Laser peening of Ti-6Al-4V and the associated effects on its high temperature fatigue

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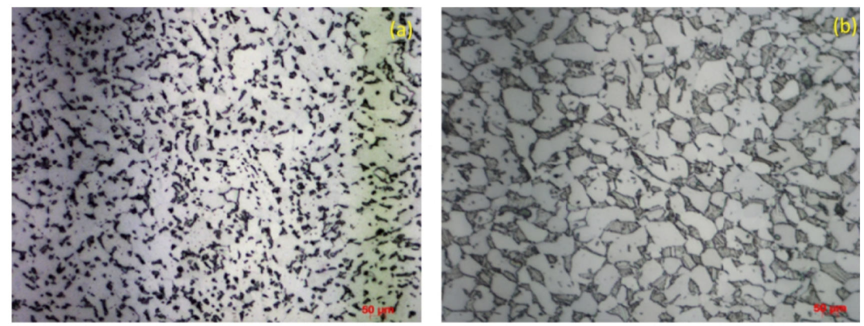
Material

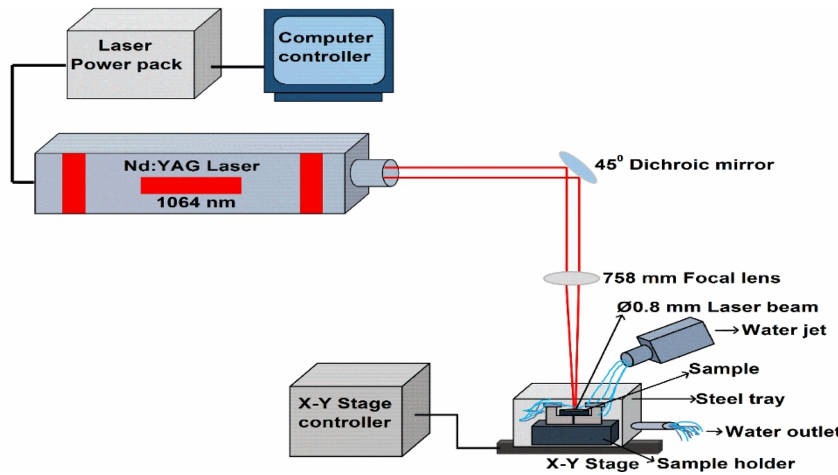
- AR (as-received, mill annealed, ASTM B348), σ_y & UTS: 840 and 950 MPa
- Solution treated (ST), 920 °C for 1 h [Max. σ_y & UTS: 950 and 1050 MPa]
  - primary α with lamellar $\alpha+\beta$ (that is, transformed β))
  - Average grain size: 10 µm

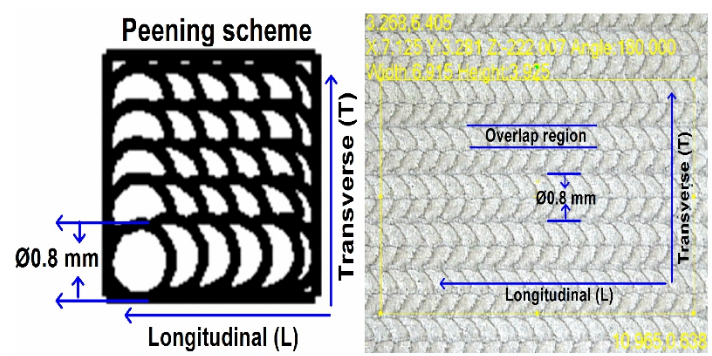


Ti-6-4 bar ((a) AR and (b) ST)

