AI translation · View original & related papers at
chinarxiv.org/items/chinaxiv-202306.00416

Homogeneity tests on neutron shield concrete (Postprint)

Authors: Koichi Okuno, Hiroshi Iikura

Date: 2023-06-18T00:00:00+00:00

Abstract

In recent years, neutrons have been investigated for applications in fields such as materials analysis and boron neutron capture therapy. To develop compact shielding for these facilities, a neutron-shielding concrete was formulated. Verification of the concrete's homogeneity is essential to ensure adequate shielding performance. In this study, neutron radiographic images of the concrete were acquired using the Thermal Neutron Radiography Facility (TNRF) at the JRR-3 research reactor, and the thermal neutron transmission ratio was estimated. The results demonstrated that the transmission ratio remained nearly uniform across all depths.

Full Text

Preamble

Homogeneity Tests on Neutron Shield Concrete

Koichi Okuno[1],* and Hiroshi Iikura[2]
[1]HAZAMA ANDO Technical Research Institute, 515-1 Karima, Tsukuba, Ibaraki, 305-0822, Japan
[2]JAEA Quantum Beam Science Directorate, 2-4 Shirakata, Tokai-mura, Naka-gun, Ibaraki, 319-1195, Japan

(Received June 30, 2013; accepted in revised form November 10, 2014; published online November 20, 2014)

Abstract: In recent years, neutrons have been studied for application in fields such as material analysis and boron neutron capture therapy. To create a compact shield for these facilities, a neutron shield concrete has been developed. Verifying the homogeneity of the concrete is important to ensure adequate shielding performance. In this research, neutron radiography images of the concrete were taken using the Thermal Neutron Radiography Facility (TNRF) of the JRR-3 research reactor, and the transmission ratio of thermal neutrons was estimated. The results showed that the transmission ratio of the concrete was almost the same at each depth.

Keywords: Neutron, Neutron radiography, Shielding, Concrete
DOI: 10.13538/j.1001-8042/nst.25.S010604

INTRODUCTION

In recent years, neutrons have been studied for application in various fields, such as material analysis and boron neutron capture therapy. To create a compact shield for such facilities, a neutron shield concrete that has the same mechanical strength as ordinary concrete has been developed [1]. This concrete contains about 15 wt% of hydrogen and about 3 wt% of B_2O_3.

It is important to verify the homogeneity of the boron and hydrogen content in the concrete to ensure adequate shielding performance. Therefore, neutron radiography images of the concrete were taken using the Thermal Neutron Radiography Facility (TNRF) of the JRR-3M research reactor, and the transmission ratio of thermal neutrons was estimated. Visualization of water penetration into concrete through cracks using neutron radiography was reported recently [2], but no application exists for visualizing homogeneity.

II. NEUTRON SHIELD CONCRETE

Neutron shield concrete uses colemanite and peridotite rocks as aggregates. Colemanite is a natural mineral rich in boron in the form of B_2O_3, while peridotite is a natural mineral rich in hydrogen atoms in the form of H_2O. These aggregate materials, together with ordinary Portland cement, form the concrete. Colemanite was used for 10 wt% of the concrete composition to improve shielding performance and production. The density of the neutron shield concrete is the same as that of ordinary concrete. Thus, the neutron shield concrete includes B_2O_3, which has a large capture cross section for thermal neutrons, and abundant H_2O, which slows down neutrons around 2 MeV via elastic scattering. This shield concrete also contains more iron in the form of Fe_2O_3 than ordinary concrete, which slows down high-energy neutrons via inelastic scattering. These effects provide the concrete with unique shielding performance.

Table 1 shows the elemental analysis for the neutron shield concrete and ordinary concrete, both of which have the same average density of 2.2 g/cm^3.

III. NEUTRON RADIOGRAPHY

Neutron radiography is a non-destructive imaging technique that uses thermal neutrons and serves as a powerful tool for inspecting materials. The difference between neutron and X-ray imaging techniques is that X-ray attenuation depends on atomic numbers, whereas neutron attenuation differs for each nucleus. Figure 1 [Figure 1: see original paper] shows the attenuation coefficient for thermal neutrons [3].

