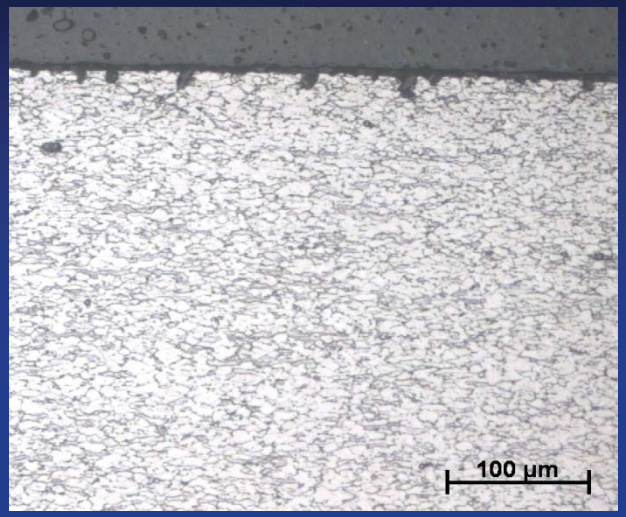
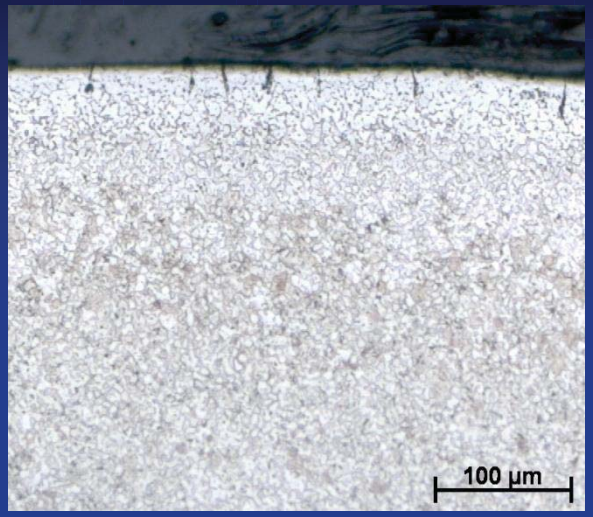
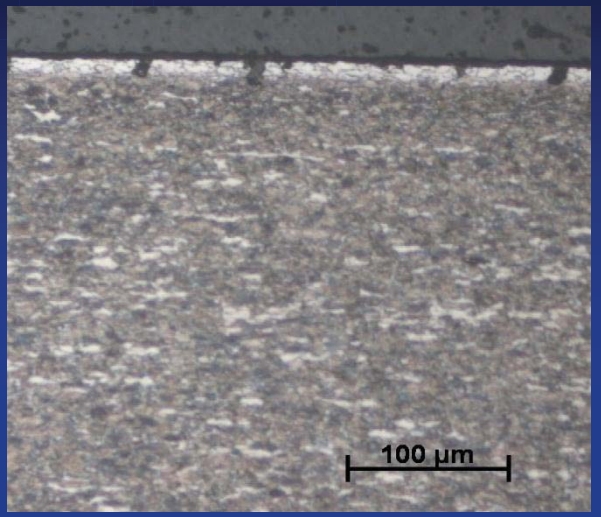
Ti 6Al – 4V – Alpha Case – 200x



