JSMPM

JOURNALS OF SUSTAINABLE MATERIALS PROCESSING AND MANAGEMENT
e-ISSN: 2821-2843

Vol. 6 No. 1 (2026) 91-99
https://publisher.uthm.edu.my/ojs/index.php/jsmpm

Comparative Assessment of SS316L vs Hydroxyapatite (HAp) Composites for Biomedical Implant Applications

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DOI: https://doi.org/10.30880/jsmpm.2026.06.01.008

Article Info

Received: 24 January 2026
Accepted: 23 April 2026
Available online: 18 May 2026

Keywords

Hydroxyapatite (HAp), composites biomaterial, implant product, SS316L, characterization

Abstract

This study presents a comparative assessment between SS316L stainless steel and hydroxyapatite (HAp)-based composites derived from bovine bone waste for sustainable biomedical implant applications. The analysis focuses on key physical and mechanical properties, including density, hardness, porosity, and compressive strength. SS316L exhibits high density (~7.9 g·cm^{-3}), hardness (~150–220 HV), and compressive strength exceeding 500 MPa, making it suitable for load-bearing applications. In contrast, HAp-based composites show lower density (~2.8–3.2 g·cm^{-3}), hardness (~40–75 HV), compressive strength (~50–200 MPa), and controlled porosity (~20–30%), which are advantageous for bone integration and bioactivity. Rather than serving as a direct replacement, HAp-based composites are better positioned as complementary biomaterials, particularly in coatings or hybrid implant systems. This study highlights the potential of waste-derived HAp composites as a sustainable material solution in biomedical engineering.

1. Introduction

The use of biomedical implants has increased steadily in recent years, particularly in orthopedic and dental applications such as fixation devices, joint components, and supporting structures. This trend has intensified the demand for reliable implant materials, while at the same time raising concerns related to raw material availability and long-term sustainability. As a consequence, alternative material sources derived from waste streams have begun to attract attention as potential solutions to reduce dependence on conventional metallic implants and to support more sustainable material cycles [1,2]. HAp by calcined bovine bone waste has received much attention due to its chemical similarity as natural bone, as well as its favorable biocompatibility and osteoconductive properties. However, its mechanical strength and brittleness limit its applications. These limitations have encouraged the development of HAp-based composite systems, using additional phases to improve mechanical performance without sacrificing bioactive behavior. Previous research by [3] have shown that combining HAp derived from bone with Titanium (Ti) and Aluminum (Al) metal constituents from recycled materials can effectively improve the mechanical characteristics of the resulting of biomaterials composites. For example, beverage cans are a recyclable metal waste with high aluminum content (reported ~95% Al in the literature), making them relevant for composite reinforcement strategies. [4]. In their composite study, the ASTM F138-based target window (porosity below 30% and hardness above 40 HV) was used as a practical benchmark, and the HAp–Al–Mg (85–10–5) composition achieved 73.3 HV hardness with 29.88% porosity, meeting the stated criteria. The same work also emphasizes the role of magnesium as a wetting agent to strengthen interfacial bonding, with the highest hardness reported at the 5% Mg level. In addition, studies reported that alloying/adding titanium can further enhance HAp composite performance through phase evolution [1,2]. In the AIP conference paper on HAp-based composites, the highest hardness and lowest porosity were obtained at 20% Ti and 850 °C, reaching 44.79 HV and 22.63% porosity, which was attributed to the formation of $CaTiO_3$ that increases composite stiffness and closes pores through improved grain fusion. The characteristics of biomaterials product required by implant materials must conform to controlled standards between mechanical and physical properties for the balance of densification and reinforcement in HAp-based biomaterial systems. On the other hand, metal implants such as SS316L are still widely used due to their corrosion resistance and strong mechanical properties, although metal biomaterials can be expensive compared to HAp, as they require complex processing paths, each of which depends on design and performance requirements. Recent research has also explored SS316L-based porous structures and SS316L coating composites using HAp to achieve a suitable bone structure as a continuing effort to improve implant compatibility through adjusting physical properties such as density and porosity. Based on a literature review, this article presents a comparative assessment between conventional metal-based biomaterials (SS316L) and HAp-based composites derived from bovine bone waste (with added metal intended to improve product performance) [1-5]. The comparison focuses on key product levels relevant to implant material selection, including physical and mechanical characteristics to clarify the position of waste-derived HAp composites as a sustainable alternative or complementary option to SS316L in application performance.

