



RESEARCH ARTICLE

OPEN ACCESS

FINITE ELEMENT ANALYSIS AND MECHANICAL TESTING OF TITANIUM ALLOY (Ti-6Al-4V) AND SILICON CARBIDE (SiC) FOR HIP IMPLANTS

Selva Babu.B^{*1}, Bubesh Kumar D.², Prabhu.L³, Sathiyaraj.S⁴^{1, 2, 3, 4}Department of Mechanical Engineering, Aarupadai Veedu Institute of Technology, Vinayaka Mission's Research Foundation (DU), Tamil Nadu, India.¹<https://orcid.org/0000-0003-4172-7882>²<https://orcid.org/0000-0002-4308-2793>³<https://orcid.org/0000-0001-9019-4555>⁴<https://orcid.org/0000-0001-8504-0412>E-mail: babu.prod@gmail.com, bubeshkumar@avit.ac.in, prabhu@avit.ac.in, sathiyaraj@avit.ac.in

ARTICLE INFO

Article History

Received: February 24, 2026

Reviewed: March 23, 2026

Accepted: April 01, 2026

Published: May 29, 2026

*Keywords:*Ti-6Al-4V titanium alloy,
Silicon Carbide,
Finite element analysis,
Solidworks 14,
Scanning electron microscopy.

ABSTRACT

Orthopedic surgical implants have traditionally been produced using conventional manufacturing techniques, with the output of these methods depending on the weight of the fabricated component and its biologically sourced materials. These hip implant composites, when exposed to physiological conditions over extended periods, particularly blood and adjacent soft tissues, are susceptible to gradual material degradation, manifesting as corrosion-induced damage and structural compromises. To address these challenges, this study focused on the development of titanium-containing composite material devices, primarily incorporating silicon carbide as a supporting component. The devices were cast via high-temperature sintering, facilitated by a specialized die assembly. The geometric design, material composition, and dimensional precision of these die sets are critical factors that determine the compressing efficiency and, consequently, the quality of the resulting sintered products. Therefore, this study emphasizes the design and application of a sintering die set optimized for cold uniaxial compression to produce cylindrical green packs characterized by a consistent layout and sufficient mechanical strength before the heated compression process. The compaction die set is a crucial component of the powder metallurgy method, which is responsible for shaping loose powder into the intended form. The die set was designed in accordance with the ASTM standards, and AISI D3 steel was used for its fabrication. This study also elaborates on the design factors, calculations, 2-D drawings, and 3-D models related to the die set. The die was manufactured using processes such as facing, turning, drilling, grinding, wire-cut electrical discharge machining (EDM), and heat treatment. The design was analyzed using SolidWorks 14 and ANSYS 2023R1. Following the evaluation of the safe load and production of the die set, the specimens were characterized. Scanning electron microscopy (SEM) evaluation identified the grain boundaries and porosity of the material, and mechanical tests demonstrated satisfactory hardness and biocompatibility.



Copyright ©2026 by authors and Galileo Institute of Technology and Education of the Amazon (ITEGAM). This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

I. INTRODUCTION

Globally, a significant number of individuals require bone replacements to treat injuries, trauma, and diseases. Historically, metal implants have been used in these patients. However, metal implants have certain limitations, including their weight, potential reactivity with human tissues and blood, and susceptibility to corrosion [1]. Corrosion can lead to implant loosening, requiring replacement, a procedure that can have substantial implications for human health. Implants are typically designed to last for a minimum of 15 years. However, recent findings suggest that some implants fail early because of fatigue corrosion. Therefore, further research on the fatigue corrosion of implants is essential, as such failures can occur within a month of implantation in the human body [2], [3]. Implant failures often result from the interaction between blood and implants, as blood is inherently corrosive in nature.

New materials are being developed for human implants, including ceramics. Ceramics, which have long been used in pottery and other applications, are also employed in various implants. When considering implants for hip replacement, factors such as the strength-to-weight ratio, corrosion resistance, and fatigue corrosion are critical. The initial research involved the use of finite element modeling to examine the design of the sintering die set and ceramic components. The uniaxial compaction process, which involves compressing powder under high pressure in a sealed chamber, was simulated using ANSYS Workbench software. The die set, which was oriented upwards, compressed the ceramic material. Pressures ranging from 350 to 1500 MPa are required for this treatment. Typically, temperatures of 1600°C are employed to shrink the mixed material within the circular die setup [4]. However, ceramic greens pose challenges when they are compressed.

Specifically, the interaction between the container's interior and the die's outer layer, as well as the interaction within the powder particles, is responsible for the permeation and round microcracking observed on the exterior of the green device. These factors can lead to surface imperfections, including restricted penetration scratches and radial microcracks, which are frequently observed in the outer areas of the compact [5]. Although these characteristics may appear detrimental, they can enhance the packing efficiency and, consequently, the material performance under specific conditions. Cold uniaxial compacting, employed across various forming methods, remains a valuable technique for molding ceramic powders by applying substantial compressive stress within a rigid die assembly. After shaping, the consolidated form is removed from the die and undergoes thermal processing, a phase that facilitates particle attachment and aggregation. This consolidation process generally occurs at high temperatures, and particle adhesion and neck growth are crucial for achieving mechanical strength, often in tightly controlled ammonia-rich environments [6]. To facilitate process development, the die-set layout and loading behavior were designed and assessed through numerical modeling using SolidWorks Software 14 and ANSYS Workbench 15.

