STATUS OF THE FATIGUE STUDIES OF THE CLIC ACCELERATING STRUCTURES

Contents:

- Quick repeat of the classical fatigue phenomena
- CLIC fatigue issues
- Laser fatigue testing (Sergio)
- Introduction to Ultrasound fatigue testing
- Status report
- Conclusions & Future plans

Quick repeat of the classical fatigue phenomena

Fatigue

- Occurs when a material experiences lengthy periods of cyclic or repeated stresses
- Failure at stress levels much lower than under static loading
- Fatigue is estimated to be responsible for approximately 90% of all metallic failures
- Failure occurs rapidly and without warning
- There is no fixed ratio between materials Yield- and Fatigue Strength
- Normally the ratio varies between 30-60%
- Fatigue Strengths are usually average values
- Failure is essentially probabilistic. The number of cycles required for failure varies between homogeneous material samples.
- The greater the applied stress, the shorter the life.
- Damage is cumulative. Materials do not recover when rested.

CLIC meeting 26.6.2003

S-N Curve

Normally d
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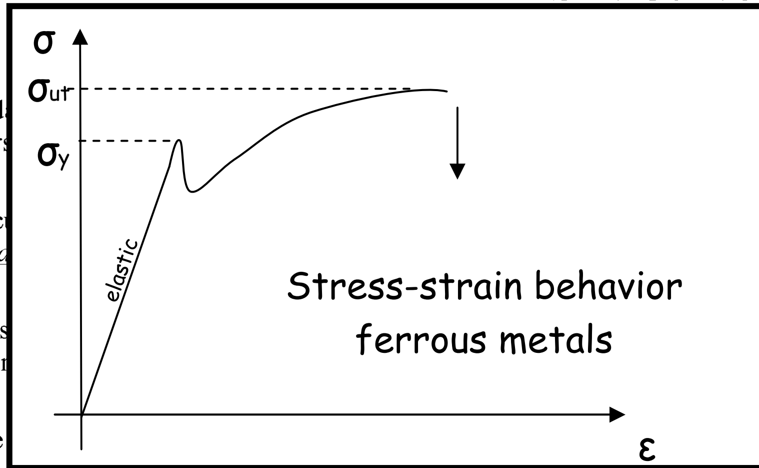
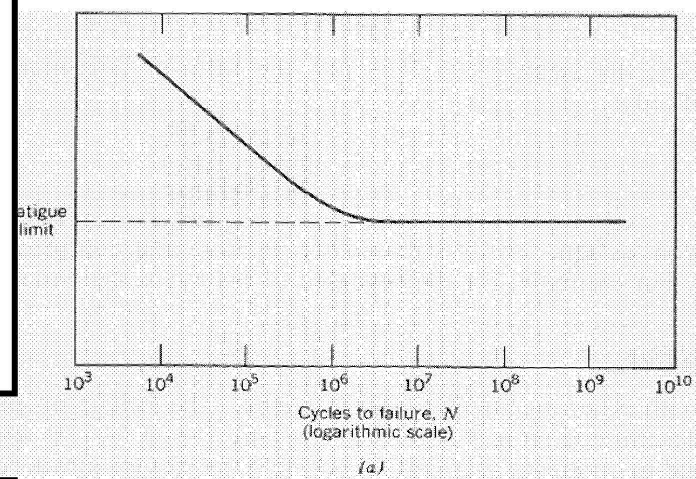
tensile strength of the material.





Fatigue strength is a term applied for nonferrous metals and alloys
(Al, Cu, M

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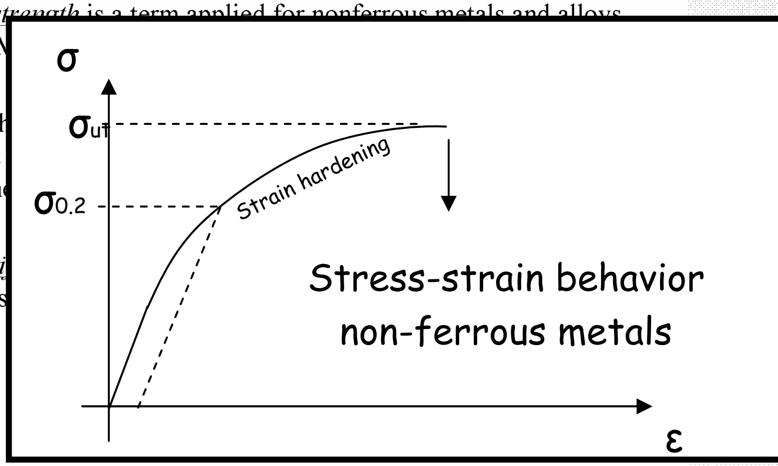

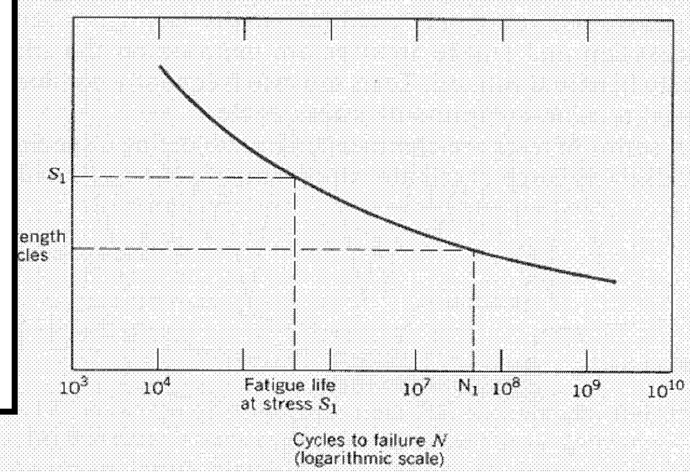

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MIL-SPEC Data Showing Effect of R

1 January 1984 **MIL-HDBK-5D Change Notice 1**

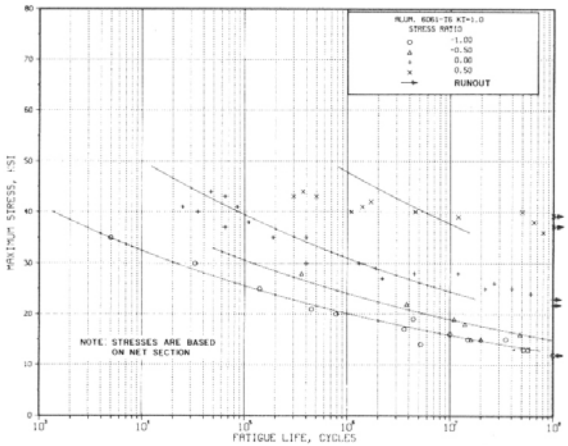


FIGURE 3.6.1.2.8. *Best-fit S/N curves for unnotched 6061-T6 aluminum alloy, various wrought products, longitudinal direction.*

Correlative Information for Figure 3.6.1.2.8

Product Form: Drawn rod, 3/4-inch diameter
Rolled bar, 1 x 7-1/2 inch

Properties:

TUS, ksi	TYS, ksi	Temp., F
45	40	RT

Specimen Details: Unnotched
0.200-inch net diameter

Surface Condition: Not specified

Reference: 3.2.1.1.8(a)

Test Parameters:

Loading – Axial
Frequency – 2000 cpm
Temperature – RT
Environment – Air

No. of Heats/Lots: Not specified

Equivalent Stress Equation:

$\text{Log } N_f = 20.68 - 9.84 \log (S_{eq})$
$S_{eq} = S_{max} (1-R)^{0.63}$
Standard Error of Estimate = 0.48
Standard Deviation in Life = 1.18
$R^2 = 83\%$

