Off-line Tests on Pitting Damage in Mercury Target

M. Futakawa

JAERI

Off-line Tests on Pitting Damage

1) SHPB: Split Hopkinson Pressure Bar

Hopkinson bar impact technique is applied to impose impact pressure on mercury.

Screening tests for various materials including surface hardening treatment.

2) MIMTM: Magnet IMpact Testing Machine

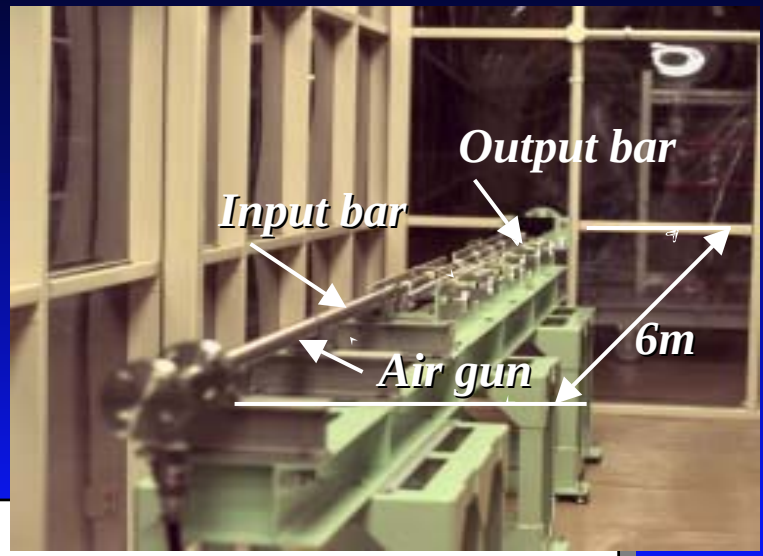
To obtain high cycle data.

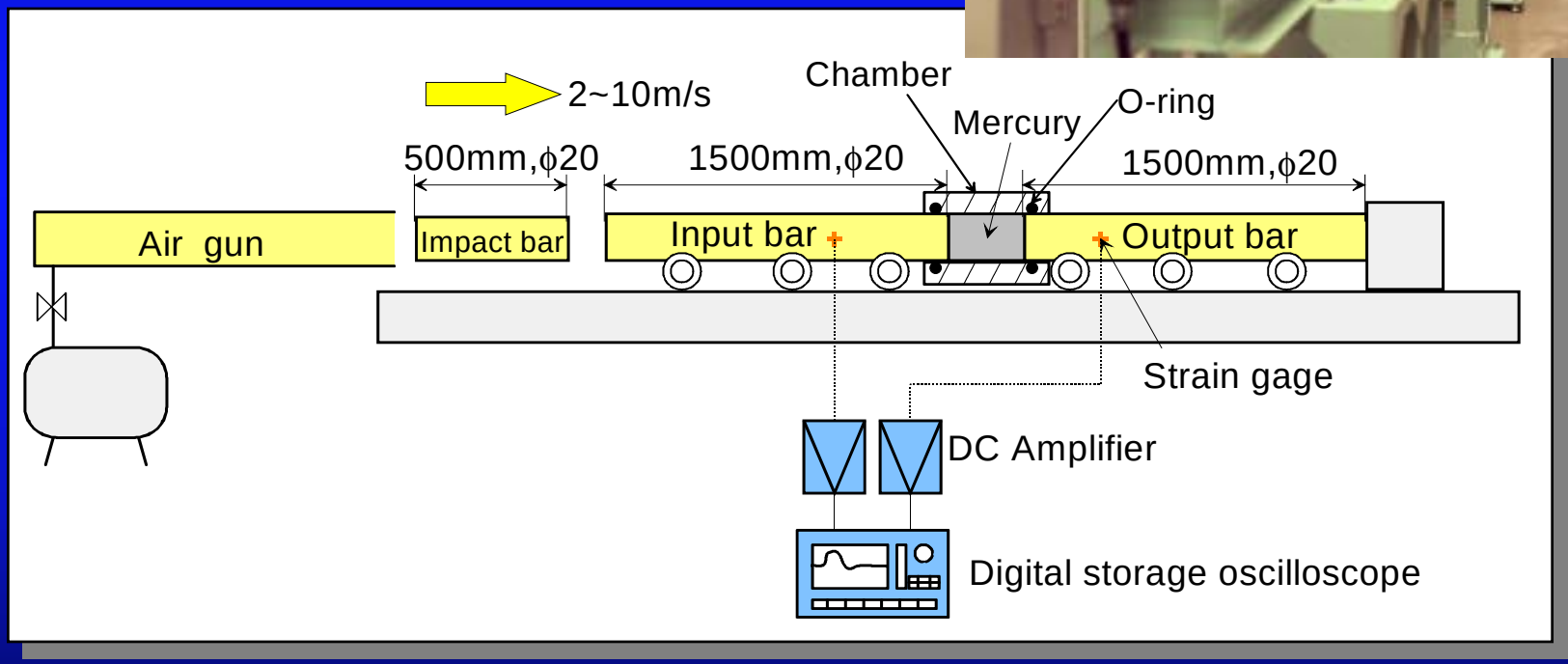
To understand pitting formation.

To estimate MDE (Mean Depth Erosion) up to over 10 million cycles.

SHPB

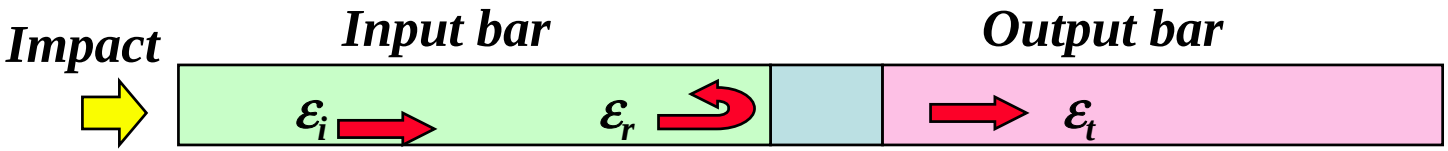
Impact compressive pressure
Max. 150 MPa

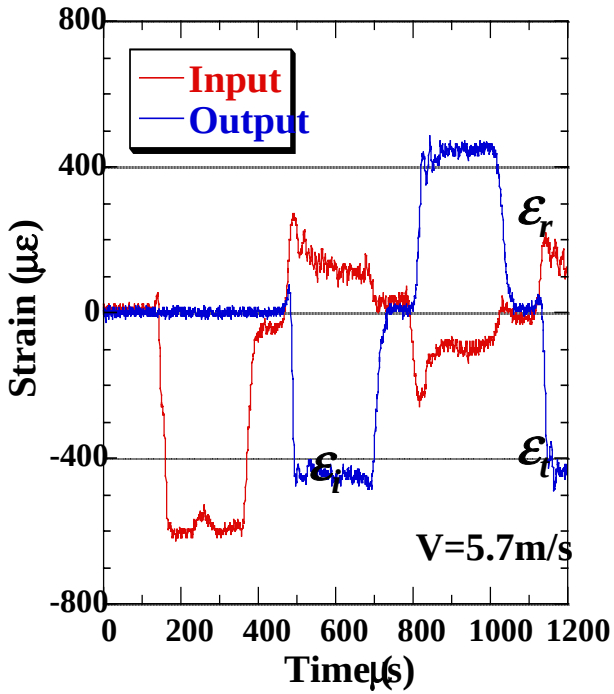




Experimental apparatus for plane-strain incident using Hopkinson bar impact technique

Strain waves & Evaluated pressure





Strain waves

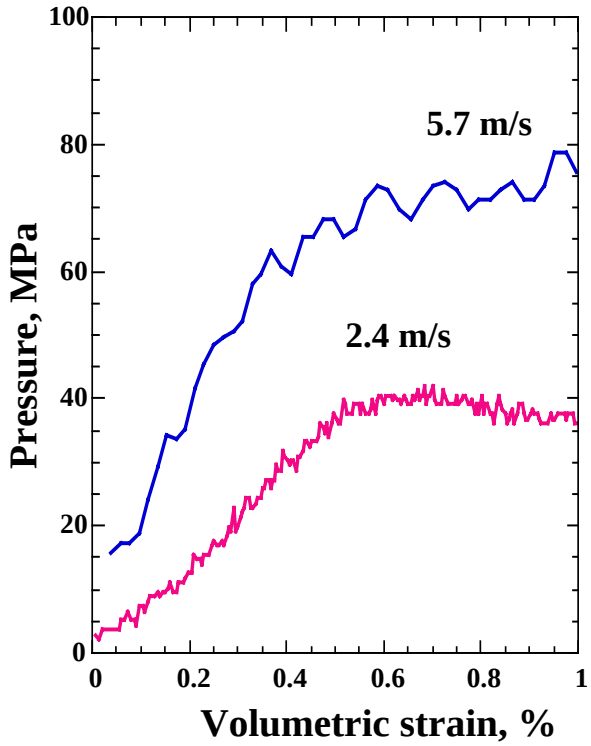
$$\varepsilon(t) = \frac{-2c_0}{L}\int_0^t \varepsilon_r(t')dt'$$

$$\sigma(t) = \frac{EA}{A_s}\varepsilon_t(t)$$

$$\sigma(t) = \frac{EA}{A_s}\varepsilon_t(t)$$

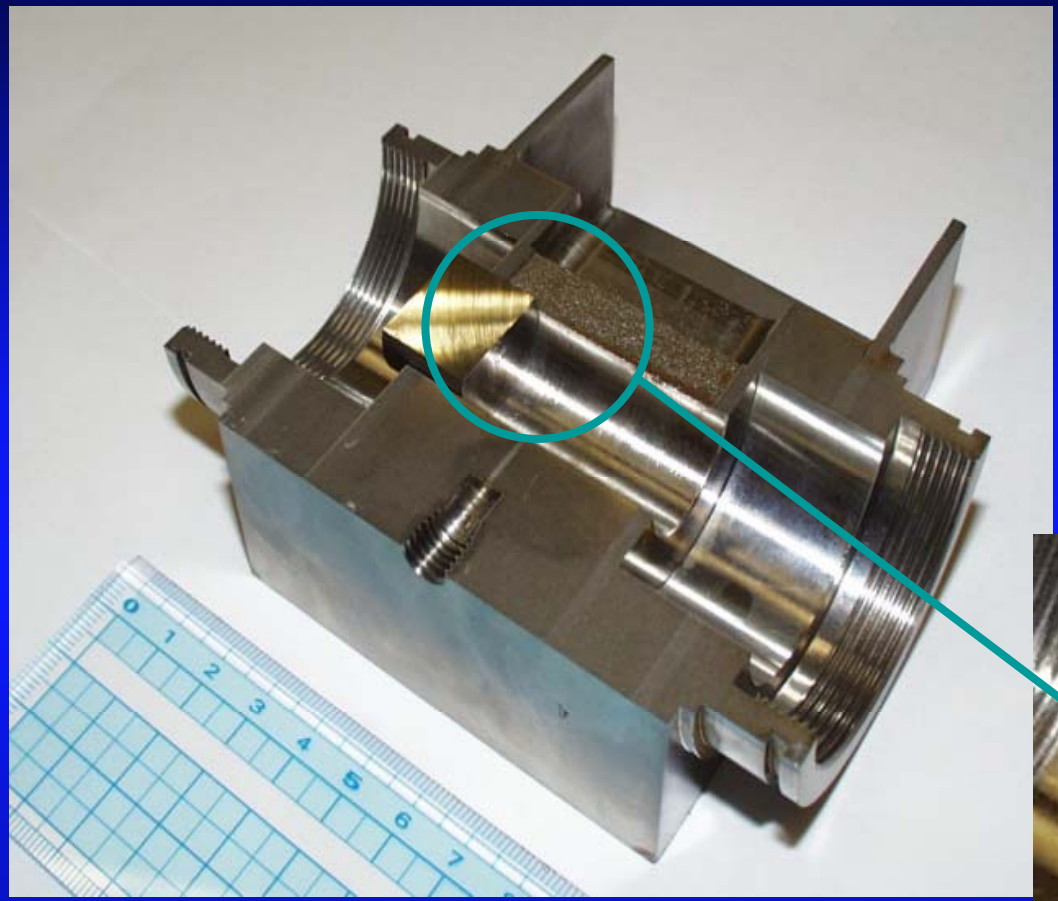
$$\sigma(t) = p(t)$$

A : Cross-sectional area of bars
As: Cross-sectional area of specimen
C_0 : Sound velocity in bars
E : Young's modulus
L : Length of specimen