The feasibility of the proposed method was confirmed by the successful production of green pellets incorporating alumina, zirconia, and hydroxyapatite. The load capacity during the compression phase was determined to be 800 kN, as estimated using a Universal Testing Machine (UTM) [7]. Concurrently, advancements in production and post-treatment techniques have enabled more precise monitoring of implant geometry, internal structure, and surface properties, thereby enhanced structural functionality and increased the potential for bone integration [8]. Advanced ceramic materials have become increasingly important in clinical settings, particularly in orthopedic prosthetics and surgical implants [9]. Bioceramics, specifically engineered for healthcare and orthodontic applications, are becoming increasingly prevalent as the demand for artificial substitutes rises in orthopedic applications. The fabrication of implants requires careful consideration, primarily because ceramic materials are susceptible to damage from environmental factors, particularly slow crack growth (SCG) in moist conditions [10].

This phenomenon is typically attributed to chemical reactions involving hydroxyl groups present in the atmosphere and highly stressed crack tips, which potentially compromise the metal-oxygen bond within the ceramic structure. Consequently, crack propagation may advance incrementally after a critical flaw dimension is reached, at which point a sudden fracture can occur without any prior macroscopic indications [11]. Among advanced ceramic systems, yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) and alumina (Al_2O_3) have gathered sustained interest for implant-related applications, primarily because of their favorable combination of mechanical strength and structural reliability. Their high resistance to surface damage, coupled with a relatively strong fracture tolerance and elastic response, renders them suitable for demanding service conditions [12]. These attributes have encouraged their widespread application, particularly in biomedical settings [13], [14], where they are routinely employed. Beyond the clinical domain, the same material characteristics support their use in various engineering applications, including oxygen-sensing devices, protective thermal coatings for cutting and optical fiber tools, and functional elements within solid-oxide fuel cell technologies.[15].

II. MATERIALS AND METHODOLOGY

II.1 PROCESSING AND TESTING METHODS

Ti-6Al-4V titanium alloy was chosen as the main matrix material because of its established role in structural and biomedical fields, where it offers a good mix of mechanical strength, corrosion resistance, and biocompatibility. To alter the mechanical properties of the matrix, SiC was added as a ceramic phase to boost stiffness and surface hardness while ensuring that the dimensional stability remained within acceptable limits. The reinforcement strategy aimed to improve the load-bearing capacity without significantly reducing the ductility. In the chosen formulations, additional oxide-based components, such as alumina, zirconia, and hydroxyapatite, were included to evaluate their functional roles in the glass. Alumina was selected for its wear and thermal degradation resistance, whereas zirconia was selected for its stress-induced transformation behavior, which is often associated with enhanced fracture toughness. Hydroxyapatite was incorporated to encourage biological interactions at the material interface of the scaffold. During powder processing, polyvinyl alcohol served as a temporary binder to aid in the formation of the green compact. To ensure consistency between the experimental data and numerical models, the elastic behavior of the titanium-silicon carbide composite was characterized using a Young's modulus of 180 GPa and a Poisson's ratio of 0.27.

II.2 POWDER PREPARATION AND BLENDING

Composite samples were created using a powder metallurgy method, which was chosen to ensure precise control over the phase distribution during the manufacturing process. Ti-6Al-4V and SiC powders were measured according to specific compositions to maintain a uniform reinforcement ratio within the metal matrix. For ceramic systems based on oxides, alumina was mixed with unstabilized zirconia in different proportions to study the effects of the composition. The powders were homogenized through ball milling, which facilitated close interactions between the metal and ceramic components while reducing clumping. This step was deemed essential for achieving an even particle distribution and minimizing density variations during the subsequent compaction and sintering stages.

II.3 COMPACTION PROCESS

Cylindrical green compacts were created by cold uniaxial pressing of the mixed powder blends. The die–punch setup facilitated the production of pellets with uniform geometries and consistent dimensions. Figure 1(a) illustrates the tooling used for compaction, depicting the two-dimensional design of the die assembly, which was developed according to the ASTM B925-08 standards. To minimize the friction between the powder and die wall, a suitable lubricant was applied during pressing, ensuring a more uniform pressure distribution and reducing density variations within the green bodies.

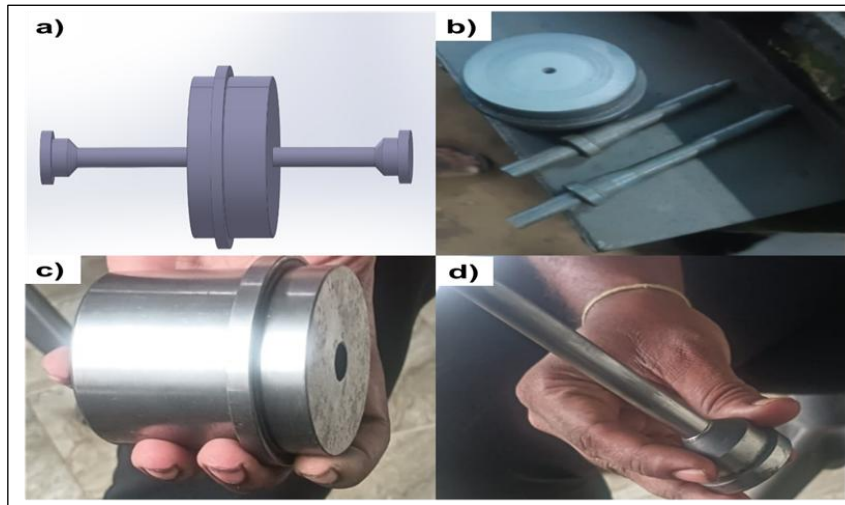


Figure 1: shows a) Model of the Die Set b) Sintering Die Set c) Die Set d) Punch.

