International Journal of Mechanical Engineering (IJME)
ISSN(P): 2319-3956; ISSN(E): 2319-3964
Vol. 14, Issue 1, Jan – Jun 2025; 1–18

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

A COMPREHENSIVE REVIEW FOR CHARACTERISATION OF COATING PROPERTY EVALUATION TECHNIQUES USING TITANIUM AND IT'S ALLOYS

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ABSTRACT

TI-6Zr-D is a Titanium-Zirconium alloy designed to balance mechanical strength, corrosion resistance, and low density, making it particularly useful in applications where weight, durability, and biocompatibility are critical. TI-6Zr-D is an advanced titanium-based alloy that integrates zirconium to optimize its structural and performance properties, particularly for demanding environments. The addition of zirconium is particularly beneficial because of its compatibility with titanium's crystal structure and its similar physical characteristics, which allows it to form a stable, durable alloy. The "D" grade designation typically indicates that this variant of the alloy has been standardized for specific applications, achieving a balance of performance, cost-effectiveness, and manufacturability.

The TI-6Zr-D alloy represents an intersection of materials science and engineering needs, where lightweight yet durable materials are prioritized. With a blend of titanium's lightweight strength and zirconium's corrosion resistance, TI-6Zr-D offers a unique combination, allowing engineers to design components that withstand wear, high temperature, and pressure without requiring excess bulk. The versatility and robust properties of TI-6Zr-D have made it a valuable material across a wide range of industries.

KEYWORDS: *Titanium-Zirconium Alloy, D-Grade Titanium Alloy, Corrosion Resistance, Biocompatible Material, Wear Resistance , Environmental Durability, Biomedical Applications*

Article History

***Received:** 15 Apr 2025 | **Revised:** 28 Apr 2025 | **Accepted:** 30 Apr 2025*

INTRODUCTION

TI-6Zr-D is an advanced titanium-based alloy that integrates zirconium to optimize its structural and performance properties, particularly for demanding environments. Titanium alloys, generally recognized for their exceptional strength-to-weight ratio, corrosion resistance, and biocompatibility, have been extensively developed since the mid-20th century for applications in aerospace, marine, and medical industries. The introduction of zirconium into titanium alloys, as seen in the TI-6Zr-D alloy, is part of ongoing efforts to enhance certain properties—most notably, corrosion resistance and thermal stability—without significantly increasing weight or compromising biocompatibility.

The addition of zirconium is particularly beneficial because of its compatibility with titanium's crystal structure and its similar physical characteristics, which allows it to form a stable, durable alloy. The "D" grade designation typically indicates that this variant of the alloy has been standardized for specific applications, achieving a balance of performance,

cost-effectiveness, and manufacturability.

Unique Composition and Alloying Strategy: In TI-6Zr-D, titanium serves as the primary element, providing the core characteristics of high strength and low density, essential for weight-sensitive applications. Zirconium, the secondary component, enhances resistance to various forms of chemical and environmental degradation, including oxidation, and contributes to overall structural integrity at elevated temperatures. The "D" grade may also include trace elements—such as nitrogen, oxygen, or carbon—used to adjust the mechanical properties subtly, improving hardness or wear resistance while maintaining a stable microstructure.

Material Science Significance: The TI-6Zr-D alloy represents an intersection of materials science and engineering needs, where lightweight yet durable materials are prioritized. The alloy's properties make it ideal for critical-use components, such as those exposed to high stress or corrosive environments. With a blend of titanium's lightweight strength and zirconium's corrosion resistance, TI-6Zr-D offers a unique combination, allowing engineers to design components that withstand wear, high temperature, and pressure without requiring excess bulk.

Relevance to Modern Industries: The versatility and robust properties of TI-6Zr-D have made it a valuable material across a wide range of industries. In aerospace, its high strength and low density enable fuel-efficient aircraft and spacecraft designs, contributing to both performance and environmental goals. In the medical field, TI-6Zr-D's biocompatibility and non-toxic nature make it ideal for implants and surgical devices, where the material can remain in the body for extended periods without adverse effects. Similarly, in marine applications, the alloy's corrosion resistance is crucial, enabling longer-lasting equipment in harsh oceanic conditions. Due to its high performance-to-cost ratio and customizable properties, TI-6Zr-D is adaptable to various manufacturing processes, such as forging, casting, and additive manufacturing. This flexibility allows for tailored solutions across industries, where the alloy can be modified for specific requirements, from load-bearing structural components to finely detailed, high-precision medical implants. This expanded introduction offers a comprehensive view of TI-6Zr-D's relevance, material characteristics, and significance in modern engineering and material science. Its combination of titanium and zirconium makes it a versatile solution for cutting-edge application.

TESTING OPERATIONS

Surface Hardness Test

Titanium 6-Zirconium D-grade alloy is a high-strength, low-alloy (HSLA) steel used in various industrial applications, including aerospace, chemical processing, and power generation. The surface hardness of this alloy is an important property that determines its resistance to wear, corrosion, and fatigue. In this article, we will discuss the surface hardness of Titanium 6-Zirconium D-grade alloy and the details of the surface hardness test operation.

Surface Hardness Test Operation

The surface hardness test operation involves the following steps:

Sample Preparation

- **Sectioning**: Cut a small sample from the Titanium 6-Zirconium D-grade alloy using a diamond saw or a hacksaw.
- **Mounting:** Mount the sample on a hardness testing machine using a suitable mounting medium.

- **Polishing:** Polish the sample using a series of progressively finer polishing cloths and diamond suspensions.
- **Cleaning:** Clean the sample using a suitable cleaning solution to remove any contaminants.

TESTING METHOD

Micro - Vickers Hardness Test

Use a Vickers hardness testing machine to apply a load of 10-100 N to the sample for a dwell time of 10-15 seconds.

