Recent Developments in US Machining

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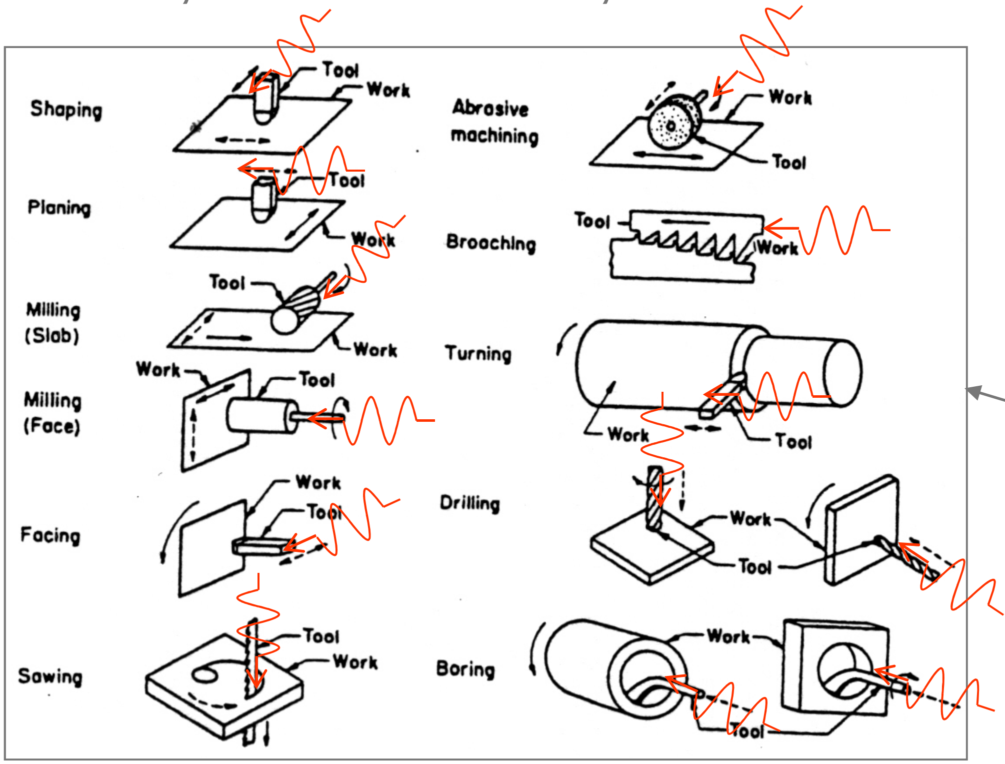
Outline

- US Machining Background
- Prior developments at EWI
- Attachment issues
- FEA modeling of collet designs
- Tool life assessment
- Summary

What is Ultrasonic Machining?

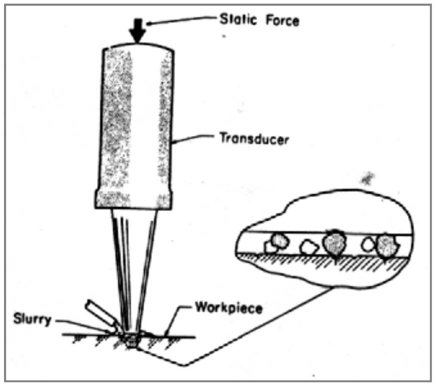
- It is application of US vibrations to “traditional” machining processes (drilling, turning, milling …) to improve performance (e.g. faster drilling, drilling of hard materials, better tool life, increased accuracy, …)



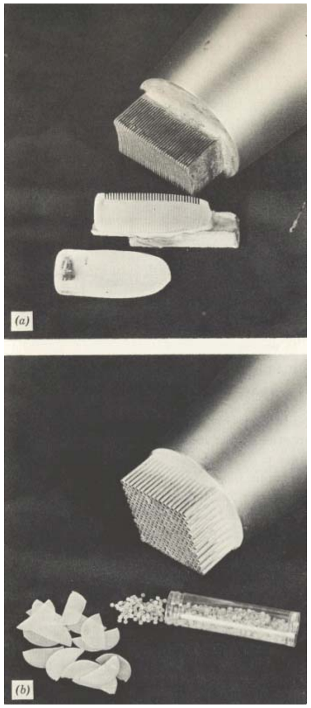
Concepts of adding US vibrations → to various machining processes

A Note on What UM is Not …

- "Ultrasonic Machining" is also used for an ultrasonic-based slurry drilling process.* It is *not* our UM.
- This process used for drilling extremely hard materials – e.g. glass, ceramics, quartz – and is able to drill unusual hole patterns. While an extremely slow, special process, it does find niche applications

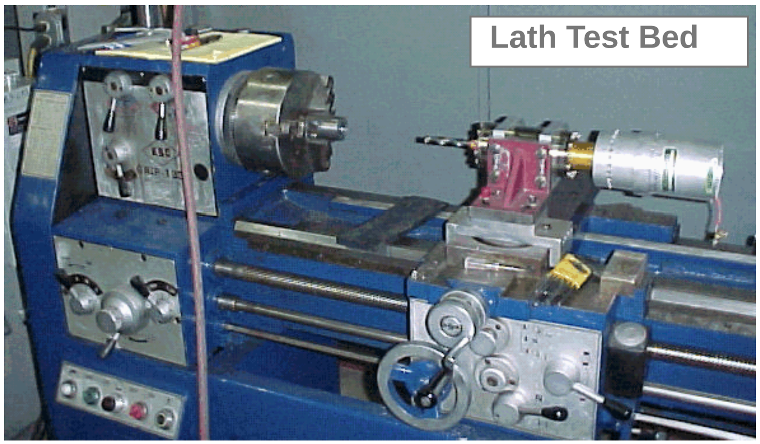


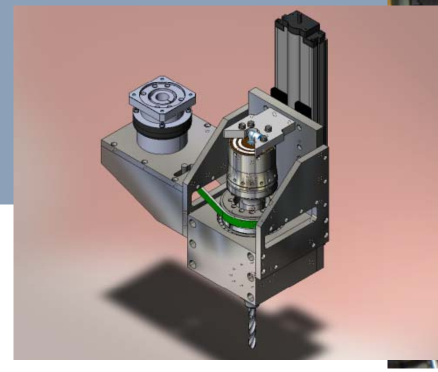
"Conventional" US Machining (aka US Impact Machining, US Drilling, US Grinding)