Source: Authors, (2026).

II.4 DESIGN AND FABRICATION OF THE SINTERING DIE SET

The die system designed for sintering was formed to meet the dual requirements of high compaction forces and prolonged exposure to elevated temperatures during its use. Its design, which includes a central die body and opposing punch components, was developed using SolidWorks 14 to ensure structural strength and precise dimensions. A 0.5 mm clearance was intentionally set between the punch, and die bore to minimize friction and reduce wear over time. AISI D3 tool steel was selected for its high chromium content and excellent wear resistance. The manufacturing process involved material removal techniques such as facing, turning, drilling, and boring, all of which were carried out using CNC lathe systems, as shown in Fig. 1(b). Following the completion of the main machining operations, the die components were subjected to a carefully achieved through heat treatment process that included stress relief, hardening, and subsequent tempering. These procedures were implemented to improve the mechanical reliability while preserving dimensional accuracy. Surface finishing was performed using a combination of cylindrical and flat grinding techniques to achieve the desired surface quality. The final die assembly and corresponding punch elements, ready for use in pellet production, are shown in Figures 1 (c) and 1 (d), respectively.

II.5 MECHANICAL PROPERTIES OF TITANIUM AND SILICON CARBIDE

Table 1 provides an overview of the methods used to assess essential physical characteristics, such as the volume of the specimen, porosity, thermal conductivity, and related thermal expansion coefficient. These data were then used to investigate how the SiC reinforcement affects the overall physical behavior of the material system. The mechanical properties of the material, including microhardness, tensile strength, elastic modulus, wear characteristics, and fracture toughness, were assessed and compared with those of monolithic Ti-6Al-4V, as detailed in Table 2.

Table 1: Titanium silicon carbide composite Physical Properties.

Property	Ti-6Al-4V	Ti-6Al-4V + 10% SiC	Remarks
Density (g/cm ³)	4.43	4.40–4.42	Slight reduction due to SiC (3.21 g/cm ³)
Porosity (%)	1–2	0.5–1.5	Decreases with better sintering
Thermal Conductivity (W/m·K)	6.7	8–10	Increases with SiC
Coefficient of Thermal Expansion (μm/m·K)	8.6	7.8	Lower expansion improves dimensional stability

Source: Authors, (2026).

Table 2: Titanium silicon carbide composite Mechanical Properties.

Property	Pure Ti-6Al-4V	Ti-6Al-4V + SiC (10 wt%)	Remarks
Microhardness (HV)	340–360	420–480	~25–30% increase due to SiC
Ultimate Tensile Strength (MPa)	950–980	1050–1150	Improved load transfer via SiC
Elastic Modulus (GPa)	110	125–135	Enhanced stiffness
Wear Rate (mm ³ /N·m)	4.5×10 ⁻⁵	1.8×10 ⁻⁵	Better wear resistance
Fracture Toughness (MPa√m)	55	52	Slight reduction (brittleness due to ceramic phase)

Source: Authors, (2026).

In crafting the experimental strategy, ensuring uniformity in procedures was prioritized throughout the different phases of material preparation, which included powder-based processing, the creation of in-house tools, and the use of advanced consolidation techniques. Traditional furnace sintering and spark plasma sintering were employed to investigate the effects of variations in thermal exposure and consolidation kinetics on microstructural evolution. Consistent protocols for specimen preparation and assessment of physical and structural properties further minimized variability. The material properties derived from the experimental data were integrated into the computational framework to bolster the reliability of the finite element simulations. Overall, the chosen methodology provides a structured approach for examining the relationships between processing conditions, changing microstructures, and the resulting functional response, as discussed in the following sections.

II.6 POWDER PROCESSING

In this study, a powder metallurgy technique was employed to fabricate uniform blends of Ti-6Al-4V and SiC particles. Additionally, the research yielded ceramic compounds such as alumina, zirconia and hydroxyapatite.