Recent developments in hydroxyapatite (HAp)-based biomaterials have expanded toward the incorporation of both metallic and ceramic reinforcement phases to improve mechanical performance while maintaining bioactivity [6–8]. The addition of metallic elements such as Ti and Mg has been reported to enhance densification, hardness, and interfacial bonding within HAp composite systems. In addition, the integration of ceramic phases, particularly spinel-type structures such as $MgAl_2O_4$, has shown promising results in improving structural stability and mechanical integrity due to their high thermal stability and strong interfacial characteristics. Previous studies have demonstrated that spinel–hydroxyapatite composites can improve hardness, microstructural uniformity, and bonding behavior within the composite system [7,8]. These findings indicate that current HAp-based biomaterials are increasingly developed as hybrid composite systems, combining bioactive ceramic matrices with reinforcing phases to achieve a balance between biological functionality and mechanical reliability [9,10].

2. Materials & Characterization

In this study, HAp-based composite systems derived from bovine bone waste are considered, including previously developed formulations incorporating metallic elements (Al, Ti, Mg) as well as ceramic-reinforced systems involving spinel phase formation. The incorporation of these secondary phases has been shown to enhance densification, interfacial bonding, and mechanical properties of the composite biomaterials, particularly in terms of hardness and structural stability.

The data presented in Table 1 were compiled through a structured literature-based analysis of representative material properties reported in peer-reviewed studies and standard references for biomedical applications [3–5]. The selection of data was based on commonly accepted ranges of physical and mechanical properties for SS316L and HAp-based composites, ensuring consistency and relevance to implant design considerations. The comparison criteria were defined based on key parameters that directly influence biomaterial performance, including density, hardness, porosity, compressive strength, fracture toughness, and bioactivity. These parameters were selected because they represent the fundamental balance between mechanical integrity and biological functionality required for implant materials.

The comparison considered in this article involves a commercial material, SS316L, and a laboratory-scale HAp-based composite derived from bovine bone waste [3]. In practice, SS316L has been widely used in orthopedic and dental implants due to its favorable mechanical strength, corrosion resistance, and established manufacturing processes. Its long-term application has positioned SS316L as a benchmark material for load-bearing biomedical components [11].

Table 1 presents a comparison of biomaterial properties based on relevant physical and mechanical characteristics associated with biomedical applications. SS316L exhibits a high density of approximately 7.9 $g \cdot cm^{-3}$, hardness in the range of 150–220 HV, and compressive strength exceeding 500 MPa, supporting its role as a standard material for load-bearing implants. Its nearly fully dense structure (<1% porosity) ensures excellent mechanical reliability and corrosion resistance; however, its high stiffness may contribute to stress-shielding effects in bone applications [11,12].

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Table 1 *The comparison by SS316L Vs HAp-based composites on product applications*

Property	SS316L Stainless Steel	HAp-Based Composites (Bone Waste–Derived)	Scientific Relevance for Biomedical Application
Material Class	Austenitic stainless-steel alloy	Bioactive ceramic	Fundamental difference in load-bearing behavior
Density (g·cm^{-3})	~7.9	~2.8–3.2	Lower density of HAp-based materials is closer to natural bone (≈1.8–2.1)
Hardness (HV)	~150–220	~40–75	SS316L suitable for high load; HAp composites sufficient for biointerface regions
Porosity (%)	< 1% (nearly fully dense)	~20–30% (controllable)	Porosity in HAp composites enhances bone ingrowth and fixation
Compressive Strength (MPa)	> 500	~50–200	SS316L dominates in structural strength
Fracture Toughness (MPa·m$^{1/2}$)	~50–100	~1–3	Explains brittleness of HAp-based systems
Bioactivity	Bioinert	Highly osteoconductive	HAp promotes direct bone bonding

From an engineering material selection perspective, the comparison can be further interpreted using simplified performance indicators. One relevant parameter is the strength-to-density ratio, which reflects the efficiency of a material in providing mechanical support relative to its weight. Although SS316L exhibits significantly higher absolute strength, its high density reduces its performance efficiency when normalized. In contrast, HAp-based composites, despite having lower strength, offer a more favorable balance between density and functional properties such as porosity and bioactivity. The controlled porosity (20–30%) contributes to osteoconductivity, which can be interpreted as a functional performance advantage in biomedical applications. Therefore, rather than direct substitution, the material selection should be based on performance mapping, where SS316L dominates in load-bearing applications, while HAp-based composites are advantageous in biointerface and bone integration roles.