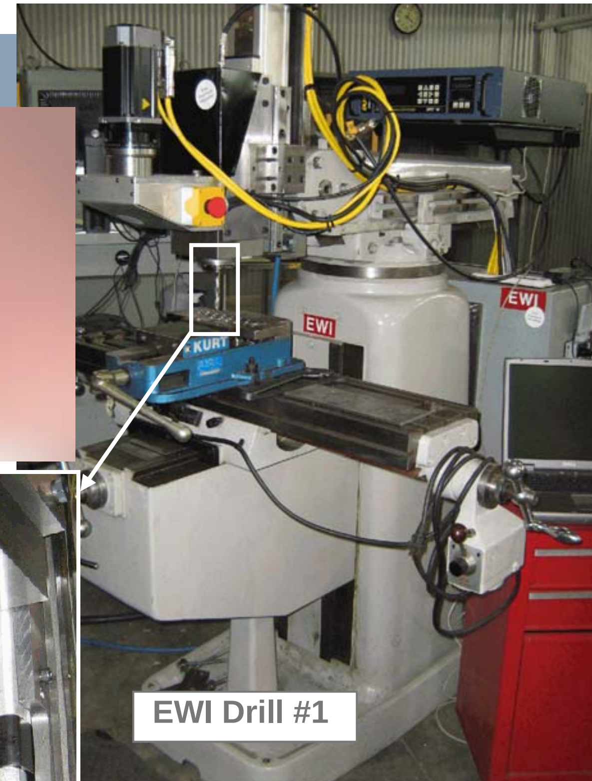


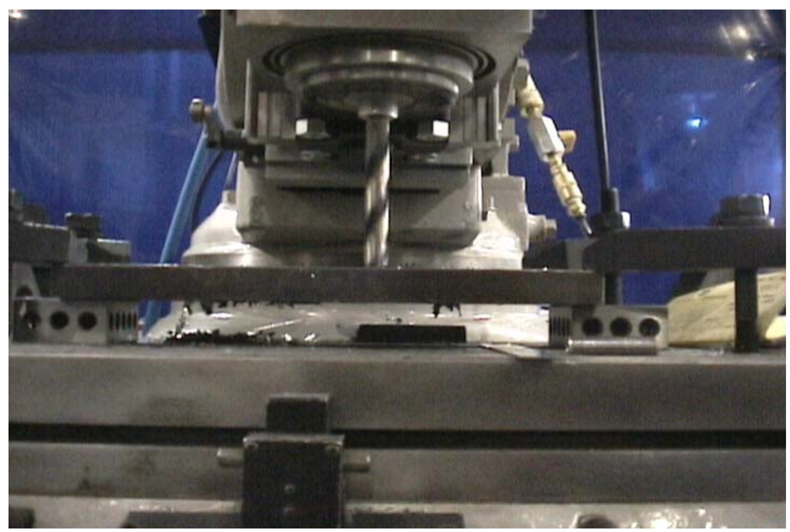
Graff, K.F., "Macrosonics in industry 5. Ultrasonic Machining," Ultrasonics (May, 1975), 103-109.

Progression of Work







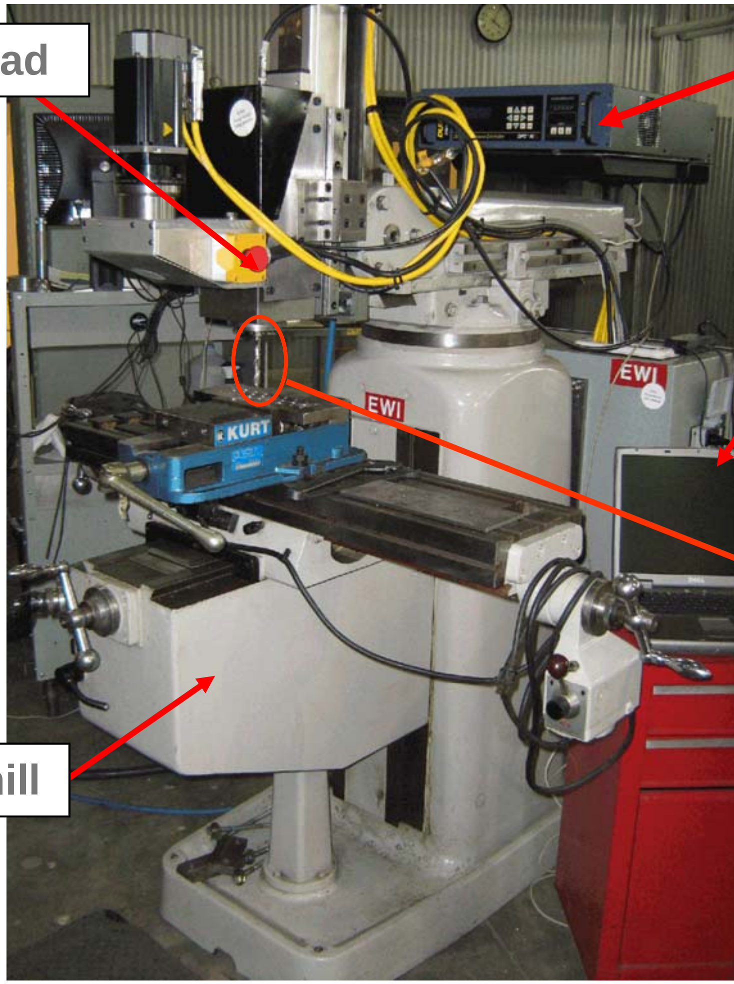


EWI Twist Drill System

Drill head

Dukane 20kHz, 5kW power supply

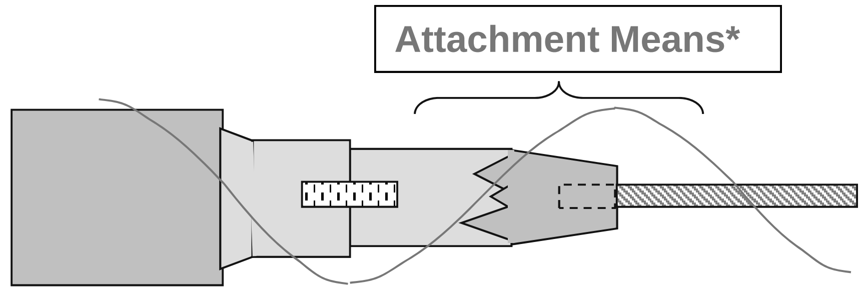
Laptop for control of drives, US, and data collection

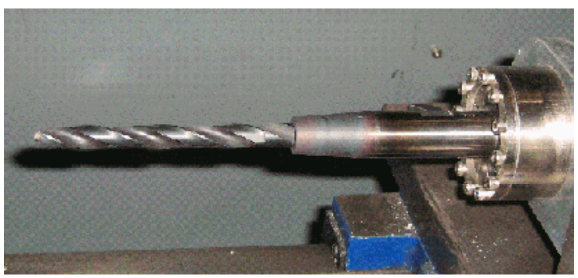


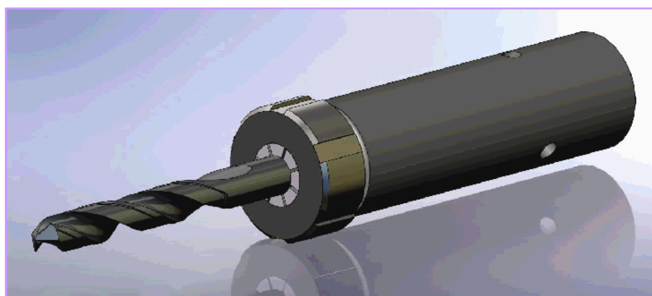
Knee mill

Attachment Means

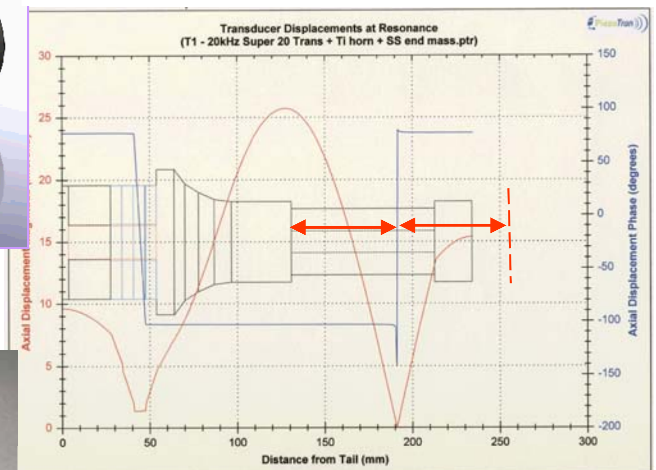
- Acoustic tuning – in principle – simple
- Acoustic tuning – in practice ……





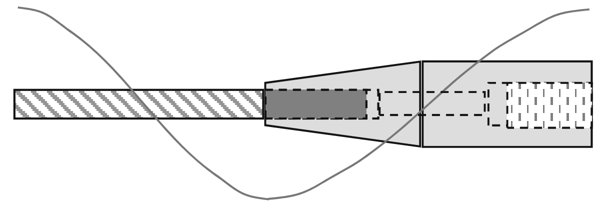


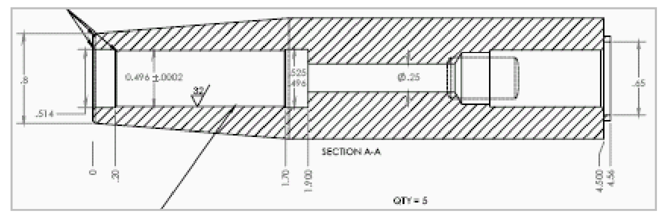
* Subject of EWI patent disclosures



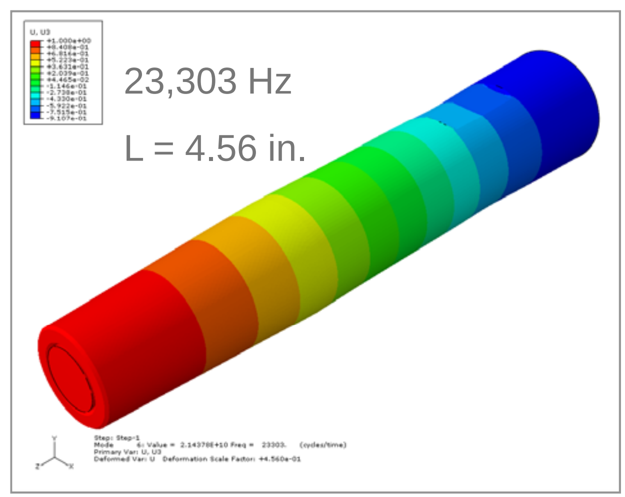
Collet Design Optimization

- Basic design concept is collet and drill will be full acoustic wavelength – with each component being a half wavelength

