SHOT PEENING APPLICATIONS AND FUTURE RESEARCH IN THE AEROSPACE INDUSTRY

—

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MONTREAL, THE AIRCRAFT INDUSTRY AND I

"It's not because an idea is crazy that it's necessary wrong" ***(Mission to Mars)***

My background

- **14 years academic**
- **18 years aircraft industry: landing gears, engines, … in Canada and France**
- **Materials & Processes Engineering…hence Shot peening**

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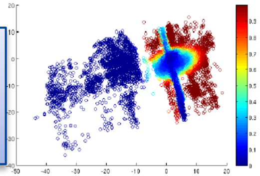
A word on Safran Tech→ Safran Research Centre

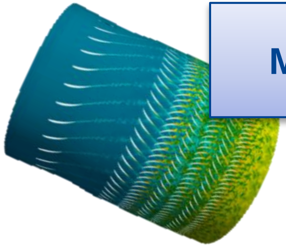
(R)evolutionary energetic architectures

New Materials & Processes

Preservation and enhancement of Numerical data

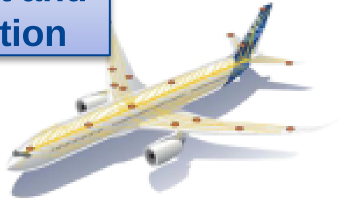


Modelling



The factory of the future

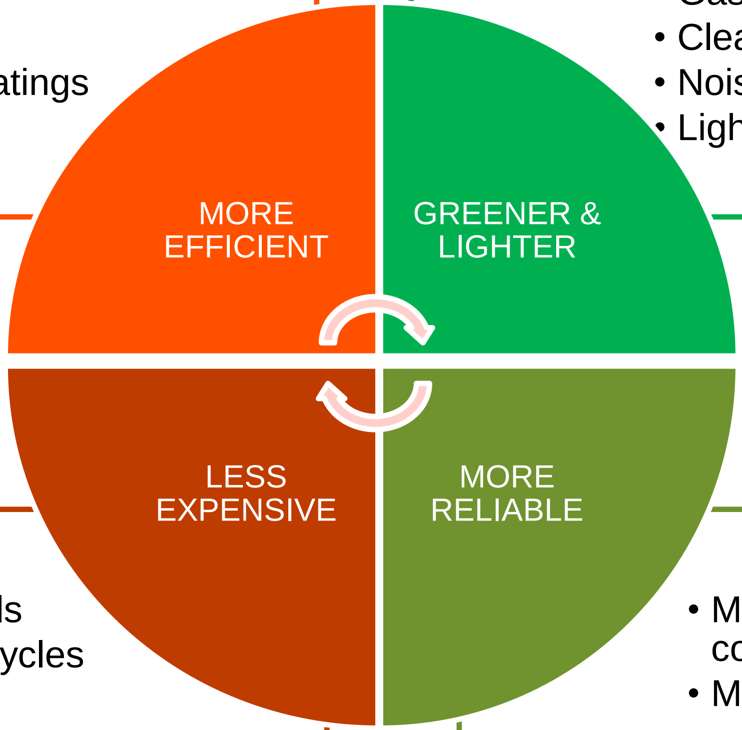
New sensor development and miniaturization



Challenges and Development trends in the aircraft industry

- Stronger Materials
- More performant coatings
- Smarter design

- Gas Emission Reduction
- Cleaner processes
- Noise reduction
- Lighter materials



- Competitive materials
- Shorter production cycles

- More dependable quality control
- More Health monitoring

PEENING IN THE AIRCRAFT INDUSTRY

Forming and strengthening of Wing skins

WALKING YOU THROUGH THIS PRESENTATION…

- Why “shot peening” is obsolete?
- Peening? What makes it interesting?
- Peening… Why?
- Peening… What we don’t like
- Designing with peening…

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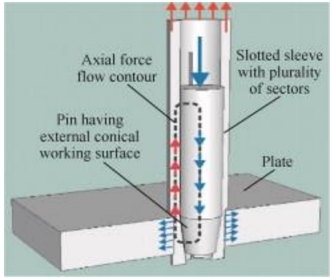
1

WHY IS « SHOT PEENING » OBSOLETE?

“Surface Compressive Straining Processes” instead of “Shot peening”?



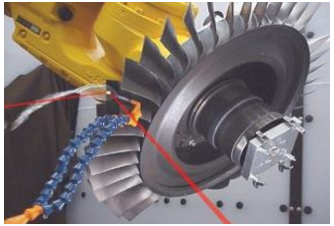
Shotless processes

- Thread rolling
- Low-Plasticity Burnishing
- Cold Expansion
- Laser Peening

Residual compressive stresses

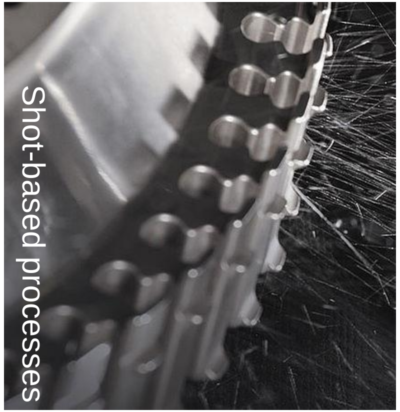
Surface strain-hardening

Grain Refinement



- Shot Peening
  Conv., warm, cryo
- US Peening
- Vibro-Peening
- Gravity Peening

Shot-based processes



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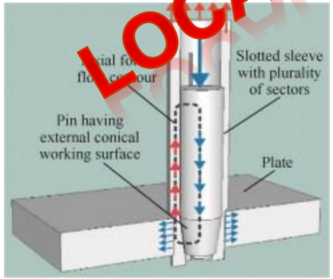
“Surface Compressive Straining Processes” instead of “Shot peening”?



Shotless processes

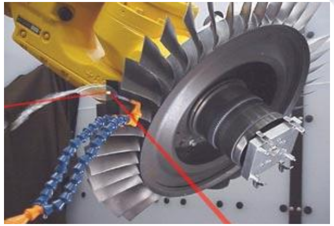
LOCALIZED PROCESS

- Thread rolling
- Low-Plasticity Burnishing
- Cold Expansion
- Laser Peening

Residual compressive stresses

Surface strain-hardening

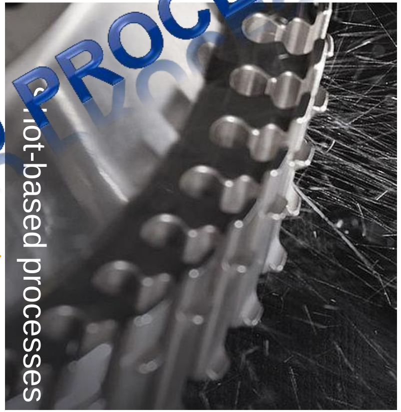
Grain Refinement



- Shot Peening
  Conv., warm, cryo
- US Peening
- Vibro-Peening
- Gravity Peening

GENERALIZED PROCESS

ot-based processes



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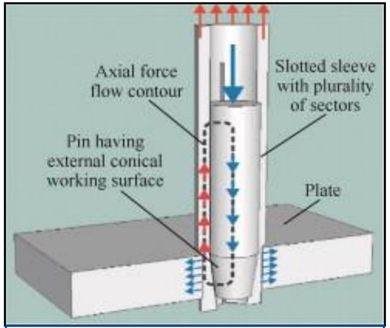
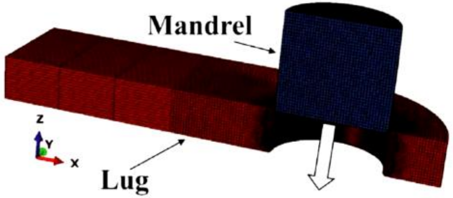
Shotless Processes inducing geometry changes



Cold Expansion

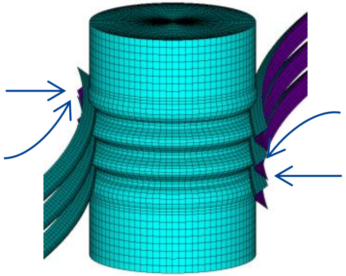


Hole cold expansion

- *Y. Huang and al., -Improving the fatigue life of 2297-T87 aluminum-lithium alloy lugs by cold expansion, J.of Mat.Process.Tech., 249, 2017*

Low Plasticity Burnishing

- *P.S. Prevey and al., Case studies of fatigue life improvements by LPB in gas turbine engine applications, ASME Turbo Expo, Atlanta-Georgia, 2003*



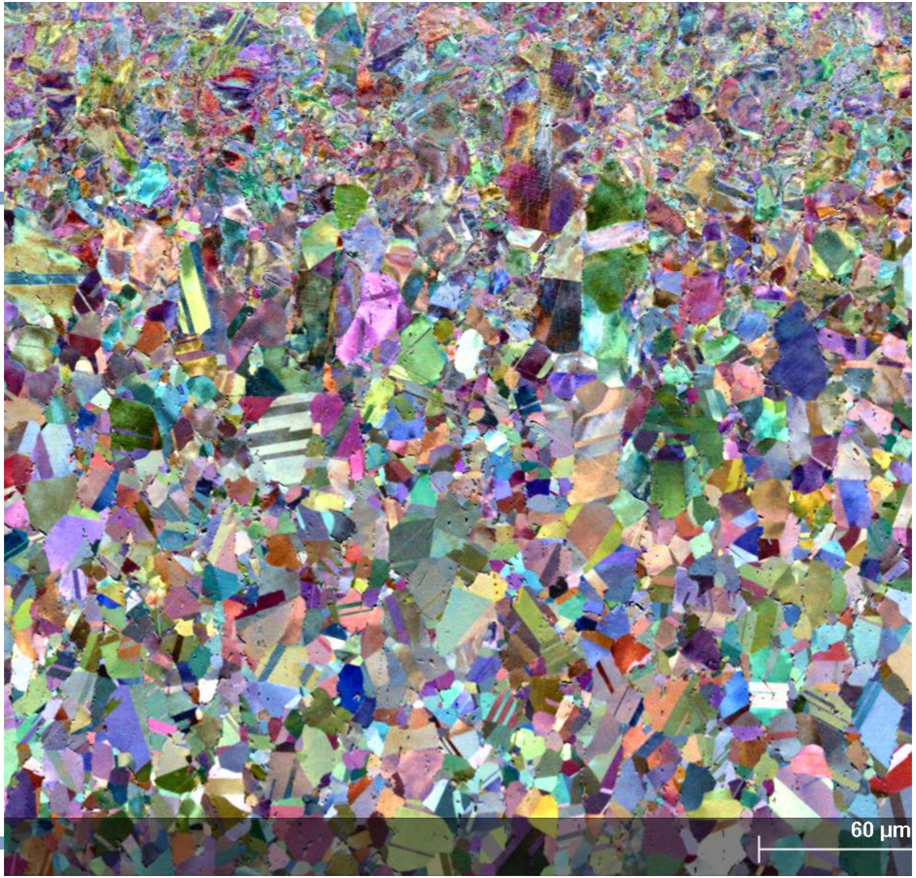
Thread rolling

- *A Furukawa and al., Estimation of the residual stress on the thread root generated by thread rolling process, Bulletin of the JSME, Mech., Vol.33, N.3, 2016*

