IOCN 2025 Conference

The 5th International Online Conference on Nanomaterials

22–24 September 2025 | Online

MDPI

Mechanical Behavior of Bioinspired Nanocomposites for Orthopedic Applications

Partha Protim Borthakur , Elora Baruah, Kalyani pathak

Department of Mechanical Engineering, Dibrugarh University, Dibrugarh, 786004, India.

INTRODUCTION & AIM

Bioinspired nanocomposites replicate the structural and mechanical properties of natural tissues (e.g., bone, nacre).

Designed to mimic hierarchical architectures found in biological systems for improved functionality.

Offer a balance of strength, toughness, and bioactivity, critical for orthopedic use.

Address limitations of traditional implant materials (e.g., brittleness, lack of biointegration).

Promote bone regeneration and integration through tailored nanoscale features.

Show potential to improve the longevity and biocompatibility of orthopedic implants.

METHOD

◦High Strength and Toughness

◦Mimic hierarchical structures found in biological materials like bone and nacre.

◦Achieve an exceptional combination of strength, stiffness, and toughness.

◦Stiffness and Deformation Mechanisms

◦Stiffness originates mainly from the extrafibrillar matrix (Subunit-B).

◦Toughness arises as mineralized collagen fibrils (Subunit-A) deform post-yield.

◦Reflects the mechanical strategy of natural bone structures.

◦Influence of Platelet Geometry

◦Aspect ratio of platelets critically influences mechanical performance.

◦Staggered configurations optimize load transfer and crack deflection.

◦Leads to enhanced fracture resistance in the composite.

RESULTS & DISCUSSION

1. Hierarchical Architecture Enhances Mechanical Performance

Nanocomposites mimicking the multi-level structure of bone and nacre exhibit enhanced toughness and strength. Staggered platelet arrangements improve crack resistance and load distribution. Aligning inorganic platelets in a layered matrix can mimic bone-like energy dissipation.

2. Role of Subunit Interactions

Extrafibrillar matrix (Subunit-B) provides stiffness, while mineralized collagen fibrils (Subunit-A) contribute to ductility and toughness.

These synergistic mechanisms enable materials to withstand orthopedic loads without brittle failure. Subunit-based models explain deformation sequences observed under compressive and tensile stress .

3. Geometry of Reinforcement Phases Matters

Aspect ratio of ceramic platelets (e.g., hydroxyapatite, alumina) strongly influences load transfer and energy absorption.

Optimal aspect ratios (≥ 10:1) in a staggered configuration yield the best mechanical resilience.

4. Toughening Mechanisms

Crack deflection, crack bridging, and pull-out mechanisms observed in composites with bioinspired lamellar designs.

These mechanisms mimic nacre’s toughening strategy and delay catastrophic failure.

5. Interface Engineering is Critical

Interfacial bonding between organic and inorganic phases affects stress transfer and fatigue resistance.

Surface-modified nanoparticles improve integration and durability under cyclic loads

CONCLUSION

Bioinspired nanocomposites replicate nature’s architecture to deliver superior mechanical performance for orthopedic use.

These materials exhibit a unique synergy of high strength, stiffness, and toughness, essential for load-bearing implants.

Hierarchical structures and platelet geometry enable energy dissipation and crack resistance.

Interface design between organic and inorganic phases is critical for durability and fatigue resistance.

In vitro and in vivo evaluations confirm excellent biocompatibility and osseointegration.

They present a promising route toward next-generation safe, strong, and long-lasting orthopedic implants.

Future research should address scalability, long-term reliability, and clinical integration.

REFERENCES

References

Yang, X., Maghsoudi-Ganjeh, M., & Zeng, X. (2023). Computational investigation of the mechanical behavior of a bone-inspired nanocomposite material. Journal of Composites Science, 7(8), 341. https://doi.org/10.3390/jcs7080341

Borthakur, P. P. (2025). Nanoparticle enhanced biodiesel blends: Recent insights and developments. Hybrid Advances, 10, 100442. https://doi.org/10.1016/j.hybadv.2025.100442

Borthakur, P. P., Sarmah, P., Das, D., & Saikia, M. (2023). Nanotechnology: Exploring its applications in mechanical engineering. Modern Trends in Mechanical Engineering, 1(1), 31–55. Bright Sky Publications.

Borthakur, B., & Borthakur, P. P. (2024). The role of thermal analysis in engine fin design: Insights and perspectives. Recent Patents on Engineering, 18(8), 153–161. Bentham Science Publishers Direct.

Pathak, K., Ahmad, M. Z., Saikia, R., Borthakur, P. P., Pramanik, P., Islam, M. A., Das, A., Abdel-Wahab, B. A., Das, D., & Gogoi, S. (2024). Nanohybrid cerasomes: Advancements in targeted drug and gene delivery. European Journal of Medicinal Chemistry Reports, 12, 100178. https://doi.org/10.1016/j.ejmcr.2024.100178.

Sonowal, K., Borthakur, P. P., Baruah, E., & Boro, P. R. (2025). Engineering TiO_2 nanoparticles: Properties, synthesis and applications in modern industries. In Emerging frontiers in mechanical engineering research: Multidisciplinary research perspectives (Vol. 1, pp. 49–71). Akinik Publisher.

Boro, P. R., Borthakur, P. P., Baruah, E., Deka, R., & Sonowal, K. (2025). A review of properties, synthesis procedure, characterization and application for silicon oxide nanoparticles. In Emerging frontiers in mechanical engineering research: Multidisciplinary research perspectives (Vol. 1, pp. 73–99). Akinik Publication.

Borthakur, P. P. (2024). The Role and Future Directions of 3D Printing in Custom Prosthetic Design. Engineering Proceedings, 81(1), 10. https://doi.org/10.3390/engproc2024081010

Song, T., Zhao, F., Wang, Y., Li, D., Lei, N., Li, X., Xiao, Y., & Zhang, X. (2021). Constructing a biomimetic nanocomposite with the in situ deposition of spherical hydroxyapatite nanoparticles to induce bone regeneration. Journal of Materials Chemistry B, 9(10), 2469–2482. https://doi.org/10.1039/d0tb02648d