JournalsPub
International Journal of
Composite Materials and Matrices
ISSN: 2582-435X
Volume 11, Issue 2, 2025
July–December
DOI (Journal): 10.37628/IJCMM
https://journals.stmjournals.com/ijcmm/
Review ijcmm

Recent Trends in Bio Ceramic and Polymer Composites for Biomedical and Dental Applications

Arvinder Singh Channi[1,*], Manjot Kaur Channi[2]

Abstract

Advanced biomaterials with great promise for use in dental and biomedical applications are bio-ceramic and polymer composites. These composites combine the flexibility, biodegradability, and processability of polymers with the mechanical strength, bioactivity, and biocompatibility of bio-ceramics. Clinical success is often limited by the biological response and tissue compatibility of conventional materials such as metals and single-phase ceramics. Oste conductivity and bone-like characteristics are exhibited by bio-ceramic materials, such as hydroxyapatite (HA), tricalcium phosphate (TCP), zirconia, and bioactive glasses, whereas polymers, like chitosan, polycaprolactone (PCL), and polyether ketone (PEEK), are recognized for their mechanical strength and ease of processing. These materials can be hybridized to create composites with improved qualities that can be used in biodegradable. The performance of these composites has been further enhanced by developments in nanotechnology and additive manufacturing techniques, which allow for fine control over surface characteristics and structure. Implants with optimum mechanical and biological qualities can be made for each patient using fabrication techniques like 3D printing, electrospinning, and freeze-drying. Bio-ceramic–polymer composites have demonstrated enhanced osseointegration and decreased bacterial colonization in dental applications, including crowns, bridges, bone grafts, and guided tissue regeneration. Poor interfacial bonding, irregular degradation rates, expensive manufacturing costs, and a lack of clinical trials are still issues, though. The goal of future research is to create intelligent composites with integrated drug delivery systems, self-repairing capabilities, and antimicrobial qualities. Overcoming these obstacles and achieving the full potential of bio-ceramic–polymer composites in next-generation biomedical devices will require sustained interdisciplinary cooperation and technological developments.

Keywords: Bio-ceramics, polymer composites, biomedical applications, hydroxyapatite (HA), tissue engineering, 3D printing

INTRODUCTION

Innovations have been manifested in the field of biomaterials science contributing importantly to the shape of biomedical engineering and dentistry. Bio ceramic and polymeric composites are some of the promising candidates of biomaterials since they offer combined mechanical strength, bioactivity and biocompatibility of bio ceramics [1]. Conventional materials, like metals and single-phase ceramics, are usually not biologically responsive and may not be compatible with the host tissues and hence their clinical success is rather short. In comparison, the negative aspects of using ceramics and polymers have seen the invention of composite materials that combine the positive aspects of both materials to handle the much-needed issues of ceramics and polymers [2, 3].

Bio ceramics have great Oste conductivity and similarity to bone structure, whereas the polymers are elastic, easy to process and degradable [4, 5]. The result of this combination or hybridization of

***Author for Correspondence**
Arvinder Singh Channi
E-mail: drarvindersingh171902@gku.ac.in

[1]Associate Professor, Department of Mechanical Engineering, Guru Kashi University, Talwandi Sabo, Punjab, India
[2]Student, Department of Electronics and Communication, National Institute of Technology, New Delhi, Delhi, India.

Received Date: October 08, 2025
Accepted Date: October 13, 2025
Published Date: October 27, 2025

Citation: Arvinder Singh Channi, Manjot Kaur Channi. Recent Trends in Bio Ceramic and Polymer Composites for Biomedical and Dental Applications. International Journal of Composite Materials and Matrices. 2025; 11(2): 1–5p.

materials is composites that can bear mechanical load and facilitate tissue regeneration. The rising concern of implants as orthopaedic and dental, the scaffold materials in tissue engineering and biodegradable drug delivery systems, demand such materials all over the world [6, 7]. Moreover, nanotechnology and additive manufacturing could be used to increase performance of these composites and provide them with fine control of structure and surface characteristics [8, 9].

OVERVIEW OF BIO-CERAMIC MATERIALS

Hydroxyapatite (HA), tricalcium phosphate (TCP), zirconia (ZrO_2), and bioactive glasses are bio ceramics that have become popular in clinical practice because of its great biocompatibility, Oste conductivity, and capacity to bond with bone [10, 11]. Hydroxyapatite especially resembles the mineral content of natural bones hence making it a good scaffold material. Bioactive glasses instead can form a fast bonding to both hard- and soft-tissues and replaceable ions that signal the cells shown in Figure 1 [12].

The properties of zirconia made this material highly applicable in dentistry owing to its strong nature and fracture toughness, and cosmetic appearance in Table 1. Tricalcium phosphate is a biodegradable ceramic and is commonly used together with HA to control the speed of degradation and the in vivo resorption [13].