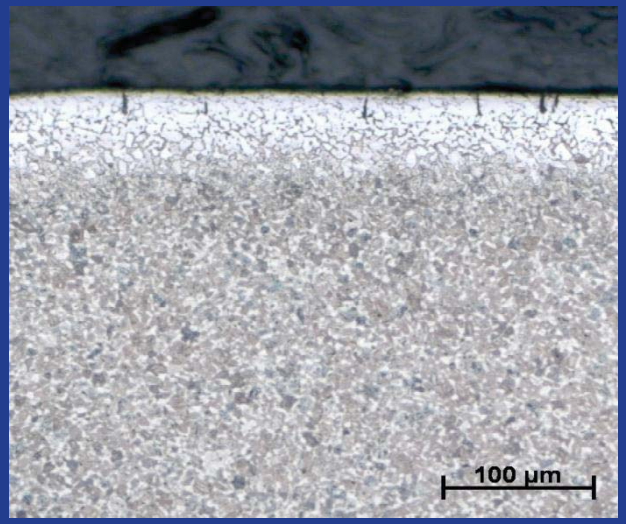
Kroll's



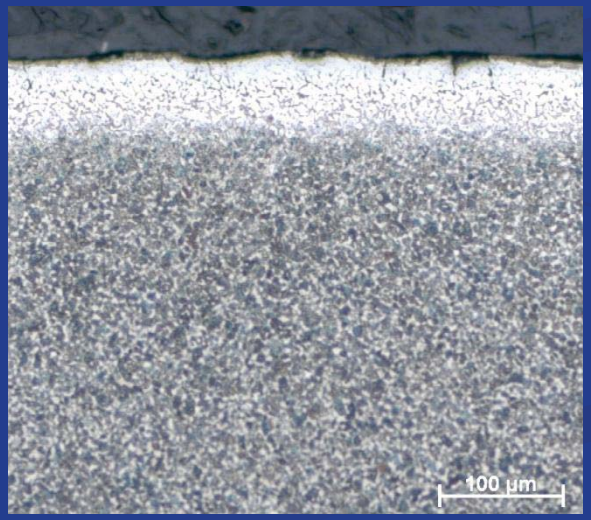
Ti



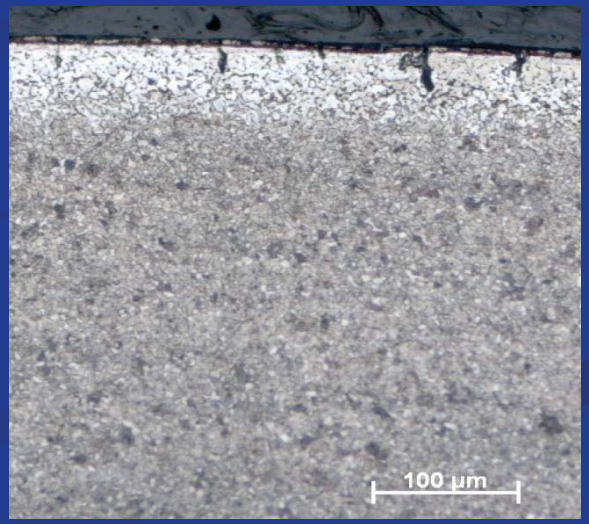
Boeing



2% HF



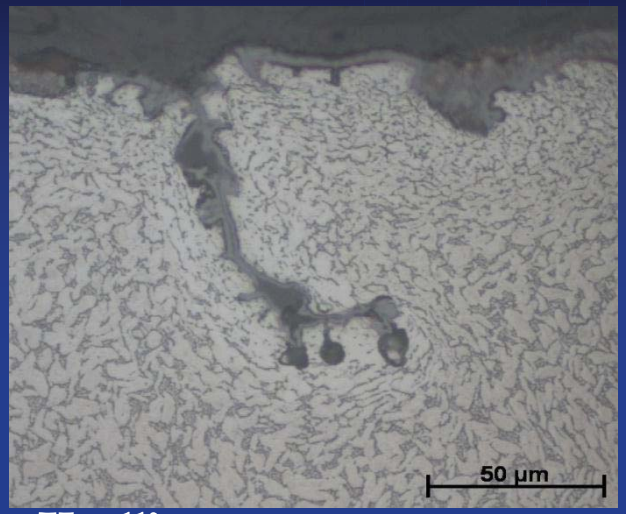
Oxalic



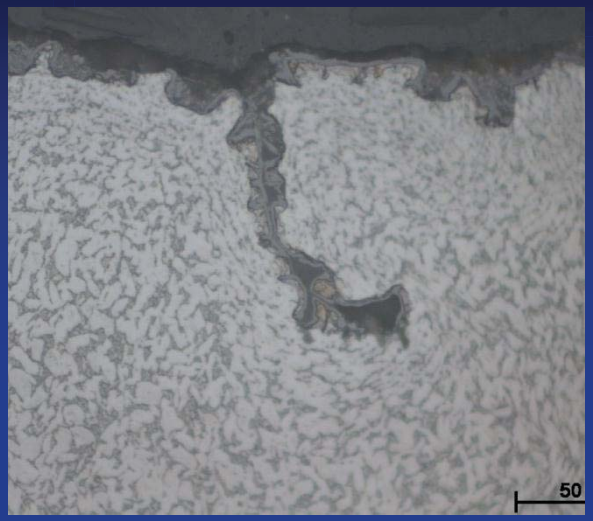
Ti & Oxalic

Frauke Hogue

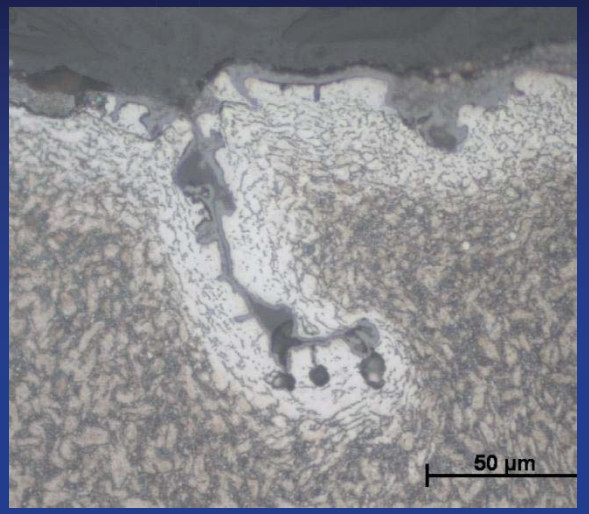
Ti 6Al – 4V – Fold with Alpha Case – 500x



Kroll's

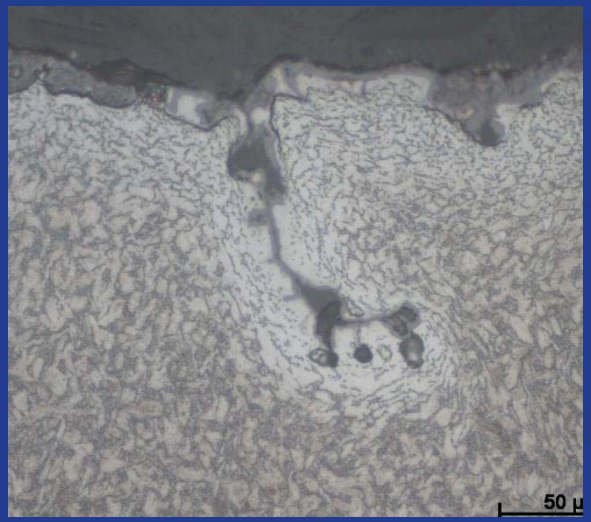


Ti

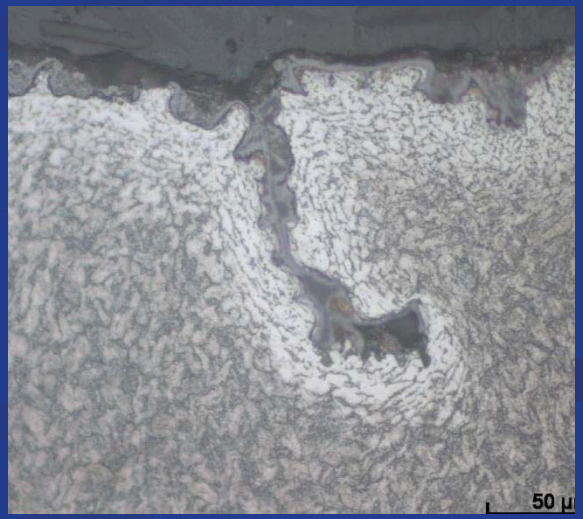


Boeing

2% HF



Oxalic



Ti & Oxalic

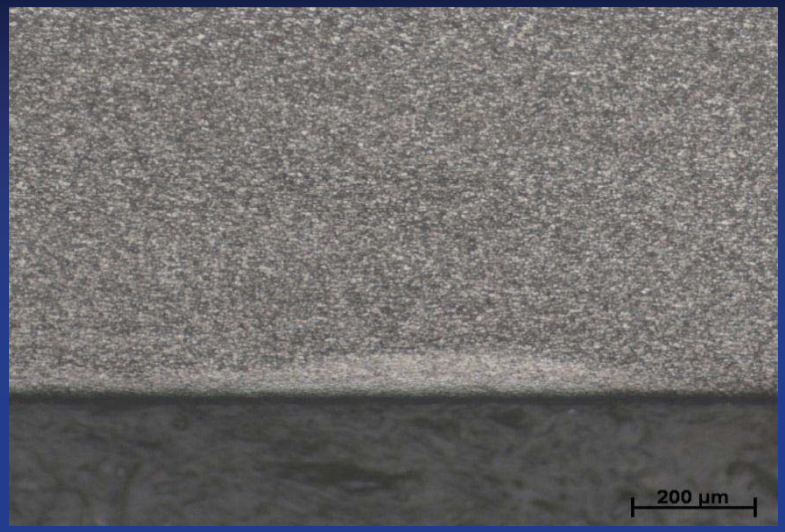
Frauke Hogue

Results

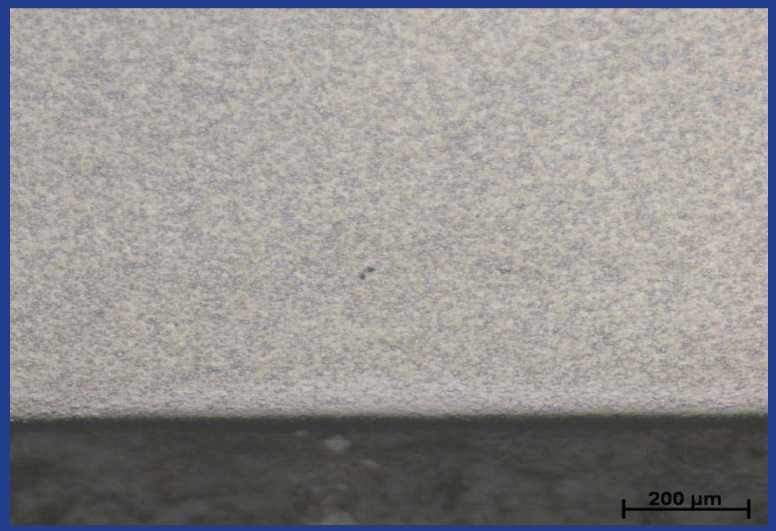
- Visual Examination:
  - Effect with 2% HF, Boeing , Oxalic & Ti + oxalic are similar
  - Base microstructure has influence on results
  - Oxalic acid etchant can be used after etching with Kroll's or Ti etch without loss of information

