# Chapter 1

# Introduction

## 1.1 Introduction

In recent years, tissue engineering has witnessed significant advancements by developing novel biomaterials that offer improved biocompatibility, mechanical strength, and bioactivity. Among these, ceramics have gained substantial attention due to their unique properties, such as high compressive strength, chemical stability, and resemblance to the mineral components of natural bone. This review focuses on a specific class of ceramic-based biomaterials that combine **Alumina Toughened Zirconia (ATZ)**, **silicon dioxide ($SiO_2$) derived from rice husk ash (RHA)**, and **hydroxyapatite (HAp) derived from animal waste bone (AWB)**. These materials represent a sustainable and cost-effective approach to fabricating advanced biomaterials for tissue engineering and biomedical applications.

**Materials Overview**

1. **Alumina Toughened Zirconia (ATZ):** ATZ is a composite material that enhances the properties of zirconia ($ZrO_2$) by incorporating alumina ($Al_2O_3$). This combination improves fracture toughness, hardness, and wear resistance, making ATZ highly suitable for load-bearing biomedical applications. Zirconia is known for its high biocompatibility and is frequently used in dental and orthopedic implants. Adding alumina further improves the material's resistance to crack propagation and mechanical degradation over time.
2. **Silicon Dioxide ($SiO_2$) from Rice Husk Ash (RHA):** Rice husk ash is an agricultural by-product rich in silica, and its use in biomaterial development contributes to waste recycling and environmental sustainability. $SiO_2$ obtained from RHA is a reinforcing phase in ceramic composites, improving bioactivity and forming a bone-like apatite layer when implanted in biological environments. Its porous structure also aids in cell attachment and proliferation, which is critical for tissue regeneration.

3. **Hydroxyapatite (HAp) from Animal Waste Bone (AWB):** Hydroxyapatite is a calcium phosphate ceramic that closely mimics the mineral composition of human bone. When sourced from animal waste bones, it reduces production costs and contributes to the sustainable use of bio-waste. HAp is highly bioactive and osteoconductive, promoting bone ingrowth and integration with host tissue. However, HAp is often combined with stronger ceramics like ATZ to improve mechanical performance due to its brittle nature.

**Processing Techniques**

Several processing methods are employed to fabricate ATZ/$SiO_2$/HAp composites, such as:

- **Sol-gel synthesis** for $SiO_2$ and homogeneous mixing.
- **Solid-state sintering** to consolidate the ceramic powders at high temperatures.
- **Hot isostatic pressing (HIP)** for improving density and strength.
- **Powder metallurgy and slip casting** for shape-forming and structure control.

These techniques are crucial for controlling the composites' microstructure, porosity, and phase distribution, influencing the final mechanical and biological properties.

**Applications in Tissue Engineering**

Due to their enhanced mechanical properties and bioactivity, these composite biomaterials are particularly suitable for:

- **Dental implants and prosthetics**: Offering excellent aesthetics, strength, and osseointegration.
- **Orthopedic implants**: Including bone grafts, joint replacements, and spinal cages.
- **Bone scaffolds**: Supporting bone regeneration and healing by providing a conducive environment for cell growth and nutrient exchange.

**Advantages**

- **Mechanical strength and durability** from ATZ.

- **Enhanced bioactivity** due to HAp and $SiO_2$ components.
- **Sustainability** through the use of agricultural and animal waste.
- **Cost-effectiveness** in comparison to fully synthetic alternatives.

**Limitations**

- **Processing challenges**, especially in maintaining uniformity and phase stability during sintering.
- **Brittleness** of ceramic materials is mitigated by composite formulations.
- **Degradation control**, as bioactive ceramics must degrade at a rate compatible with tissue regeneration.

### 1.1.1 Motivation & Objectives

The driving force behind this work is the urgent need to explore waste valorization strategies that address environmental challenges and support the production of affordable ceramic-based biomaterials utilizing waste, promoting sustainable development.

The primary objective of the present work is to contribute to

- Waste Valorization and fostering biocircularity in biomaterial production by integrating waste materials into the fabrication process of biomaterials
- Thorough investigation of the potential of rice husk ash (RHA), an agricultural waste, and animal waste bone (AWB), a bio waste, in their respective roles in biomaterial fabrication
- Development of low-cost biomaterials that exhibit superior biocompatibility. To achieve this, Alumina-toughened zirconia (ATZ) bioceramics were fabricated by incorporating RHA and AWB as doping agents
- Sustainable application of waste products, enhancement of the circularity of the biomaterial production process, and creation of cost-effective biomaterials with enhanced biocompatibility for potential applications in various biomedical fields

### 1.1.2 Thesis Organization

The structure of the thesis is as follows.

The main aim of the presented chapter is to provide insight into and understanding of the basics of biomaterials employed for biomedical applications. The characteristics of biomaterials are briefly explained, and the major focus is on explaining the factors responsible fordesigning bio-implants. Apart from this, a dedicated section on bone metabolism has been added inorder to conceptualize and visualize the interaction of synthetic biomaterials with the natural system. The subsequent chapters will explain the content mentioned below to achieve the objective.

**Chapter 2** explains the background and literature review, designed to summarize previous work doneby researchers in the field associated with the desired area of interest.

**Chapter 3** will describe this work's goal, the material selected for preparing composites, and the method adopted to synthesize the composite.

**Chapter 4** explains the various characterization techniques adopted to study the composite's physical, mechanical, and biological properties.

**Chapter 5** explains the physico-mechanical properties of silica compacts fabricated using rice husk-derived amorphous and crystalline silica.

**Chapter 6** explains the Microstructural characterization and biocompatibility evolution of RHA-derived amorphous and crystalline silica doped Alumina toughened Zirconia biocomposite.

**Chapter 7** explains how to strengthen bio-circularity by reinforcing waste-derived Triphasic calcium phosphate to fabricate alumina-toughened Zirconia biocomposite with enhanced bioactivity.

**Chapter 8** concludes the thesis with a thorough overview of all the effort done. It provides final comments on the results, successes, and contributions made over the research. Furthermore, this chapter offers potential research directions that might be followed to improve biowaste disposal issues, environmental sustainability, and the use of agricultural and animal waste.