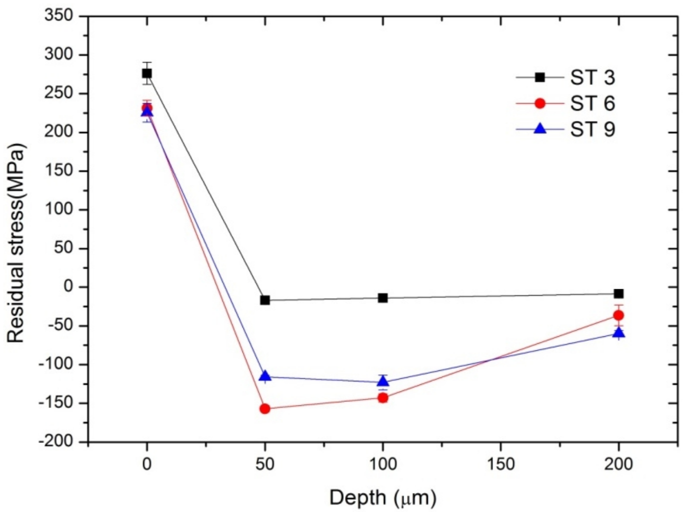
LPwC

- Wavelength 1064 nm with FWHM of pulses at 10 ns and repetition rate at 10 Hz.
- Diameter of the spot: 0.8 mm; overlap: 70%.
- Variable power density (1-10 GW cm^{-2}) and/or multiple peening
- Running water overlay (thickness of around 1 mm).





Residual Stress

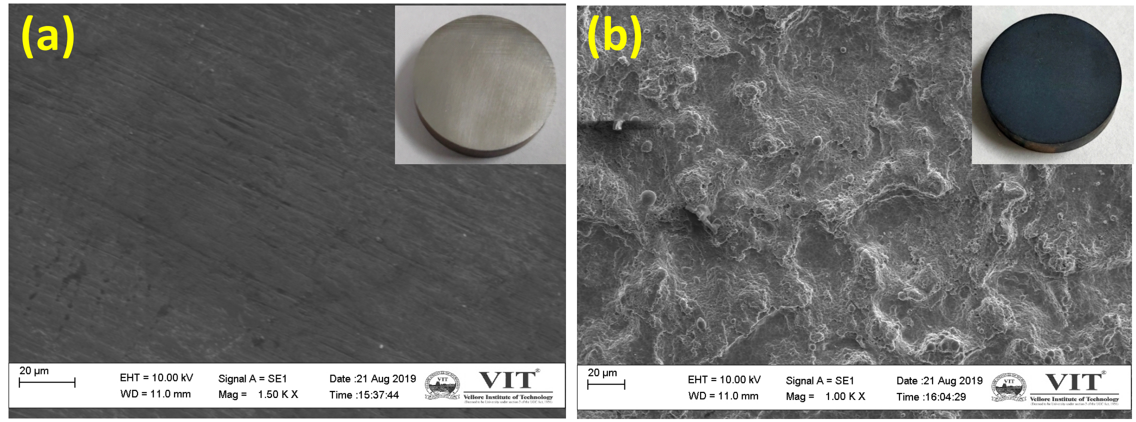


- $2\theta = 142°$, (2 1 3) plane
- Measurements along 0, 45 and 90° were **isotropic**
- Measurements at 3 locations (at each depth) were **uniform**

- Issue # 1: Max. compressive stress is low
  - Solution: Switch to AR samples solves this
  - **Conclusion: Residual stress is a function of volume fraction of α and β phases**
- Issue # 2: Surface tensile stress