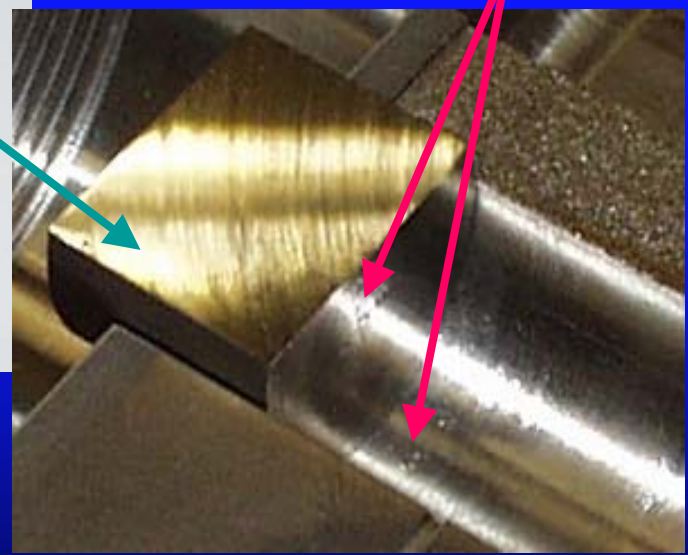
Evaluated pressure

Pits on inside wall of chamber



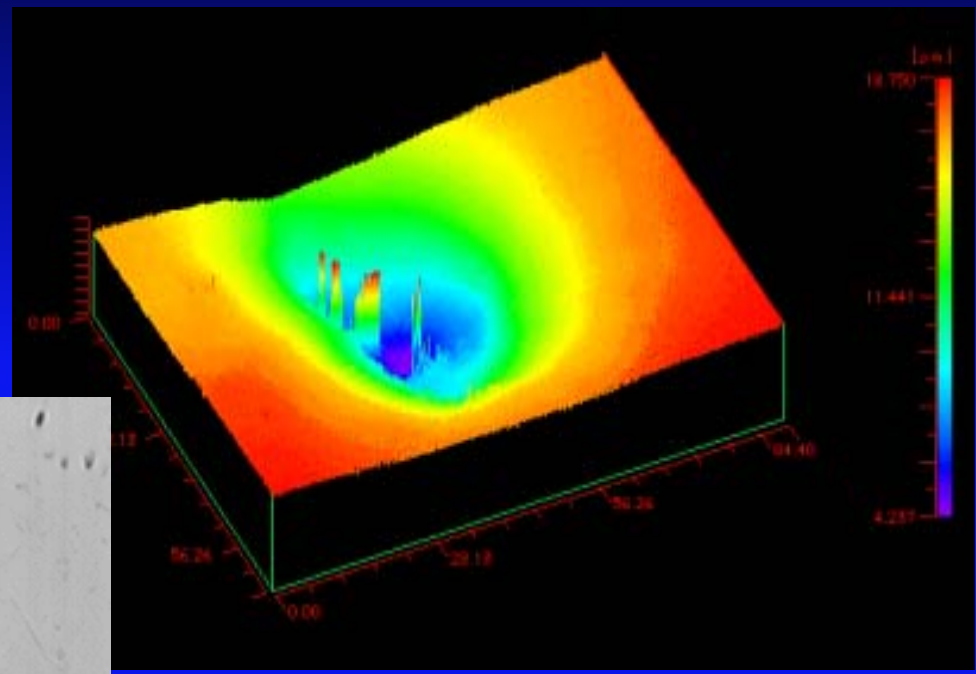
Cross-section of chamber

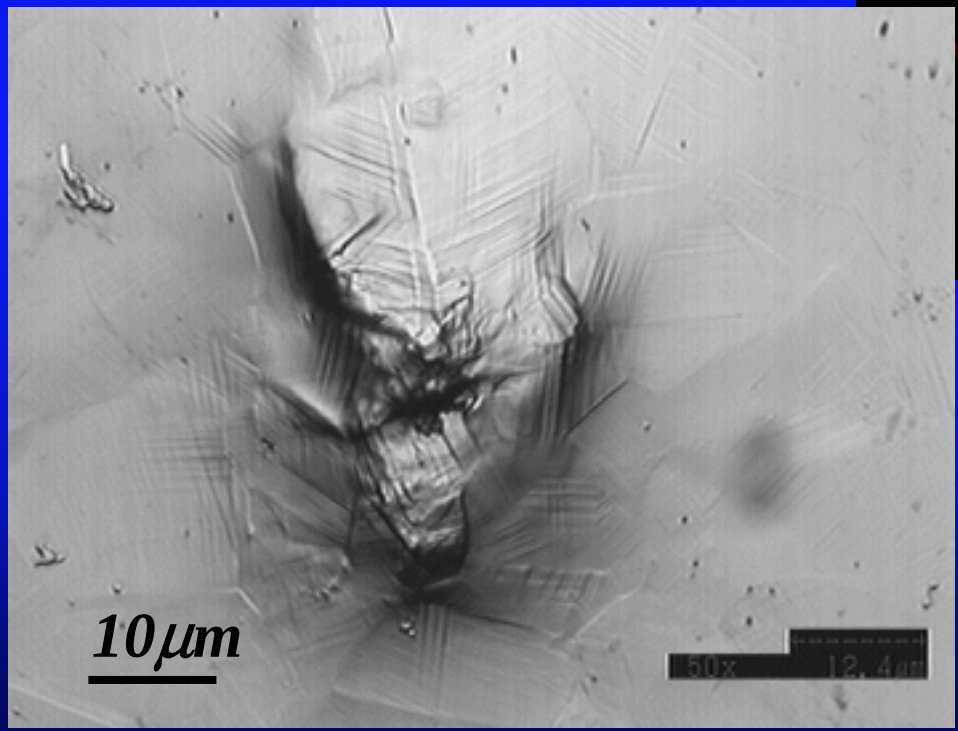
Pits



Many pits were observed on the end of Hopkinson bar and inside wall of chamber after impact tests with 20 MPa to 150 MPa of pressure in Hg.

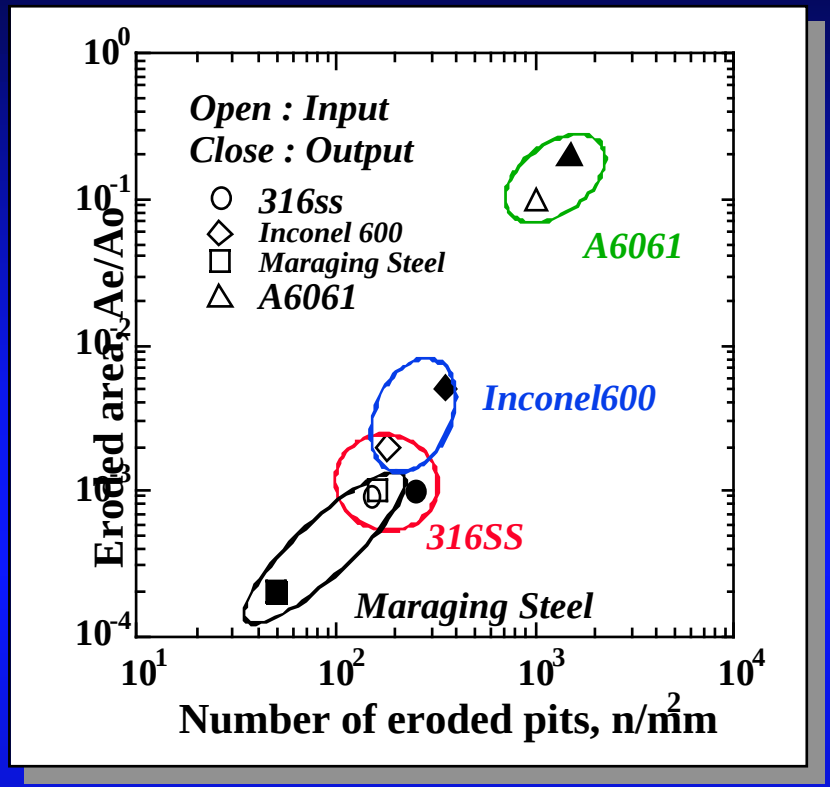
3D Image by Laser Micro Scope





Many Slip Lines Around Pits
Localized pressure beyond yield stress

Impact erosion damage related with hardness



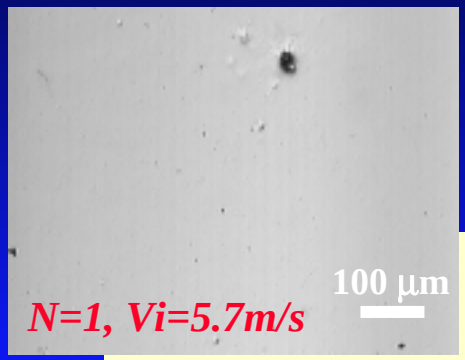
Order of damage

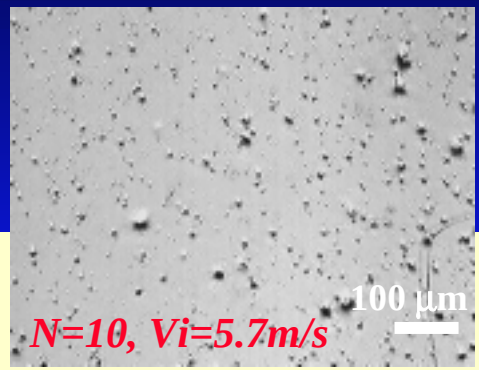
A6061>Inc.600

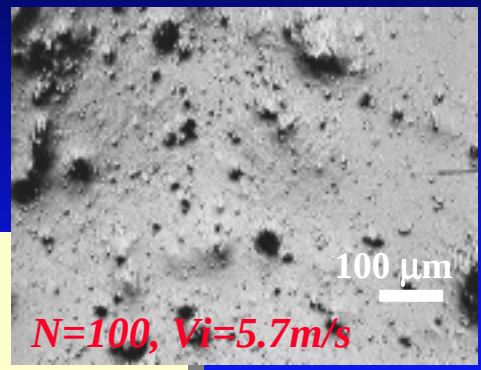
≈316SS>M. S.

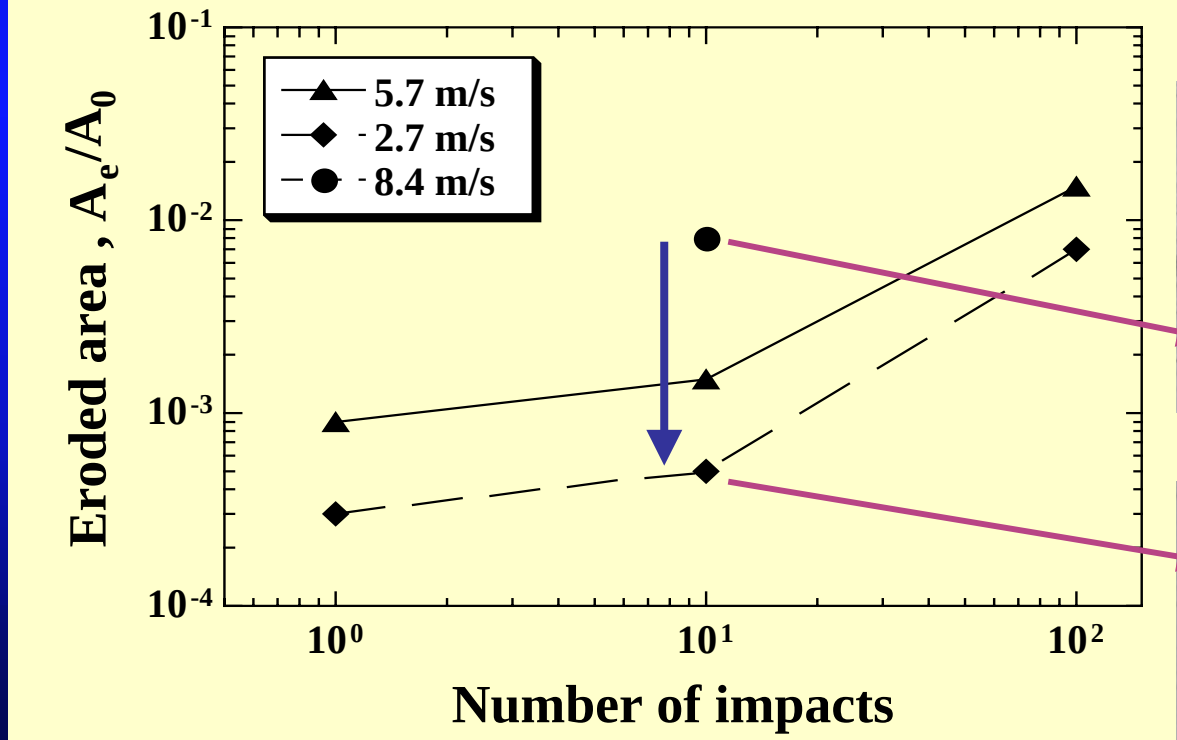
	316SS	A6061	Inconel 600	Maraging steel
Hv(MPa)	211	129	215	310
Yield stress (MPa)	204	283	356	1910