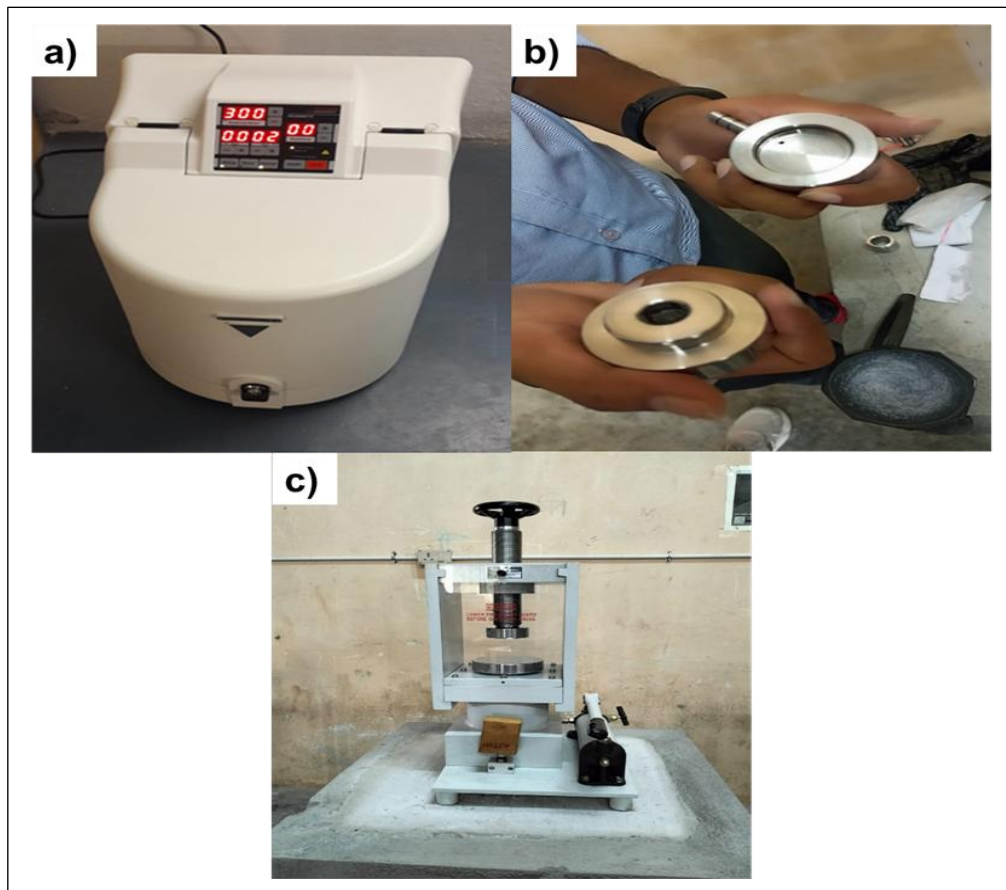


Figure 2: a) Ball milling machine, b) Steel die punch, c) Pallet machine.
Source: Authors, (2026).

As illustrated in Figure 2 (a), ball milling was used to break up agglomerates and ensure an even particle distribution before compression. Surface analysis verified the absence of macroscopic fragmentation, indicating that the selected grinding time and rotational speed were effective in creating a homogeneous mixture. The cold compression grinding process, using a specially designed steel die and pressing equipment (Figure 2 (b)), resulted in green pellets with adequate dimensional stability and handling strength, with no visible breakage or boundary fractures after their ejection. The observed movement suggests that lubrication was successful and that the weight was distributed evenly throughout the crushing process. This was further enhanced by employing high-power compression equipment (Figure 2 (c)), which applied consistent pressure, resulting in a uniform green density.

III. RESULTS AND DISCUSSION

III.1 SEM ANALYSIS

The SEM image, taken at an increased frequency of 20 kV and a magnification of 5,000 $\times$, reveals the external morphology of the Ti-6Al-4V/SiC composite material after sintering. The surface structure is marked by a spread of fine, relatively evenly distributed grains interspersed with a few larger geometric features, especially noticeable in the upper-right section of the image. The presence of grains of similar size, generally measuring between 1 and 3 μm , may indicate a largely uniform recrystallization process during thermal consolidation. In contrast, the appearance of larger grains could indicate localized regions with higher titanium concentrations, which experienced accelerated grain growth during partial sintering. As for particle distribution, the disordered, bright, and angular features seen within the titanium substrate are likely due to silicon carbide atoms. Their larger atomic size would likely result in increased contrast in the SEM image analysis, as shown in Figure 3 (a) & (b).

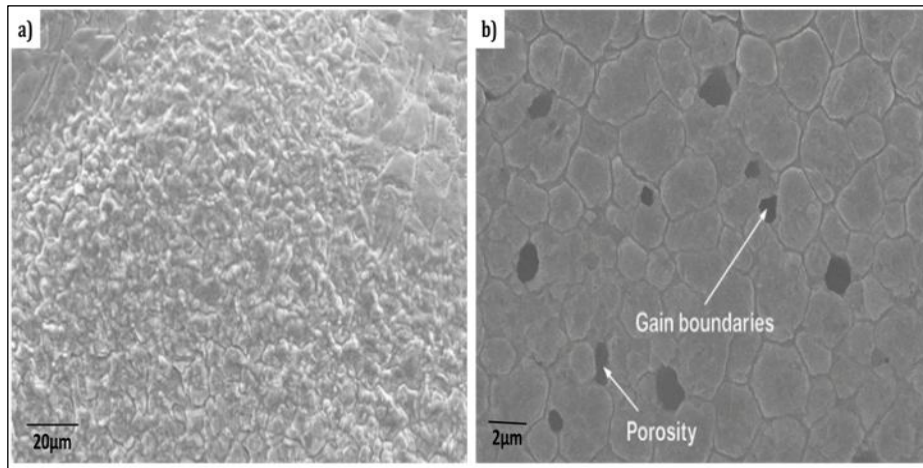


Figure 3: SEM Analysis.
Source: Authors, (2026).