Sample Size = 55

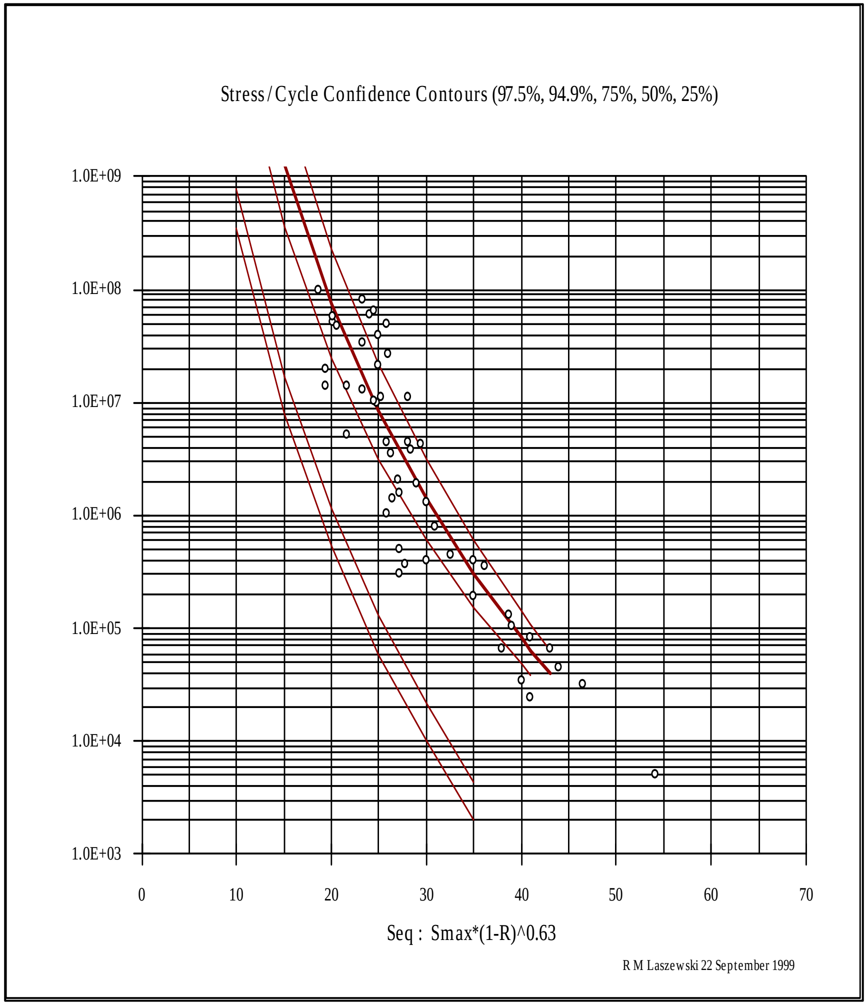
[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above]

3-244

- This is the page from the MIL-SPEC handbook that was used for the statistical analysis of the scatter in fatigue test data.
- The analytical model assumes that all test data regardless of R can be plotted as a straight line on a log-log plot after all the data points are corrected for R.
- The biggest problem with this data presentation style is that the trend lines represent 50% confidence at a given life and we need >95% confidence of ability to reach 200 x 10^6 cycles.

Review of the Stress Analysis of the MiniBooNE Horn MH1, Larry Bartoszek, P.E. 1/20/00, BARTOSZEK ENGINEERING

Confidence Curves on Equivalent Stress data plot



- This graph plots 55 MIL-SPEC data points corrected for R by the equation at bottom. The y axis is number of cycles to failure, the x axis is equivalent stress in ksi.
- From this graph we concluded that the equivalent stress for >97.5% confidence at $2x10^8$ cycles was 10 ksi.

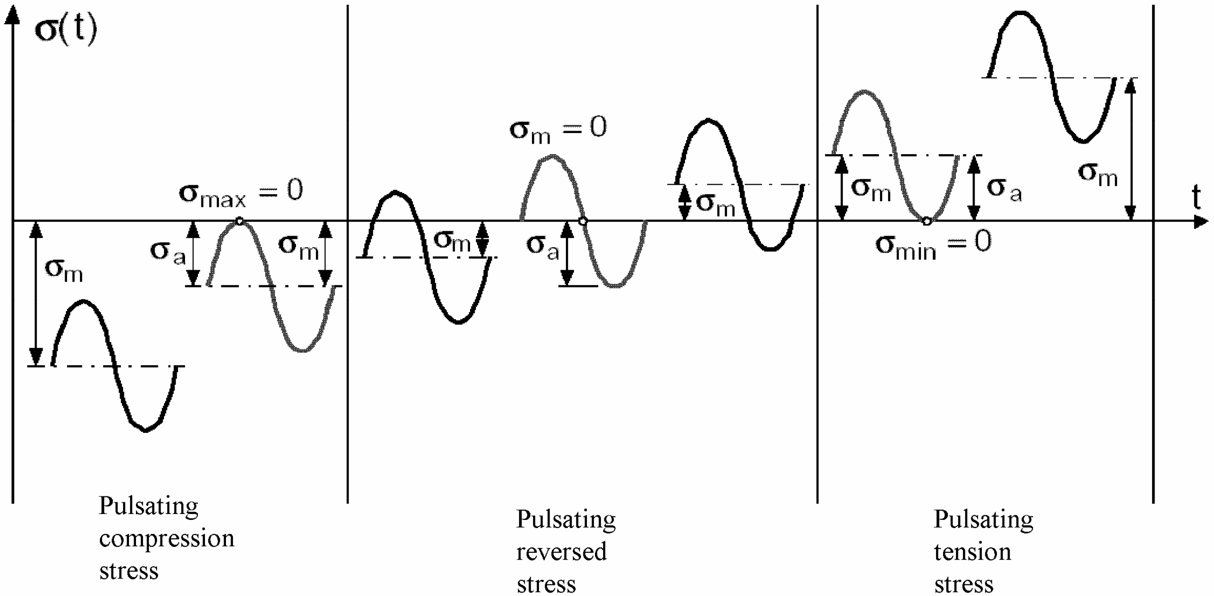
Review of the Stress Analysis of the MiniBooNE Horn MH1, Larry Bartoszek, P.E. 1/20/00, BARTOSZEK ENGINEERING

Things that have an effect on fatigue strength

- Grain size
- Corrosion
- Frequency
- Vacuum
- The Average Mean Stress

- Surface roughness
- Cold-Working
- Thermal treatment
- Operating temperature
- Alloying

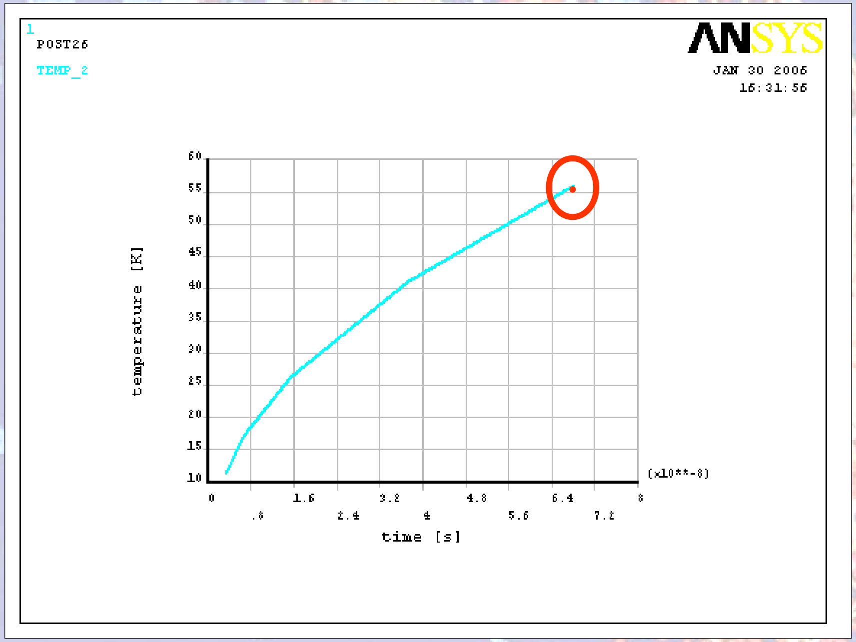
- For example, shot peening puts the surface in a state of compressive stress which inhibits crack formation thus improving fatigue life.