Compared with SS316L, HAp-based composites exhibit a significantly lower bulk density, typically in range of 2.8–3.2 g/cm^3, which is closer to that of human bone. Their mechanical response is characterized by moderate property on hardness and compressive strength, with reported values varying depending on composition and processing conditions. Although these mechanical properties do not reach those of SS316L, the intentionally introduced porosity, typically around 20–30%, plays an important functional role rather than being a weakness. This porosity supports tissue ingrowth and enhances the bioanchoring of the implant within the surrounding bone. It should also be noted that the fracture resistance of HAp-based materials remains relatively low, reflecting the intrinsic brittleness of ceramic-dominated systems. This characteristic limit their direct use in applications subjected to high mechanical loads. Practically, SS316L behaves as a bioinert material and relies primarily on mechanical fixation for stability, whereas HAp-based composites actively interact with bone tissue through osteoconductive mechanisms. Therefore, HAp-based systems are more realistic for applications such as bone fillers, surface coatings, or bioactive components in hybrid implants, rather than serving as a sole replacement for load-bearing metal implants [1,2,4,13].

SS316L products on the market are implant materials that have been produced based on the following standards: ASTM F138 / F138M; ASTM F139 / F139M; ISO 5832-1; ISO 7153-1; EN 10088-3; EN ISO 5832-1; ASTM A240 / A276; ISO 10993; ASTM F86 [14-22], by fabrication and manufacturing flows that comply with procedures of regulatory acceptance. However, HAp-based composites derived from bone waste are an advanced material innovation that does not yet have market potential, requiring added value through the principles of sustainability and a circular economy. Overall, the data in Table 1 shows a comparison of SS316L products with HAp-based composites that play a role in biomedical implant applications [23]. The comparison in Table 1 highlights SS316L as a well-established implant material, supported by standardized production lines, regulatory approvals, and long-term clinical use. Its consistent mechanical performance and biomaterial properties make SS316L a reliable reference material for biomedical implant applications. In contrast, HAp-based composites derived from bone waste are still in the synthetic development stage. While offering superior bioactivity and strong sustainability advantages in line with circular economy principles, their mechanical reliability and standardization are still limited. Therefore, these composites require further material optimization and regulatory validation before reaching market readiness, positioning them as promising but complementary alternatives, not replacements for SS316 [21-25].

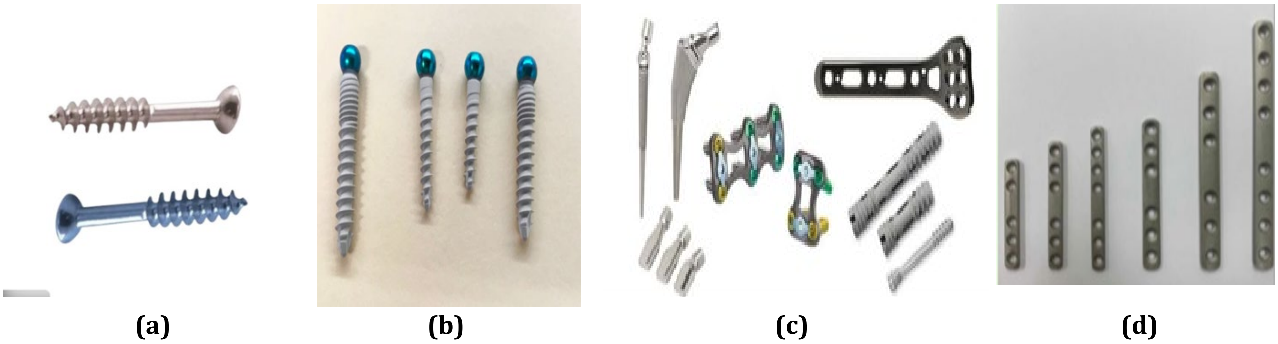

Fig. 1 *The component of biomaterials implant product (a) Orthopedic bone; (b) Orthopedic bone screws by Hap; (c) Orthopedic internal fixation devices; (d) Orthopedic bone plate [20-22]*

The product of orthopedic implant shown in the figure 1. Represent typical load-bearing medical devices such as bone plates, screws, and fixation systems commonly manufactured from implant-grade of SS316L made from by stainless steel. The components are designed to provide mechanical stability, precise load transfer, and structural support during the bone healing process based on standardization [19,20]. Their geometry, surface finish, and dimensional accuracy are tailored to meet strict clinical and regulatory requirements, ensuring reliability under physiological loading conditions. As standardized products, such implants serve as practical references for evaluating the performance and feasibility of emerging biomaterials intended for similar biomedical applications [26,27].

3. Microstructural Evolution and Phase Formation

To provide a broader understanding of composite material behavior, microstructural evolution and phase formation mechanisms in metal–ceramic systems are considered as an analogous reference. Studies on Ti/SiC composites [24,25] show that a relatively homogeneous distribution of reinforcement particles within the titanium matrix can be achieved at controlled synthesis temperatures (~900 °C), resulting in improved grain uniformity and mechanical stability. This condition promotes interfacial diffusion and reaction, leading to the formation of secondary phases such as TiC, TiO_2, and Ti–Si intermetallic compounds, which contribute to grain refinement and enhanced bonding. Although based on Ti/SiC systems, these mechanisms are relevant to HAp-based composites, particularly in understanding interfacial behavior, diffusion processes, and reinforcement effects in composite biomaterials.