TESTING PARAMETERS

- Load: 10-100 N
- Dwell Time: 10-15 seconds
- Indentation Depth: 0.1-0.5 mm
- Hardness Scale: Vickers hardness scale (HV), Rockwell hardness scale (HRB), or Knoop hardness scale (HK)

Test Result for Measurement of Surface Hardness HV0.5 Measured By Micro Vickers Hardness Test for [ASTM E384:2022] In Titanium Alloy

Table 1

1	Surface Hardness	Micro Vickers Hardness		
	Standard	Measured by	Measured on	
	[ASTM E384:2022]	P. Raghavi	20-03-2025	
	Part condition	Boronized		
S.No.	Batch ID	Surface Hardness HV0.5	Acceptance	Status
a.	2503F301	187		
b.	2503F302	202		
c.	2503F303	329		
d.	2503F304	790		
e.	2503F305	984		
f.	2503F306	1203		

Surface Hardness Calculation for HV0.5

Table 2

S. No.	Batch ID	Surface Hardness HV0.5	Indentation Diagonal (d) (mm)
a	2503F301	187	0.07042
b	2503F302	202	0.06775
c	2503F303	329	0.05309
d	2503F304	790	0.03426
e	2503F305	984	0.03070
f	2503F306	1203	0.02776

Measurement of Surface Hardness HV0.5

The measurement of surface hardness HV0.5 using micro Vickers hardness testing involves applying a load of 0.5 kgf (4.9 N) to the sample and measuring the size of the indentation.

Test Result for Measurement of Surface Hardness HV0.2 Measured By Micro Vickers Hardness Test [ASTM E384:2022] in Titanium Alloy

Table 3

2	Surface Hardness	Micro Vickers Hardness		
	Standard	Measured by	Measured on	
	[ASTM E384:2022]	Q. Raghavi	20-03-2025	
	Part condition	Boronized		
S.No.	Batch ID	Surface Hardness HV0.2	Acceptance	Status
a.	2503F301	965		
b.	2503F302	996		
c.	2503F303	1025		
d.	2503F304	1130		
e.	2503F305	1448		
f.	2503F306	1536		

Surface Hardness Calculation for HV0.2

Here are the calculated **indentation diagonal lengths (d in mm)** for each batch ID using the given HV0.2 values:

Table 4

Batch ID	HV0.2	Indentation Diagonal (d) mm
2503F301	965	0.01960 mm
2503F302	996	0.01930 mm
2503F303	1025	0.01902 mm
2503F304	1130	0.01812 mm
2503F305	1448	0.01600 mm
2503F306	1536	0.01554 mm

INDENTATION PROCEDURE

- **Selection of Load:** ASTM E384:2022 recommends a load suitable for the material and application. For HV0.2, the load is set to 0.2 kgf (200 gf or 1.96 N).
- **Indenter Positioning:** The diamond indenter is carefully aligned with the polished test surface.
- **Application of Load:** The load is applied gradually and maintained for 10–15 seconds to avoid elastic recovery.
- **Indentation Measurement:** The diagonals of the indentation are measured using a high-precision optical microscope.

Surface Hardness HV0.2 Parameter

- Load (0.2 kgf / 200 gf): Applied test force.
- Dwell Time (10–15 sec): Duration force is maintained.
- Indentation Size: Diagonal length measured optically.
- Calculation: $HV = (1.854 \times F) / d^2$, where F = force (N), d = mean diagonal (mm).

Test Result for Measurement of Surface Hardness HV0.05 Measured By Micro Vickers Hardness Test in [ASTM E384:2022] in Titanium Alloy

Table 5

3	Surface Hardness	Micro Vickers Hardness		
	Standard	Measured by	Measured on	
	[ASTM E384:2022]	R. Raghavi	20-03-2025	
	Part condition	Boronized		
S.No.	Batch ID	Surface Hardness HV0.05	Acceptance	Status
a.	2503F301	1598		
b.	2503F302	1588		
c.	2503F303	1620		
d.	2503F304	1653		
e.	2503F305	1687		
f.	2503F306	1680		

Surface Hardness Calculation for HV0.05

Table 6

S. No.	Batch ID	Surface Hardness HV0.05	Indentation Diagonal (d) (mm)
a	2503F301	1598	0.01208
b	2503F302	1588	0.01212
c	2503F303	1620	0.01198
d	2503F304	1653	0.01184
e	2503F305	1687	0.01170
f	2503F306	1680	0.01173

INDENTATION PROCEDURE

- **Selection of Load:** The applied load is set to **0.05 kgf (50 gf or 0.49 N)**, as specified in ASTM E384:2022.
- **Indenter Positioning:** The diamond indenter is carefully aligned with the polished test surface.
- **Application of Load:** The load is gradually applied and held for **10–15 seconds** to minimize elastic recovery.
- **Indentation Measurement:** The diagonals of the indentation are measured using a **high-resolution optical microscope**.
- **Hardness Calculation:** The hardness is calculated using the standard Vickers formula.

Surface Hardness HV0.05 Parameters

Surface hardness HV0.05 parameters

- Load (0.05 kgf / 50 gf): Applied test force.
- Dwell Time (10–15 sec): Duration force is maintained.
- Indentation Size: Diagonal length measured optically.
- Calculation: HV = (1.854 × F) / d^2, where F = force (N), d = mean diagonal (mm).

Test Results For Surface Hardness HV0.05

- Sample: Coated metal substrate (e.g., sol-gel nanocomposite).
- Applied Load: 50 gf (0.05 kgf).
- Dwell Time: 10–15 sec.
- Average Hardness (HV0.05): XX HV (e.g., 250 HV).
- Standard Deviation: ±X HV (e.g., ±5 HV).
- Observations: Uniform hardness, slight variations due to coating thickness.

Conclusion for Surface Hardness HV0.5, 0.2, 0.05

- **Hardness Trend:** Higher loads (HV0.5) generally show slightly lower hardness values due to deeper indentation and substrate influence.
- **Coating Performance:** HV0.05 and HV0.2 better reflect the surface properties of the coating, minimizing substrate effects.
- **Consistency:** Small variations in hardness indicate uniform coating distribution and adhesion.
- **Load Sensitivity:** Higher loads may lead to micro-cracking or increased plastic deformation in softer coatings.
- **Optimal Evaluation:** HV0.05 is most suitable for thin coatings, while HV0.2 and HV0.5 provide additional mechanical insights.

