Application of neutron radiography to industries and large structure inspection

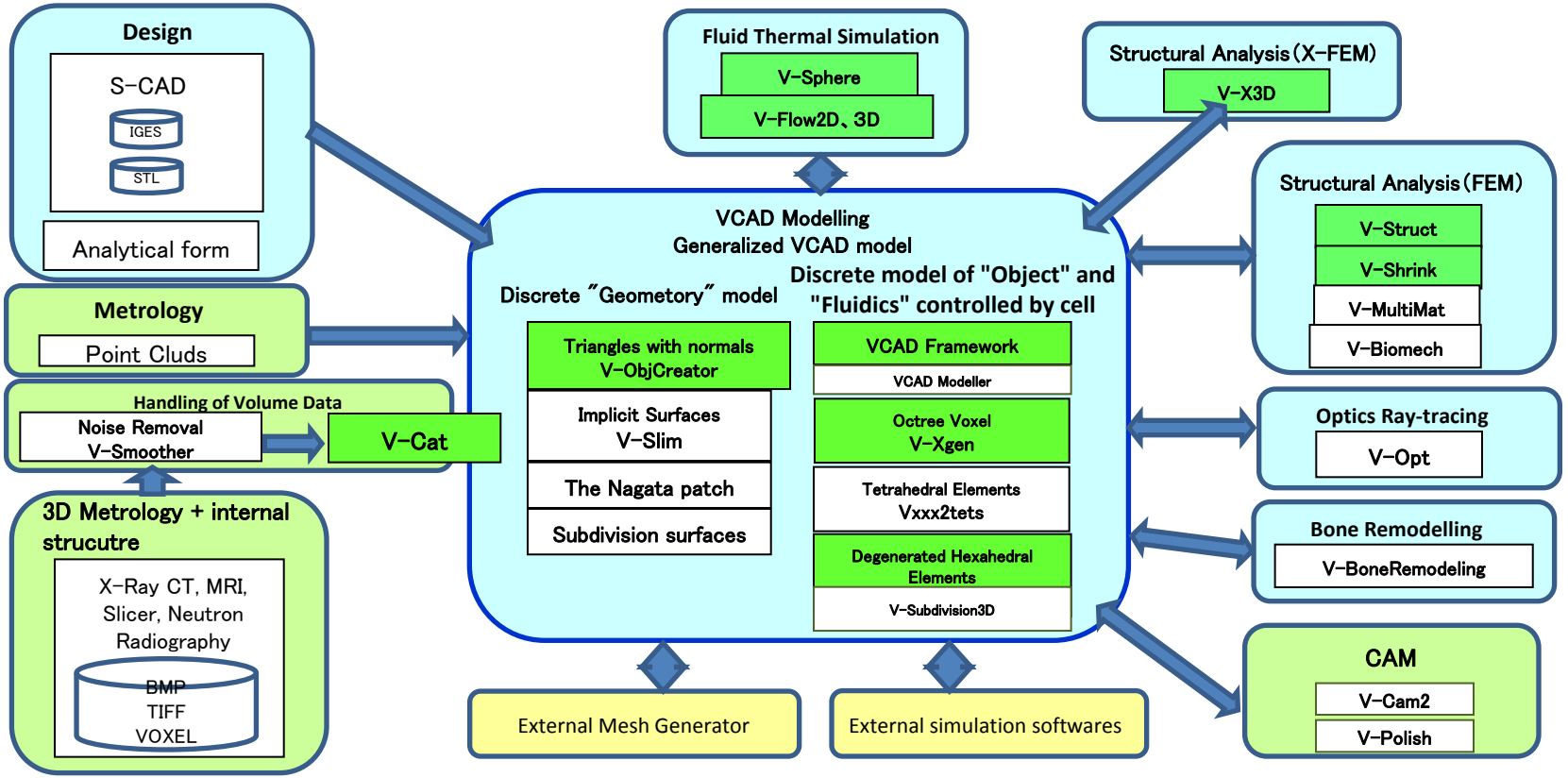
Yutaka YAMAGATA
RIKEN, Innovation Center,
VCAD Applied Fabrication Team

Demands for non-destructive testing in industries

- Recent problems in production technology in Japan
  - Lower cost, energy efficient, recycled material, high quality, product liability
  - Slim, lean but sufficient design for optimum cost/performance
- Utilization of computer simulation in the design process is keen
  - Optimize hydrodynamic form
  - Minimize car body weight
  - Simple and sufficient design of engines, motors and batteries
- Computer simulation (Structural, CFD/thermal, molding...) are not always accurate without metrological data
  - Methodology to "measure" real physical phenomena become important
  - Fluid visualization, stress measurement, temperature, magnetic/electric field, chemical reaction and so on
- Significance of Non-destructive testing goes up
  - Product liability, quality control

VCAD System Research Program

- VCAD System (Volume CAD) can realize compter model based on "real" object - VCAD model
- Based on VCAD model, various computational simulations can be carried out (CFD, Structural, molding, optical ...)
- These simulations are far realistic than those based on CAD models



V-Sphere **Software in public release**

type "VCAD" at Google to see VCAD Website http://vcad-hpsv.riken.jp/en/

3D Volume data input method to VCAD System

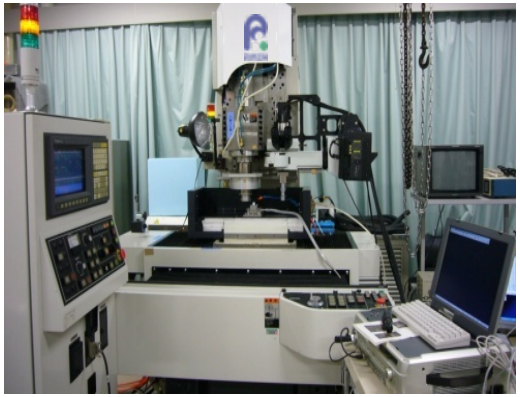
Metrology of volume 3D data of real "objects"

