Simulation, Manufacturing, and Characterization of Bioactive Glass Fibre-Reinforced PLA Composites for Bone Regeneration

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Abstract

The mechanical mismatch between conventional implant materials and native bone tissue remains one of the foremost engineering challenges in orthopaedic surgery. Metallic osteosynthesis fixation devices, including plates and screws fabricated from stainless steel or titanium alloys, possess an elastic modulus substantially exceeding that of cortical bone (approximately 110 - 200GPa versus 15 - 25GPa), resulting in a well-documented phenomenon termed stress shielding. This mechanical incompatibility reduces the physiological load transmitted to the periimplant bone, leading to progressive bone resorption, implant loosening, and an increased susceptibility to periprosthetic fractures following device replacement. Polymer-based alternatives offer reduced stiffness are not applicable in load-bearing anatomical regions.

To address these demands, research effort has been directed towards composite materials that combine a bioresorbable polymer matrix with mechanically reinforcing, bioactive glass-fibres (BGF). Bioactive glasses represent a particularly promising material class owing to their well-established osteoconductivity, capacity to form a hydroxyapatite surface layer upon exposure to physiological fluids, and tunable degradation kinetics. The integration of BGF into a polylactic acid (PLA) matrix is hypothesised to yield composites whose mechanical properties approach those of cortical bone, while simultaneously supporting osteogenesis at the implant–tissue interface and undergoing controlled bioresorption.

In the present investigation, multiple hybrid yarn production methods for BGF–PLA composite preforms were systematically developed, characterised, and compared. BGF of designation 1-06 were developed and spun in-house, while commercial PLA fibres were sourced externally. Composite plate specimens were consolidated via a hot-melt press. Mechanical characterisation comprised uniaxial tensile testing and three-point bending, performed in accordance with standardised protocols. Degradation behaviour was assessed by immersing BGF, unreinforced PLA, and BGF–PLA composite specimens in phosphate-buffered saline (PBS) at 37∘C for up to four weeks. Following incubation, aged specimens and non-immersed reference controls were mechanically tested and the results systematically compared. The study thereby provides a comprehensive evaluation of the structure-property relationships governing BGF-PLA composites as candidate materials for fibre-reinforced osteosynthesis plates

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