2

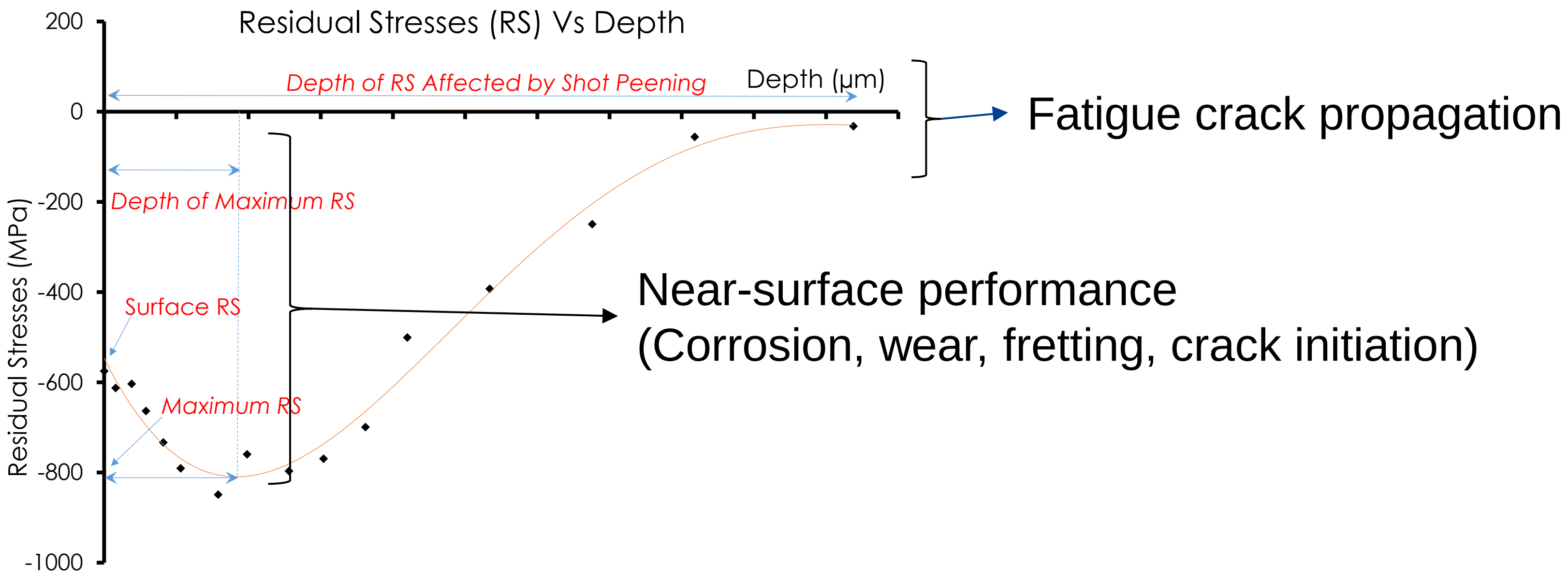
PEENING…WHAT MAKES IT INTERESTING?

How does it change materials performance?



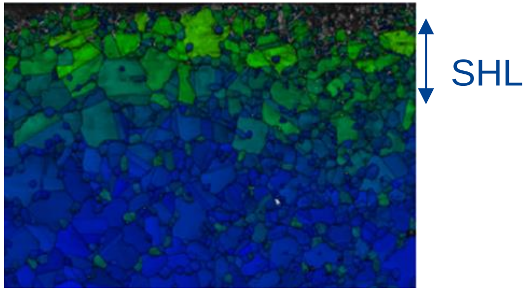
EBSD on shot peened In718 DA, Safran Tech, 2017

Is it surface compressive residual stresses?

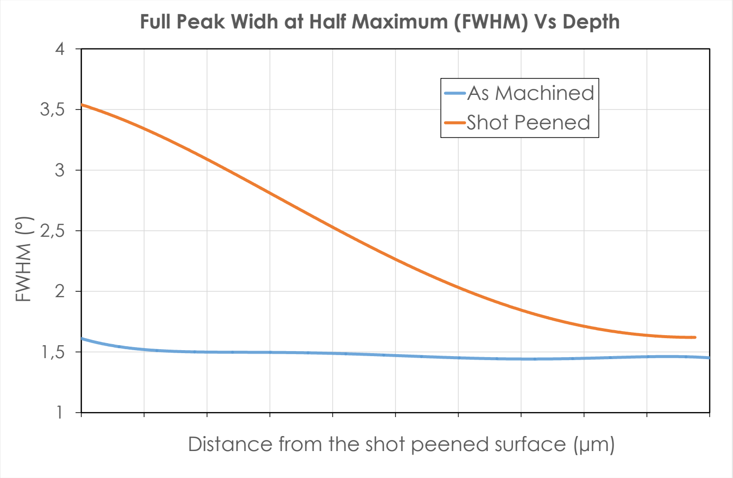


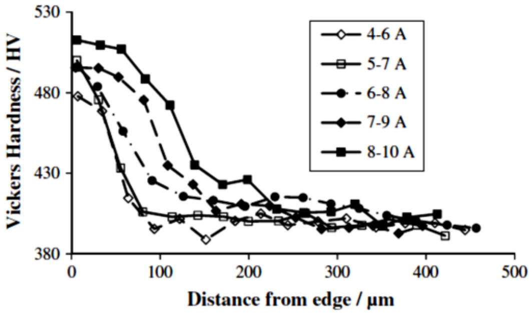
- ✓ **Depth of compressive stresses affected by SP**
- ✓ **Depth of maximum compressive stress**
- ✓ **Maximum compressive residual stresses**
- ✓ **Surface compressive stress**

Is it surface strain hardening/Cold working?



EBSD – Udimet 720Li Ni-superalloy – Shot peened





D.J.Child and al., Acta Materialia, Vo.59, 2011

- ✓ **Is cold working a beneficial effect of peening?**
  - **→Increase surface hardness**
  - **→Believed to be the reason of CRS relaxation: less CW, less CRS relaxation**
  - **→Produce a strain hardened layer (SHL)**
  - **→ is SHL the controlling factor?**

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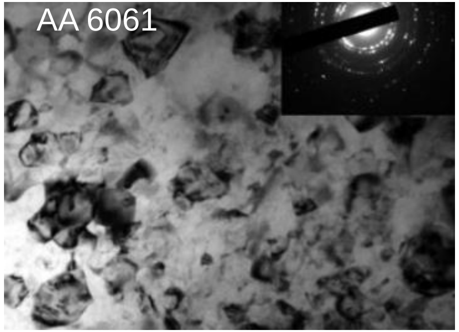
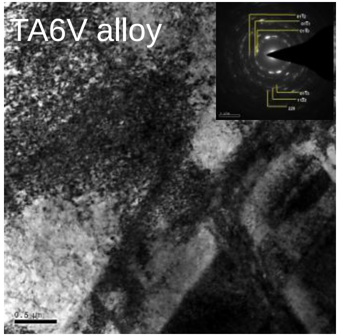
Is it the near-surface microstructure modification?

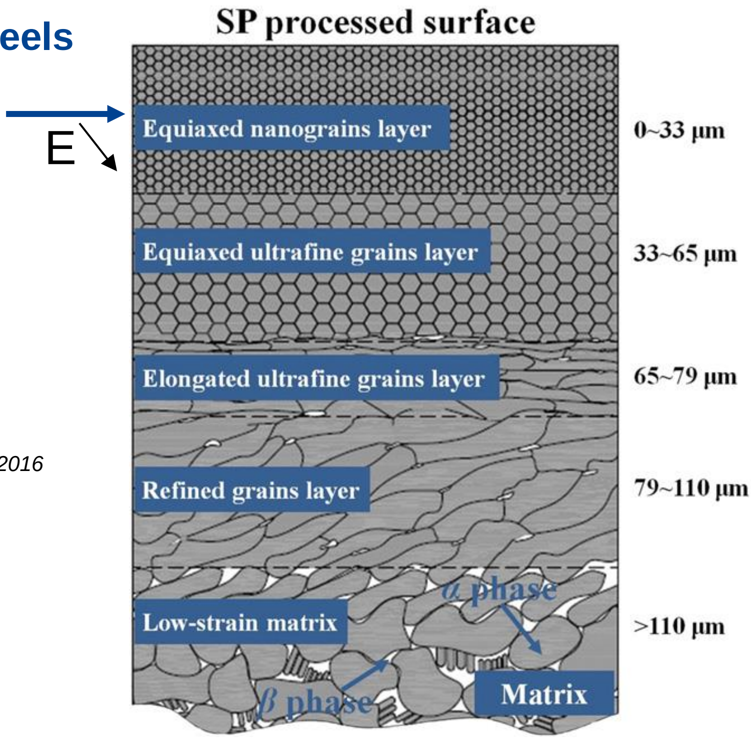
✓ **Nano-crystallization → Al-alloys, Ti-alloys and stainless steels**



B.Chen and al., J.Mater.Res., vol.29, N.24, 2014



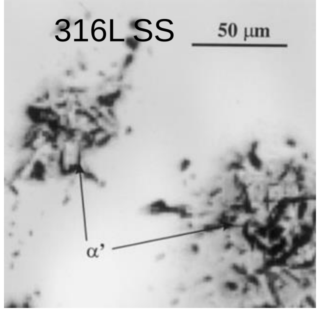
S.Kumar and al., Journal of Materials Design, Vol.110, 2016



Microstructure characteristics in TA6V after SP

Liu and al., Materials Characterization, Vol.123, 2017

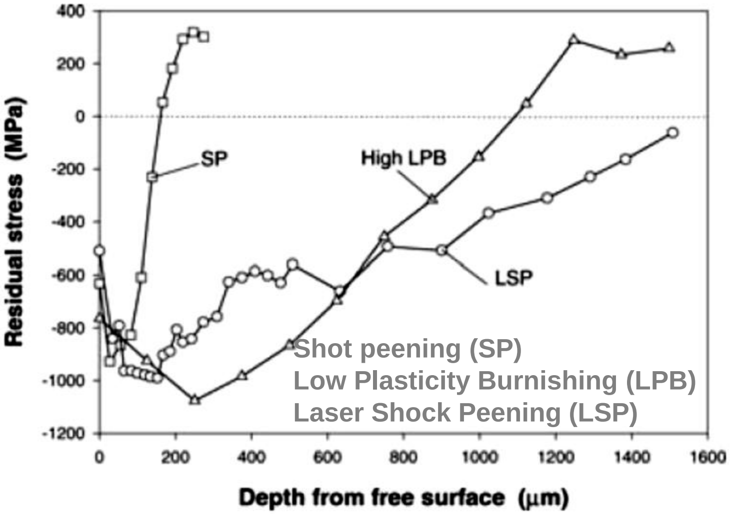
✓ **Microstructure → Martensitic transformation of SS**



