IOWA STATE UNIVERSITY

Center for Nondestructive Evaluation

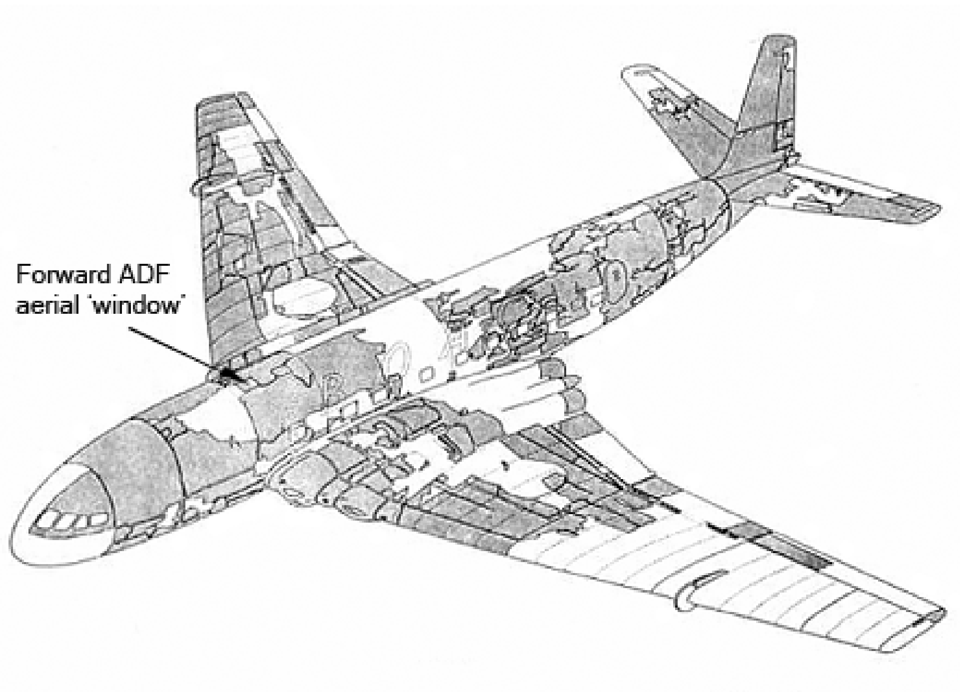
Zerstörungsfreie Charakterisierung der Degradation von Werkstoffen und Bauteilen im Einsatz

Nach wie vor eine Herausforderung für konventionelle und moderne Werkstoffe zur Anwendung im Leichtbau

Norbert Meyendorf

de Havilland Comet
BOAC Flight 781 and South African Airways Flight 201

Two de Havilland Comet passenger jets broke up in mid-air and crashed within a few months of each other in 1954. As a result, systematic tests were conducted on a fuselage immersed and pressurized in a water tank. After the equivalent of 3,000 flights investigators at the Royal Aircraft Establishment (RAE) were able to conclude that the crash had been due to **failure of the pressure cabin at the forward Automatic Direction Finder window in the roof**. This 'window' was in fact one of two apertures for the aerials of an electronic navigation system in which opaque fiberglass panels took the place of the window 'glass'**. The failure was a result of metal fatigue caused by the repeated pressurization and de-pressurization of the aircraft cabin.**



Damage Airbus Cracks

Airbus orders more frequent A380 wing inspections due to fatigue checks

Europe's Airbus (AIR.PA) has ordered more frequent inspections of the wings of the world's largest passenger jet after discovering unexpected levels of metal fatigue during testing on an A380 factory mock-up, industry sources said on Thursday.

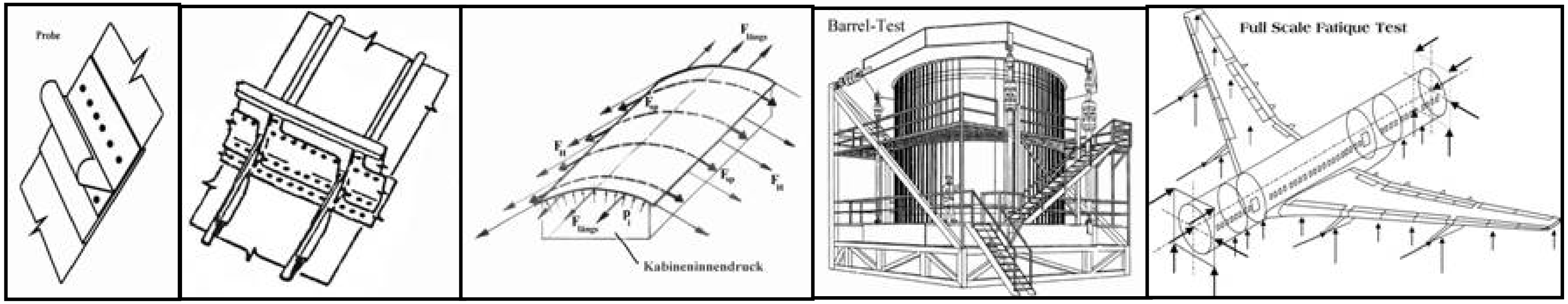
http://www.reuters.com/article/us-airbus-group-a-idUSBREA252DE20140306
Business | Thu Mar 6, 2014 5:42pm EST
Related: Aerospace & Defense

Airbus A380 Full Scale Fatigue Test

Schwarberg, IABG Dresden

New Materials

The introduction of new materials and technologies requires a multitude of investigations and verifications known as testing pyramid starting with coupons and components to complete aircraft structures. Static and dynamic properties are examined



Coupon test | Panel test | Curved Panel test | Barrel test | Full scale fatigue test

Why this is not sufficient

- Complex design
- Material inhomogeneity
- Test conditions versus real load cycles
- Temperature effect
- Materials scatter
- Microstructure changes during service
- Aging

Things Effecting Fatigue Damage

- Internal defects / stress concentrators
- Interaction with other effects
- Corrosion
- Creep
- Change of material properties due to service load
- ……

Understanding the Widespread Fatigue

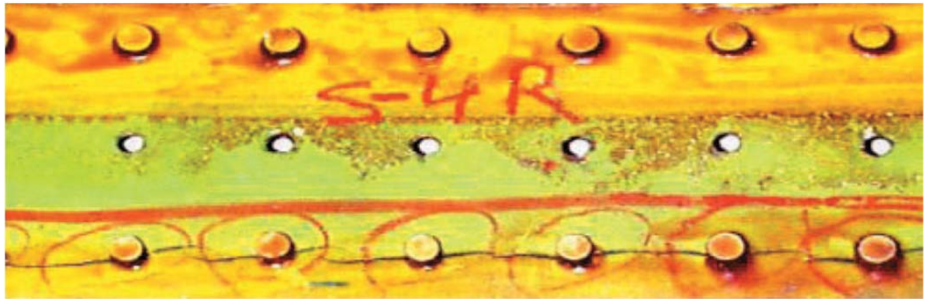
WWW.boeing.com/BoeingEdge/aerom

AERO_2012q4_article2.pdfagazineNew Damage Rule

The **development of widespread fatigue damage (WFD) in airplane structure is a concern for older airplanes**. The U.S. Federal Aviation Administration (FAA) has published a rule that will limit the commercial usage of older airplanes, requiring service actions to preclude the onset of WFD and retirement.

By Amos W. Hoggard, Technical Fellow (Retired), Aging Airplane Safety Rule/Widespread Fatigue Damage Program, and

Stephen R. Johnson, Aging Airplane Safety Rule/Widespread Fatigue Damage Program Manager, Chief Structures Engineer



What happens if the material properties change during service due to service conditions???

Example from Nuclear Industry

ELSEVIER

Nuclear Engineering and Design 206 (2001) 337–350

Nuclear Engineering and Design

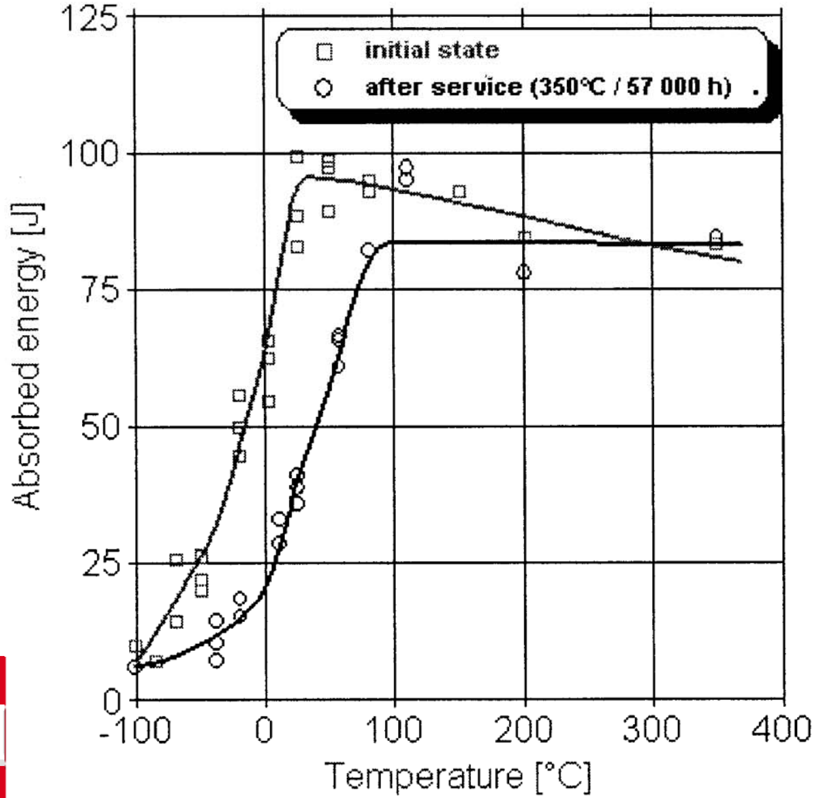
www.elsevier.com/locate/nucengdes

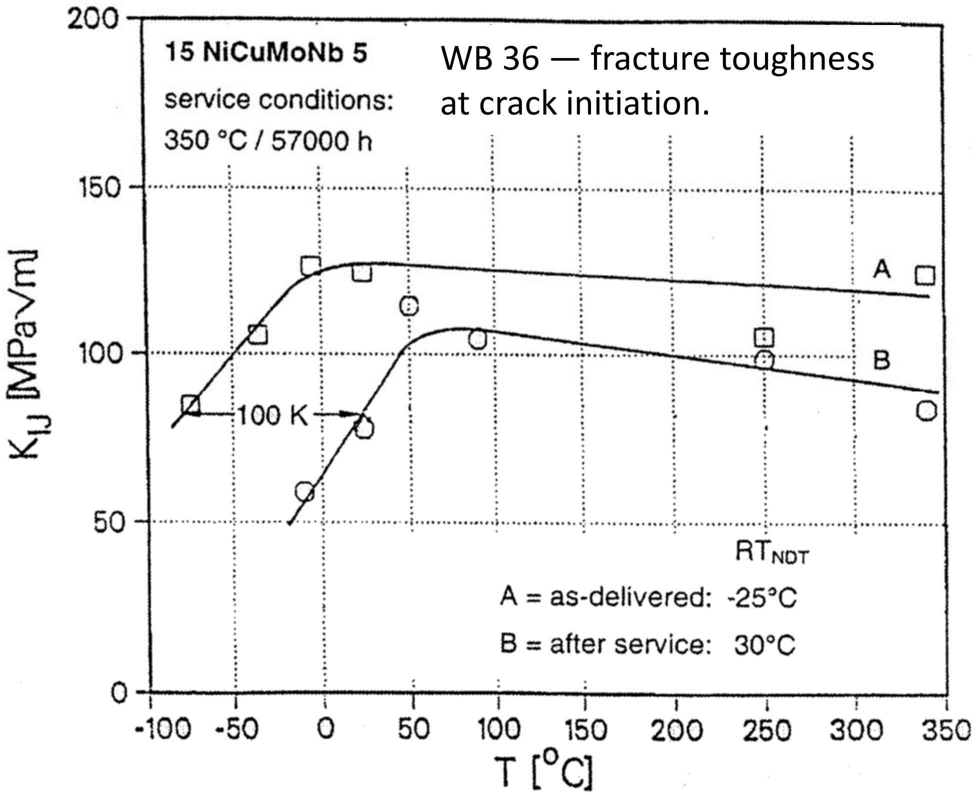
Copper precipitates in 15 NiCuMoNb 5 (WB 36) steel: material properties and microstructure, atomistic simulation, and micromagnetic NDE techniques

I. Altpeter [a,*], G. Dobmann [a], K.-H. Katerbau [b], M. Schick [b], P. Binkele [b], P. Kizler [b], S. Schmauder [b]

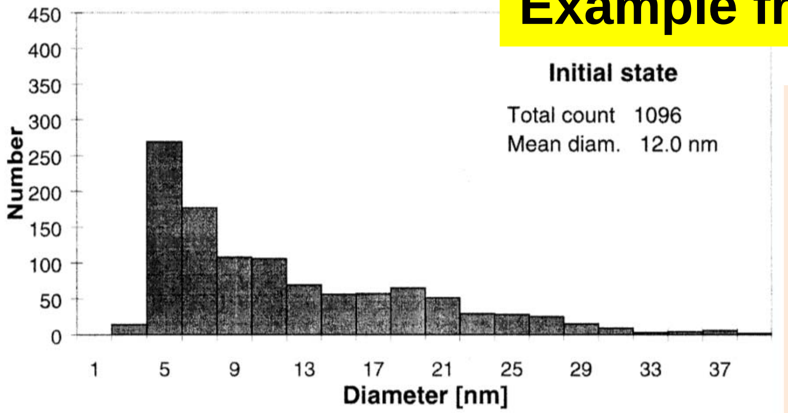
[a] *Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren IZFP, Universität, Geb. 37, 66123 Saarbrücken, Germany*
[b] *MPA Stuttgart, Germany*

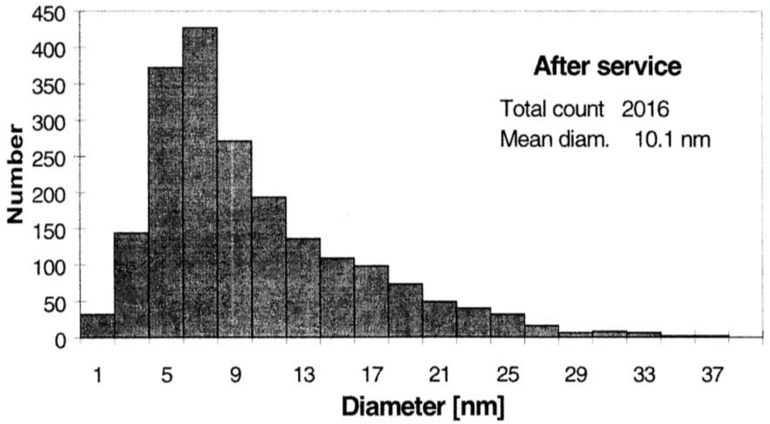
Accepted 24 November 2000



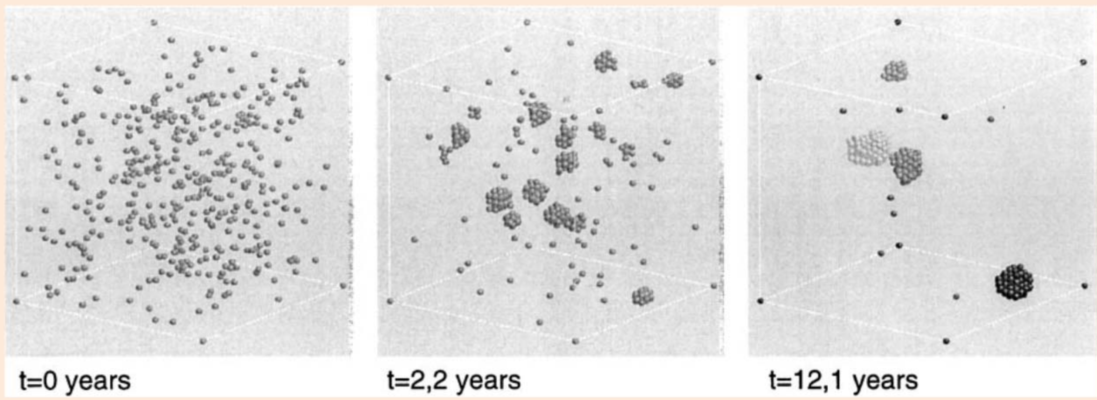


Example from Nuclear Industry

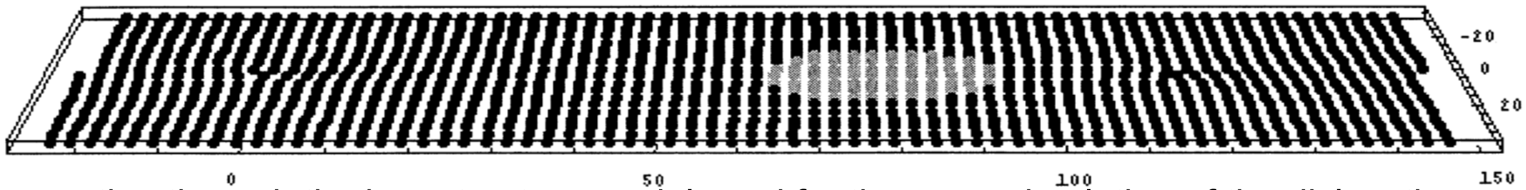




WB 36 — size distribution of the copper precipitates.