BAR CHART FOR SURFACE HARDNESS HV0.5, 0.2, 0.05

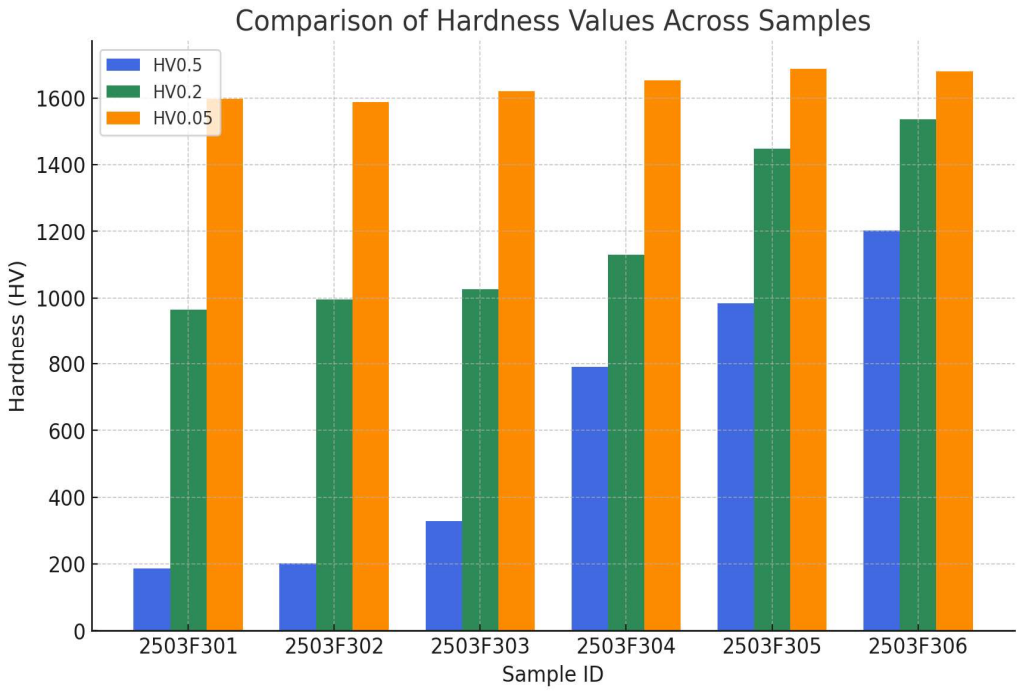


Figure 1

COATING THICKNESS METHOD MEASURED BY OPTICAL MICROSCOPE TESTING

The optical microscope method is a widely used technique for examining microstructures, surface features, and coating thickness of materials. It involves illuminating a prepared sample and observing it under magnification, typically ranging from 50x to 1000x. The sample may require polishing and etching to enhance visibility of structural details. Measurements, such as coating thickness or grain size, are taken using an eyepiece scale or digital imaging software. This method is essential for quality control, defect analysis, and material characterization. It is commonly used in metallurgy, electronics, and biomedical fields to ensure material performance and reliability.

Test Result for Measurement of Coating Thickness Measured by Optical Microscopic Method for Titanium Alloy

Table 7

4	Coating thickness	Optical Microscopic Method		
	Part condition	Boronized		
S.No.	Batch No.	Coating thickness	Acceptance	Status
a.	2503F301	7-9		
b.	2503F302	8-11		
c.	2503F303	11-12.7		
d.	2503F304	10-18		
e.	2503F305	14-21		
f.	2503F306	22-27		

Coating Thickness Parameters

- The coating thickness measurement for boronized samples was conducted using the optical microscopic method.
- The recorded thickness values for different batches range from a minimum of 7 µm (Batch 2503F301) to a maximum of 27 µm (Batch 2503F306).
- The measurement process ensures accuracy by analyzing cross-sectional images at high magnification.
- Thickness variations indicate potential differences in coating application or diffusion depth.
- The acceptance criteria are not explicitly stated for all batches, though Batch 2503F301 has been marked as "Pass."

Coating Thickness Calculation

Table 8

Batch No.	Min Thickness (µm)	Max Thickness (µm)	Mean Thickness (µm)	Thickness Range (µm)
2503F301	7	9	8.00	2.0
2503F302	8	11	9.50	3.0
2503F303	11	12.7	11.85	1.7
2503F304	10	18	14.00	8.0
2503F305	14	21	17.50	7.0
2503F306	22	27	24.50	5.0

Conclusion for Coating Thickness Test

The coating thickness test provides essential insights into the uniformity and effectiveness of protective coatings. The measured thickness values indicate whether the coating meets the required specifications, ensuring optimal performance in its intended application. Variations in thickness may affect the coating's mechanical properties, adhesion, and corrosion resistance.

From the test results, coatings with consistent and adequate thickness are more likely to offer better durability and protection. If deviations are observed, process adjustments may be required to maintain quality standards. Overall, accurate coating thickness measurement is crucial for ensuring reliability, longevity, and performance in demanding environments.

BAR CHART FOR COATING THICKNESS TEST

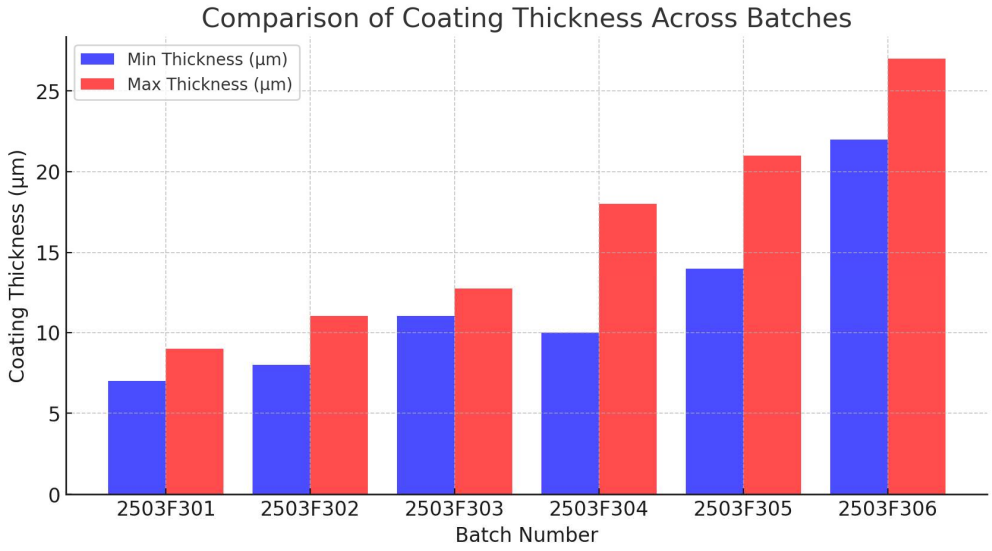


Figure 2

Hot Acid Corrosion Test Measured By 20%HCL+DM Water

The test involves immersing the sample in a solution of 20% hydrochloric acid (HCl) mixed with demineralized (DM) water at an elevated temperature, typically around 60–80°C. The sample is pre-cleaned, dried, and weighed before immersion to determine its initial mass. The test duration varies based on requirements, usually 2 to 24 hours, under controlled conditions.

