Session Discussions fell in two categories

A.] Grain size-scale up (bottom-up) understanding of mechanical properties, as probed by monochromatic beam ~ 80 keV diffraction. For this group the powder diffraction insertion device would be useful in its present form, with additional facilities.

B.] The greatest part of the discussion focused on the unanimous recognition of the need for materials/engineering diffraction facility for crystal-phase and strain field mapping. This 30-200 keV diffraction facility (dominantly white beam) requires a multi-pole superconducting wiggler insertion device.
Micromechanical Behavior of Metallic Alloys

1. Real answers come from a blend of models and tests.
2. Metallic crystals deform according to their orientation and neighborhood - micromechanically multiaxial.
3. Crystals subdivide during deformation.
4. Building realistic model specimens requires 3D structural information.
A.2 Strain Pole Figures and Stress Distributions

- Powder diffraction
- Diffractometer
- Fatigue-rated load frame
- Measure strain pole figures
- Calculate stress

"specimen holder" 400 pound mechanical testing machine

\[ \sigma_{12} \]

180 MPa
Single Grain, Single Spot Experiments - 3DXRD

A.3

Detector B

APS - 1IDC
Risoe

Detector A

"pocket size" load frame

- Energy > 50 keV, beamsize - 10’s of grains
- Detector A ~ .7m, rings - Single grain stress
- Detector B ~ 8m, single spots - grain subdivision
Grain Reconstruction

- Diffraction-based grain “tomography”
- Non-destructive reconstructive method
- Forward projection - Bob Suter CMU

APS -1IDC
• White beam energy dispersive (EDXRD) + monochromatic x-ray diffraction
• 30-200 keV range, multi-pole superconducting wiggler.
• crystal-phase and strain field mapping

Diamond JEEP Materials & Processing facility prototype.

More Hutches for NSLS-II
fatigue crack
steel
α-Fe

Transmission detector (radiography)

\[ E_{hkl} [\text{in keV}] = \frac{6.199}{d_{hkl} \sin \theta} \]

\[ 3-12^\circ \sim 2\theta \]

Ge-Detector

1m diff. coll.

 incident collimation system

coating

specimen

strain

Like having imbedded inter-atomic strain gauges.

Diffraction volume

x-y-z positioning system

Energy Dispersive Diffraction

- Fingerprint of structures phase evolution/mapping
- Precision lattice parameter shifts

“White Beam”

NSLS ring

Wiggler

\[ \theta = \frac{\Delta k}{k} \]

Precision lattice parameter shifts

\[ \theta = \frac{\Delta k}{k} \]
Hardening of cement - hydration reaction - followed by Si-O polymerisation - lots of heat given out early - unstable phases formed (e.g. 31keV peak)

**EDXRD:** penetration & fast data acquisition

**Chemical Kinetics** (crystal structures vs time)

**THINK BATTERIES**

Hardening of cement
- hydration reaction
- followed by Si-O polymerisation
- lots of heat given out early
- unstable phases formed (e.g. 31keV peak)

**Jupe et al, PR, B53. R14 697 (1996) hydration of tricalcium aluminate**
Chemical Spatial Distribution (crystal structures vs position map)

THINK OPERATING BATTERIES & FUEL CELLS…

Tomographic Energy-Dispersive Diffraction Imaging (TEDDI)

6×13 mm area in bulk (80 mm. thick) concrete block

Paul Barnes Birkbeck College, presentation on Internet
(Adv. of TEDDI for studies of mat. chem. proc.and env. syst.)

Future: Map crystal structures vs. position, time, temperature, voltage/current (batteries-fuel cells)... and their combinations
Aerospace/energy: Turbojet Engine
– prolusion and electric peak power generation

Hostile environment
– high strength (low weight)
– high temperatures
– high part $ 
– high cost of failure
– advanced materials

Compressor blades and mounting
Ti-6-4 alloy

Engineered Compressive Stresses
- fatigue life extension (nX)
- foreign object impact (FOI) damage reduction
Selected examples of compressive stress engineering

Laser Peening (Shock Peening)

Shot Peening

Used extensively in Ti-6-4 engine component processing

Application: X-ray profiling of stresses
- Depth & magnitude of compression
- relaxation under temperature/load
- validation of finite element calculations
destructive residual stress measurement techniques

Low Plasticity Burnishing (LPB)

Under study

Excerpts from Proceedings 2007 Residual Stress Summit & Internet
Ti-6-4 alloy aerospace specimen

E = 118 GPa  \( v = 0.33 \)

M. Shepard  AF Lab.  WPAFB

Shot peened surfaces

Compression magnitude & depth profiled (detailed)

Ti-6Al-4V

NSLS Croft et al

20 \( \mu m \) resolution

Can now study relaxation fatigue, \( T(C^o) + \) stress + ...