Results of a Monte Carlo simulation on formation and growth of copper precipitates; only the copper, not the iron atoms are shown.



Cross-section through the iron structure model used for the nano-simulation of the dislocation movement; scale in 1Å, (0.1nm).

Precipitations in AA 7075-T6

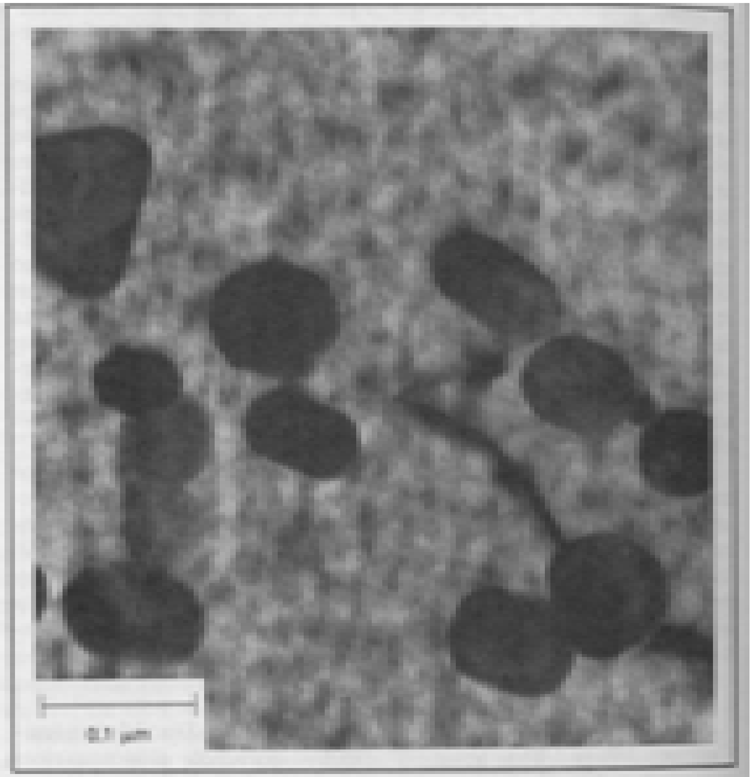
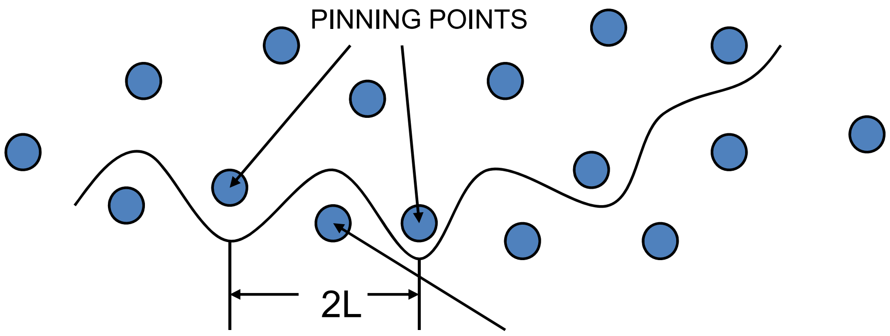
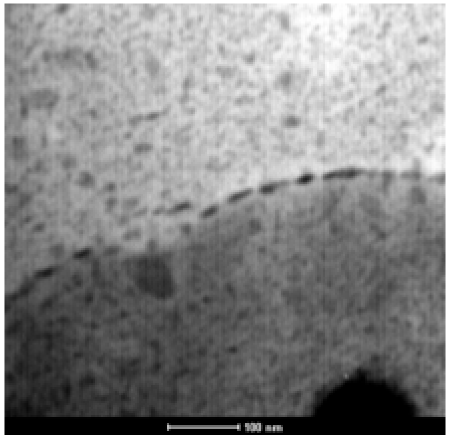


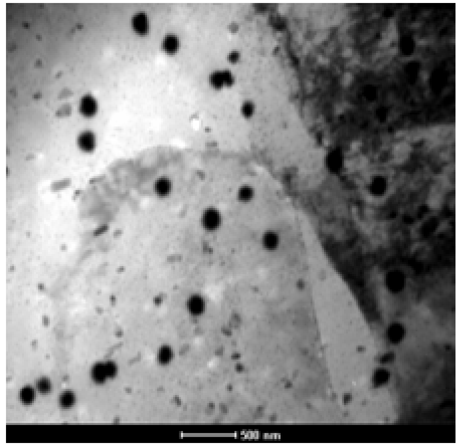
Fig. 7. Transmission electron micrograph of 7075-W aged 25 years at room temperature. The large particles are $Al_{12}Mg_2Cr$ dispersoid. The GP zones throughout the structure have an average diameter of 1.2 nm (12 Å), and an approximate density of 4×10^{18} zones per cm^{-3}. The yield strength of the as-quenched 7075-W was 150 MPa (22 ksi). After 25 years, yield strength had increased to 465 MPa (67 ksi).

Interaction of precipitates with dislocation





Fine phase precipitates

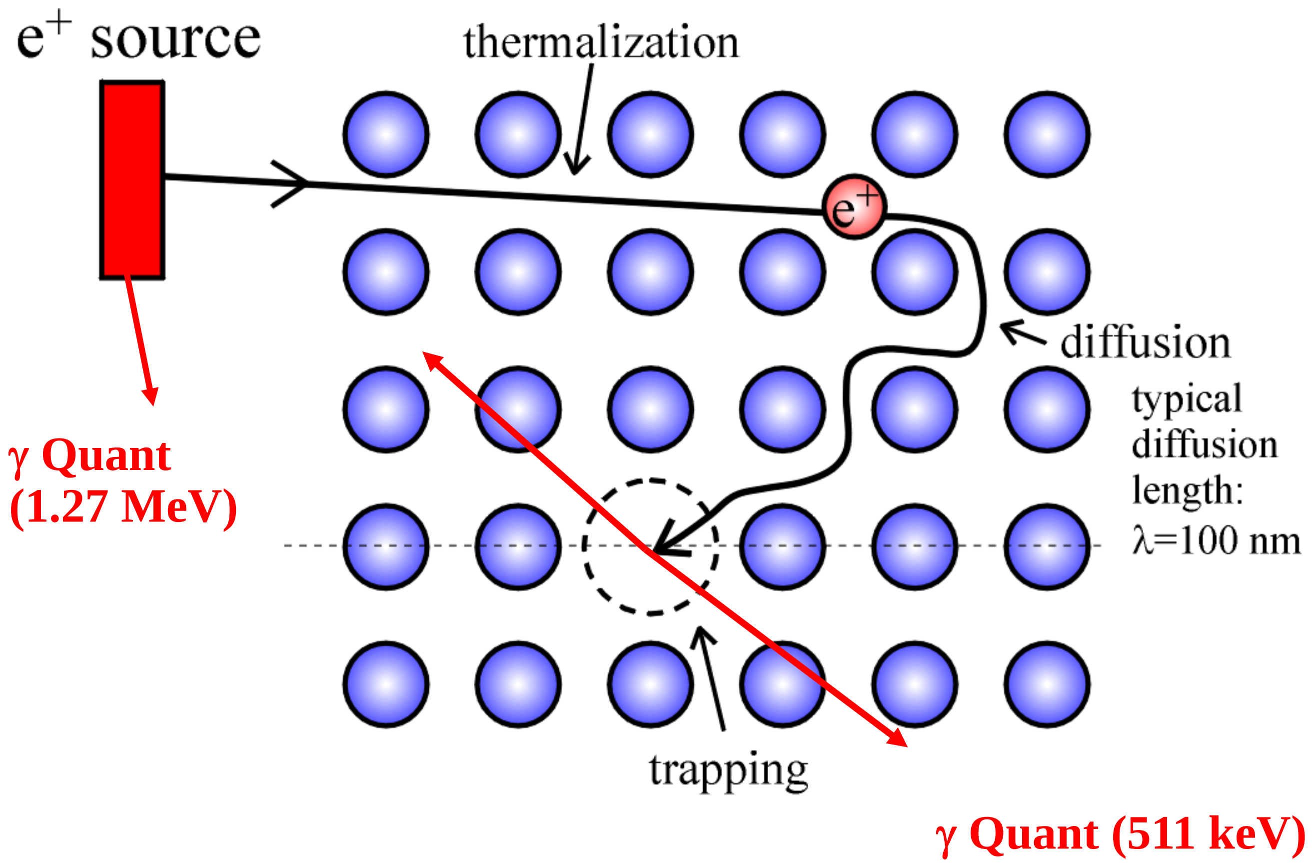


Coarse phase precipitates

Reference: Edited by J. Hatch, Aluminum: Properties and Physical Metallurgy, American Society for Metals, 1984, p145

Reference: S. Kuhr, A Microstructural Characterization of Aluminum 7075-T6 Treated with the Retrogression and Re-Aging Process

Positron Annihilation Technique

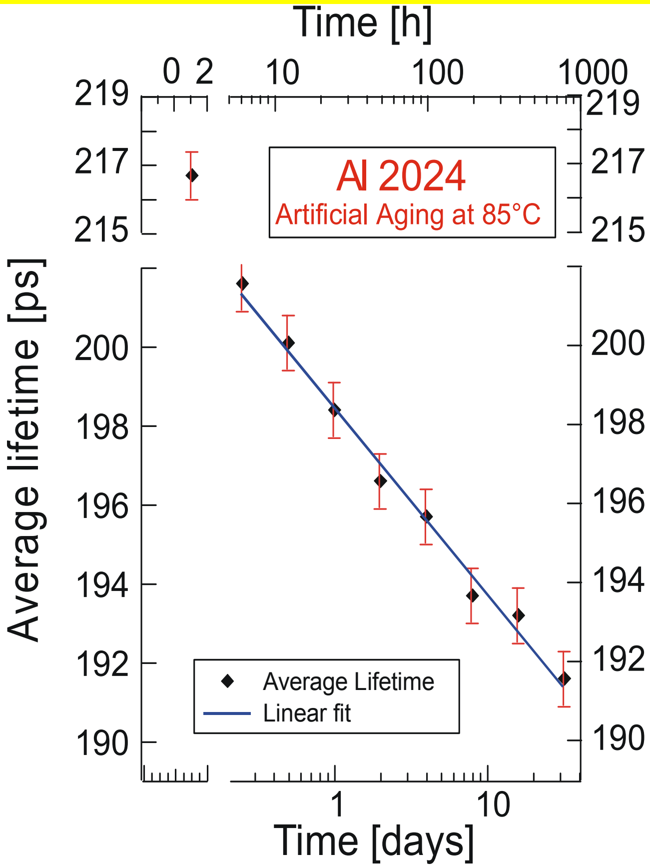


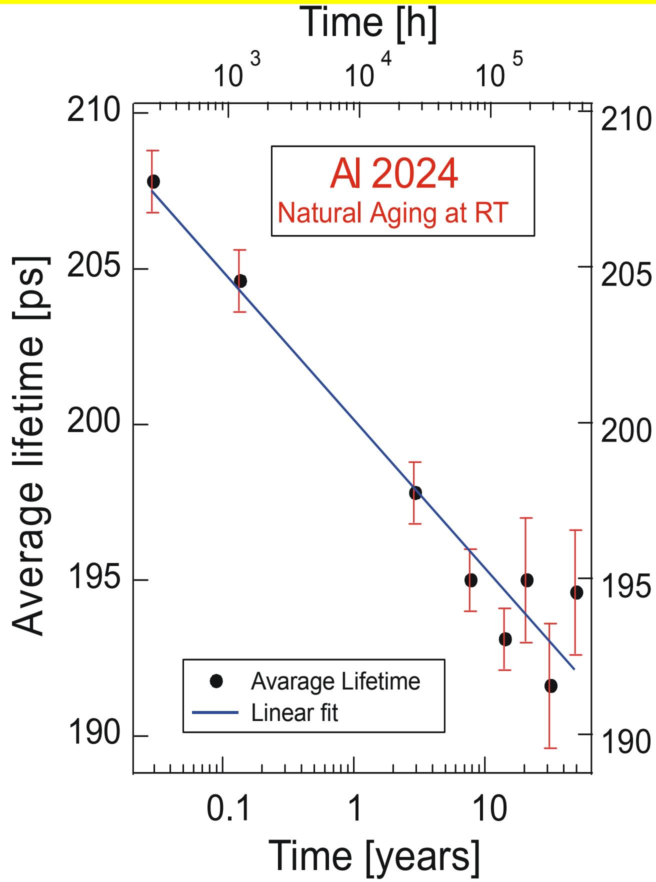
Annihilation parameters depend on

- **Chemical composition of the alloy**
- **Defects (point defects, dislocations ➔ coherent /incoherent precepitations)**

Aging of Aluminium Alloys: Positron Lifetime Data

Increase of Cu content in GP zones => positron lifetime decreases





- Exponential change of positron lifetime
- Change in chemical composition and microstructure (GP2 zones)

T. E. M. Staab, E. Zschech, R. Krause-Rehberg, J. Mater. Sci. 35, 4667 (2000)

Bloomberg

Airbus Identifies 'Cracking Behavior' in A400M Military Aircraft

Andrea Rothman May 14, 2016 — 1:00 AM CEST

"As part of the normal quality control processes in the A400M fleet we have identified a material issue," Airbus said in a statement late Friday. **"It concerns a previously unknown cracking behavior of an aluminum alloys material**. The issue is not impacting flight safety and does not require any immediate measures beyond a program of inspections and repairs that can be incorporated into the normal maintenance and upgrades schedules."

http://www.bloomberg.com/news/articles/2016-05-13/airbus-identifies-cracking-behavior-in-a 400m-military-aircraft

DIE WELT

That is behind the Cracks in the Airbus Fuselage

Das steckt hinter den Rissen im Airbus-Rumpf,
Die Welt 26.04.16

- **Already in 2011 an AL Zn alloy showed an unknown material behavior. First indication during full scale fatigue test in Dresden**

Hinter den Kulissen gibt es aber Aufregung um die Abläufe. So räumt die für den A400M-Bau verantwortliche Rüstungs- und Sicherheitssparte ein, dass bereits 2011 eine Aluminium-Legierung "ein vorher unbekanntes Materialverhalten" zeigte. Da hatte das erste A400M-Modell schon längst seinen Erstflug. In Branchenkreisen ist zu hören, dass 2011 die Auffälligkeiten bei Bauteilen aus modernen Aluminium-Zink-Legierungen bei einem Zeitraffer-Belastungstest am Boden auffielen. Dabei wurde bei einer A400M in einer Testhalle in Dresden ein komplettes Flugzeugleben simuliert.