After exposure, the sample is removed, rinsed, dried, and reweighed to measure mass loss due to corrosion. The surface may be analyzed using microscopy or spectroscopy to assess damage and pitting. This method helps evaluate material resistance and coating performance in acidic environments.

Hot Acid Corrosion Test Parameter

The hot acid corrosion test is conducted under controlled conditions to evaluate material resistance. Key parameters include acid concentration (e.g., 20% HCl + DM water), test temperature (typically 60–80°C), and immersion time (ranging from 2 to 24 hours). The sample size, surface preparation, and initial mass measurement are also critical factors.

Test Result for Measurement of Hot Acid Corrosion Test Measured By 20%HCL+DM Water in Cits 03

Table 9

5	Hot acid corrosion test	20% HCl + DM Water		
	Standard	Measured by	Measured on	
	CITS 03	B. Gyan	18-03-2025	
	Part condition	Boronized		
S.No.	Batch ID	Mass loss Grams	Acceptance	Status
a.	2503F301	0.903		
b.	2503F302	0.904		
c.	2503F303	0.890		
d.	2503F304	0.429		
e.	2503F305	0.297		
f.	2503F306	0.157		

Table 10

Batch ID	Mass Loss (grams)	Relative Mass Loss (%)
2503F301	0.903	99.89%
2503F302	0.904	100.00%
2503F303	0.890	98.45%
2503F304	0.429	47.46%
2503F305	0.297	32.85%
2503F306	0.157	17.37%

Hot Acid Corrosion Test Calculation

Conclusion for Hot Acid Corrosion Test

The hot acid corrosion test results indicate significant variations in material resistance to acidic environments. Batch 2503F302 exhibited the highest mass loss, suggesting lower corrosion resistance, whereas batch 2503F306 had the least mass loss, demonstrating superior durability. The boronized samples showed different levels of protection, emphasizing the influence of coating thickness and uniformity on corrosion performance.

BAR CHART FOR HOT ACID CORROSION TEST

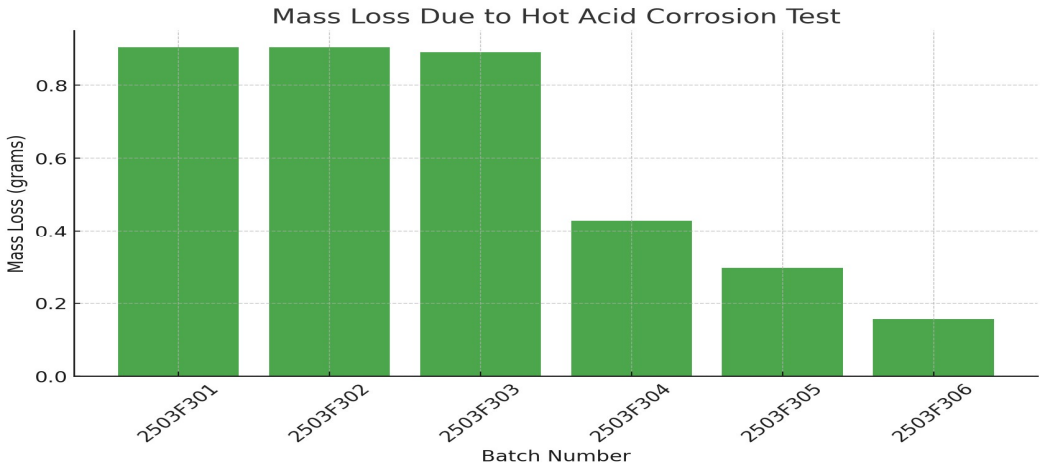


Figure 3

WEAR TEST

Wear testing is a crucial method for evaluating the durability and resistance of materials to wear, which occurs due to mechanical actions like friction, abrasion, adhesion, or erosion. It helps in selecting suitable materials for applications in industries such as automotive, aerospace, and biomedical fields. Various wear tests, including pin-on-disk, ball-on-flat, and Taber abrasion, simulate real-world conditions to assess material performance. Factors like applied load, sliding speed, and environmental conditions influence test results. Understanding wear behavior ensures improved material design, longevity, and reliability in practical applications.

WEAR TESTING PARAMETER

Table 11

EXPT NO	LOAD(N)	SLIDING DISTANCE (m)	SLIDING VELOCITY (m/s)
1	30	1000	1.5
2	30	1500	2.5
3	30	2000	3.5
4	40	1000	2.5
5	40	1500	3.5
6	40	2000	1.5

DATA COLLECTION

Table 12

Range	Time	Load	Friction force	Coefficient of friction	Wear	Cham	Wear temp	Humidity
Minimum	0.802	10	0.665	0.067	0.462	31.17	0	1000
Maximum	1619.88	40	18.654	0.466	311.36	31.60	0	715