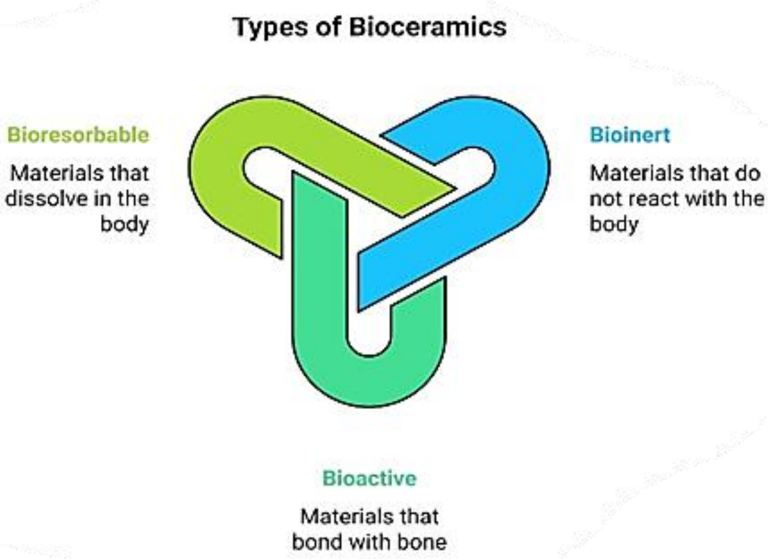

Figure 1. Types of bio-ceramic.

Table 1. Key bio-ceramic properties.

Material	Mechanical Strength (MPa)	Bioactivity	Application
Hydroxyapatite (HA)	~100	High	Bone fillers, coatings
Bioactive Glass	~50–60	Very High	Implants, Scaffolds
Zirconia (ZrO_2)	~900	Moderate	Dental Crowns, Implants

OVERVIEW OF BIOMEDICAL POLYMERS

Polymers, such as chitosan, polylactic acid (PLA), polycaprolactone (PCL), and polyether ether ketone (PEEK), have found widespread use in biomedical applications due to their flexibility, biodegradability, and chemical tailorable properties [14, 15].

Chitosan, a natural polysaccharide, exhibits antibacterial properties and supports cell attachment, while PLA and PCL are synthetic polyesters known for their controlled degradation and excellent biocompatibility [16]. PEEK, a high-performance thermoplastic, offers remarkable mechanical strength, making it ideal for load-bearing implants. However, polymers often face limitations in bioactivity, making their combination with bioactive ceramics essential for improving overall performance [17].

BIO-CERAMIC–POLYMER COMPOSITES

The combination of bioceramics and polymers lead to a hybrid set of composite materials where the advantage of both the materials were retained in Table 2. To illustrate, HA–PLA composites improve mechanical properties and bioactivity when compared to its individual components [18]. These composite materials will be made with intended microstructure and bonding between the interfaces to achieve the highest performance shown in Figure 2.

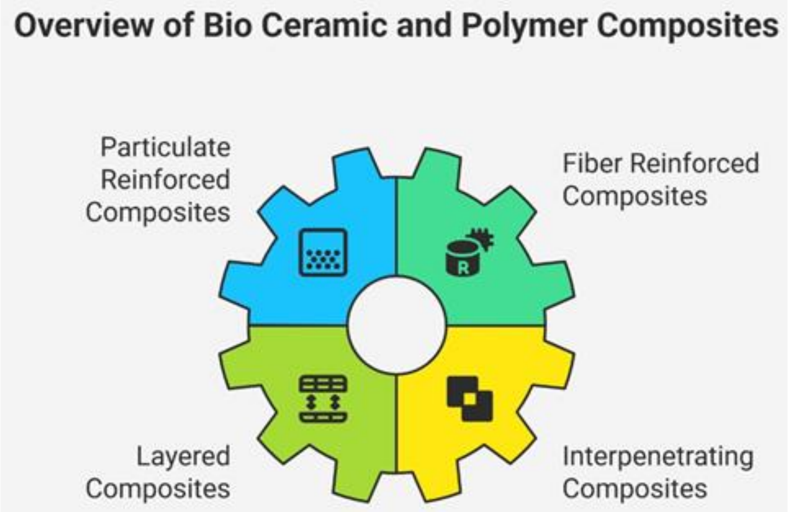

Figure 2. Classification of bio-ceramic and polymer composites.

Table 2. Biomedical applications of composite system.