INPUT to VCAD

- CAD Design data
- Surface metrology
- volume 3D data

X-ray CT fo industrial and medical

Confocal laser microscopy



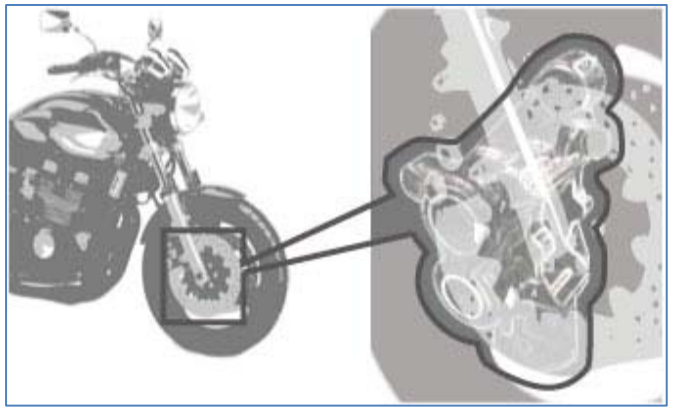
3D internal structure microscopy (Slicer)

Neutron Radiography (JRR-3)

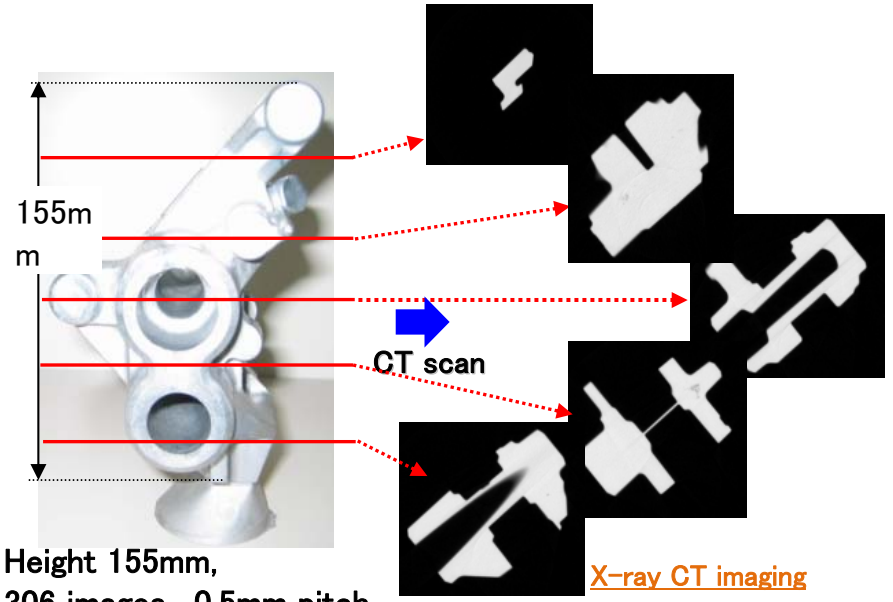
Example of simulation based on "real" object

- Based on X-ray CT image, a "real" simulation of aluminum casted brake caliper is conducted using VCAD system softwares

1. Measurment of actual product



motorcycle brake caliper : cast aluminum



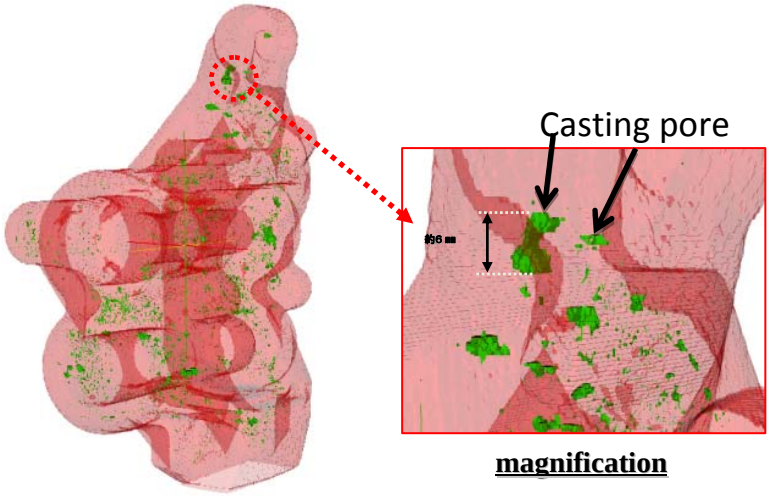
Height 155mm,
306 images , 0.5mm pitch

An X-ray CT scanning device is used to measure 3D shape of industrial parts. VCAD software "V-Cat" can extract the information from the X-ray CT scan or MRI tomograms and transfer a variety of information on the material into the VCAD framework, which already contains information on the complex internal structure and material distribution.

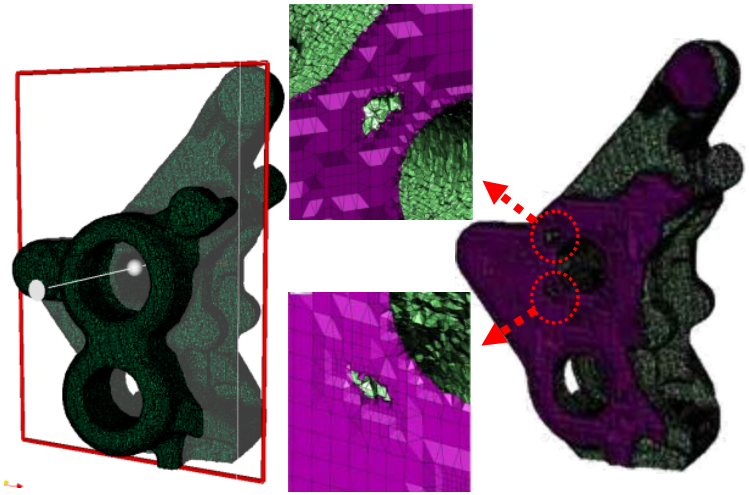
X-ray CT instrumentation

2. Representation of actual product data

VCAD data can grasp quantitatively the size of each pore and theist relative position. VCAD data makes it possible to detect the hidden defects of a product while it is still in the casting stage.