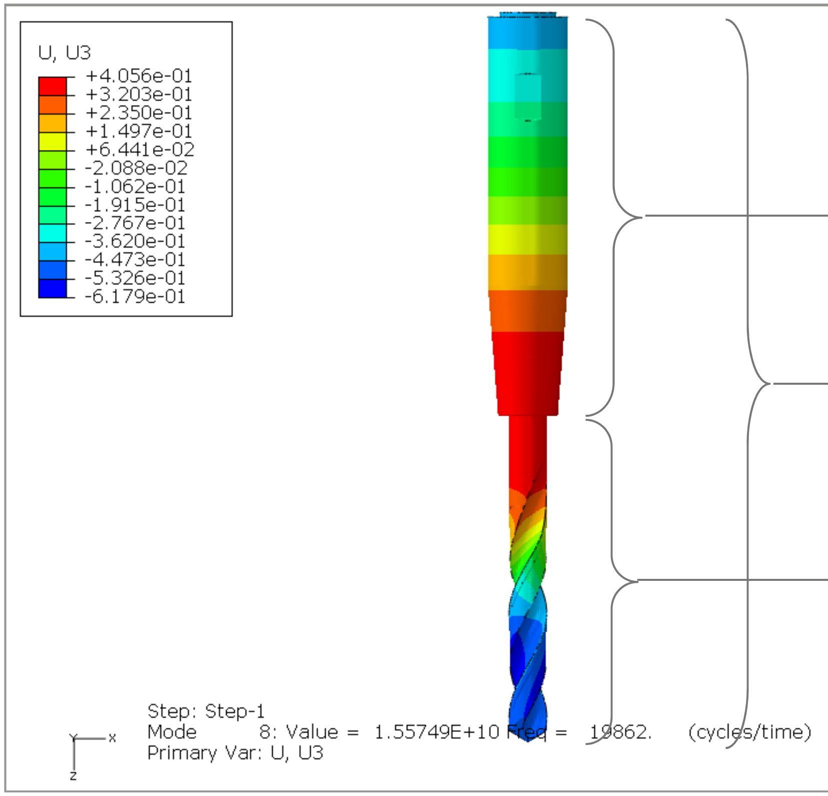




- Details of the collet
  - Collet design based on Kennametal “Shrinker” series
  - Shrink Fit = 0.004-0.001
- Key issues to address
  - Excessive losses at resonance
  - Difficult to remove worn tools



Collet Design Optimization (cont.)



Collet alone *
19,832 Hz
L = 5.36”

Collet + Drill
19,862 Hz
L = 9.01 in.

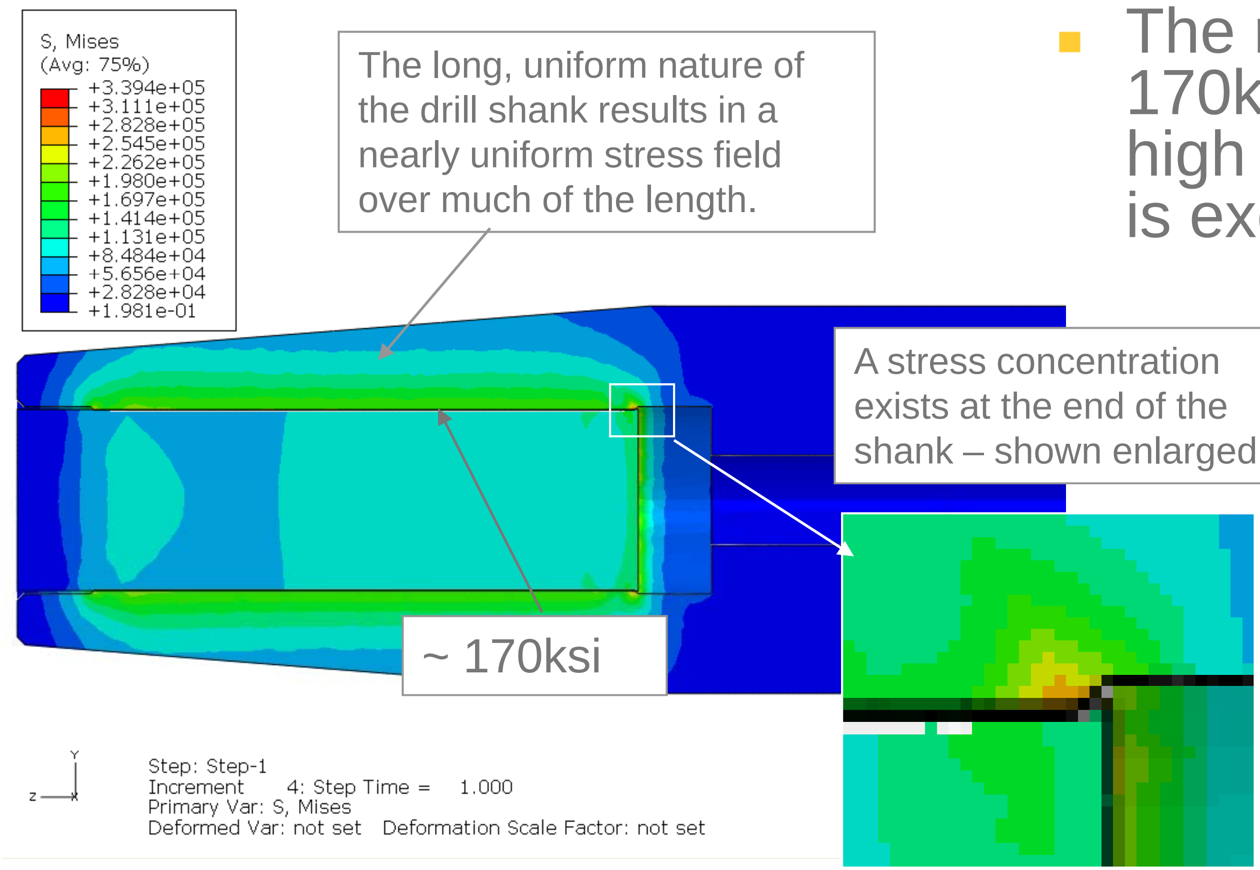
Drill alone
20,044 Hz
L = 4.33 i

* Shank @ 1.9 in. insertion, stud @ 1 in.

19,940-kHz

Collet Design Optimization (cont.)

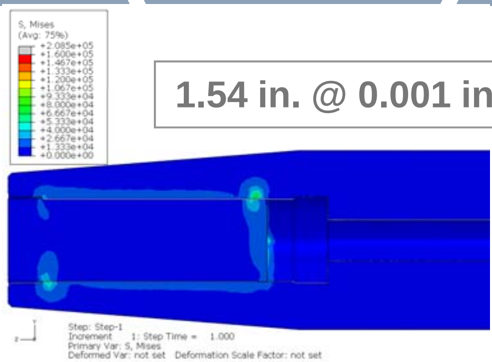
- Shrink fit stresses
  - Example result. The result for interference of 0.004 in. and shank depth of 1.70 in. is shown below



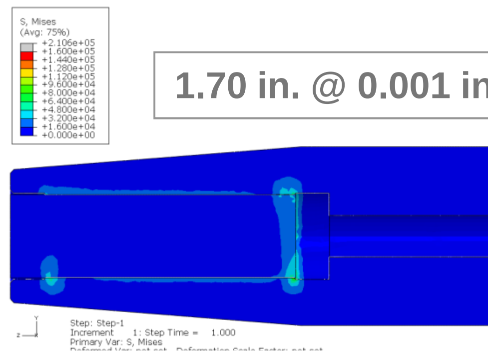
- The max stress of 170ksi is clearly too high – thus 0.004 in. is excessive

Collet Design Optimization (cont.)