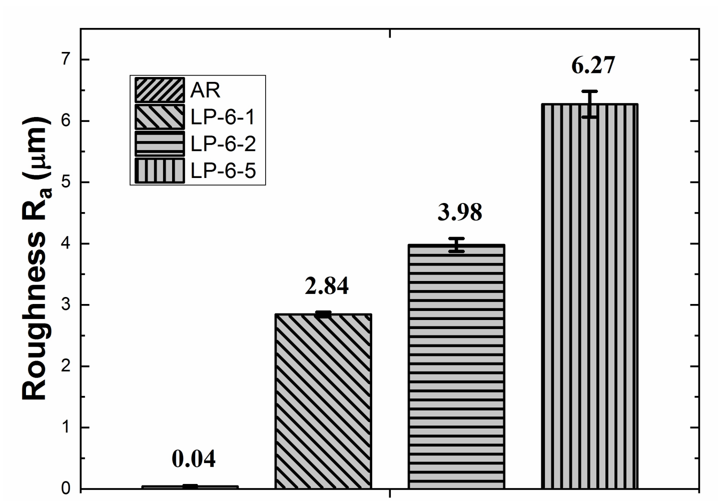
Probable causes of TRS

1. Surface melting and re-solidification?



(a) unpeened and (b) LP-6-2 sample

2. Surface damage

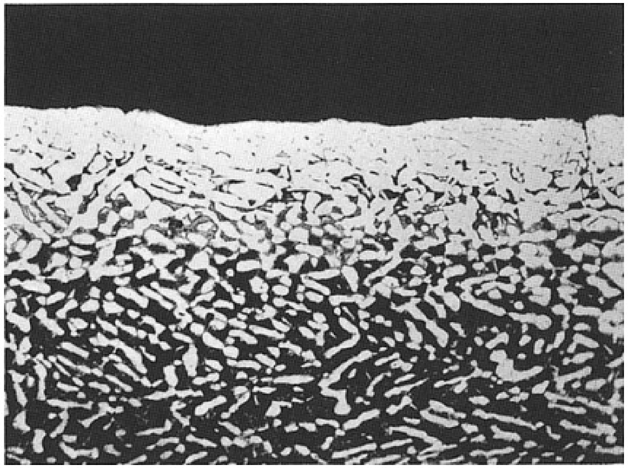


Limiting (thermal) damage

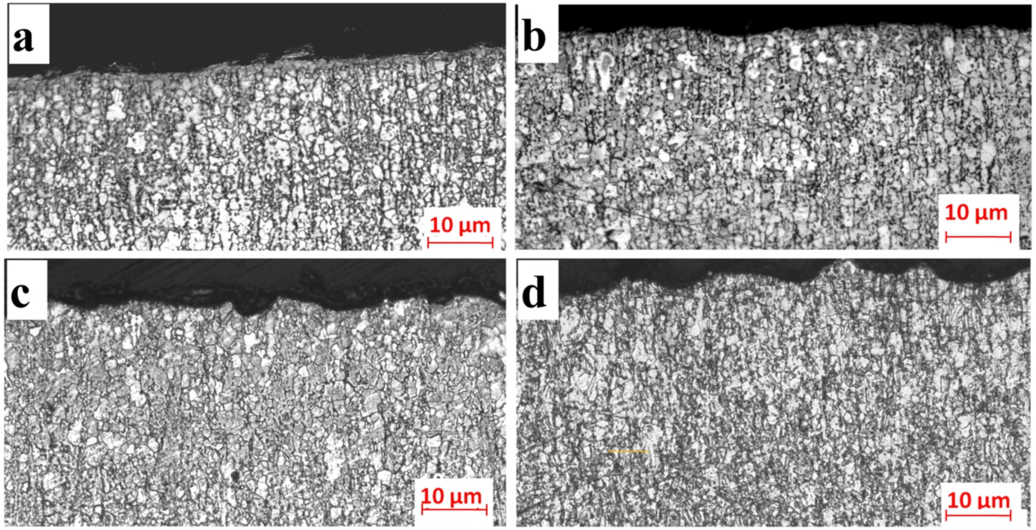
- Black paint, Al paint, Al foil and black tape
- Coatings cannot be sustained

Oxygen concentration at surface

EDX: 3.6 wt% (unpeened) & 36 wt% (LP-6-2) $\Rightarrow$ α case?

