

# Design and Fabrication of a PLA - Based Composite Orthopedic Bone Plate for Femur Fracture Fixation Using Additive Manufacturing

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## Abstract:

The growing demand for patient-specific, lightweight, and biocompatible orthopaedic implants has encouraged extensive research into advanced materials and modern manufacturing methods. This project focuses on the design and fabrication of a polylactic acid (PLA)-based composite orthopaedic bone plate for femur fracture fixation using additive manufacturing technology. PLA, a biodegradable and biocompatible polymer, provides several advantages over conventional metallic implants, including reduced stress shielding, easier fabrication, and improved environmental sustainability. By reinforcing PLA with appropriate composite materials and utilizing additive manufacturing techniques, particularly 3D printing, this study aims to develop a customized bone plate with enhanced mechanical strength, precise structural geometry, and improved compatibility with human bone. Additive manufacturing offers significant benefits such as high design flexibility, rapid prototyping, and cost-effective production of complex implant structures tailored to individual patient needs. Furthermore, the project focuses on optimizing the design parameters and fabrication conditions to ensure that the fabricated bone plate achieves sufficient load-bearing capacity required for femoral fracture fixation.

## I. INTRODUCTION

### INTRODUCTION

The increasing demand for patient-specific, lightweight, and biocompatible orthopaedic implants has driven significant research into advanced materials and manufacturing techniques. This project focuses on the design and fabrication of a polylactic acid (PLA)-based composite orthopaedic bone plate for femur fracture fixation using additive manufacturing. PLA, a biodegradable and biocompatible polymer, offers advantages such as reduced stress shielding, ease of fabrication, and environmental sustainability when compared to conventional metallic implants. By reinforcing PLA with suitable composite materials and employing additive manufacturing, particularly 3D printing, the study aims to develop a customized bone plate with improved mechanical strength, precise geometry, and enhanced compatibility with human bone. The paper also emphasizes the optimization of design parameters and fabrication settings to achieve adequate load-bearing capability suitable for femoral fracture fixation.

### 2. NEED OF THE STUDY.

Femoral fractures are among the most serious orthopaedic injuries and often require surgical fixation using bone plates to stabilize the fractured bone and promote proper healing. Conventional bone plates are typically made from metallic materials such as stainless steel and titanium alloys. Although these materials provide high mechanical strength, they also present several limitations, including stress shielding, higher weight, potential corrosion, and the need for secondary surgery to remove the implant after healing. These challenges highlight the need for alternative materials that are lightweight, biocompatible, and better suited to match the mechanical properties of natural bone.

Polylactic acid (PLA), a biodegradable and biocompatible polymer, has gained attention as a promising material for biomedical applications. PLA-based composites can potentially reduce stress shielding and eliminate the need for implant removal surgeries, as the material gradually degrades in the body over time. However, pure PLA has limited mechanical strength for load-bearing applications such as femur fracture fixation. Reinforcing PLA with suitable composite materials can significantly enhance its mechanical properties, making it more suitable for orthopaedic implant applications.

Additionally, conventional manufacturing methods limit the ability to produce patient-specific implants with complex geometries. Additive manufacturing, particularly 3D printing, offers a powerful solution by enabling the fabrication of customized implants with high precision, reduced material waste, and faster production times. This technology allows implants to be designed according to patient-specific anatomical requirements, improving the fit, stability, and overall treatment outcome.

Therefore, this study is necessary to explore the design and fabrication of a PLA-based composite orthopaedic bone plate using additive manufacturing. The research aims to develop a lightweight, biodegradable, and mechanically reliable implant that can provide effective femur fracture fixation while overcoming the limitations associated with conventional metallic bone plates.

### 3. Femur Bone

The femur, commonly known as the thigh bone, is the longest, strongest, and heaviest bone in the human body. It extends from the hip joint to the knee joint and plays a crucial role in supporting body weight and enabling movements such as walking, running, and jumping. The femur consists of a rounded head that fits into the hip socket, a long shaft, and a lower end that forms part of the knee joint. Due to the high loads it carries, the femur is essential for maintaining stability and mobility in the human body.