P.Kumar and al., IRJET, Vol.3, N.5, 2016
P.Peyre, Mat.Sc. And Eng., A280, 2000

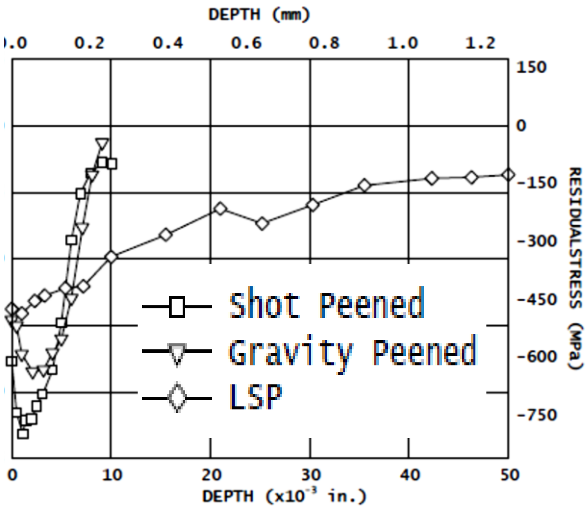
Material and process influence

Residual stresses in In718

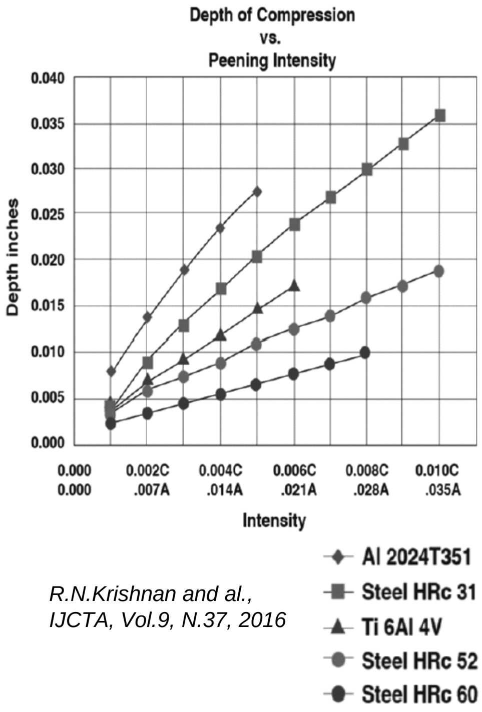


W. Zhuang and al, J. of Eng. Gaz Turbine, Vol.125, 2003

Residual stresses in TA6V



P. Prévey and al., Proceedings of the 17h Heat treating Conference, 1998



R.N.Krishnan and al., IJCTA, Vol.9, N.37, 2016

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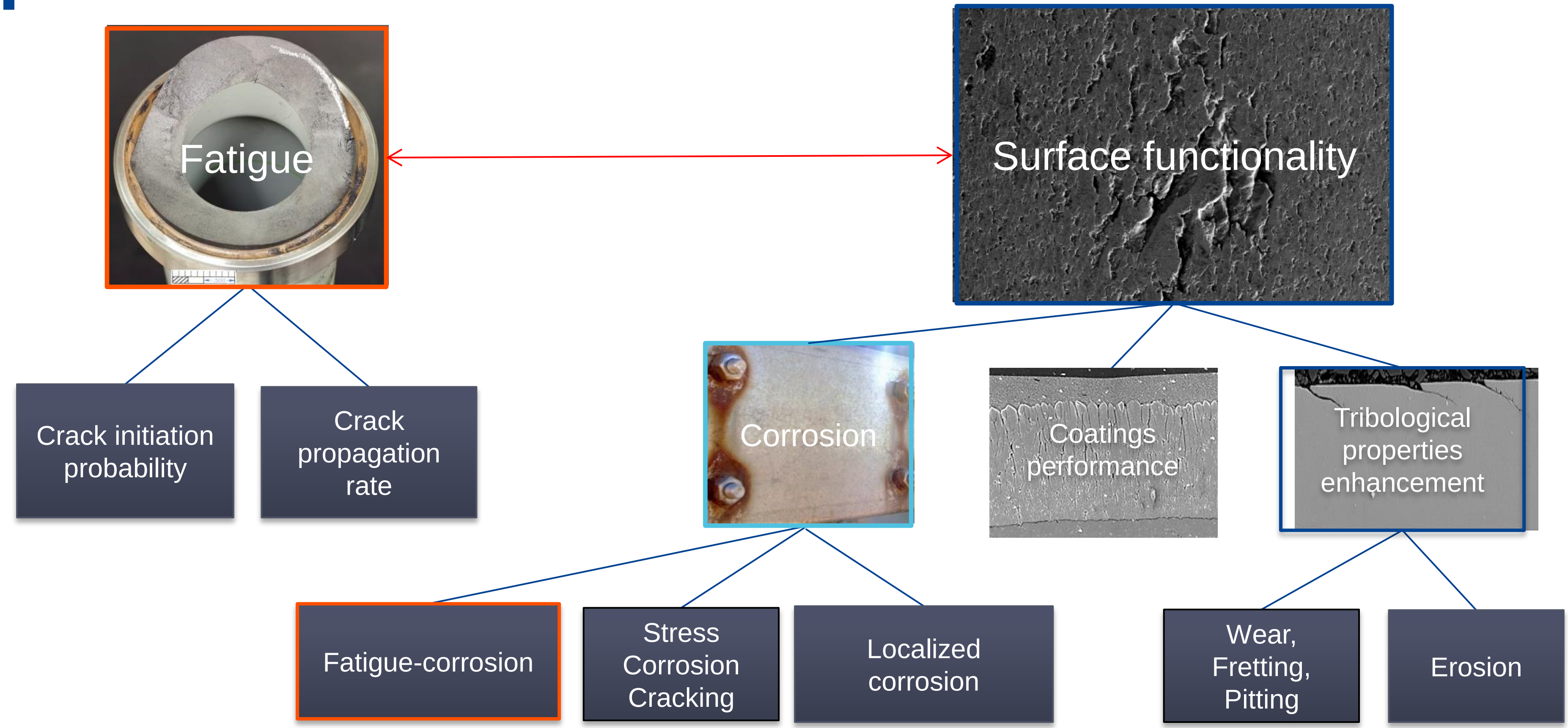
PEENING…WHY?

For what scope?

Almen fixtures on fan blades – Ref.: Guyson Corp.

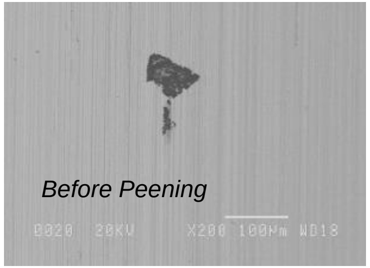
What aircraft components performance can peening improve?

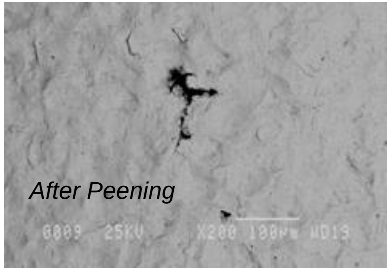


Fatigue improvement → How shot peening Mitigates defect impact on fatigue

✓ **Reducing probability of crack initiation in materials defects**

→ *Mitigating Inclusions impact in U720 PM Ni-superalloy HP Turbine disk*

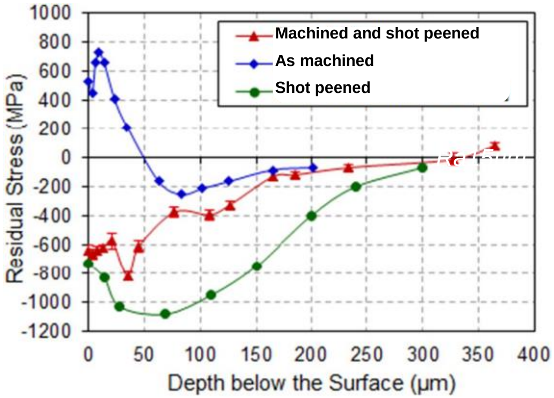




R.L.Barrie and al., Mat.Sc. And Eng. A, Vol.474, pp.71-81, 2008

✓ **Improving surface integrity**

→ *In-718 Ni-superalloy LP Turbine disk: Mitigating machining defects*

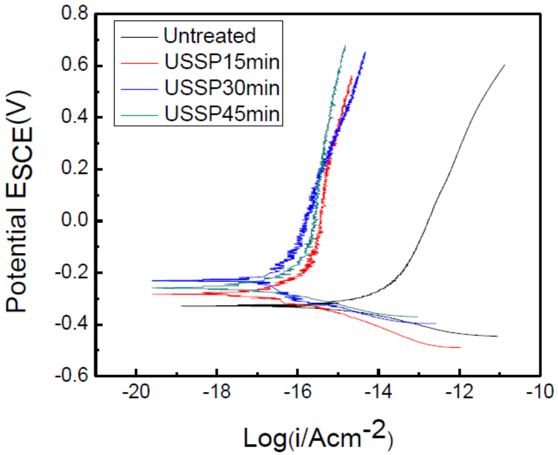


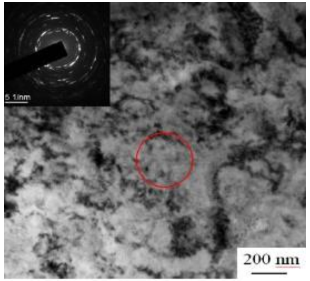
A.Chamanfar and al., Mat. Caract., Vol.132, 2017

Corrosion and Stress-Corrosion resistance improvement → Impact of peening process

- ✓ **Peening process should be customized for lower Ra or shotless processes preferred**

→ *TA6V Corrosion resistance in 3%NaCl improved by US peening*

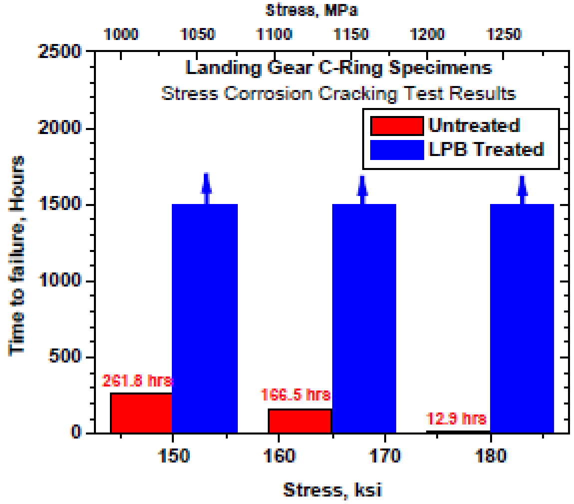




C.Zang and al., Int.J. Electrochem. Sc., Vol.10, pp.9167-9178, 2015

- ✓ **Stress-corrosion cracking resistance**

→ *300M SCC resistance in 3%NaCl improved by Low-Plasticity Burnishing*

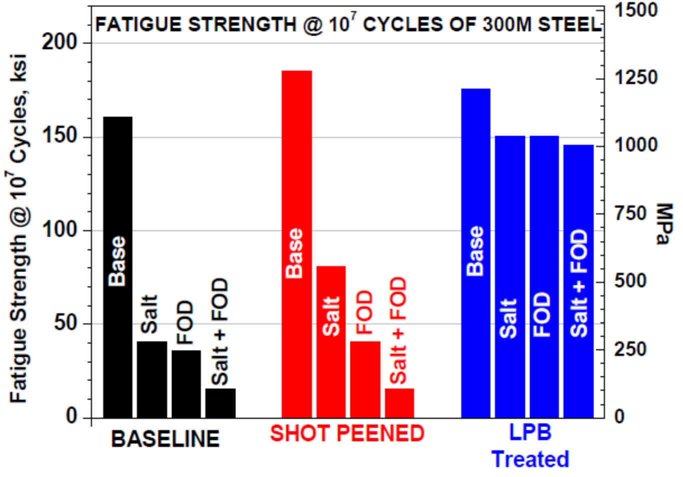


D.Hornbag and al., Lambda Technology Tech Paper, #07ATC-104, 2007

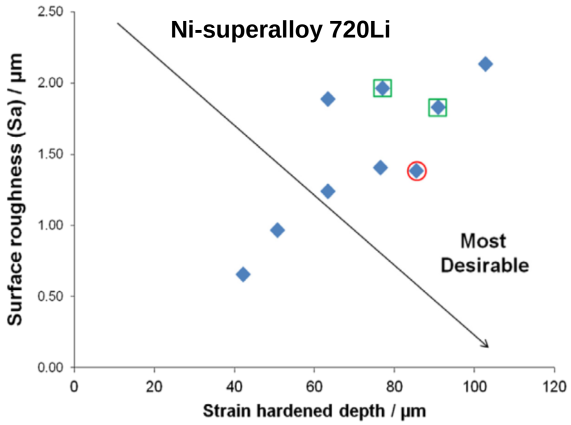
Fatigue-corrosion improvement (Room and High-temperature)

