ICANS XIX,
19th meeting on Collaboration of Advanced Neutron Sources
March 8 – 12, 2010
Grindelwald, Switzerland

Neutron radiography for the structual simulation using VCAD system

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ABSTRACT

The VCAD system is a wide collection of software being developed at RIKEN VCAD system research program, which include tomography, region separation, existing 3D CAD interface, modeling, mesh generation, structural and fluid dynamics simulation, and visualization. We applied this software to neutron radiography and CT. The measurement was made at a multi-purpose monochrome thermal neutron port (MUSASI-L) in guide hall at JAEA JRR-3, Japan. Although the beam flux of MUSASI port is not strong compared to other radiography facilities, quite practical radiography images including CT image were obtained in relatively short exposure time. The neutron radiography measurements were also compared with the X-ray CT images. Multi-material mechanical analysis of a volumetric (3D) image reconstructed by neutron CT using VCAD software was discussed, in order to be applied to functional evaluation of actual product and feedback to manufacturing process in industry

1. Introduction

X-ray imaging is widely applied as a non-destructive investigation method of industrial products in manufacturing process. Neutron imaging is attractive in industrial application field, partly because neutron has high transparency of heavy elements, especially iron. For application of neutron imaging to manufacturing process investigation and large constructs (e.g. buildings or bridges) monitoring, small neutron imaging devices are highly demanded, which enable an in-factory or on-site observation. Furthermore, image acquisition techniques under low flux neutron beam are also necessary. In this article, the neutron radiography measurements for industrial application using MUSASI-L were performed and some of results were compared to the X-ray images.

Multi-material structural analysis of a volumetric image reconstructed by neutron CT will be discussed in this article. VCAD software (Figure 1) represents quantitatively 3D shapes and inner structures of actual objects measured by computerized tomographic devices (X-ray, MRI, etc.). VCAD software can pursue a numerical structural analysis using measurement data of actual products. The result of the analysis is capable to be applied for a functional evaluation of industrial product and a degradation diagnosis of large constructs.

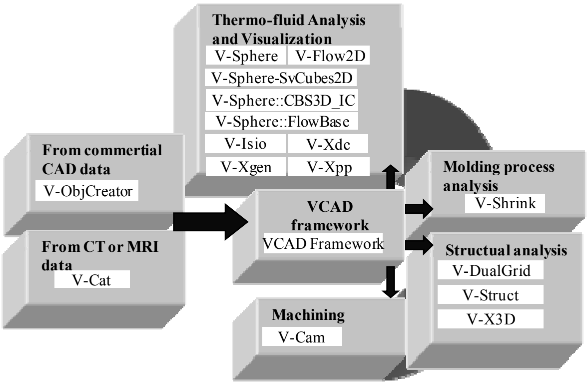

Fig. 1. VCAD software titles

2. Neutron radiography using monochrome thermal neutron beamline

Several neutron radiography experiments of industrial components are conducted on thermal neutron beamline of JAEA JRR-3 reactor. Figure 2 illustrates an outline of MUSASI-L beamport used in the experiments, which emits a monochrome (13.5meV, wavelength 2.46Å, bandwidth: 1%) low divergence neutron beam, whose flux is about ~10^6 n/cm^2/sec. Imaging plates (IP) for neutron (Fujifilm) are used for image acquisition. A resolution of scanner is 50 micrometers.

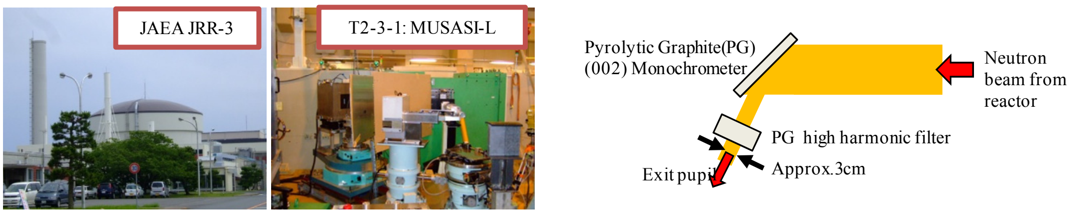

Fig. 2. MUSASI-L beamline, JAEA reactor JRR-3

Figure 3 shows results of metal step parts observatory. The metal step parts (A: thickness 5mm to 50mm with 5mm increment, B,E: pure almuminum, C,F: 0.45% carbon steel (JIS S45C), D : nickel-based heat resisting alloys) are measured on MUSASI-L. Exposure time is 5 minutes. The results are compared with images by an industrial X-ray CT instrumentation. In case of F, 1st to 6th steps from its top were observed clearly, however only up to 3rd step in case of C. It shows an important advantage of neutron.