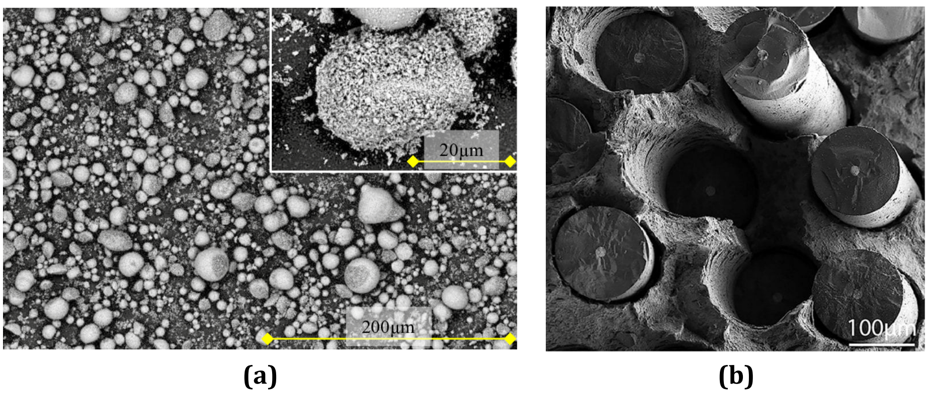

Fig. 2 *Representative of microstructural and reaction-induced phase formation in Ti/SiC composites; (a) SEM micrograph of hydroxyapatite-based powder morphology; (b) SEM micrograph illustrating the porous microstructure of a bone-interfacing biomaterial [24]*

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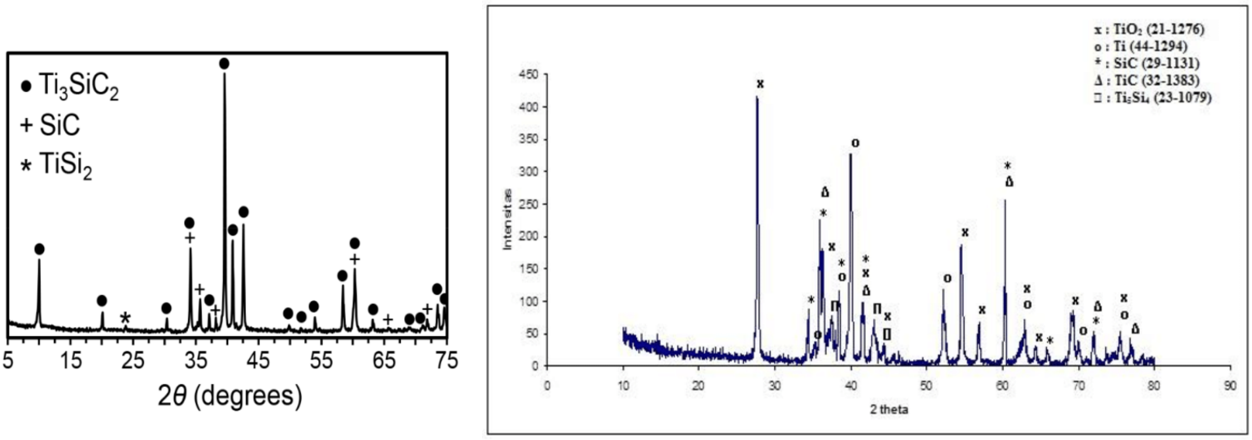


(a) **(b)**

Fig. 3 *Patters of X-ray diffraction patterns for biomaterial systems (a) Phase formation of Ti/SiC; (b) After thermal processing*

Figure 3 presents the X-ray diffraction (XRD) patterns of the composite system, showing the presence of dominant hydroxyapatite (HAp) peaks along with secondary phases. The characteristic diffraction peaks of HAp are observed at typical 2θ positions, indicating the preservation of the primary bioactive phase.

In addition, the appearance of secondary phases, such as spinel-related structures or other reaction products, suggests interfacial interactions between the constituent materials during processing. These phase formations are associated with improved densification and structural stability, which contribute to enhanced mechanical performance of the composite system.

