Tomography of Dental Composites Under Multiaxial Loading

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Statement of Purpose: The intent of this study is to investigate the feasibility of using a high resolution microtomography system developed at beamline 2-BM of the Advanced Photon Source (APS) at Argonne National Laboratories (Argonne, IL) to characterize dental composite materials subjected to multiaxial loading by quantifying the fracture surface area. X-ray microtomography at the APS allows three-dimensional imaging at the 1-10 µm scale, with near video-rate data acquisition and pipelined processing.

Methods: Specimen samples were formed using Renew (Bisco Inc., Schaumburg, IL, USA), a commercial microfill composite. Sample specimens (r=3.12 mm, h=8 mm) were light-cured and polished on 600 grit paper to ensure a level surface. A compressive load was applied to each sample at a loading rate of 0.255 mm per minute to induce multiaxial compressive stress states. Specimen were placed in aluminum (Al) or polycarbonate (PC) rings having an inner diameter of 6.3 mm and varying confinement λ (λ=ratio of the ring's outer/inner diameter). Upon compressive loading, the ring constrains radial expansion of the specimen, generating confinement stresses.

Tomographic data was generated from samples in the 2BM beamline at the APS. 1024 X-Y parallel plane slices along the vertical axis of the specimen were collected. By stacking the slices, 3D tomographic images can be obtained. MATLAB was used as the development environment for the analysis software on a dual processor Intel Xeon based machine with 6GB of RAM. The specimen is segmented from the background for each parallel plane slice. The specimen is segmented using *optimal thresholding*. Differentiating between cracks and solid within the specimen boundary is accomplished via *gradient vector flow,* a variant of *active contour modeling*.

Results/Discussion: Because dental composites are generally placed within existing natural teeth, the composite restoration experiences radial and axial stresses, introducing 3D compressive stress states. Composite materials withstand significantly higher loads when multiaxially loaded. Since this loading configuration more closely represents the complex loading that composite materials encounter in vivo, it is of interest to fully characterize dental composite materials under multiaxial loading in order to understand the failure mechanisms.

Despite high resolution and image quality from the APS, noise, low contrast and artifacts are ongoing issues in imaging. The specimen is segmented using optimal thresholding technique, which assumes tomographic data has a bimodal Gaussian distribution.

The surface area of the cracks was measured by summing the number of voxel edges that represent the boundary between crack and solid; ie. voxels that possessed an edge in the solid region as well as an edge in the void region. Figure 1 shows a 2D slice of a sample after loading. Crack area is determined and represented as a fraction of the solid specimen. Stacking the 2D data sets results in a 3-dimensional representation of the crack volume within each sample specimen, as shown in Figure 2.

Maximum loading conditions and crack area results are listed in Table 1. It appears that the crack area decreases as a result of increasing confinement, as represented by increasing ring OD/ID. This decrease is attributed to the increase in confinement stress. Composite samples withstand significantly higher axial loads with increasing confinement.

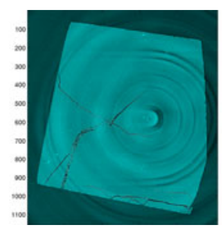

Figure 1. 2D tomographic image displays cracks after multiaxial compression loading.

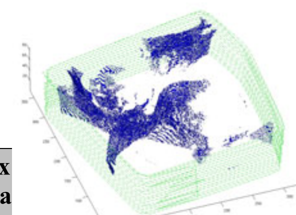

Figure 2. 3D image of cracks within sample specimen. Green demarcates specimen boundaries, blue represents crack volume.

Table 1

Ring	Ring OD/ID	Crack Area/Solid Volume	Max Load (kN)	Max Axia Stress (MPa)	Stress (MPa)
Al	1.25	0.6%	15	497	245
Al	1.25	0.9%	15	497	245
PC	1.5	0.3%	10	319	19
PC	1.5	0.5%	10	319	19
Al	1.5	0.0%	27	855	653
Al	1.5	0.1%	22	668	561
Al	1.5	0.1%	22	668	561
PC	2	0.1%	17	538	65
PC	2	0.4%	14	443	54
PC	2	0.4%	17	538	65
PC	2	0.5%	14	443	54

Conclusions: Multiaxial compressive testing more closely represents the complex loading dental restorations experience *in vivo*. Quantitative analysis of microtomographic images can be a tool to characterize dental composites when subjected to multiaxial loading. Supported by NIDCR grant DE07979. Use of the Advanced Photon Source was supported by the US DOE, Contract No. W-31-109-ENG-38.