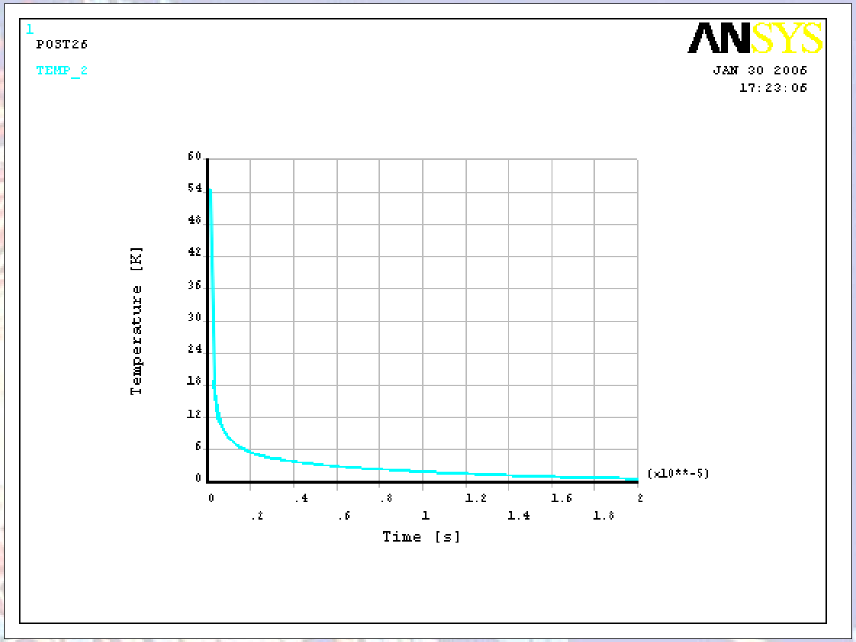
CLIC meeting 26.6.2003

CLIC fatigue issues

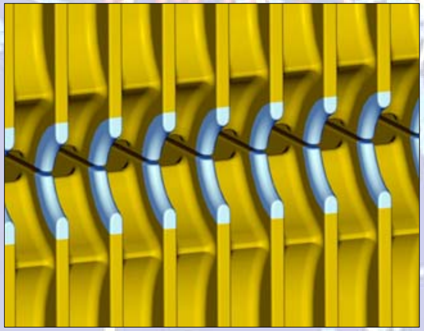
Simulated surface heating of HDS140 structure in Copper Zirconium C15000

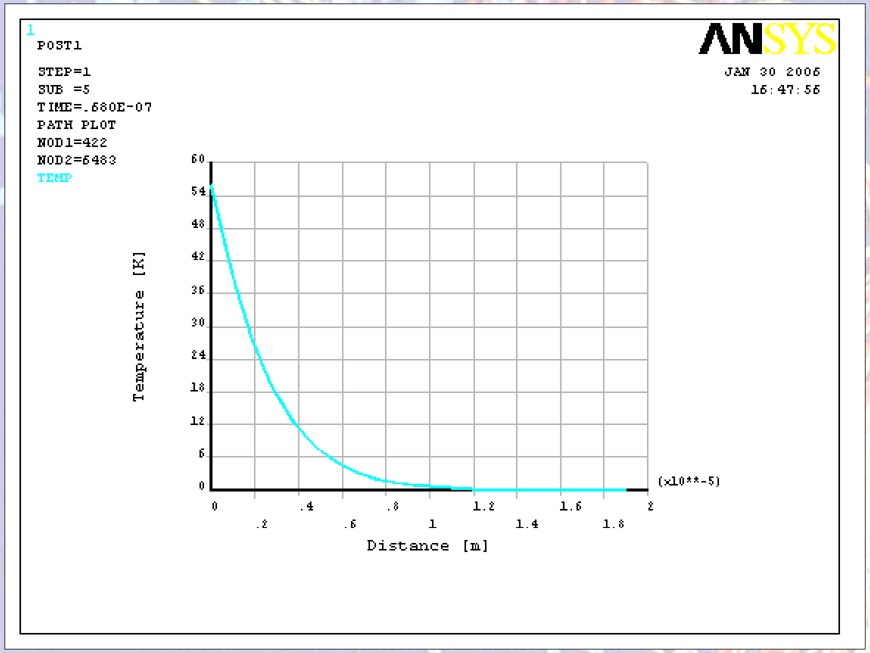


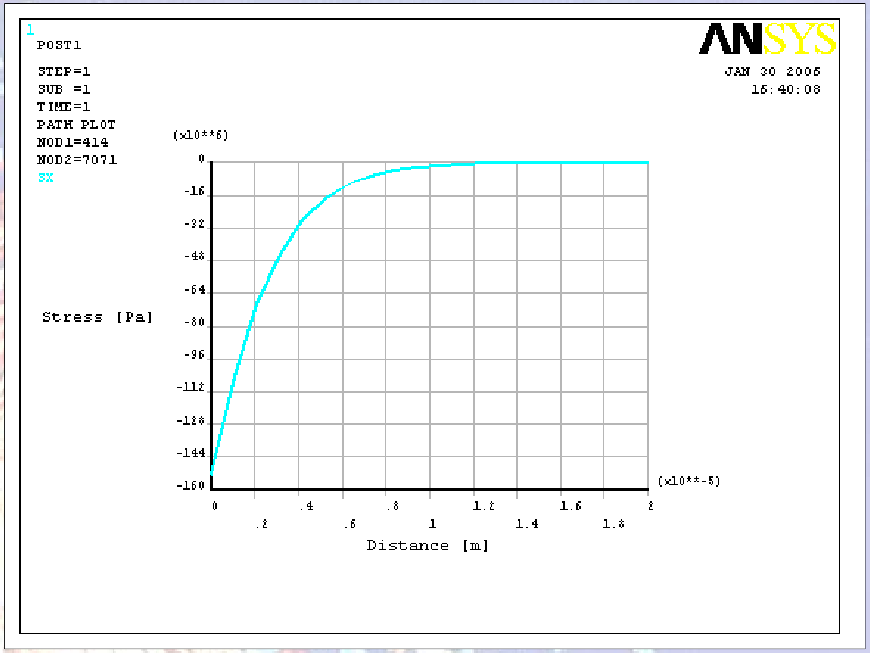
Surface heating during 68 ns pulse



Surface cooling between the pulses (Idle time 6.7 ms)





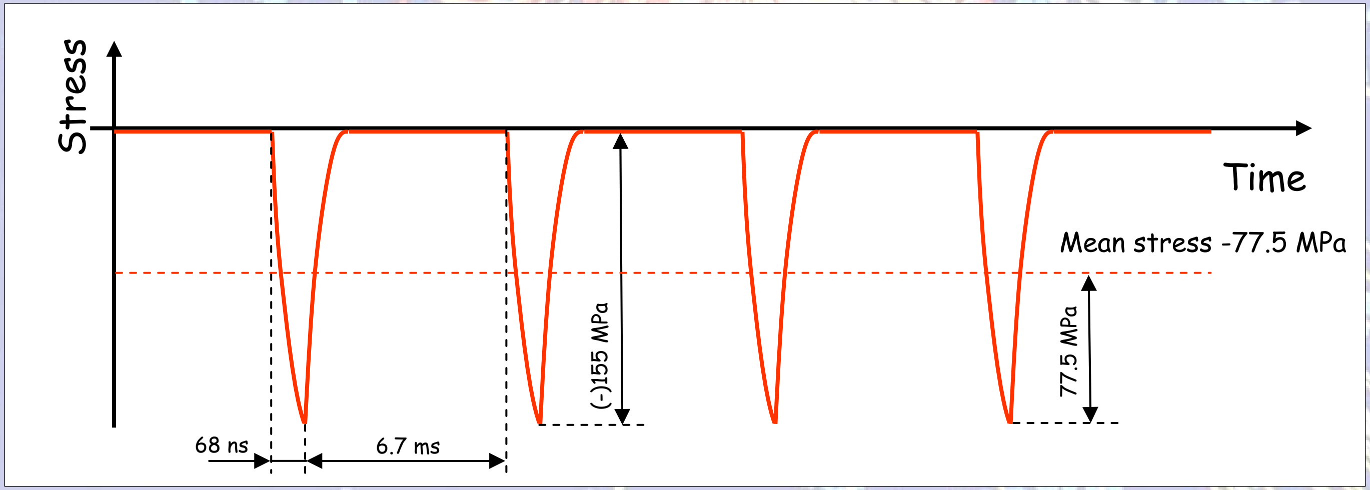


Max Temperature- and Stress profiles of 68 ns pulse

- **Fully compressive cyclic stress condition**
- **Cyclic peak-to-peak stress 155 MPa**
- **Cyclic Stress Amplitude 77.5 MPa**

CLIC number of cycles:

Repetition rate	**150 Hz**
Estimated lifetime	**20 years**
	9 months / year
	7 days / week
	24 hours / day
Total N	**7×10^{10}**



CLIC

+ Vacuum
+ Compressive mean stress
+ Smooth surfaces
+ "Room" temperature
+ "Fast" stress cycle

- Copper alloys are non-ferrous metals
- High criteria of failure due to surface currents. Already a small change in surface roughness is crucial.
- Possible joining method, HIP, softens the material (CuZr)
- Extremely high number of cycles
- Extremely high number of parts, the probability of a failure arises
- The "RF-fatigue" lifetime is difficult to test.

