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Multi-axial damage and failure of medical grade carbon fibre reinforced PEEK laminates: experimental testing and computational modelling

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Abstract

Orthopaedic devices using unidirectional carbon fibre reinforced poly-ether-ether-ketone (PEEK) laminates potentially offer several benefits over metallic implants including: anisotropic material properties; radiolucency and strength to weight ratio. However, despite FDA clearance of PEEK-OPTIMA™ Ultra-Reinforced, no investigation of the mechanical properties or failure mechanisms of a medical grade unidirectional laminate material has been published to date, thus hindering the development of first-generation laminated orthopaedic devices. This study presents the first investigation of the mechanical behaviour and failure mechanisms of PEEK-OPTIMA™ Ultra-Reinforced. The following multi-axial suite of experimental tests are presented: 0° and 90° tension and compression, in-plane shear, mode I and mode II fracture toughness, compression of ±45° laminates and flexure of 0°, 90° and ±45° laminates. Three damage mechanisms are uncovered: (1) inter-laminar delamination, (2) intra-laminar cracking and (3) anisotropic plasticity. A computational damage and failure model that incorporates all three damage mechanisms is developed. The model accurately predicts the complex multi-mode failure mechanisms observed experimentally. The ability of a model to predict diverse damage mechanisms under multiple loading directions conditions is critical for the safe design of fibre reinforced laminated orthopaedic devices subjected to complex physiological loading conditions.

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