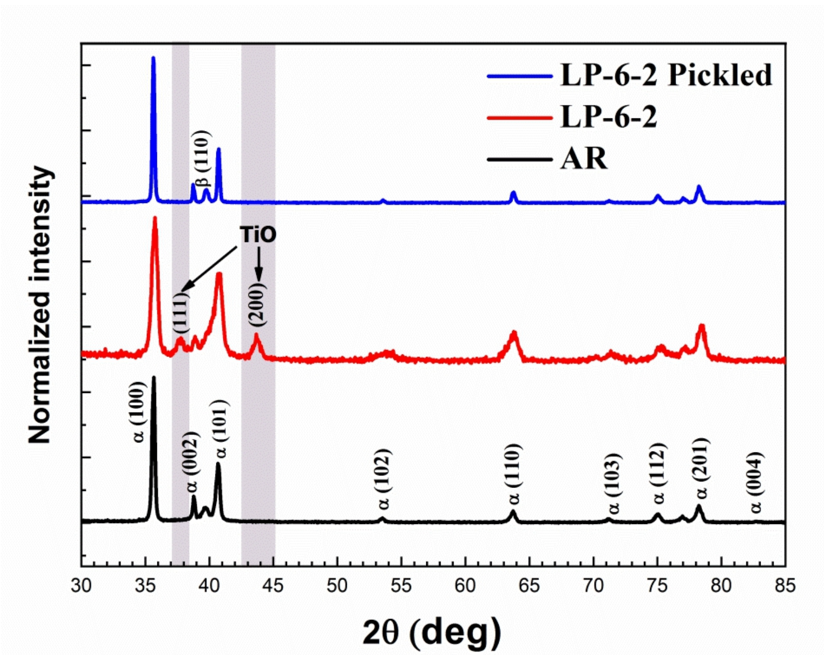


Typical α case [M.J. Donachie, Titanium: A technical guide, 2nd ed, 2000, ASM International]