What could be done:

- Select a good material
    - CuZr, GlidCop, CuCrZr…
- Develop other joining method than HIPping
    - Explosion Bonding…
- Hope that the HIPped material (CuZr) is still good enough
    - Will be shown by the near future tests
- Select a material that doesn't soften during HIPing
    - GlidCop…
- Strengthen the material (CuZr) after HIPping
    - CIP
    - Explosion hardening
    - Cavitation Shot-less Peening

Cav03-OS-2-3-002

Fifth International Symposium on Cavitation (CAV2003)
Osaka, Japan, November 1-4, 2003

IMPROVEMENT OF FATIGUE STRENGTH ON STAINLESS STEEL BY CAVITATING JET IN AIR

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ABSTRACT

Beneficial residual stresses can be introduced on the surface of materials thereby impeding the initiation and/or development

quiescent media due to interfacial instabilities caused by density differences, rupture when subjected to large velocity gradients, deform and disintegrate due to turbulent flow conditions,

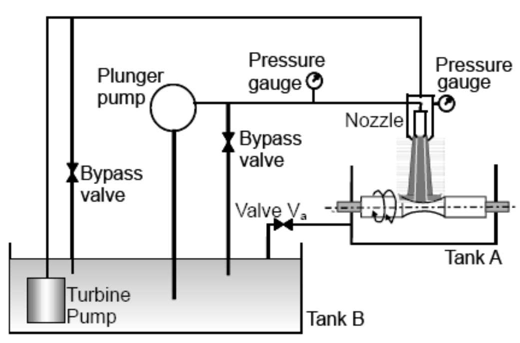
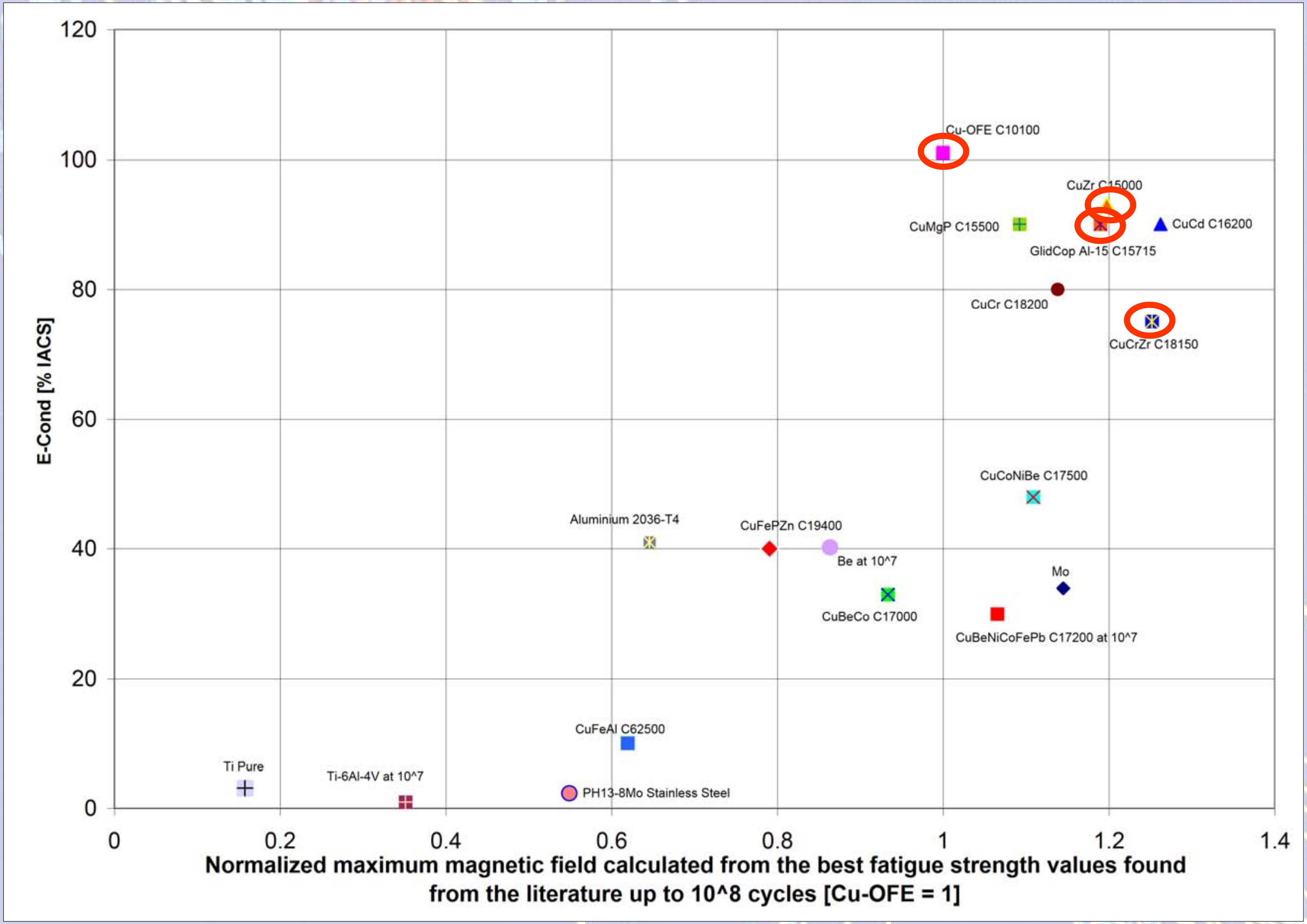


Fig. 2 Cavitating jet apparatus

Cavitation Shot-less Peening

- Surface hardening of HIPped material
- Compressive residual stress
- Good surface roughness could be preserved
- Tests in collaboration with Tohoku University (Japan) under way


120
100
80
60
40
20
0
E-Cond [% IACS]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Normalized maximum magnetic field calculated from the best fatigue strength values found from the literature up to 10^8 cycles [Cu-OFE = 1]
Cu-OFE C10100
CuZr C15000
CuMgP C15500
CuCd C16200
GlidCop Al-15 C15715
CuCr C18200
CuCrZr C18150
CuCoNiBe C17500
Aluminium 2036-T4
CuFePZn C19400
Be at 10^7
Mo
CuBeCo C17000
CuBeNiCoFePb C17200 at 10^7
CuFeAl C62500
Ti Pure
Ti-6Al-4V at 10^7
PH13-8Mo Stainless Steel

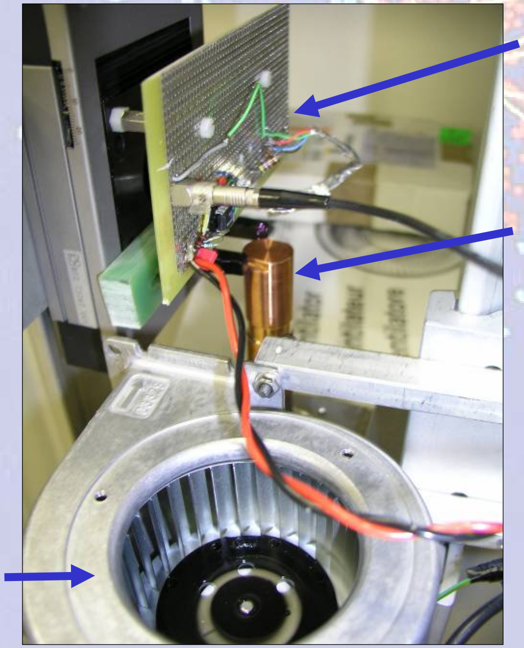
Sergio

Introduction to Ultrasound fatigue testing

CLIC

- Cyclic mechanical stressing of material at frequency of 24 kHz.
- High cycle fatigue data within a reasonable testing time. CLIC lifetime 7×10^{10} cycles in 30 days.
- Will be used to extend the laser fatigue data up to high cycle region.
- Tests for Cu-OFE, CuZr, CuCr1Zr & GlidCop Al-15 under way.