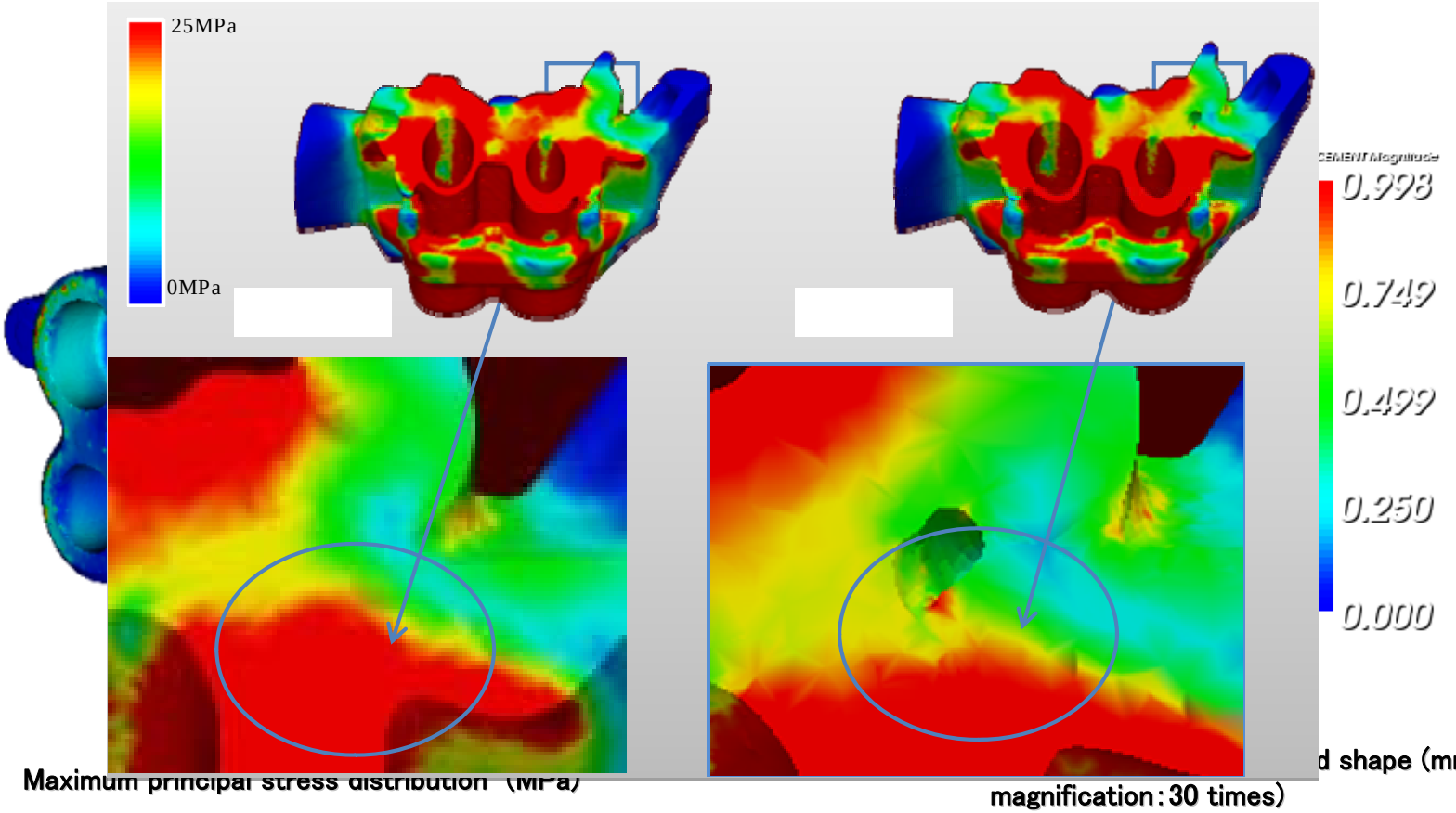
Detecting casting defects



Meshing and application of boundary conditions for structure analysis

3. Structure analysis using measurement data

VCAD software “V-Struct” can dealing with VCAD data of actual product measurement and analyze numerically static fracture strength. The VCAD system can be operated easily, from the extraction of measurement data to structure analysis.



Structure analysis result with measurement data

Limitation of X-ray CT and possibility of neutron radiography

- Limitation of X-ray CT
  - Penetration depth, especially for heavy metals including steel
  - Not able to observe light elements; plastic, water and oil
- These are well-known problems in X-ray imaging, but due to the increasing demand for "real" object modelling and simulation, they are very important.
  - Neutron radiography can solve these problems

Cast iron valves

Cast iron gear box

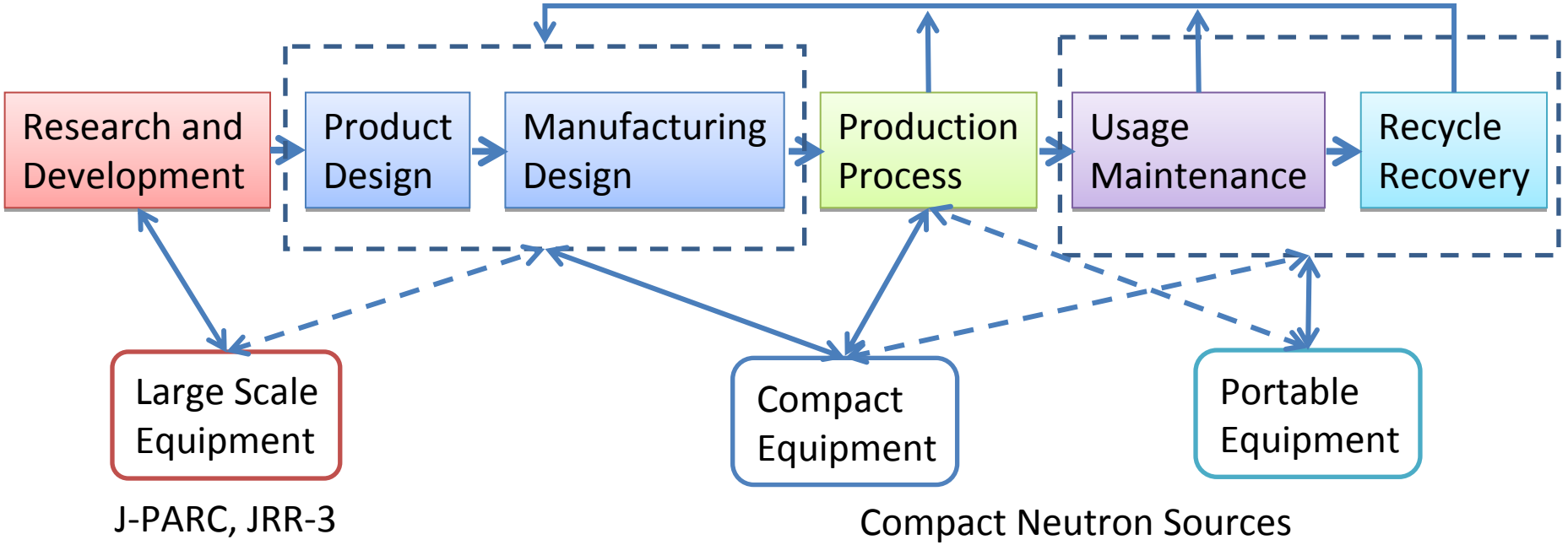
Large steel welded components

Plastic injection molded parts with metal inserts

truck for train

How neutron radiography is used in industrial R&D

- Depending on the phase of production process, characteristics of measuring instrument may differ
  - R&D phase : precision analysis with large scale equipment
  - Production design phase: Less precise analysis with compact and convenient equipment
  - Mass production, maintenance, recycle phase: On-site analysis using portable equipment