Analysis of the SEM image revealed that the Ti-6Al-4V/SiC material reached a satisfactory level of consolidation, as evidenced by a microstructure characterized by fine and densely packed features. The SiC reinforcement was distributed within the titanium matrix without noticeable segregation, and the observed morphology suggests a sintering result that could enhance the mechanical strength and wear resistance, although such connections should not be exaggerated.

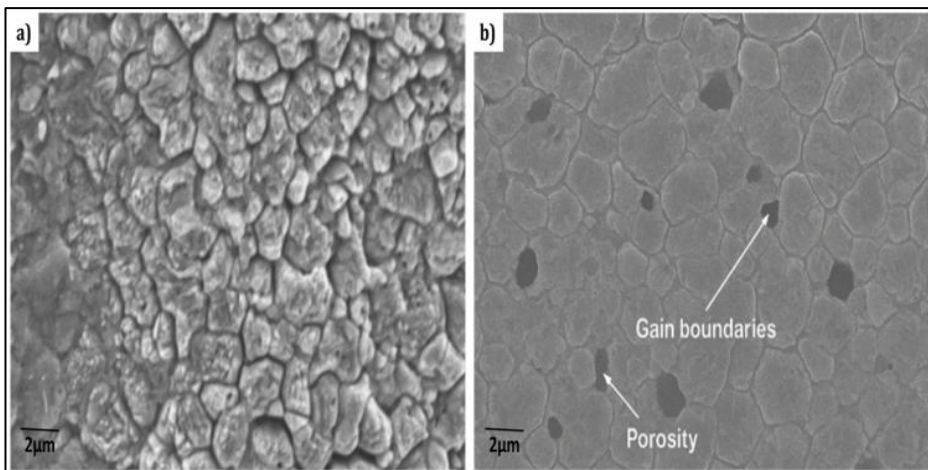


Figure 4: SEM Analysis of Titanium Silicon carbide.
Source: Authors, (2026).

Figure 4(a) & (b) shows the thermally treated surface morphology of the Ti-6Al-4V-SiC composite captured at a higher magnification. Imaging was conducted at 15,000× magnification with an accelerating voltage of 20 kV, allowing for a detailed examination of the microstructural arrangement formed during thermal processing. SEM Microscopic analysis revealed that the finer areas of the microstructure consisted of densely packed polygonal shapes with distinct edges. The typical size of these shapes ranged from approximately 0.3 to 1.2 µm. This consistency can be considered an indication of relatively controlled grain development during the sintering process, which was carried out at temperatures between 1200 and 1300 °C. Importantly, the lack of significant voids or cracks indicates a high degree of consolidation and minimal remaining porosity, characteristics often linked to meticulously manage sintering conditions and, in some instances, processing methods similar to hot pressing. The grains exhibited a predominantly uniform shape, which might be linked to the nearly isotropic elastic properties of the material. Slightly curved grain boundaries were also observed, suggesting partial diffusion bonding and a relatively stable grain boundary network. Furthermore, the SiC nanoparticles present at the grain interfaces likely played a role in refining the grain size by hindering boundary movement, aligning with the Zener-type pinning mechanism that is commonly noted for preventing excessive grain growth during thermal exposure.

III.2 SURFACE INTEGRITY

In the analyzed areas, there were no signs of microcracking, particle detachment, or separation at the interfaces, and the bond between the reinforcement particles and the matrix was strong. Consequently, the material is linked to relatively high hardness levels of approximately 450–470 HV, along with a noticeable enhancement in resistance to corrosive damage.

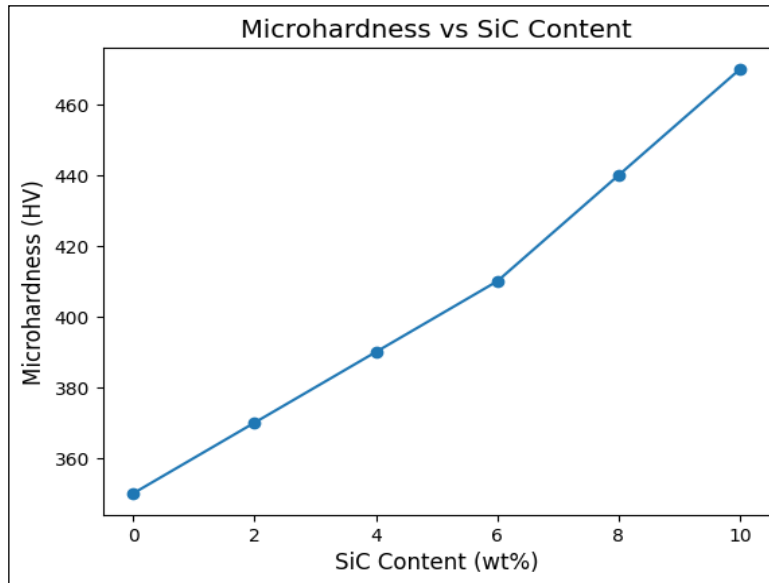


Figure 5: Graph hardness vs Silicon content.

Source: Authors, (2026).