Composite Type	Application	Benefit
HA/PLA	Dental Fillers	Bioactivity + degradability
Chitosan/ZrO2	Parodontal membranes	Strength + antibacterial
PEEK/Bioactive glass	Spinal implants	Load-bearing + bone bonding

FABRICATION TECHNIQUES

The strategies of fabrication, including 3D printing, electrospinning, freeze-drying, and sol-gel synthesis, provide the possibility of a scaffold architecture and porosity being controlled [19, 20]. Such techniques enable us to devise the manufacture of the materials that can most closely resemble the extracellular matrix, necessary to afford care to infiltration by the cell, and integration within the tissue in Figure 3.

Hybrid fabrication planning, which combines traditional with new technology are in the process of investigating as well. Computer-aided manufacturing (CAM) and computer-aided design (CAD) allow the design of patient-specific implants with maximized geometrical shapes and mechanical characteristics, and it is especially applicable to personalized medicine [21].

DENTAL APPLICATIONS

Bio-ceramic–polymer composites in dentistry may be found in crowns, bridges, roots of canal filling, bone graft replacements, and guided tissue regeneration (GTR) membranes [22]. Bio-active composites used in dentistry has been demonstrated to enhance Osseo integration and reduce bacteria colonization and healing after a surgery [23].

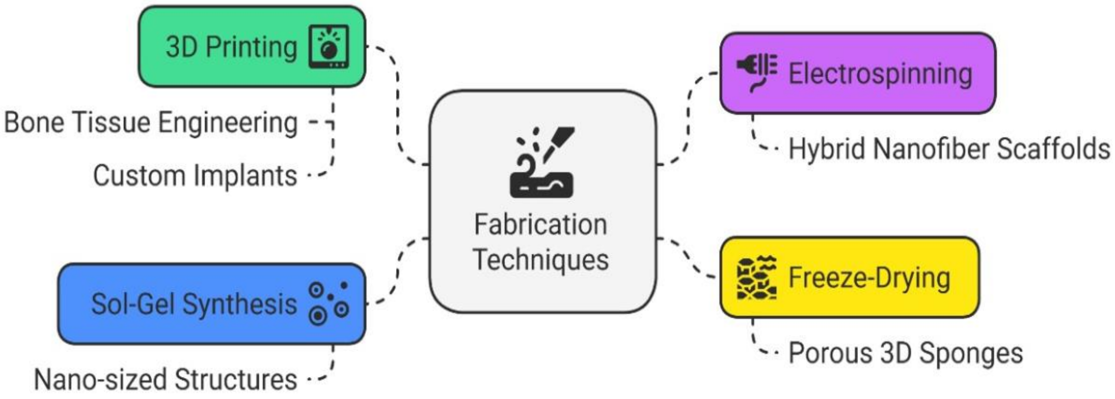

Figure 3. Fabrication techniques in biomedical engineering.

Composites made of zircon address the cosmetic need in prosthetics of the teeth but when based on HA encourage the development of alveolar bone. Chitosan and bio-ceramic GTR membranes have demonstrated good results in the treatment of periodontal diseases.

CHALLENGES AND FUTURE PROSPECTS

Despite significant progress, several challenges remain in the field. These include poor interfacial bonding between ceramic and polymer phases, inconsistent degradation profiles, limited clinical trials and long-term follow-up data, as well as high production costs and scalability issues.

Further studies are going to be devoted to the creation of intelligent composites, endowed with such features as antimicrobial action, a self-repairing feature, or drug delivery. Also, material design with the help of AI, biosensors integration to monitor health in real-time or the development of 3D printing of personalized biomaterials will transform the area [24].

CONCLUSIONS

Bio-ceramic and polymer composites are a transformative class of biomaterials for biomedical and dental applications. Through careful design and fabrication, these materials can mimic the mechanical and biological properties of native tissues. Continued interdisciplinary collaboration and technological advancements will be key in overcoming current limitations and fully realizing the potential of these composites in next-generation biomedical devices.

REFERENCES

1. Hench LL. Bioceramics: From concept to clinic. J Am Ceram Soc. 1991;74:1487–1510. doi: 10.1111/j.1151-2916.1991.tb07112.x.
2. Wang J, Zhang L, Wang K. Bioactive ceramic-based materials: Beneficial properties and potential applications in dental repair and regeneration. Expert Rev Med Devices. 2024;19(5):257–278. doi: 10.1080/17460751.2024.2343555.
3. Ratner BD, Hoffman AS, Schoen FJ. Biomaterials Science: An Introduction to Materials in Medicine. 2nd ed. San Diego: Academic Press; 2004. ISBN: 9780080470368.
4. Adeleke AS, Bushroa AR, Sopyan I. Recent development of calcium phosphate-based coatings on titanium alloy implants. Surf Eng Appl Electrochem. 2017;53(5):419–433. doi: 10.3103/S1068375517050027.
5. O'Brien FJ. Biomaterials & scaffolds for tissue engineering. Mater Today. 2011;14:88–95. doi: 10.1016/S1369-7021(11)70058-X.
6. Liu X, Ma P. Polymeric scaffolds for bone tissue engineering: 2nd special edition on musculoskeletal bioengineering. Ann Biomed Eng. 2004;32(3). doi: 10.1023/B:ABME.0000017544.36001.8e.
7. Bose S, Vahabzadeh S, Bandyopadhyay A. Bone tissue engineering using 3D printing. Mater Today. 2013;16:496–504. doi: 10.1016/j.mattod.2013.11.017.