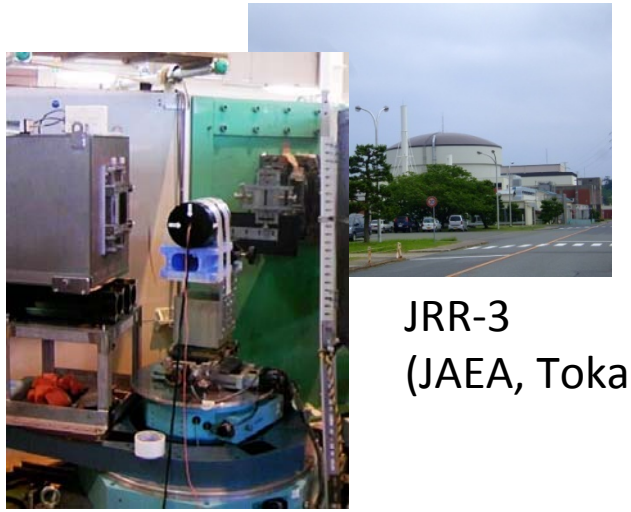


Neutron radiography examples

- Neutron radiography experiments are conducted at JRR-3 guide hall MUSASI-H/L ports, which have similar beam flux expected for compact neutron source.

Steel pyramid, Cylinder with slits

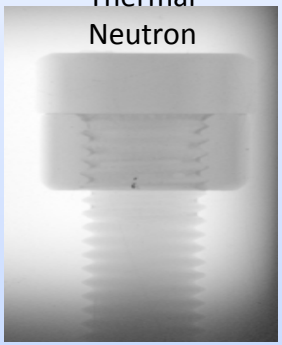
- Radiography experiments are conduced at MUSASI-L ports.
- Beam flux is close to compact neutron source.
- Imaging plates and high sensitivity CCD camera with scintillater plate were used.



JRR-3
(JAEA, Tokai)

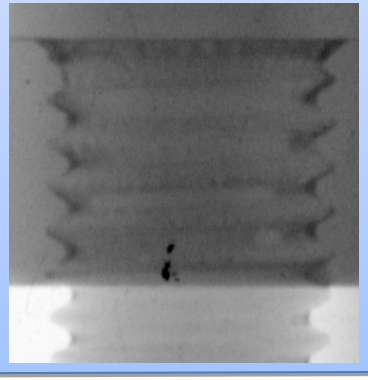
MUSASI-L
2.4 Å, semi-monochromatic
flux ~ 8×10^5 n/cm2/sec
Beam diameter ~ 5cmx4cm

X-ray
(450kV)