B.7
Laser peened Ti-6-4

NSLS X17B1

DEEP COMPRESSION!

Example*

(*Representative of x-ray capabilities only not of optimized processing technique.)

Compare shot peened Ti-6-4

Excerpts from Proceedings
2007 Residual Stress Summit & Internet
Laser peened Ti-6-4

NSLS X17B1

DEEP COMPRESSION!

Compare shot peened Ti-6-4

DEEP COMPRESSION!
Turbine Blades and Vanes
Understanding/advancing complex turbine blade structures (residual stresses)

TBC compressive stress
- accumulated damage - relaxation
- dramatic mean stress drop
- $\Delta T$ currently limited

At issue: Loss of the engine part, engine, or a class A mishap.

Application: X-ray profiling of stresses & relaxation in complex structure.
Profiling of plasma sprayed alumina-ceramic coatings on Ti (life enhancement)
4-point bending

\[ \text{Ti} \quad \text{Al}_2\text{O}_3 \quad \text{Ti-[110]} \]

Load response study composite layers

\[ \gamma\text{-Al}_2\text{O}_3 \text{ (spinel)} \quad [440] \]

\[ \text{Bond- coat} \quad [102] \]

\[ \text{Ti (hcp)-substrate} \quad [110] \]

\[ \text{Energy (keV)} \]

\[ \text{Nano-alumina-coating} \]

\[ \text{as-prepared} \]

\[ \text{Ti} \quad \text{Substrate} \quad x_3 \]

\[ \gamma\text{-Al}_2\text{O}_3 \text{ (spinel)} \quad [440] \]

\[ \text{Energy (keV)} \]

\[ \text{Load response study composite layers} \]

\[ x_3 \]

\[ \text{NSLS X17B1} \]
Rivet/bolt holes
- stress concentration
– fatigue failure

Split sleeve cold working
(expansion)
- compressive stress

Aerospace applications

Excerpts from Proceedings
2007 Residual Stress Summit
& Internet
Split sleeve cold worked results

$\varepsilon_{\theta\theta}$ - crucial compression

dramatic & long ranged

$\varepsilon_{rr}$ – more complicated

EDXRD NSLS X17B1

Example*

(*Representative of x-ray capabilities only not of optimized processing technique.)

Ti-alloy

![Graph showing stress strains](image)
Fatigue Crack Strain Field Work

Crack Tip Strain Mapping

NSLS X17B1

Crack Front and OL “scar” Mapping/Imaging

(immediately after overload, OL)

B.15
Welding applications example

X-ray strain/phase mapping could be used to validate FE assumptions/calculation for crucial dissimilar metal weld studies or nuclear power applications.
Gear fatigue cracking and compressive stress mitigation

Test Gears:
- Single Tooth Bending
- Dynamic Testing

Amenable to in-situ x-ray studies

Excerpts from Proceedings 2007 Residual Stress Summit & Internet

(Korsunsky et al., Oxford & SRS, 2002)
Some Capabilities/Concerns
Superconducting wiggler 30 – 200 keV
Multiple Hutches e.g. 5 - 3 simultaneous
white beam or monochromatic hutches (Side scattering monochromatic )

Last hutch (s) beyond confines of present building (e.g. Diamond JEEP materials line with hutch 11m X 7m)

In situ high capacity multi-axial loading frame + In situ high temperature

Magnetic field capacity

New software + software/inter computer interface.
Full integration between motor driving computer control and data collection control.
Real-time (during run, point by point) data processing
( currently only possible only after scan)
Data storage of sample positions with spectral data
Naming a chronology of data sets--- storage/retrevial capacities...

Laser scanners – digital image of specimen/component sample (e.g. SSCANSS) for rapid sample change, alignment and mapping.