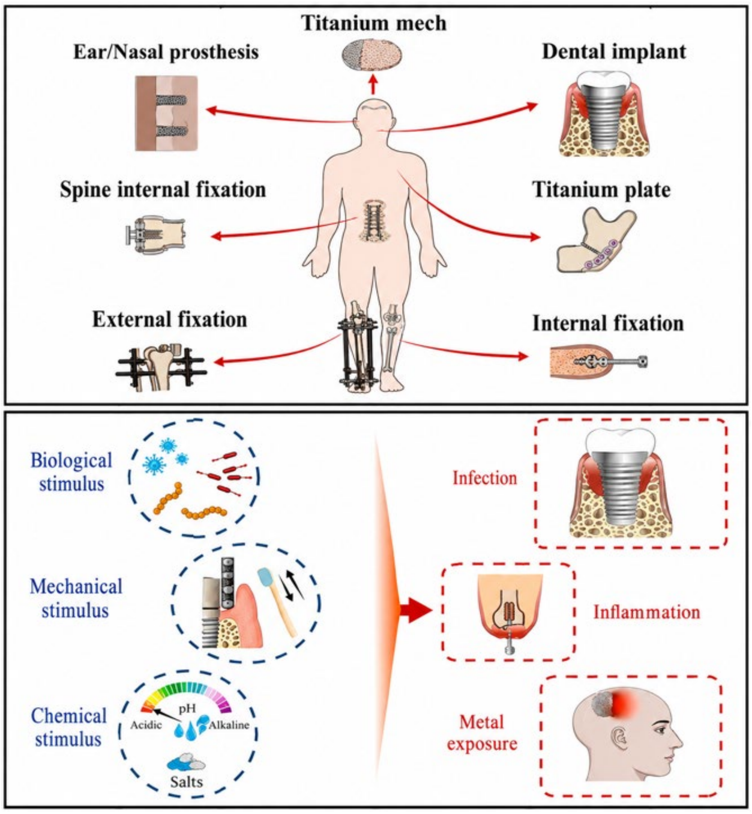
These observations are consistent with interfacial reaction mechanisms reported in titanium-based ceramic composites [24,25], where elevated processing temperatures promote uniform reinforcement distribution, enhanced interfacial diffusion, and the formation of secondary phases such as TiC, TiO_2, and Ti–Si intermetallic compounds. These phases play a critical role in grain refinement, interfacial bonding, and overall mechanical stability through effective load transfer mechanisms. Similar phenomena have also been widely reported in metal–ceramic composite systems, where interfacial reactions and phase evolution significantly influence composite performance and structural integrity [28,29].

In a comparable manner, such interfacial mechanisms are relevant to HAp-based composite systems, particularly in understanding phase evolution, bonding behavior, and reinforcement effects in bioactive materials. Previous studies have shown that the incorporation of metallic phases into HAp matrices can enhance mechanical properties while maintaining bioactivity, especially through improved interfacial compatibility and microstructural stability [30,31]. Therefore, the interpretation of Ti/SiC systems provides a useful analogical framework for explaining strengthening mechanisms in HAp-based biomaterial composites.

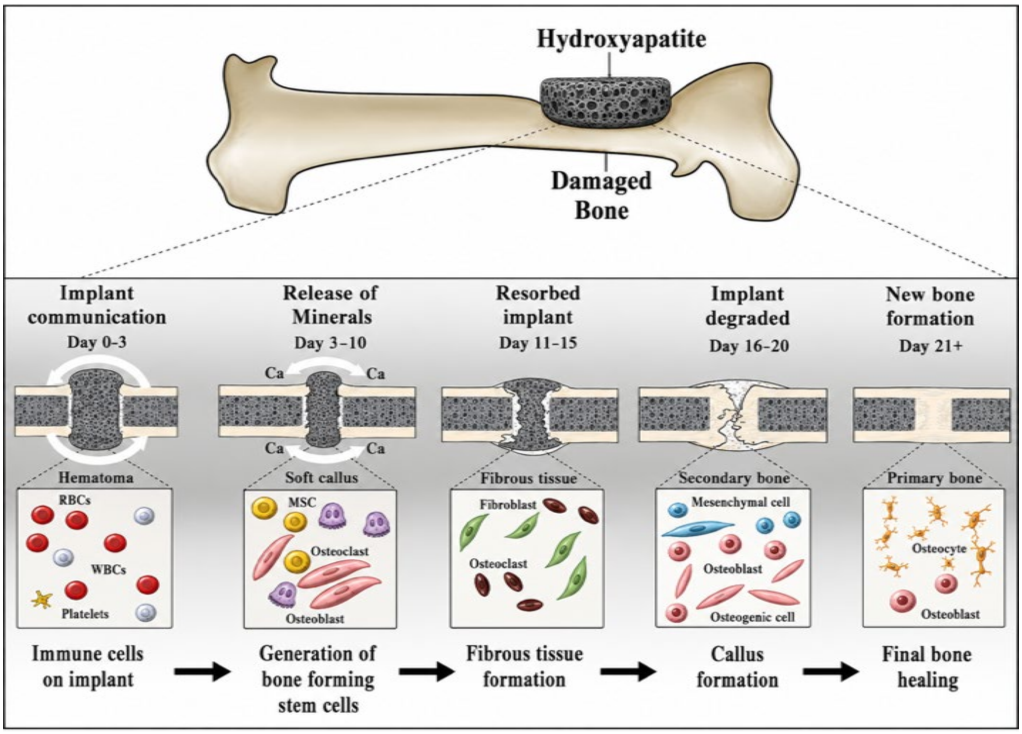
4. Commercial Comparison: SS316L and Hydroxyapatite-Based Biomaterials