(a) unpeened, (b) LP-6-1, (c) LP-6-2 and (d) LP-6-5

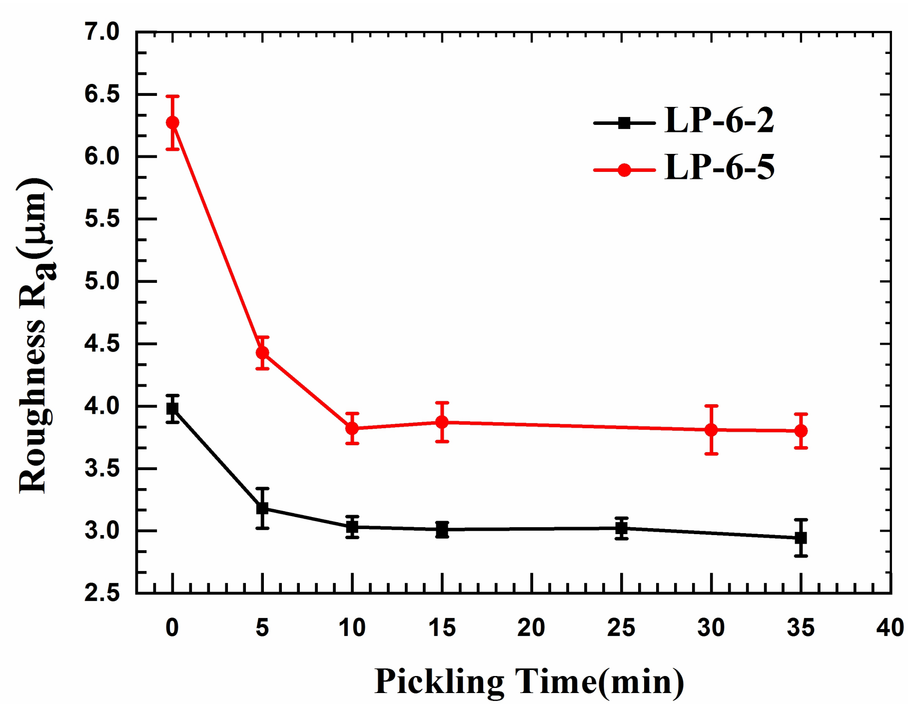
Oxide formation



TiO: Major peak @ 43.6625° (JCPDS No. 00-008-0117) & a minor peak ~38°

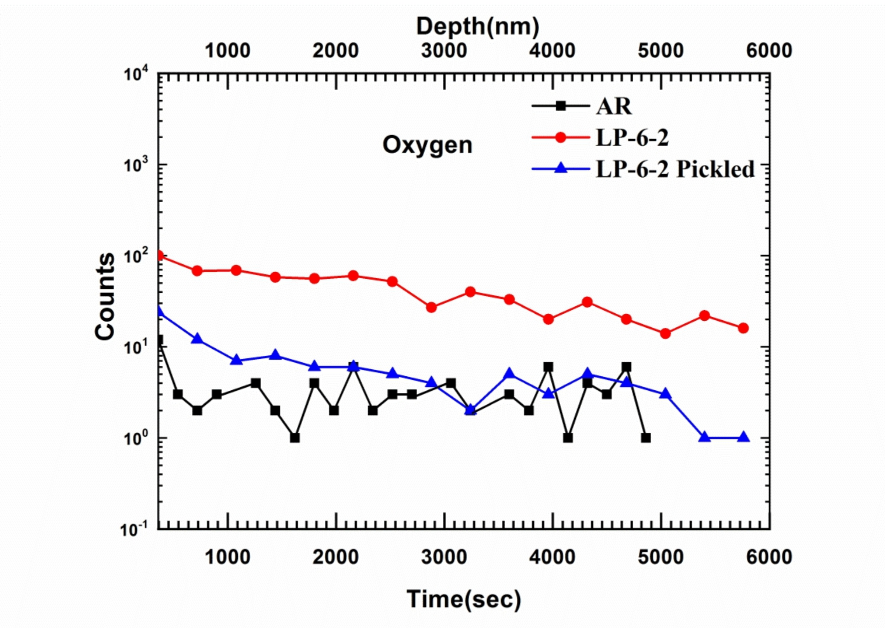
Acid pickling

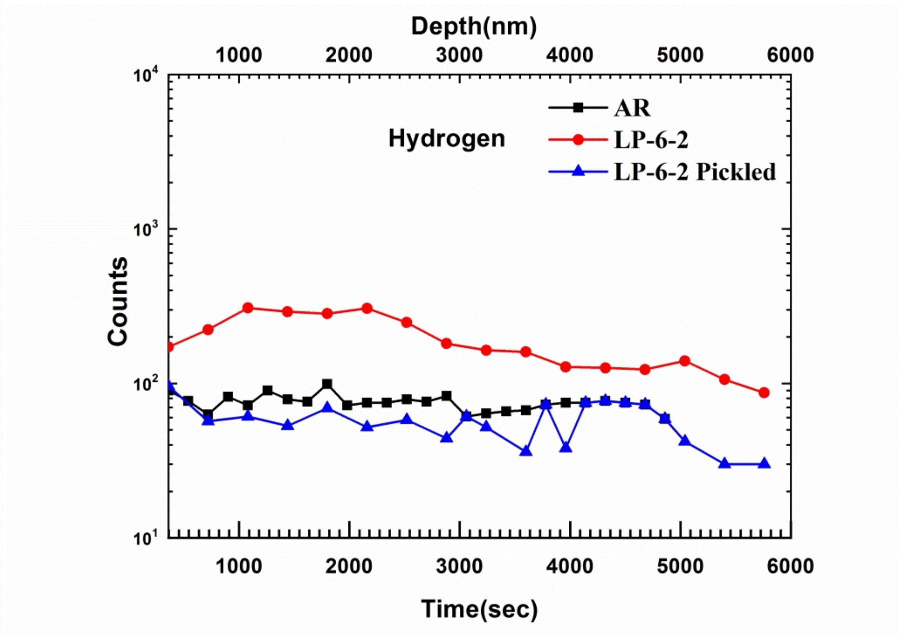
Aqueous solution of 1.67% HF, 33.67% HNO_3 (all in wt%)