Grinding Burn on Bearing Surface – 100x

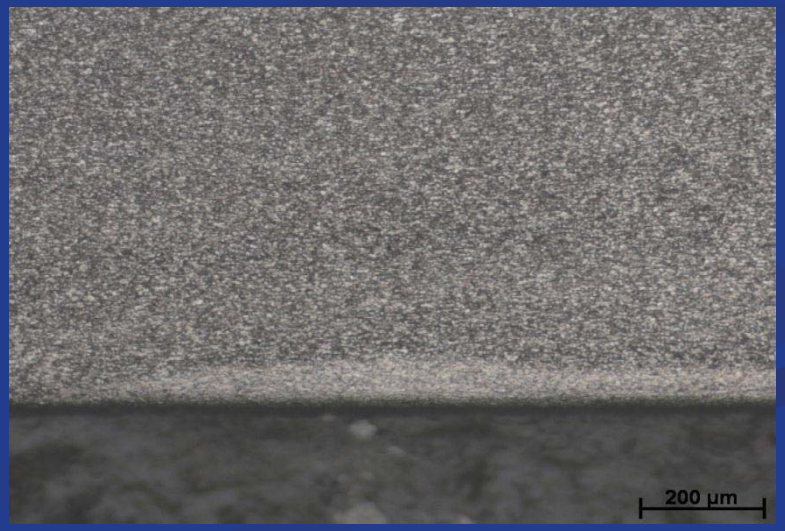
Kroll's



Oxalic



Kroll's



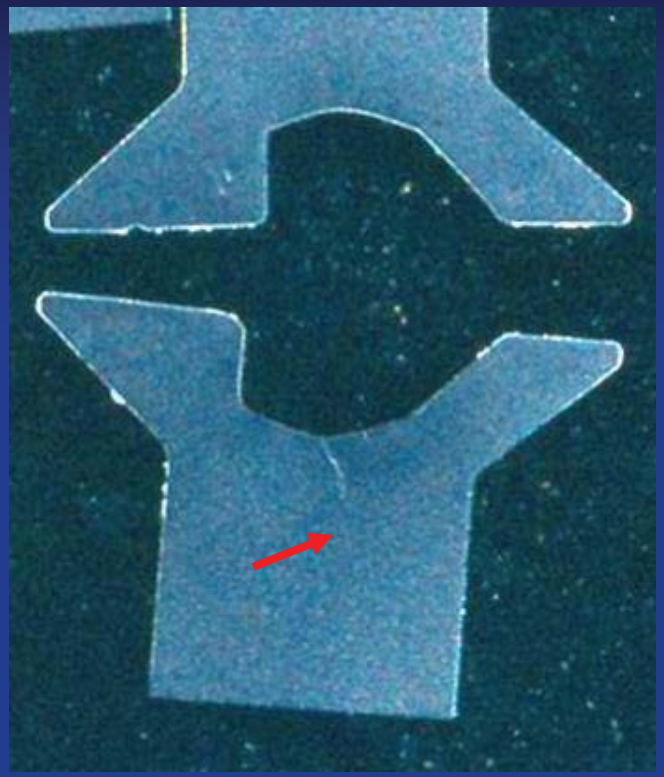
Oxalic

Frauke Hogue

Results

- Visual Examination:
  - Oxalic acid etchant is the best to detect grinding burns on the bearing surface

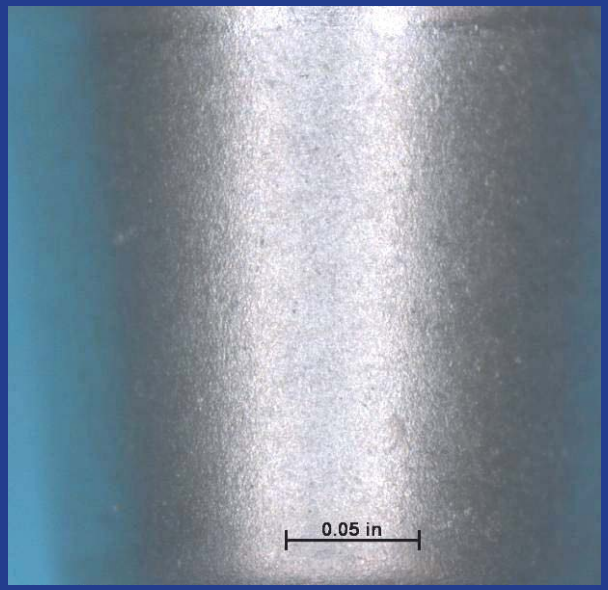
Liquid Metal Embrittlement

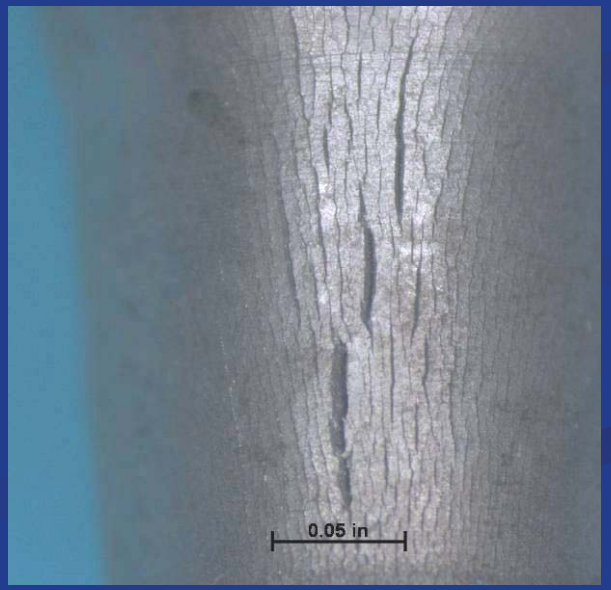


- **Sectioning of Cd plated titanium can cause cracks in unusual locations**

Ti 3 Al – 2.5 V - Annealed

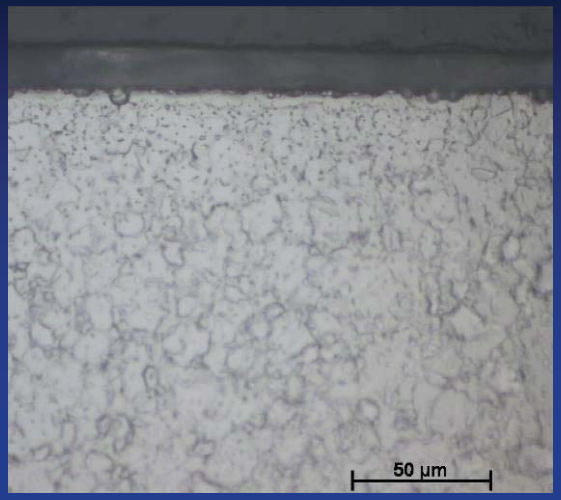
- A very thin, distinct case was found on machined parts after 1400°F annealing
- Bend test showed cracks in these parts
- Case is not on all parts and not on all surfaces



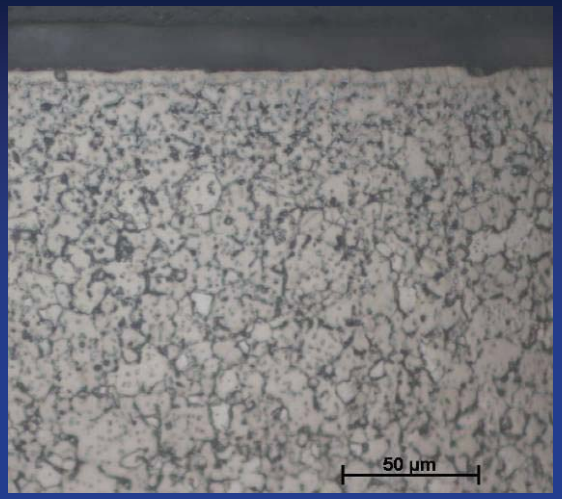


Frauke Hogue

Ti 3Al – 2.5V Annealed Loc "A" 500x



Kroll's



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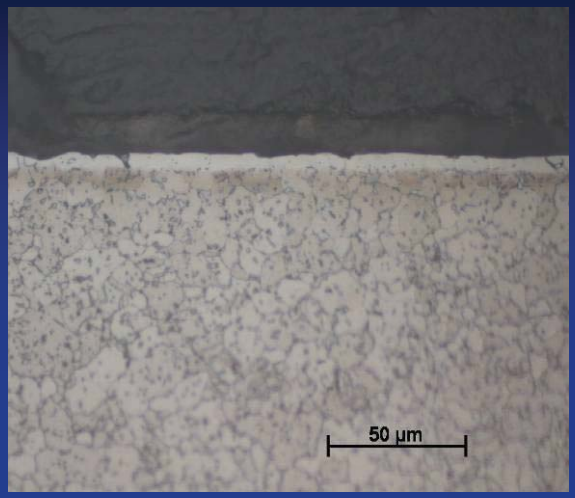
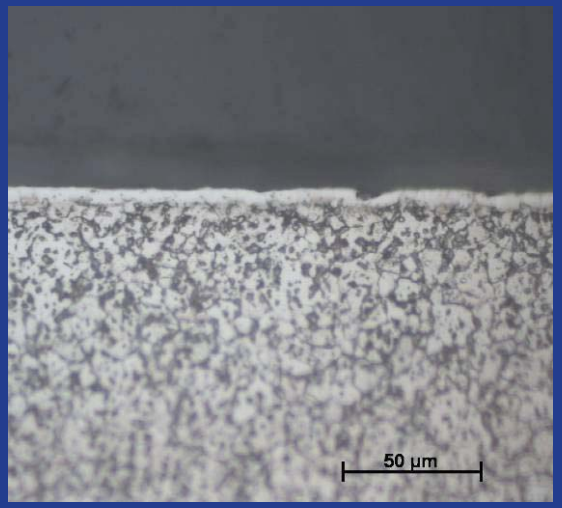
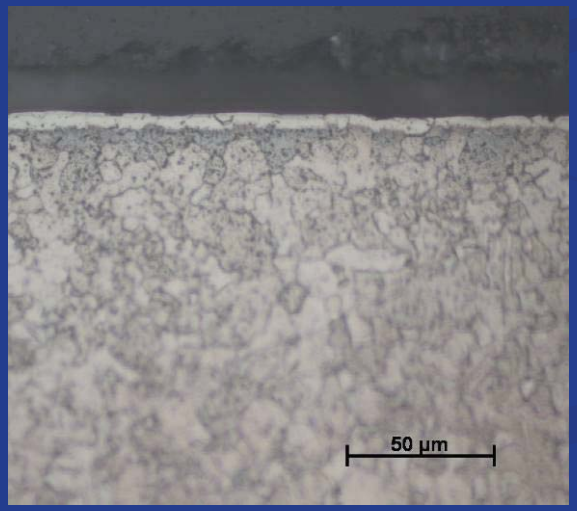


