Ministry of Science & Technology

Bi-layered single-piece dental implant reduces the need for surgical interventions

Posted On: 08 SEP 2026 5:20PM by PIB Delhi

Researchers have developed a bi-layered structure integrating titanium alloy and zirconia components for dental applications that enhances durability, interfacial stability, and biocompatibility while reducing surgical complexity.

Traditional dental implants consist of three components: a fixture embedded in the jawbone, an abutment connecting the fixture and crown, and the crown itself. These multi-component assemblies are susceptible to micromovements at the abutment interface, which can compromise osseointegration and lead to implant loosening.

Furthermore, such systems typically require two to three surgical procedures, increasing patient discomfort and clinical complexity. Although titanium alloys and zirconia are widely used due to their biocompatibility and mechanical strength, each material has inherent limitations. Ti6Al4V can be susceptible to corrosion and gum recession in the moist environment of the mouth, while zirconia, although aesthetically appealing and corrosion-resistant, may degrade over time due to hydrolysis, affecting its long-term stability.

To overcome these challenges, scientists at the International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), an autonomous institute of the Department of Science and Technology (DST) have designed a functionally integrated bi-layered structure that integrates titanium alloy (Ti6Al4V) and yttria-stabilized zirconia (YSZ) into a unified structure to address persistent limitations of conventional implants.

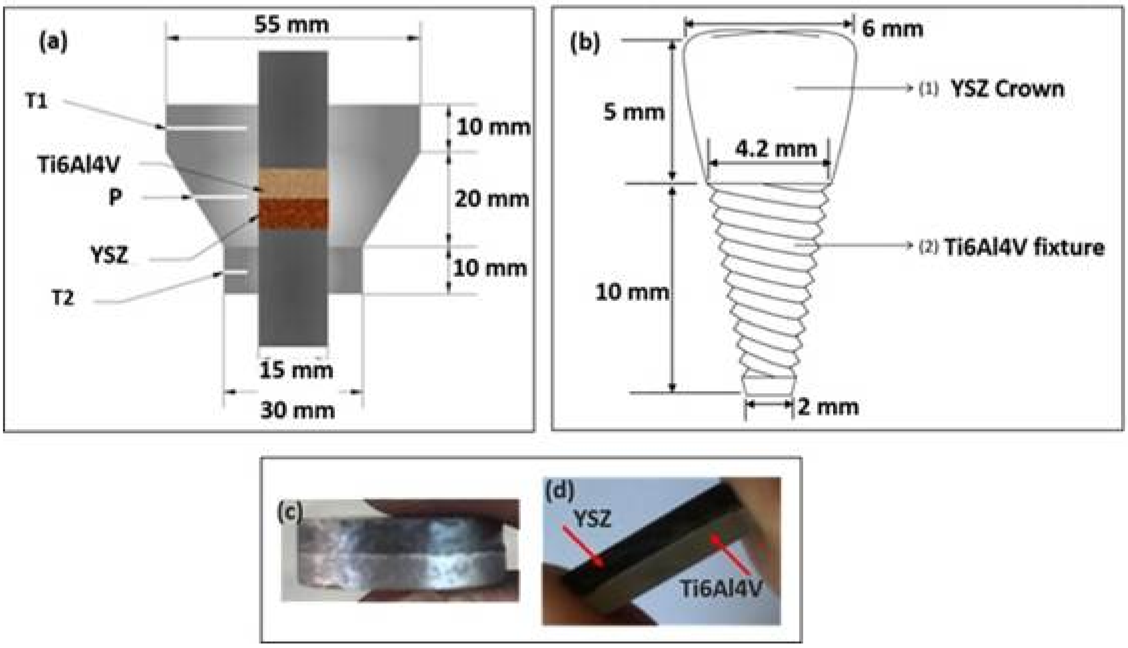

Fig 1: (a) Schematic diagram of a tapered graphite die; (b) Schematic of the bi-layered Ti6Al4V-YSZ dental implant; (c) Bi-layer sample of 8YSZ (top) and Ti6Al4V (bottom); (d) cross section of the Bi-layered sample.