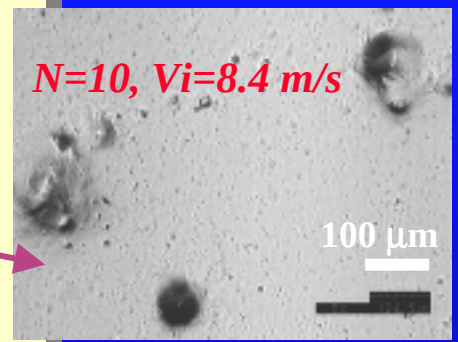
Impact number and velocity dependency

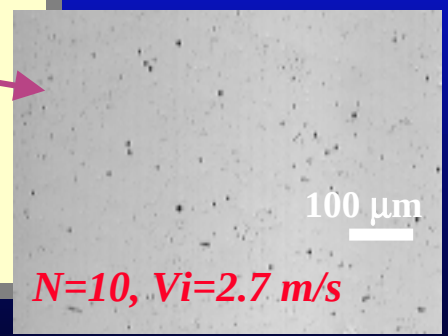




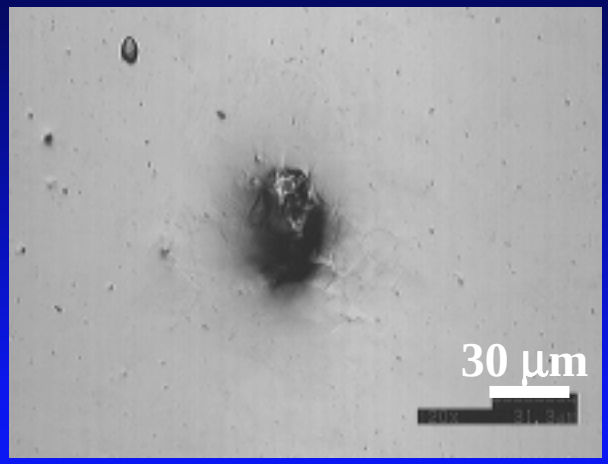


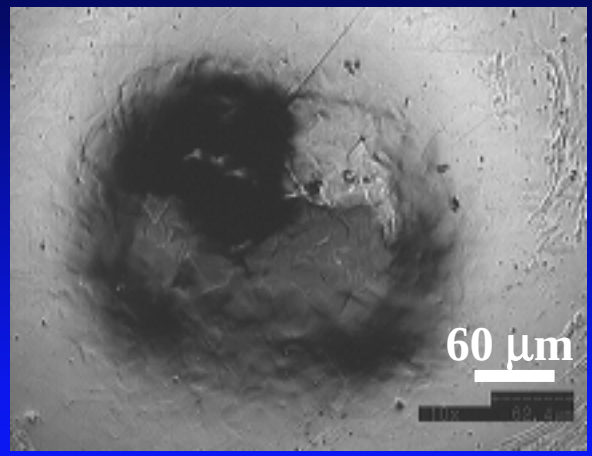


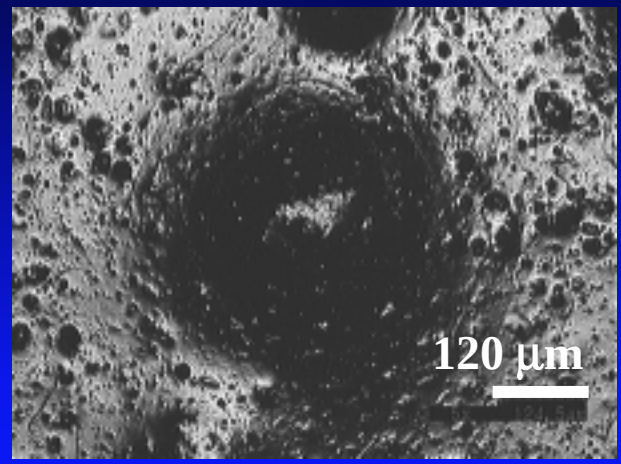


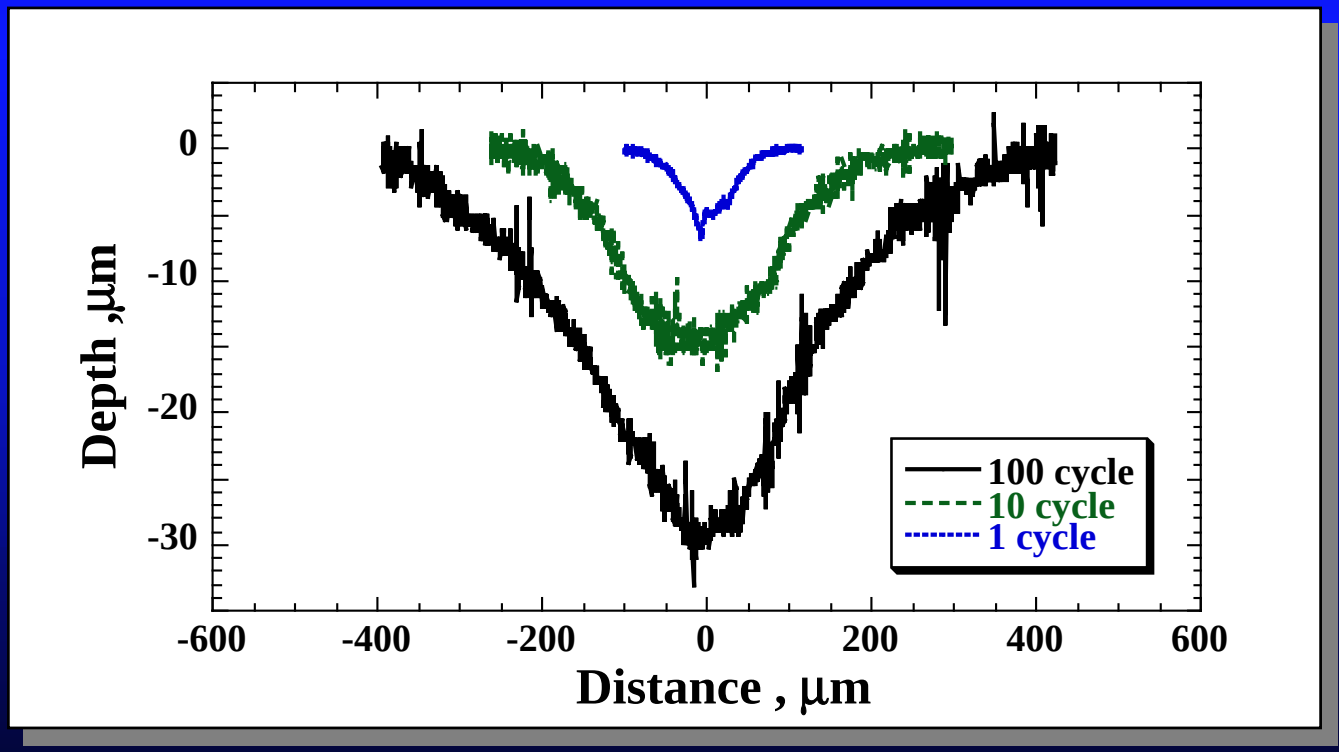


Depth profiles at 1, 10 and 100 impacts





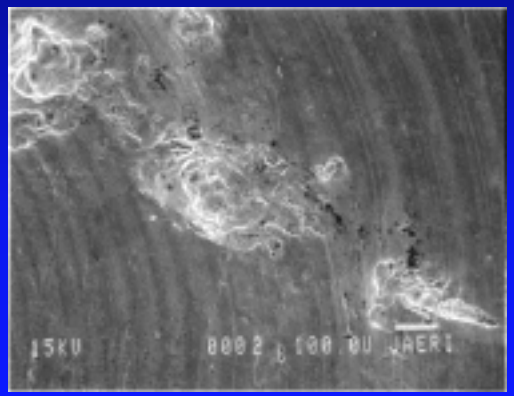




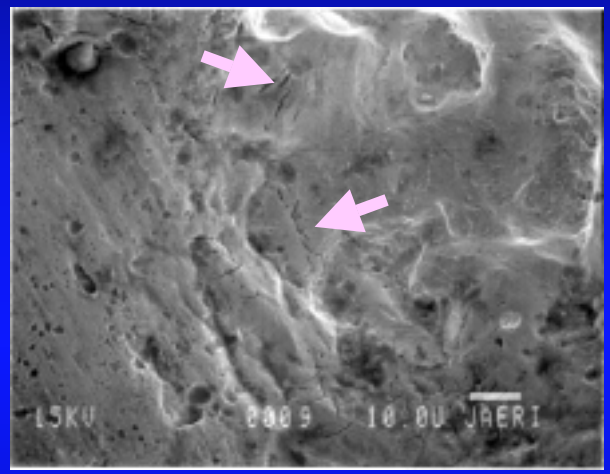
Impact velocity
5.7 m/s

Max. depth
ca 30 μm
after 100 cycles

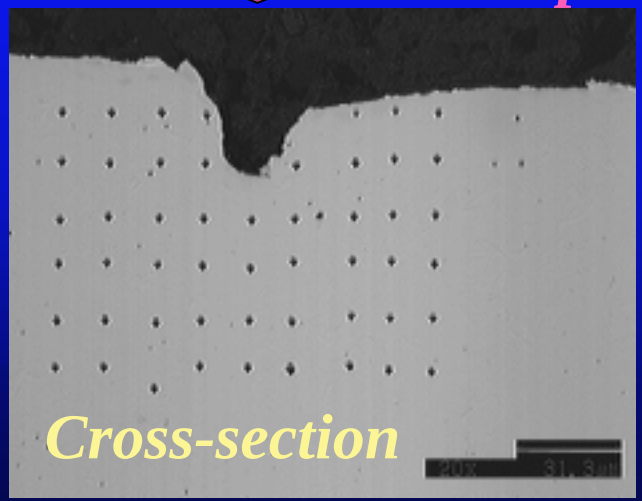
How do pits grow up to millions ?



Erosion



Isolate pit



Surface is peeled, how much ?

Depth after 10 million cycles?

20 MPa to 150 MPa of compressive pressure were imposed into Hg by SHPB.

M I M T M

Magnetic IMpact Testing Machine

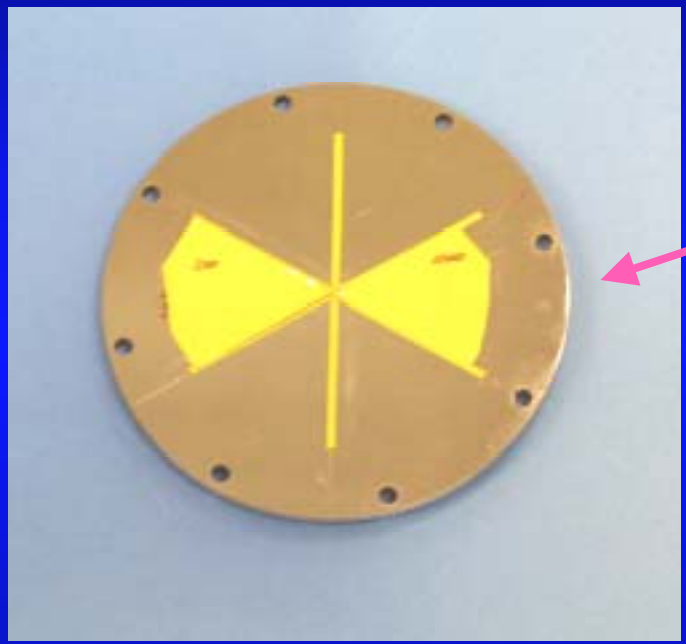
10 million cycles impact erosion testing machine to estimate high cycle pitting damage up to 10 million

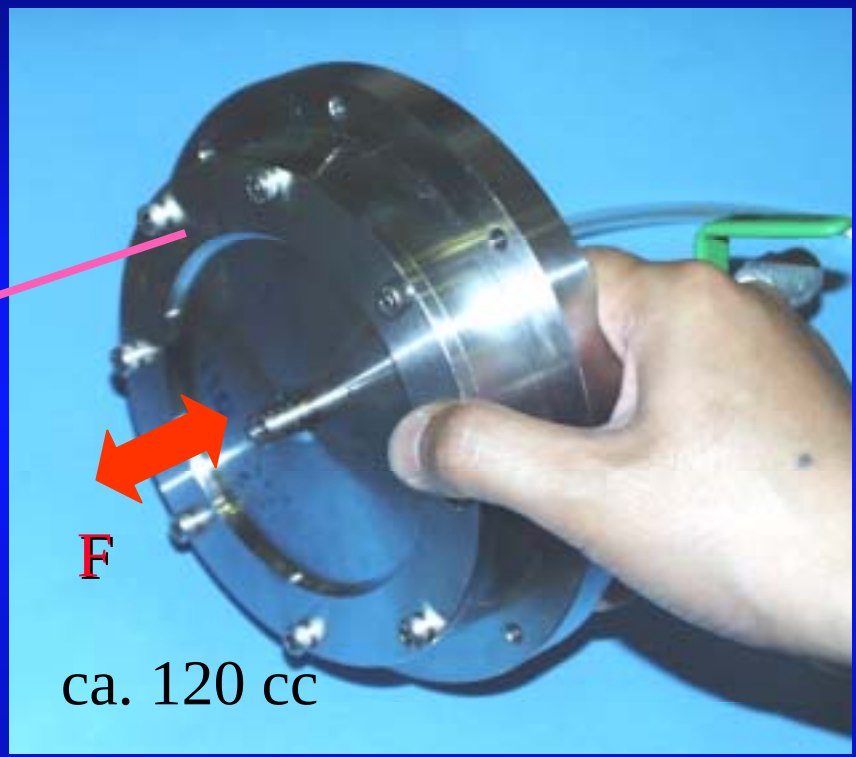
Driving force : Electric magnet force
Max. force : ca 400 kgf
Max. acc. : ca 200 G