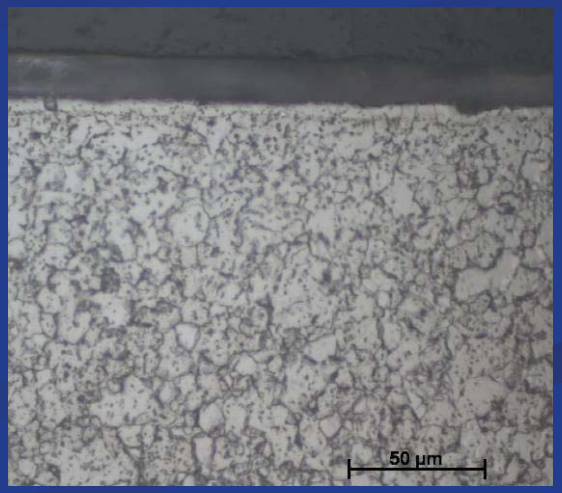
Boeing



2% HF



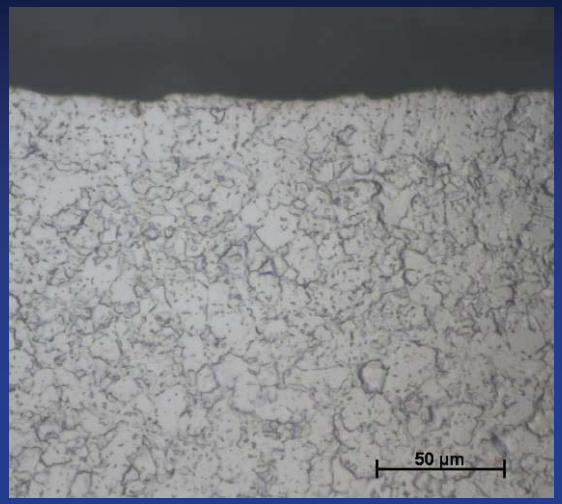
Oxalic



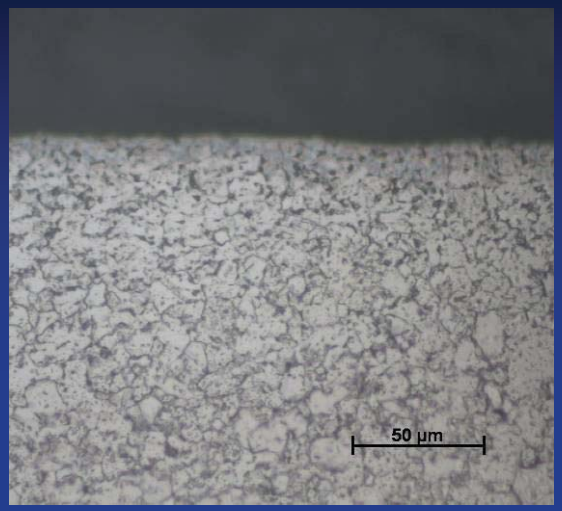
Ti & Oxalic

Frauke Hogue

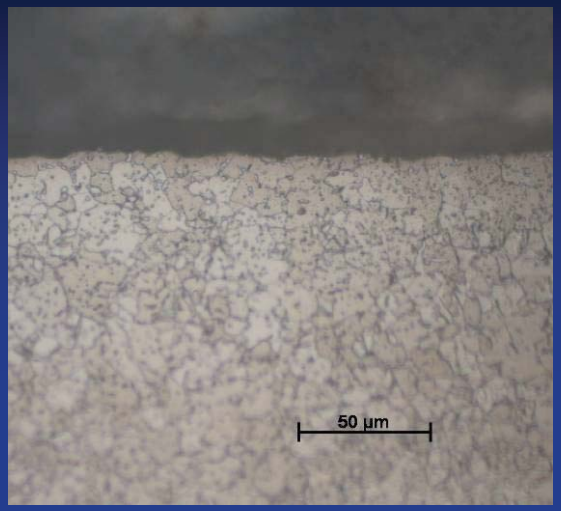
Ti 3Al – 2.5V Annealed Loc "B" 500x



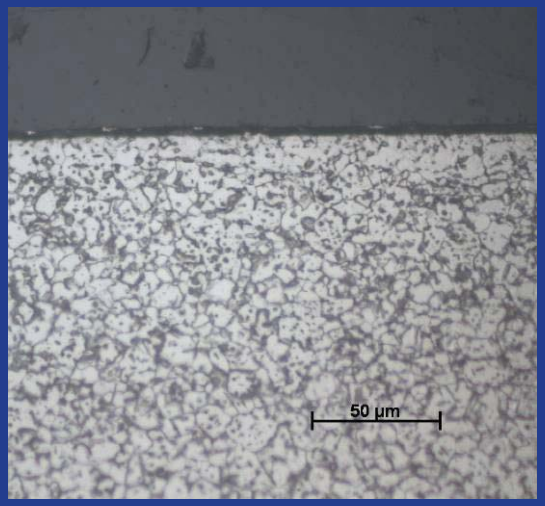
Kroll's



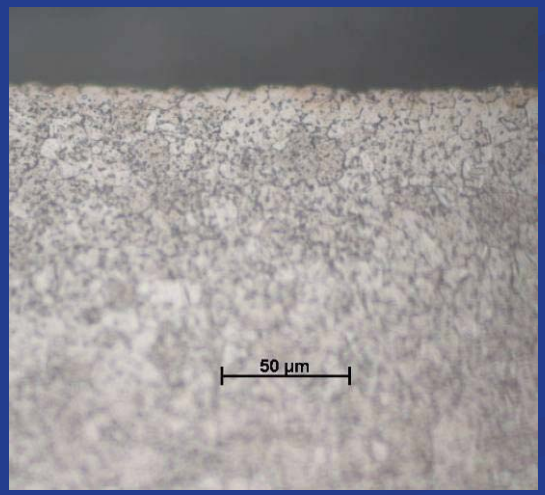
Ti



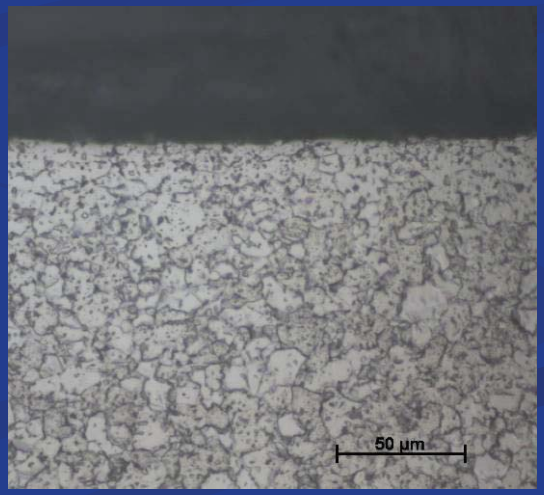
Boeing



2% HF



Oxalic



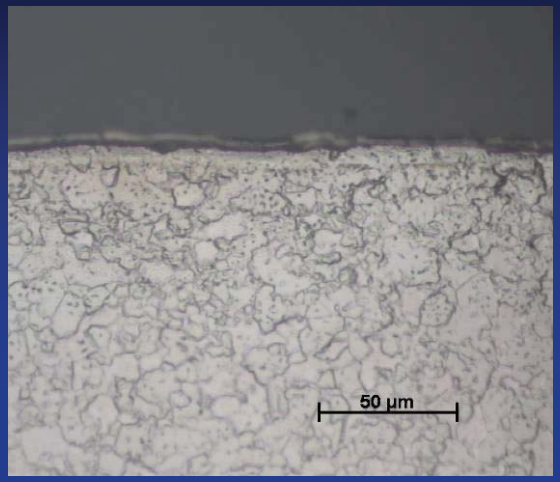
Ti & Oxalic

Frauke Hogue

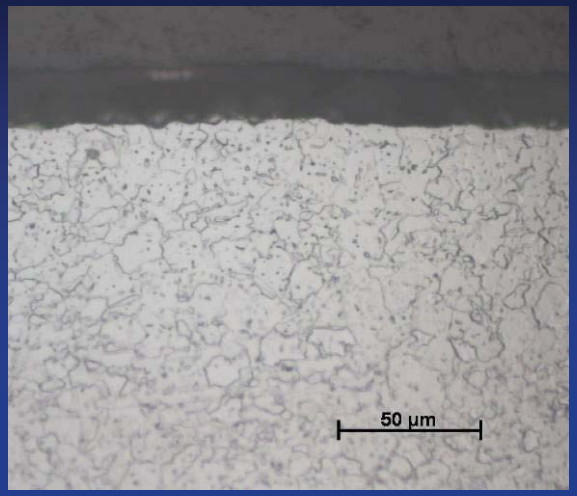
Results

- Locations “A” & “B” on the same part
- Generally contamination from furnace atmosphere is on all surfaces
- Very distinct layer
- ‘Looks’ different than alpha case
- Create alpha case by annealing for 1 hr in air at 1400°F

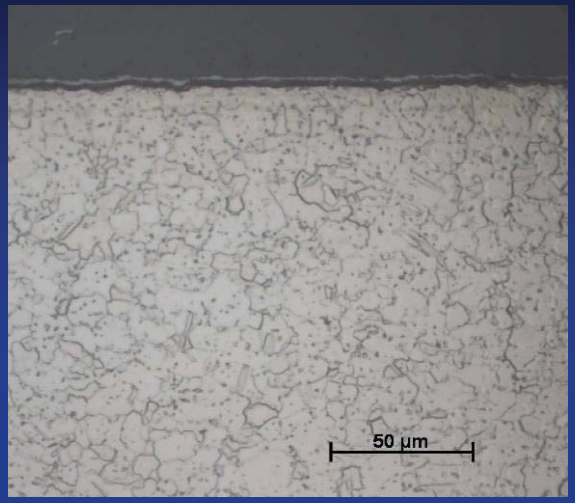
