlined in the ASTM E1820 testing standard. The J-integral, representing the strain energy release rate under non-linear elastic conditions, was calculated as follows in Eq. 1:

$$J = (1.9A)/Bb \quad (1)$$

where A is the total area under the load-displacement curve, B is the sample thickness, and b is the length of the uncracked ligament. The fracture toughness was then converted into terms of K, stress intensity factor, by back-calculating J-integral values for mode I fracture in plane strain according to Eq. 2:

$$J=K^2(1-v^2)/E \quad (2)$$

where E is the Young's modulus, calculated using the rule of mixtures, and v is the Poisson's ratio, taken to be 0.3 for all samples.

Results and Discussion

The laminated structures displayed stable crack growth and R-curve behaviour due to the large number of interfaces which enable various toughening mechanisms, such as crack deflection and micro-delamination. The crack initiation toughness appears to be lower when using the elastic-compliance method. However, final valid crack-growth toughness is similar comparing the results of the two methods. Of the four polymer groups, PMMA exhibited the highest valid crack-growth toughness of 11.37±2.4 MPa.m$^{1/2}$ for elastic-compliance method, and 12.12±2.23 MPa.m$^{1/2}$ measured with the monotonic method. Both are ≈3 times higher than the fracture toughness of monolithic alumina. Representative load-displacement curves for the different test methods of PMMA composites is shown in Fig. 1.

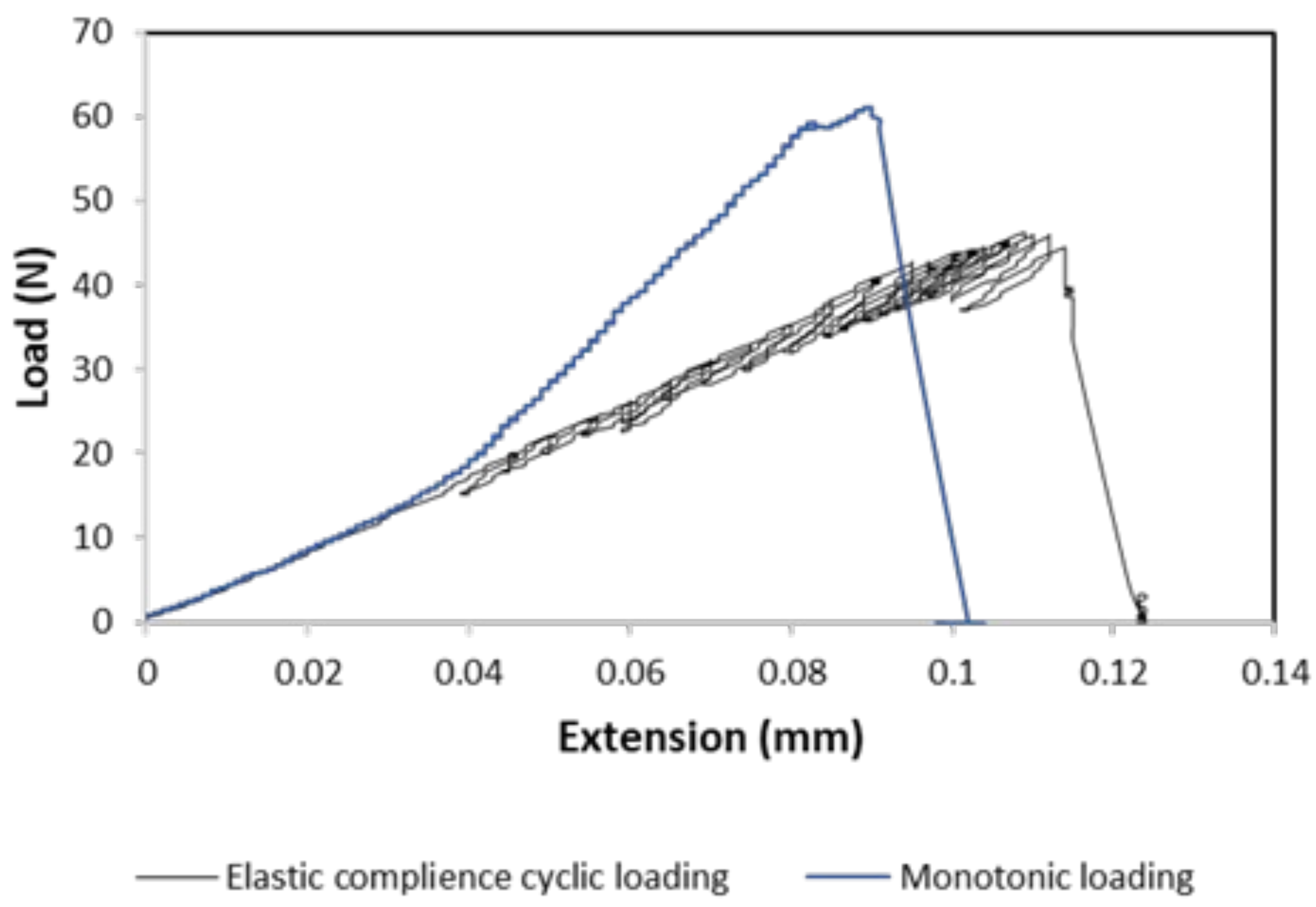

Figure 1. Loading curves for monotonic and elastic-compliance tests of alumina/PMMA composite.

Summary

In this study, in situ mechanical microscopy was used to determine the fracture toughness of laminated alumina-based composites with different polymer phases. The laminated structure displayed R-curve behaviour and fracture toughness's higher than monolithic alumina, with PMMA composites having higher toughness. This work is important for the development of new dental composites as it provides some insight into potential material combinations. Future work will look at investigating the effect of ceramic fraction with different polymers to determine a composition with an optimised fracture toughness.

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