- **The material was approved for application since 2008**

Die Experten standen vor einem Rätsel, zumal das Material der Alu-Legierung bereits seit 2008 für den Einsatz zugelassen war. Daher begannen auch ab Herbst 2013 die A400M-Auslieferungen, zuerst an Frankreich. Eingekreist wurde die Risse-Ursache erst zwei Jahre nach dem Belastungstests in Airbus-Laboren in einer ersten Ursachenvermutung.

- **Explanation in 2015: Mixture of chemical composition, pressure, stress, temperature (service conditions). It is not corrosion!**

Nach weiteren Forschungen und Tests gelang es 2015, eine Erklärung herauszufiltern. Die Rede ist von einem komplexen Mix aus der chemischen Zusammensetzung der Alu-Zink-Legierung und anderen Faktoren wie Druck, Dehnung und Temperatur, kurz Umwelteinflüssen. Laut Airbus handelt es sich nicht um Korrosion.

- **The AL Zn alloy will also be used for A 350**

Im Fokus stehe der Rumpfabschnitt, der die Belastungen der Tragflächen aushalten muss. Bislang sind gut zwei Dutzend A400M-Modelle ausgeliefert. In Luftfahrtkreisen ist zu hören, dass Bauteile aus der umstrittenen Aluminium-Zink-Legierung auch beim neuen Langstreckenmodell A350 zum Einsatz kommen – allerdings im kleinen Maßstab.

- **For insiders the A400M material fiasco is a proof for risks** (that might result) **from the competition for new aircraft materials**

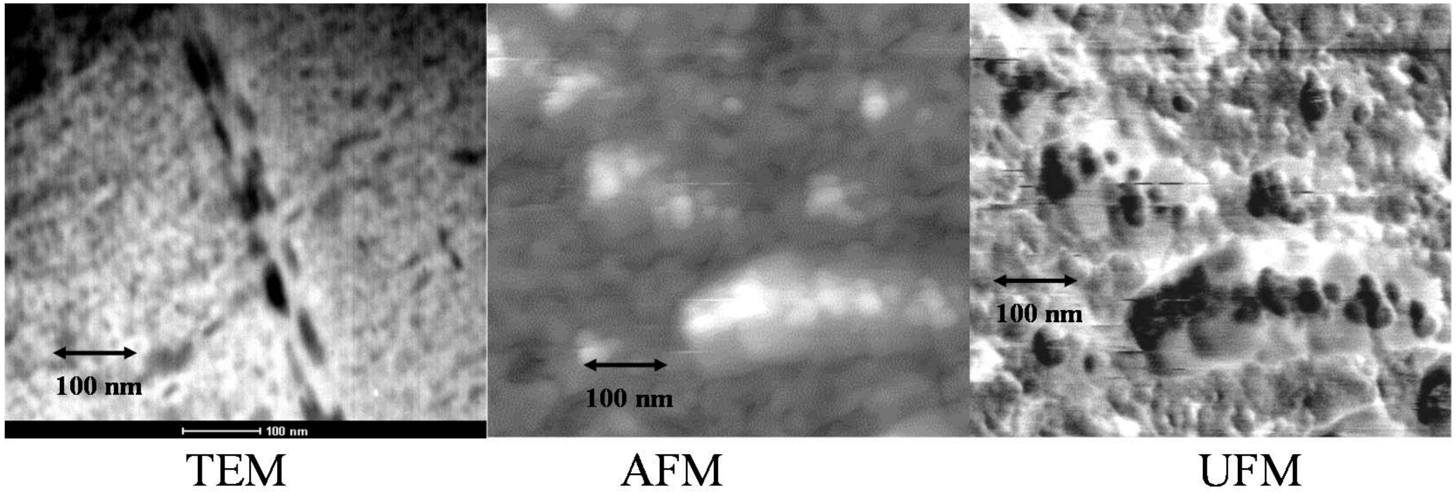
Für Branchenkenner ist das A400M-Materialdebakel ein Beleg für die Risiken aus dem Wettbewerb um neue Flugzeugwerkstoffe. Auf der einen Seite stehen die großen Hersteller von Aluminium-Legierungen, wie Alcoa (USA) oder Constellium (Niederlande), die Angst um ihr Geschäft haben, seitdem hochfeste und leichte Kohlefaserwerkstoffe (CFK) in den Flugzeugbau Einzug halten.

The Material?

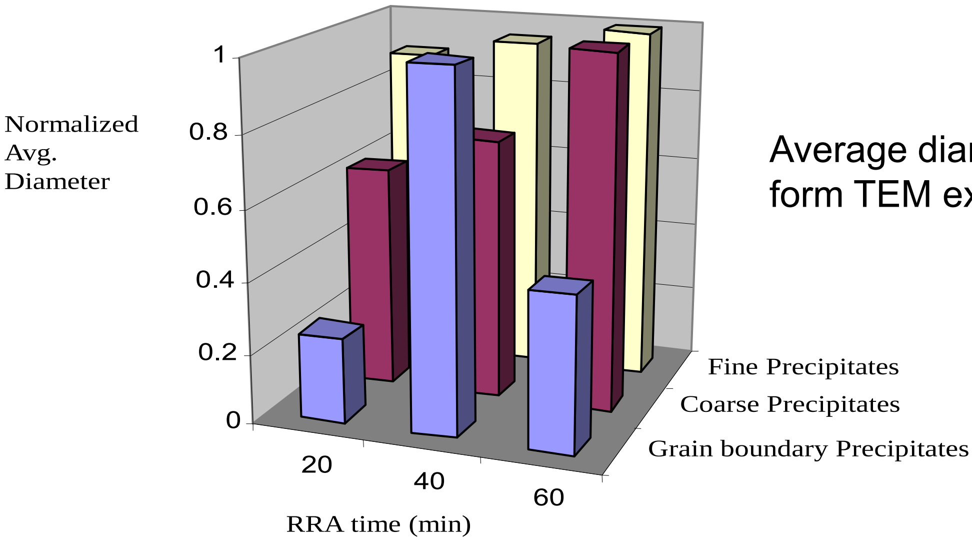
EN AW-7030 ; Al Zn5.5Mg1Cu???

- Well known as: **Al Zn5.5Mg1Cu → AA7075**
- Can be compared but has higher Copper content
- General 7075 characteristics and uses (from Alcoa):The T7351 temper (can be compared to RRA) offers high strength and improved stress-corrosion cracking resistance.
- Applications: Aircraft fittings, gears and shafts, fuse parts, meter shafts and gears, missile parts, regulating valve parts, worm gears, keys, aircraft, aerospace and defense applications; bike frames, all terrain vehicle (ATV) sprockets.
- **Mechanical properties and SCC are very sensitive to heat treatment.**

Retrogression and Re-Aging of AA 7075-6



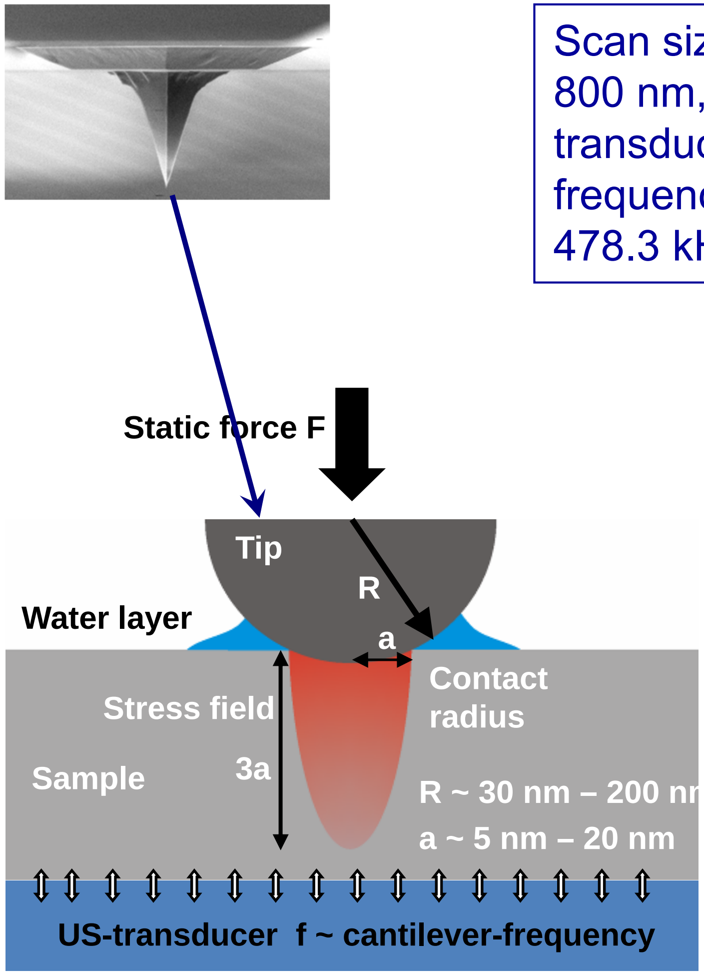
Images of material after 40 minutes RRA time.



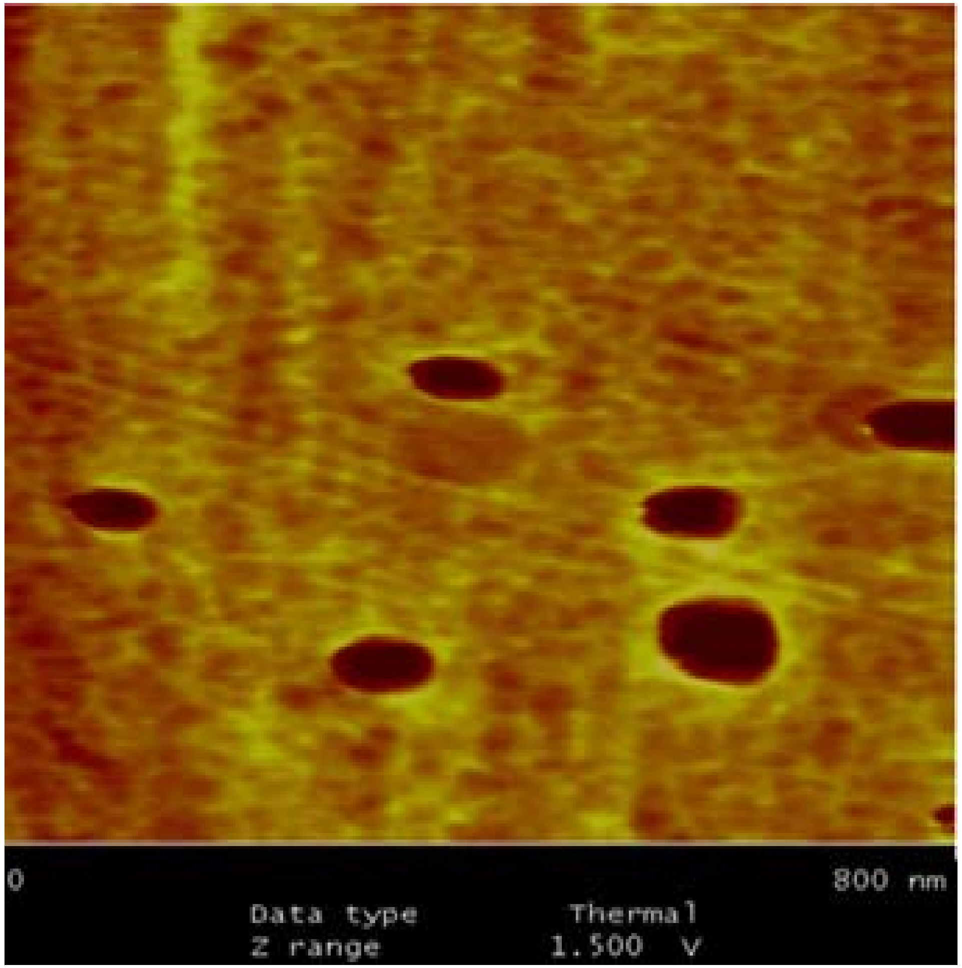
Average diameter of precipitations form TEM experiment

Meyendorf N., Sathish S., Ananthula R., Siddoju A., Kuhr S. Retrogression and Re-Aging (RRA) of 7075-T6 Corrosion Prone Parts; **Part: Nondestructive Microstructure Characterization, Delivery Order No. F42620-00-D-0039**

NDE of Precipitations in AA 7075



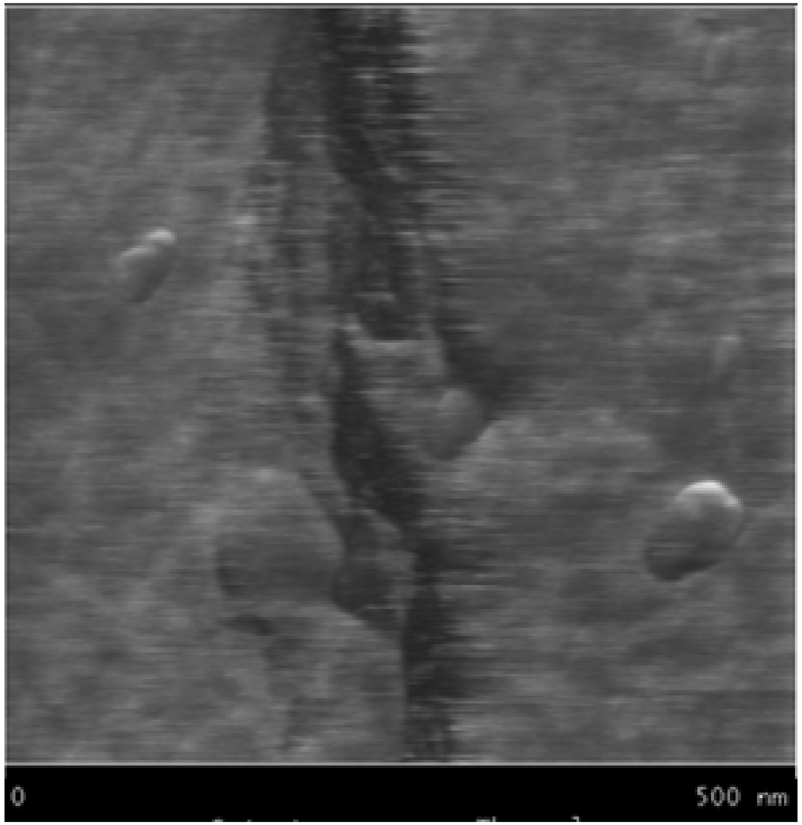
Scan size 800 nm, transducer frequency 478.3 kHz