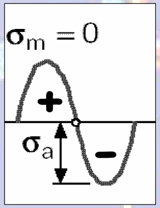
Ultrasound fatigue test samples



Calibration card measures the displacement amplitude of the specimen's tip

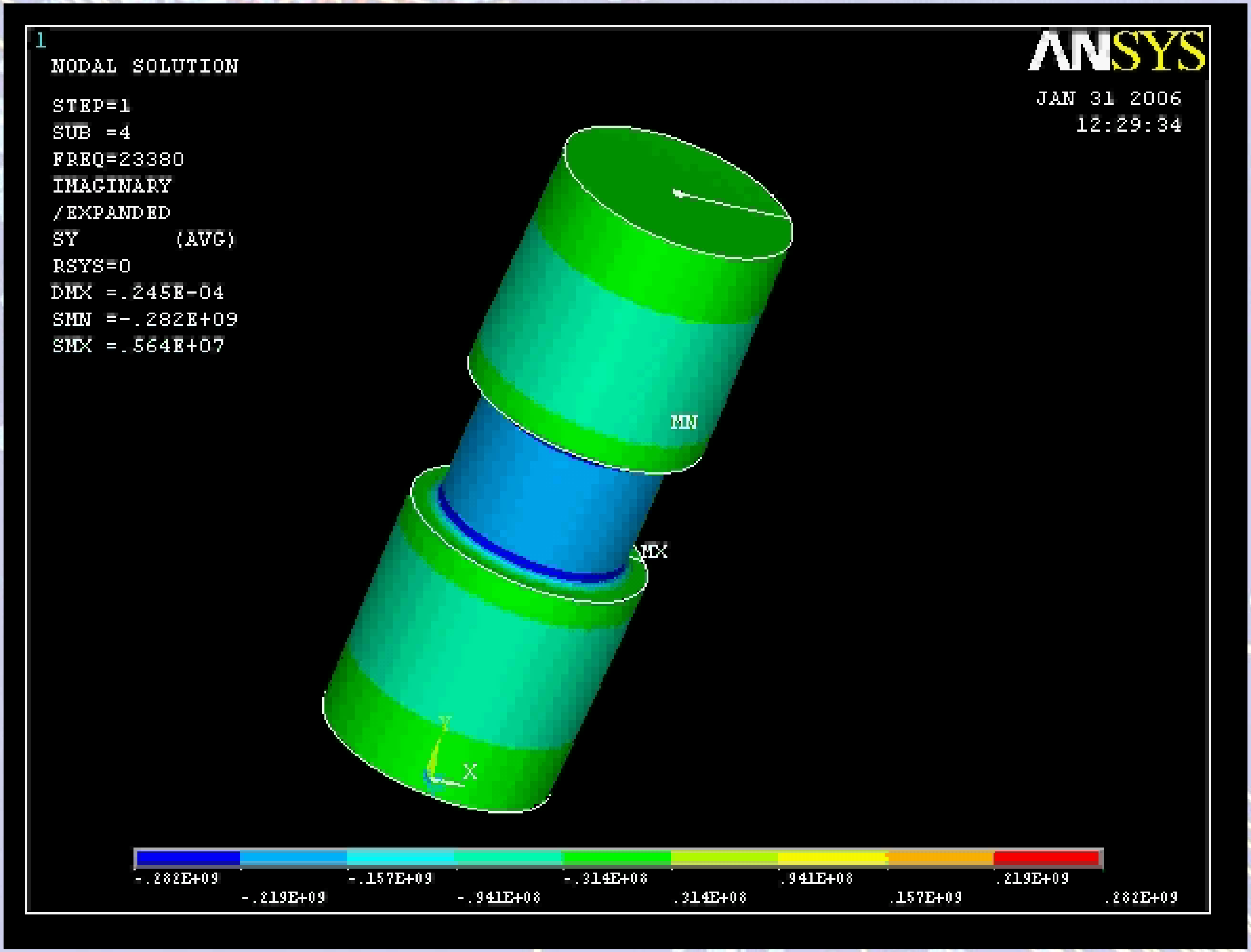
Fatigue test specimen

Air Cooling

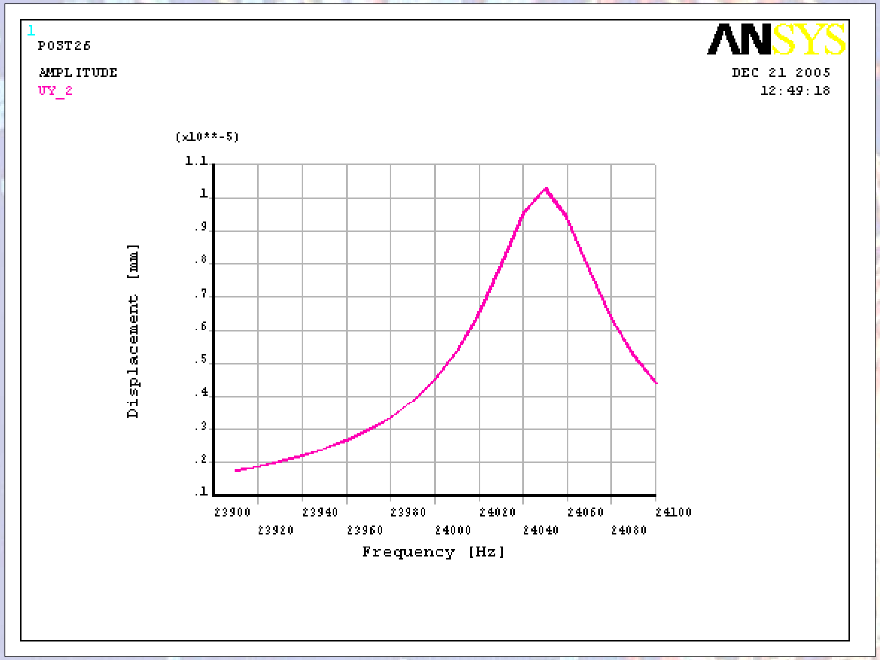


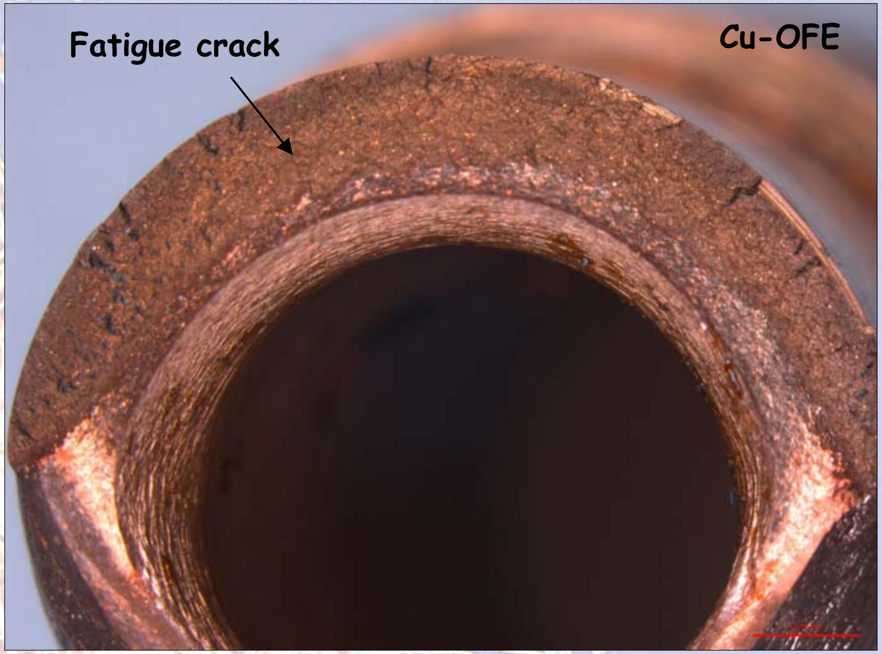
Reversed stress condition

Ultrasound fatigue test setup

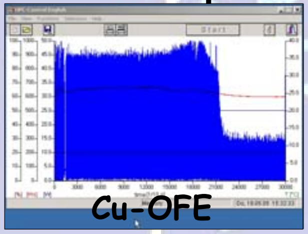


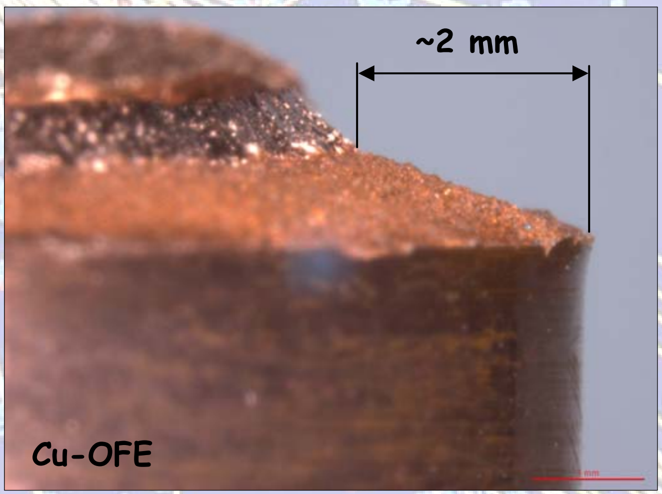
Simulated sonotrode vibration

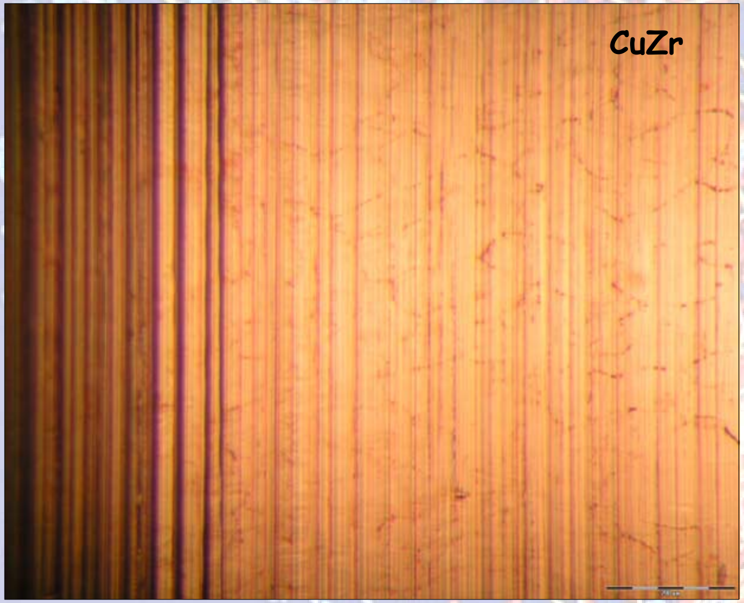




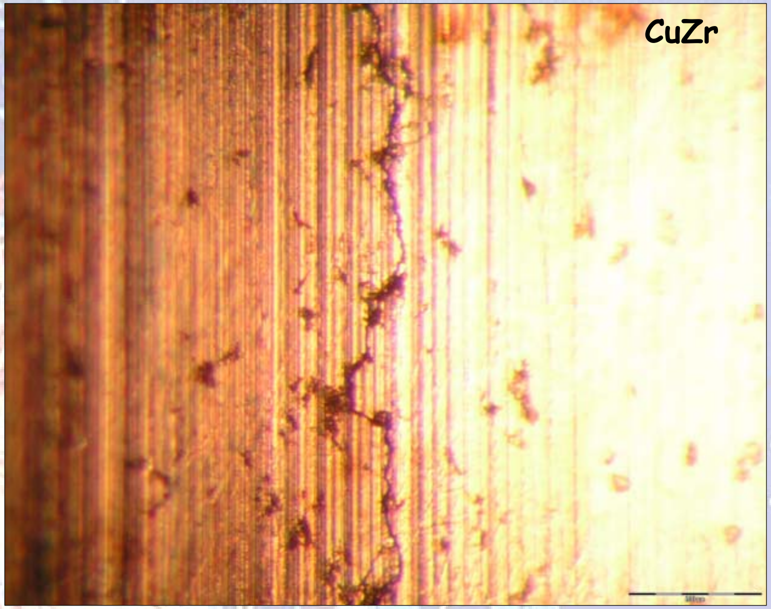