20 μm removed in 10 min

SIMS profiles

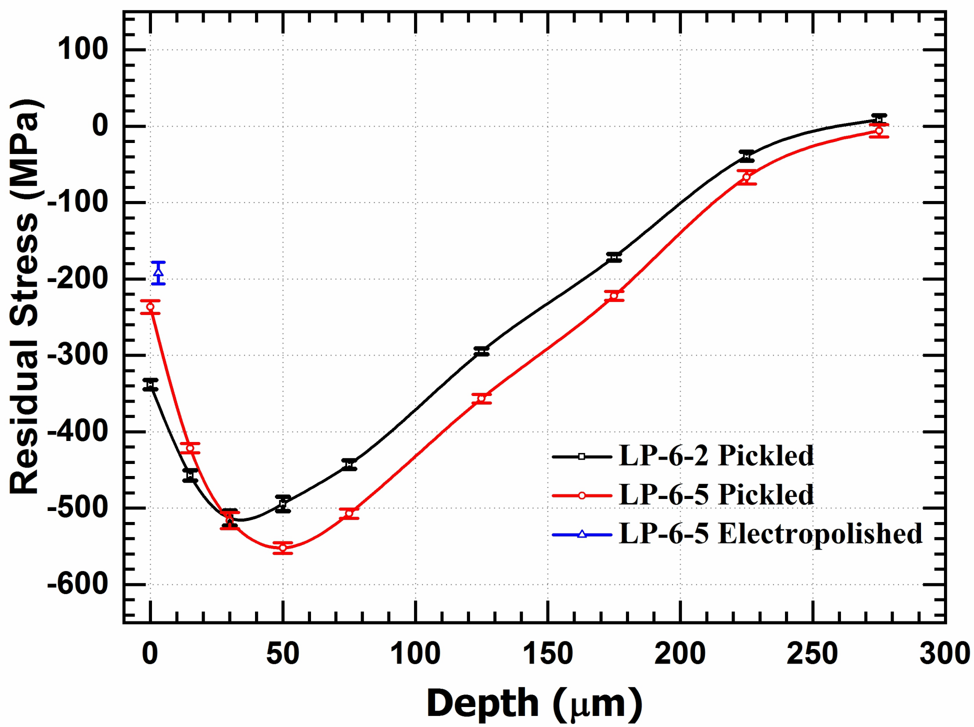




Oxygen rich layer < 10 µm
Consistent with EDX

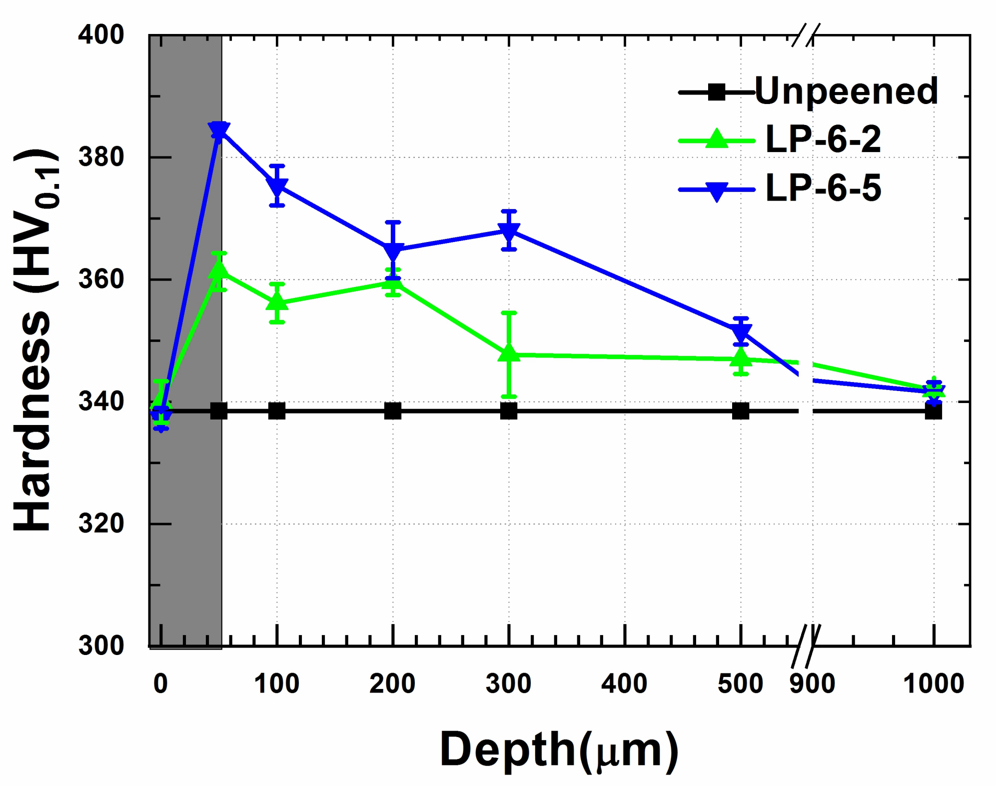
No hydrogen embrittlement

Residual stress profile



- Surface TRS: + 65 MPa
- RS: **uniform** & **isotropic**
- Region < max. CRS ⇒ thermally affected
- Pickling does not affect the profile