### 3.1. Properties of Different Bone Plate Materials

| Property                         | Titanium (Ti-6Al-4V)                                      | Cobalt–Chromium Alloy                    | Stainless Steel (316L)                 | PLA Composite (e.g., PLA/HA)                   |
|----------------------------------|-----------------------------------------------------------|------------------------------------------|----------------------------------------|------------------------------------------------|
| Density (g/cm <sup>3</sup> )     | 4.5 (Lightweight)                                         | 8.3–9.2 (Very heavy)                     | 7.9–8.0 (Heavy)                        | 1.2–1.3 (Very lightweight)                     |
| Elastic Modulus (GPa)            | 105–120 (closer to bone)                                  | 220–230 (very stiff)                     | 190–200 (stiff)                        | 2–7 (near cancellous bone)                     |
| Yield Strength (MPa)             | 800–900                                                   | 600–1000                                 | 200–600                                | 50–150 (depending on filler)                   |
| Biocompatibility                 | Excellent                                                 | Good                                     | Good                                   | Excellent (bio-based)                          |
| Corrosion Resistance             | Excellent                                                 | Excellent                                | Good                                   | Not applicable (polymeric)                     |
| Degradation                      | Non-degradable                                            | Non-degradable                           | Non-degradable                         | Biodegradable (months–years)                   |
| Typical Surface Reaction in Body | Forms stable oxide layer                                  | May release Co/Cr ions                   | May release Ni/Cr ions                 | Hydrolysis into lactic acid                    |
| Cost                             | High                                                      | Very high                                | Low                                    | Low–Moderate                                   |
| Advantages                       | Lightweight, strong, biocompatible, low imaging artifacts | Highest strength and wear resistance     | Cheap, easy to machine                 | Resorbable, light, customizable by 3D printing |
| Limitations                      | Expensive, lower hardness                                 | Heaviest, imaging artifacts, ion release | Moderate corrosion, allergic reactions | Low strength, degradation can weaken fixation  |

Table 1: Properties of Different Bone Plate Materials

### 3.3. Material Selection

**Polylactic Acid (PLA) and Hydroxyapatite** were selected for their combined biocompatibility, biodegradability, and strong osteoconductive behaviours. A 75–25 PLA to Hydroxyapatite ratio provides an effective balance of mechanical strength and biological performance. Hydroxyapatite addition enhances stiffness, compressive strength, and overall structural stability compared to pure PLA. The composite supports improved cell attachment, osseointegration, and natural bone healing response. The PLA–HA blend shows good compatibility with FDM/FFF additive manufacturing, enabling customizable and reliable bone plate fabrication

Furthermore, the composite material reduces stress shielding by providing mechanical properties closer to that of natural bone. Its biodegradable nature eliminates the need for secondary implant removal surgery after bone healing. The material also allows better integration with surrounding tissues, improving long-term implant performance. These advantages make the PLA–HA composite a promising material for developing lightweight, patient-specific orthopaedic implants using additive manufacturing techniques.

### 3.4. PLA – HA Filament Making

Effective pre-drying of both PLA pellets and Hydroxyapatite feedstock is performed for 4–6 hours at 45–55°C to prevent bubbles and ensure material integrity. Abrasion-resistant tooling, such as a hardened steel screw and die, is used for the 3devo machine to manage the ceramic filler and ensure consistent filament production. An elevated temperature profile (45–50 °C) is implemented during extrusion to compensate for increased melt viscosity and maintain smooth material flow. A reduced screw speed is maintained on the 3devo machine to achieve stable filament diameter and uniform filler dispersion. Mandatory post-production drying and sealed storage with desiccant are required before the filament is used for printing to preserve its quality.

### 3.5. Microscopic Analysis of PLA – HA Filament

**Topographical Roughness (500x):** The "mountainous" and irregular surface profile increases the effective surface area, which is vital for cell anchoring and protein adsorption in biomedical applications. **Platelet-Like Network (5.0k x):** The composite shows a "flaky" or layered morphology, indicating that the 25% HA loading has successfully created an interconnected mineral network throughout the polymer. **Dense Mineral Dispersion (10.0k x):** Bright globular clusters confirm that the Hydroxyapatite is densely and uniformly distributed, providing consistent bioactive properties across the filament. **Optimal Phase Adhesion (15.0k x):** High-magnification shows the HA particles are deeply embedded and "wetted" by the PLA, signifying strong interfacial bonding which helps maintain mechanical integrity. **Biocompatible Porosity (Global):** The visible network of micropores and voids across all scales facilitates osteointegration, allowing biological fluids and bone cells to penetrate the material.