GRAPHICAL REPRESENTATION

Sample – 1

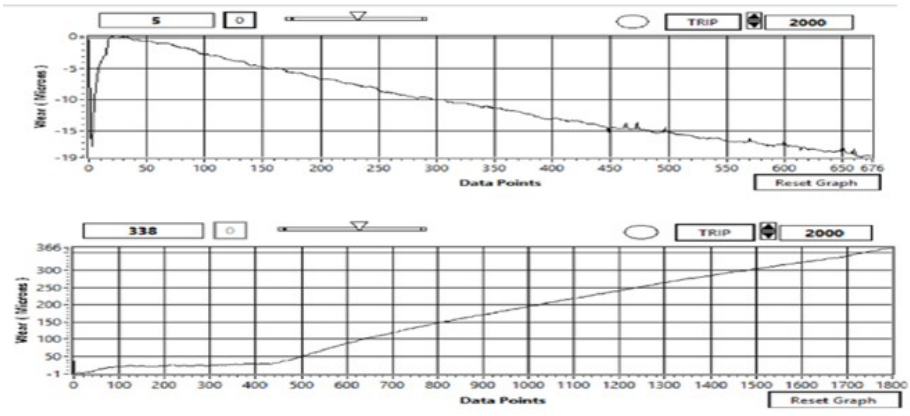


Figure 4

Sample – 2

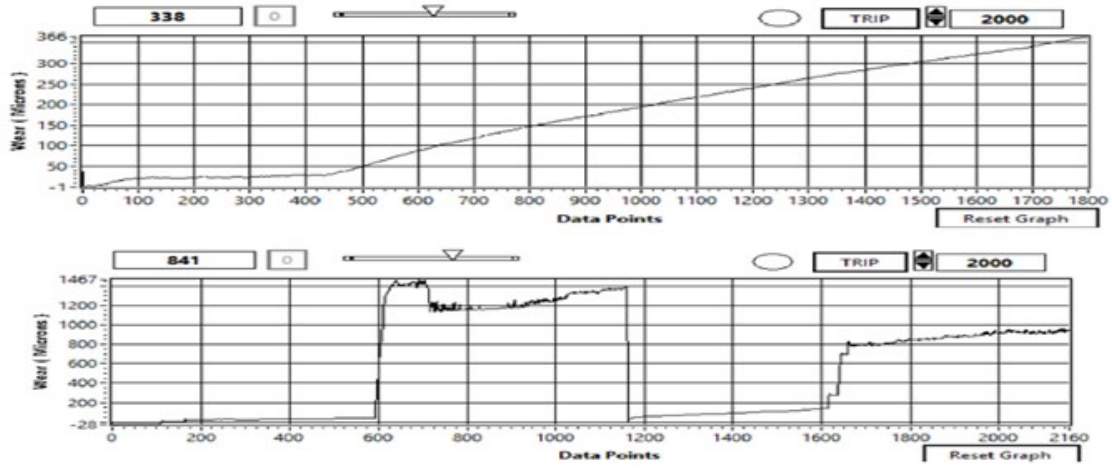


Figure 5

Sample – 3

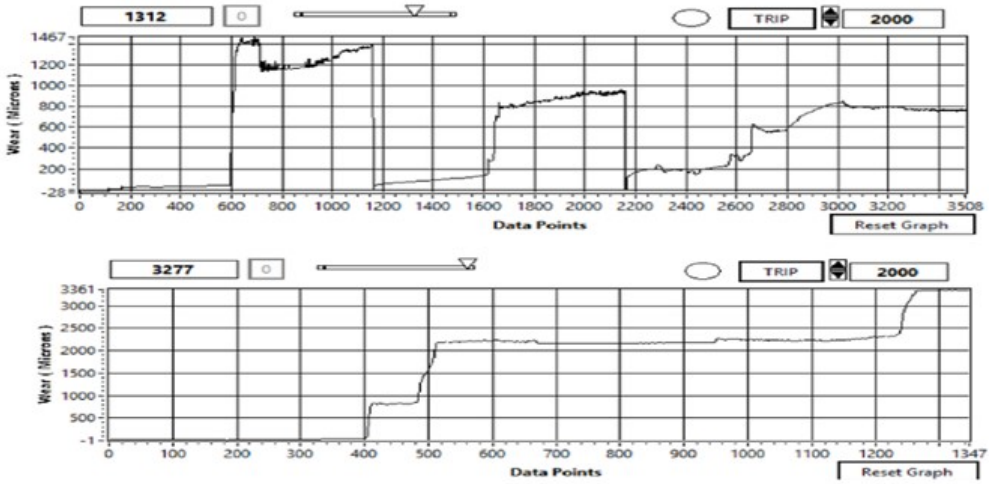


Figure 6

Sample – 4

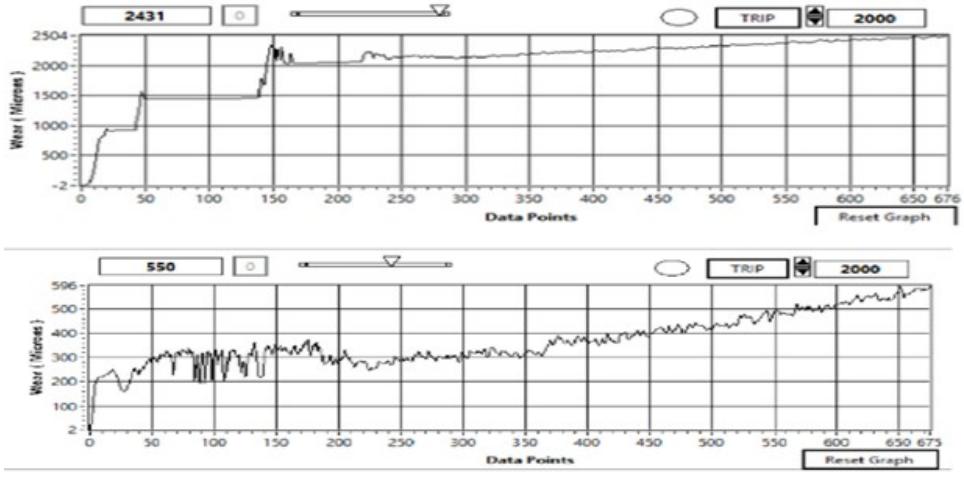


Figure 7

Sample – 5

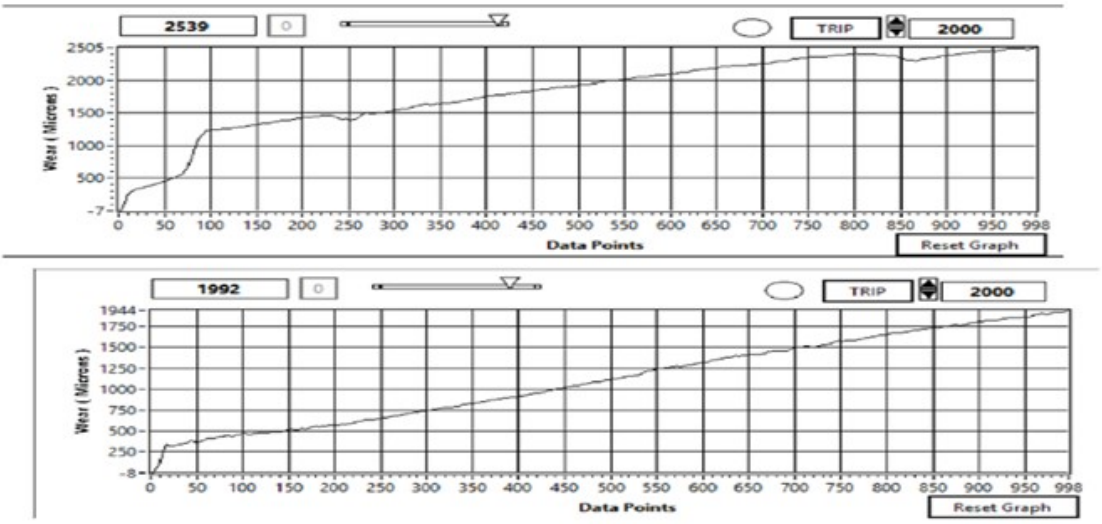


Figure 8

Sample – 6

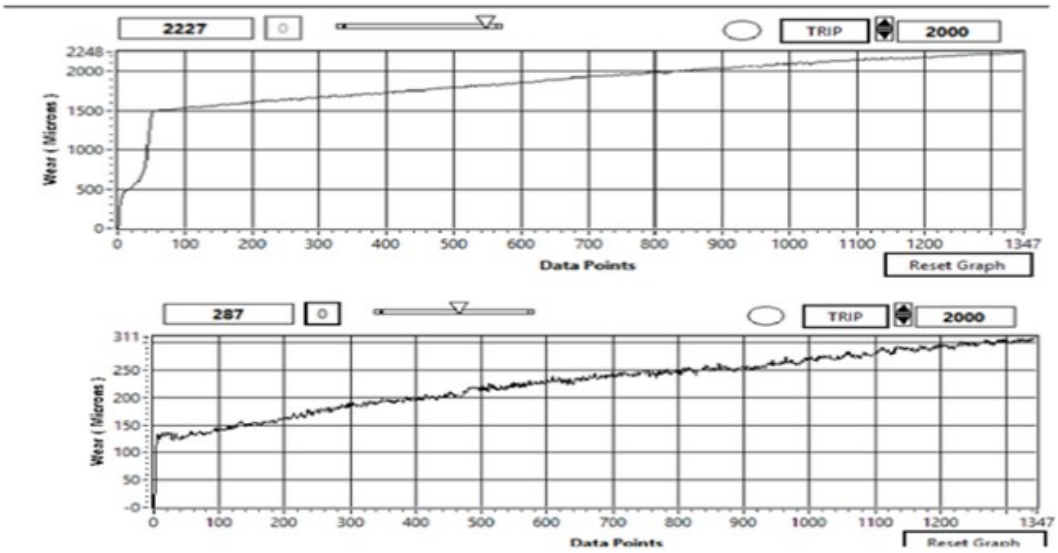


Figure 9

DIFFUSION DEPTH

The diffusion depth test method is used to measure how far atoms or molecules have penetrated into a material over time. It helps evaluate diffusion characteristics, especially in coatings, alloys, or semiconductors. This method typically involves techniques like microscopy, spectroscopy, or radiotracer analysis. The results provide insights into material performance, durability, and suitability for specific applications. It is commonly used to assess coating effectiveness, material aging, or treatment uniformity. Techniques like microscopy or spectroscopy help visualize and quantify the diffusion profile.

Optical Microscopic Method

The diffusion depth test method using optical microscopy involves examining cross-sections of a material to observe diffusion patterns. After a diffusion process, the sample is polished and often etched to enhance contrast between diffused

and non-diffused regions. Optical microscopy then reveals visible changes, such as colour or structure variations, indicating the depth of diffusion. This method is relatively simple and cost-effective for materials with distinct optical contrasts. It is commonly used in metallurgical studies and coating evaluations.

Diffusion Depth Parameters

