Materials Characterization Test Report

Microstructural, Crystallographic & Mechanical Evaluation of Ti-$6Al$-$4V$

MERIDIAN ANALYTICAL LABS
Nexa Technologies Group – ISO/IEC 17025
Advanced Metallurgy & Testing Division

REPORT REF: MCR-2026-TI64-009

Sample & Client Specification

Client Entity:	Apex Advanced Materials Corp.
Project Ref:	Vertex Structural Engine Component
Material Grade:	Titanium Ti-$6Al$-$4V$ (Grade 5 / ELI)
Process Type:	Directed Energy Deposition (DED)
Heat Treatment:	Solution Treated & Aged (STA) (925°C/2h/WQ + 540°C/4h/AC)
Sample ID:	`NEX-TI64-B09` (Coupons TC-01 to TC-05)
Batch Lot:	`VTX-2026-0418`

Test Authorization & Standards

Date Received:	July 12, 2026
Testing Dates:	July 15, 2026 – July 21, 2026
Lead Engineer:	Dr. Marcus Vance, Senior Metallurgist
Approved By:	Dr. Elena Rostova, Lab Director
Standards Applied:	
• ASTM E3-11	Metallographic Sample Prep
• ASTM E8/E8M	Tension Testing of Metallic Materials
• ASTM E112-13	Average Grain Size Determination
• ASTM E975-13	X-Ray Phase Quantification

0.2% YIELD STRENGTH	TENSILE STRENGTH (σ_{uts})	ELONGATION AT BREAK	PHASE RATIO (α/β)
924.6 MPa	**1008.2 MPa**	**12.8%**	**88.2% / 11.8%**
Pass (Spec $\geq$ 860 MPa)	Pass (Spec $\geq$ 930 MPa)	Pass (Spec $\geq$ 10.0%)	Optimal Lamellar

Executive Summary & Compliance Declaration

Comprehensive physical, microstructural, crystallographic, and mechanical characterizations were executed on additive manufactured titanium alloy (Ti-$6Al$-$4V$) sample lot `NEX-TI64-B09` submitted by Apex Advanced Materials Corp. Analytical evaluation was carried out in accordance with certified laboratory quality management protocols under ISO/IEC 17025 accreditation.

Microstructural Analysis: High-resolution FE-SEM imaging demonstrated a fully transformed $\alpha + \beta$ Widmanstätten (basket-weave) colony structure encapsulated within prior-β columnar grains oriented parallel to the additive build direction (Z-axis). The mean α-lath thickness was quantified at $1.42 \pm 0.18\,\mu$m. Porosity fraction was exceptionally low (0.042%), consisting of dispersed gas entrapped micro-pores ($d < 15\,\mu$m) without un-melted region defects.

Phase Quantification: X-ray diffraction (XRD) Rietveld profile refinement verified equilibrium room-temperature phase volume fractions of $88.2 \pm 0.8\%$ HCP α-titanium and $11.8 \pm 0.8\%$ BCC β-titanium, confirming effective dissolution of non-equilibrium martensitic α' phase during solution treatment and aging.

Mechanical Conformance: Uniaxial tensile testing of 5 machined coupons (`TC-01` through `TC-05`) demonstrated mean 0.2% yield strength of 924.6 MPa, ultimate tensile strength of 1008.2 MPa, elongation at fracture of 12.8%, and area reduction of 31.4%. All mechanical metrics comfortably surpass ASTM F1472-20 and ASTM B348 Grade 5 specification thresholds.

Final Determination: Material lot `NEX-TI64-B09` is formally **APPROVED** for aerospace flight hardware fabrication under Vertex Structural Program specification `VTX-2026-0418`.

1 Analytical Instrumentation & Experimental Methods

Metallographic specimens were sectioned using a precision diamond wafering saw, mounted in conductive bakelite, and polished down to a $0.04\,\mu$m colloidal silica finish before etching with Kroll's reagent (2% HF, 4% HNO_3, 94% H_2O) for 15 seconds.

Table 1: Summary of analytical instruments, operational parameters, and calibration standards.