Rising rate : ca 1G/μs
Frequency of cycles : max. 20 Hz

MIMTM

Test section with disk specimen



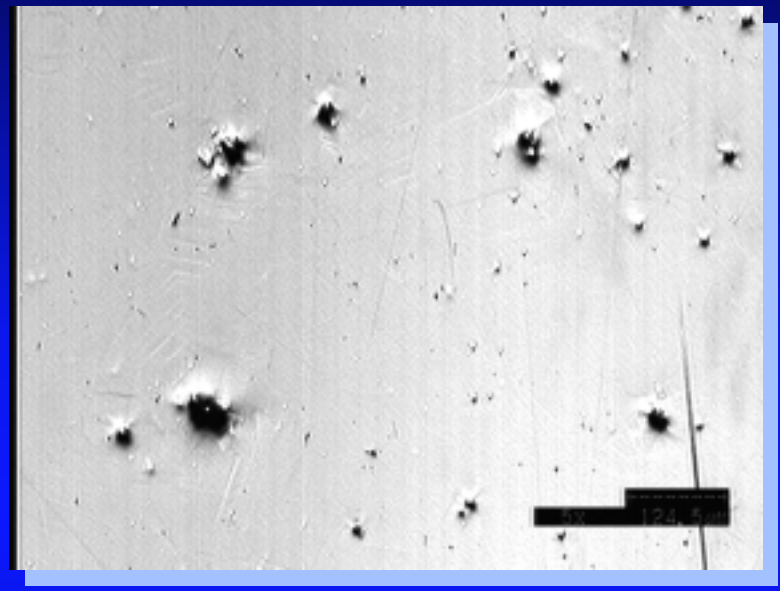


Controlled wave shape : Triangle, Rectangle (Ten.-Com.)
Holding time : 0 -2 ms

Similar morphology of pits in MIMTM as those in WNR

MIMTM

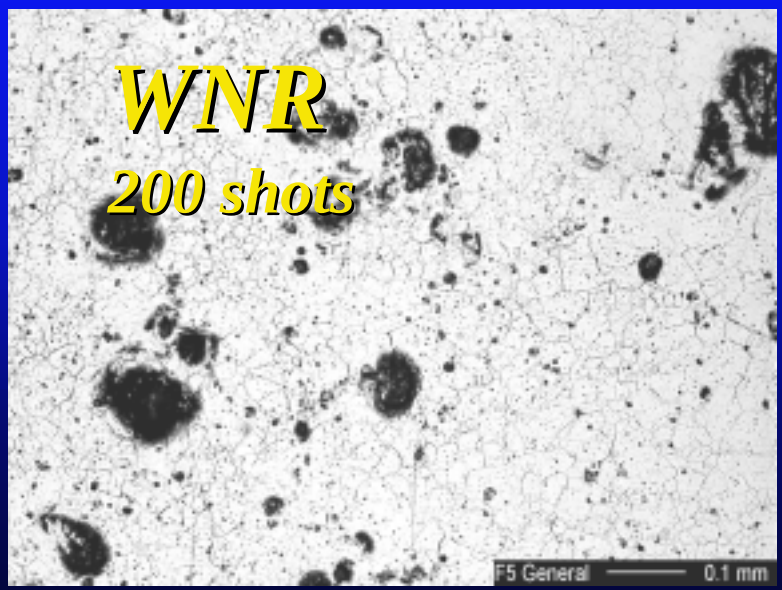
200 cycles

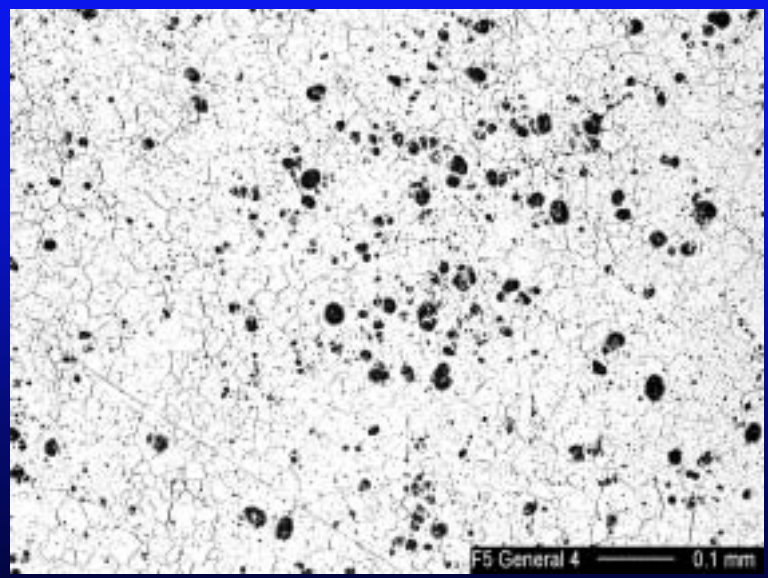


100 μm

WNR

200 shots



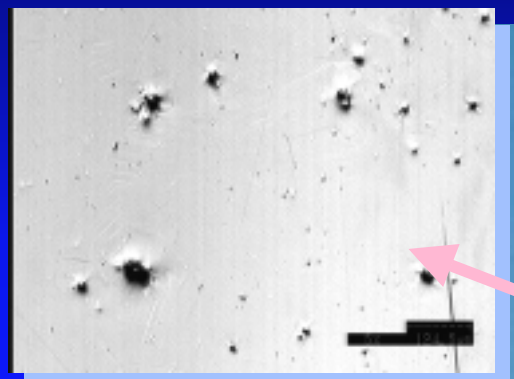


MIMTM

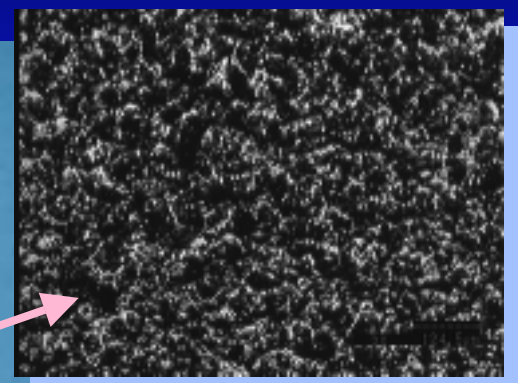
Plate specimen

Pitting degradation
up to 10 million cycles

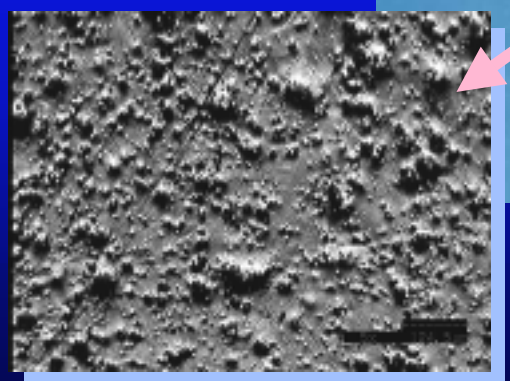
E7



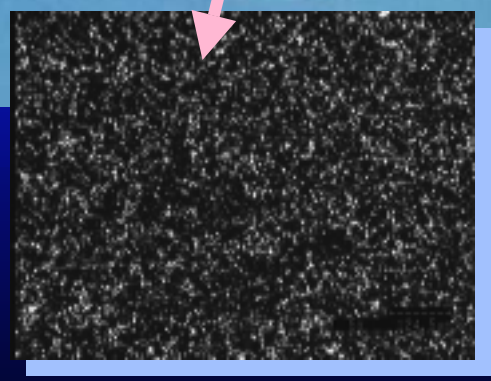
200



E5

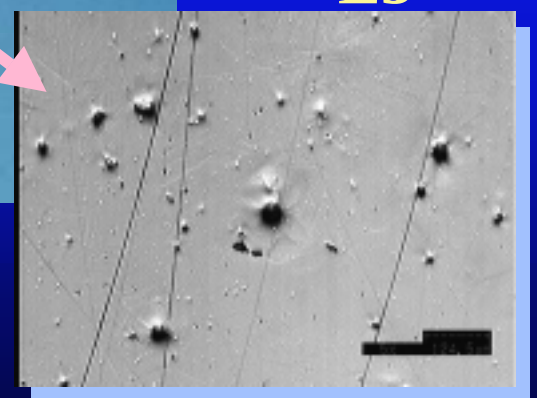


E4



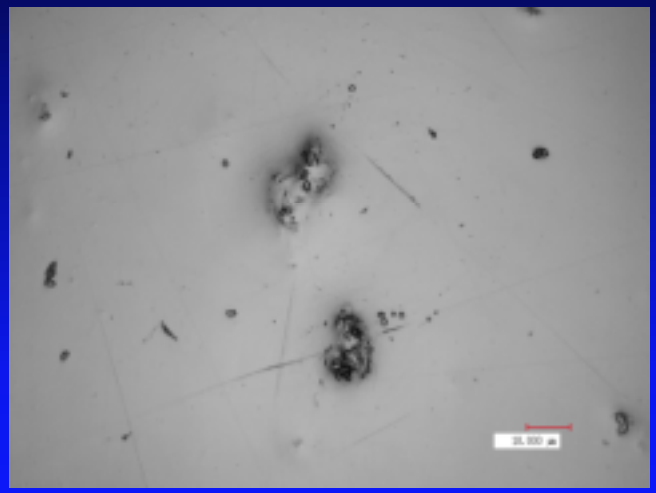
E6

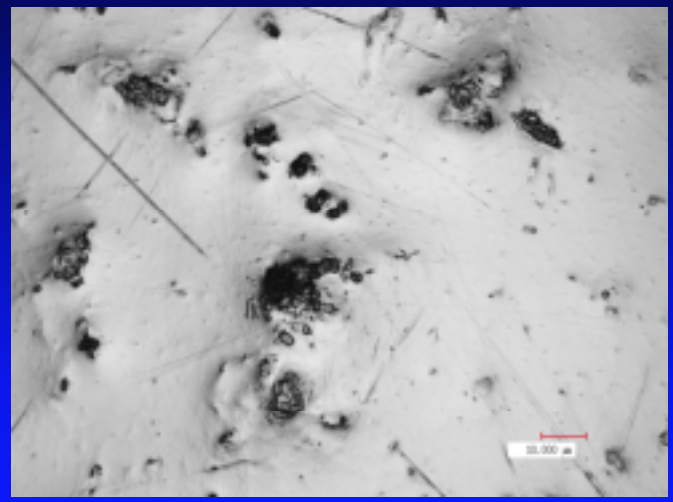
E3

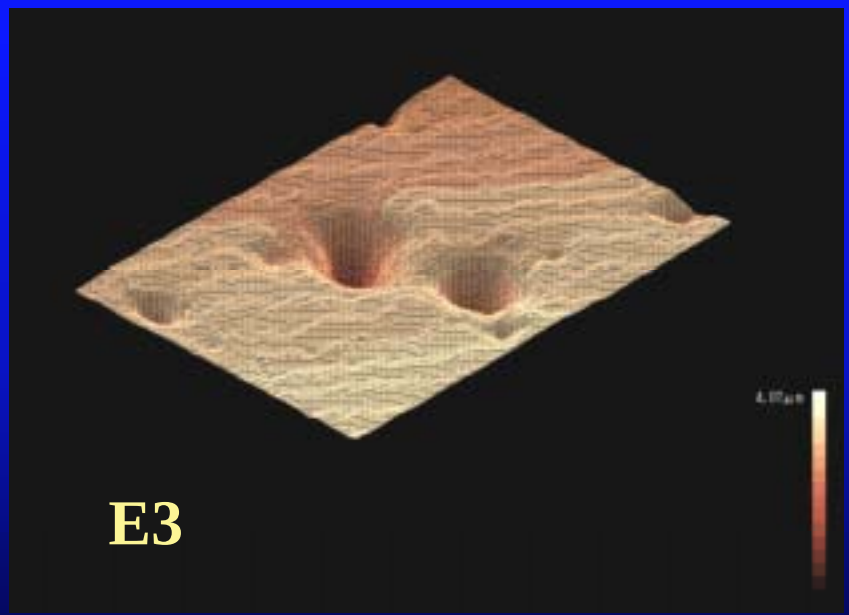


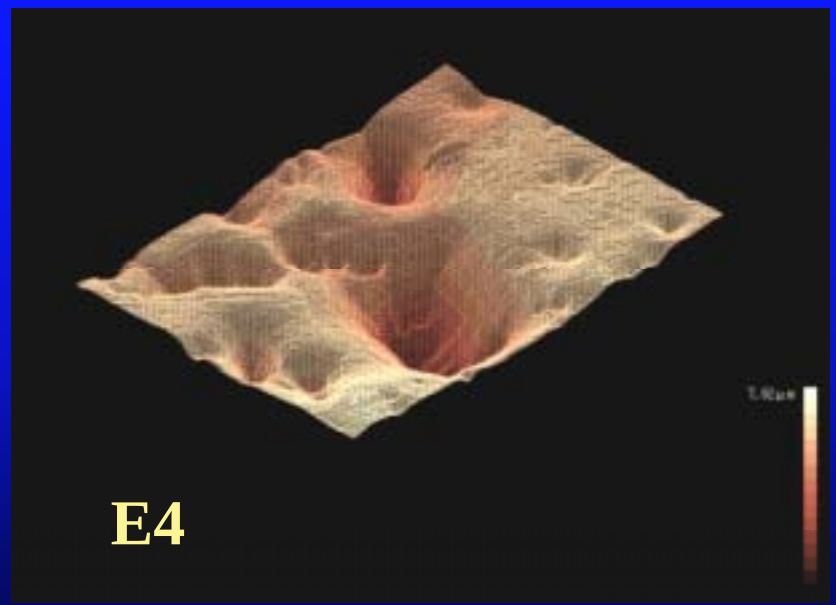
100µm

Pit formation (Phase 1: <1E4)