NDE of Precipitations in AA 7075

Scan size 800 nm, transducer frequency 478.3 kHz

Scan size 500 nm, transducer frequency 146.3 kHz



Conclusion

- New high tech materials might change their designed properties due to service conditions
- Usually modeling and lab tests do not consider these effects
- NDE or continuous monitoring (SHM) will be required even if no fatigue is predicted by the designers of the structure

Accidents by fatigue

- **Others**
- The 1862 Hartley Colliery Disaster was caused by the fracture of a steam engine beam and killed 220 people.
- The 1919 Great Molasses Flood has been attributed to a fatigue failure.
- The 1948 Northwest Airlines Flight 421 crash due to fatigue failure in a wing spar root
- The 1957 "Mt. Pinatubo", presidential plane of Philippine President Ramon Magsaysay, crashed due to engine failure caused by metal fatigue.
- The 1965 capsize of the UK's first offshore oil platform, the Sea Gem, was due to fatigue in part of the suspension system linking the hull to the legs.
- The 1968 Los Angeles Airways Flight 417 lost one of its main rotor blades due to fatigue failure.
- The 1968 MacRobertson Miller Airlines Flight 1750 that lost a wing due to improper maintenance leading to fatigue failure
- The 1977 Dan-Air Boeing 707 crash caused by fatigue failure resulting in the loss of the right horizontal stabilizer
- The 1980 LOT Flight 7 that crashed due to fatigue in an engine turbine shaft resulting in engine disintegration leading to loss of control
- The 1985 Japan Airlines Flight 123 crashed after the aircraft lost its vertical stabilizer due to faulty repairs on the rear bulkhead.
- The 1988 Aloha Airlines Flight 243 suffered an explosive decompression due to fatigue failure.
- The 1989 United Airlines Flight 232 lost its tail engine due to fatigue failure in a fan disk hub.
- The 1992 El Al Flight 1862 lost both engines on its right-wing due to fatigue failure in the pylon mounting of the #3 Engine.
- The 1998 Eschede train disaster was caused by fatigue failure of a single composite wheel.
- The 2000 Hatfield rail crash was likely caused by rolling contact fatigue.
- The 2002 China Airlines Flight 611 had disintegrated in-flight due to fatigue failure.
- The 2005 Chalk's Ocean Airways Flight 101 lost its right wing due to fatigue failure brought about by inadequate maintenance practices.
- **The 2009 Viareggio train derailment due to fatigue failure.**

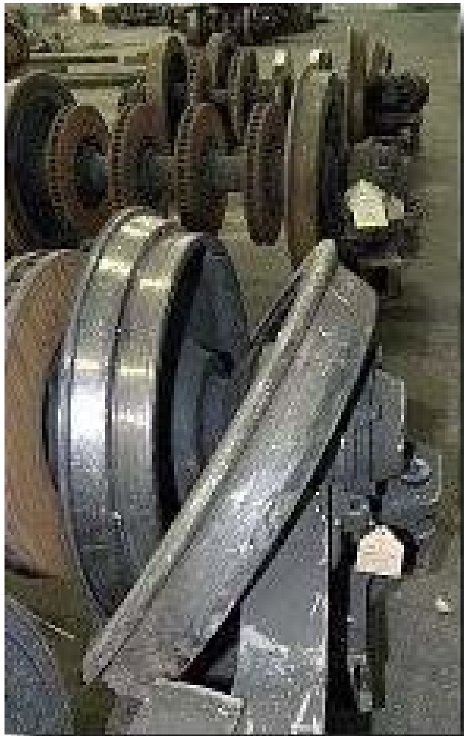
Viareggio train derailment

https://en.wikipedia.org/wiki/Viareggio_train_derailment

The failure of an axle on the wagon that derailed is being investigated as a possible cause.[13][19] Italian Transport Minister Altero Matteoli informed the Italian Parliament on 1 July that a **defective axle may have caused the accident**.[16]

ICE Accident, June 3, 1998 Eschede

Crack in wheel rim



Ref: www.rheinzeitung.de

High speed train
accident in Eschede
101 people died

ICE 518, July 9, 2008 Cologne

Source: DDP

As a consequence to this event. Deutsche Bahn has significantly reduced the intervals for axle inspections **from 250 000 to 60 000 km**.

Impact of Information on our Business
(»Bad News are good News«)

Eschede, 3. June 1998

ICE 518 Main Station Colon

(Foto: 9.7.2008 – KStA)

Why is this happening??

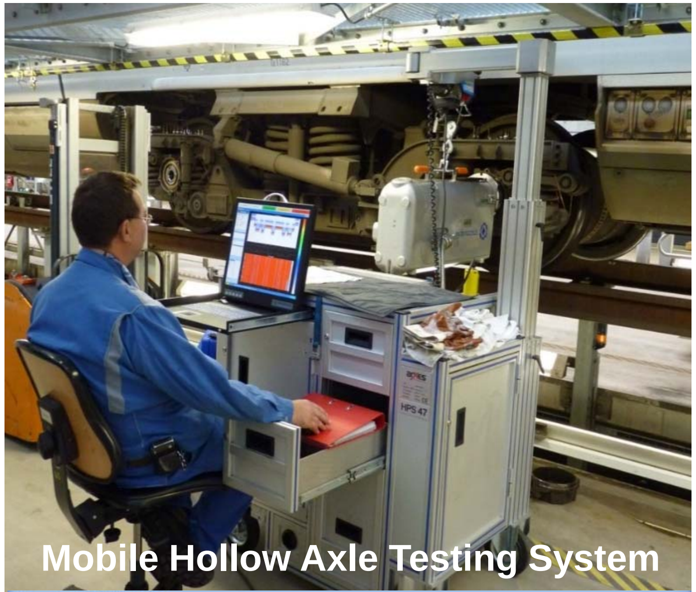
- ✓ Material Properties are known
- ✓ Loading conditions are known
- ✓ Modelling of the structure is done
- ✓ Testing for all structural dimensions performed

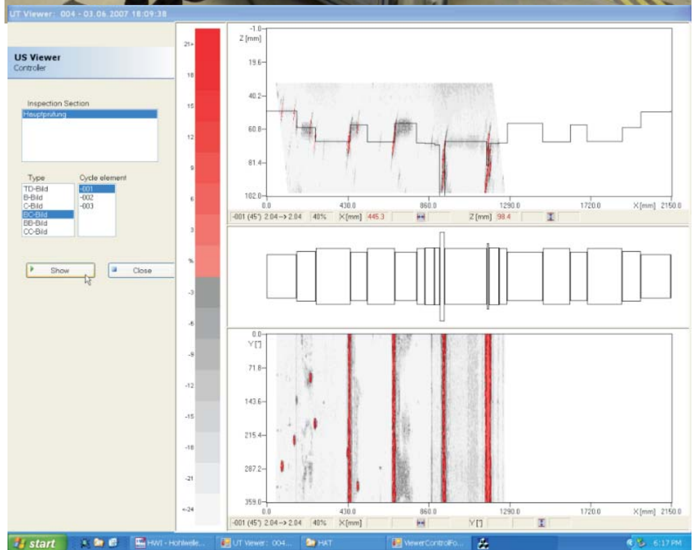
Usually coincidence of undetected defect(s) (inclusion, pores) **<u>and</u>** cyclic loading

Early Detection of Fatigue NDE

- **Macroscopic Cracks**
- **Stress concentrators**
- **Microstructure effects/** Precipitations, dislocations, lattice defects
- **Microstructure effects /**Phase Transformations
- **Microcracks**
- **Mesostructure????**

NDE for Railroad Axels and Wheels





Required sequence of inspection cycles

Deutsche Bahn has significantly reduced the intervals for axle inspections from 250,000 to 60,000 km as a consequence of the Accident in Cologne

Early Detection of Fatigue NDE

Macroscopic Cracks

- only at the end of life,
- usually start from the surface
- Techniques: Visual, Eddy Current, Ultrasound, Optics

Stress concentrators

- Technique: Thermoelastic effect, “Spate”

Microstructure effects/ Precipitations, dislocations, lattice defects

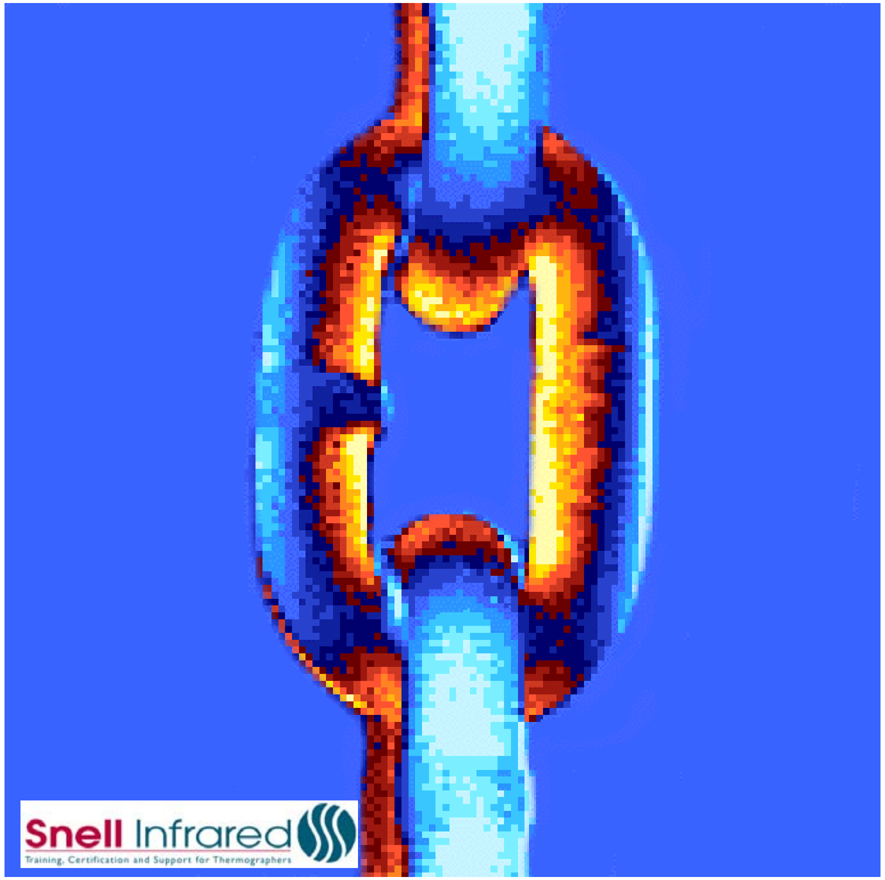
Microstructure effects /Phase Transformations

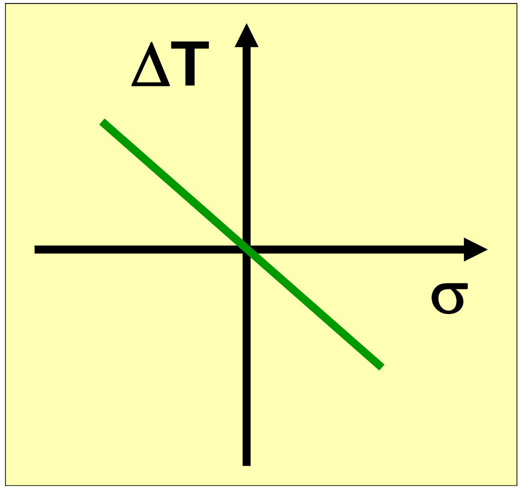
Microcracks

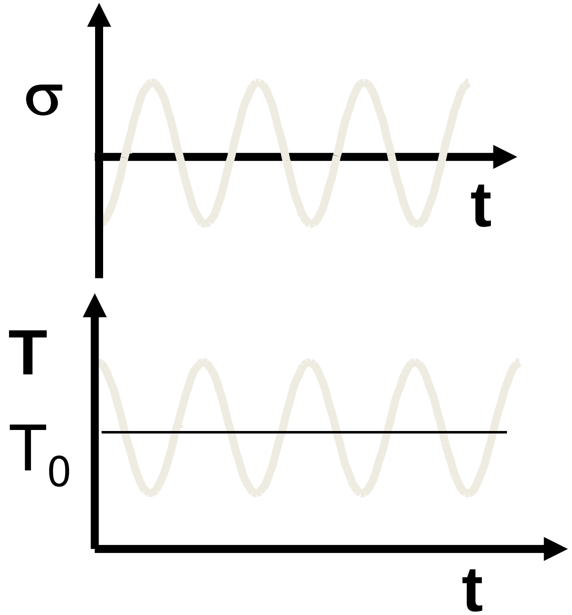
Mesostructure????

Thermoelastic Effect

DeltaTherm 1000 image of the stresses in a chain link loaded at 10Hz.
Image acquisition time: 30s.
Courtesy Stress Photonics, Madison, WI.







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Microstructure effects/ Precipitations, dislocations, lattice defects

- Techniques: Internal damping, Heat dissipation (thermography), Electric conductivity, Ultrasonic absorption, Nonlinear ultrasound, Positron annihilation

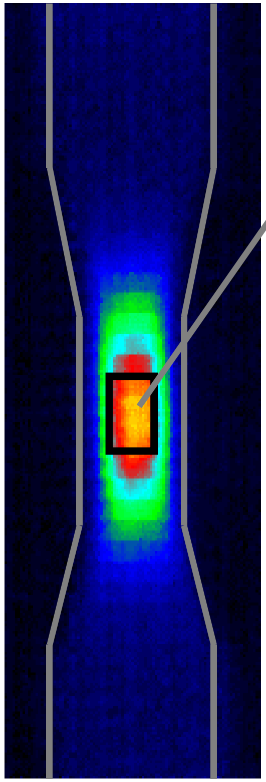
Microstructure effects /Phase Transformations