Practical commercial applications of SS316L stainless steel continue to dominate the biomedical implant product sector, particularly for components required to withstand significant mechanical loads. Its adoption in orthopedic systems, such as fixation devices and joint support elements, is closely linked to its stable mechanical response, resistance to corrosion in physiological environments, and predictable performance during use. These characteristics should support the establishment of standardized manufacturing lines and facilitate regulatory approvals for decades of clinical applications. Consequently, SS316L is generally selected when structural reliability and fatigue resistance are primary design considerations. Unlike emerging biomaterials, its commercial position is driven not by product standardization and novelty, but by the accumulation of proven clinical results verified by standards. This established status explains why SS316L remains the reference material for load-bearing implants, even as alternative biomaterials continue to be explored for complementary biological functions.

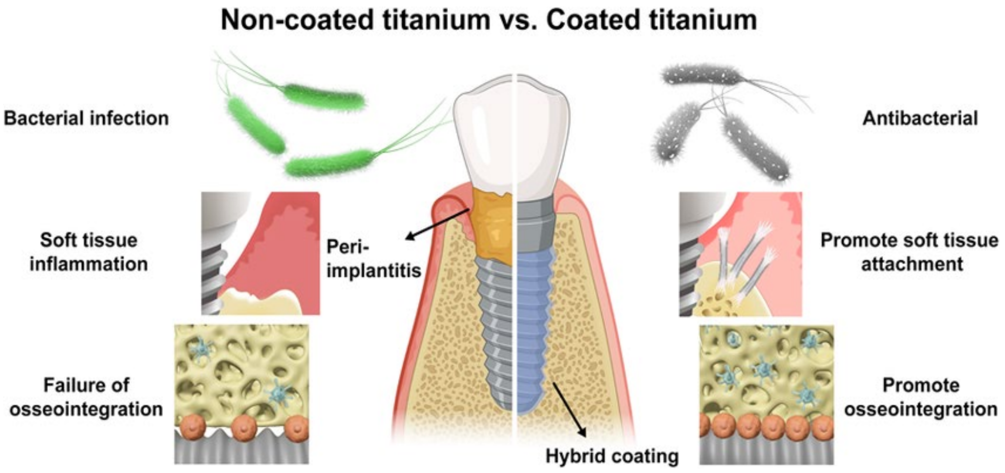
Figure 4 is presented in an enlarged format to provide clearer visualization of the comparative performance between SS316L and HAp-based biomaterials. HAp-based biomaterials produced from bovine bone waste by bovine bone waste were currently position within a developing segment of biomedical product on market, where their used guid more by biological functionality than by structural performance. The applications, for materials are rarely intended to replace metallic implants directly especially SS316L, but are instead utilized in roles that emphasize interaction with bone tissue, such as bioactive coatings, bone fillers, and components within hybrid implant system as well. Their relevance in these applications is largely associated with their inherent osteoconductive behavior, which supports interfacial bonding between the implant surface and surrounding bone. An additional aspect that contributes to the growing interest in bone derived of HAp composites is the origin of the raw material itself. The use of bovine bone waste has addressed the growing focus on sustainable material sourcing in medical engineering. While this sustainability aspect does not replace mechanical requirements, it does provide added value in material selection, particularly for applications where biological performance and environmental considerations are considered simultaneously.



(a)



(b)



(c)

Fig. 4 *Commercial of biomaterial product between SS316L vs HAp-based biomaterials (a) SS316L for load-bearing implants application; (b) Applications of Hap; (c) Compositites of SS316L–HAp implants*

Overall, the comparison shows that SS316L and HAp-based biomaterials have met different functional demands in implant design. HAp as a direct replacement. SS316L continues to meet the requirements regarding mechanical stability and long-term structural support, especially under load-bearing conditions. In parallel, HAp-based materials provide biological advantages at the bone-implant interface, where osteoconductivity and surface interactions play a dominant role. This functional separation supports the development of hybrid material concepts, where a metal substrate ensures mechanical integrity while a bioactive phase is introduced to improve the interfacial response with the surrounding tissue. Such a hybrid configuration allows each material system to operate within its optimal performance domain, offering a balanced approach to implant design that integrates mechanical reliability with improved biological integration.