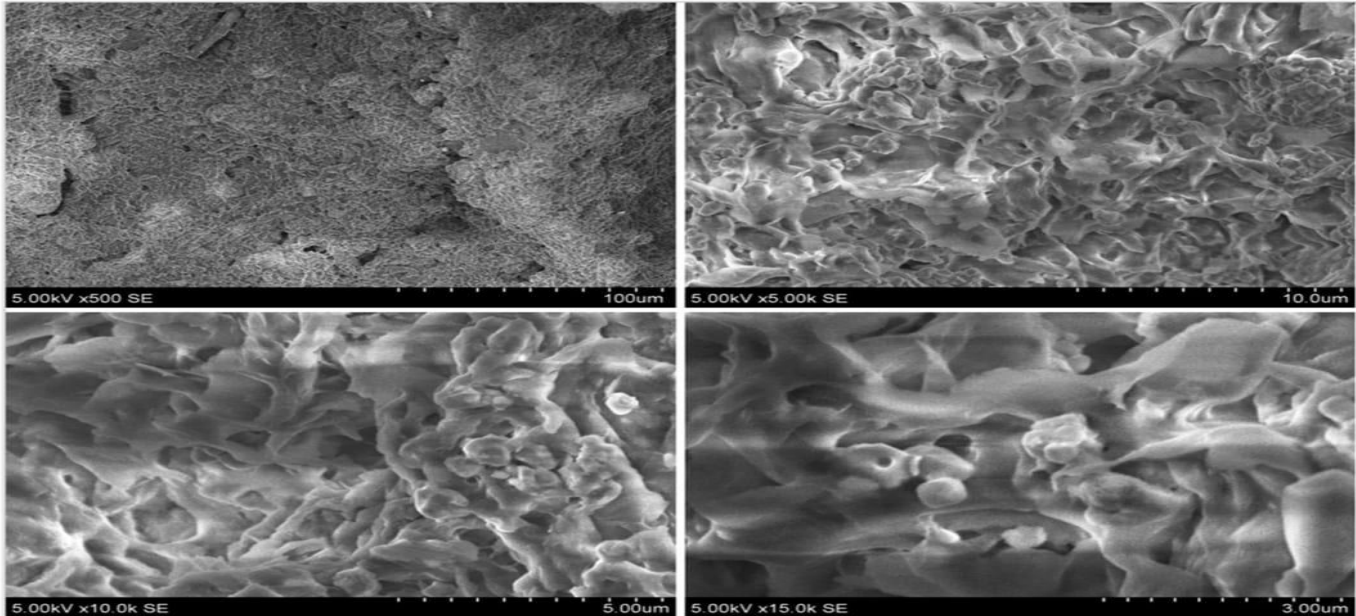


Fig 1: Microscopic Analysis of PLA – HA Filament

### 3.5. Osteoconductivity Test

The ability of the material or scaffold to support bone cell attachment and guided bone growth (osteoconductive) is evaluated. The sample is immersed in a fluorescent solution consisting of fluorescein sodium and phosphate buffer, which simulates biological conditions. Incubation is carried out for 72 hours to allow sufficient interaction and penetration of the fluorescent solution. Fluorescent labeling is used to visualize cell adhesion, migration, and surface integration under fluorescence microscopy, and uniform and deep fluorescence penetration is considered an indication of good osteoconductive behavior of the material.

## IV. RESULTS AND DISCUSSION

### 4.1 Results of Mechanical Testing

Material testing was conducted by following ASTM standards to ensure accuracy and reliability. the composite exhibited a density of 0.49 g/cc as per ASTM D792, indicating lightweight characteristics suitable for biomedical applications. Hardness (shore D) value of 52 was obtained according to ASTM D2240, reflecting adequate surface resistance. the material demonstrated a compressive strength of 9.65 mpa under ASTM D695 testing conditions. the overall test results indicate that the developed PLA-based composite possesses mechanical properties appropriate for fracture fixation applications. The overall test results indicate that the developed PLA-based composite possesses mechanical properties appropriate for fracture fixation applications. These results suggest that the material can provide sufficient structural support while maintaining low weight. the use of additive manufacturing also allows precise control over the geometry and internal structure of the implant. further optimization of the composite composition and printing parameters can enhance the mechanical performance and durability of the bone plate. this study demonstrates the potential of PLA -based composites as a promising alternative to conventional metallic bone plates in orthopaedic applications.

### REFERENCES

- [1] Optimization of 3D Printing Parameters of Biodegradable Polylactic Acid/Hydroxyapatite Composite Bone Plates, Patiguli Aihemaiti, Houfeng Jiang, Wurikaixi Aiyiti, Ayiguli Kasimu, 2022
- [2] Evaluation of PLA gyroid scaffold for long bone fracture treatment: numerical and experimental study, A. Sabik, A. Andrzejewska-Sroka, K. Daszkiewicz, M. Rucka, W. Witkowski, 2025
- [3] Materials evolution of bone plates for internal fixation of bone fractures: A review, Junlei Li, Ling Qin, Ke Yang, Zhijie Ma, Yongxuan Wang, Liangliang Cheng, Dewei Zhao, 2020
- [4] A critical review on bone plates: state of the art and future directions, Gourav Sardana, Subrata Bandhu Ghosh, Sanchita Bandyopadhyay-Ghosh, 2025
- [5] Three-Dimensional Printing and Biomaterials in the Repairment of Bone Defects; Hydroxyapatite PLA Filaments, İsmail Kaya, Meryem Cansu Şahin, İlker Deniz Cingöz, Nevin Aydın, Murat Atar, Ceren Kızmazoğlu, Salih Kavuncu, Hasan Emre Aydın, 2019

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