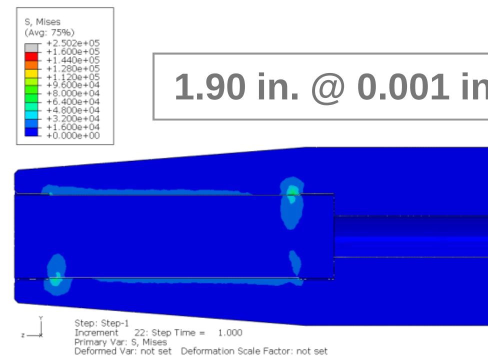
1.54 in. @ 0.001 in.



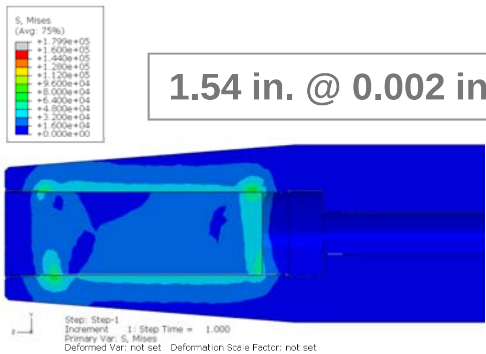
1.70 in. @ 0.001 in.



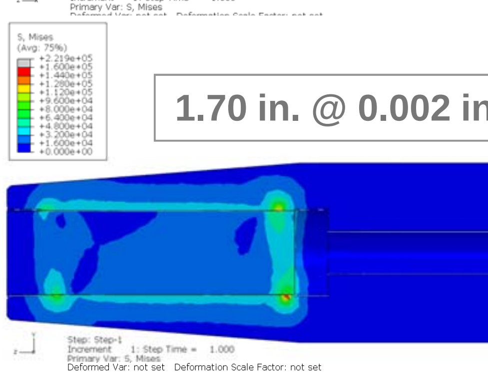
1.90 in. @ 0.001 in.



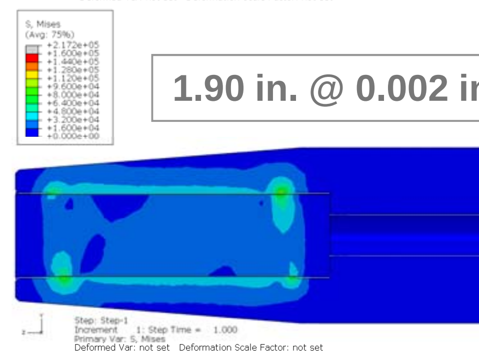
1.54 in. @ 0.002 in.



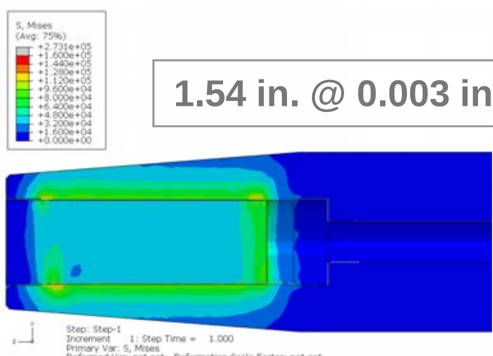
1.70 in. @ 0.002 in.



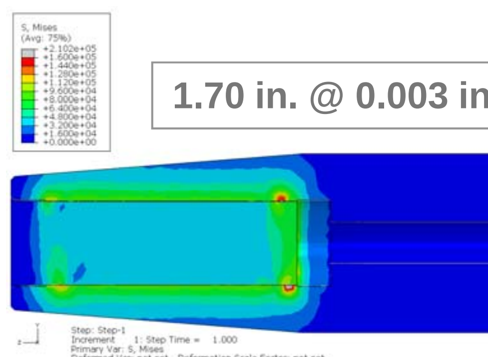
1.90 in. @ 0.002 in.



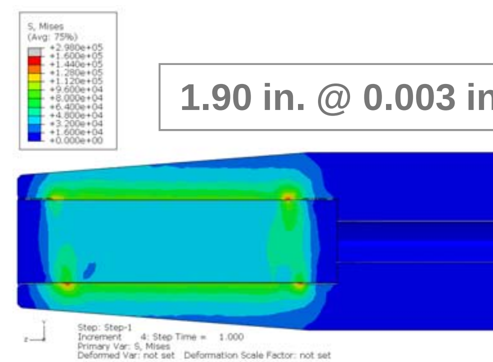
1.54 in. @ 0.003 in.



1.70 in. @ 0.003 in.



1.90 in. @ 0.003 in.



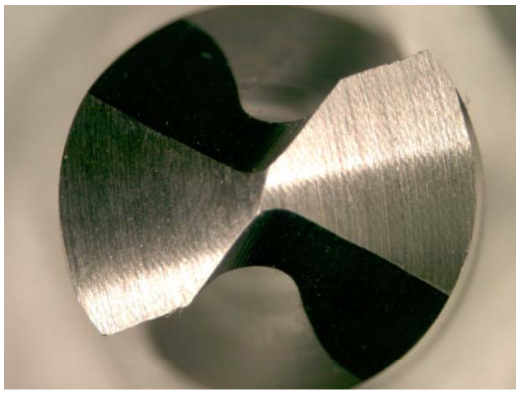
Titanium Drilling

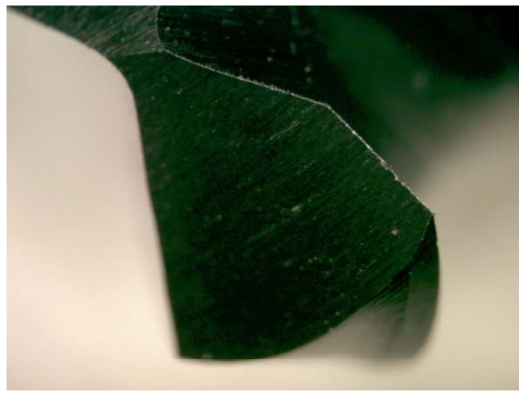
- Acquisition of Techniks tool setter
  - Incorporated design revisions to collet
- Worked with tool supplier to select drills for target materials
  - Guhring HSS 217 - 0.5-in. diameter

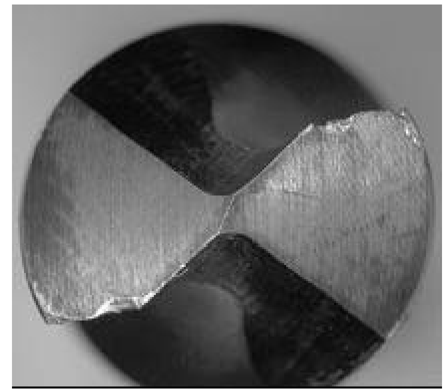
EWI Celebrating 25 Years of Joining Innovation

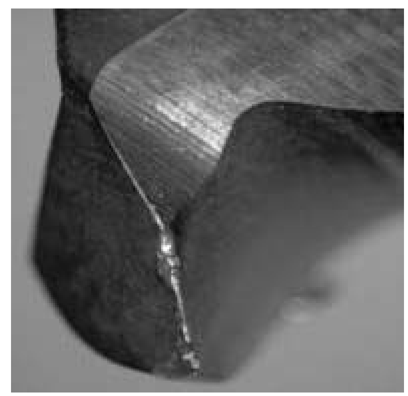
Titanium Drilling (cont.)