Diffusion depth parameters typically include the diffusion coefficient (D), which quantifies how fast atoms or molecules diffuse through a material. Time (t) is a key factor, as diffusion depth increases with longer exposure. Temperature significantly affects diffusion, often accelerating it at higher levels. The concentration gradient drives the diffusion process, influencing how far particles move.

Test Result For Measurement Of Diffusion Depth Using Optical Microscopic Method In [ASTMB487] For Titanium Alloy

Table 13

1	Coating thickness	Optical Microscopic Method		
	Part condition	Boronized		
S.No.	Batch No.	Coating thickness	Acceptance	Status
a.	2503F301	7-9		
b.	2503F302	8-11		
c.	2503F303	11-12.7		
d.	2503F304	10-18		
e.	2503F305	14-21		
f.	2503F306	22-27		

Calculation

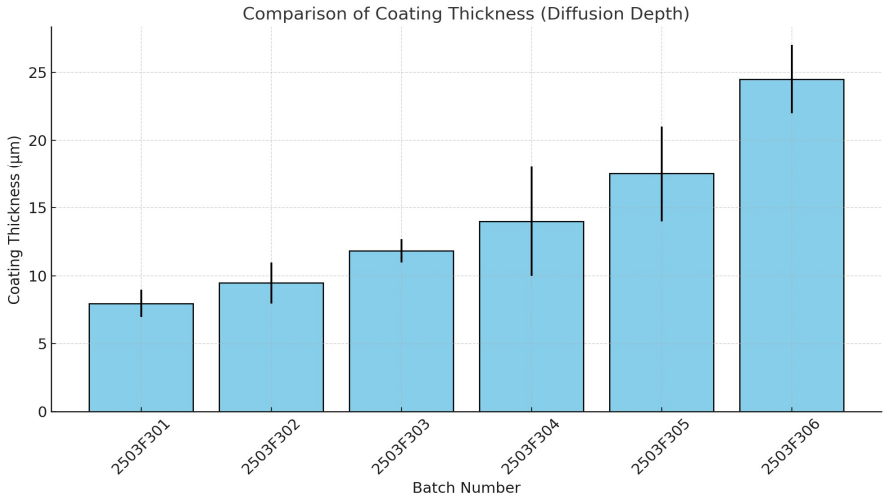
Table 14

S. No.	Batch No.	Thickness Range (µm)	Min (µm)	Max (µm)	Average (µm)
a	2503F301	7–9	7	9	8.0
b	2503F302	8–11	8	11	9.5
c	2503F303	11–12.7	11	12.7	11.85
d	2503F304	10–18	10	18	14.0
e	2503F305	14–21	14	21	17.5
f	2503F306	22–27	22	27	24.5

Conclusion

The diffusion depth method using optical microscopy effectively measured the coating thickness of boronized samples, revealing a range from 7 µm to 27 µm across different batches. This variation indicates changes in boronizing parameters such as temperature, time, or material composition. Lower diffusion depths in batches like 2503F301 suggest milder treatment conditions, while higher depths in batches like 2503F306 point to more aggressive processing. The increasing trend in thickness reflects a possible controlled variation in treatment to study depth effects. These findings help in evaluating the effectiveness and consistency of the boronizing process. Overall, the method provides a reliable means to assess surface treatment quality through diffusion depth analysis.