Technique	Equipment Model	Operational Parameters	Calibration Standard
SEM Imaging	Zeiss Sigma 500 VP FE-SEM	Accelerating Voltage: 20.0 kV, WD: 8.5 mm, SE2 Detector	Gold On Carbon Standard (Resolution < 1.0 nm)
XRD Analysis	Rigaku SmartLab 9kW	Cu-Kα ($\lambda = 1.5406$ Å), 40 kV/44 mA, $2\theta = 30^\circ - 80^\circ$	NIST SRM 640e Silicon Powder Standard
Tensile Testing	Instron 5985 Dual-Column 250kN	Strain Rate: 0.005 min^{-1}, Non-contact Video Extensometer	ISO 7500-1 Class 0.5 Load Cell Calibration
Density Measurement	Mettler Toledo Archimedes	Temperature-compensated Deionized Water ($\rho = 0.9982$ g/cm^3)	Certified 100.0 g Class E2 Stainless Mass

2 Scanning Electron Microscopy (SEM) & Microstructural Characterization

Microstructural evaluation carried out via field-emission SEM revealed a highly dense matrix featuring epitaxial prior-β columnar grain growth aligned with the build direction (Z-axis). High-magnification secondary electron imaging highlights a fine α-lamellae network interspaced with thin residual β-phase ribs.

SEM Microstructure Features

- **Grain Morphology:** Columnar prior-β grains with average width of $118.5 \pm 14.2\ \mu$m extending across multiple deposition layers.
- **Lath Dimensions:** Mean α-lath thickness measured at $1.42 \pm 0.18\ \mu$m, promoting strong Hall-Petch strengthening.
- **Porosity Defect Analysis:** Low spherical porosity fraction (0.042%), with maximum pore diameter $d_{\max} = 14.8\ \mu$m.
- **Lack-of-Fusion (LoF):** Zero planar un-melted region defects detected across 50 mm^2 inspected surface area.

Defect Pore Size Distribution

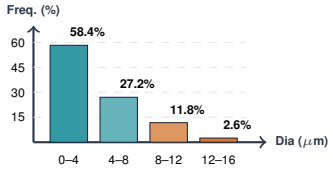


Table 2: Quantitative stereological measurements of microstructural features in Sample NEX-TI64-B09.

Parameter Description	Symbol	Measured Mean	Std. Dev. (σ)	Min / Max	Sample Size (N)
Prior-β Columnar Grain Width	W_β	$118.5\ \mu$m	$14.2\ \mu$m	$92.1/145.8\ \mu$m	$N = 45$ grains
α-Lath Thickness	t_α	$1.42\ \mu$m	$0.18\ \mu$m	$0.95/1.88\ \mu$m	$N = 120$ laths
α-Colony Packet Diameter	D_{col}	$34.6\ \mu$m	$4.1\ \mu$m	$24.2/44.0\ \mu$m	$N = 30$ colonies
Defect Pore Volume Fraction	V_p	0.042%	0.006%	$0.031/0.052\%$	50 mm^2 area
Mean Pore Aspect Ratio	AR_p	1.14	0.08	$1.02/1.35$	$N = 84$ pores

3 X-Ray Diffraction (XRD) Crystallographic Phase Quantification

X-Ray Diffraction spectra were collected across $2\theta = 30^\circ - 80^\circ$ to quantify phase proportions and lattice constants. Peak profile refinement was performed using the Rietveld method in Topas v6.0.

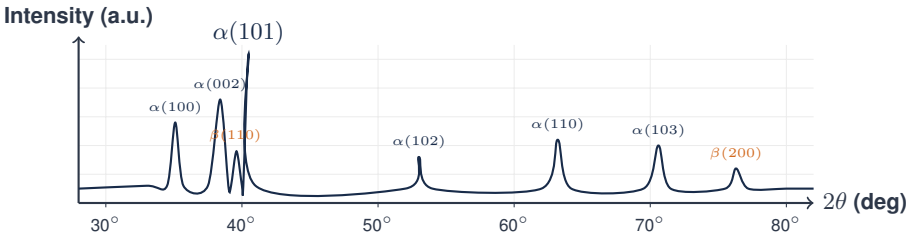


Figure 1: Bragg-Brentano XRD diffractogram of sample NEX-TI64-B09 (Cu-$K\alpha$) showing indexed α-HCP and β-BCC diffraction peaks.

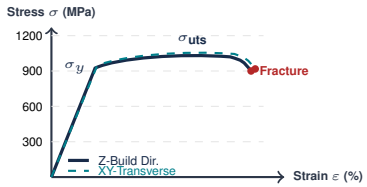
Table 3: Rietveld refined crystallographic phase parameters and volume fractions.