5. Conclusion

This study presents a comparative assessment between SS316L and hydroxyapatite (HAp)-based composites derived from bovine bone waste for biomedical implant applications. The results indicate that SS316L provides superior mechanical strength and structural stability, making it suitable for load-bearing applications. In contrast, HAp-based composites exhibit lower density, controlled porosity, and enhanced bioactivity, which are advantageous for bone integration.

The findings suggest that HAp-based composites are not intended to directly replace metallic biomaterials but rather to complement them, particularly in hybrid or coating-based systems. The incorporation of additional phases, including metallic and ceramic reinforcements, plays a significant role in improving the mechanical performance of HAp-based materials.

Furthermore, the utilization of bovine bone waste as a raw material supports sustainable material development and aligns with circular economy principles. Overall, this study highlights the potential of HAp-based composites as a sustainable and functional biomaterial for future implant applications.

Acknowledgement

The authors gratefully acknowledge the support from the Department of Metallurgical Engineering, Universitas Sultan Ageng Tirtayasa (UNTIRTA), Indonesia, for providing research facilities and technical assistance during this study. Appreciation is also extended to the Department of Production and Management, Polytechnic University of Tirana, Albania, for academic collaboration and constructive discussions that contributed to the development of this work. The authors further acknowledge all colleagues and laboratory staff who supported material preparation and characterization activities.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Author Contribution

*All authors contributed to the **conception and design of the study**. **Material preparation**, **data collection**, and **characterization** were performed collaboratively. **Data analysis and interpretation** were conducted jointly by the authors. The manuscript was written through contributions from all authors, and all authors reviewed and approved the final version of the manuscript.*

References

[1] Harun, W. S. W., Asri, R. I. M., Alias, J., Zulkifli, F. H., Kadirgama, K., Ghani, S. A. C., & Shariffuddin, J. H. M. (2018). A comprehensive review of hydroxyapatite-based coatings adhesion on metallic biomaterials. Ceramics International, 44(2), 1250-1268. https://doi.org/10.1016/j.ceramint.2017.10.162

[2] Bose, S., Roy, M., & Bandyopadhyay, A. (2012). Recent advances in bone tissue engineering scaffolds. Trends in biotechnology, 30(10), 546-554. https://doi.org/10.1016/j.tibtech.2012.07.005

[3] Pramono, A., Timuda, G. E., Rifai, G. P. A., & Khaerudini, D. S. (2022). Synthesis of spinel-hydroxyapatite composite utilizing bovine bone and beverage can. Crystals, 12(1), 96. https://doi.org/10.3390/cryst12010096

[4] Dorozhkin, S. V. (2010). Bioceramics of calcium orthophosphates. Biomaterials, 31(7), 1465-1485. https://doi.org/10.1016/j.biomaterials.2009.11.050

[5] Al-Mamun, N. S., Deen, K. M., Haider, W., Asselin, E., & Shabib, I. (2020). Corrosion behavior and biocompatibility of additively manufactured 316L stainless steel in a physiological environment: the effect of citrate ions. Additive Manufacturing, 34, 101237. https://doi.org/10.1016/j.addma.2020.101237

[6] Pramono, A., Sulaiman, F., Milandia, A., Warfian, B., Suryana, Juniarsih, A., & Khaerudini, D. S. (2024). Formation of tricalcium phosphate (TCP) in hydroxyapatite (HAp)-Based composites. AIP Conference Proceedings, 2891, p. 020002. https://doi.org/10.1063/5.0208224

[7] Farazin, A., & Darghiasi, S. F. (2025). Hydroxyapatite-based nanocomposite scaffolds for bone regeneration. International Journal of Applied Ceramic Technology, 22(6), e70041. https://doi.org/10.1111/ijac.70041

[8] Ramesh, S., Loo, Z. Z., Tan, C. Y., Chew, W. K., Ching, Y. C., Tarlochan, F., Chandran, H., Krishnasamy, S., Bang, L. T., & Sarhan, A. A. (2018). Characterization of biogenic hydroxyapatite derived from animal bones for biomedical applications. Ceramics International, 44(9), 10525-10530. https://doi.org/10.1016/j.ceramint.2018.03.072

[9] Miracle, D. B. (2005). Metal matrix composites–from science to technological significance. Composites science and technology, 65(15-16), 2526-2540. https://doi.org/10.1016/j.compscitech.2005.05.027

[10] Chawla, K.K. (2012). Metal Matrix Composites. In: Composite Materials. Springer, New York, NY. https://doi.org/10.1007/978-0-387-74365-3_6

[11] Ratner, B. D., Hoffman, A. S., Schoen, F. J., & Lemons, J. E. (2004). Biomaterials science: an introduction to materials in medicine. Elsevier.