Ti 3Al – 2.5V – 1 hr Air – 500x



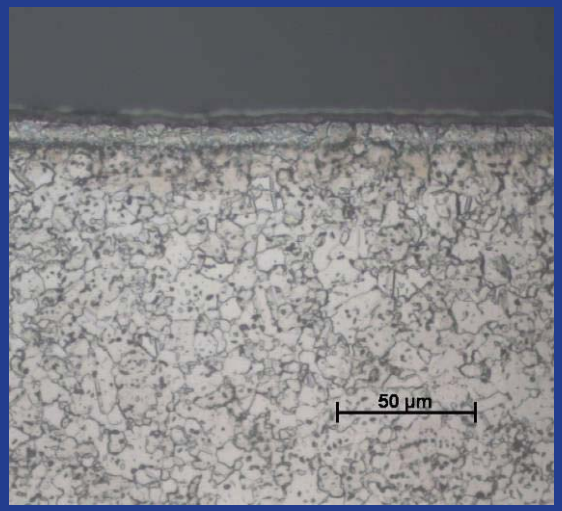
Kroll's



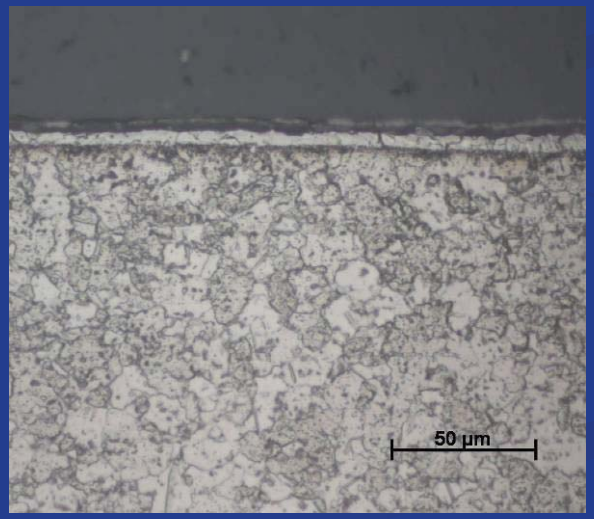
Ti



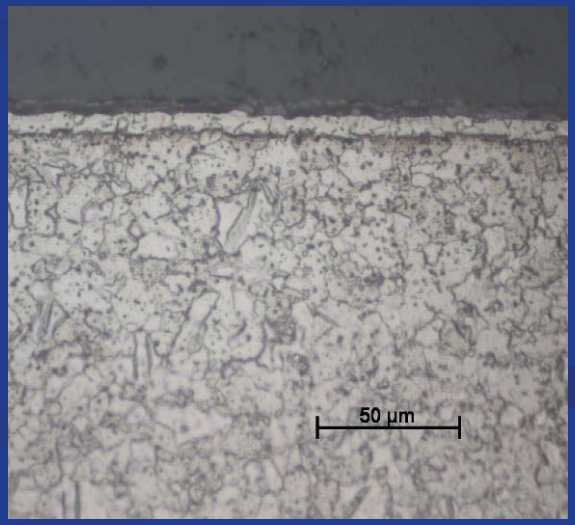
Boeing



2% HF



Oxalic



Ti & Oxalic

Frauke Hogue

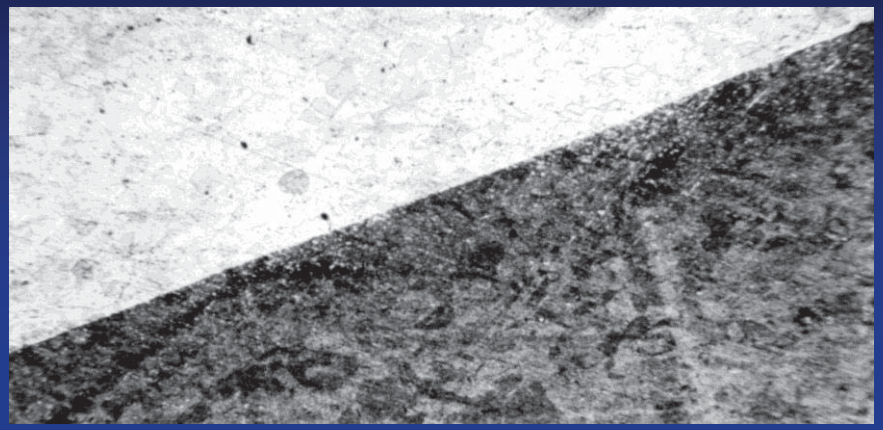
Conclusions

- 60 min air @ 1400°F looks similar and has same depth as 60 min in vacuum or argon
- Alpha case should be on all surfaces
- Is it really alpha case?
- More investigation is necessary: EDS and / or Auger analysis

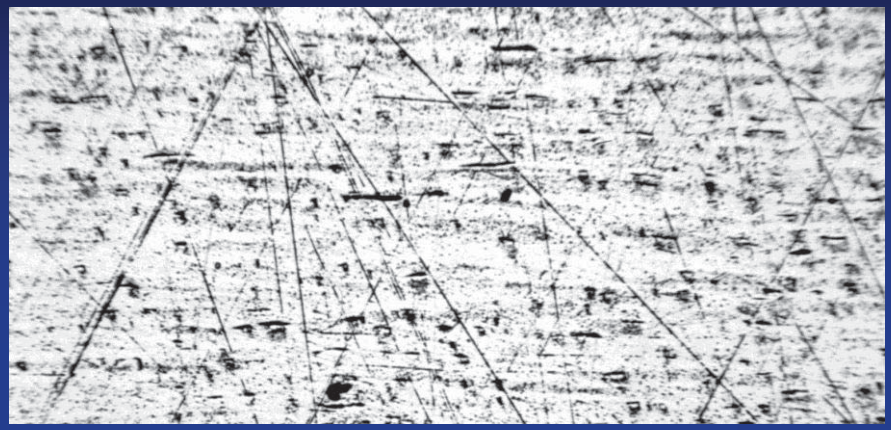
Super Alloys

- Alloys such as A286 and Inconel 718 are highly corrosion resistant
- Difficult to etch correctly
- Commonly used etchants:
  - 'Battleship' – 80% HCl, 20% H_2O_2
  - Marble's Reagent (ASTM # 25)
  - Super Alloy Etch – 6 ml H_2O, 60ml HCl, 6g $CuCl_2$