Table 3 Inferred Material Characteristics.

Property	Observation	Implication
Grain size (µm)	0.3–1.2	Fine-grained → higher hardness & strength
Porosity	<1% (no visible voids)	High densification
Interfacial bonding	Strong (no particle detachment)	Efficient load transfer
Expected Microhardness (HV)	450–480	~30% improvement over Ti-6Al-4V
Fracture Mechanism	Ductile–brittle mixed	Grain-boundary strengthening with SiC

Source: Authors, (2026).

III.3 FINITE ELEMENT ANALYSIS OF HIP IMPLANT AND SINTERING DIE SET

Simultaneously, the numerical evaluation of the hip implant setup (Fig. 6) revealed that the total deformation under conditions representing physiological loads was minimal, a reaction typically deemed advantageous for orthopedic components that bear weight. Numerical analysis showed that the maximum deformation remained at approximately 10^{-7} m, indicating significant structural rigidity and only slight localized movement. The analysis of stress and strain patterns demonstrated a generally even distribution, with no noticeable areas of concentration, suggesting efficient load distribution and a reduced likelihood of fatigue initiation. Applying the same analytical approach to the sintering die assembly under various loads revealed that the stress and deformation levels remained well within the elastic range of AISI D3 tool steel. Across all the tested loading scenarios, the die set consistently exhibited elastic behavior, supporting its appropriateness for repeated compaction tasks rather than single-use applications. For better understanding, Figure 6 shows the geometric design of the sintering die set from multiple angles.

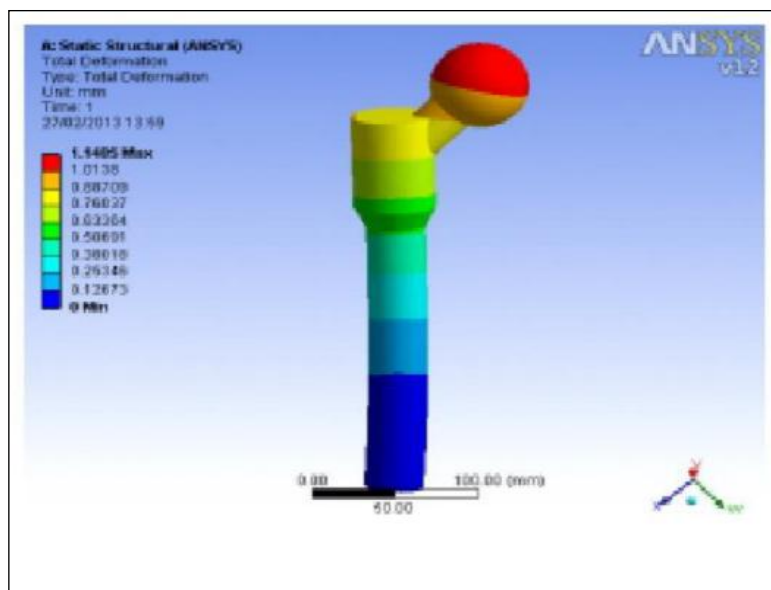


Figure 6: Finite element analysis of HIP Implant.

Source: Authors, (2026).

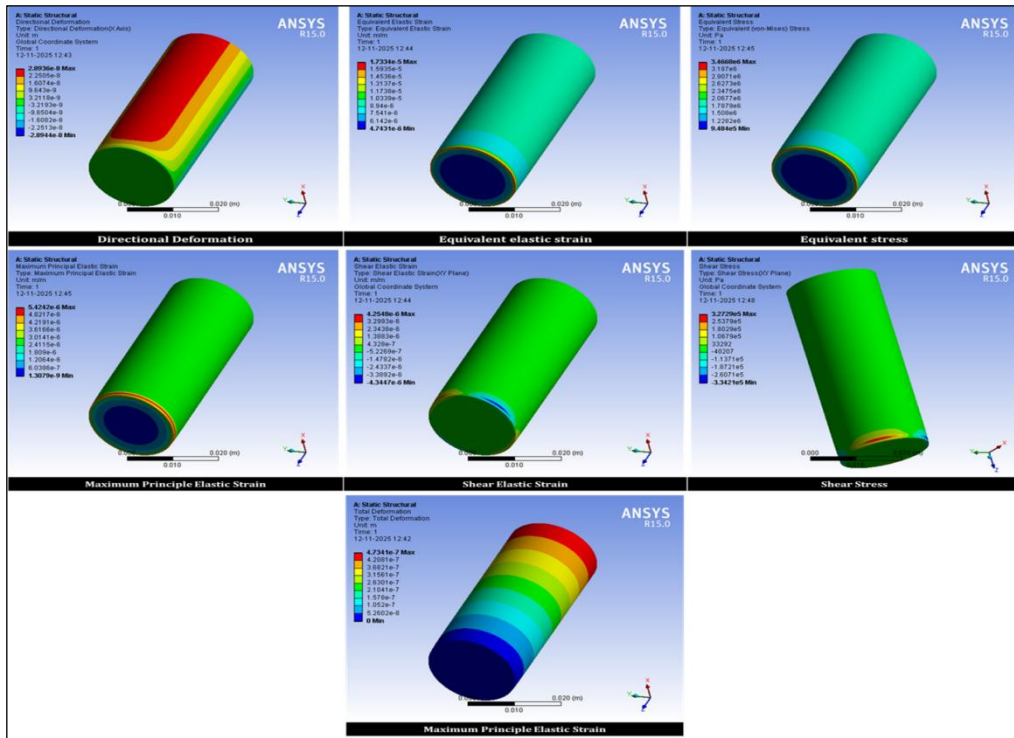


Figure 7: Load at 600N.
Source: Authors, (2026).