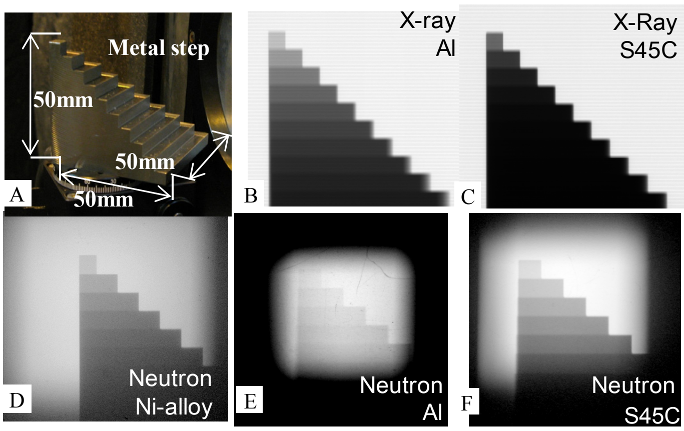

Fig. 3. Metal step parts (A) and images measured by X-ray CT instrument (B,C) and neutron and imaging plates (IP) (D, E, F).

Small gap investigation technique using neutron absorbent solution is tested (Fig.4). A stainless steel M12 screw and a nut (Fig.4A) were observed by X-ray CT instrumentation (Fig.4B) and neutron (Fig.4 C, D) using IP. Boric acid solution is filled in a gap between the screw and the nut as a neutron absorbent. A small gap less than 0.1 mm in stainless steel assembly parts was observed using this method.

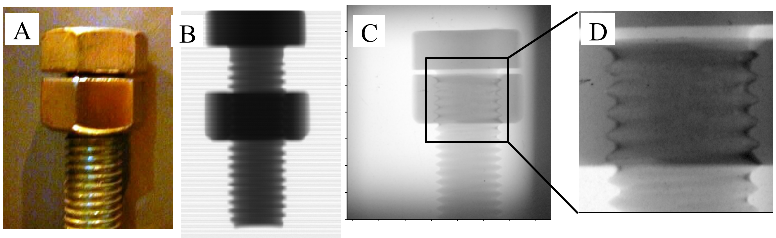

Fig. 4. Small gap investigation using neutron absorbent solution (A: photo, B: X-ray, C: neutron, D: a partially magnified image of C) .

Figure 5 is a result of a 15 cm length fragment of damaged iron bridge pair. Figure 5(a) is front view and 5(b) is side view of the fragment. A and B are neutron radiography images of rectangle areas (A', B'). Some cracks (white arrow) were observed clearly.

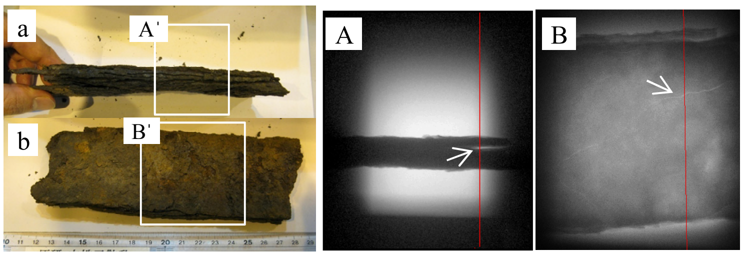

Fig. 5. A fragment of a damaged iron bridge pair observatory (a and b: photo., A and B: neutron image, white arrow: crack)

Figure 6(A) is a stainless steel plate (JIS SKD11, 10mm thick). White arrows illustrate cracks induced by a tensile fatigue testing machine around a trimmed circle. Figure 6 (B) is a neuton image and (C) is an X-ray image. Cracks in B is observed obviously, comparing with (C).

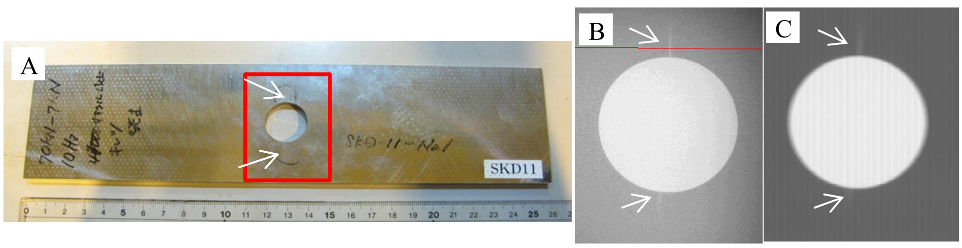

Fig. 6. Cracks in stainless steel plate (JIS SKD11, 10mm thick) induced by a tensile fatigue testing machine. Comparison between neutron (B) and X-ray(C) image is pursued.

Cycloolefin polymer (COP) inside an injection molding die (steel, 70mm thick) is observed (Fig. 7). COP is very popular material as mould optics such as camera lenses of cellular phones. The result shows possibility of visualization of injection molding process.