- The operating frequency of the Ultrasound unit is 24 kHz ± 1 kHz.
- A crack changes the resonant frequency of the sample.
- When the crack is about 2 mm deep, the sample is 1 kHz off the resonance and the device stops the "normal" operation.
- Material characterization at same time



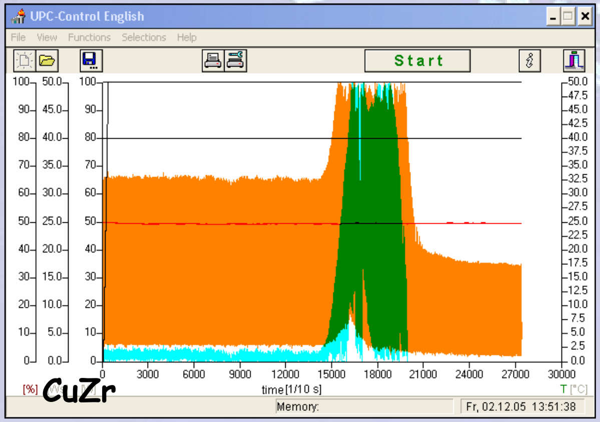


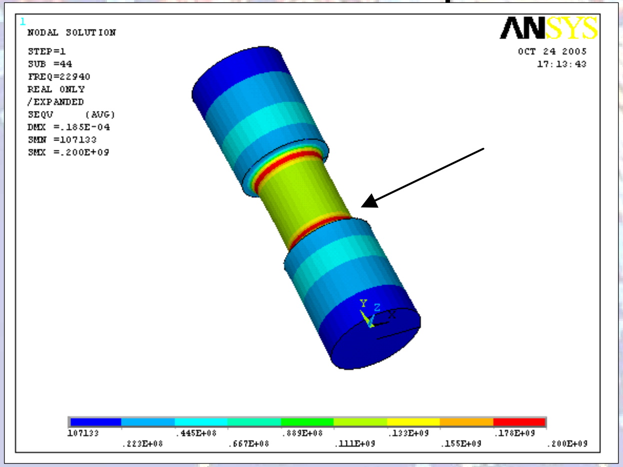


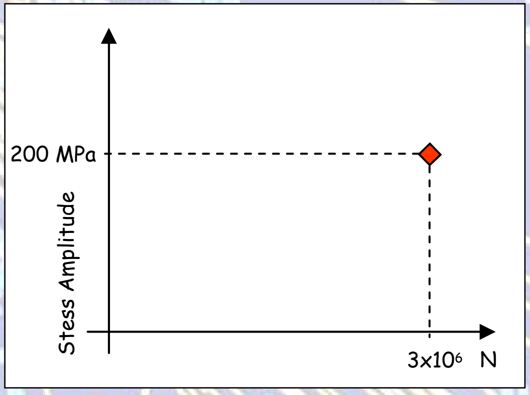
Diamond turned specimen before



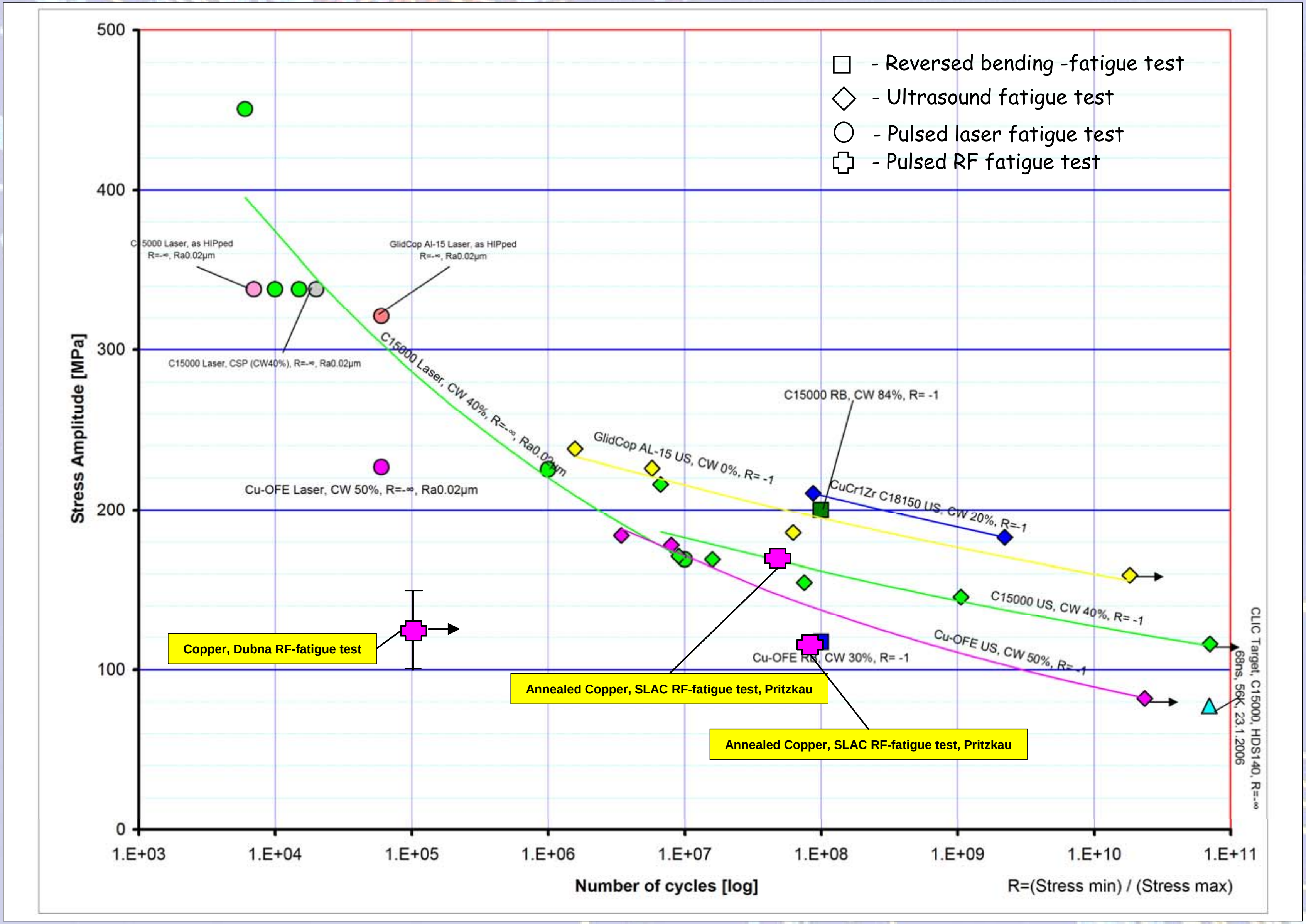
After $3*10^6$ cycles at stress amplitude 200 MPa