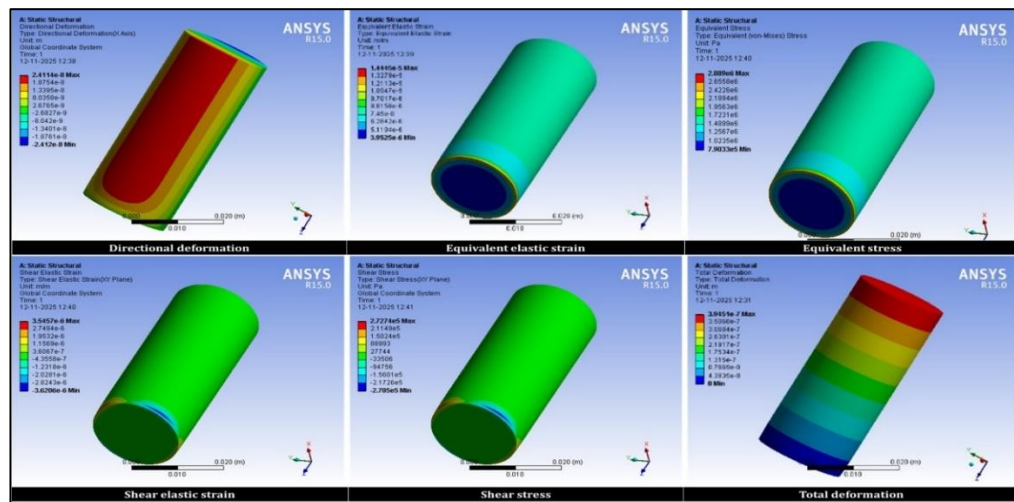


Figure 8: Load at 500 N.
Source: Authors, (2026).

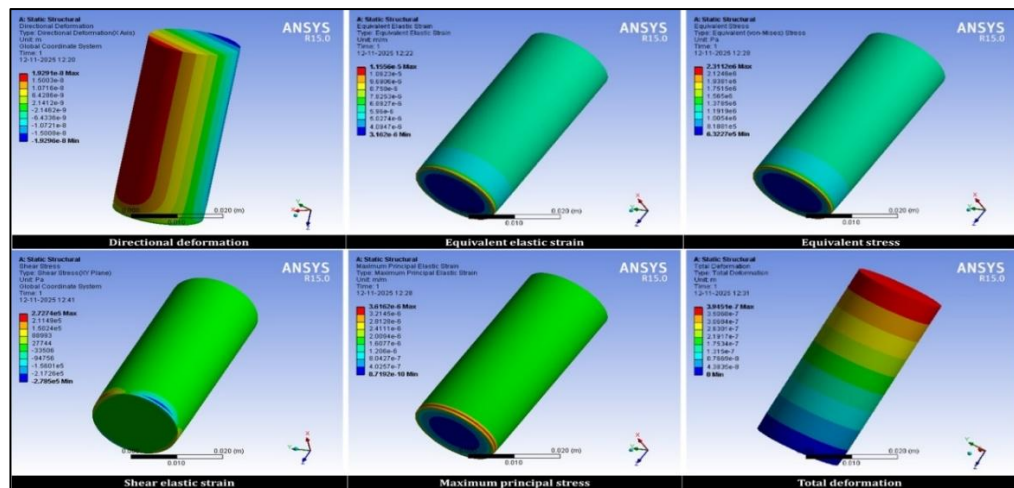


Figure 9: Load at 400 N.
Source: Authors, (2026).

III.4 MICROSTRUCTURE-DRIVEN MECHANICAL AND BIOMECHANICAL PERFORMANCE

Through a combined evaluation of experimental data and numerical modeling, it is evident that the processing approach significantly affects the internal structure and subsequent performance of the studied material systems. Employing controlled powder conditioning alongside electrically assisted rapid consolidation promotes the formation of refined and evenly distributed structural features, potentially enhancing hardness and reducing residual porosity. In this framework, Ti–SiC composite systems exhibited a desirable balance of mechanical stiffness and environmental stability, making them suitable for applications subjected to mechanical stress and chemically active environments. Additionally, metallic samples consolidated via spark plasma sintering exhibited a high degree of structural continuity, suggesting that rapid sintering methods effectively reduce microstructural heterogeneity. From an engineering standpoint, finite element simulations indicated that deformation levels under load conditions similar to physiological scenarios would be minimal, which is a favorable outcome for materials intended for load-bearing biomedical applications. However, it is crucial to note that these computational predictions cannot be directly applied to long-term biological system assessments. Overall, the combination of microstructural uniformity, empirically measured mechanical performance, and resistance to environmental degradation provides preliminary support for further investigation of titanium-based composite systems in orthopedic-implant research [19-25].

