2024「中技社科技獎學金」
2024 CTCI Foundation Science and Technology Scholarship
境外生生活助學金
Living Grant for International Graduate Students

A Novel Biodegradable Bio-Polymer-Reinforced Bio-Glass Composite Material for Bone Regenerative Implants in Injection Molding

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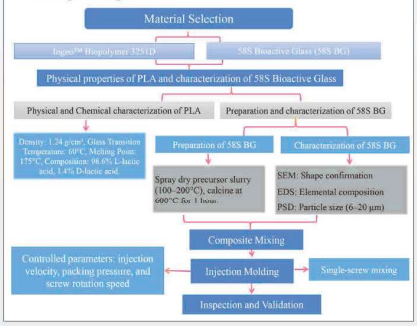
Abstract

Polylactic acid (PLA) and bioglass (BG) composites are emerging as promising materials for bone regenerative implants, addressing challenges such as limited bone regeneration and poor integration.This study aims to develop PLA/BG composites using mixed-screw injection molding, with Ingeo™ Biopolymer 3251D PLA as the matrix and 58S BG microspheres as reinforcement. Key injection molding parameters will be optimized to enhance mechanical properties, with injection velocity set at 40 mm/s (low) and 80 mm/s (high), packing pressure at 50 MPa (low) and 90 MPa (high), and screw rotation speed at 60 rpm (low) and 120 rpm (high). Thermal analysis will assess heat resistance, including the thermal cracking temperature, which is critical for sterilization. Degradation behavior will be studied in simulated body fluid (SBF) to encourage hydroxyapatite formation and promote bone integration. Degradation rates and changes in mechanical properties will be monitored in phosphate-buffered saline (PBS), with biocompatibility tests evaluating cell viability and osteogenic differentiation potential. Further evaluations will include stress concentration analysis, micro-CT particle distribution, and in vivo testing on mice to assess implant degradation and tissue response. Additionally, Moldex3D simulation results for PLA composites (shrinkage ratio of 0.00411 mm/mm, Von Mises stress of 13.25 MPa) align with technical data. This alignment validates the processability of Ingeo™ Biopolymer 3251D PLA in injection molding, ensuring optimal parameter selection, improved precision, and reduced defects.

1. Sample Preparation



2. Materials and Method

2.1 Preparation and Fabrication of PLA/BG Composite Materials

The mixture proportion of PLA/BG composites

Material	Wt% of Filler	Vol% of Filler	Density (g/cm³)
PLA	0%	0%	1.24
PLA/5 wt% BG	5%	2.22%	1.27
PLA/10 wt% BG	10%	4.58%	1.31

2.2 L8 Orthogonal Experimental Design and Process Optimization

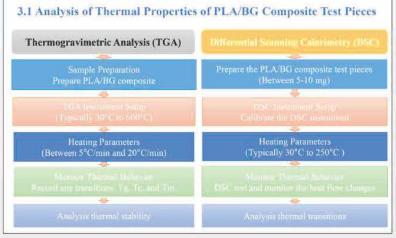
FANUC injection machine Setting			
Parameter	Stage	Value	Unit
Nozzle temperature	1st	(a)	°C
Barrel temperature	2nd, 3rd, & 4th	(a)-5, (a)-10& (a)-15 resp.	°C
Mold temperature		50	°C
Max. injection pressure		100	MPa
Injection velocity		(b)	mm/sec
Packing pressure/time	1st	(c)/5	MPa/sec
Back pressure		0.5	MPa
Cooling time		28	Sec

Injection Molding Parameters		
Parameter	Value	Unit
Melt temperature	180	° C
Injection velocity	(a)	mm/sec
Packing pressure	(b)	MPa
Screw rotation speed	(c)	rpm
Mold temperature	50	° C
Packing time	5	sec
Cooling time	28	Sec
Injection pressure	150	Mpa

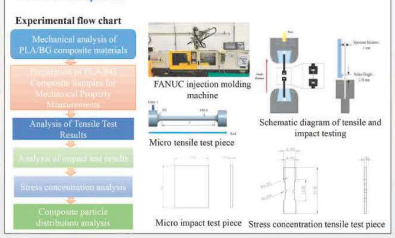
L8 (2^3 – 0, Orthogonal experimental design			
Run	Injection velocity (mm/s) (a)	Packing Pressure (MPa) (b)	Screw Rotation Speed (rpm) (c)
1	40 (-)	60 (-)	70 (-)
2	80 (+)	60 (-)	70 (-)
3	40 (-)	100 (+)	70 (-)
4	80 (+)	100 (+)	70 (-)
5	40(-)	60 (-)	140 (+)
6	80 (+)	60 (-)	140 (+)
7	40 (-)	100 (+)	140 (+)
8	80(+)	100 (+)	140 (+)