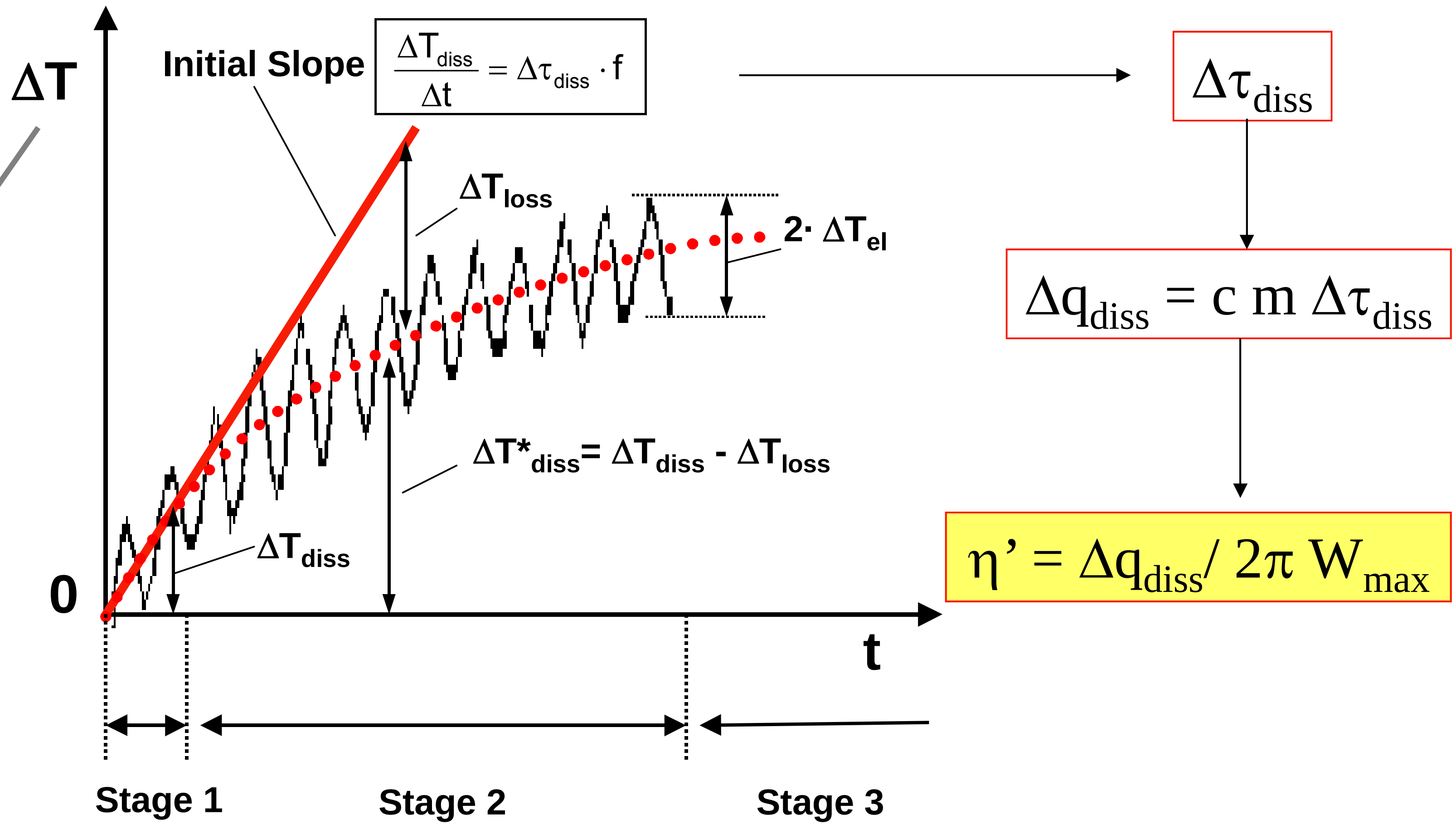
Microcracks

Mesostructure????

Temperature Due to Mechanical Loading & Evaluation of The Initial Slope

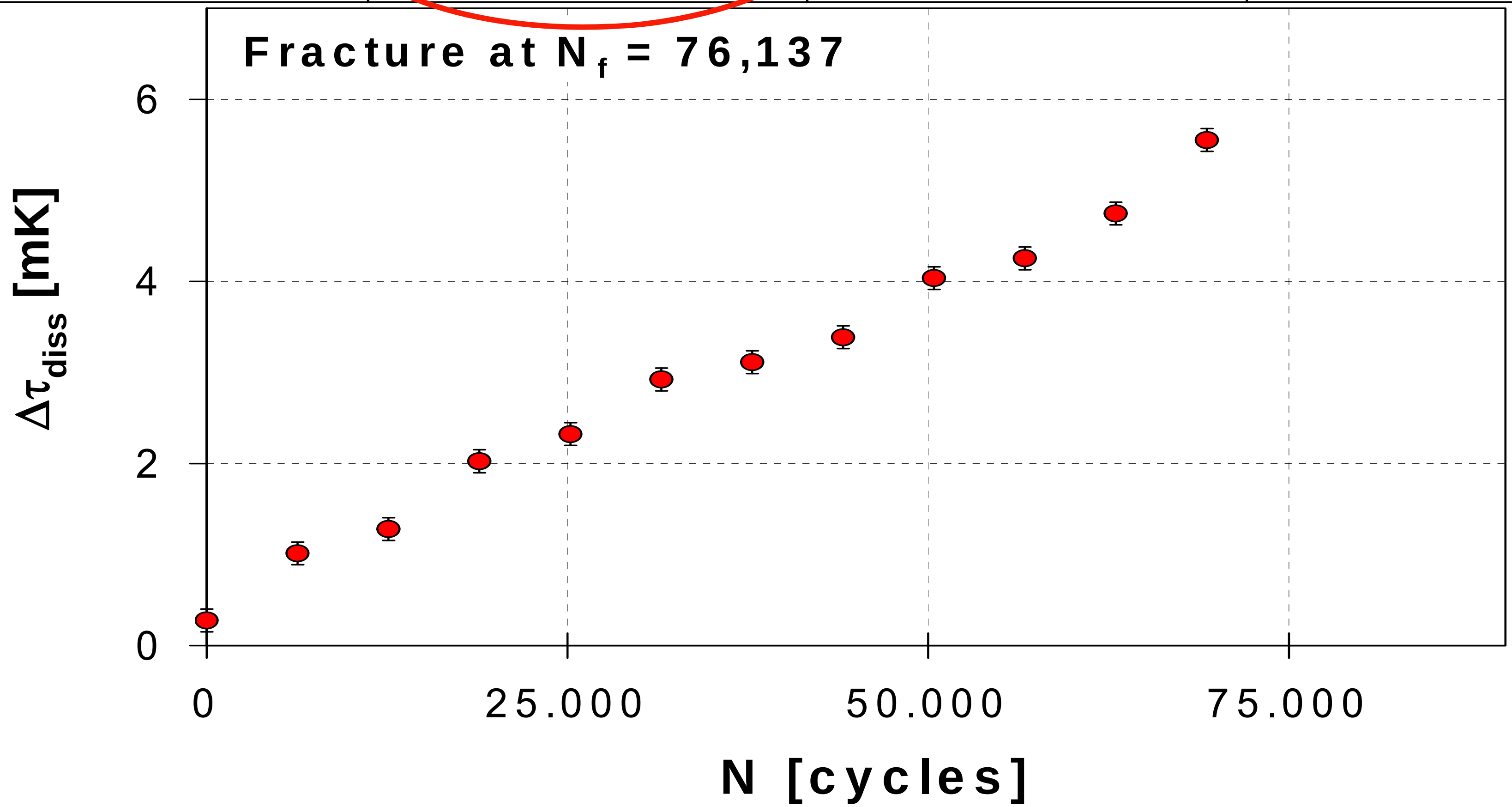
$$\Delta T(t) = T(t) - T_0 = \Delta T_{el}(t) + \Delta T_{diss}(t) + \Delta T_{loss}(t)$$





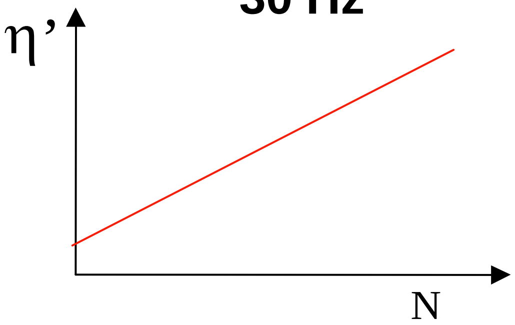
FATIGUE Ti-6Al-V4 LOW FREQUNCY EXCITATION

	Mechanical Loading	Power Ultrasonics	Nonlinear Acoustics
Loading frequency	30 Hz	20 kHz	10 MHz
Max. Stress	500 MPa	50 MPa	0.5 MPa



MEASUREMENT OF INTERNAL DAMPING

30 Hz

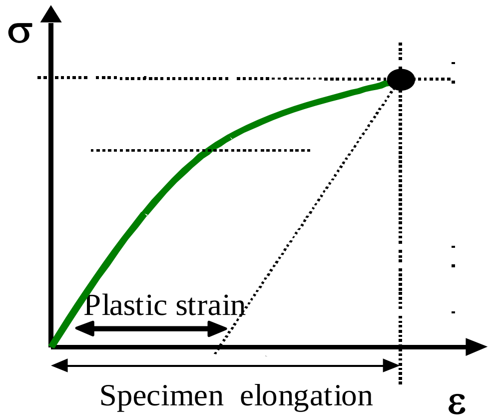


Moving dislocations

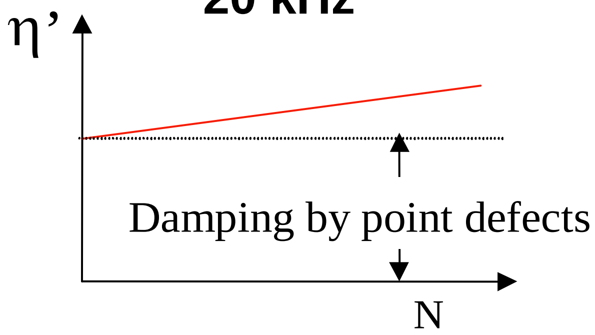
Local plastic deformation

$\Delta\tau_{diss} = a*\sigma_a^{m+1}$

m: ***Ramberg-Osgood Exponent***



20 kHz

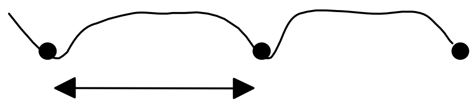


Oscillating dislocations pinned by point defects grain boundaries ...

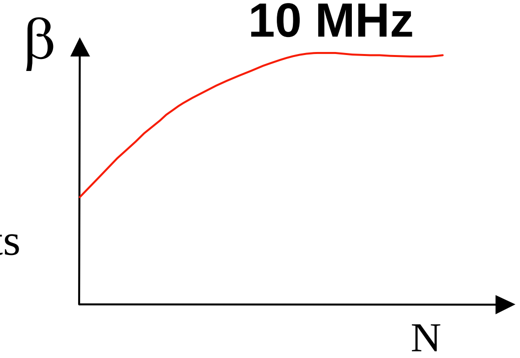
$\eta' - \eta'_0$ prop. Λ

$\Delta\tau_{diss} - \Delta\tau_{diss0}$ prop. Λ

Dependence of concentration of pinning points and Temperature expected



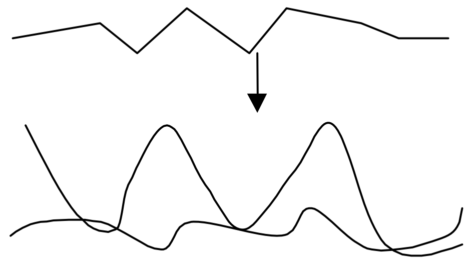
10 MHz



Dislocation / phonon interaction

β prop. $\Lambda * L^4$

formation of dislocation network reduces free dislocation length L and modifies process



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- Techniques: Internal damping, Heat dissipation (thermography), Electric conductivity, Ultrasonic absorption, Nonlinear ultrasound, Positron annihilation,

Microstructure effects /Phase Transformations

- Formation of ferromagnetic martensitic phases in austenite
- Techniques: Ultrasonic damping, Permeability measurement (Ferritoscope, Squid, Eddy Current)

Microcracks

- preferred for ductile materials
- Techniques: Replica, Optics, Ultrasound Microscopy, Nonlinear Ultrasound???

Mesostructure????

COMPARISON OF MATERIALS

X6 CrNiNb 18 10

Ti-6Al-4V

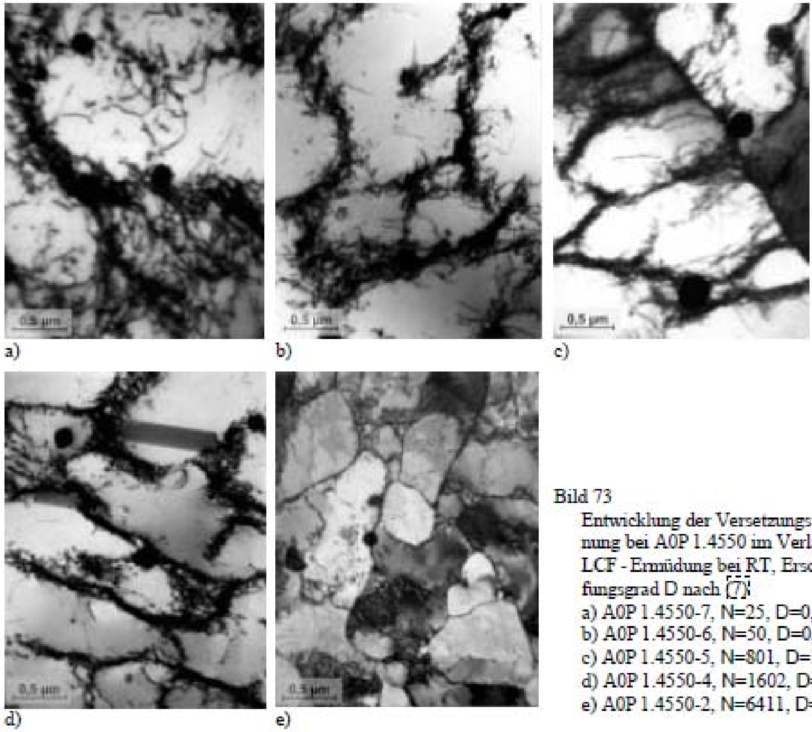
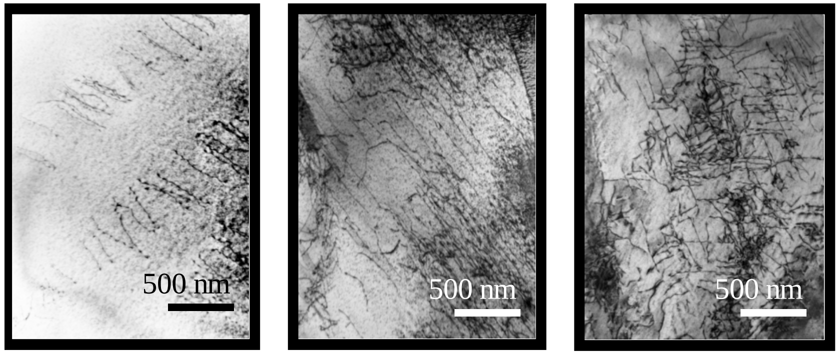
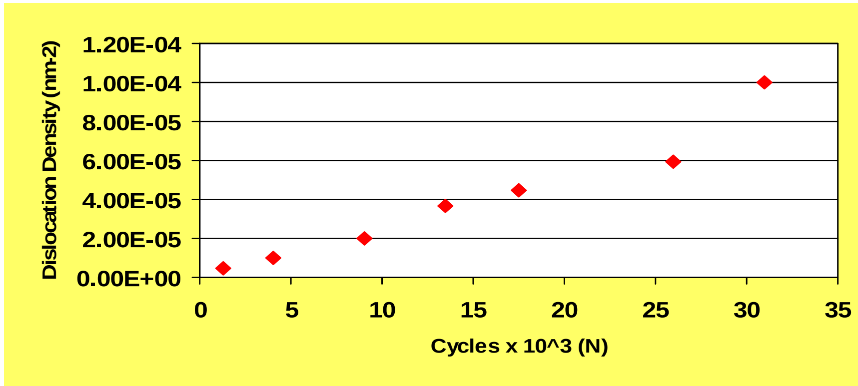