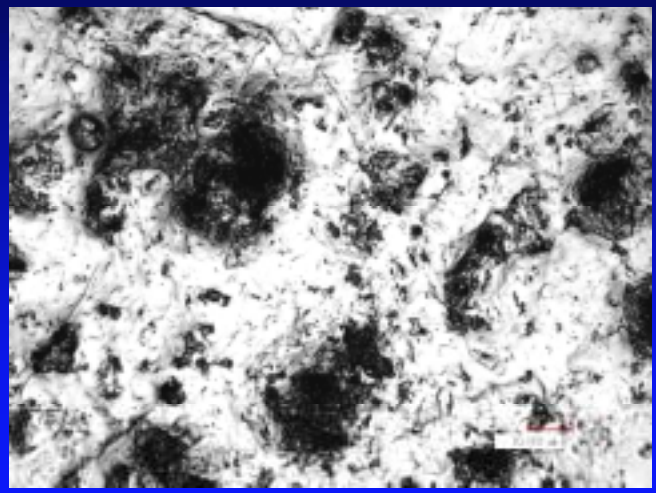


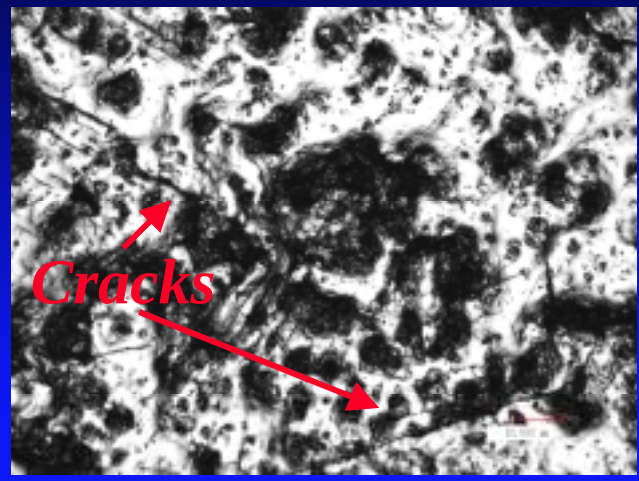


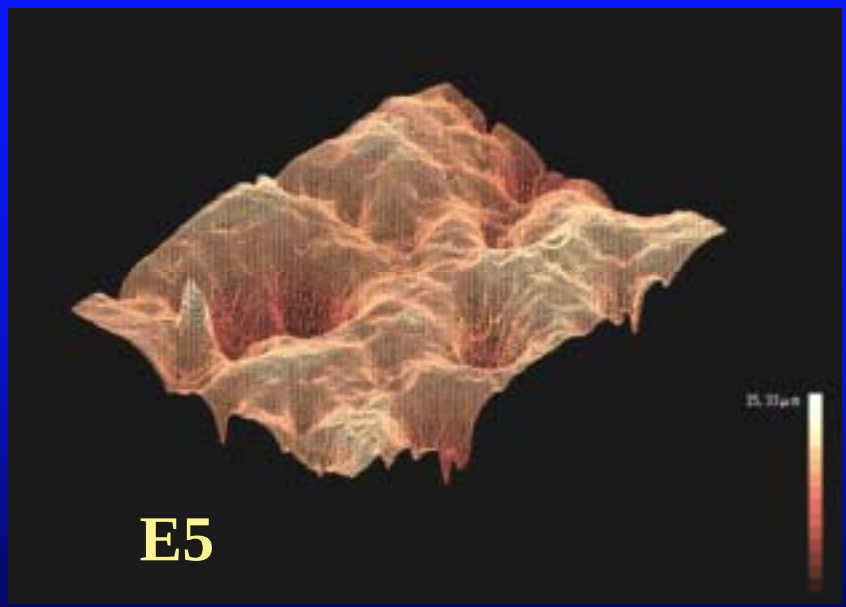


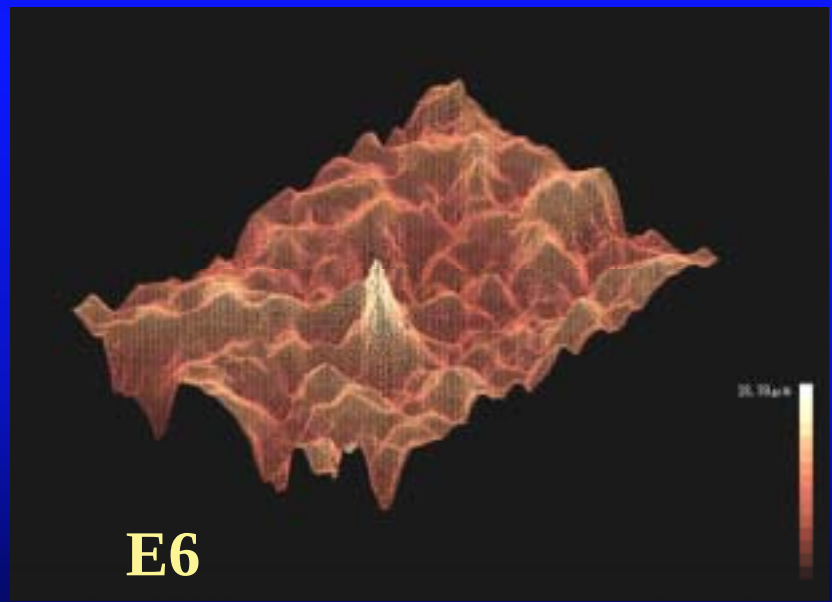
Plastic deformation is induced by shock waves and microjet hitting against surface. Individual isolate pits are formed.

Pit formation (Phase 2 : 1E5 to 1E6)



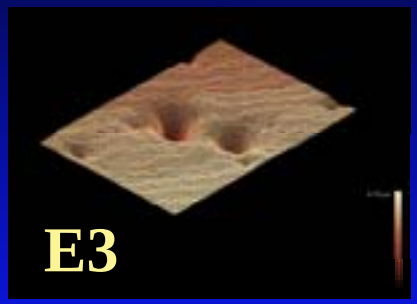


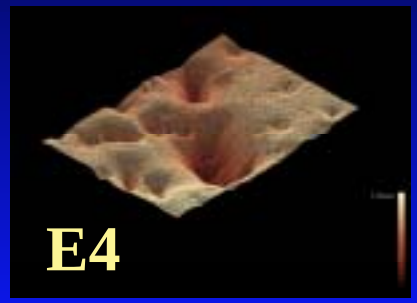


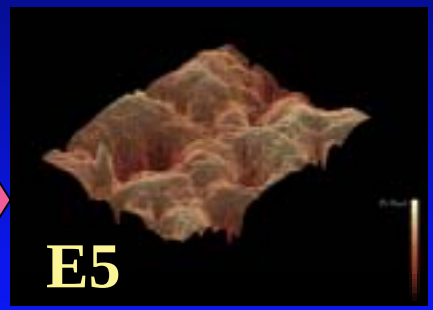


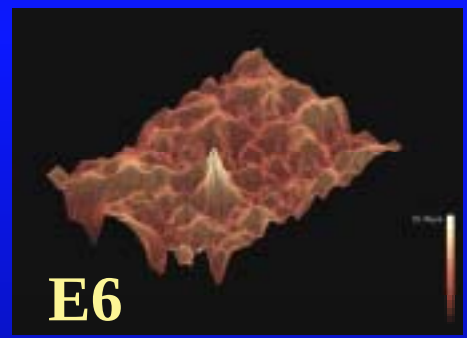
Isolate pits are combined or overlapped by cyclic bubble collapse that cases a sort of fatigue damage.

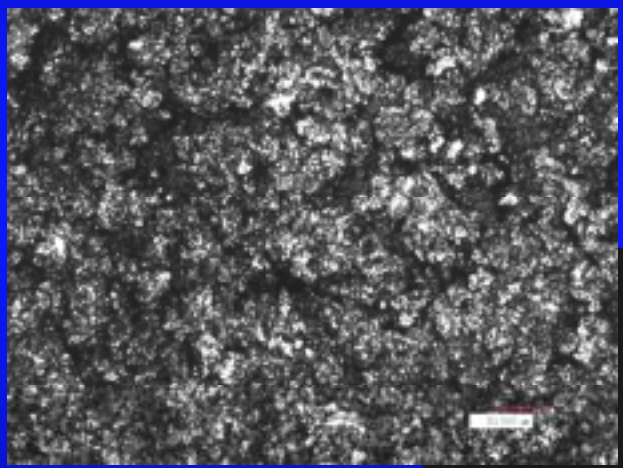
Pit formation (Phase 3 : 1E6 to 1E7)

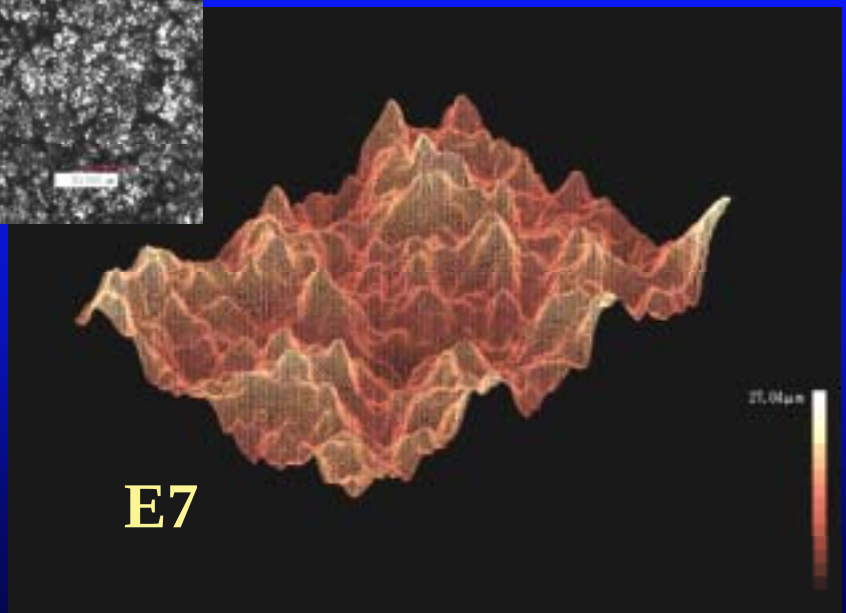












Localized damage ? Inhomogeneous erosion

Mass loss starts by homogeneous erosion with fatigue damage.

Button specimen

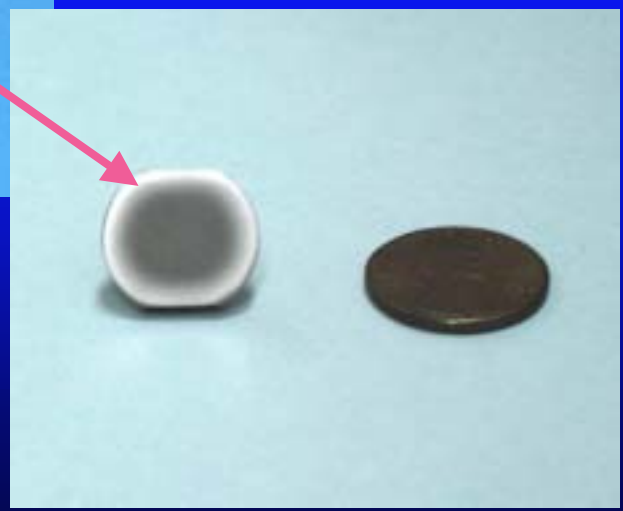
Pitting in high cycles

> 10 milliom

Surface hardening

316ssCW

Kolsterising



Weight loss

Micro-balance

Morphology characterization

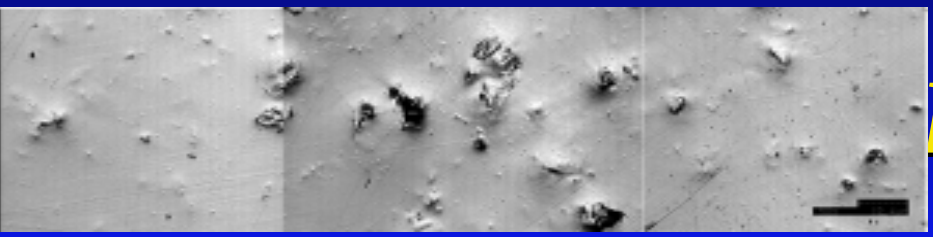
SEM, LM

Pitting damage in 316ssCW & Kolst.