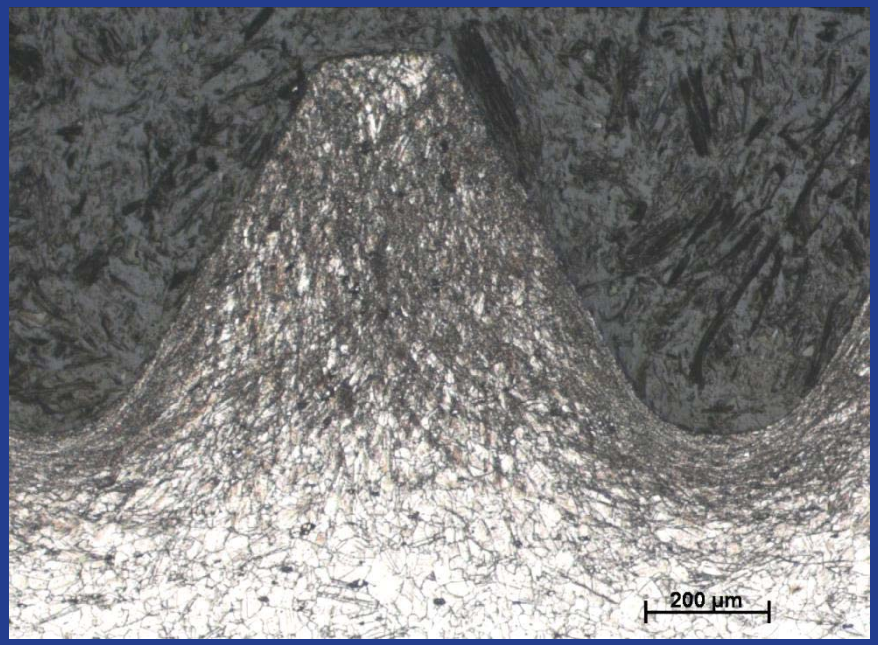
Etching NOT Acceptable



Stained and structure not visible

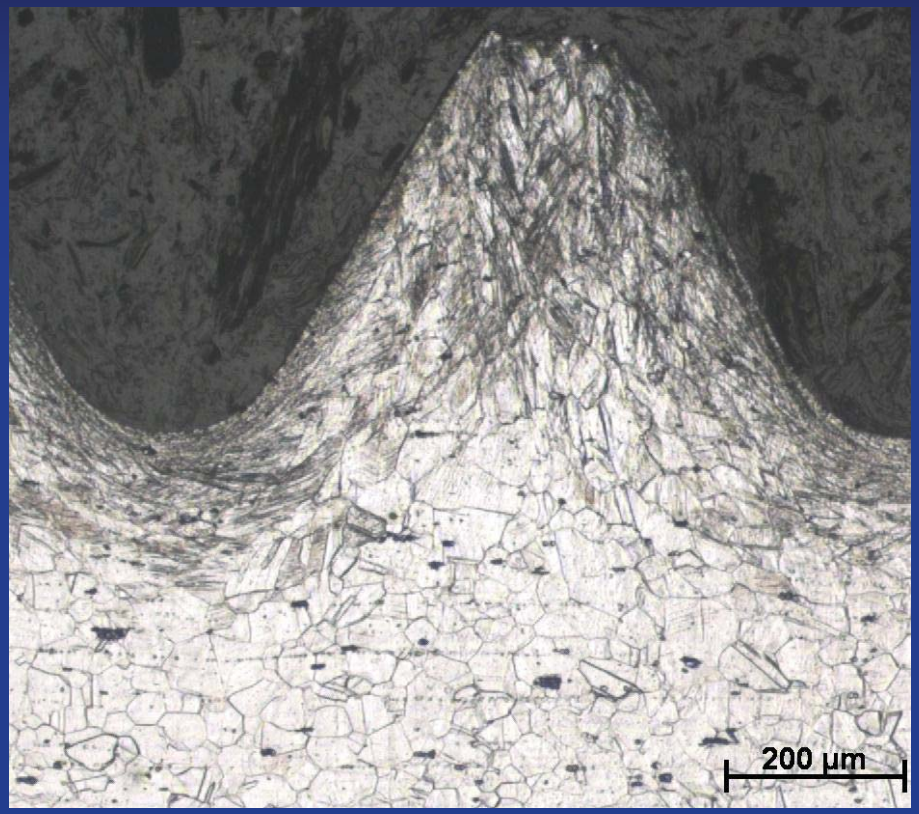


Structure not visible, too many scratches

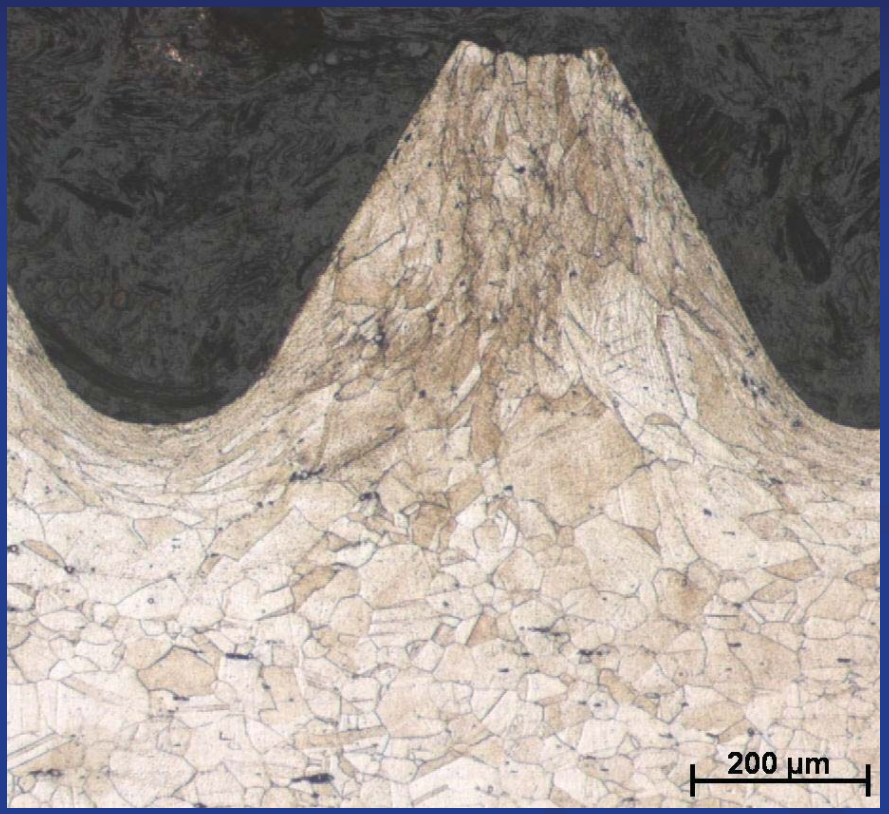


Etching too dark, laps would be difficult to detect

A 286

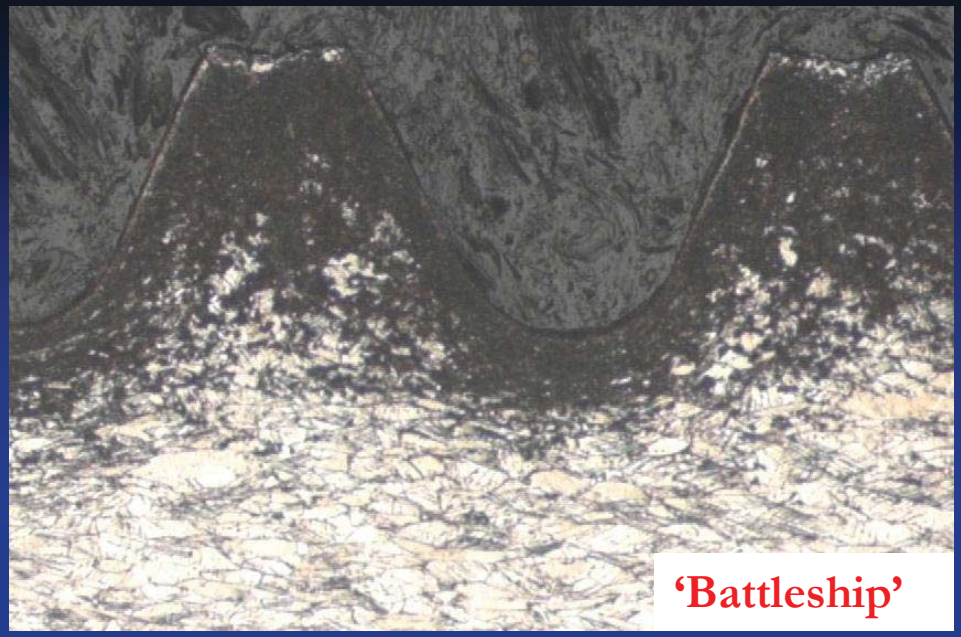


'Battleship'