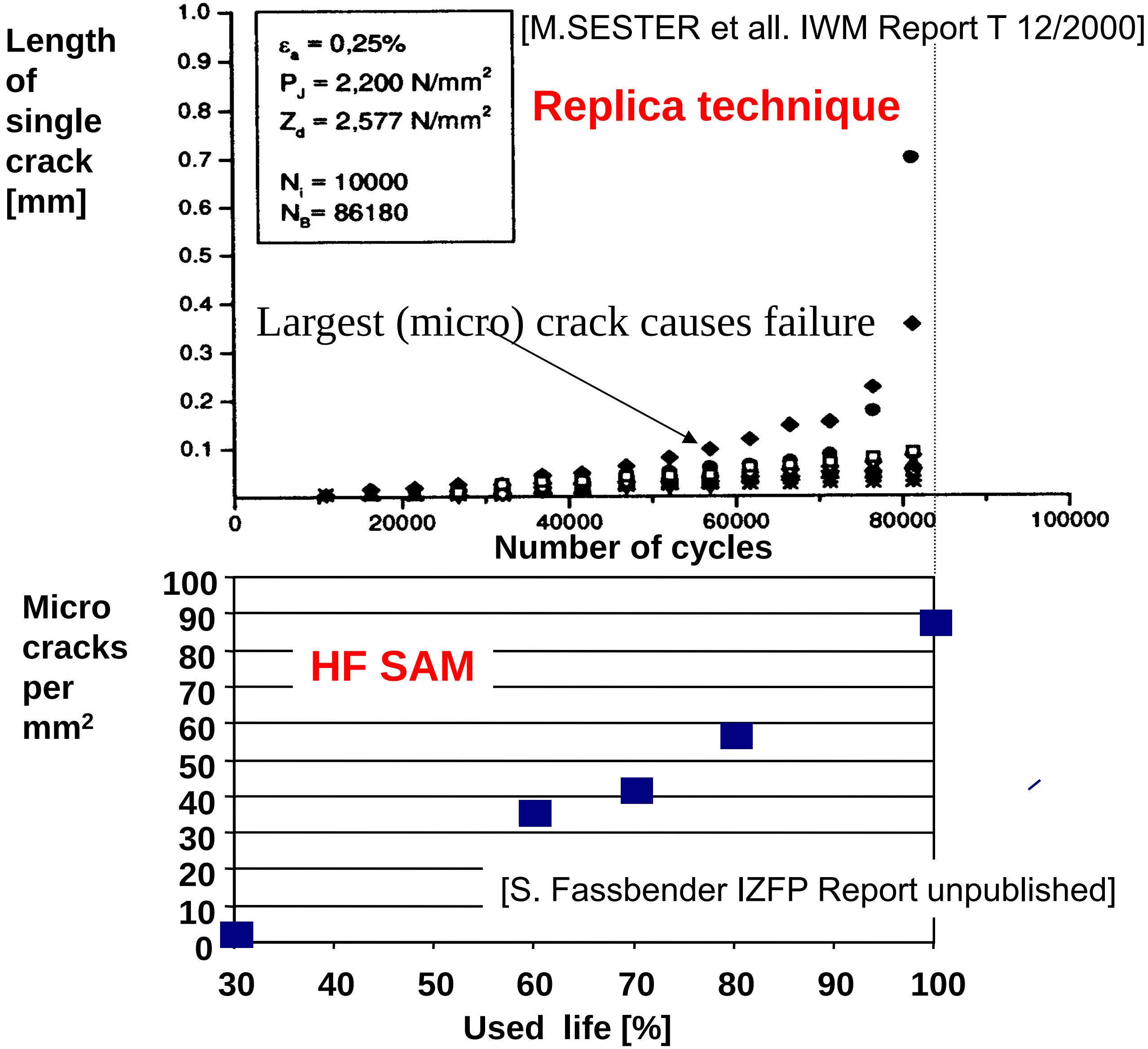
Bild 73
Entwicklung der Versetzungsanordnung bei A0P 1.4550 im Verlauf der LCF - Ermüdung bei RT, Erschöpfungsgrad D nach [7]
a) A0P 1.4550-7, N=25, D=0,39%
b) A0P 1.4550-6, N=50, D=0,78%
c) A0P 1.4550-5, N=801, D=12,5%
d) A0P 1.4550-4, N=1602, D=25%
e) A0P 1.4550-2, N=6411, D=100%



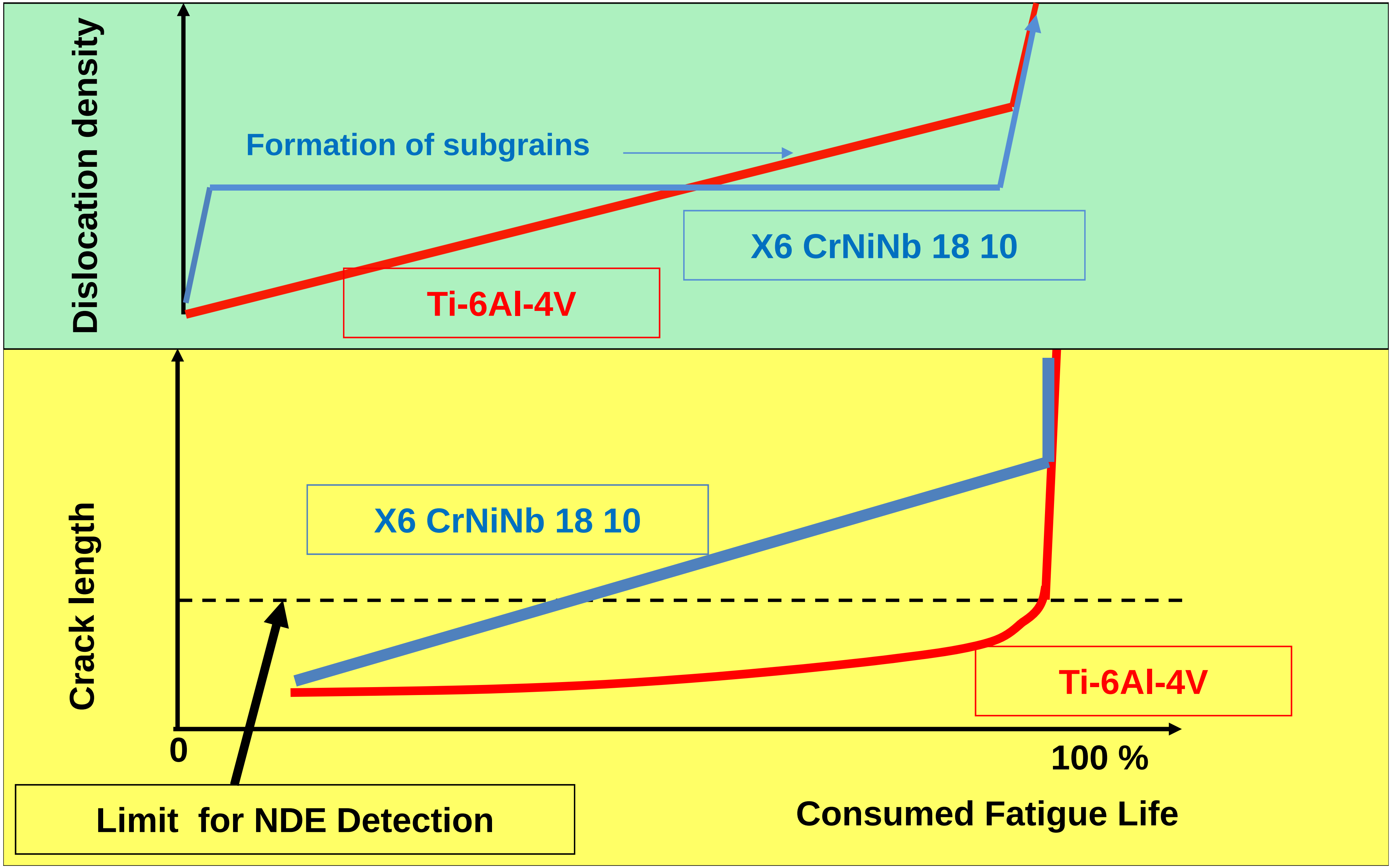


Source:
Volker Schloß: Martensitic Transformation of Austenitic Steinless Steels, Microstructure Changes, and Possibilities of Early Detection of Fatigue Damage. PhD Thesis, Freiburg 2001

Micro crack growth during Fatigue of X6 CrNiNb 18 10



COMPARISON OF MATERIALS



Early Detection of Fatigue NDE

Macroscopic Cracks

- only at the end of life,
- usually start form the surface
- Techniques: Visual, Eddy Current, Ultrasound, Optics

Stress concentrators

- Techniques: Thermoelastic effect, “Spate”

Microstructure effects/ Precipitations, dislocations, lattice defects

- Techniques: Internal damping, Heat dissipation (thermography), Electric conductivity, Ultrasonic absorption, Nonlinear ultrasound, Positron annihilation,

Microstructure effects /Phase Transformations

- Formation of ferromagnetic martensitic phases in austenite
- Techniques: Ultrasonic damping, Permeability measurement (Ferritoscope, Squid, Eddy Current)

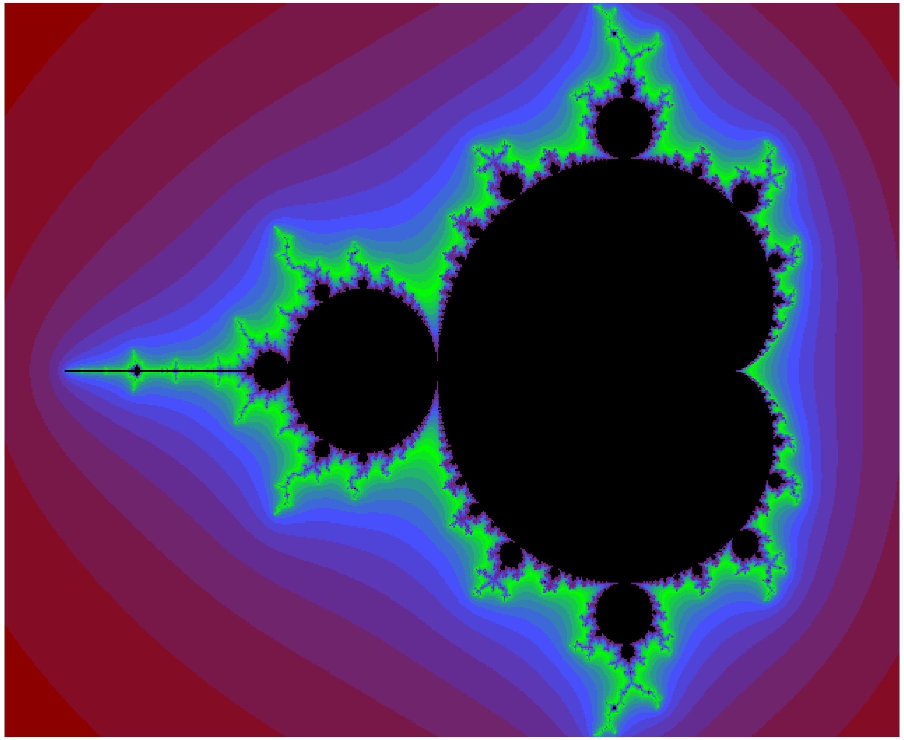
Microcracks

- preferred for ductile materials
- Techniques: Replica, Optics, Ultrasound Microscopy, Nonlinear Ultrasound???

Mesostructure????

- Techniques: Fractal analysis of date from different imaging techniques

Fractal Dimension (DF)



Source: Wikipedia

A **fractal** is "a rough or fragmented geometric shape that can be split into parts, each of which is (at least approximately) a reduced-size copy of the whole," a property called self-similarity. Roots of mathematical interest on fractals can be traced back to the late 19th Century; however, the term "fractal" was coined by Benoît Mandelbrot in 1975 and was derived from the Latin fractus meaning "broken" or "fractured“. A mathematical fractal is based on an equation that undergoes iteration, a form of feedback based on recursion.

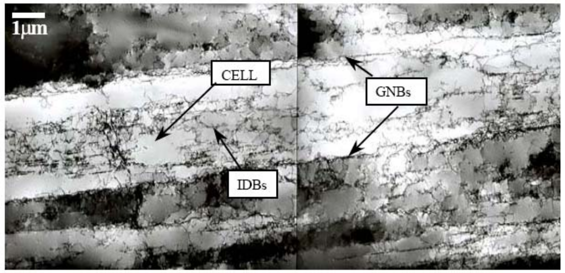
Fractal Dimension

The fractal dimension, D, is a statistical quantity that gives an indication of how completely a fractal appears to fill space, as one zooms down to finer and finer scales.

Phenomena of Material Fatigue

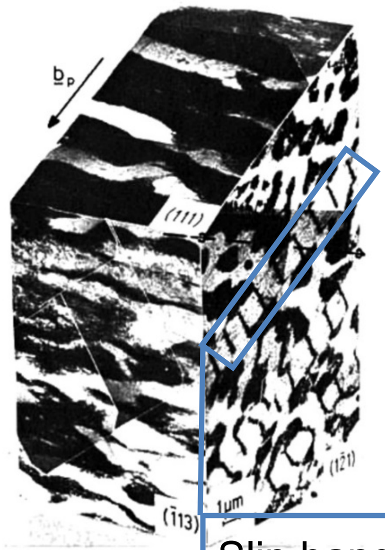
What happens in the material?

Micro level



Dislocations:
GND – geometrical necessary
IND – interface network
Cells (Mughrabi, 83)
➡ Continuum mechanics

Conventional Approach



Slip bands

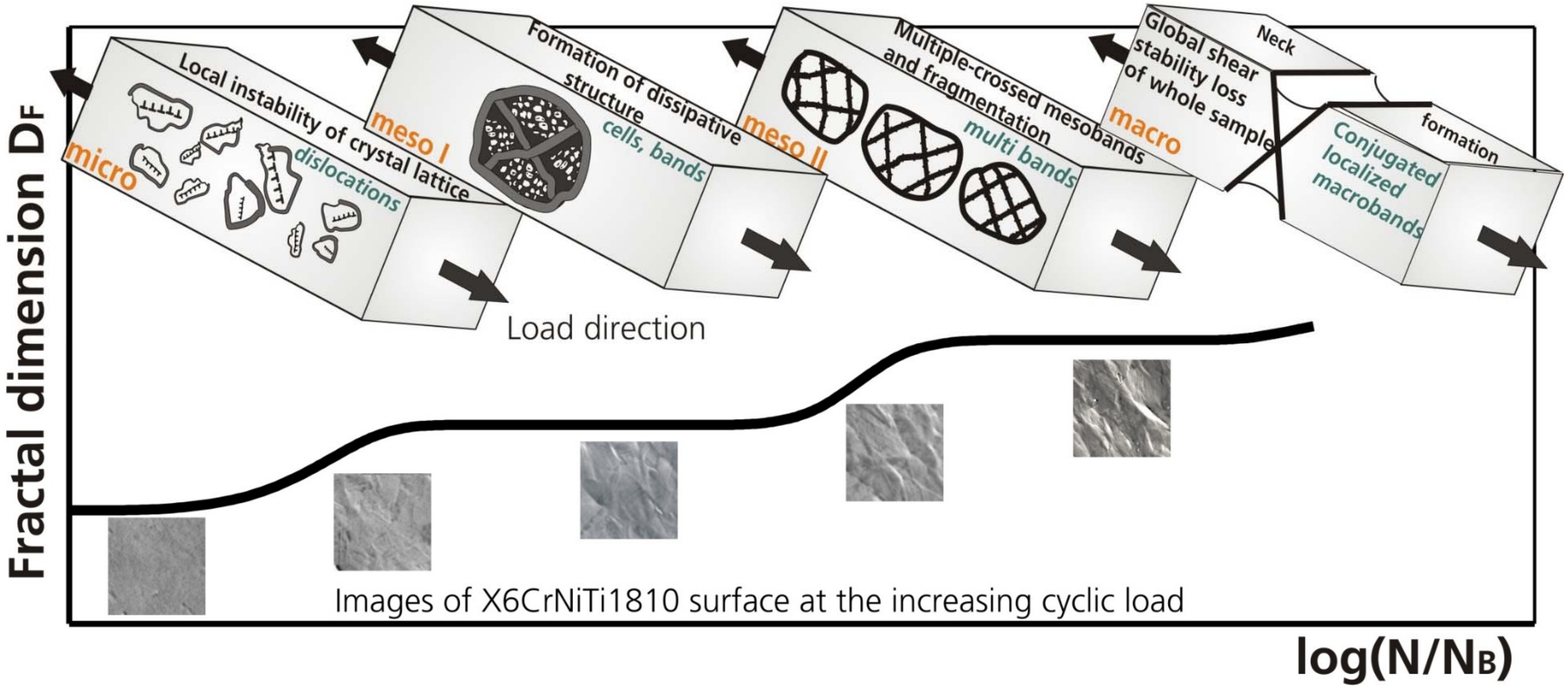
Macro level

Mini cracks, fatal crack ➡ Fracture mechanics

source: H. Mughrabi, F. Ackermann: »Persistent slip bands in fatigued face centered and body centered cubic metals«