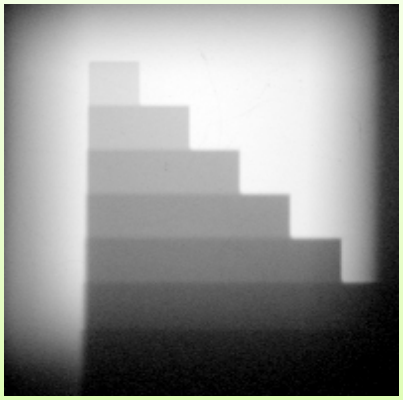


Thermal
Neutron

M12 Screw

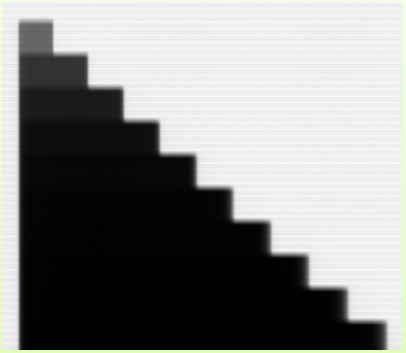


Magnified
Image



Thermal neutron
radiography image

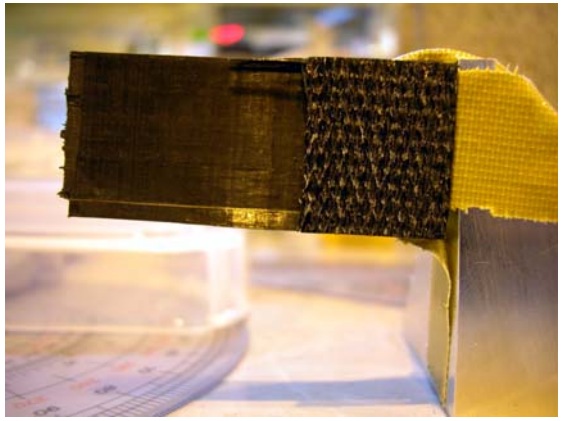
5cm
Steel pyramid

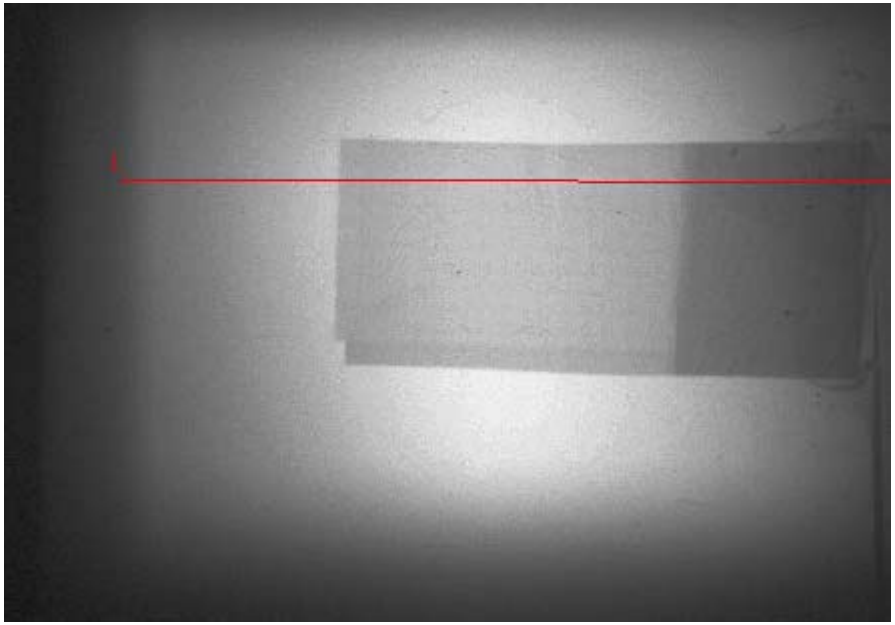


X-ray image（450kV）

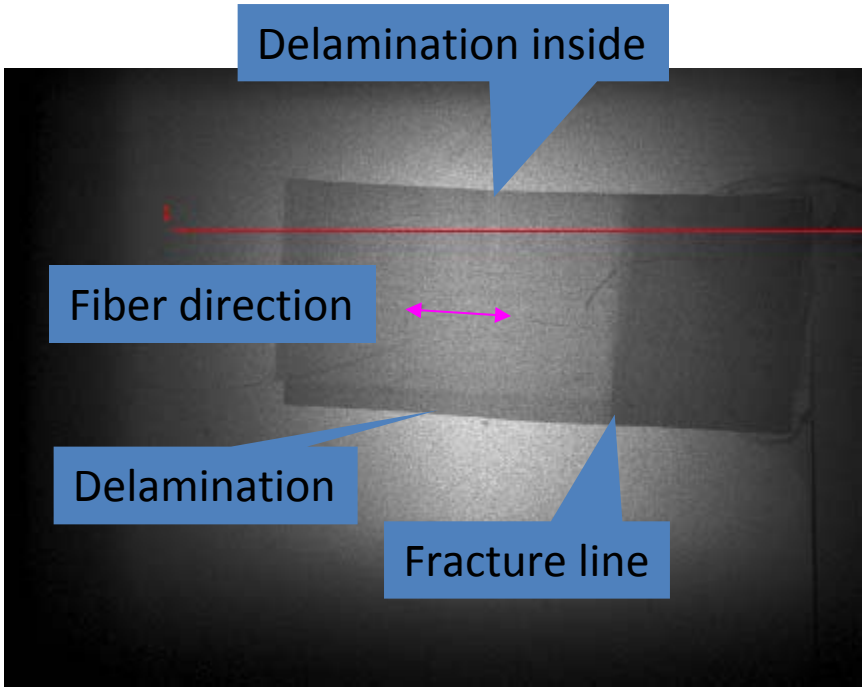
Composite material

- Carbon fiber composite material after fracture test.
- Fiber structure inside sample such as delamination, fiber direction can be observed.
- Effect of scattered neutron beam can be lowered by taking certain distance from IP.





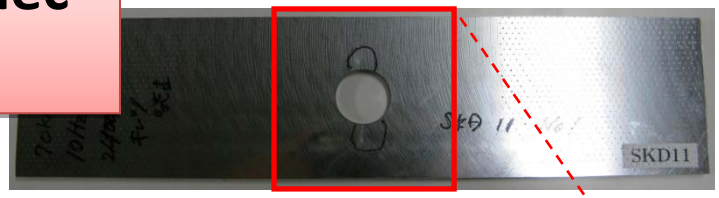
Sample on the IP
(Strong scattered beam)

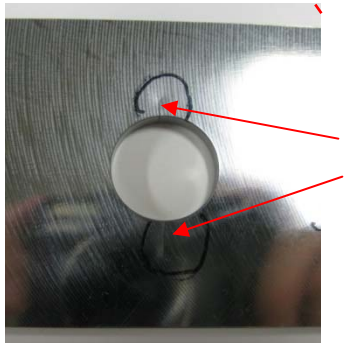


10mm distance from IP
(Scattered beam lowered)

Crack caused by fatigue failure test

Test piece

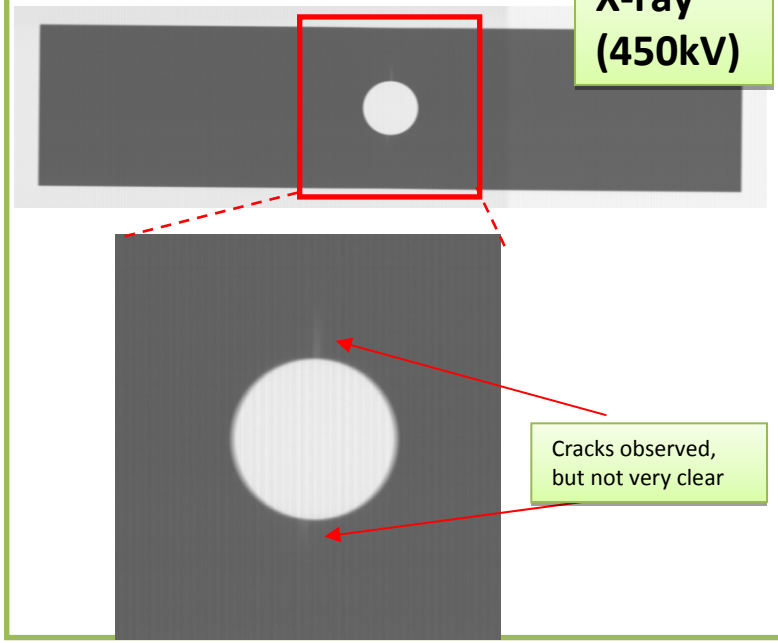




Material : tool steel
Tensile force: 70KN—7KN
Rep. freq. : 10KHz
Rep. Cycles: 24,000

Crack is visible at surface, although not open.