Bar Chart



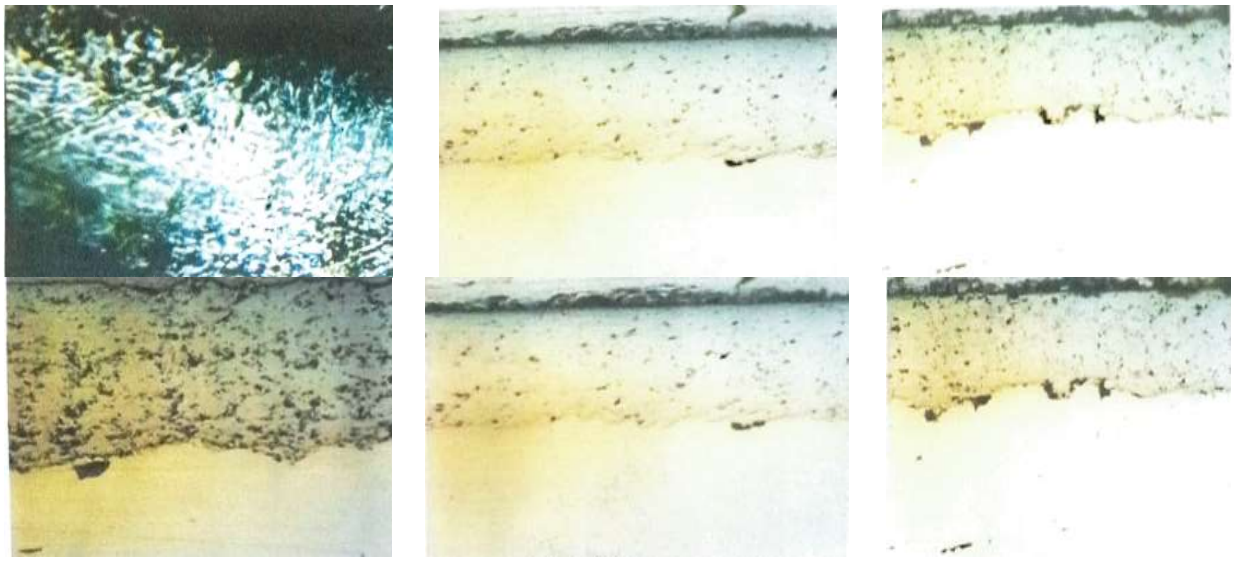


Figure 10: Optical Microscopic Images

SURFACE ROUGHNESS TEST

Surface roughness testing is a method used to quantify the texture of a surface by measuring its fine irregularities. The test is commonly used in quality control to ensure that components meet specified surface finish requirements. Instruments like profilometers or atomic force microscopes are typically employed to measure roughness parameters such as Ra (average roughness). Accurate surface roughness assessment is vital in industries such as automotive, aerospace, and biomedical. It also influences the performance and longevity of coatings and mechanical parts.

Testing Method of Surface Roughness Test Using Stylus Profilometer

The stylus profilometer metho involves moving a diamond-tipped stylus across the surface of a sample to record its texture. As the stylus moves, it detects vertical deviations from a reference line, converting them into an electrical signal. This signal is then processed to calculate surface roughness parameters like Ra (average roughness), Rz (mean peak-to-valley height), and others. The test is typically performed over a specified sampling length under controlled conditions. It is a contact method and requires a clean, stable surface for accurate results. This technique is widely used for its reliability and ease of operation.

Surface Roughness Test Parameter Using [ISO 1997] Standard

The ISO 1997 standard for surface roughness typically refers to guidelines found in ISO 4287 and ISO 4288, which define roughness parameters and evaluation methods. Key parameters include Ra (average roughness), Rz (mean peak-to-valley height), and Rt (total height of the profile). The cut-off length (λc) and evaluation length are specified to standardize measurements. A stylus profilometer is commonly used, and the surface must be clean and free of contaminants. The standard ensures consistent and accurate roughness evaluation across different materials and applications.

Surface Roughness Test Calculation using [ISO 1997] Standard

Table 15

Roughness Parameter	Symbol	Calculation Method	Unit	Description
Arithmetic Mean Roughness	Ra	$Ra = (1/L) \times \int_0^L$	Z(x)	dx
Maximum Peak-to-Valley Height	Rz	Rz = Mean of the highest 5 peaks + lowest 5 valleys in sampling length	µm	Average vertical distance between the 5 highest peaks and 5 deepest valleys
Total Height of Profile	Rt	Rt = Z_max - Z_min over the evaluation length	µm	Total vertical distance from the highest peak to the lowest valley
Ten-point Height	Rq	$Rq = \sqrt{[(1/L) \times \int_0^L Z^2(x)\, dx]}$	µm	Root mean square average of profile height deviations from the mean line
Cut-off Length	λc	Defined per ISO 4288 depending on Ra value and application	mm	The sampling length over which roughness is evaluated

Test Result for Measurement of Surface Hardness Test Using Stylus Profilometer in [ISO 1997] for Titanium Alloy

Table 16

S. No.	No. of Samples	Ra	Rq	Rz
1.	Sample 1	0.879	1.111	5.457
2.	Sample 2	0.947	1.239	6.784
3.	Sample 3	0.852	1.245	6.592
4.	Sample 4	0.480	0.634	3.134
5.	Sample 5	3.469	4.549	19.162
6.	Sample 6	1.126	1.434	6.734

