Nondestructive Determination of Water Content in Concrete Using Am-Be Neutron Source - Experimental Verification-

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New nondestructive measurement technique has been developed with an AmBe neutron source to evaluate the amount of water in concrete. A concrete wall is irradiated with fast neutrons to activate a gold foil set on the concrete. By evaluating in advance the relation of the gold activity and water content by calculations, we can determine the water content in the concrete, the water content of which is not known. In this study, to validate the present technique experiments were performed with concrete samples having different water contents, which were made from only cement and water. It was confirmed from the experiments that water content could be estimated by the present nondestructive measurement technique though the system is still simple with cement and water. Now we are examining the validity for concretes made from cement, water and sand.

1. Introduction

Concrete is often used in nuclear facilities for radiation shield. Shielding performance of neutrons depends mainly on water in concrete, because neutrons are mainly moderated by hydrogen atoms in water contained in concrete. However, concrete loses its contained water as time passes. It can affect the ability of radiation shield. We want to know water content in concrete for confirmation of the shielding performance of nuclear facilities and for high-precision neutronics experiments. However, destructive methods to measure water content in concrete are not suitable in nuclear facilities. So It is necessary to establish a new technique to nondestructively determine water content in concrete.

In the present study, a new nondestructive measurement technique is developed to evaluate the amount of water in concrete, and to validate the present technique experiments are performed with concrete samples having different water contents, which are made from only cement and water.

2. Nondestructive measurement technique

It is known from previous studies that when a concrete sample is irradiated with neutrons, the neutrons are moderated according to water content in the concrete. In other words, the number of fast neutrons moderated to thermal neutrons is determined mainly by the amount of water in the concrete. By combining the property explained above with the foil activation method, water content in concrete can be determined by the following procedure developed in the previous study [1].

As in an experimental system shown in Fig. 2.1, a gold foil and Am-Be neutron source are placed on the concrete. The concrete is irradiated with fast neutrons by the Am-Be neutron source. Then, the neutrons are moderated mainly by hydrogens in the concrete, moderated neutrons are leaking from the concrete surface. The moderated neutrons enter the gold foil and activate it. Fast neutrons can be well moderated, if the amount of water increases. As a result, the gold foil can be well activated. It means that there should be a correlation between the water content in the concrete and the gold activity. In this study, to make the calibration curve of gold activity to water content, series simulation calculations were performed using MCNP5 [2], that is, gold activities are calculated for various concretes having various water contents. Other conditions are as follows: Irradiation time is one day. The source intensity of Am-Be is 2.4×10^{6} n/s. The composition of the concrete used by calculation is shown in Table 2.1. From the result, a calibration curve of the gold activity to the water content in the concrete was obtained.

Figure 2.2 shows the calibration curve obtained by the series simulations using MCNP5. Figure 2.3 shows an enlarged view of the calibration curve for the low water content region of 0 to 0.01 mol/cc. From Fig. 2.3, as an exception concrete containing carbon which is a light atom (ANSI) and extremely high density concrete (heavy concrete) deviate slightly from the trend of other concretes. However, for other concretes, regardless of the density and composition, it can be seen that the gold activity changes depending only on water content in the concrete. By using this calibration curve, it is possible to measure the water content in a concrete wall, the water content of which is not known, with a gold foil and AmBe neutron source. When the thickness of concrete is 40 cm or more, the activity of gold foil is constant regardless of the thickness of concrete, so Fig. 2.2 can be used. On the contrary, when the thickness of concrete is 40 cm or less, the activity of gold foil changes depending on the thickness of concrete. Therefore, for concrete with a thickness of 40 cm or less, it is necessary to create a calibration curve for each thickness.

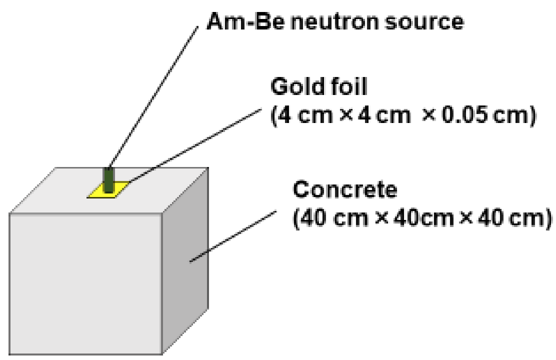

Fig 2.1 simulation system.