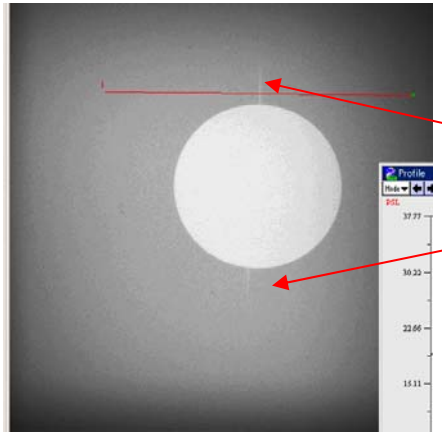
X-ray (450kV)



Cracks observed, but not very clear

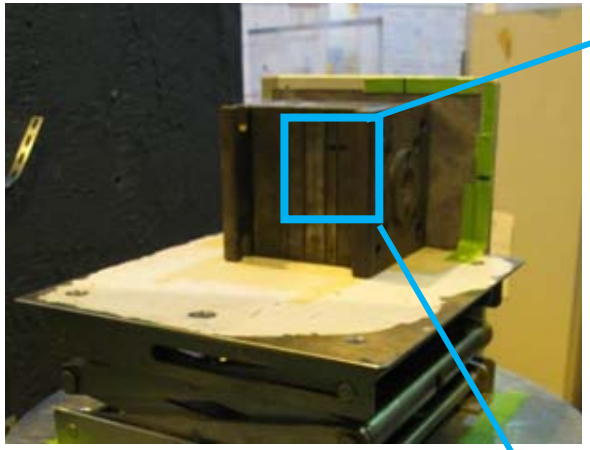
- It was possible to observe unopened fatigue crack both by X-ray and NR, but NR image seems to be clearer. (Possibly resolution difference in imaging system.)
- It may be possible to detect cracks inside thick steel object using NR.