3. Experimental Setup

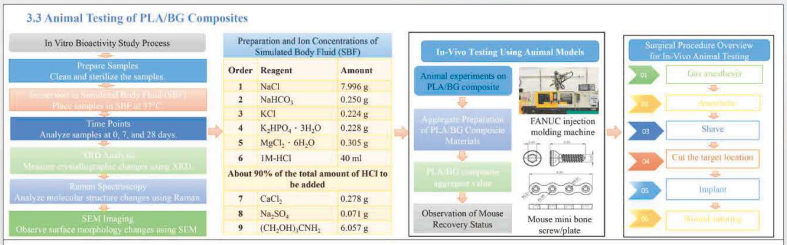
3.1 Analysis of Thermal Properties of PLA/BG Composite Test Pieces



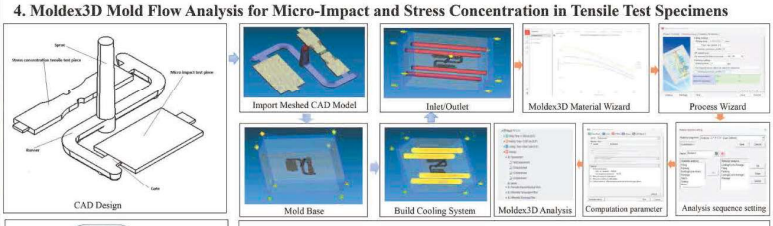
3.2 Effect of Injection Molding Parameters on Mechanical Properties of PLA/BG Composites

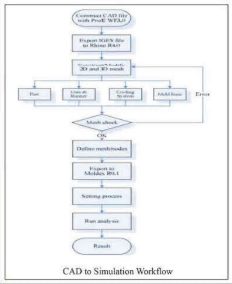


3.3 Animal Testing of PLA/BG Composites

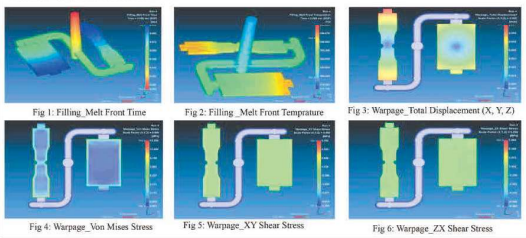


4. Moldex3D Mold Flow Analysis for Micro-Impact and Stress Concentration in Tensile Test Specimens





5.Result and Discussion



6. Expected Outcomes

This research aims to establish the viability of PLA/BG composites as bone implants, focusing on mechanical strength, thermal stability, controlled degradation, and biocompatibility. It provides insights into process optimization for industrial-scale manufacturing and clinical applications, as follows:

- Improves tensile and impact properties of PLA/BG composites for bone implants.
- Increases thermal resistance, predicts degradation, and ensures biocompatibility for safe clinical use.
- Streamlines production and ensures readiness for medical applications of PLA/BG implants.

Conclusion

Moldex3D simulation results for PLA show a shrinkage ratio of 0.00411 mm/mm, aligning with the technical data range of 0.0762–0.127 mm/mm. With a Von Mises stress of 13.25 MPa (below the yield strength of 62 MPa) and a flexural strength of 108 MPa, the material demonstrates favorable mechanical properties. The strain and reduced temperature differential indicate no risk of mechanical failure, confirming the material's suitability for safe injection molding and high-quality part production.

Reference

[1] Chen, C.-C. A., & Cheng, Y.-H. (2023). Study on polylactide/bioglass composites for bone applications by mixed-screw injection molding process. https://etheses.lib.ntust.edu.tw/thesis/detail/500088fc8c786941164604f1e585bf17/
[2] Chen, C.-C. A., & Tung, Y.-W. (2023). Study on the mechanical properties and biological testing analysis of new mixed screws directly injection molded into polylactic acid and Bioglass composite materials. https://hdl.handle.net/11296/cmjf8t.