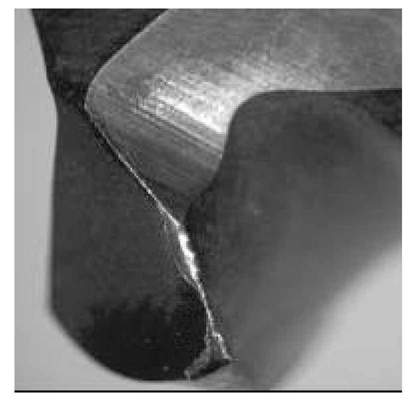
- Titanium drilling w/out US

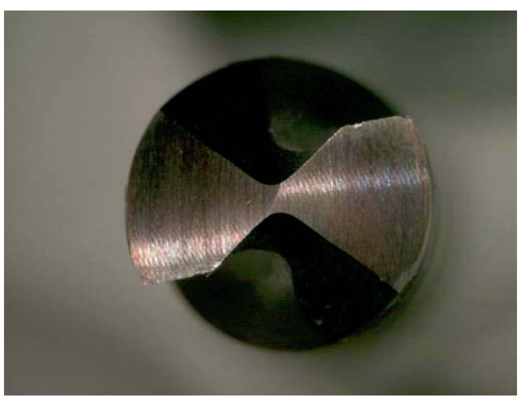




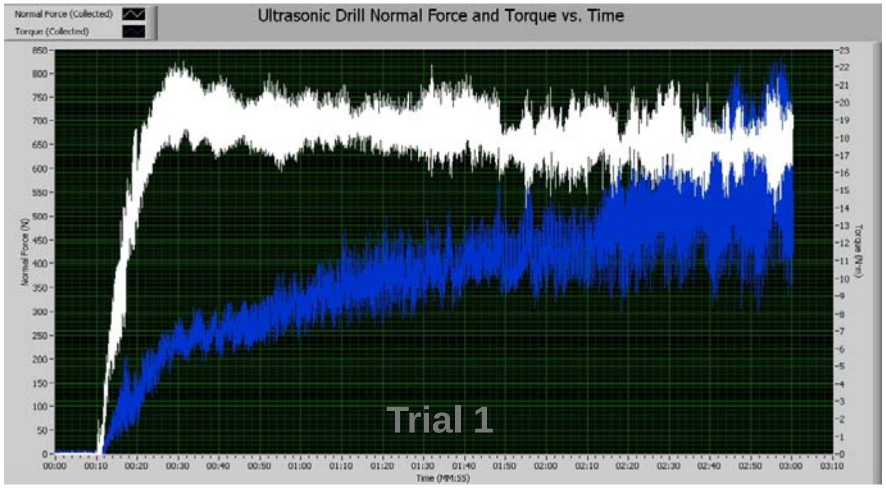


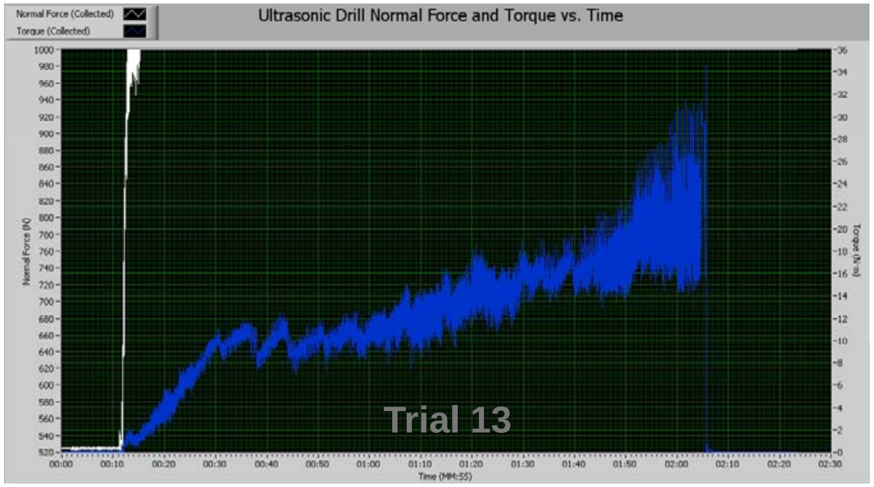






Titanium Drilling (cont.)

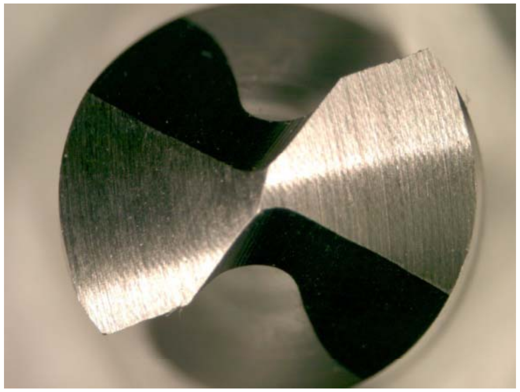
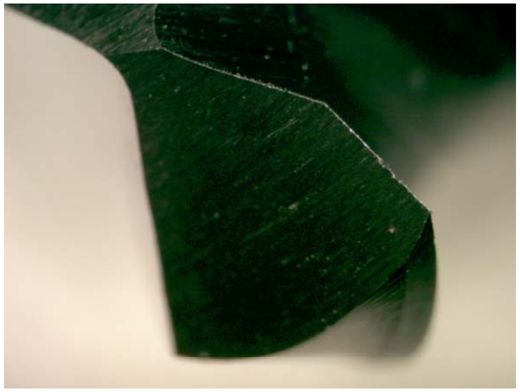
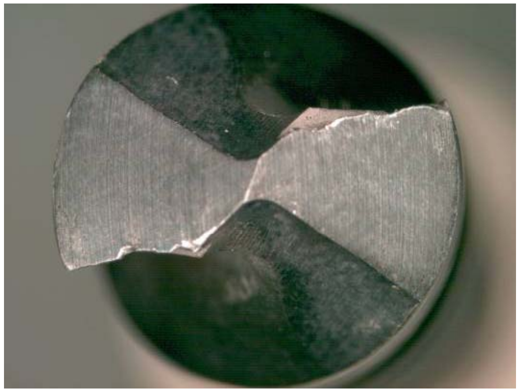
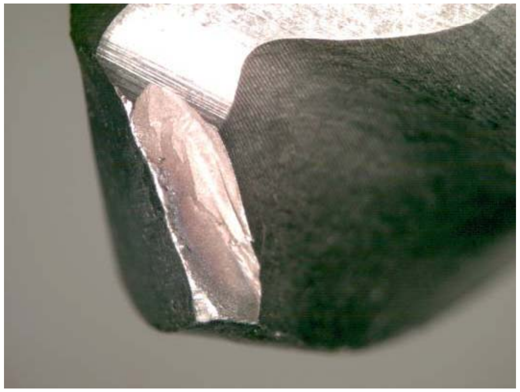
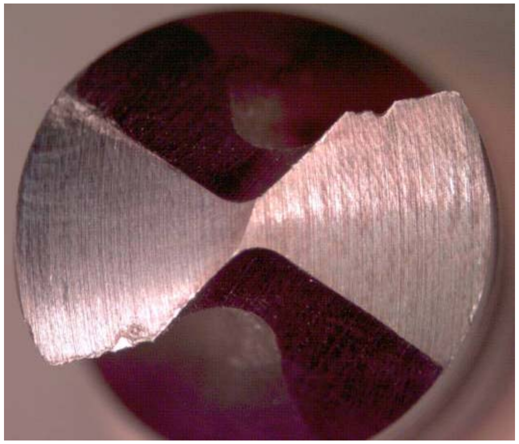
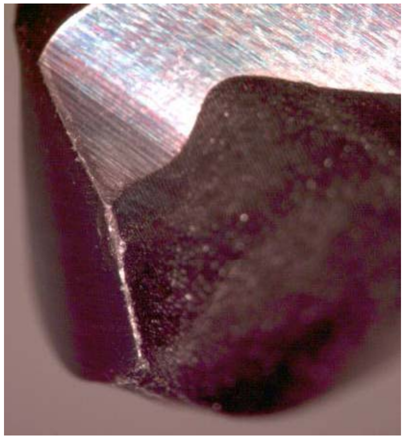