→ 300M fatigue strength in 3%NaCl improved by Low-Plasticity Burnishing

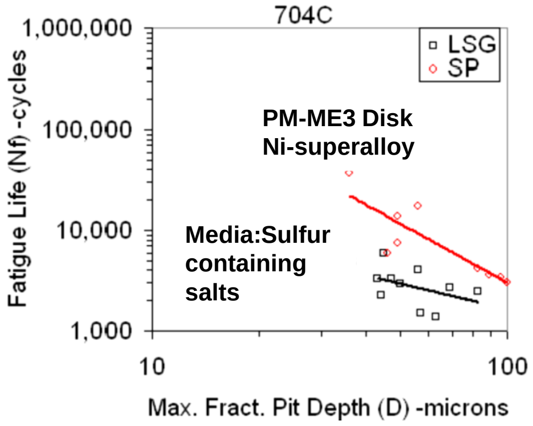
→ High-strain hardened depth + low surface roughness are needed → Shot peening process control is paramount



P.S.Prevey and al., Proceedings of the 6th Aircraft corrosion workshop, 2004



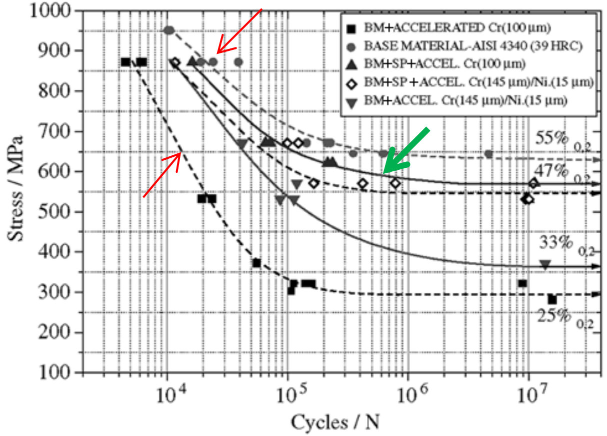
G.J.Gibson and al., Materials at high temperatures, Vol.33, N.3, 2016



P.Gabb and al., NASA/TM-215629, 2009

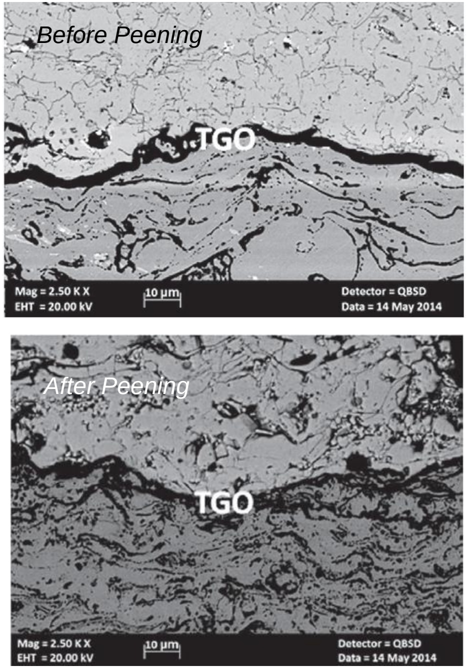
Peening for Coating

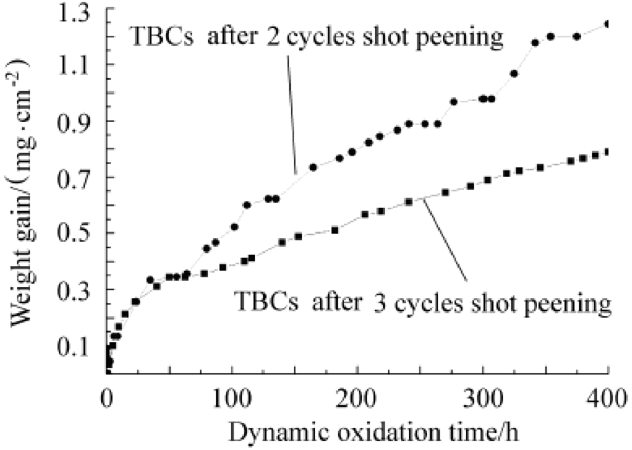
→ Mitigating fatigue debit due to plating 4340 HSS for aircraft applications



M.P.Nascimento and al., Materials Research, Vol.5, N.2, pp.95-100, 2002

→ Increasing cyclic oxidation life of engine bladesTBC McrAlY/YSZ systems by decreasing TGO growth kinetics





Z.Zou and al., Chinese J. of Aeronautics, Vol.20, pp.145-147, 2007

A.C. Karaoglanli and al., Appl. Sur.Sc., Vol.354, pp.314-322, 2015

- ✓ **Reduce fatigue debit linked to coating →Cr, Ni on high-strength steels; anodizing for Al alloys**
- ✓ **Delay excessive oxidation of TGO in TBC systems**
- ✓ **Counter tensile stresses due to coating/Substrate mismatch**

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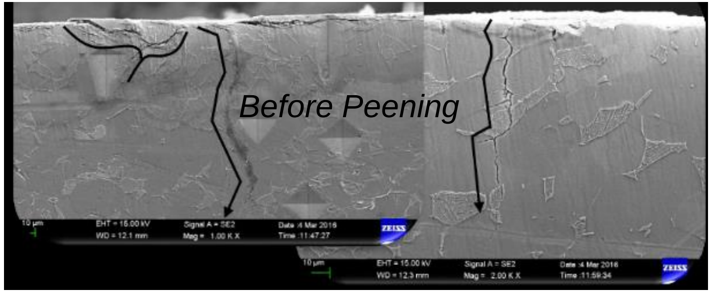
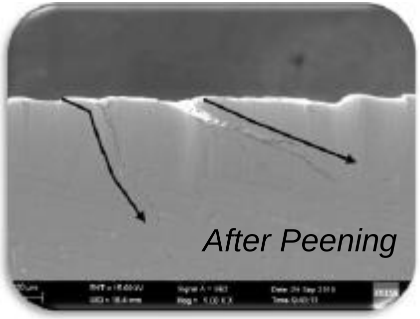
Tribological properties → Fretting and Wear (peening improve H/E)

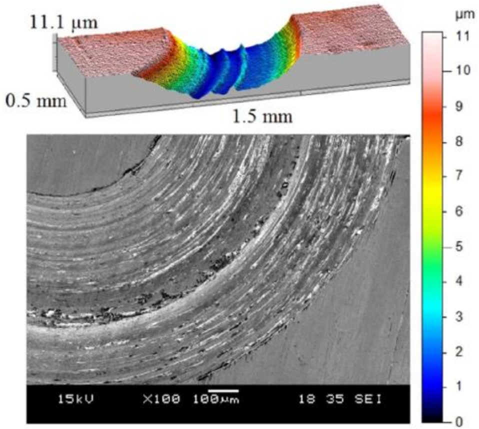
✓ **Fretting fatigue at the engine disk/blade attachment (TA6V)**



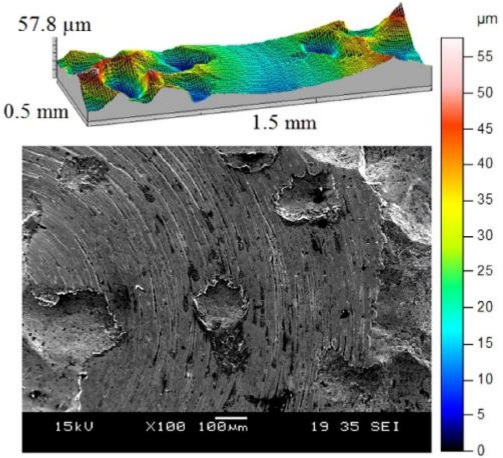


Q. Yang and al., Wear, 2016

✓ **Wear of aircraft steels (4340)**



without shot peening



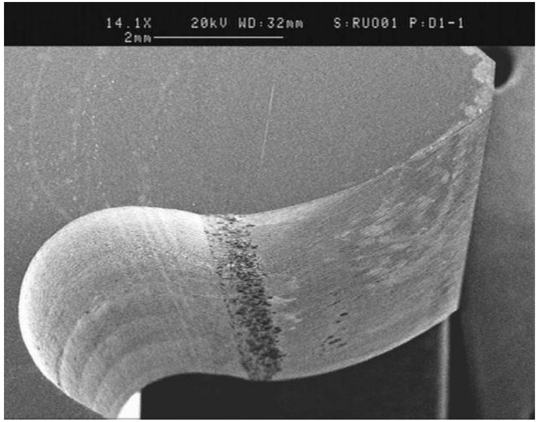
with shot peening

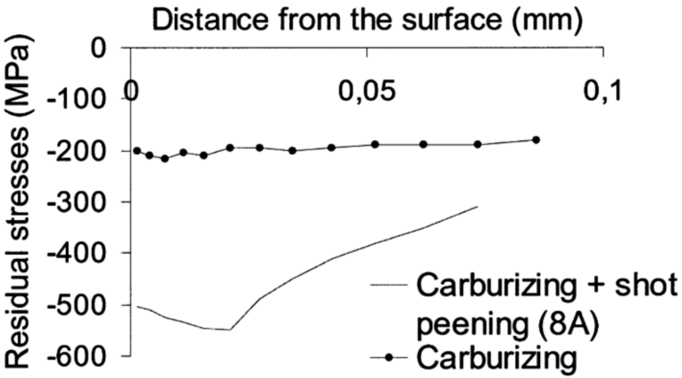
P.Q.Trung and al., Surf.Topogr.Metrol.Prop., Vol.4, 2016