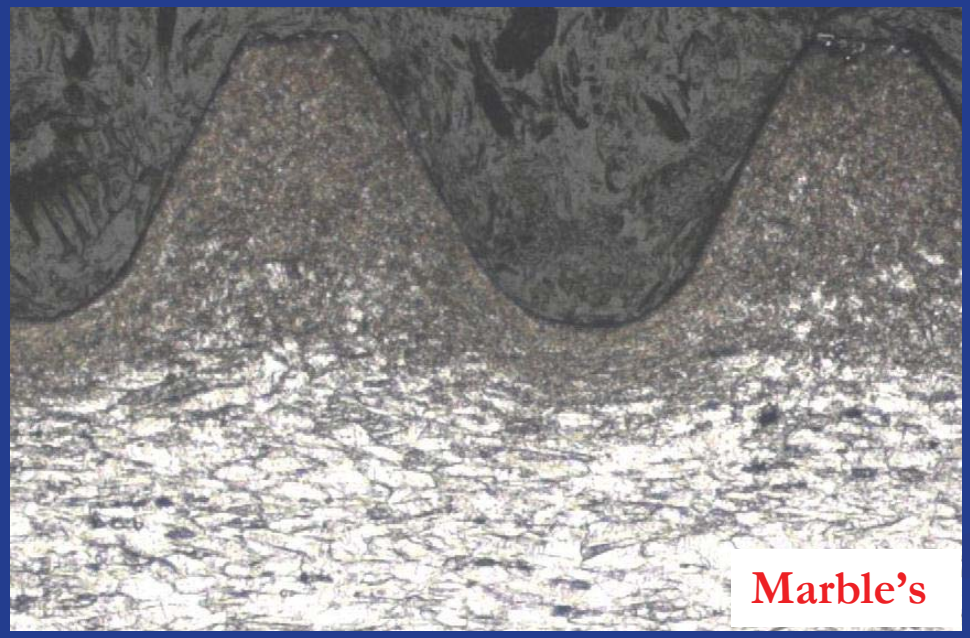


Marble's Reagent

A 286



'Battleship'



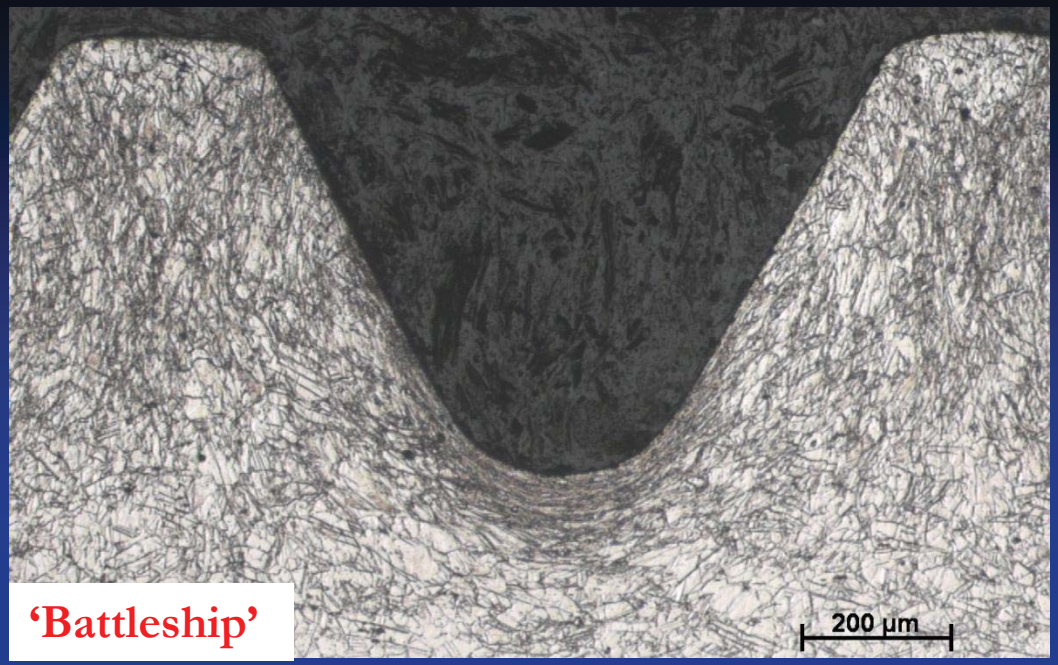
Marble's

- Shelf life of 'Battleship' is very short
- Very aggressive etchant

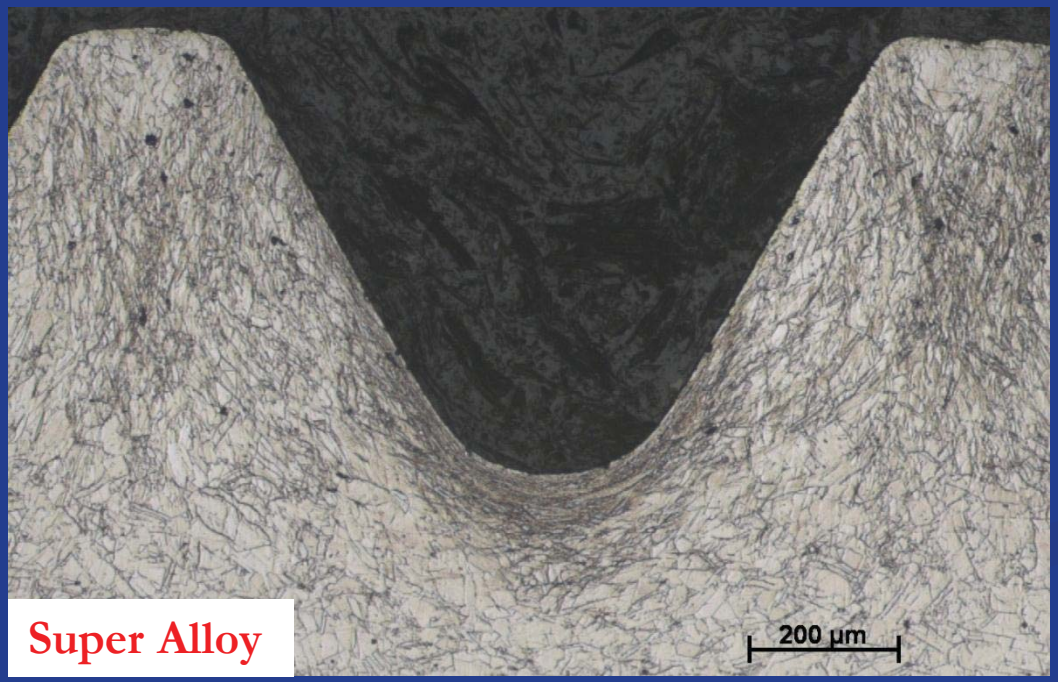
- Marble's can be kept
- More latitude in etching

- Part was aged after thread rolling

Inconel 718



'Battleship'