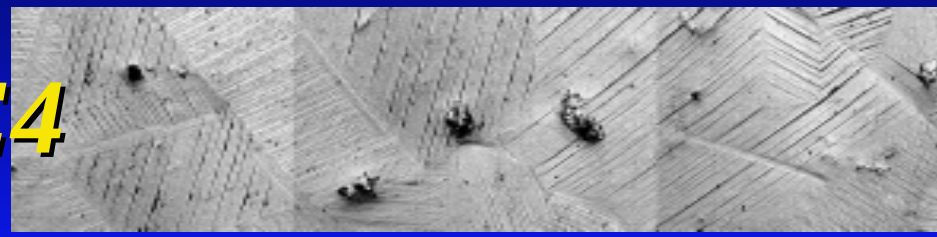
316ssCW

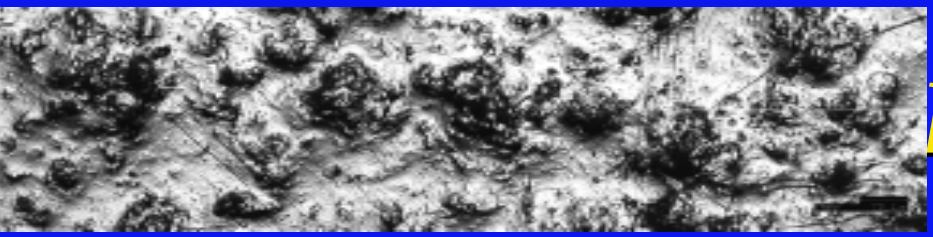
Kolsterising

25µm

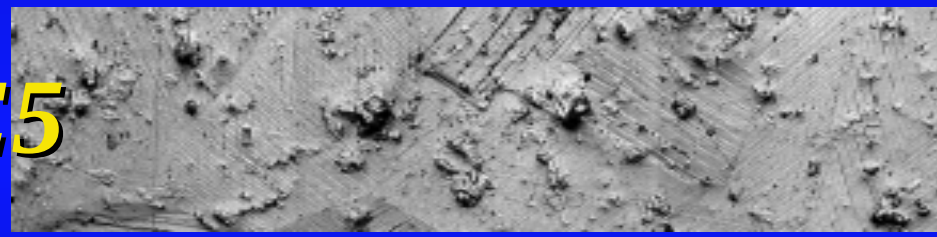


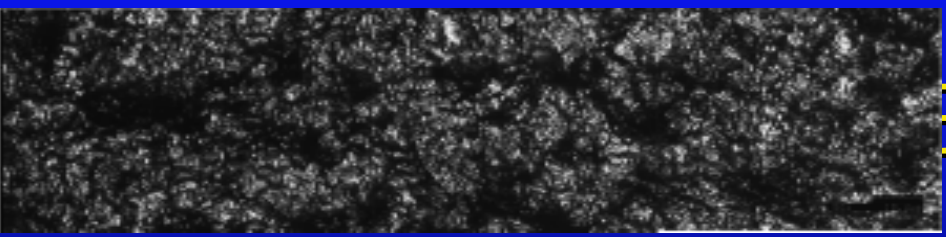
E4



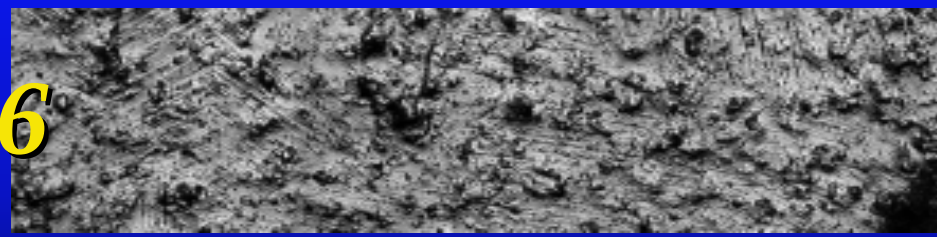


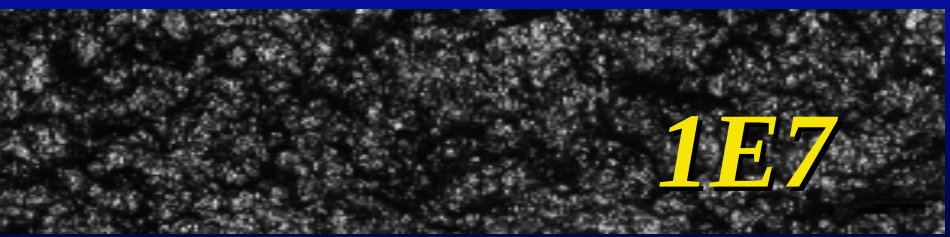
E5



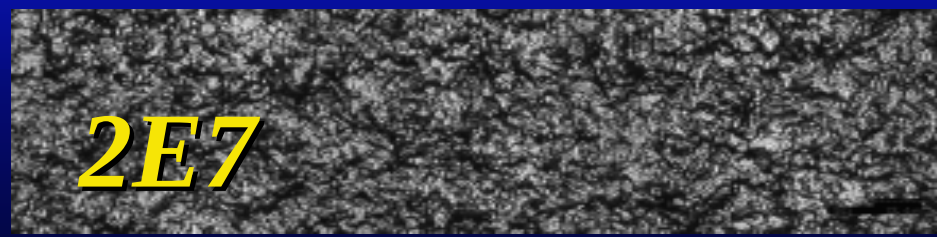


E6





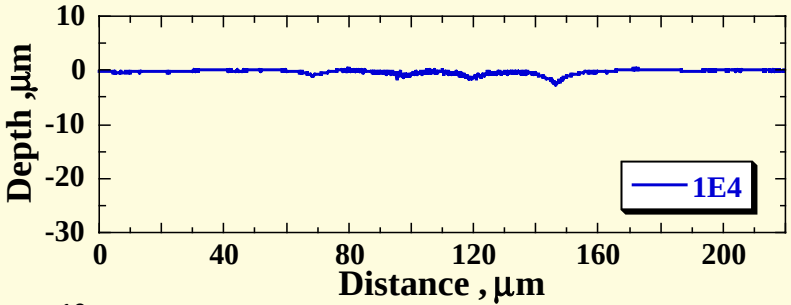
1E7

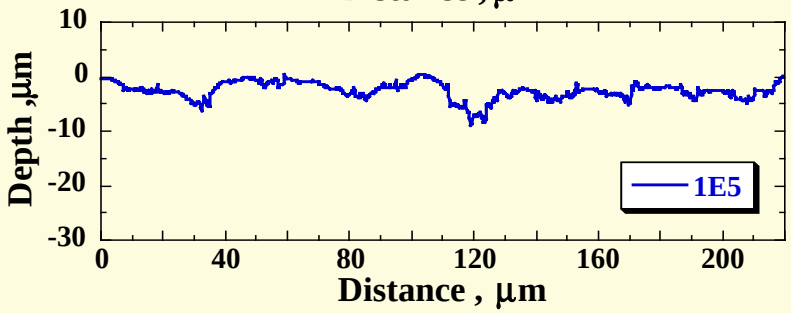


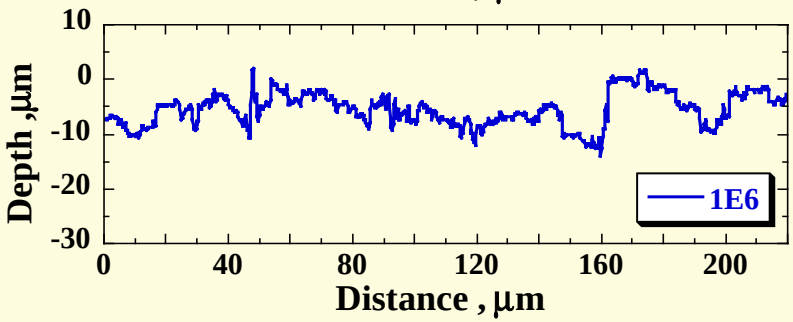
2E7

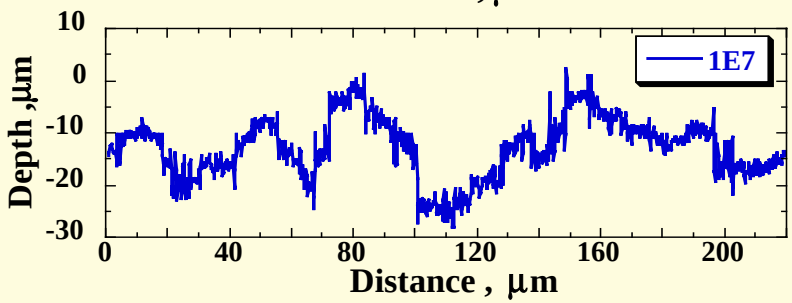
Roughness measurement

316ssCW

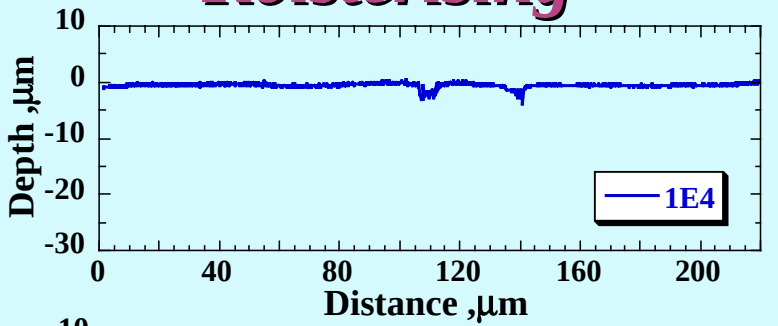


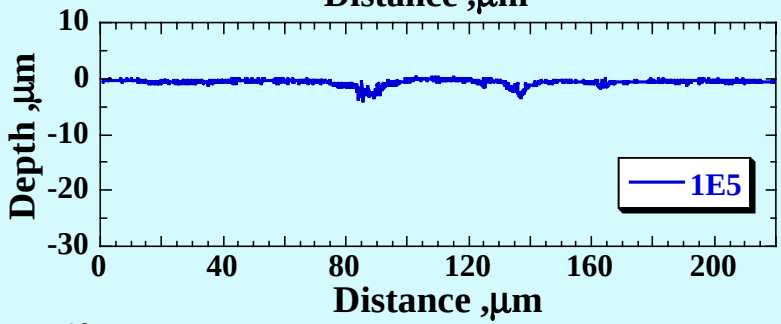