Table 2.1 Composition of concretes. [3]

	Ordinary concrete			Serpentinite concrete (wt%)	Heavy concrete (wt%)
	JAERI (wt%)	ANSI (wt%)	JRR-4 (wt%)		
H	0.416	0.208	0.894	1.916	0.45
C	0	5.582	0	0	0
O	50.74	49.339	50.534	50.415	31.392
Na	0	0	1.498	0.062	0
Mg	0.115	0.209	0.698	16.9	0.047
Al	0.446	0.511	5.501	1.28	0.199
Si	38.606	18.808	28.8	15.5	2.982
S	0.07	0.082	0.304	0.016	1.936
K	0	0	1.798	0.077	0
Ca	6.869	24.949	7.692	6.95	4.081
Ti	0	0	0	0.005	0
Mn	0	0	0	0.79	0
Fe	2.738	0	2.281	6.8	58.913
Ni	0	0.312	0	0	0
Total	100	100	100	100	100
density (g/cc)	2.05	2.33	2.24	2.275	3.35

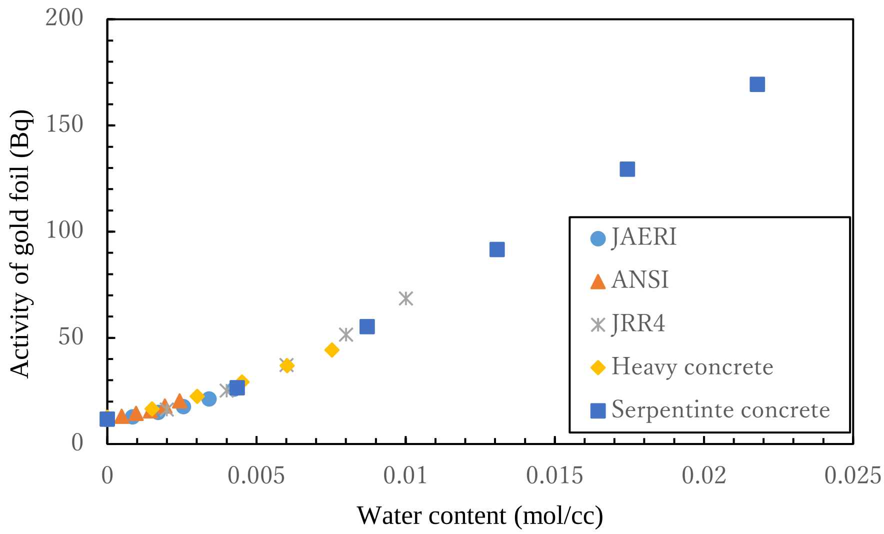

Fig 2.2 calibration curves of gold activity to water content.

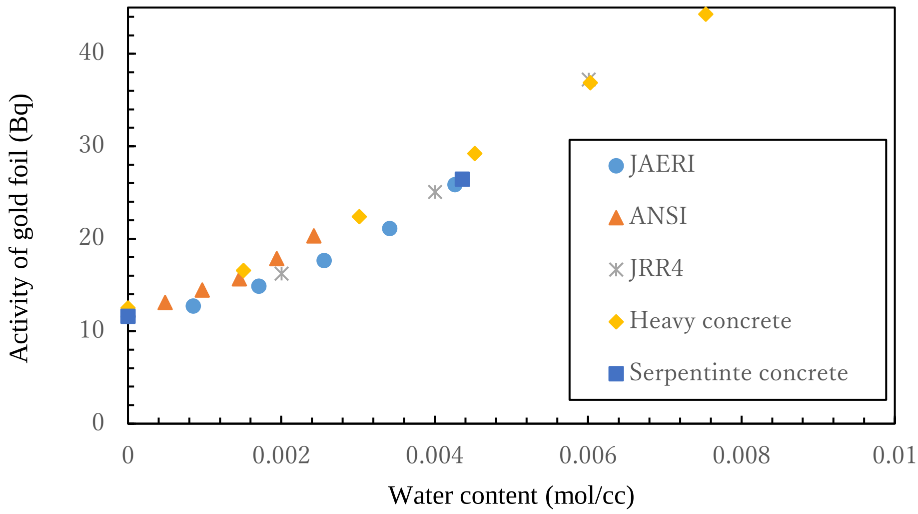

Fig 2.3 calibration curves for low water content.

3. Experiment

In order to confirm the validity of the present technique, experiments were performed with four concrete samples having different water contents, which were made from only cement and water, meaning they have no aggregate. An example of the experimental system is shown in Fig. 3.1. Four concretes made very carefully by ourselves have water contents as 0.0209, 0.0241, 0.0267 and 0.0272 mol/cc. As a way to know the water content accurately, we measured the mass ratio of cement and water before mixing. Next, we mixed cement and water, and we measured the mass of the concrete before it hardens. After that, the water content in the concrete before solidification is measured by multiplying the mass and the mass ratio of water and water before mixing. Finally, the difference between the mass of the concrete after solidification and the mass of the concrete before solidification is measured, and the difference is the amount of evaporation of water, and the water content in the concrete is obtained by subtracting that amount. The densities of the four concretes are 2.09, 2.05, 2.03, and 2.04 g/cc. The ratio of the amount of substance of four concretes is shown in Table 4.1, 4.2, 4.3 and 4.4. The size of concretes is 40 cm in length, 40 cm in width, and 40 cm in height. A gold foil and Am-Be neutron source were placed on the concrete as shown in Fig. 3.1, and a gold foil was activated on each concrete by neutron irradiation with the Am-Be neutron source for one day. The intensity of Am-Be source is 2.4×10^6 n/s. We measured the activation of each gold foil with a germanium semiconductor detector. The gold activities obtained by the experiments were compared with the predicted gold activities.