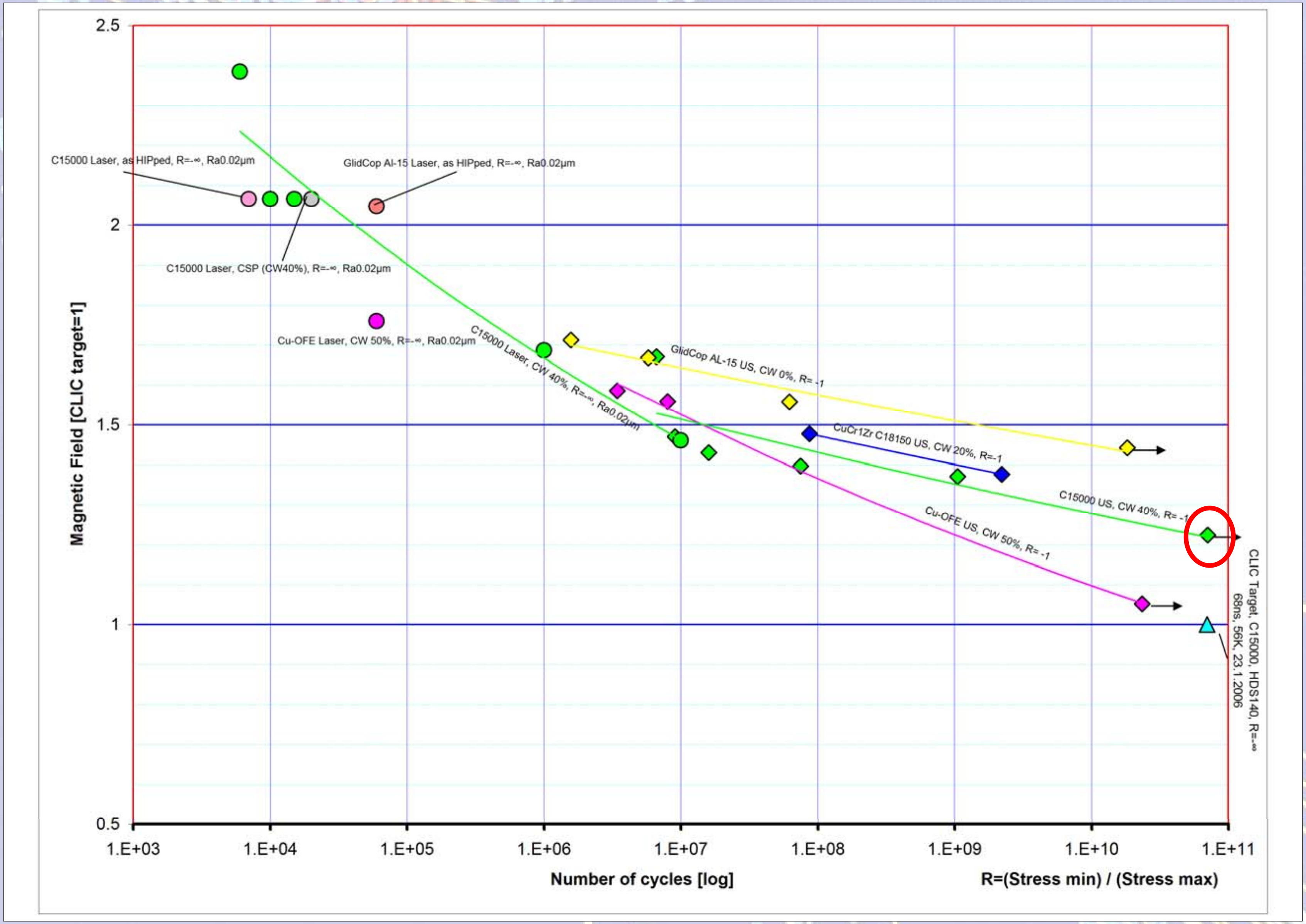




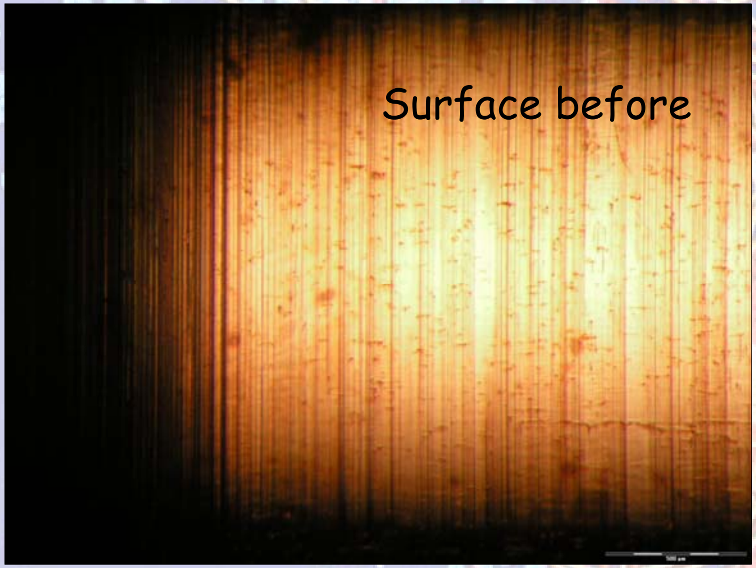
Status report

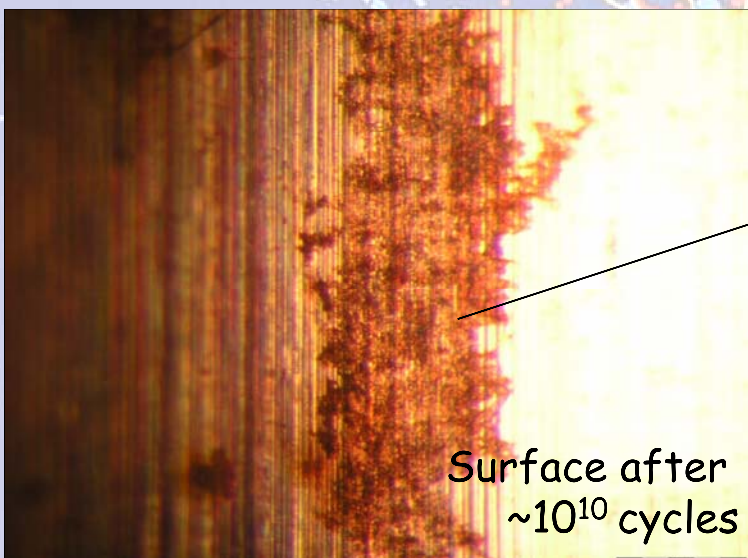


- Reversed bending -fatigue test
- Ultrasound fatigue test
- Pulsed laser fatigue test
- Pulsed RF fatigue test
Stress Amplitude [MPa]
500
400
300
200
100
0
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
1.E+09
1.E+10
1.E+11
Number of cycles [log]
R=(Stress min) / (Stress max)
C 5000 Laser, as HIPped
R=-∞, Ra0.02µm
GlidCop Al-15 Laser, as HIPped
R=-∞, Ra0.02µm
C15000 Laser, CSP (CW40%), R=-∞, Ra0.02µm
C15000 Laser, CW 40%, R=-∞, Ra0.02µm
Cu-OFE Laser, CW 50%, R=-∞, Ra0.02µm
GlidCop AL-15 US, CW 0%, R= -1
C15000 RB, CW 84%, R= -1
CuCr1Zr C18150 US, CW 20%, R=-1
C15000 US, CW 40%, R= -1
Cu-OFE US, CW 50%, R= -1
Cu-OFE RB, CW 30%, R= -1
Copper, Dubna RF-fatigue test
Annealed Copper, SLAC RF-fatigue test, Pritzkau
Annealed Copper, SLAC RF-fatigue test, Pritzkau
CLIC Target, C15000, HDS140, R=-∞
68ns, 56K, 23.1.2006