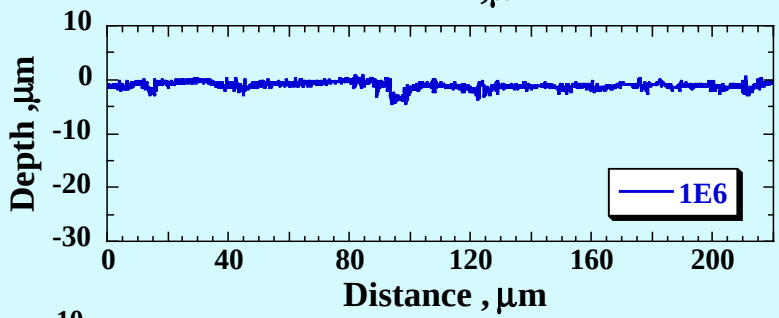


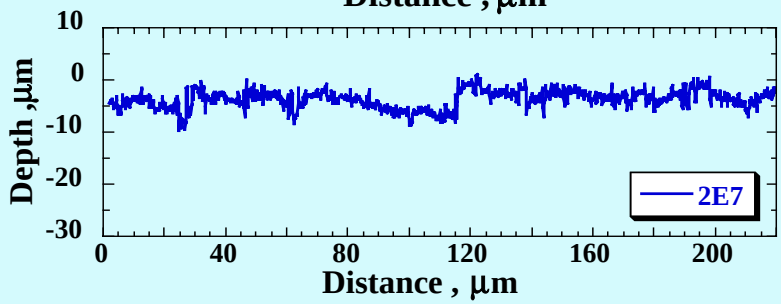


Kolsterising

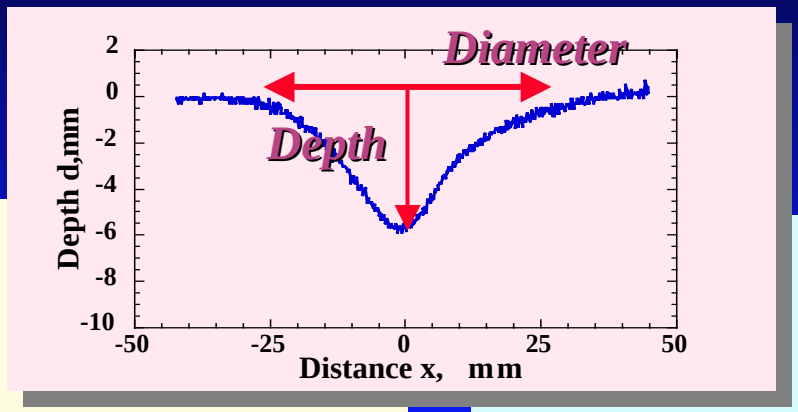




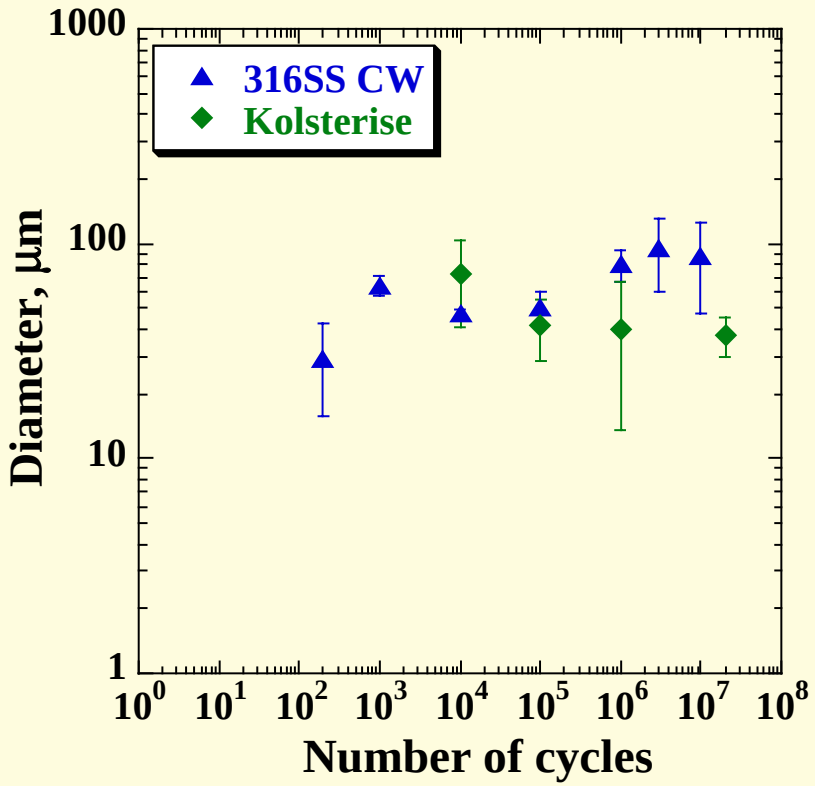




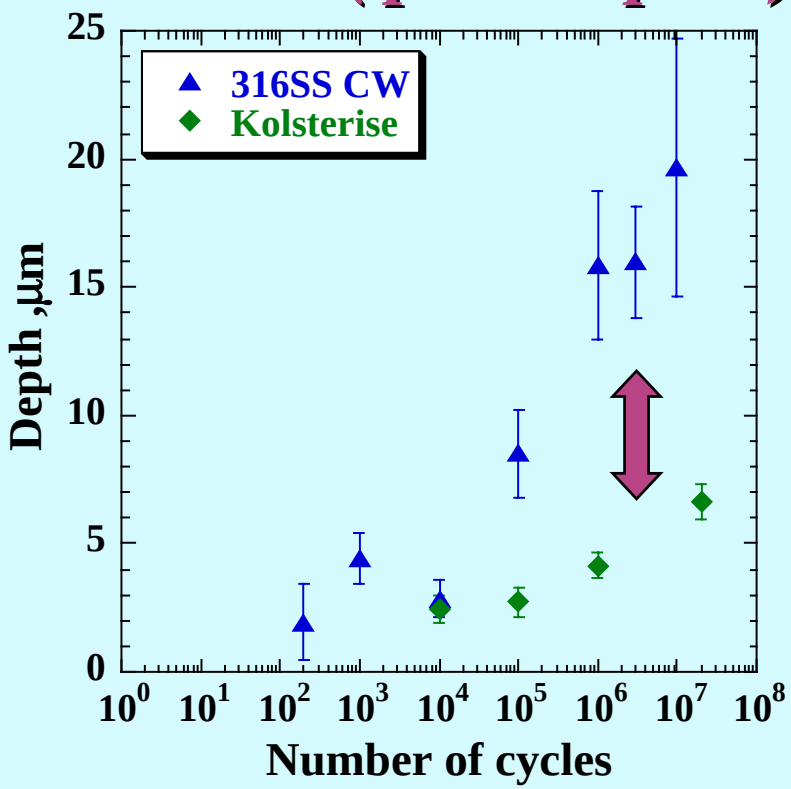
Characterization of pit morphology



Diameter

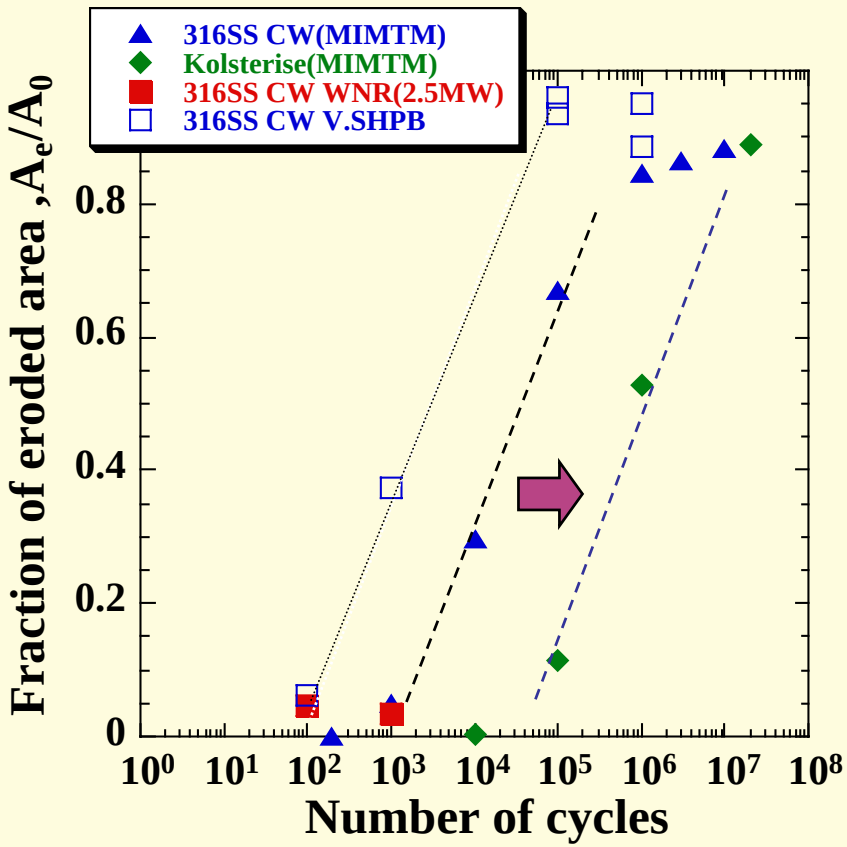


Depth (peak to peak)

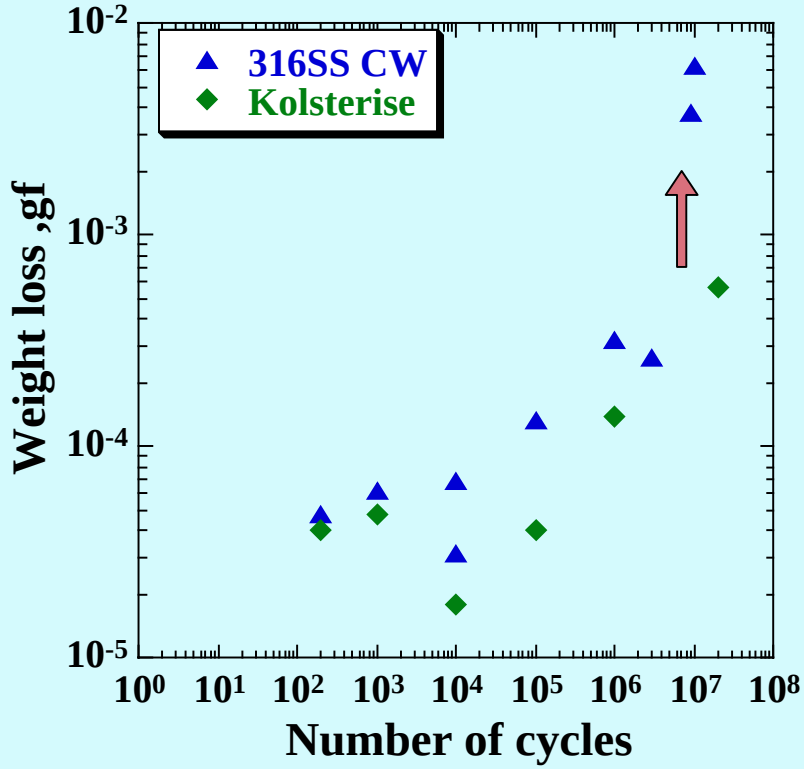


Fraction of eroded area & weight loss

Eroded area

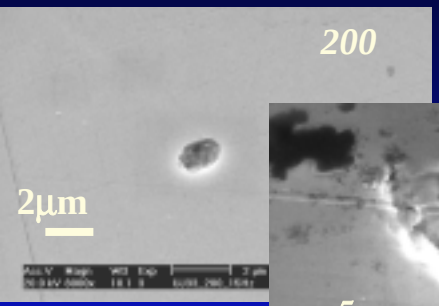


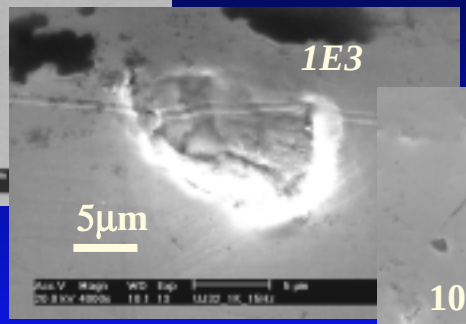
Weight loss

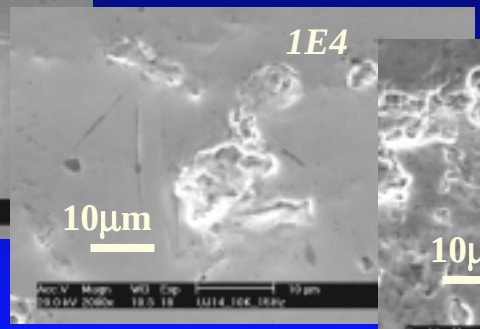


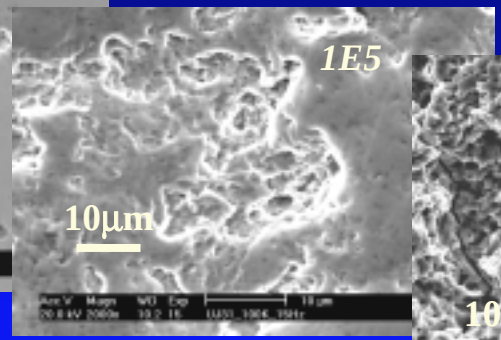
Kolsterising is expected to reduce pitting damage.