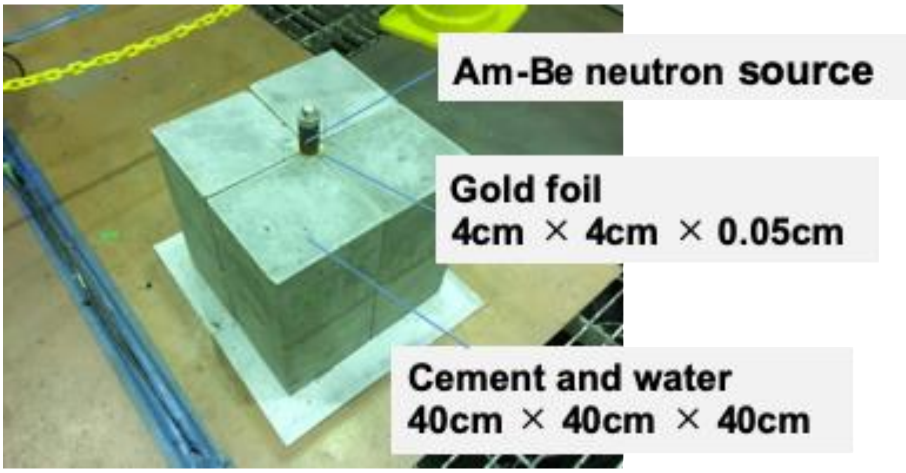

Fig 3.1 Experimental system.

Table 3.1 Ratio of the amount of substance in concrete 0.0209 (mol/cc)

element	H	O	Si	Al	Fe	Ca	Mg	S	Na	K
Amount of substance (%)	31.87	45.14	4.75	1.15	0.48	15.46	0.60	0.37	0.08	0.11

Table 3.2 Ratio of the amount of substance in concrete 0.0241 (mol/cc)

element	H	O	Si	Al	Fe	Ca	Mg	S	Na	K
Amount of substance (%)	35.20	44.01	4.30	1.04	0.43	13.98	0.54	0.33	0.08	0.10

Table 3.3 Ratio of the amount of substance in concrete 0.0267 (mol/cc)

element	H	O	Si	Al	Fe	Ca	Mg	S	Na	K
Amount of substance (%)	37.68	43.17	3.96	0.96	0.40	12.88	0.50	0.31	0.07	0.09

Table 3.4 Ratio of the amount of substance in concrete 0.0272 (mol/cc)

element	H	O	Si	Al	Fe	Ca	Mg	S	Na	K
Amount of substance (%)	37.90	43.11	3.93	0.95	0.39	12.76	0.49	0.31	0.07	0.09

4. Results

Figure 4.1 shows the result of comparing the experimental value of the gold activity with the calculated value. As a result, the calculated and experimental values agree well within the experimental errors. In the next step, we plan to carry out experiments with real concretes with aggregates, and thereafter measure a real concrete wall in our facility, OKTAVIAN. For that purpose, now we are examining how to fix the real number of hydrogens in concrete for validation of the presently proposed method.

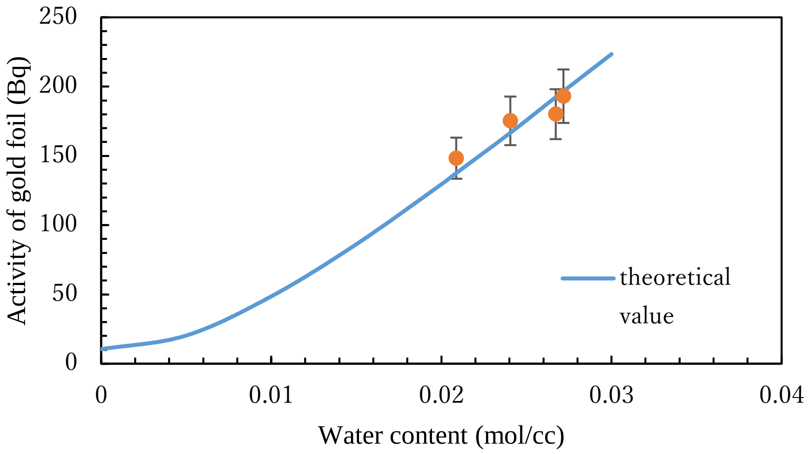

Fig 4.1 Experiment result.

5. Conclusion

It was confirmed from the experiments that water content could be estimated by the present nondestructive measurement technique though the system is still simple with cement and water.

In the next step, we will confirm the validity for aggregate concretes, concretes containing carbon and heavy concretes. Finally, we will apply to a real concrete wall in an actual nuclear facility.

References

[1] Y. Nishiyama, et al., Nondestructive Determination of Water Content in Concrete by Foil Activation Method –Feasibility study by Numerical Simulation-, JAEA-Conf 2017-001, 2018, pp.211-217.

[2] Los Alamos National Laboratory, A General Monte Carlo N-Particle Transport Code ver.5.

[3] D. Ito, Monte Carlo Calculation Hand Book, AESJ, 2006, p.224.