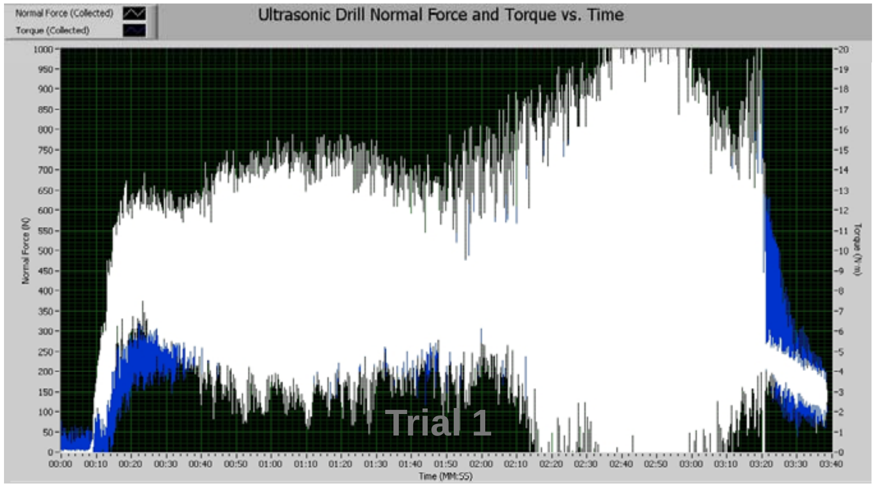
- Conducted 13 trials with varying penetration
  - **No** trial drilled the full depth of the 1.5-in. thick Ti-6Al-4V block
- Drilled 6 holes before normal exceeded 1000 N
- No cutting fluids
- Initial starting F_N = 700-N

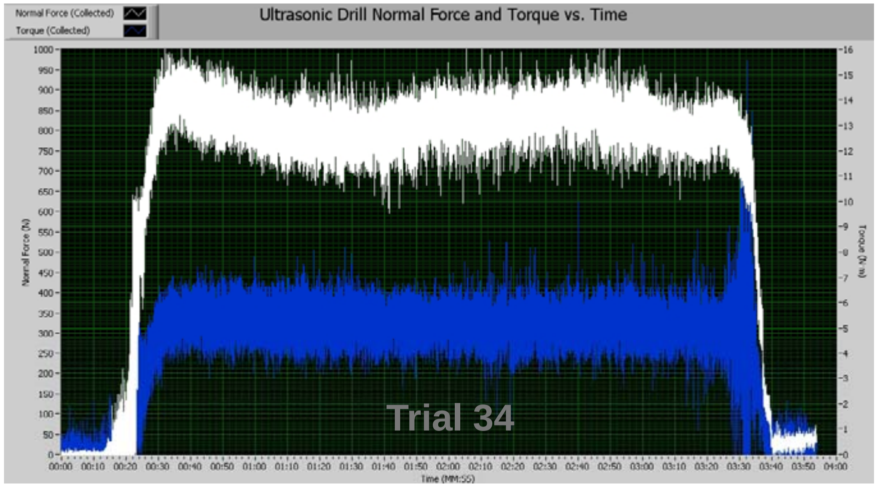
Titanium Drilling (cont.)

- Titanium drilling w/ US

Titanium Drilling (cont.)

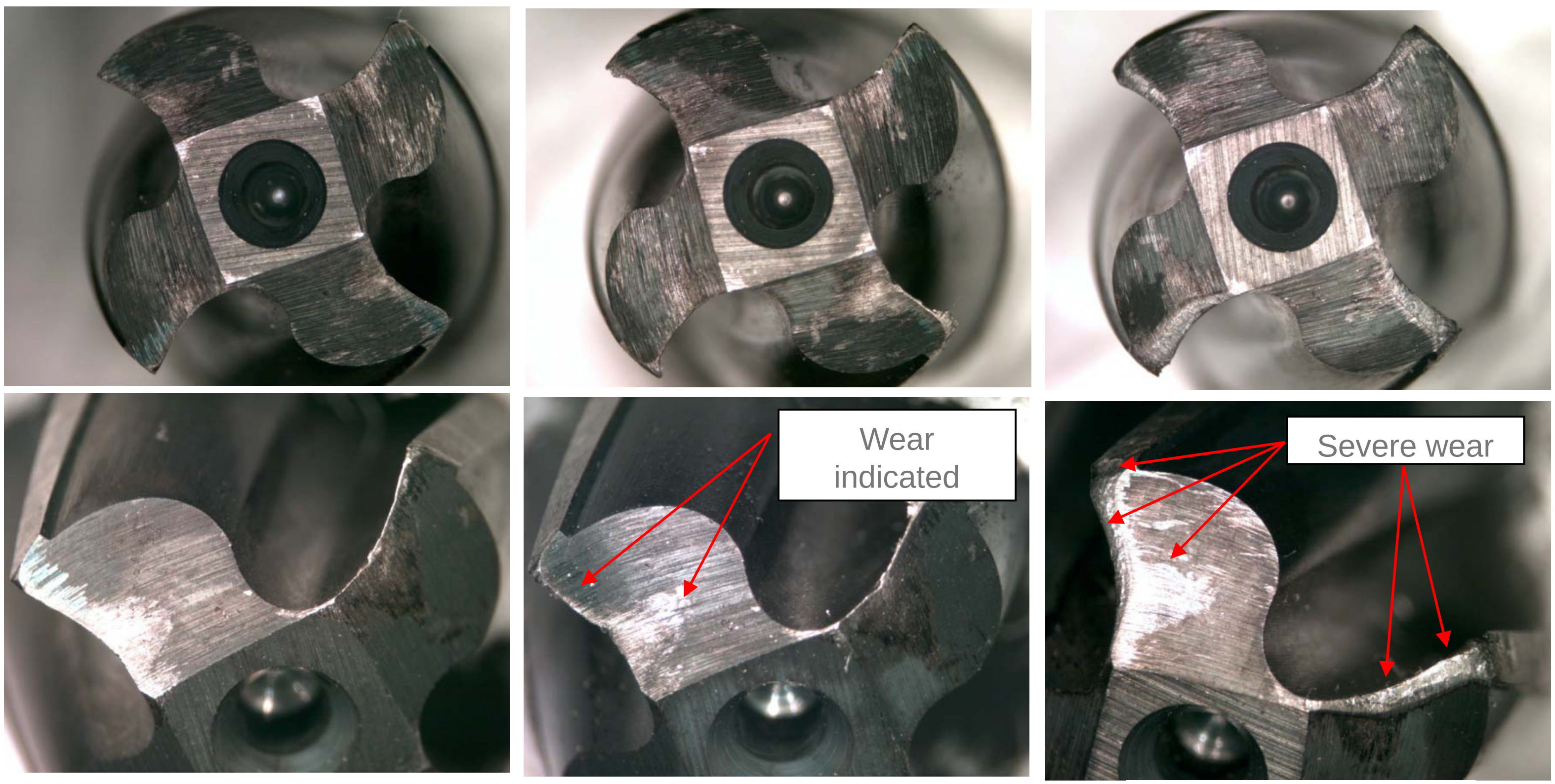




- Conducted 34 trials successfully through entire plate
- Drilled 6 holes before normal exceeded 1000 N
- No cutting fluids
- Initial starting F_N = 400-N
- Max force did exceed 1,000-N in some cases around break through

Tool Life Assessment Cont.