SEM micrograph & weight loss

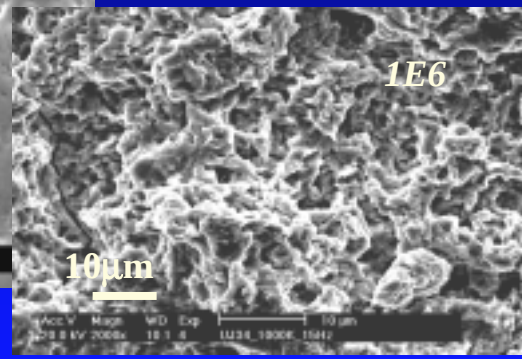




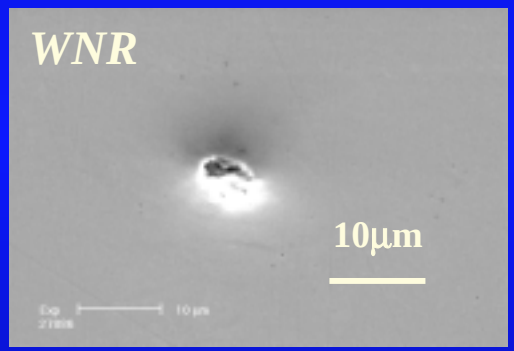


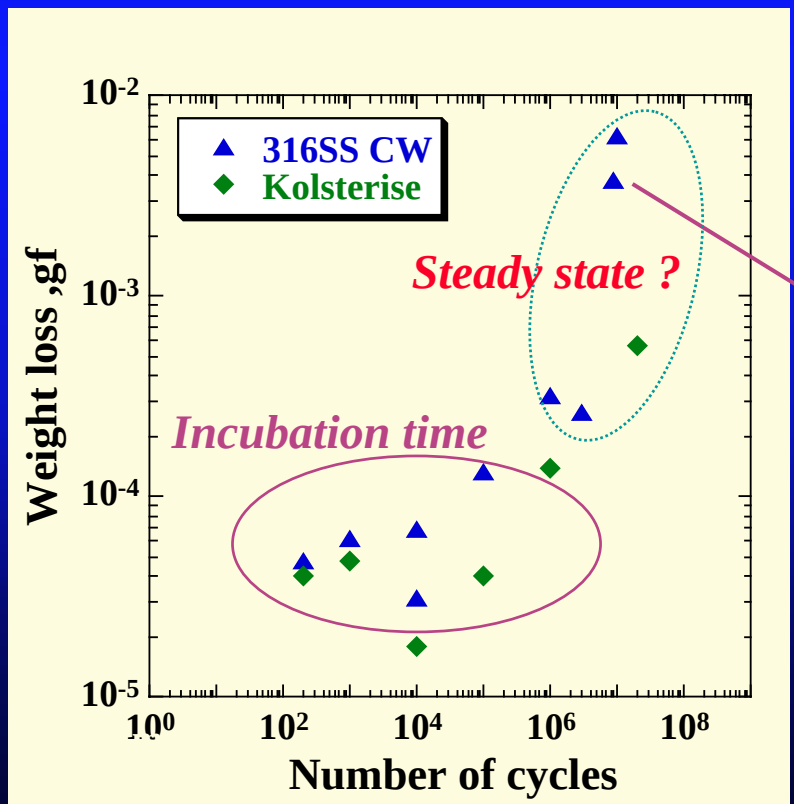


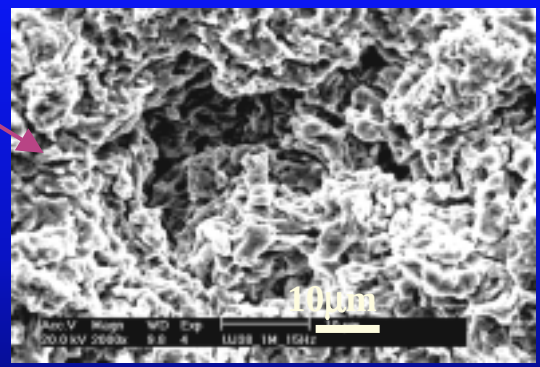
316ss CW



Homogeneous erosion

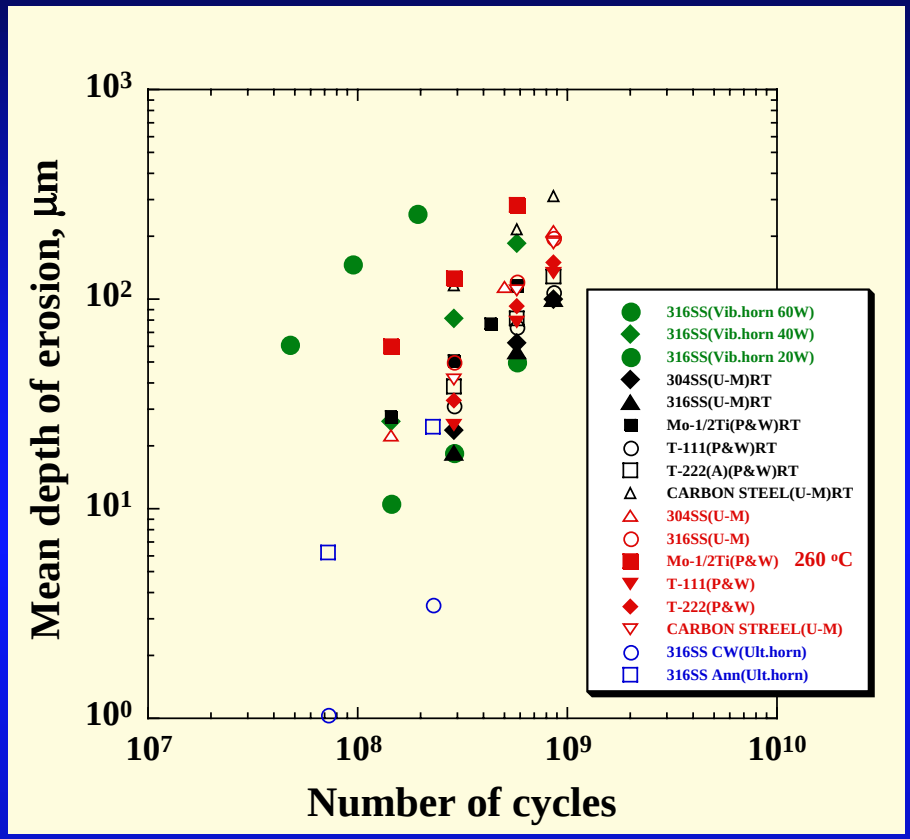


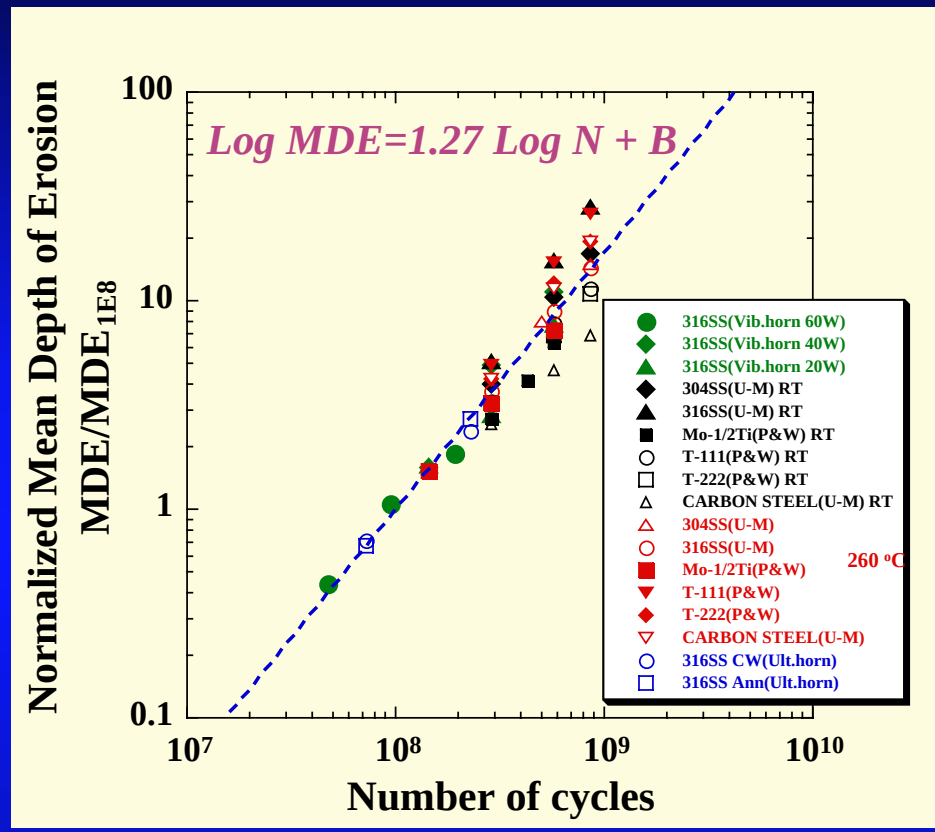




Tiny hole

What can we learn from classical vibra. horn data ?





11 kinds of materials and various conditions

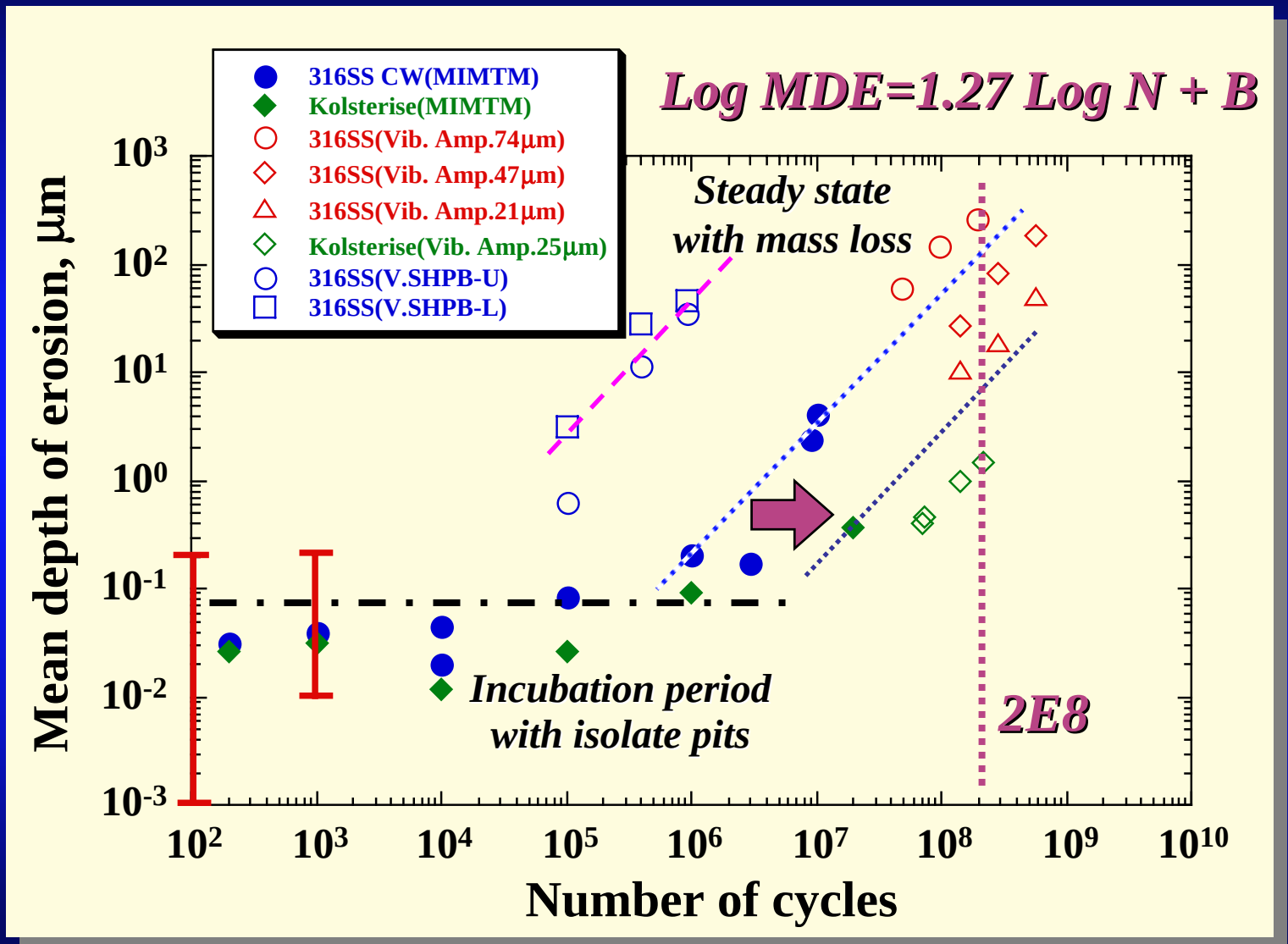
Data by Hammitt, et al.+ M.D.Kass+ S.Pawel

As normalized by MDE at 1E8 cycles of sine wave vib. of 20 kHz,

$$\textit{Log MDE} = A \textit{ Log } N + B$$

A=1.27 for mercury, B= f (materials, temp.,pressure , etc.)

Extrapolation of MDE to 1E9



Kolsterising can expand incubation period .

Conclusion & Remarks

1) *In the results of 3166ss by the MIMTM , the pitting damage formation up to 10 million is divided into some phases: Phase 1, isolate individual pits are formed up to 1E4 cycles; Phase 2, pits are combined and overlapped and fraction of eroded area gets to be nearly 1 between 1E5 and 1E6 cycles, and; Phase 3, homogeneous erosion with mass loss starts between 1E6 and 1E7 cycles.*
2) *Hardening surface treatment is efficient to reduce pitting damage. Kolsterising specimens show less erosion and weight loss. Kolserlising has obvious pitting damage only at cycles above 1 million.*
3) *Future needs:*

   Residual strength after imposed with pitting damage. Fatigue.
   Frequency effect for pitting damage. Hg flowing effect.
   Irradiation effect on hardening treatment.
   On beam tests.