Hardness



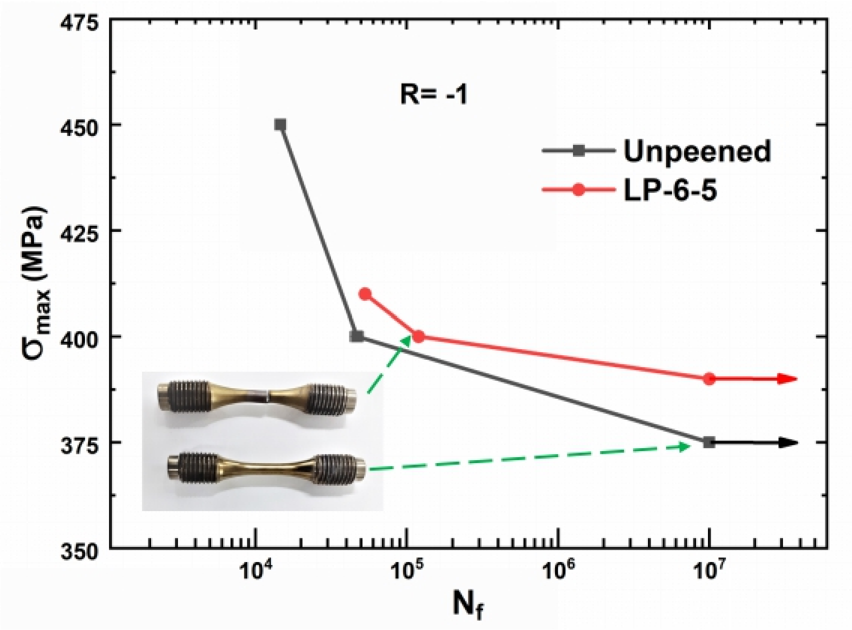
- Hardness maxima away from surface
- No embrittlement
- Large work hardened depth (500 μm)

EBSD

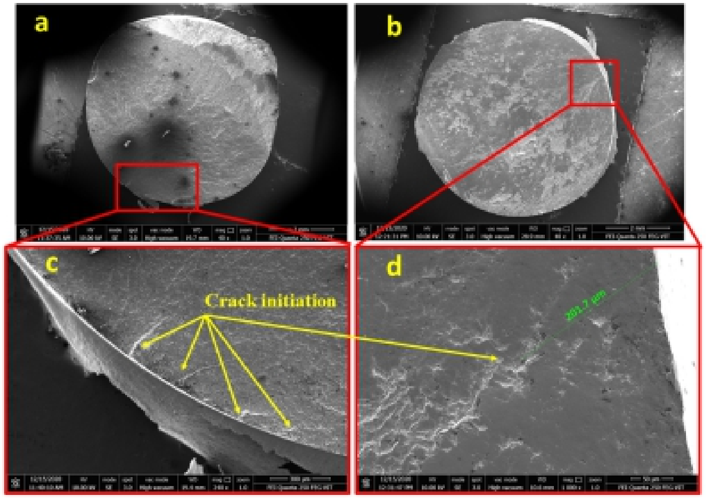
Misorientation Angle	Unpeened	LP-6-2	LP-6-5
2-5°	0.309	0.283	0.321
5-15°	0.125	0.116	0.129
15-18°	0.566	0.601	0.549

Condition	Average grain size (µm)	Ultra-fine grains (< 1 µm)	Fine grains (1-5 µm)	Coarse grains (5-18 µm)
Unpeened	4.675	0.016	0.424	0.560
LP-6-2	4.407	0.020	0.434	0.546
LP-6-5	4.968	0.018	0.447	0.535

S-N Curve



Fatigue life improvement by 2.5 to 3 times at σ_{max} = 400 MPa and 300 °C



Crack initiation site shifted from surface to sub-surface (at the end of compressive stress zone) after peening

Summary

- Residual stress distribution in Ti-6Al-4V after LPwC depends on volume fractions of α and β phases
- Maximum CRS of 0.66 σ_y can be induced by LPwC
- Oxygen rich TRS region (< 20 μm) can be eliminated by pickling without embrittlement
- LPwC marginally improves misorientation angle and grain refinement
- Fatigue life improved by 2.5 to 3 times at σ_{max} = 400 MPa and 300 °C, by shifting of crack initiation sites to the sub-surface