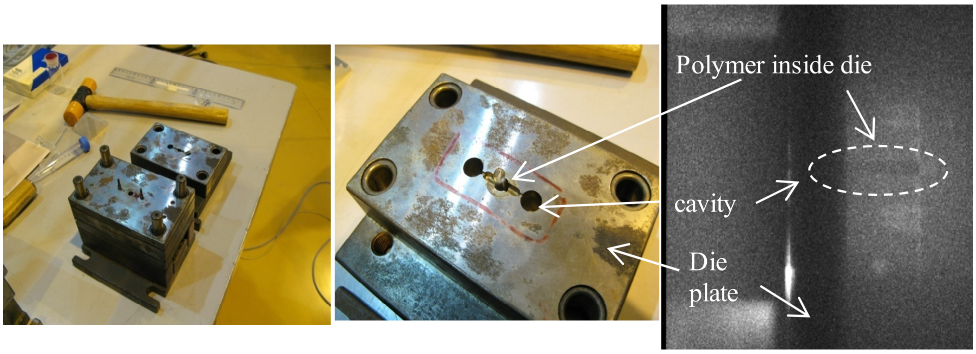

Fig. 7. An injection molding die (steel, 70mm thick) and cycloolefin polymer (COP) inside.

3. VCAD software application to neutron CT images

An application of VCAD software to numerical mechanical analysis using neutron CT images is discussed in this section. General numerical simulation software only can treat CAD data like IGES as geometry data which represent designed ideal shapes of products. Simulation using VCAD software can process not only by CAD data but also actual product geometry data acquired from X-ray CT, MRI, three dimensional shape instrumentation and neutron CT.

In order to demonstrate this method, an experiment of neutron CT has been executed (Fig. 8). A concrete fragment (35mm thickness) is rotated 180 degrees. 300 pictures by neutron radiography are acquired by liquid nitrogen chilled CCD camera and a LiF/ZnS(Ag) scintillator plate in every 0.6 deg rotation. Figure 8(D) is one of CT-reconstructed images. 30 shots of direct beam image and 29 shots of beam-off (dark) image are also used for a reconstruction calculation. Figure 8(D) shows that concrete is surely multi-material which consists of stone aggregate and cement.

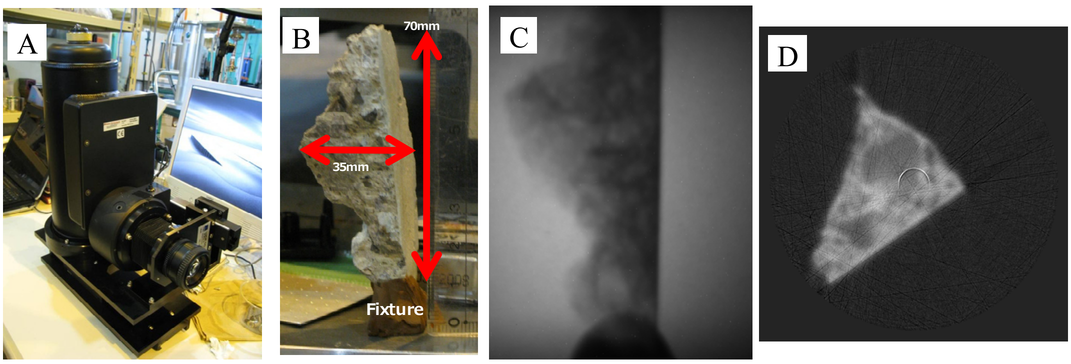

Fig. 8. Neutron computerized tomography of a ragment of concrete pillar.

Using V-Cat, one of the VCAD software we developed, the 3D image reconstructed by neutron CT can be separated by image intensity segmentation, displayed by volume rendering using different transparency with type of materials, and converted into multi-material mesh, which is suitable for numerical finite elment simulation, by a dual-grid mesh generating method. Multi-material mechanical analysis of obtained mesh data can be performed by numerical finite element method and mechanical properties of the materials using V-Struct (solver) and V-Femis (pre/post processor). The mechanical analysis will offer practicable information for functional evaluation of actual industrial product and feedback to manufacturing process in industry.

4. Conclusion

The neutron radiography measurements of industrial parts using MUSASI-L were compared to the X-ray CT images. A 3D image of the concrete fragment was acquired using neutron CT for multi-material structural analysis using VCAD software. The VCAD system is able to provide computer-based assistance for all stages of the manufacturing process from design, measurement, simulation and machining. Neutron radiography of industrial products combined with VCAD simulation (such as mechanical strength, rupture, thermo-fluid, fabrication process and so on) enables fabrication process improvement and performance and lifetime evaluation of actual industrial parts. As a further study, we are planning to construct accelerator-based compact neutron source to be utilized in-factory or on-site for industrial applications. Neutron radiography is expected to be widely utilized for industrial applications.

5. Acknowledgements

This work was performed under the Common-Use Facility Program of Japan Atomic Energy Agency (JAEA). An iron bridge specimen is offered by Center for Advanced Engineering Structural Assessment and Research (CAESAR) of Public Works Research Institute (PWRI) Japan.