Tribological properties → Contact fatigue of gears

✓ **Contact fatigue of carburized steel gears**

M.Guagliano and al., Eng.Fail.Anal., Vol.9, 2002

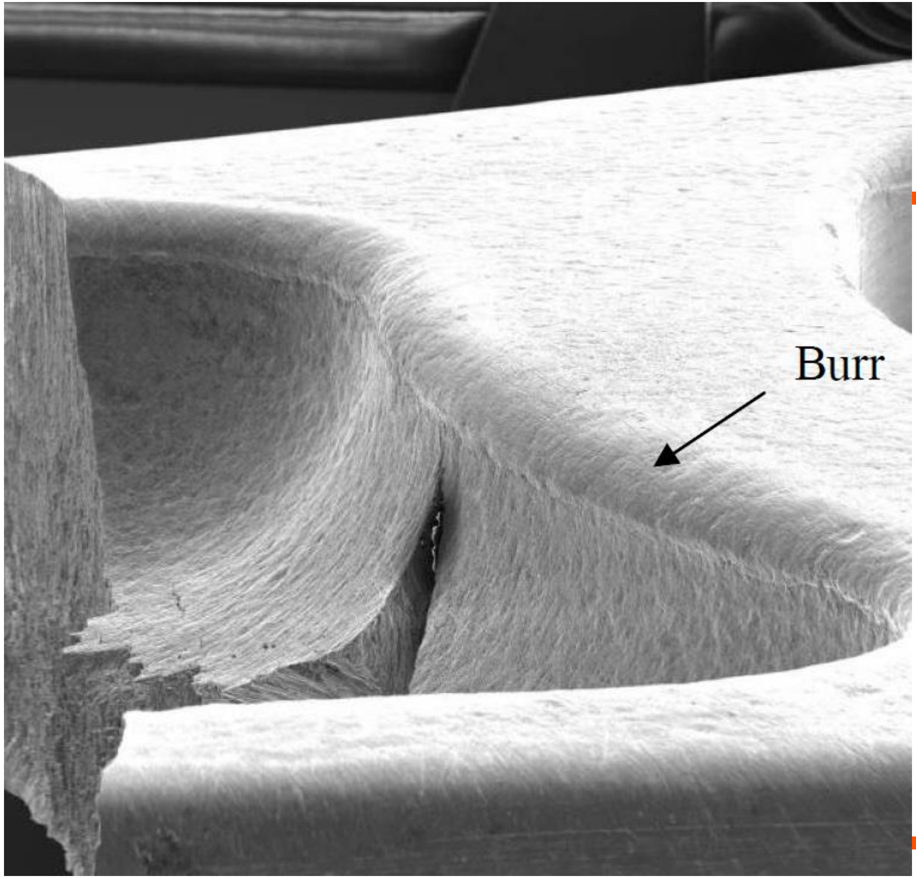




ΔKI
ΔKII
ΔKeq

Stress intensity factor values, according to numerical computation

	With no residual stresses	8 A shot-peening	12 A shot-peening	14 A shot-peening
ΔK_{I}	10.1 MPa $\sqrt{m}$	7.5 MPa $\sqrt{m}$	5.8 MPa $\sqrt{m}$	3.4 MPa $\sqrt{m}$
ΔK_{II}	4.1 MPa $\sqrt{m}$	3.6 MPa $\sqrt{m}$	3.2 MPa $\sqrt{m}$	2.9 MPa $\sqrt{m}$
ΔK_{eq}	10.8 MPa $\sqrt{m}$	8.3 MPa $\sqrt{m}$	6.6 MPa $\sqrt{m}$	4.4 MPa $\sqrt{m}$



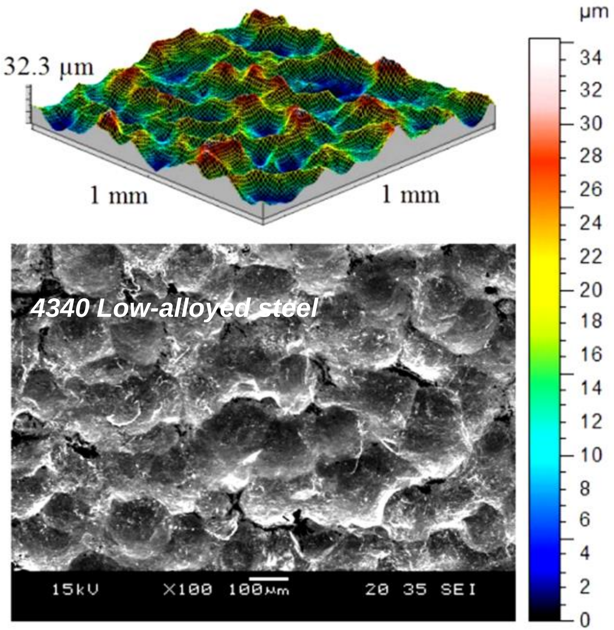
Hugues Helicopter 369 accident -2014

4

WHAT WE DON'T LIKE?

YES, BUT…

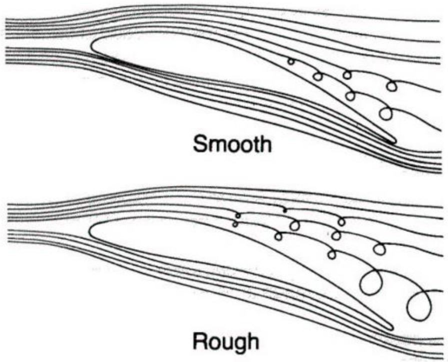
Surface finish comes with the package



P.Q.Trung and al., Surf.Topogr.: Metrol. Prop. 4, 2016

✓ Roughness, surface defects

- → Reduce fatigue resistance effectiveness especially for LCF
- → Creates air turbulence In Aircraft engines where gas path passages have to be smoother (reduces fuel efficiency)



J.F.Loersch and al., ICSP1, 1969, 649-669

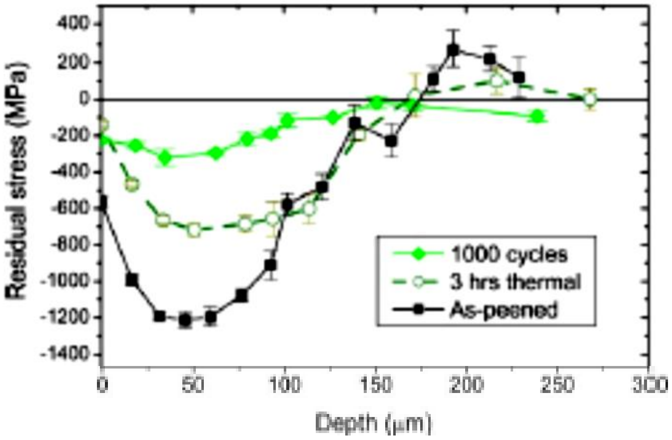
Instability of shot peening positive effects

✓ **Relaxation of compressive residual stresses**

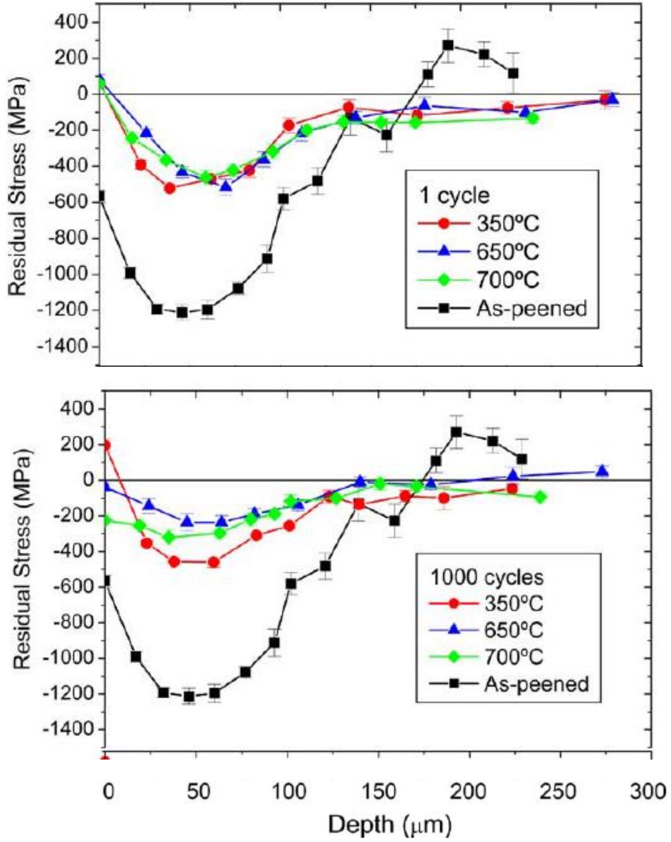
→ **Mainly due to mechanical cycling**

Residual stresses Udimet 720Li @ 700°C

Thermomechanical Vs thermal relaxation



Residual stresses Udimet 720Li evolution
Fatigue cycling @ 1.2% strain



A. Evans and al., Int.J. of Fatigue, 27, 2005

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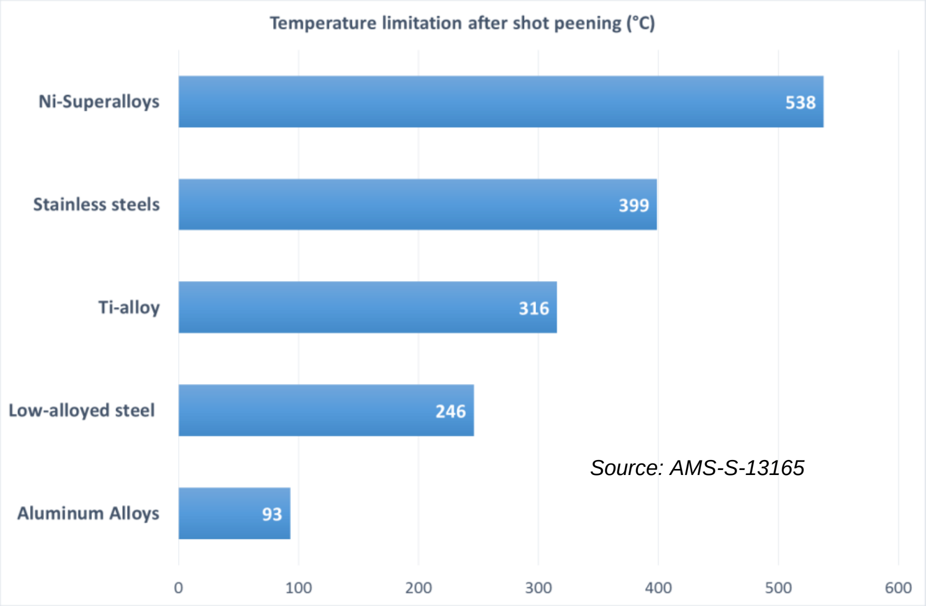
Instability of shot peening positive effects

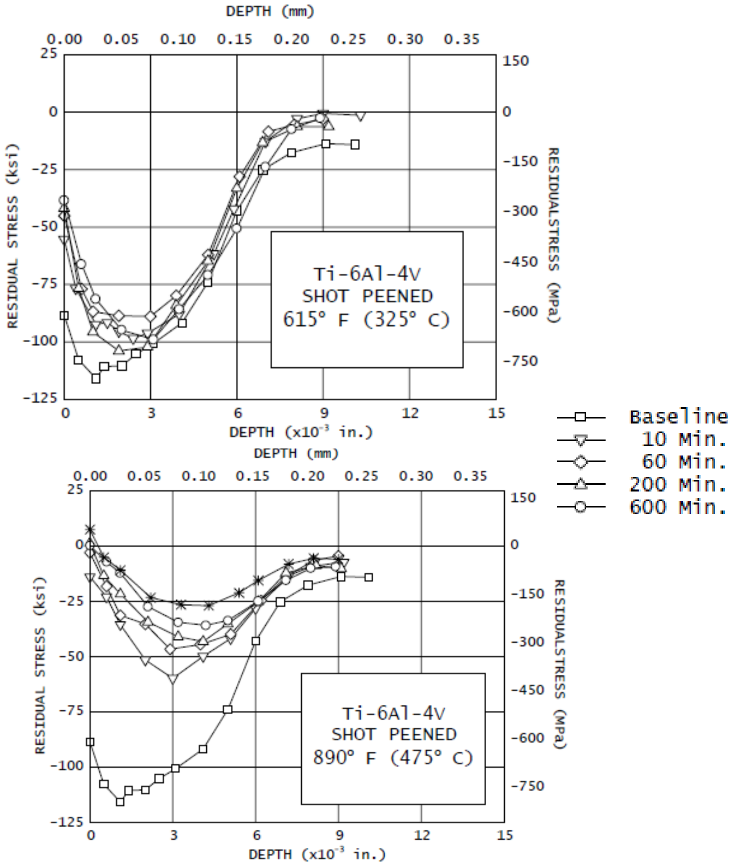
✓ **Relaxation of compressive residual stresses**