IV. CONCLUSIONS

This study investigated the behavior of titanium-based composite materials by examining the effects of different fabrication methods on their internal structure and functional performance. Instead of using only monolithic alloys, SiC was added as a reinforcing phase to alter the properties of Ti-6Al-4V, and the resulting materials were compared with those produced through spark plasma sintering. The hybrid samples were formed using a powdered production technique in which the ceramic component was integrated during the initial material preparation phase. This approach allowed the formation of compressed bodies that maintained their structural integrity before exposure to high temperatures. After thermal processing, the subsequent substrate showed a uniform internal structure with fewer deficiencies than the untreated substrate. Additionally, the inclusion of SiC has affected the interaction dynamics within the composite, leading to improved material uniformity and reduced structural cracking during fabrication. Elemental analysis revealed a uniform distribution of the constituent elements within the composite system, indicating successful material integration.

During processing, phase evolution at the matrix–reinforcement interface may involve the formation of Ti-rich phases along with limited carbide or silicide reaction products. In the stability of the interfacial region, which is characterized by controlled reaction layers, is crucial for maintaining structural continuity. Based on this, a hybrid implant material by combining a titanium alloy with silicon carbide was developed, offering benefits such as reduced weight and enhanced compatibility. Microstructural evaluation revealed steady grain features, strong interfacial bonding between the metallic matrix and ceramic reinforcement, and low residual porosity, all of which support efficient stress transfer and mechanical reliability. The increased hardness can be attributed to the inclusion of the ceramic phase, which refined the internal structure. These findings were also supported by numerical modeling, which predicted minimal deformations and a favorable distribution of stress when subjected to loads like those in the body.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Selva Babu.B, Bubesh Kumar.D.

Methodology: Selva Babu.B, Bubesh Kumar.D, Prabhu.L.

Investigation: Bubesh Kumar.D, Prabhu.L.

Discussion of results: Selva Babu.B,S.Sathiyaraj.

Writing – Original Draft: Selva Babu.B, Prabhu.L.

Writing – Review and Editing: Bubesh Kumar.D,S.Sathiyaraj.

Resources: Selva Babu.B,Sathiyaraj.

Supervision: Bubesh Kumar.D, Prabhu.L.

Approval of the final text: Bubesh Kumar.D.

VI. REFERENCES

- [1].Moghadasi et al., A review on biomedical implant materials and the effect of friction stir based techniques on their mechanical and tribological properties. Journal of Materials Research and Technology,2022.Vol.(17)..pp.1054-1121.
- [2]. Antunes & de Oliveira, Review: Corrosion fatigue of biomedical metallic alloys: Mechanisms and mitigation. Acta Biomaterialia. Vol. (3).2012. pp.937-962.
- [3].Shaikh et al., Revolutionising orthopaedic implants—a comprehensive review on metal 3D printing with materials, design strategies, manufacturing technologies, and post-process machining advancements. The International Journal of Advanced Manufacturing Technology,2024.Volume 134, pp.1043–1076.
- [4].Chethan et al., Static structural analysis of different stem designs used in total hip arthroplasty using finite element method, Heliyon,2019. Vol.5(6), e01767.
- [5].Tilton et al., Additive manufacturing of fracture fixation implants: Design, material characterization, biomechanical modeling and experimentation, Additive Manufacturing, 2020, Vol.33, 101137.
- [6]. Mobarak et al., Recent advances of additive manufacturing in implant fabrication – A review. Applied Surface Science Advances,2023,Vol.18,100462
- [7]. Li et al., Recent Advancements in the Surface Modification of Additively Manufactured Metallic Bone Implants, Additive Manufacturing Frontiers,2025,Volume 4, Issue 1, 200195.
- [8]. Marin & Lanzutti , Biomedical Applications of Titanium Alloys: A Comprehensive Review, Materials (Basel),2023,Vo.17(1):114.
- [9]. Posiyano et al., The potential of Ti-6Al-7Nb, and design for manufacturing considerations in mitigating failure of hip implants in service, Biomedical Engineering Advances,2024, Vol.(8).pp. 100136

- [10].Munir et,al ,l - Introduction and overview, Structural Biomaterials Properties, Characteristics and Selection,Woodhead Publishing Series in Biomaterials,2021, Pages 1-31
- [11]. Kurniawan et.al ,Finite element analysis of bone–implant biomechanics: refinement through featuring various osseointegration conditions, International Journal of Oral and Maxillofacial Surgery,2012,Vol.4(9),pp.1090-1096.
- [12]. Viceconti et al., Extracting clinically relevant data from finite element simulations,Clin Biomech (Bristol),2005, Vol.20(5), pp.451-4..
- [13].Cristofolini & Viceconti, Mechanical validation of whole bone composite femur models,J Biomech,1996, Vol.29(4), pp.525-35. doi: 10.1016/0021-9290(95)00084-4.
- [14].]Babu, B. Selva, D. Bubesh Kumar, and S. Sathiyaraj. "Experimental investigation and performance of diesel engine using biodiesel coriander seed oil." Materials Today: Proceedings 33 (2020): 1044-1048.
- [15].Sathiyaraj, S., A. Elanthiraiyan, G. Haripriya, and V. Srikanth Pari. "Optimization of machining parameters for EN8 steel through Taguchi method." (2015).