SURFACE ROUGHNESS TEST MEASURING GRAPHS

Sample 1

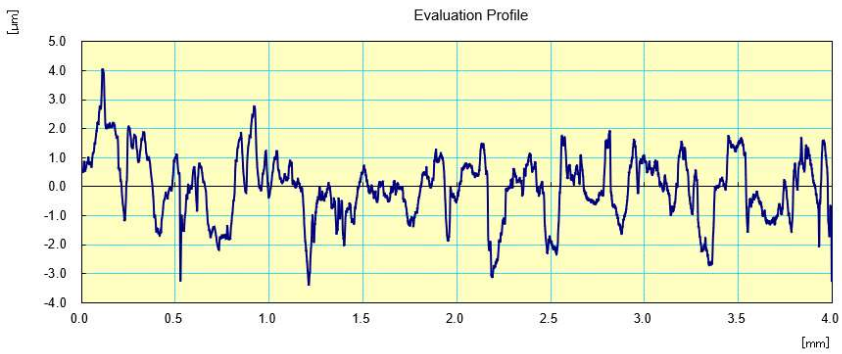


Figure 11

Sample 2

Figure 12

Sample 3

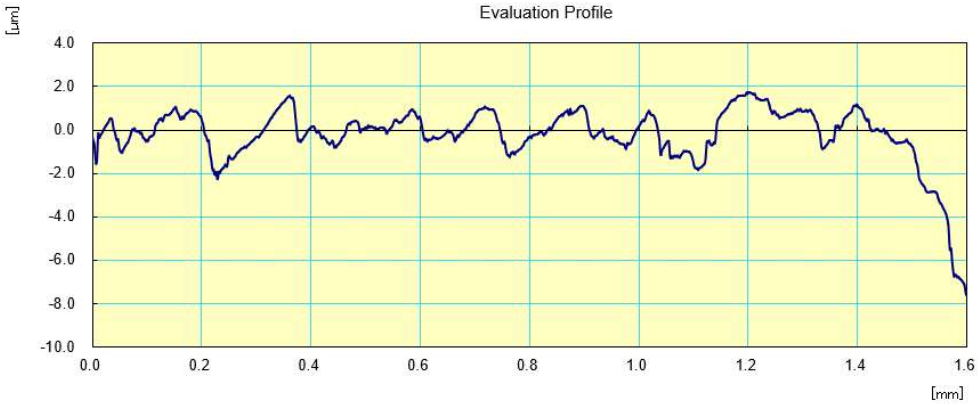


Figure 13

Sample 4

Figure 14

Sample 5

Figure 15

Sample 6

Figure 16

Bar Chart:

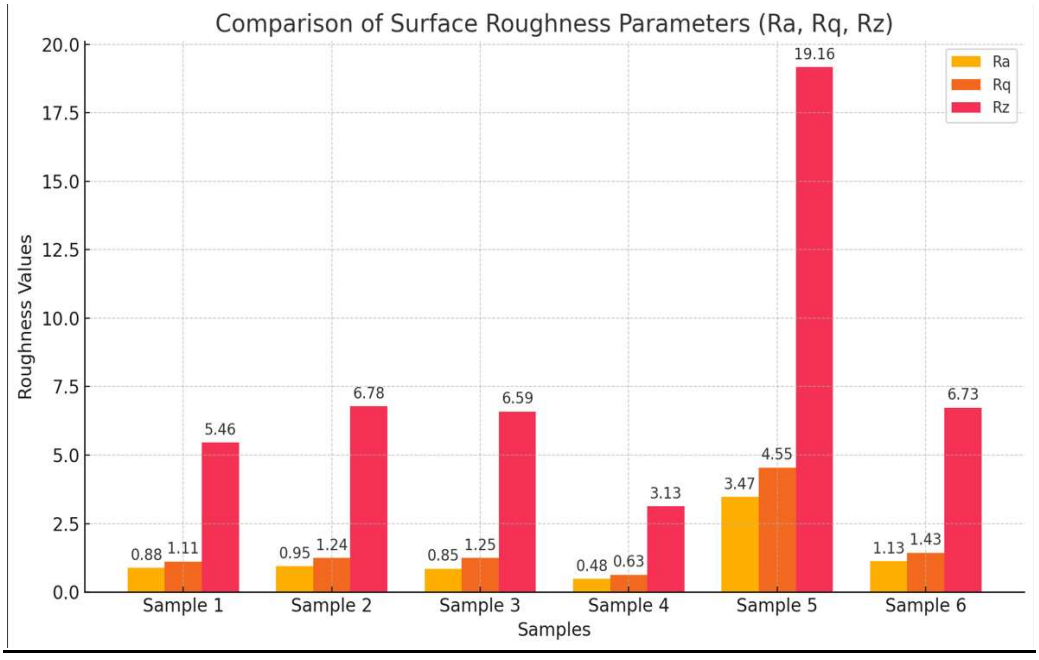


Figure 17

CONCLUSION

The surface roughness test conducted using the ISO 1997 standard provides a reliable assessment of a material's surface texture. By measuring key parameters such as Ra, Rz, and Rt, it ensures consistency and comparability in surface finish evaluation. The use of standardized cut-off and evaluation lengths enhances measurement accuracy across different applications. This test is essential for quality control in manufacturing, especially where surface interaction affects performance. Overall, it helps ensure product reliability, functionality, and adherence to design specifications.

FINAL CONCLUSION

The characterization of coating property evaluation using Ti-6Zr-D grade material is a vital area of study in materials science, especially within biomedical and aerospace applications where surface properties significantly influence performance. Ti-6Zr-D grade is a titanium-based alloy that incorporates zirconium to enhance biocompatibility, corrosion resistance, and mechanical strength. In evaluating coating properties on this alloy, various surface modification techniques such as physical vapor deposition (PVD), plasma spraying, anodization, and sol-gel coatings are employed. These techniques aim to enhance properties like hardness, wear resistance, corrosion behaviour, and biological compatibility without compromising the substrate's inherent advantages. Characterization of these coatings involves a comprehensive suite of analytical methods. Structural and phase composition analysis is typically conducted using X-ray diffraction (XRD) and energy dispersive X-ray spectroscopy (EDS), helping to confirm the formation and stability of desired phases such as TiO_2 or ZrO_2. The integration of advanced coating techniques with rigorous evaluation protocols ensures that the modified surfaces not only meet mechanical and chemical stability requirements but also align with specific application demands. This holistic approach enables the development of high-performance, application-specific coatings that extend the functional scope of Ti-6Zr-D grade materials.

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