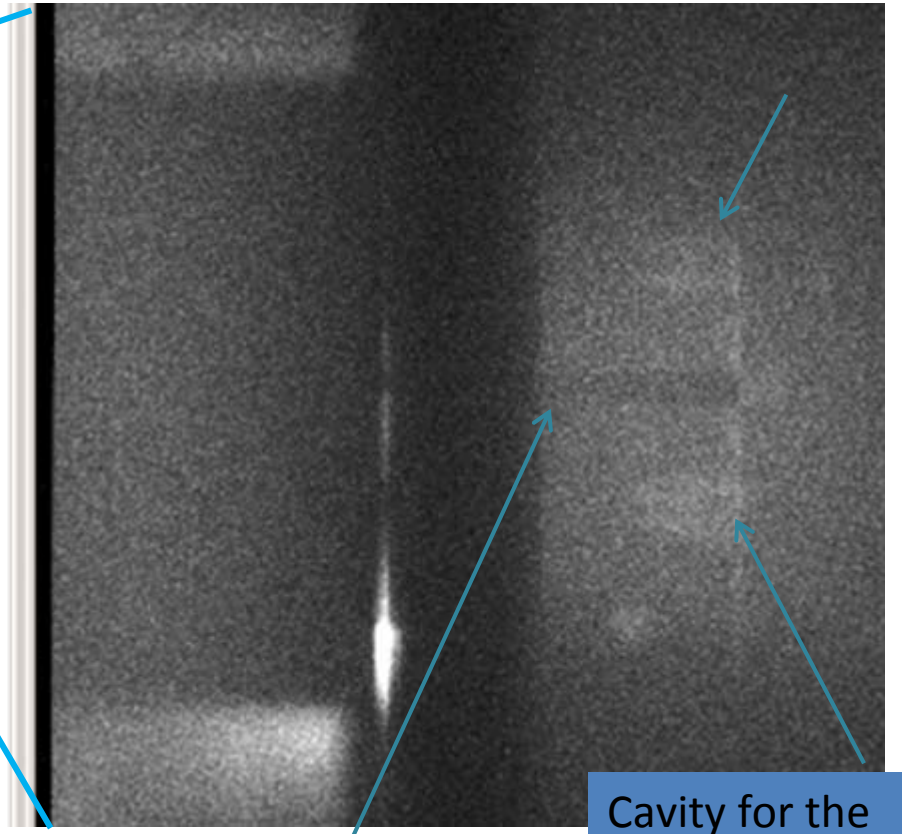
Neutron Radiography

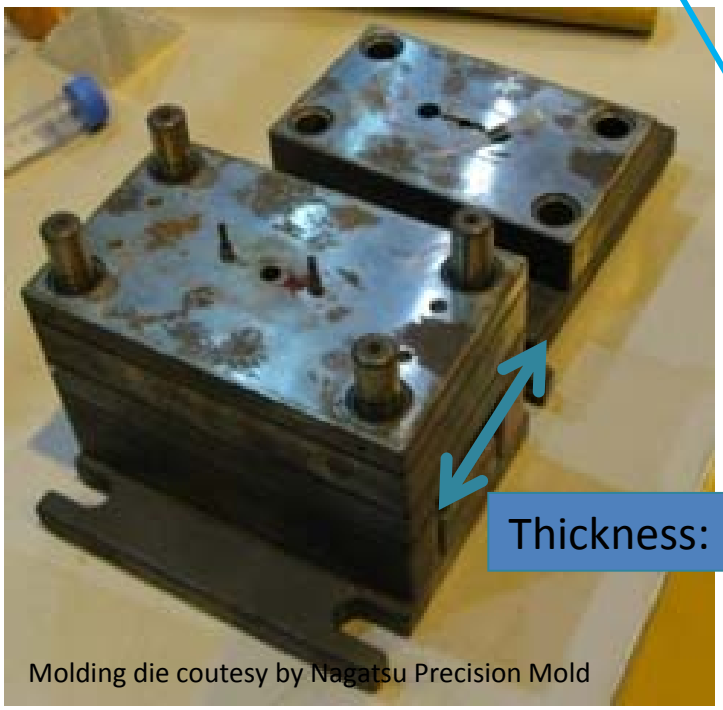


Clearer image of crack

Plastic injection molding die







Thickness: 7．5cm

Molding die coutesy by Nagatsu Precision Mold

Cavity for the product

Plastic material inside runner

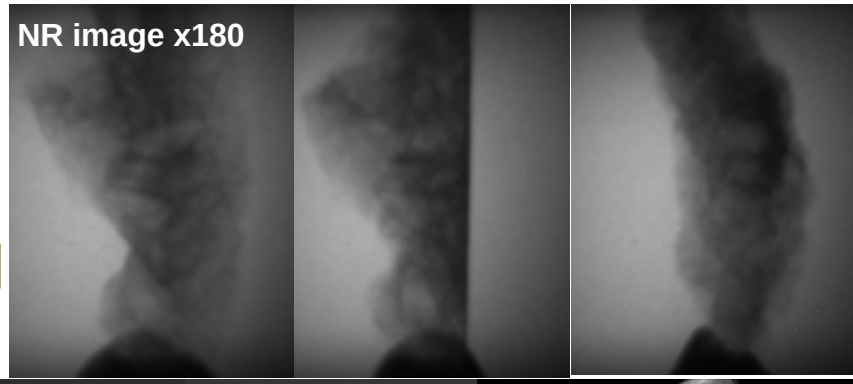
Exp. time: 60min by IP

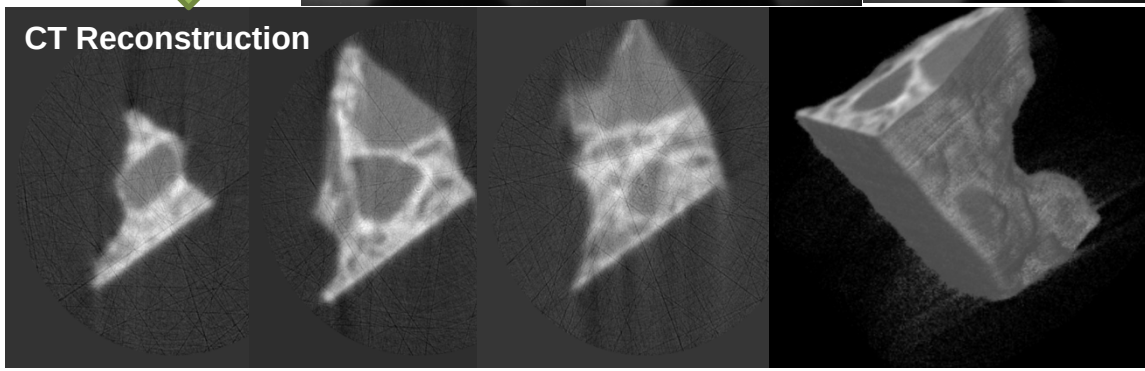
It was possible to distinguish empty cavity and filled runner inside molding die.

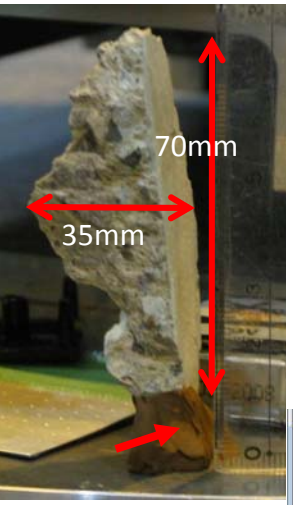
Concrete sample

-CT reconstruction and simulation-

- Material : Cement and aggregates
- NR image taken by LiF/ZnS:Ag scintillator + CCD at MUSASI-L (JRR-3)
- After CT reconstruction, cement and aggregates are separated by V-Cat software and mesh was generated.