→ **Material and temperature related**



Source: AMS-S-13165

Residual stresses thermal relaxation in TA6V



P. Prévey and al., Proceedings of the 17h Heat treating Conference, 1998

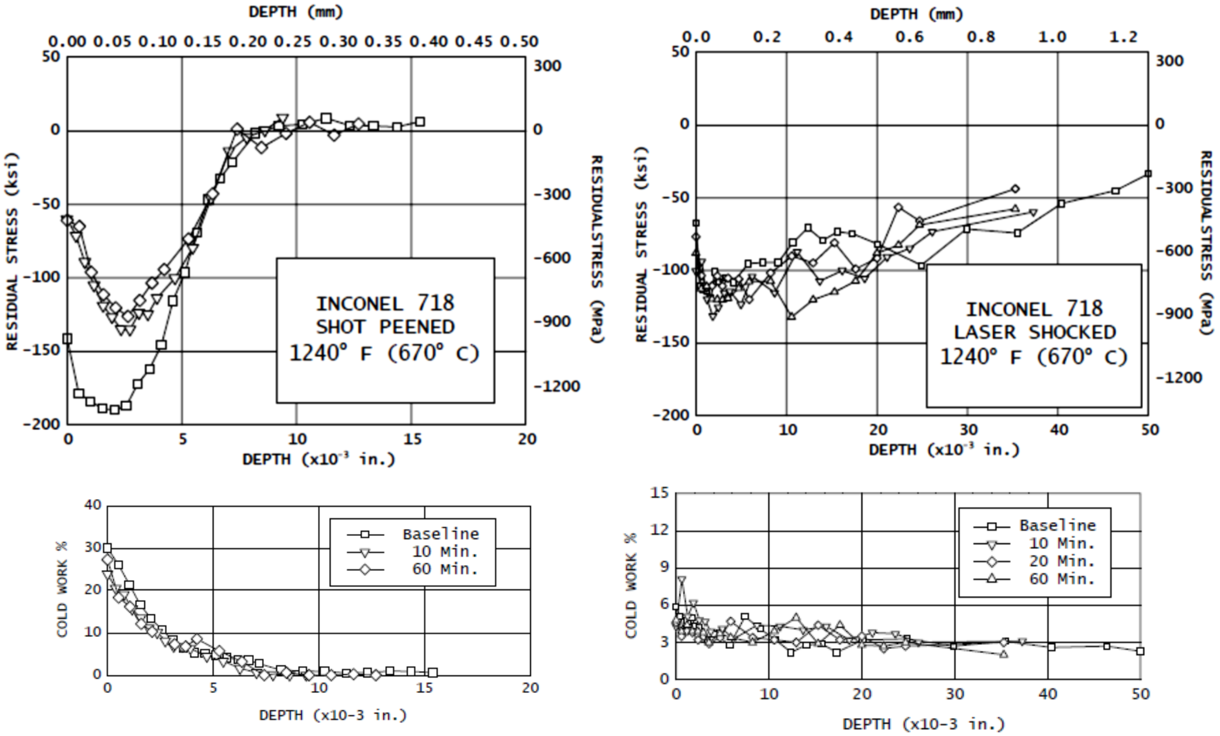
Instability of shot peening positive effects

✓ Relaxation of compressive residual stresses

→ Process dependant

LSP residual stresses are lower than shot peening's but deeper and thermally more stable

LSP Cold work is 3X lower than shot peening's BUT deeper

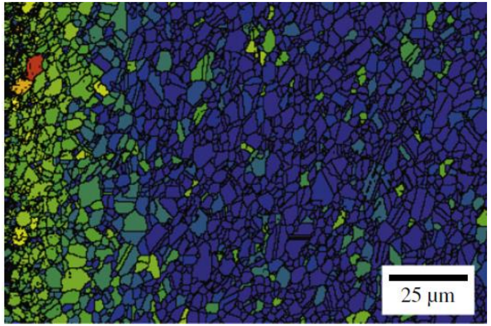


P. Prévey and al., Proceedings of the 17h Heat treating Conference, 1998

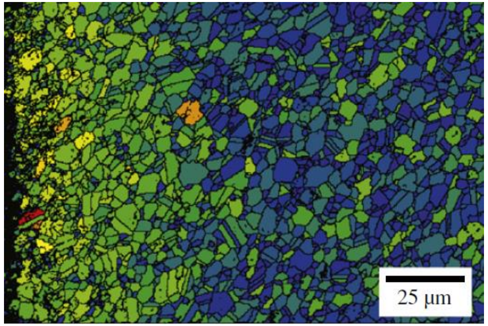
Instability of shot peening effects

✓ **Instability of the Surface Hardened layer**

→ **recrystallization of the SHL during fatigue cycling**

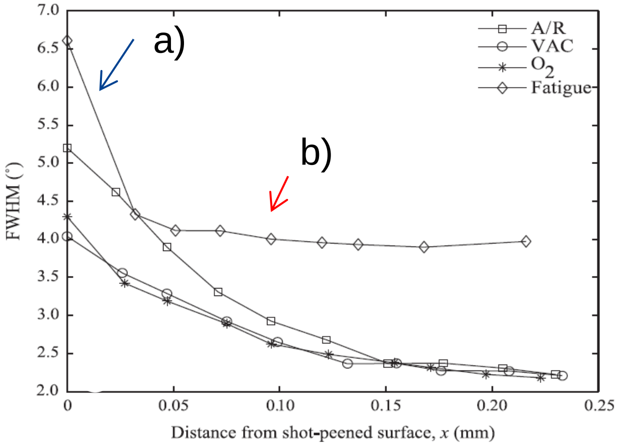


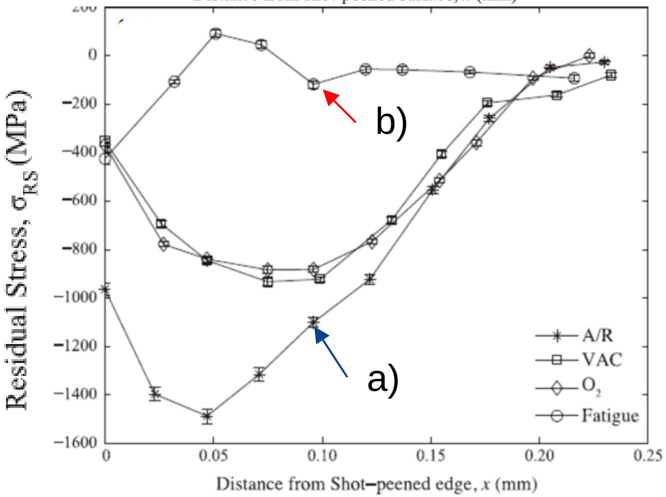
a) Ni-superalloy RR1000 As-Shot peened



b) After 144 fatigue cycles at 850MPa/700°C

B.J. Foss and al., Acta Materiala, Vol.61, 2013





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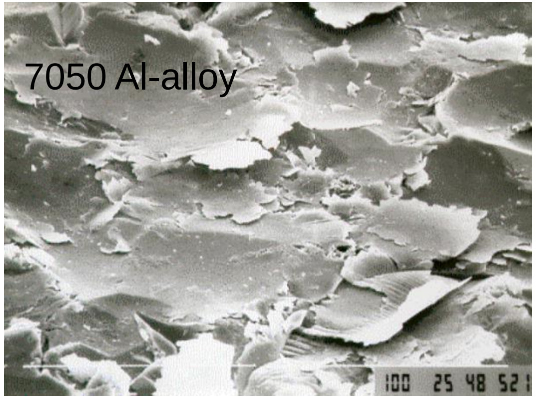
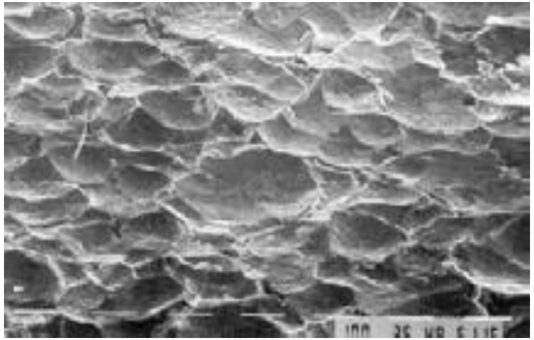
Defects induced in real components

✓ **SP poor control → surface « lifting » , smearing on F18 parts**



Over-pressure or excessive time

P.K.Sharp and al., Defence Sci.&Tech. Org, Australia 2001



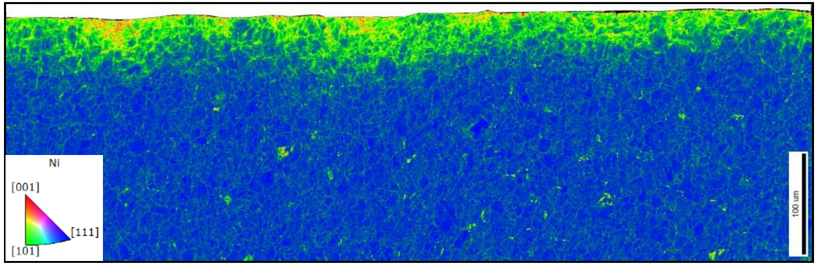
Low angle

✓ **Material folding at edges, chamfers of an engine component**

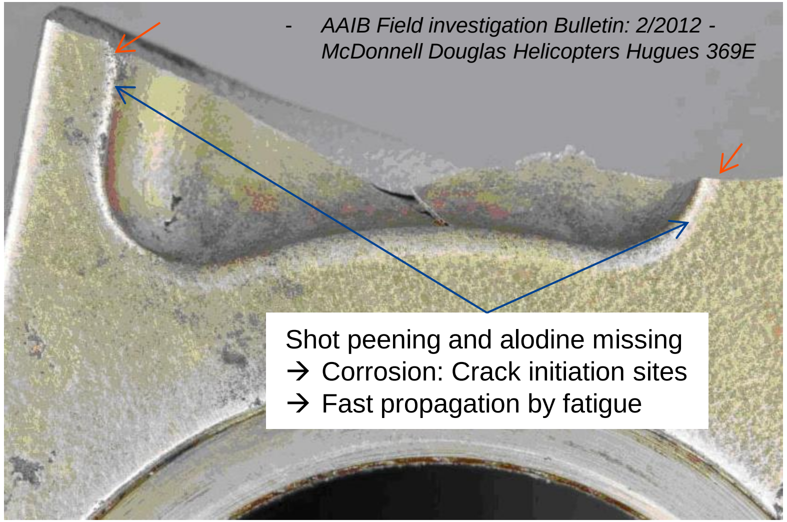
Cross section

…and lack of homogeneity of shot peening?

✓ **Expected near-surface changes? How to control homogeneity of strain worked layer on components?**



Inhomogeneity of the Strain Hardened Layer evidenced by EBSD on IN718DA – coverage control was OK!