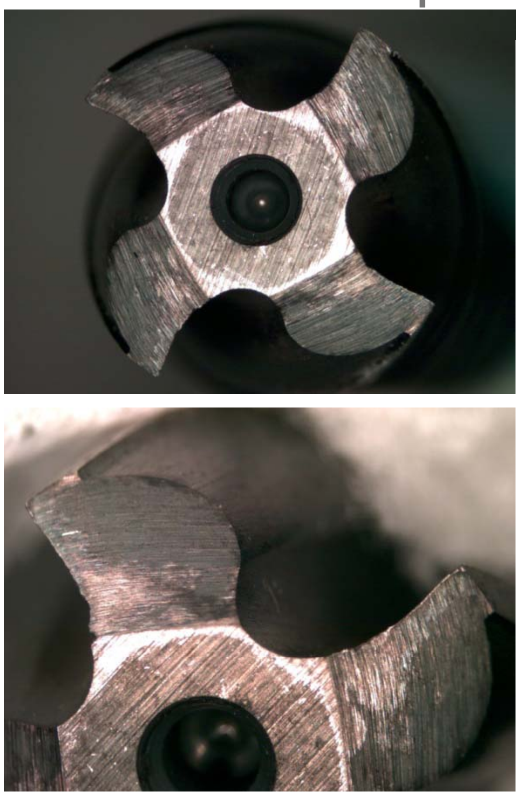
- Tool Performance Without US
  - Cutting edge wear indicated on second pass
  - Third pass showed significant wear



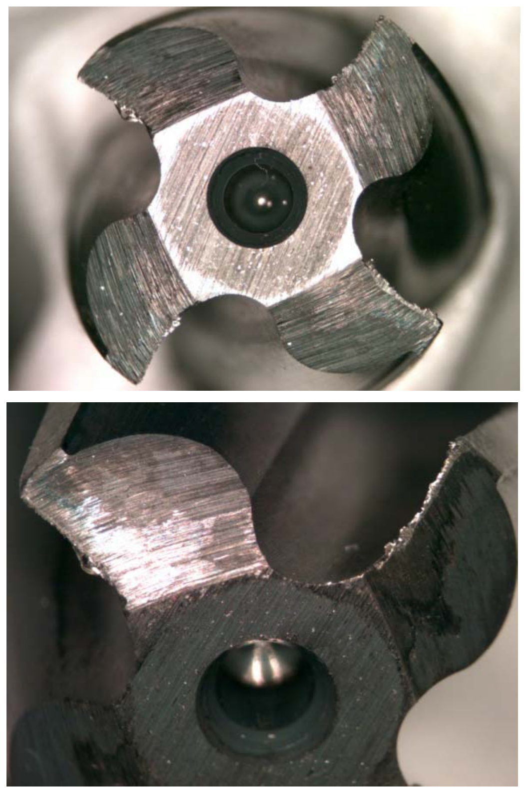
Hole 1 Hole 2 Hole 3

Tool Life Assessment Cont.

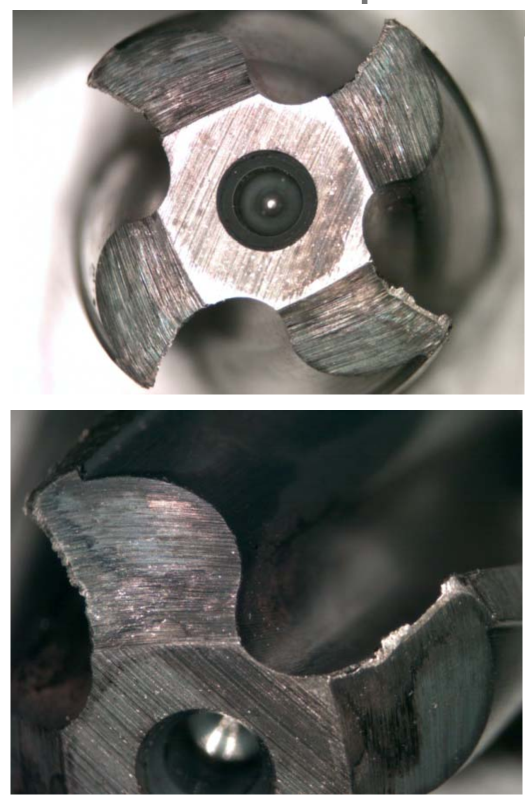
- Tool Performance With US
  - Minor indications of wear indicated
  - Overall performance not affected after third pass



Hole 1



Hole 2

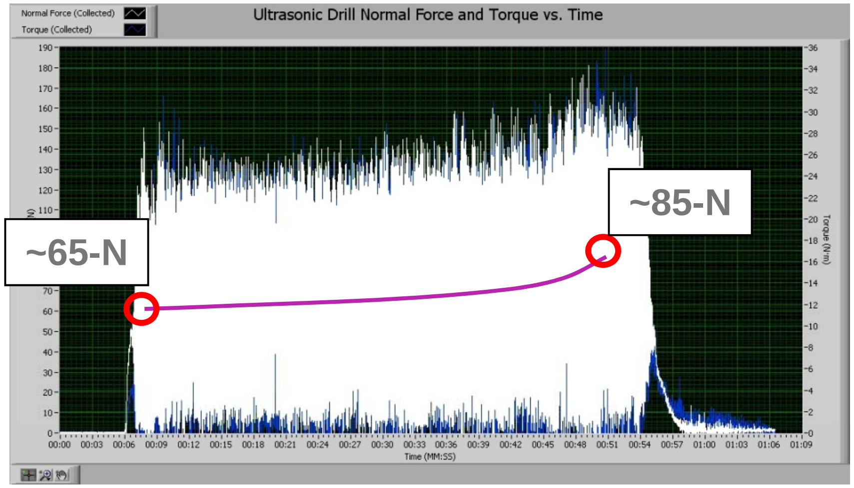


Hole 3

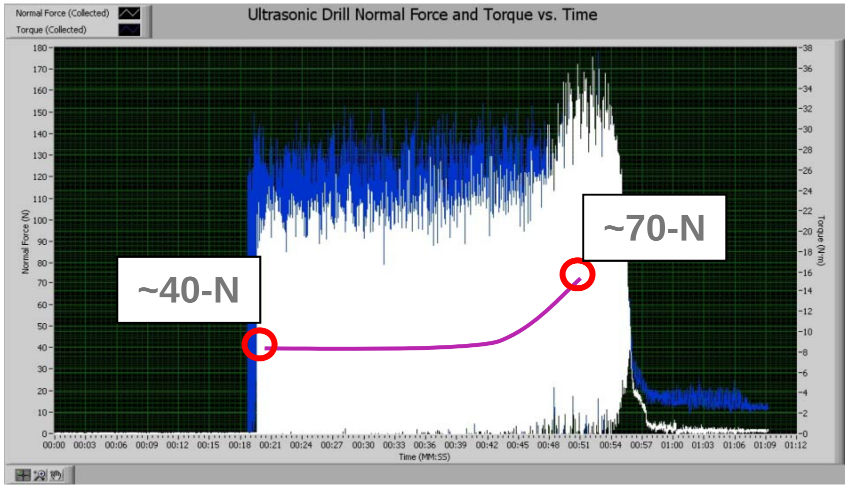
Tool Life Assessment Cont.

- Evaluating Normal Force and Torque Graphs
  - Key trend indicated by tool wear in which the loads increase as wear increases.
    - This is indicated by the initial starting normal force which is translated to the subsequent trial starting out with normal force comparative to the ending force of the preceding trial.