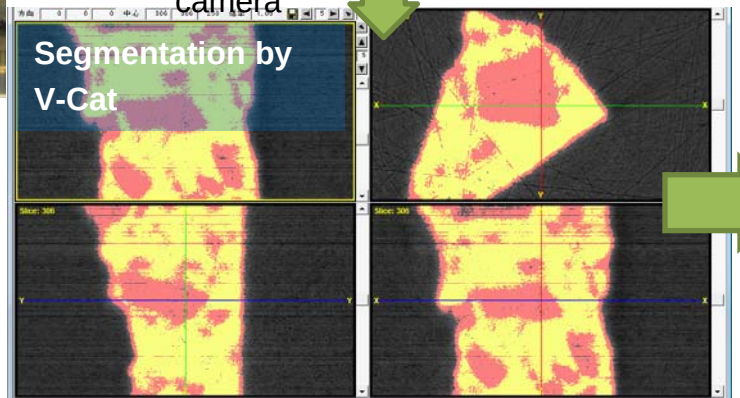




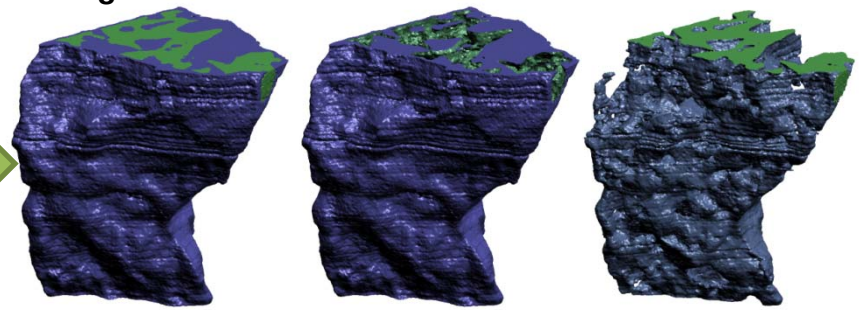


Concrete sample

Cooled CCD camera



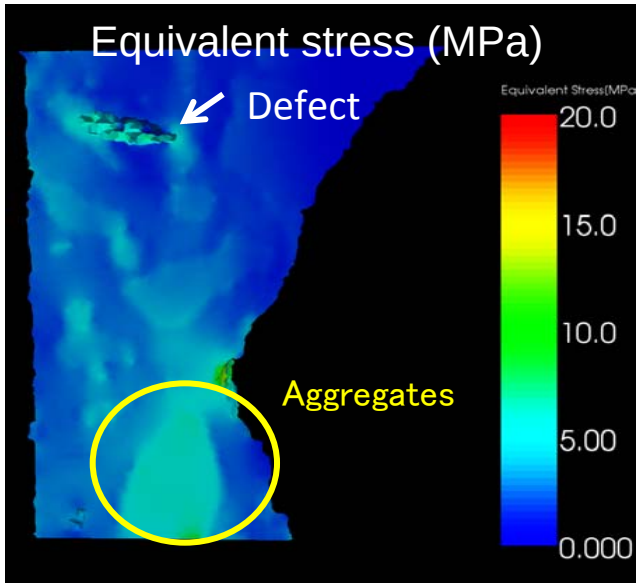
Mesh generation



Structural simulation by V-Struct

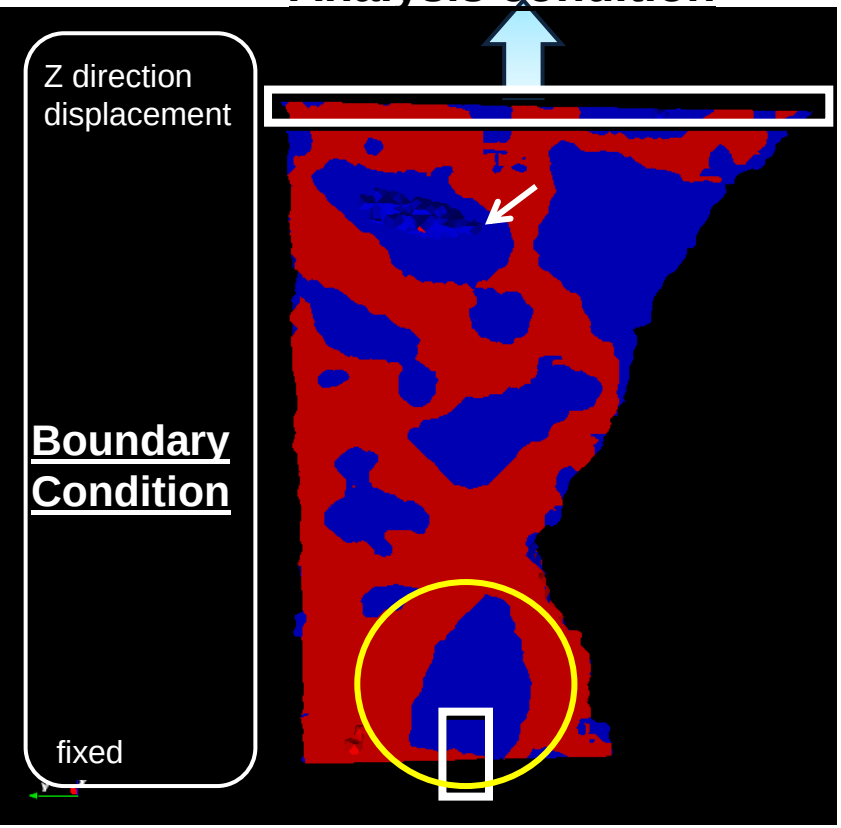
Analysis conducted by V-Struct .
Evaluation of multi-material sample is possible by NR and VCAD softwares.

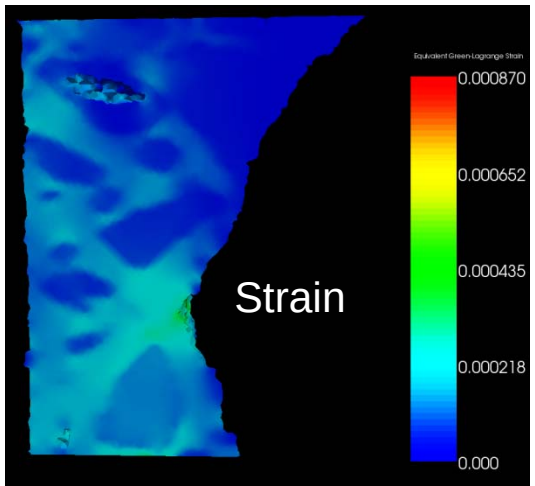
For detail, please come to Poster!

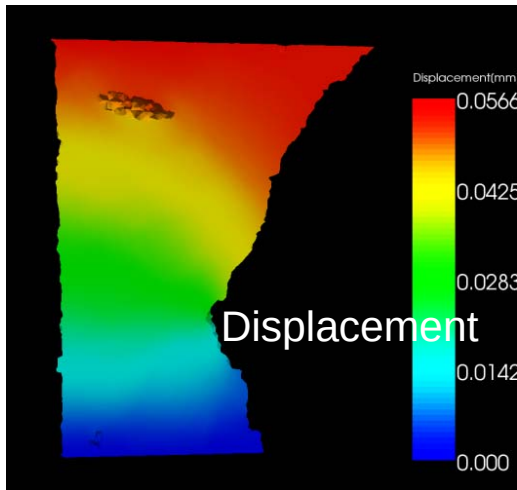


Stress concentration to boundary of differet materials observed.

Analysis condition







Movements toward compact neutron imaging system and its applications at RIKEN

- A committee for the discussion of compact neutron imaging systems and its application to manufacturing technologies and large structure inspection was called for at RIKEN.
- 38 members from universities, research institutes and companies participated in the discussion.
- Three working group was organized: compact neutron imaging system WG, manufacturing technology application WG, and large structure inspection application WG.
- Each WG proposed possible applications of neutron imaging and feasibility was discussed.

- Besides, two symposiums are organized by RIKEN in collaboration with PWRI, KEK and JAEA.

Manufacturing process applications
-applications proposed by committee disucssion-

1. Lean design

Stress/ strain measurement

Engine components

Drive Shaft

2. Electric components for hybrid/electric car

（1）Optimization of motor

（2）Performance optimization/ safety inspection of batteries

Strain measurement by pulsed neutron imaging (by Kiyanagi et al.)

Magnetic field (Nature Physics)

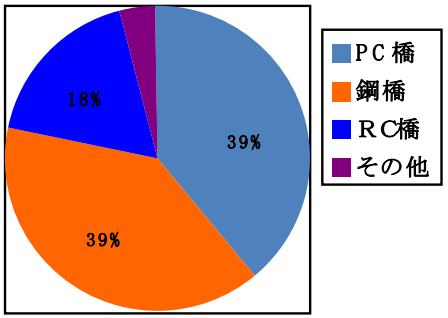
Temperature measurement (Kiyanagi et al.)

Fuelcell/ battery observation

Inspection of large structures

-Bridges, buildings, civil engineering-

- Bridge structures
  - Pre-stressed concrete, reinforced concrete, steel
- Inspection possibilities
  - Pre-stressed concrete beam
  - Steel reinforcement, steel truss strucuture, composite strucutre
  - Salt corrosion



Salt corrosion damage

Inspection of PC beams

Inspection of steel strucutures

Summary

- It has proved that neutron radiography at beam flux around 10^5 to 10^6 (n/cm^2/sec) is quite useful in industrial applications, thanks to the advances in imaging detectors.
- It is not possible to obtain high-speed image or movies with this flux, although still images or CT reconstruction is possible with acceptable time and quality.
- Radiography image to computational simulation was demonstrated using VCAD system softwares, which will be a useful tool to industrial applications.
- If it is possible to obtain more material information like residual stress/strain, element recognition, temperature, magnetic filed .. , these information will be extremely useful in industrial applications combined with radiography image data.
- Compact neutron source will be very useful for industrial applications in the phase of product design, production and maintenance.

Future plan at RIKEN

- Construct small accelerator based neutron source at RIKEN and start radiography experiments/ services with computer modeling/simulation. (CT reconstruction, region separation, meshing, and simulation)
- Organize a industrial consortium for neutron imaging applications.
- Continue facility development toward advanced neutron imaging. (stress/strain, temperature, elements, magnetic ..)
- Search for the possibility of portable neutron source for safety inspection of large structures.

Collaborators and acknowledgements

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