Mesoscopic Deformation Structures

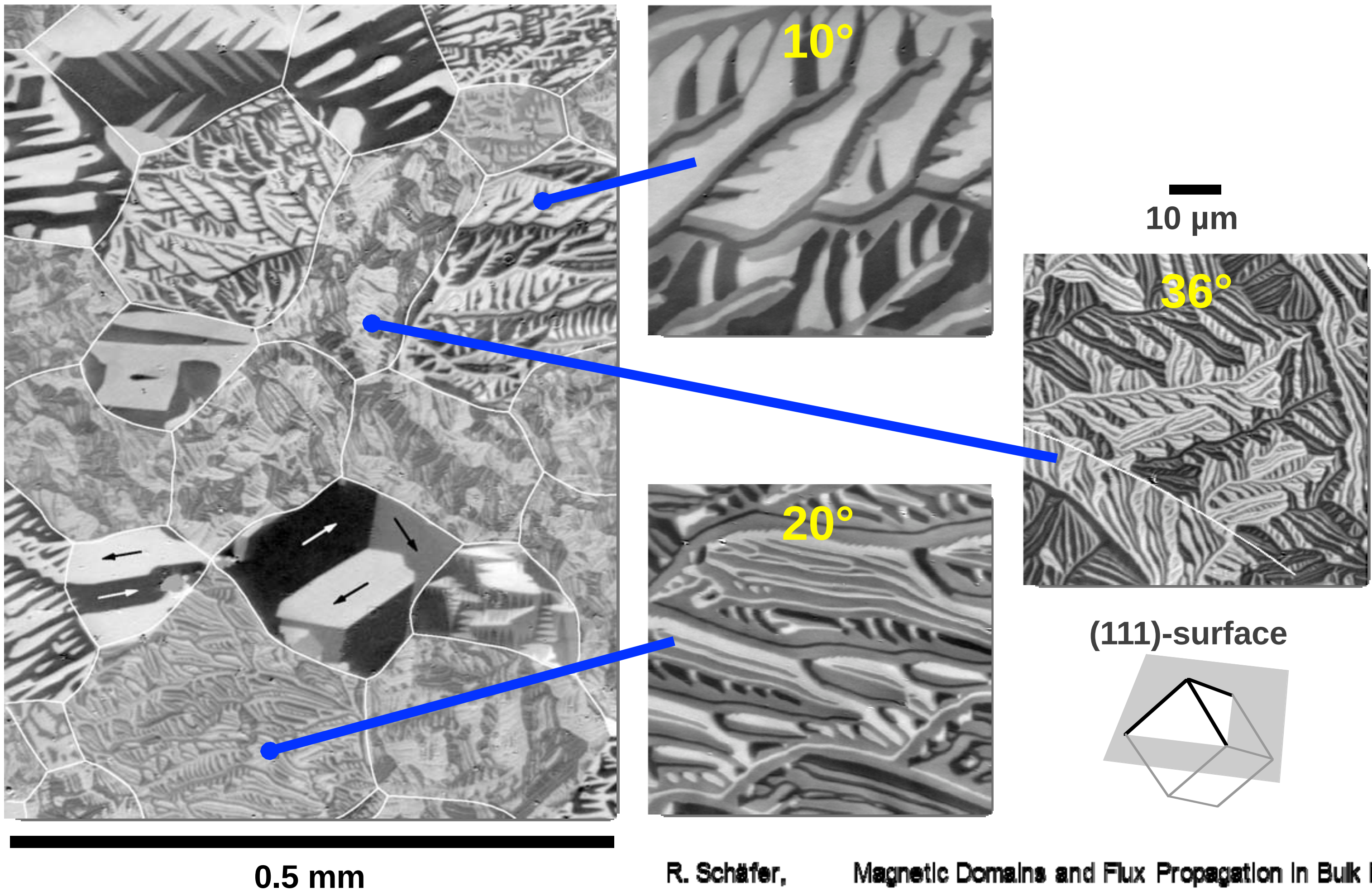
Scale levels of shear stability loss in deformed solid



N - cycles number , N_B - number of the cycles till the sample break

Juergen Schreiber[1],Ulana Cikalova[1], Andrey Bulavinov[2], Sandra Dugan[3], Hans-Peter Maier[3],
Reactor Safety Research: Public Project 129 925 , »Evaluation of the materials fatigue and the residual lifetime of industrial components by the scaling behavior of noise signals - Fractal analysis II «

Non-oriented FeSi Sheet

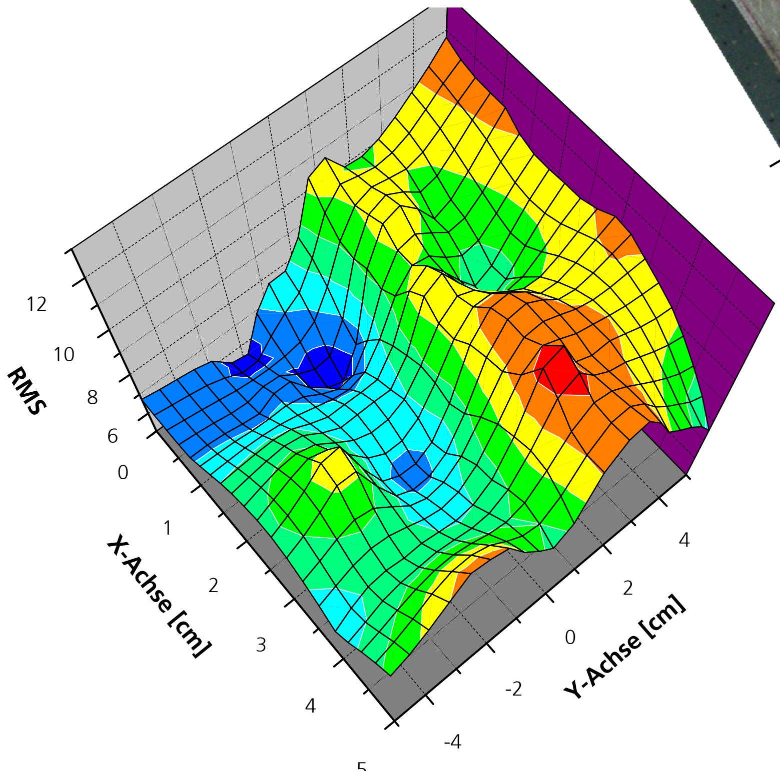


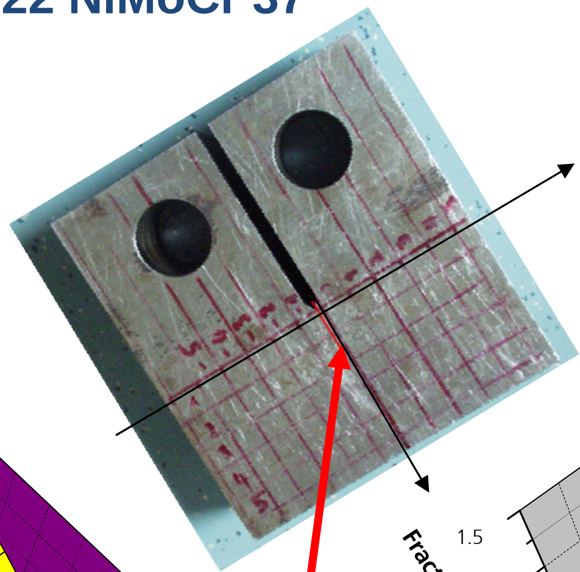
R. Schäfer, Magnetic Domains and Flux Propagation in Bulk Magnetic Material; Leibniz Inst. for Solid State and Materials Research (IFW) Dresden, Germany

Barkhausen Map of Fatigued CT Sample

22 NiMoCr 37

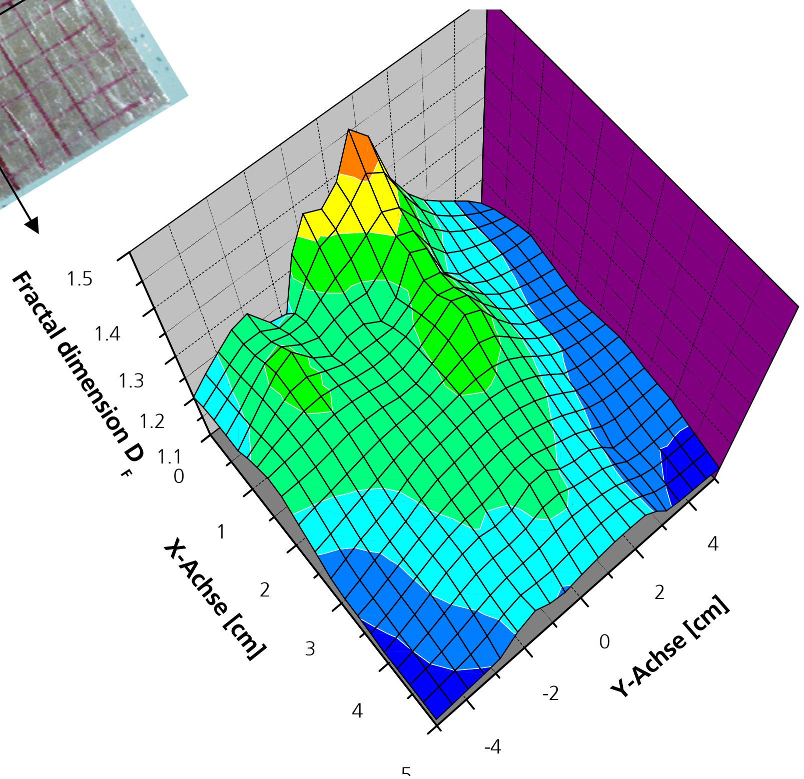
RMS ~ Residual Stress





Crack

Fractal Dimension



Fatigue in Composite Materials

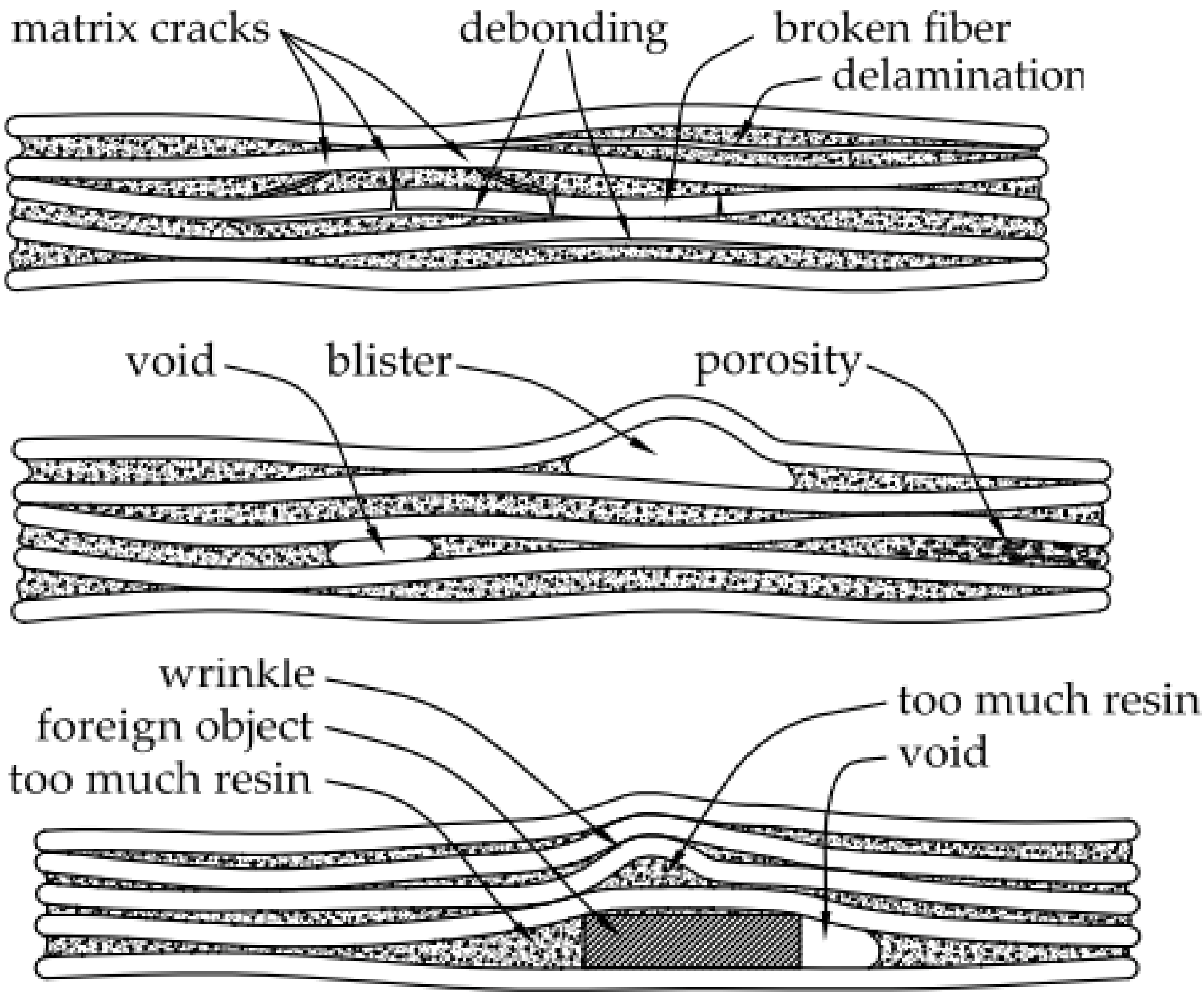
- In metals the nucleation and growth of damage is well understood.
- Many decades of experience exist
- For composite materials damage nucleation and growth is still a matter of research
- Practical experience for material behavior under service conditions is limited
- For these materials NDE Techniques can help to examine degradation processes

Common Composite Defects

matrix crack, broken fibers, debonding and delamination

when air gets trapped between layers

inclusion and wrinkle



ZHU, Hong-yan, Di-hong LI, Dong-xing ZHANG, Bao-chang WU, and Yu-yong CHEN. 2009. "Influence of Voids on Interlaminar Shear Strength of carbon/epoxy Fabric Laminates." Transactions of Nonferrous Metals Society of China 19, Supplement 2 (0): s470-s475.