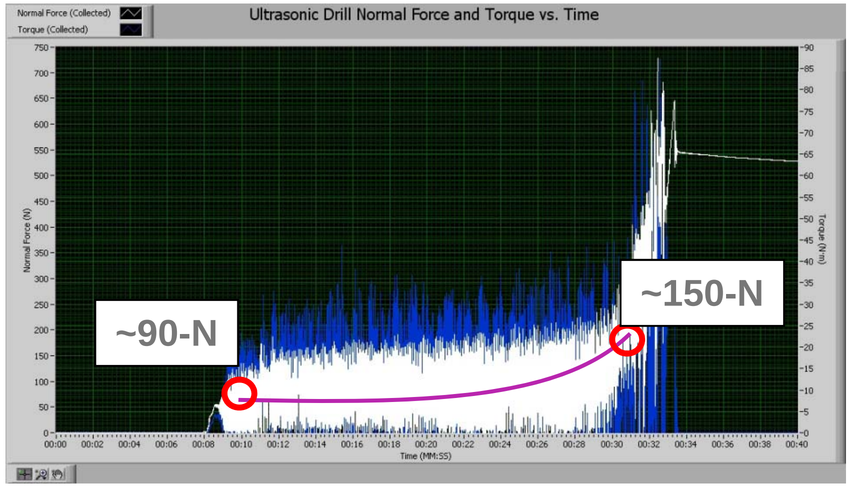
Hole 2 – W/out US



Hole 1 – W/out US



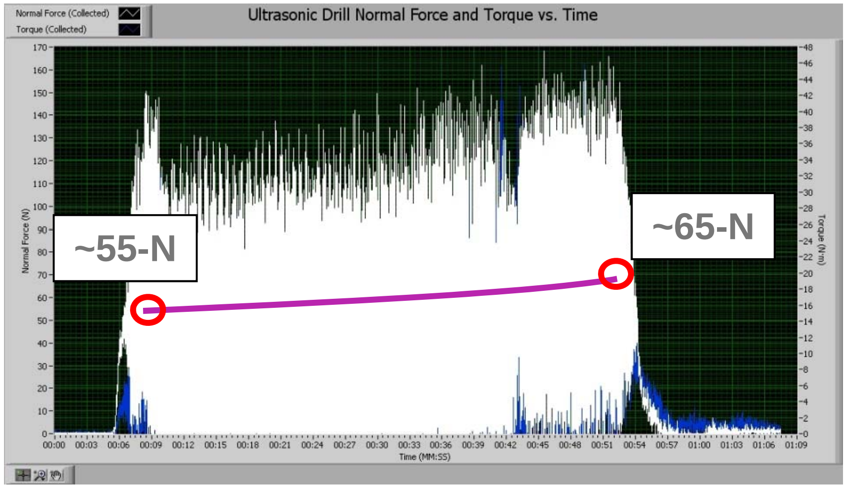
Hole 3 – W/out US



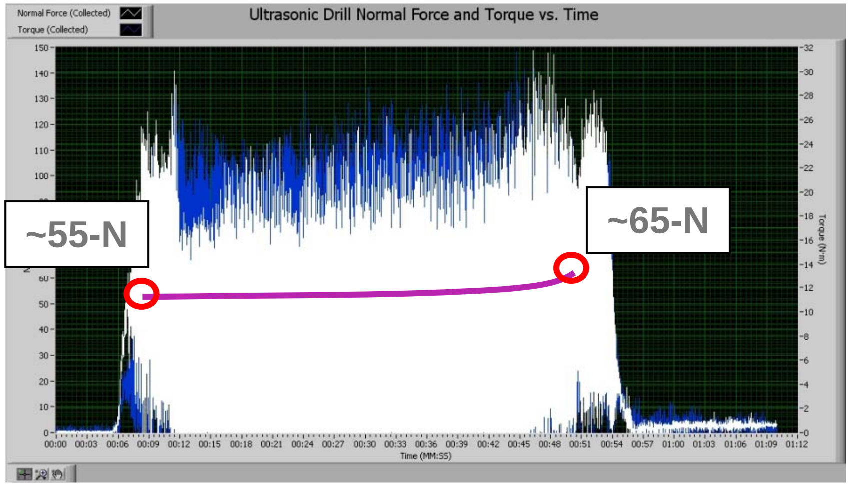
Tool Life Assessment Cont.

- Evaluating Normal Force and Torque Graphs
  - Normal force and torque comparable to those without US energy
  - Force trend indicated by tool wear not as prevalent

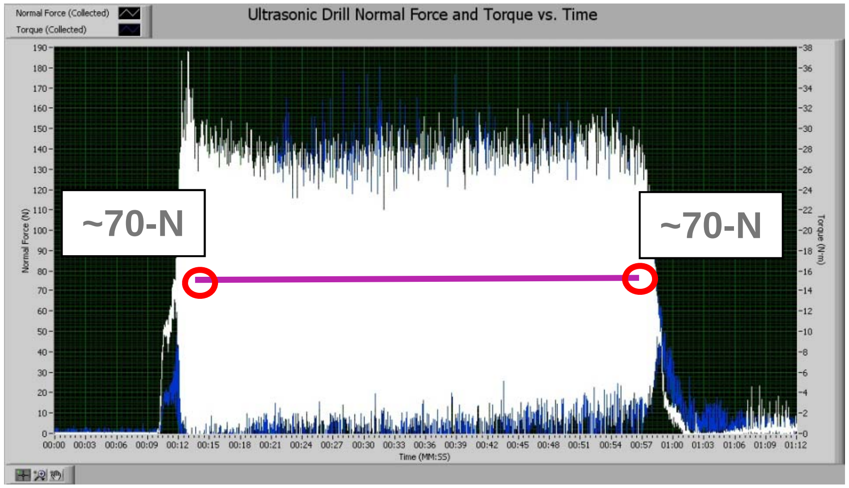
Hole 2 – with US



Hole 1 – with US



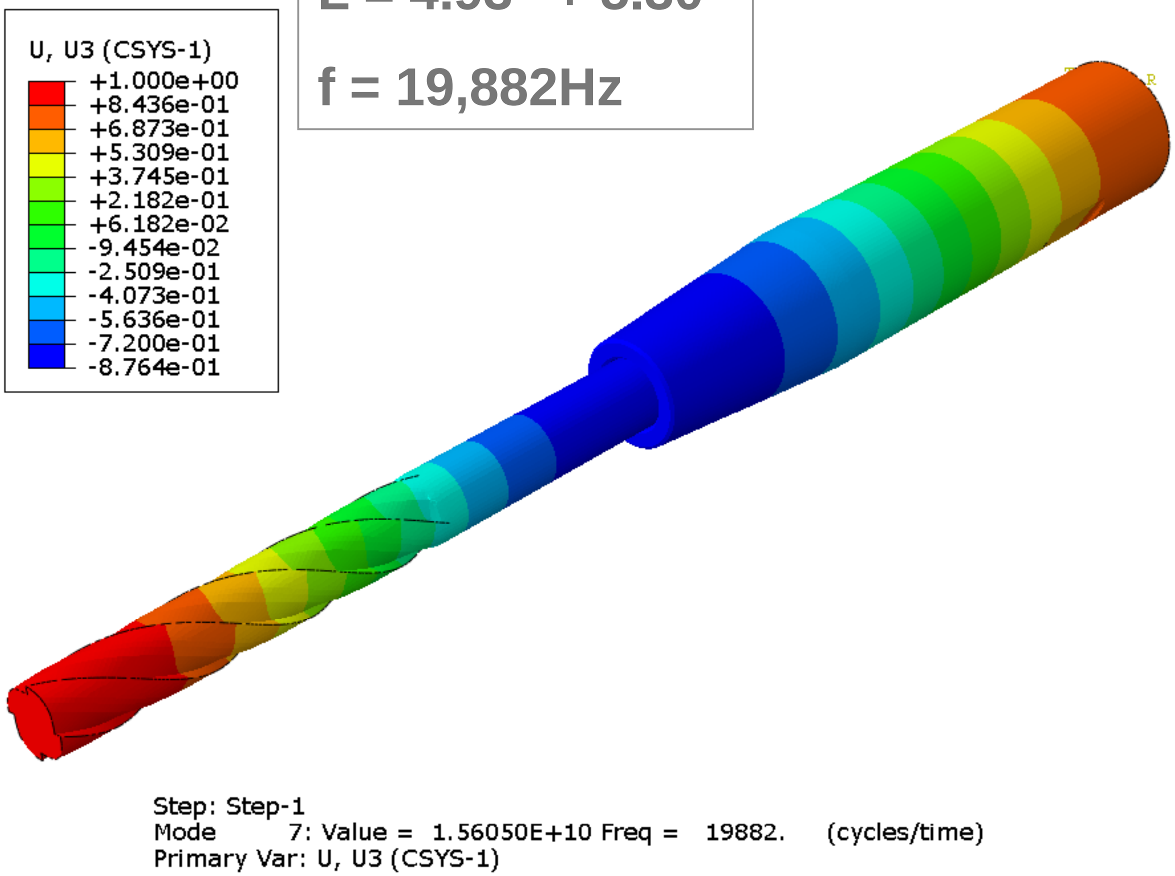
Hole 3 – with US



Milling – Collet Assembly

L = 4.93” + 5.30”

f = 19,882Hz



Summary

- Feeds and speeds for US Machining operations are not the same
  - In many cases, productivity is improved by 2x and is required
  - Conventional drilling could not penetrate plate thickness, whereas US trials successfully drilled 34 holes
    - ~14 5/8-in. engagement vs. ~51-in. engagement
- Have seen indications in which monitoring normal force and torque can be used for evaluating tool life
- Hole quality negligible between two processes
  - Hole quality remains ±0.003-in
- Process successfully transferred to milling applications

Questions?

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