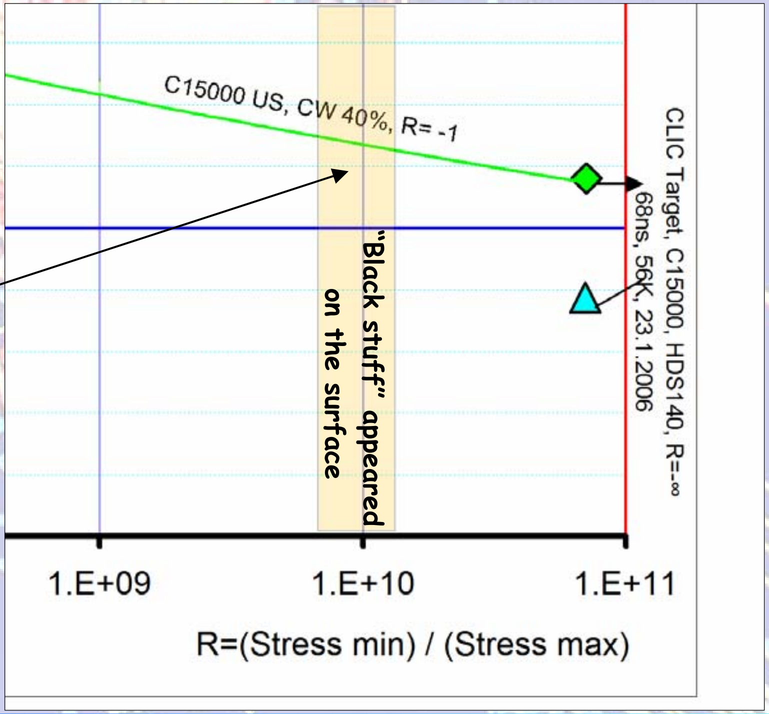


Magnetic Field [CLIC target=1]
Number of cycles [log]
R=(Stress min) / (Stress max)
C15000 Laser, as HIPped, R=-∞, Ra0.02µm
GlidCop Al-15 Laser, as HIPped, R=-∞, Ra0.02µm
C15000 Laser, CSP (CW40%), R=-∞, Ra0.02µm
Cu-OFE Laser, CW 50%, R=-∞, Ra0.02µm
C15000 Laser, CW 40%, R=-∞, Ra0.02µm
GlidCop AL-15 US, CW 0%, R= -1
CuCr1Zr C18150 US, CW 20%, R=-1
C15000 US, CW 40%, R= -1
Cu-OFE US, CW 50%, R= -1
CLIC Target, C15000, HDS140, R=-∞ 68ns, 56K, 23.1.2006





- The 40% Cold Worked CuZr sample survived the CLIC lifetime without a crack.
- Something happened on the surface already around 10^{10} cycles.
- If the surface roughness is increased, this could be dangerous for the RF induced fatigue.

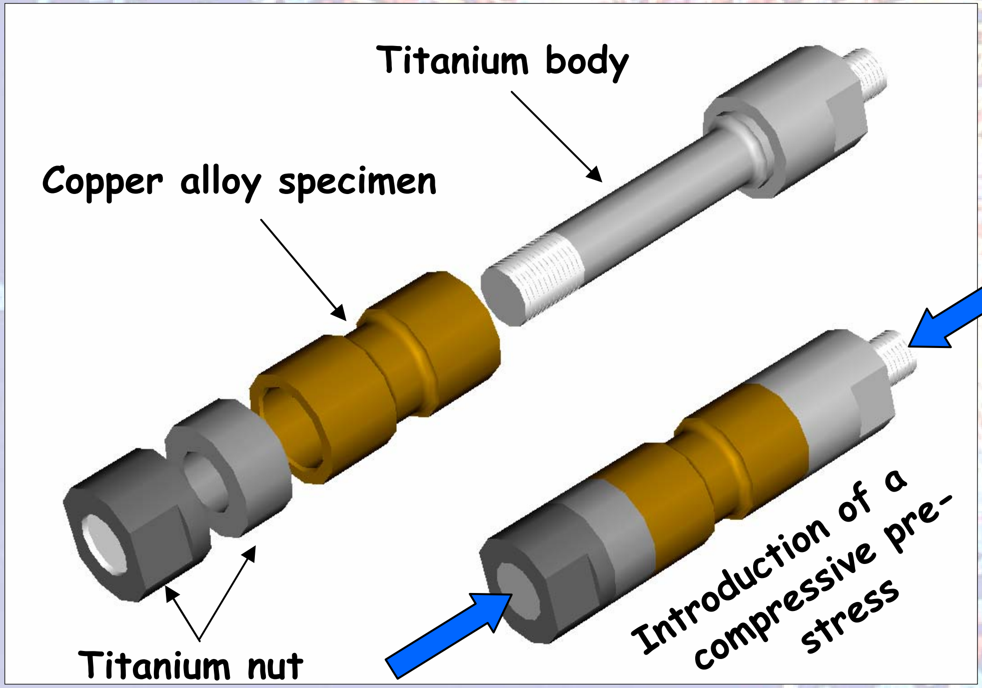


Future Plans, Ultrasound tests

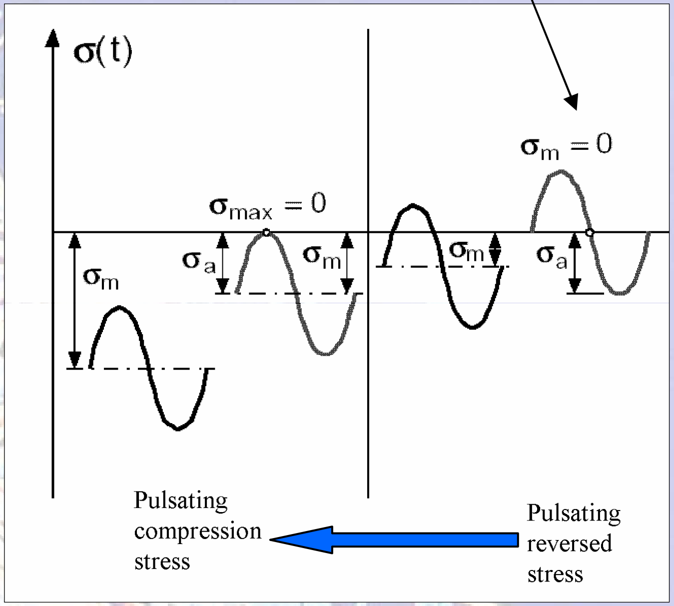
- Complete the fatigue data for Cu-OFE and CuCrZr
- Perform fatigue tests for Copper Zirconium at different states
  - "as HIPped" –state
  - Surface hardened by Shot Peening
  - High ratio of Cold Working (80%)
- Investigate the surface effects during the mechanical cyclic loading.
- Vary the stress condition (next slide)

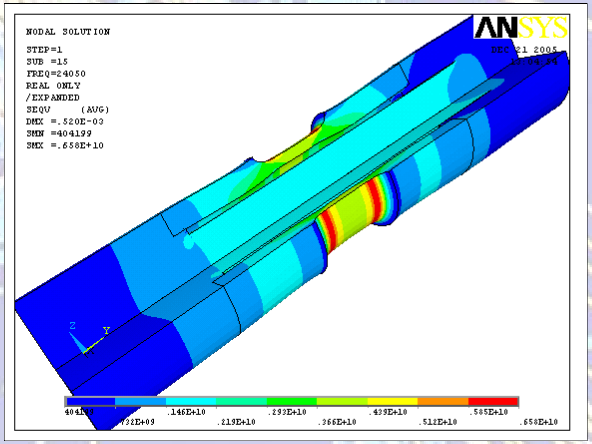
CLIC

Varying the stress condition by a special pre-stressed specimen



Standard ultrasound stress condition





Conclusions

Looks like the two (laser and ultrasound) methods can be connected and the total CLIC lifetime be predicted.

↓

The calibration with RF fatigue experiment is needed!

The up-to-date results shows that the CLIC structures could perhaps be based on even an existing material without reducing the target parameters.

The material should be from the group of High Conductivity Copper Alloys (Lower conductivity -> Higher Stress).

More attention must be paid on the high cycle surface effects during the Ultrasound experiment. Could be crucial for RF.

The fatigue data for the same materials at different states should be collected, especially at “soft” states.

The High Cycle fatigue behavior at different stress conditions should be tested.

Perform more data for statistics.

Many thanks to:

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Thibaut Lefevre
Harri Hellgren
Keith Richardson
Peter Brown

Prof. Hitoshi Soyama
Prof. Simo-Pekka Hannula