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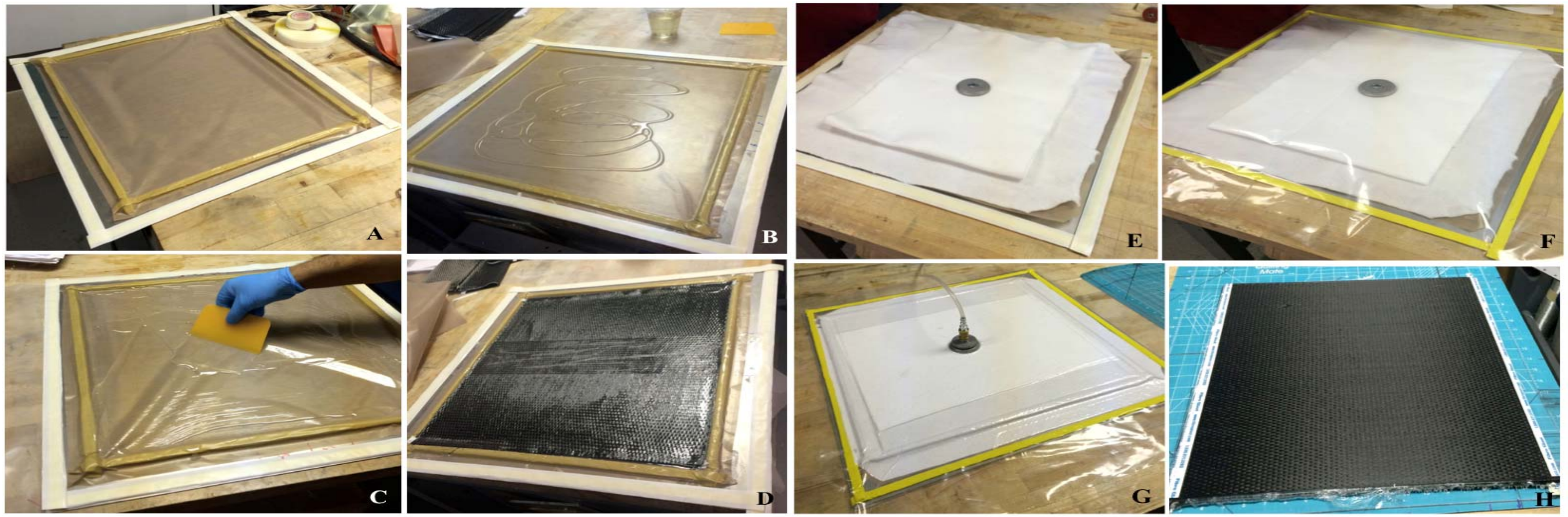
Approach: Panel Fabrication (Vacuum Bagging)



Hand laying up steps: (A) dam structure (B) Resin laying up (C) Resin distributing (D) Placing the Teflon insert at the panel mid-plane; on top of four layers (E) Placing breather (F) Placing vacuum bag and fiber and resin ready to be subjected to vacuum (G) **Applying vacuum bagging for 24 hours** (G) Panels after vacuum bagging-hard (H) Final shape of panels after being cured and ready to be cut.

Characterization Methods Applied

Imaging Techniques

- X-ray Imaging and Laminography (BAM)
- UT Volume Scans (TU Dresden and AMIC GmbH)
- HF Eddy Current (IKTS)
- Pulsed- and Pulsed Phase Thermography (NanoTest GmbH)
- Look in Thermography (NanoTest GmbH)

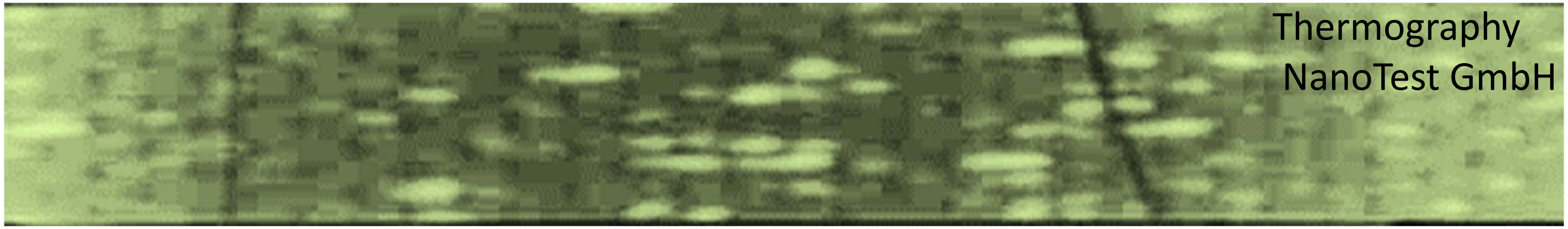
Integral Characterization Methods

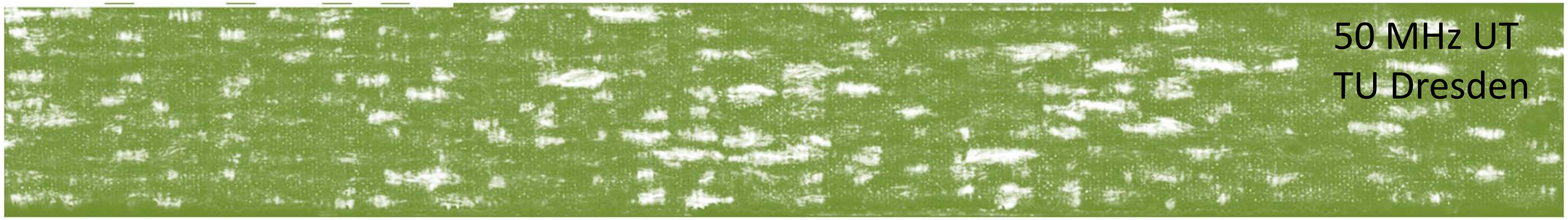
- Thermal Conductivity (NanoTest GmbH)
- X-ray Refraction (BAM)

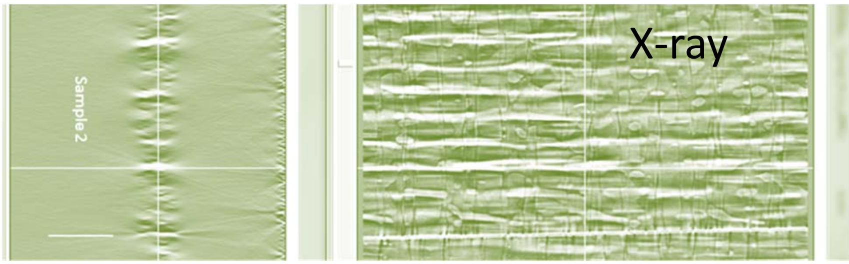
Destructive Techniques

- Serial Sectioning (Univ. Dayton)
- Fatigue Test (Univ. Dayton)

Comparison of Images for the Similar Coupon

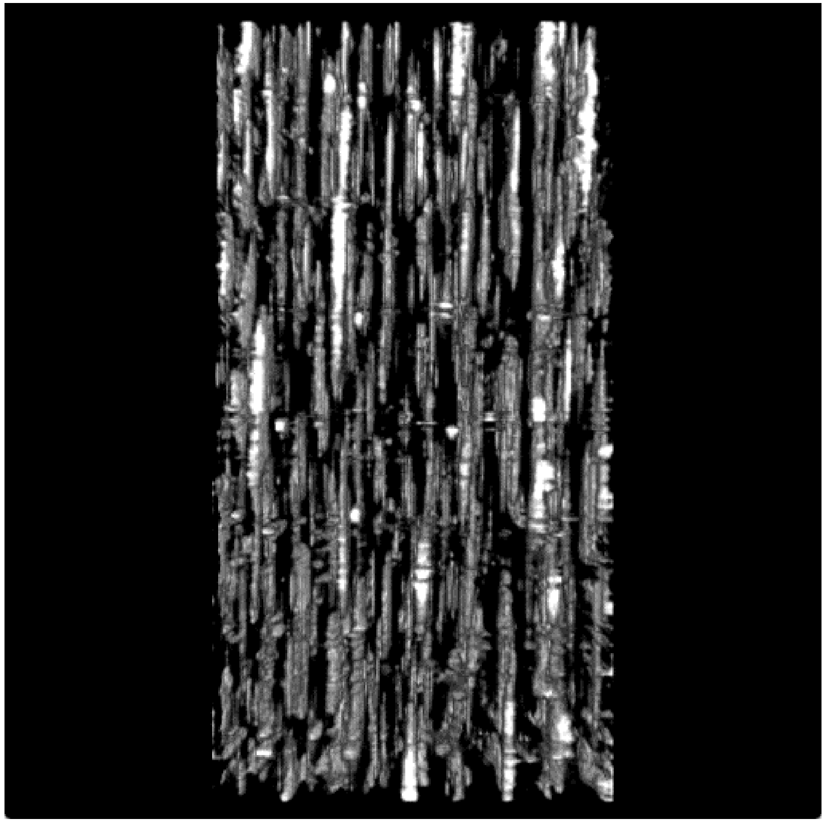






BAM

X-ray Laminography 3D Reconstruction



- What we see are a lot of artifacts for instance
- Imaging techniques provide a lot of information
- Extracting the relevant information is the challenge

Result Summary & Conclusion

Vacuum Level	Discontinuity Content measured by NDE	Bulk Thermal Conductivity W/mK	Void Volume Fraction measured by X-Ray Refraction	Mode I interlaminar fracture toughness (G_{IC}) kJ/m^2	Void Volume Fraction measured by Serial Sectioning
0 %	3.7-4.8 %	0.64 %	1.04 %	0.1	≈4.5%
50 %	3.1-3.9 %	0.69 %	0.89 %	0.15	≈2.5%
100 %	1.3-2.1 %	0.75 %	0.85 %	0.2	≈2.0%

- In this study, instead of giving a result of discontinuity percentages in each method, the parameters and features caused by discontinuity which appeared in the results of all imaging and averaging NDE methods were correlated; for example, **thermal results** correlated with ultrasonic **back scattering** with **density difference** by X-Ray techniques etc.
- Then, these NDE parameters and features were correlated with the mechanical testing performance and serial sectioning result.

Not a Summary

- NDE can provide a lot of useful (or useless) data about the structure, loading conditions, and health of a material or component.
- However, it is very unlikely that only by processing of NDE data and combining this with any kind of modelling reliable life predictions are successful, due to the complexity of design, material structure, and real world loading conditions (combines mechanical, thermal, chemical…).
- After decades of research worldwide we don’t have applicable solutions for metallic components, for composites the situation is even more complex.
- The worst case will be additive manufacturing, where uncertainties in the printing process and the resulting microstructure arise.

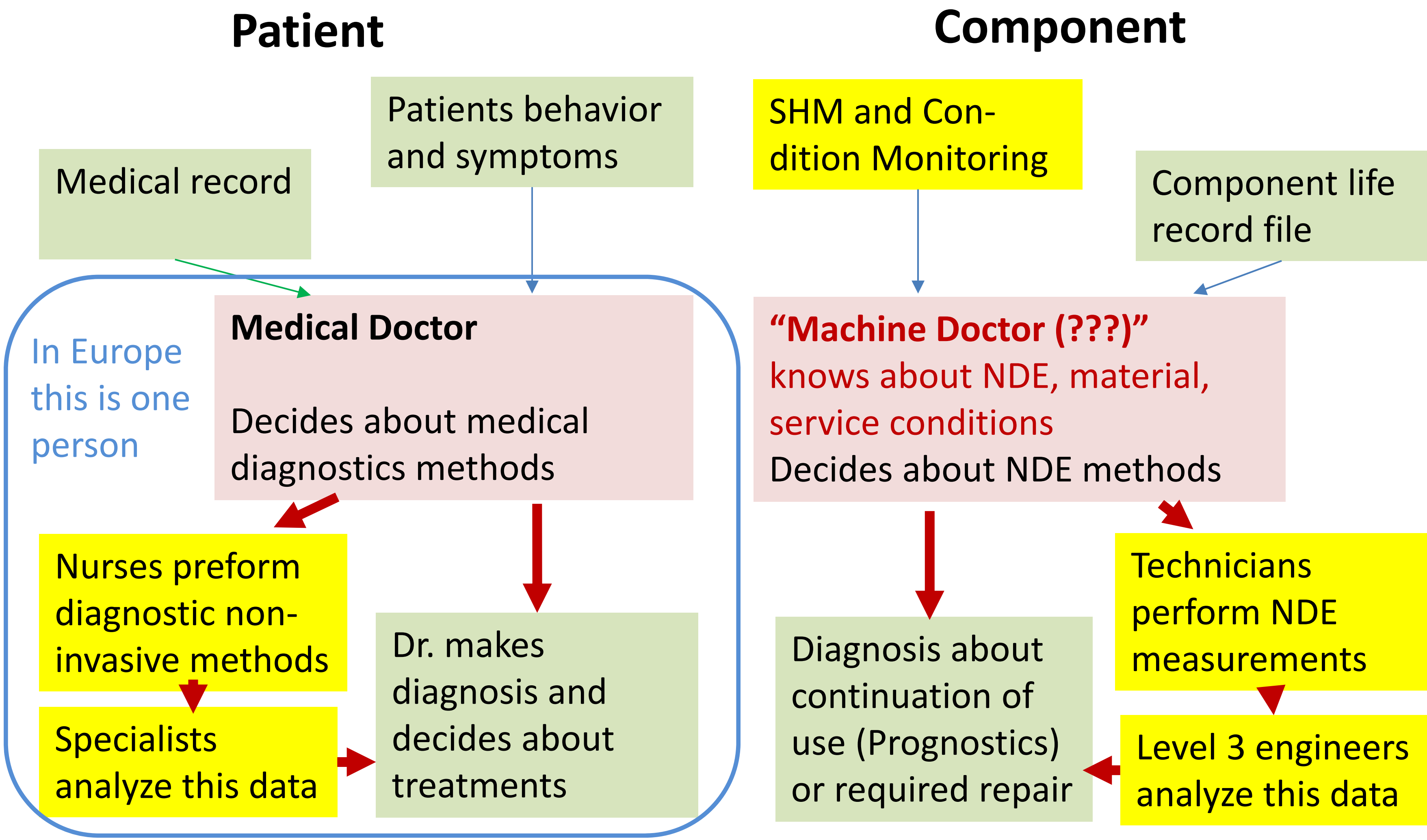
We need a new way of thinking in NDE

The traditional NDE philosophy:

=> One Component,
⇒ One Inspector,
⇒ One Instrument,
⇒ Decisions based on rules and standards,
will not satisfy future challenges where we theoretically print a complete aircraft.

We shall learn from medicine how to be successful in the future.

Learning from Medicine



Conclusion

- Todays technology provides us with excellent measurement tools, affordable, simple to handle, and high performance that we can access from everywhere, but we have to know what data we need and how to analyze.

- The Internet allows to use specialists worldwide to discuss results and decisions, but we have to know whom to ask.

- Powerful modeling tools make us believe that we can understand everything, but it is all based on assumptions.

- What we need to face future challenges in a world of composites, 3D printed components, smart structures and materials, and infinite data and information is a:

⇒ **"Machine Doctor" who knows about the potential of NDE methods**

⇒ **but also the materials structure and properties, design concept and service conditions.**