When the neutron beam irradiates a sample, the camera located behind the sample takes a picture with black-and-white contrast. Substantial attenuation of thermal neutrons in elements such as hydrogen and boron will cause these regions to appear shadowed in the radiographic image. Therefore, while water is not visible in X-ray imaging, it is clearly visible in neutron radiographs because of its high hydrogen content. As shown in Fig. 1, hydrogen, lithium, boron, and similar elements have a large attenuation ratio, whereas silicon, calcium, oxygen, aluminum, and others have a small attenuation ratio.

A thermal neutron beam can be found in a research reactor. The TNRF is installed at the JRR-3M research reactor of the Japan Atomic Energy Agency. Table 2 shows the specifications of the TNRF, and Fig. 2 [Figure 2: see original paper] shows its experimental system. In this setup, the thermal neutron beam comes from the JRR-3M and impacts the object. The fluorescent converter is a combination of a scintillator and Gd or ^{6}Li. When a thermal neutron is captured by Gd or ^{6}Li, the scintillator fluoresces. The fluorescence is scattered by a mirror, and then a photograph or video image is taken with a cold CCD camera.

IV. EXPERIMENT

Ordinary concrete and neutron shield concrete were used as experimental samples. As shown in Fig. 3 [Figure 3: see original paper], 20 mm thick slices were obtained from a concrete cylinder sample of $ $100 mm (diameter), starting at the surface and proceeding to greater depths of the core sample, and used for the experiment. Each sliced concrete sample was set in front of the fluorescent converter. The experimental setup is shown in Fig. 4 [Figure 4: see original paper].

V. RESULTS AND DISCUSSION

The intensity of the neutron beam that passes through the concrete sample is described by the following equation [4]:

$$I = I_0 \exp(\text{cid:16cid:88cid:17})$$

where (cid:80) is the macroscopic cross section, t is the sample thickness, I is the intensity of the neutron beam that passes through the sample, and I_0 is the incident intensity of the neutron beam.

The neutron radiography images and the respective transmission ratio of each, measured along a line through their centers, are shown in Fig. 5 [Figure 5: see original paper]. In these images, the intensity of neutrons appears as contrasting black and white, which can be read as digital bit data. These images were produced from image processing software through digital bit analysis. A transmission ratio of 1.00 (white) means no shielding, while a ratio of 0.00 (black) means complete shielding.

As shown in Fig. 5, the transmission ratio of each concrete sample was almost the same for each depth. No large frequency appears in the graph, which indicates good homogeneity at the center line and thus no breaks in the shielding. The transmission ratio of the neutron shield concrete is almost half that of ordinary concrete, which indicates that its shielding performance is almost twice as good as that of ordinary concrete.

VI. CONCLUSION

Tests on the homogeneity of neutron shield concrete were performed using neutron radiography. The results showed that the transmission ratio of the concrete was almost the same at each depth. Thus, neutron radiography imaging is useful for this type of investigation. The result of this study is still qualitative; therefore, the future plan is to develop this study to perform quantitative analysis and accurate estimation.

REFERENCES

[1] Koichi O, Masayoshi K, Hitoshi Y, Development of Novel Neutron Shielding Concrete, Nucl Technol, 2009, 168: 545–552.
[2] Manabu K, Ippei M, Takafumi N, et al. Visualization of water penetration into concrete through cracks by neutron radiography, Proc. of International Seminar on durability and lifecycle evaluation of concrete structures, 2006, 69–76.
[3] Domanus J C. Neutron Radiography Handbook, D. Reidel Publ. Co., Dordrecht, 1981.
[4] Hawesworth M R. Neutron Radiography: Equipment and Methods, Atom. Energy Rev, 1977, 15: 169–220.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv — Machine translation. Verify with original.