8. Asefnejad A, Movahedi M, Poodineh Hajipour F. Smart Materials for Tissue Engineering Application. Tehran: Entesharat Norozi; 2019. ISBN: 978-662-02-0594-4.
9. Dash M, Chiellini F, Ottenbrite RM, Chiellini E. Chitosan—A versatile semi-synthetic polymer in biomedical applications. Prog Polym Sci. 2011;36:981–1014. doi: 10.1016/j.progpolymsci.2011.02.001.
10. Dorozhkin SV. Bioceramics of calcium orthophosphates. Biomaterials. 2010;31:1465–1485. doi: 10.1016/j.biomaterials.2009.11.050.
11. Abd El-Ghany OS, Sherief AH. Zirconia-based ceramics: Some clinical and biological aspects – review. Future Dent J. 2016;2:55–64. doi: 10.1016/j.fdj.2016.10.002.
12. Skallevold HE, Rokaya D, Khurshid Z, Zafar MS. Bioactive glass applications in dentistry. Int J Mol Sci. 2019;20(23):5960. doi: 10.3390/ijms20235960.
13. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials. 1999;20:1–25. doi: 10.1016/S0142-9612(98)00010-6.
14. Mano JF, Silva GA, Azevedo HS, Malafaya PB, Sousa RA, Silva SS, et al. Natural origin biodegradable systems in tissue engineering and regenerative medicine: Present status and some moving trends. J R Soc Interface. 2007;4:999–1030. doi: 10.1098/rsif.2007.0220.
15. Middleton JC, Tipton AJ. Synthetic biodegradable polymers as orthopaedic biomaterials. Biomaterials. 2000;21:2335–2346. doi: 10.1016/S0142-9612(00)00101-0.
16. Khan MUA, Abd Razak SI, Mohamed Ansari MN, Mohamed Zulkifli R, Ahmad Zawawi N, Arshad M. Development of biodegradable bio-based composite for bone tissue engineering: Synthesis, characterization and in vitro biocompatible evaluation. Polym (Basel). 2021;13:3611. doi: 10.3390/polym13213611.
17. Senra MR, Marques MFV, Monteiro SN. Poly(ether-ether-ketone) for biomedical applications: From enhancing bioactivity to reinforced-bioactive composites—an overview. Polym (Basel). 2023;15:373. doi: 10.3390/polym15020373.
18. Asghari F, Samiei M, Adibkia K, Akbarzadeh A, Davaran S. Biodegradable and biocompatible polymers for tissue engineering application: A review. Artif Cells Nanomed Biotechnol. 2016;45(2):185–192. doi: 10.3109/21691401.2016.1146731.
19. Szymczyk P, Labowska MB, Detyna J, Michalak I, Gruber P. A review of fabrication polymer scaffolds for biomedical applications using additive manufacturing techniques. Biocybern Biomed Eng. 2020;40:1–15. doi: 10.1016/j.bbe.2020.01.015.
20. Hasan A, Morshed M, Memic A, Hassan S, Webster TJ, Marei HE. Nanoparticles in tissue engineering: Applications, challenges and prospects. Int J Nanomedicine. 2018;13:5637–5655. doi: 10.2147/IJN.S153758.
21. Pupilli F, Ruffini A, Dapporto M, Tavoni M, Tampieri A, Sprio S. Design strategies and biomimetic approaches for calcium phosphate scaffolds in bone tissue regeneration. Biomimetics (Basel). 2022;7(3):112. doi: 10.3390/biomimetics7030112.
22. Imre B, Pukánszky B. Compatibilization in bio-based and biodegradable polymer blends. Eur Polym J. 2013;49(6):1215–1233. doi: 10.1016/j.eurpolymj.2013.01.019.
23. Liu W, Zu L, Wang S, Li J, Fei X, Geng M, et al. Tailored biomedical materials for wound healing. Burns Trauma. 2023;11:1–19. doi: 10.1093/burnst/tkad040.
24. Yu JJ, Park SA, Kim WD, Ha T, Xin YZ, Lee J, et al. Current advances in 3D bioprinting technology and its applications for tissue engineering. Polym (Basel). 2020;12(12):2958. doi: 10.3390/polym12122958.