- ✓ **Coverage: Relies on human eye skills**
- ✓ **Non-homogeneity: Even when 100% coverage is met**
- ✓ **Shot peening can make NDI difficult by masking small cracks**

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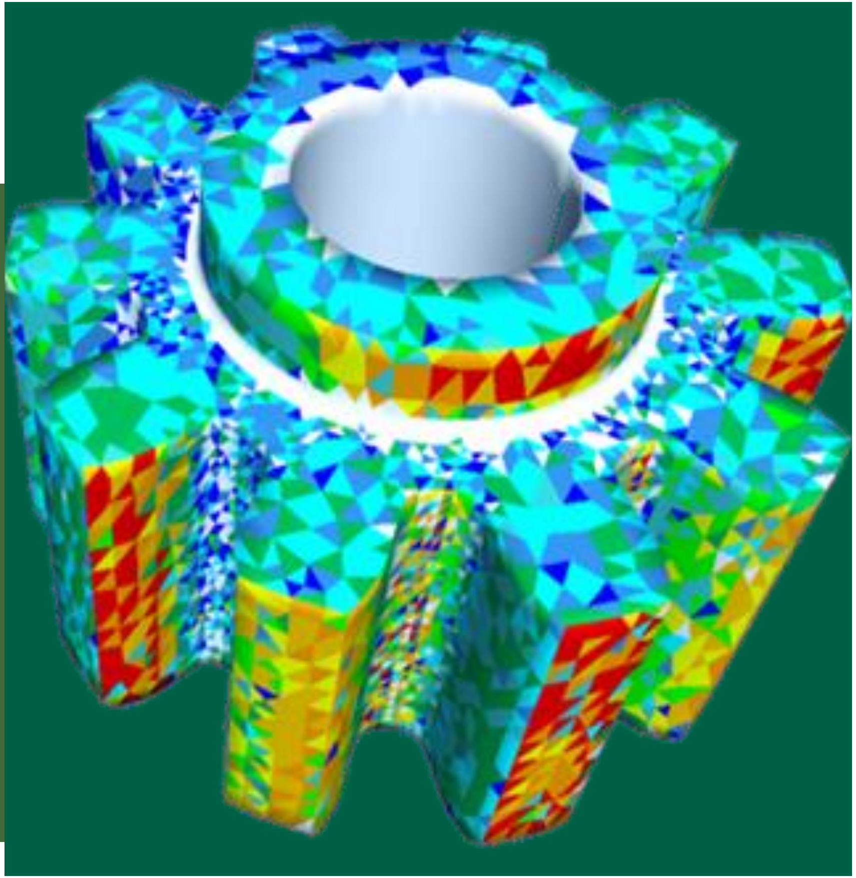
5

DESIGNING WITH PEENING?

"Detection, Prediction and Avoidance"

Should peening stay just a "NICE TO HAVE"?



J. Badreddine, PhD Thesis, 2014

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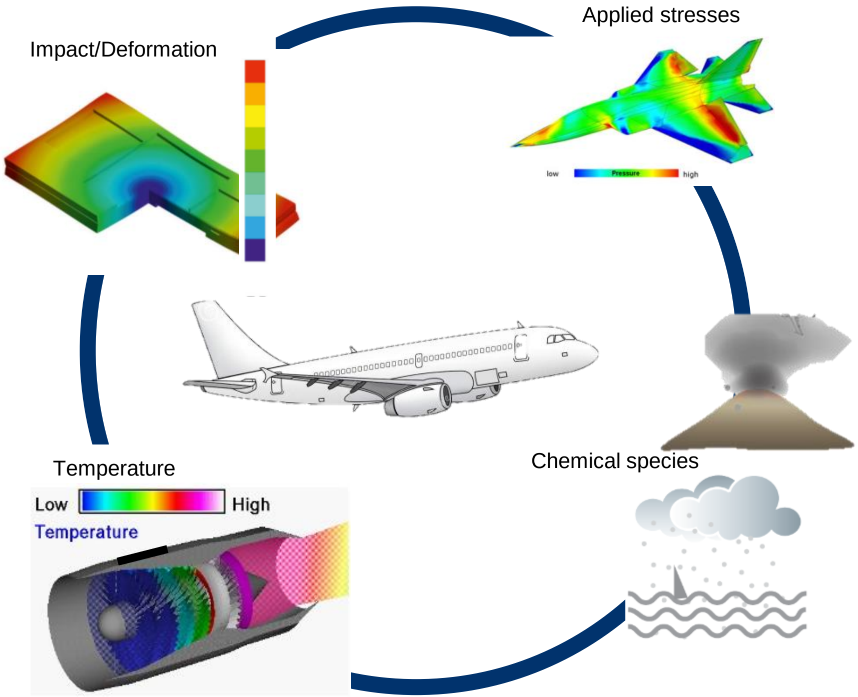
What happens to peening induced conditions during operations?
Considerations for components design



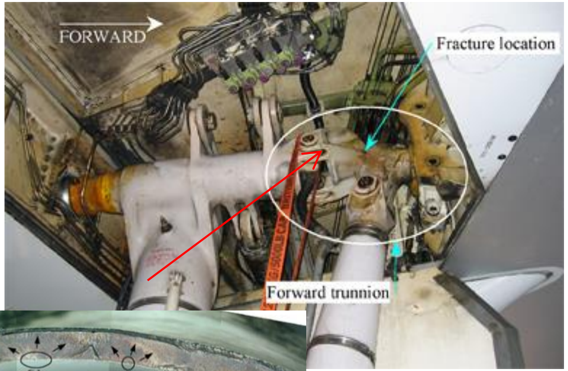
- ✓ Mechanical surface stress relaxation
- ✓ Mechanical surface damage (erosion, FOD)
- ✓ Thermal surface stress relaxation (temperature, friction)
- ✓ Chemical surface damage (corrosion, oxidation)

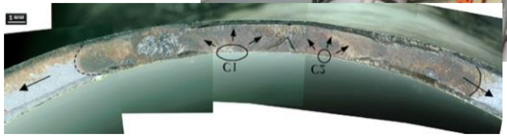
What makes the design still conservative?...Incidents related to SP defects

Non-homogeneous shot peening

McDonnell Douglas Helicopters Hugues 369E (2011) → 7075-Al Tail rotor blade pitch horn

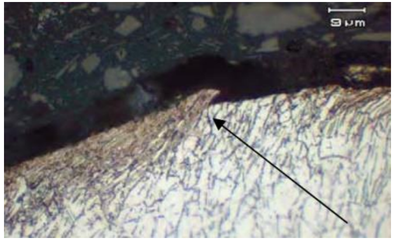
Boeing Co747-300 – Japan Air (2005) → Failure of steel LG Trunion fork during towing



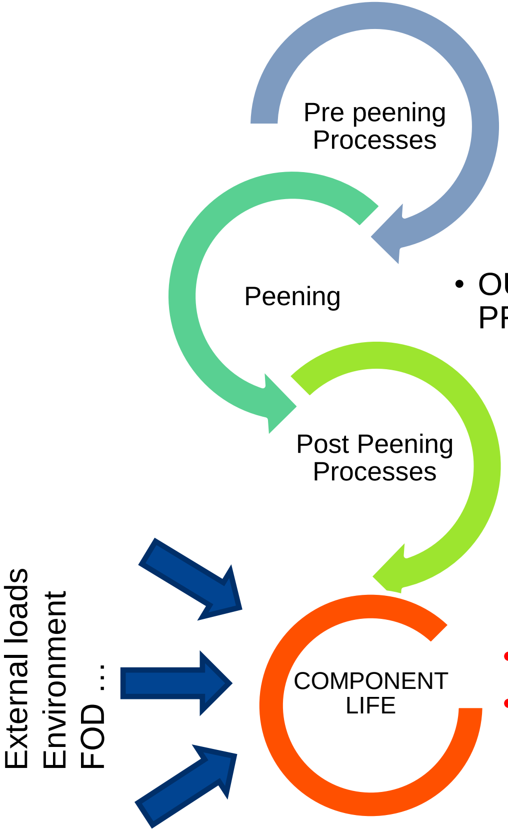


Peening surface fold

Boeing 767- Air New Zealand (2002) → Ni-Superalloy Turbine disk failure at fir tree slot



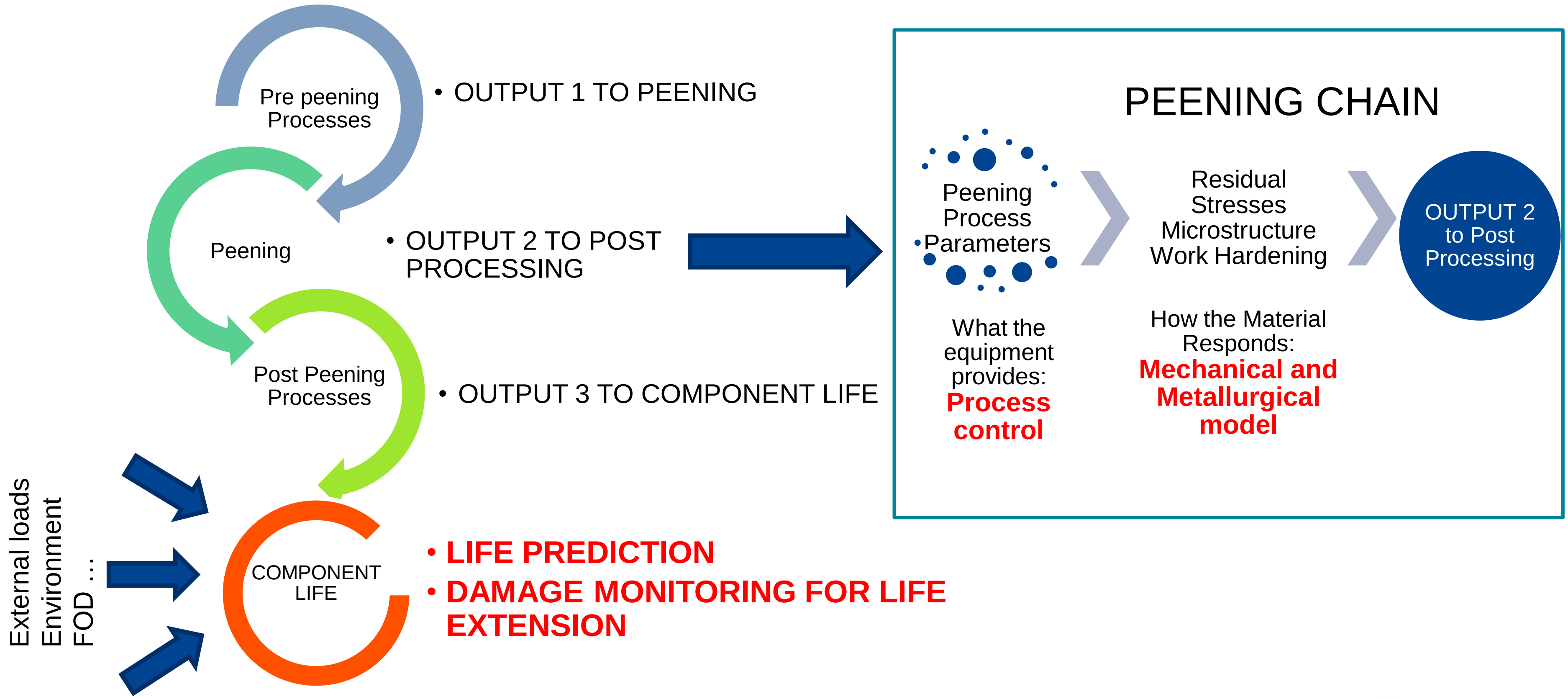
Working on design approaches → The chain that should be addressed