In the structure, the Ti6Al4V serves as the load-bearing fixture for strong jawbone integration, and YSZ forms the crown region to provide superior wear resistance and aesthetics.

The implant was fabricated using Spark Plasma Sintering (SPS), an advanced powder metallurgy technique. A custom-designed tapered graphite die enabled precise temperature control during sintering, allowing simultaneous densification of Ti6Al4V and YSZ, despite their widely differing sintering temperatures.

This approach achieved a density of 99.5% in the material, producing a strong, defect-free bi-layered structure in a single processing step. After sintering, machining trials were conducted using a 5-axis CNC machine to produce the threaded implant shape. Some challenges related to tool movement along curved surfaces were observed, and process optimization is currently underway.

The overall fabrication approach remains highly reproducible and suitable for scaling up to industrial production.

Tests confirmed a distinct, well-bonded interface without cracks, delamination, pores, or secondary phases. Analysis revealed fine YSZ grains (~0.3 μm), while Ti6Al4V grains near the interface were refined to 0.3–1 μm compared to the bulk. No noticeable elemental diffusion was observed across the interface, indicating a stable ceramic–metal transition zone. The fabrication route demonstrates high reproducibility, making the process scalable for industrial production.

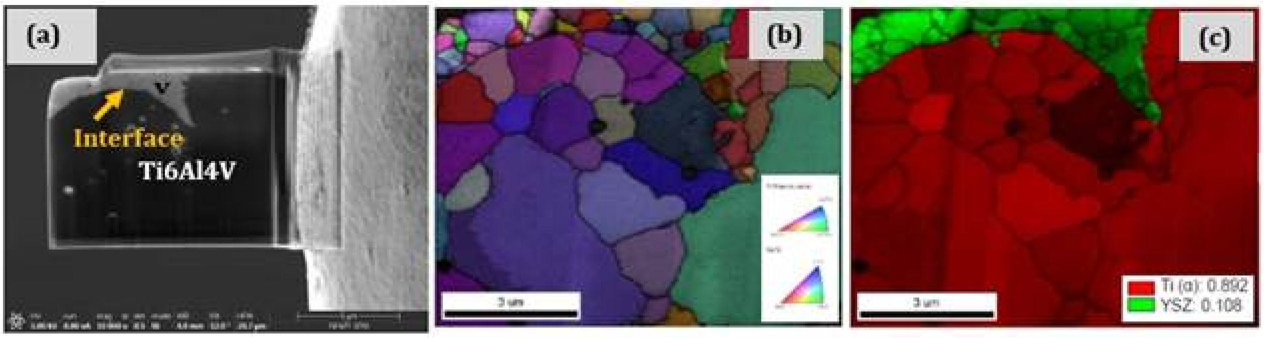

Figure 2: (a) Region of Interest (ROI) of Bi-layered sample; (b) TKD-IPF; (c) TKD-phase map overlaid with Image Quality map for representation.

Mechanical evaluation of the dense, bi-layered structure showed hardness values up to 1350 HV, compressive strength of approximately 1550 MPa, and flexural strength of approximately 310 MPa, comparable to or exceeding those of commercial implant materials. In vitro biological studies confirmed non-cytotoxic behavior and excellent biocompatibility. MTT assays (colorimetric test used to measure cellular metabolic activity) using L929 mouse fibroblast cells showed metabolic activity exceeding 90% across all tested concentrations, surpassing the minimum threshold for biomaterials. Hemolysis tests indicated negligible red blood cell damage, validating suitability for dental applications.

By integrating mechanical robustness, corrosion resistance, aesthetic performance, and biological safety into a single-piece architecture, ARCI's bi-layered implant reduces the need for surgical interventions while improving long-term stability and patient outcomes. The innovation aligns with India's growing demand for affordable, high-performance dental implants and strengthens indigenous biomedical device development.

This work has been published in the journal Materials Letters on ScienceDirect.

Publication link: https://doi.org/10.1016/j.matlet.2023.134403

For further clarifications, please contact: dibyenduc@arci.res.in

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