Super Alloy

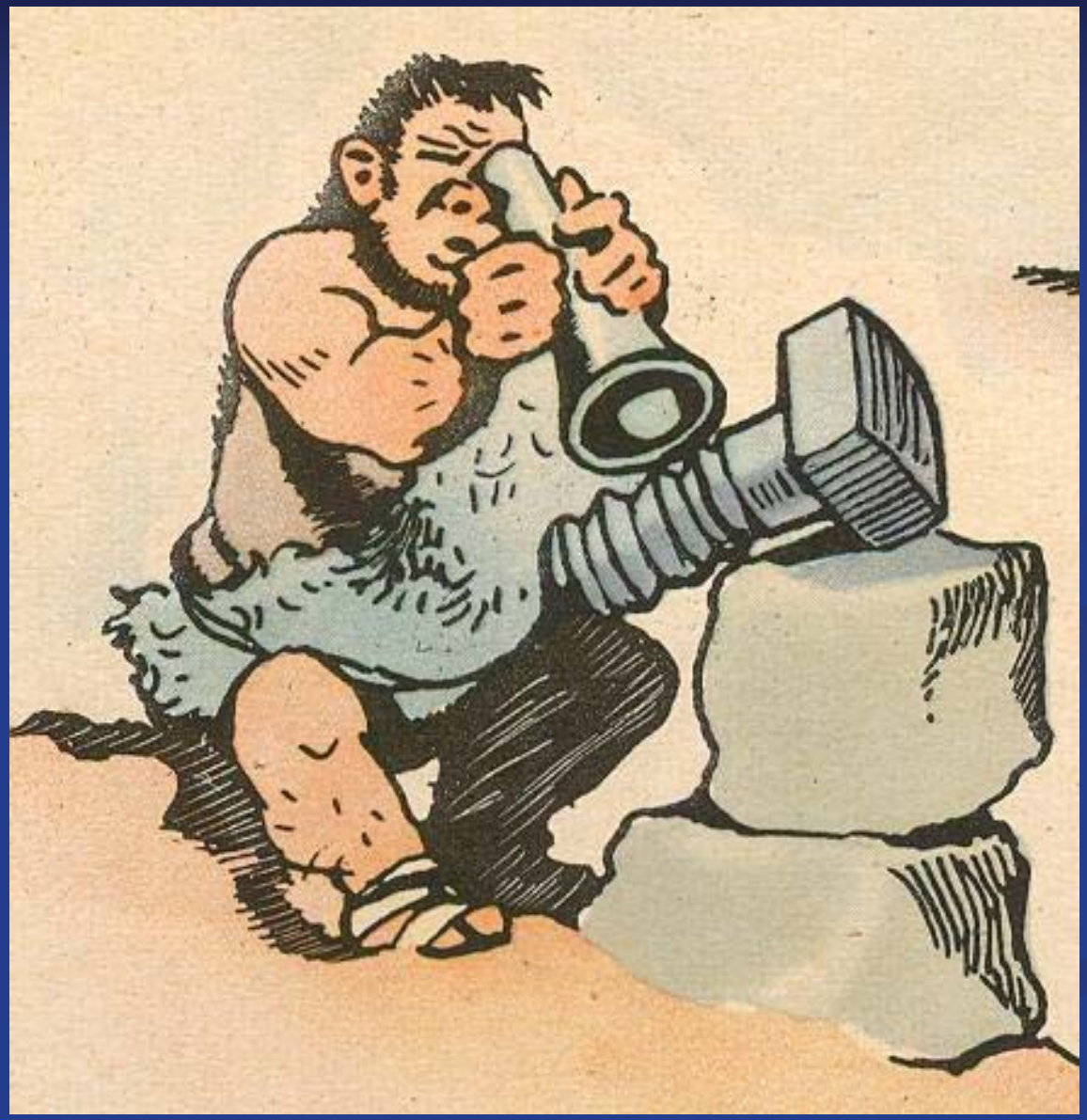
- Results are same as for A 286 material
- Super Alloy etch has a long shelf life
- Etching times are longer, not so easy to over-etch

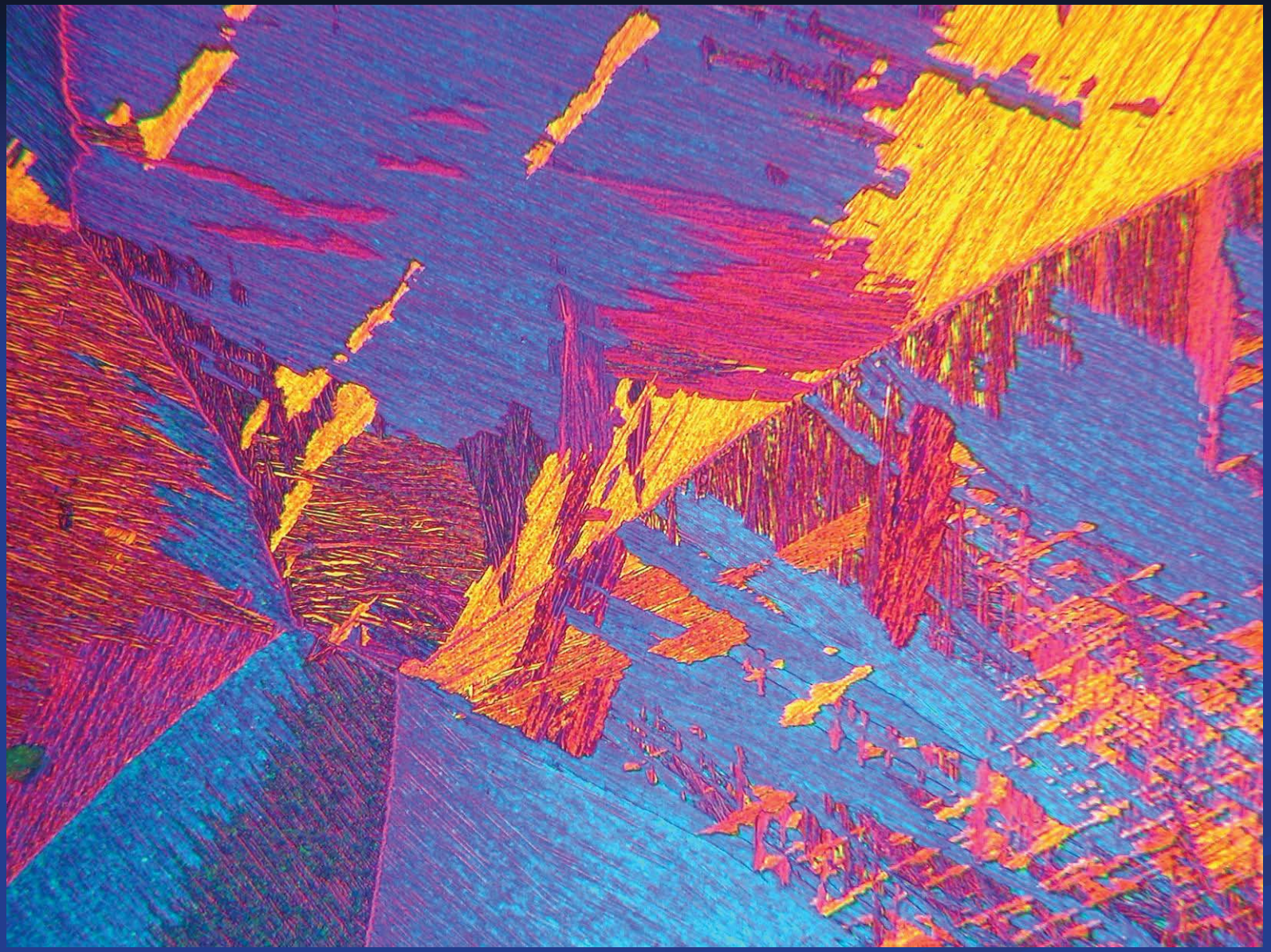
Results

- Both etchants show the same structure IF etched correctly
- 'Battleship' has to be prepared fresh and etches very rapidly
- Marble's and Super Alloy Etch keep and etching rate can be controlled easier

- Metallographers need to understand results from different etchants
- Training is essential
- Reference library of samples with structures and conditions is recommended

The Metallographer 20,000 Years Ago





Ti 6Al - 4V – Cast – Polarized light with Sensitive tint