- OUTPUT 1 TO PEENING
- OUTPUT 2 TO POST PROCESSING
- OUTPUT 3 TO COMPONENT LIFE

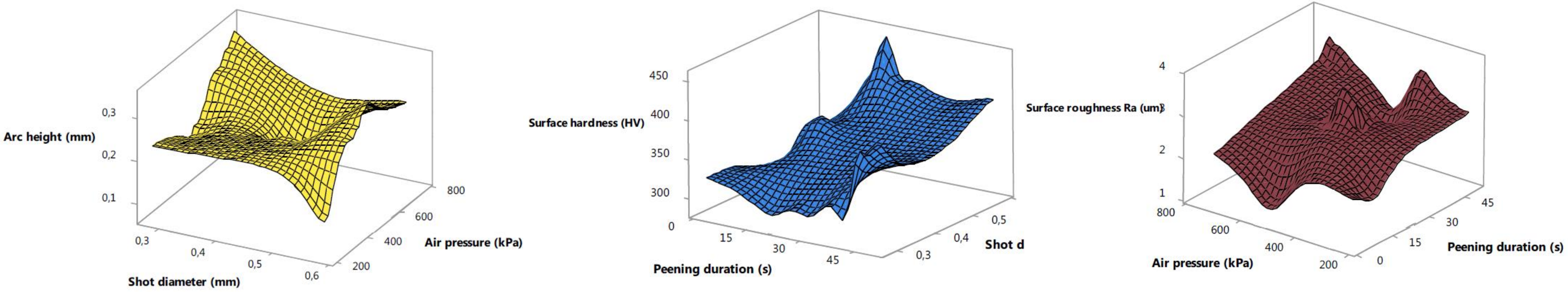
- **LIFE PREDICTION**
- **DAMAGE MONITORING FOR LIFE EXTENSION**

Working on design approaches → The chain that should be addressed



Working on Process Control → Methods for process optimization

→ **Statistical methods (Surface response) – to address the impact of significant parameters of the process on process outputs**



O. Unal, Optimization of shot peening parameters by response surface methodology, Surface & Coating Technology, vol.35, 2016

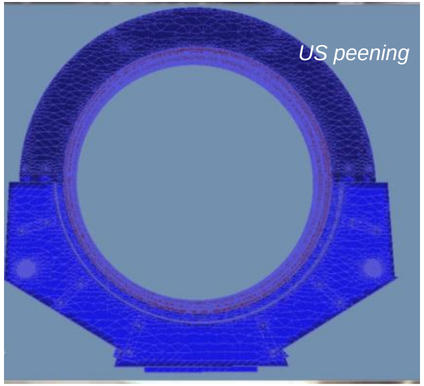
→ **Big Data:The use of historical data for Data Analytics**

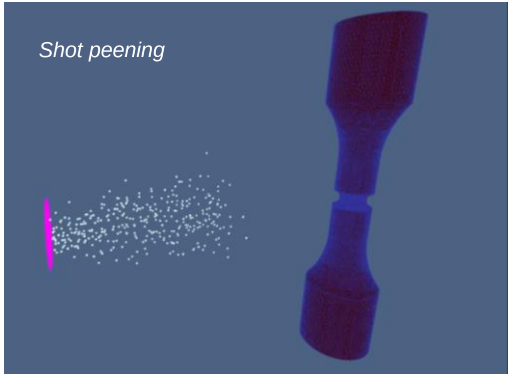
Working on Process Control → Methods for process optimization

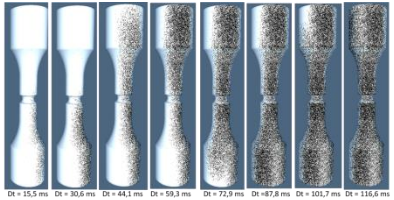
→ FE models – shot stream and impact modelling

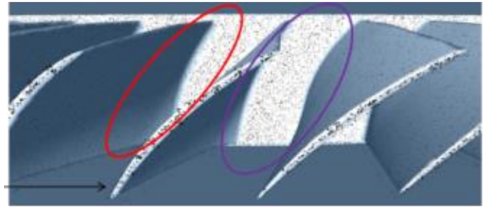
Input: media characteristics, equipment characteristics, part position and movement, process duration

Output: shots velocity and energy, impact density, angles of impact, *Almen intensity, coverage*







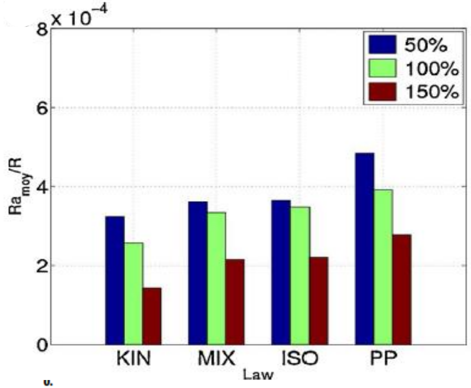


J. Badreddine – Safran 2014-2016

Working on Material response → How to predict it?

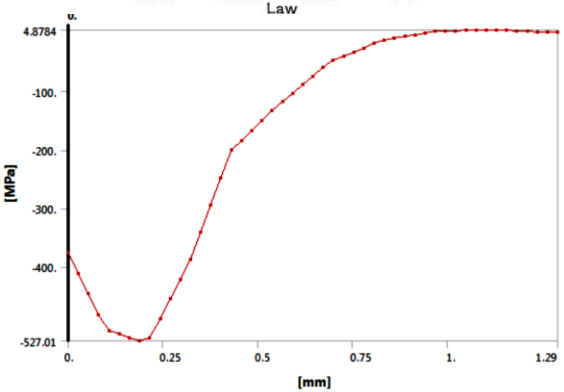
Input: shots velocity and energy, impact density, angles of impact, *Almen intensity, coverage*

Output: Residual stresses, surface texture, near-surface microstructure modifications



Calculated Ra for different coverage using different hardening laws

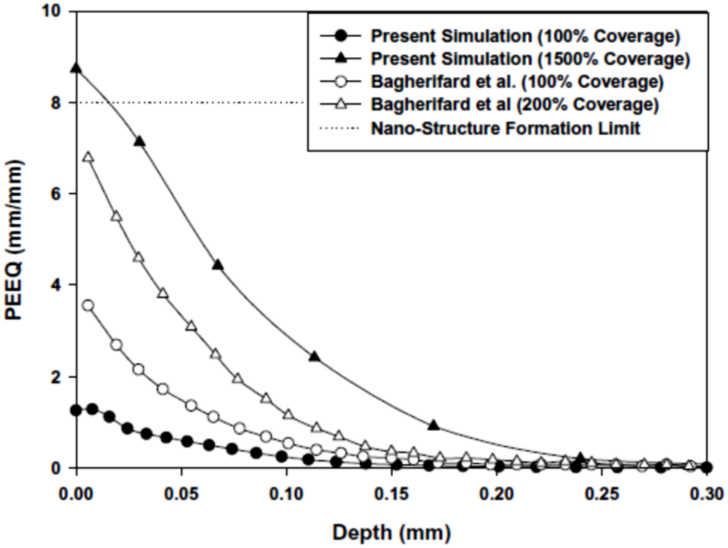
M.Taro and al., J.of Mat.Process.Tech., V.217, 2015



Numerical RS profile using FEM-DEM simplified simulation

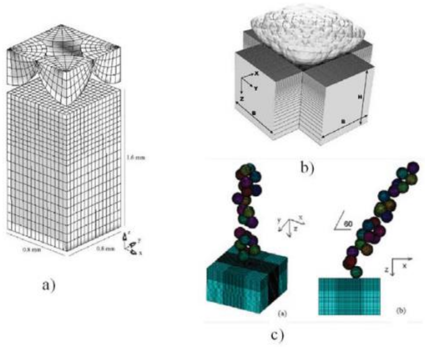
A.B.Edward, Procedia Manufacturing, V.7, 2017

Calculated Plastic Equivalent Strain for different coverages and approaches



S.M. Hassani, Procedia Engineering, V.10, 2011

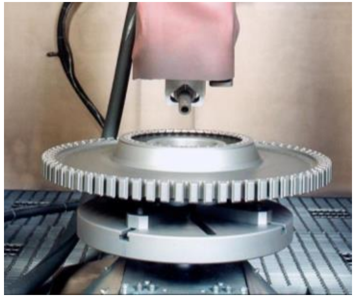
Working on Material response → from the unit cell to the real part



Some FE modelling approaches using unit cells

Baskaran and al., Int. J.of Struct.Changes in solids, vo.2, N.2, 2010

?



Working on improving reliability of the inspection process (Quality control)

- ✓ **Controlling surface quality**

  → Be able to spot surface defects produced by shot peening and related processes (folds, rolled edges,…)

- ✓ **Controlling coverage → Going beyond human eye**

  → Image analysis, others…

- ✓ **Easy ways to measure compressive RS in complex geometries**

Measuring CRS in aircraft complex geometries?

Working on design approaches for life prediction to account for surface enhancement procedures

- → Need the “real stress field” of critical life-limiting areas in real parts geometries (→ CRS)
- → Need impacted surface materials constitutive law (Appropriate testing!)
- → Need to take into account all impacting surface engineering treatments
- → Need to take into account not only fatigue but also the other influential environmental effects → corrosion, erosion, FOD, …
- → Need to take into account near-surface microstructure modification → Metallurgical models

Working on improving diagnostics and monitoring of components (Structural Health Monitoring)

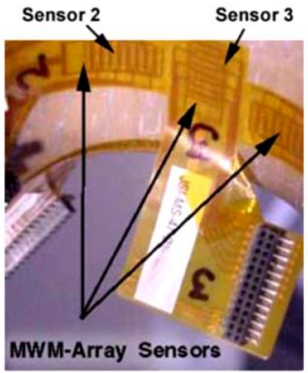
✓ **Following compressive stresses relaxation to determine residual life → Abnormal loading can relax CRS in a non-predicted way!**

→ **Collecting data from embedded sensors (strain gages, AE sensors, …)**

→ **Developing algorithms to analyze sensors data and determine residual life (data analytics)**

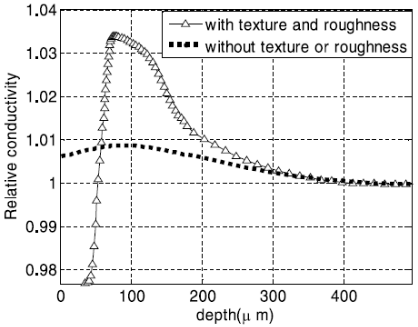
✓ **Material response through controlling the changes of strain-hardened layer**

→ **Eddy current can spot surface texturing**



Magnetic sensor mounted on a critical surface of a Landing gear component for overload detection

N. Goldfine and al., 2006 SEM Annual Conference



Y.Shen and al., Int. J.of Non Destr. Eval., V.29, 2010

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In Conclusion…

✓ **Shot peening was, is and will stay a mandatory special process for critical parts**

✓ **For the peening to be taken into account in the design, this threefold strategy is needed:**

1. **Prediction**
   a. To increase the process reproducibility
   b. To predict the occurrence of defect in a given geometry
   c. To predict compressive stress relaxation during operation
2. **Avoidance**
   a. To avoid/decrease the probability of harmful effect occurrence
   b. To work on processes that produce stable compressive stresses
   c. To focus on processes that improve surface finish
3. **Detection**
   a. NDT to ensure right coverage of the components
   b. NDT for the detection of SP-related defects
   c. In-situ monitoring of compressive stress relaxation

✓ **…and keep trying to understand…**

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