[12] Geetha, M., Singh, A. K., Asokamani, R., & Gogia, A. K. (2009). Ti based biomaterials, the ultimate choice for orthopaedic implants–A review. Progress in materials science, 54(3), 397-425. https://doi.org/10.1016/j.pmatsci.2008.06.004

[13] Niinomi, M. (2008). Mechanical biocompatibilities of titanium alloys for biomedical applications. Journal of the mechanical behavior of biomedical materials, 1(1), 30-42. https://doi.org/10.1016/j.jmbbm.2007.07.001

[14] ASTM International. ASTM F138/F138M – Standard Specification for Wrought 18Cr-14Ni-2.5Mo Stainless Steel Bar and Wire for Surgical Implants. ASTM International, West Conshohocken, PA

[15] ASTM International. ASTM F139/F139M – Standard Specification for Wrought 18Cr-14Ni-2.5Mo Stainless Steel Sheet and Strip for Surgical Implants. ASTM International, West Conshohocken, PA

[16] ASTM International. ASTM F86 – Standard Practice for Surface Preparation and Marking of Metallic Surgical Implants. ASTM International, West Conshohocken, PA.

[17] ASTM International. ASTM A240/A240M – Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications. ASTM International.

[18] International Organization for Standardization. ISO 5832-1: Implants for surgery — Metallic materials — Part 1: Wrought stainless steel. ISO, Geneva.

[19] International Organization for Standardization. ISO 7153-1: Surgical instruments — Metallic materials — Part 1: Stainless steel. ISO, Geneva.

[20] International Organization for Standardization. ISO 10993-1: Biological evaluation of medical devices — Part 1: Evaluation and testing within a risk management process. ISO, Geneva.

[21] European Committee for Standardization. EN ISO 5832-1: Implants for surgery — Metallic materials — Wrought stainless steel. CEN, Brussels

[22] European Committee for Standardization. EN 10088-3: Stainless steels — Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products. CEN, Brussels.

[23] Davis, J. R. (2003). Handbook of materials for medical devices. ASM International.

[24] Pramono, A., Dhoska, K., Moezzi, R., Milandia, A. (2021). Ti/SiC based metal matrix composites by using self-propagating high temperatures synthesis (SHS). Revue des Composites et des Matériaux Avancés-Journal of Composite and Advanced Materials, 31(3), 125-129. https://doi.org/10.18280/rcma.310302

[25] Yang, Q., Xu, Z., Li, L., & Li, P. (2023). Microstructure and performance research on ceramic-enhanced inconel 718 matrix composite using laser additive manufacturing. Metals, 13(9), 1525. https://doi.org/10.3390/met13091525

[26] Zivic, F., Affatato, S., Trajanovic, M., Schnabelrauch, M., Grujovic, N., & Choy, K. L. (Eds.). (2017). Biomaterials in clinical practice: advances in clinical research and medical devices. Springer.

[27] DePuy Synthes, Stainless Steel Locking Compression Plate (LCP) System. Raynham, MA, USA: DePuy Synthes, Johnson & Johnson, 2020. https://www.jnjmedtech.com/en-US/product/locking-compression-plate-system

[28] Zhang, M., Ma, D., Wang, J., Dai, S., Xue, Y., & Zhu, L. (2025). Enhancing interfacial bonding in metal matrix composites: challenges, methods, and future prospects. Critical Reviews in Solid State and Materials Sciences, 1-54. https://doi.org/10.1080/10408436.2025.2542367

[29] Hatim, A., Khaddoudi, D., Abida, F., Ouydir, H. A. A., Kouzbour, S., Agunaou, M., El Hafiane, Y., Abourriche, A., Benhammou, A., Hatim, Z., & Abouliatim, Y (2025). Low-Cost and Sustainable Hydroxyapatite Synthesis Using Technical-Grade Phosphoric Acid for Environmental Applications: Structural and Morphological Insights. Open Ceramics, 100870. https://doi.org/10.1016/j.oceram.2025.100870

[30] Omigbodun, F. T., Oladapo, B. I., & Osa-uwagboe, N. (2026). Exploring the frontier of Polylactic Acid/Hydroxyapatite composites in bone regeneration and their revolutionary biomedical applications–A review. Journal of Reinforced Plastics and Composites, 45(5-6), 1230-1250. https://doi.org/10.1177/07316844241278045