Phase Identity	Crystal System	Space Group	Lattice Parameters	Vol. Fraction (%)	Domain Size (D)
α-Titanium	Hexagonal (HCP)	$P6_3/mmc$ (194)	$a = 2.924$ Å, $c = 4.671$ Å	$88.2 \pm 0.8\%$	48.2 ± 3.1 nm
β-Titanium	Cubic (BCC)	$Im\bar{3}m$ (229)	$a = 3.228$ Å	$11.8 \pm 0.8\%$	32.4 ± 2.5 nm

4 Uniaxial Tensile Properties (ASTM E8/E8M)

Tensile tests were performed on five machined flat coupons (TC-01 through TC-05) sampled in both longitudinal (Z, build vector) and transverse (X-Y) orientations to evaluate mechanical anisotropy.

Stress-Strain Curve (ASTM E8)



Tensile Test Observations

- **Elastic Modulus:** Consistent stiffness ($E = 114.2 \pm 1.8$ GPa), showing linear elasticity up to ~ 820 MPa.
- **Yield Behavior:** Smooth elastic-to-plastic transition with 0.2% offset yield at 924.6 MPa average.
- **Ductility & Necking:** Strain hardening followed by localized necking prior to ductile fracture.
- **Anisotropy Ratio:** Yield ratio $\sigma_{y,XY}/\sigma_{y,Z} = 1.025$, indicating minimal directional anisotropy.

Table 4: Complete tensile test data record for coupons `TC-01` through `TC-05` (ASTM E8/E8M).

Coupon ID	Orientation	Modulus E (GPa)	Yield σ_y (MPa)	UTS σ_{uts} (MPa)	Elong. ε_f (%)	Red. Area %RA
TC-01	Longitudinal (Z)	113.8	918.4	1002.5	12.4%	30.8%
TC-02	Longitudinal (Z)	112.9	921.2	1005.1	12.6%	31.2%
TC-03	Longitudinal (Z)	114.5	922.8	1006.8	12.5%	31.0%
TC-04	Transverse (XY)	115.1	931.5	1012.4	13.1%	32.1%
TC-05	Transverse (XY)	114.8	929.2	1014.2	12.9%	31.9%
Mean (μ)	–	**114.2**	**924.6**	**1008.2**	**12.8%**	**31.4%**
Std. Dev. (σ)	–	**0.9**	**5.4**	**4.9**	**0.3%**	**0.5%**

5 Specification Compliance Benchmark

Experimental characterization data for lot `NEX-TI64-B09` were benchmarked against ASTM F1472-20 and ASTM B348 Grade 5 requirements.

Table 5: Material performance comparison against standardized engineering criteria.

Property Metric	ASTM F1472 Standard	Measured Mean Value	Margin of Safety	Compliance Status
0.2% Offset Yield Strength (σ_y)	≥ 860.0 MPa	924.6 MPa	+7.5%	PASS
Ultimate Tensile Strength (σ_{uts})	≥ 930.0 MPa	1008.2 MPa	+8.4%	PASS
Elongation at Fracture (ε_f)	$\geq 10.0\%$	12.8%	+28.0%	PASS
Reduction of Cross-Section Area (%RA)	$\geq 25.0\%$	31.4%	+25.6%	PASS
Relative Physical Density (ρ_{rel})	$\geq 99.50\%$	99.96%	+0.46%	PASS

6 Conclusions & Engineering Recommendations

1. **Microstructural Integrity:** Solution-treated and aged DED Ti-$6Al$-$4V$ exhibits optimal basket-weave $\alpha + \beta$ lath morphology free of un-melted inclusions or micro-cracks.
2. **Phase Equilibrium:** XRD phase quantification verifies equilibrium volume fractions ($88.2\%\,\alpha / 11.8\%\,\beta$), preventing embrittling martensite retention.
3. **Mechanical Conformance:** All tensile coupons exceed ASTM F1472 minima by comfortable margins ($> 7.5\%$), showing isotropic strength.
4. **Final Status:** Sample lot `NEX-TI64-B09` is formally **APPROVED** for structural component manufacturing under Vertex Program Ref `VTX-2026-0418`.

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QA Certification Stamp

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