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QUANTITATIVE NEUTRON RADIOGRAPHY USING NEUTRON ABSORBING HONEYCOMB - BASIC RESEARCH AND APPLICATION -

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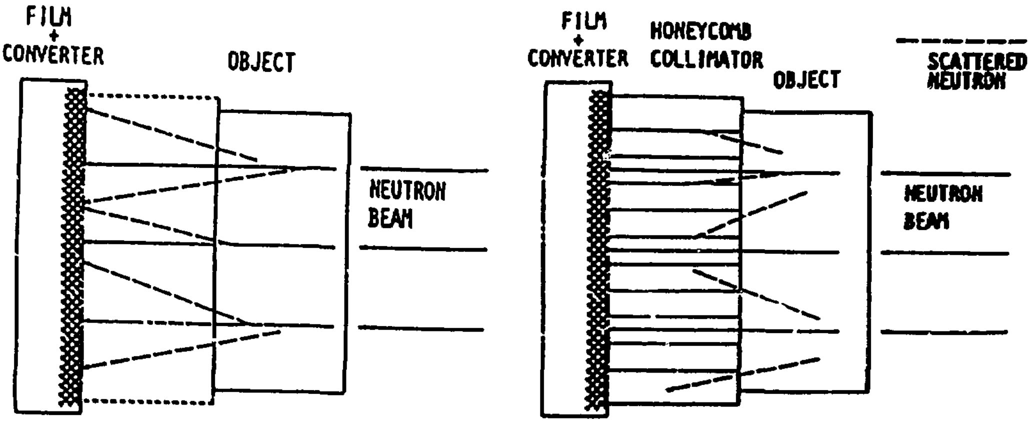
ABSTRACT

This investigation concerns quantitative neutron radiography and computed tomography by using a neutron absorbing honeycomb collimator. By setting the neutron absorbing honeycomb collimator between object and imaging system, neutrons scattered in the object were absorbed by the honeycomb material and eliminated before coming to the imaging system, but the neutrons which were transmitted the object without interaction could reach the imaging system. The image by purely transmitted neutrons gives the quantitative information. Two honeycombs were prepared with coating of boron nitride and gadolinium oxide and evaluated for the quantitative application. The relation between the neutron total cross section and the attenuation coefficient confirmed that they were in a fairly good agreement. Application to quantitative computed tomography was also successfully conducted. The new neutron radiography method using the neutron-absorbing honeycomb collimator for the elimination of the scattered neutrons improved remarkably the quantitativeness of the neutron radiography and computed tomography.

INTRODUCTION

The visualization technique of the distribution of neutron cross section in object such as metal hydride[1, 2] by neutron radiography neutron television is very useful for scientific investigation as well as industrial nondestructive testing. However, on the observation of the high scattering cross section object by neutron radiography, scattered neutrons from the object degrade the quantitativeness of the neutron radiographic image due to overlap between purely transmitted and scattered neutrons as shown schematically in Fig. 1 (a). In the case of the neutron computed tomography, CT value indicates no quantitative information due to the scatted neutron effect[3]. Procedure for one-dimensional remove of scattered neutrons from neutron radiograph was proposed by H. Kobayashi and applied to obtain the neutron removal cross section of matter[4]. This procedure was applied to the neutron computed tomography using neutron television by M. Yokoi[5]. Further development of this method was attempted to extend to the two-



(a) Without honeycomb collimator (b) With honeycomb collimator

Fig. 1 Schematic neutron radiography systems with and without honeycomb collimator for quantitative neutron radiography

dimensional remove of the scattered neutrons by Y. Murata[6].

In order to evaluate the observed two-dimensional image of neutron radiography and neutron television more quantitatively, the effects of the (L/D) ratio, divergent neutron beam, and scattered neutron from object should be removed from the image of neutron radiograph by using the hard as well as soft imaging system. An elimination method of the effect of the scattered neutrons was proposed and developed by using boron nitride and gadolinium honeycomb collimators[7, 8]. This investigation concerns to extend the effectiveness of the honeycomb collimator for the television neutron radiography and computed tomography.

HONEYCOMB COLLIMATOR[7, 8]

As shown in Fig. 1 (b), a honeycomb collimator which was made of neutron absorbing material was set between object and imaging system. Scattered neutrons from the object material were absorbed by the honeycomb collimator before reaching the imaging systems such as converter/optical film and converter/television camera. Consequently, the image on the converter was formed by the purely transmitted neutrons through object. This image must be more quantitative than the conventional one as Fig. 1 (a). But the image of the quantitative neutron radiography contains the image of the honeycomb collimator itself. So the image of the object sample which was overlapped by the honeycomb collimator corresponds to a kind of two-dimensional neutron detection system. However, the elimination of overlapped honeycomb collimator image may be preferred. Specification of the boron nitride coated honeycomb collimator (BNHC) and the gadolinium oxide coated honeycomb collimator (GdHC) used in this study was indicated in Table 1.

EXPERIMENTS AND RESULTS

Quantitative Neutron Radiography by Film Method

Table 1. Specification of the honeycomb collimator.

Dimension	300mm W x 300mm H x 100mm L	
Unit honeycomb	3mm equivalent D x 100mm L	
Honeycomb material	aluminum 0.033mm T	
Neutron absorbing material		
	boron nitride coating	0.1mm T
	gadolinium oxide coating	0.1mm T
Geometrical (L/D) ratio	33 (100mm / 3mm)	

Experiment of quantitative neutron radiography by film method was conducted using the BNHC and GdHC collimators. Step wedge metal samples (Fe, Al, Pb, Cu) were prepared as standard. The neutron radiography facility at the E-2 thermal neutron beam hole in the Kyoto University Reactor[7] was utilized for the quantitative neutron radiography test. Imaging system consisted of gadolinium converter/Kodak SR film (14-18 minutes exposure) combination. Exposed film was developed under the condition of 25℃ and 5 minutes by using the usual film development equipment. Optical film density was measured by using a simple densitometer (SDM) and a 2-dimensional scanner (2DS). Fig. 2 shows the relation between the neutron attenuation coefficient and the total thermal neutron macroscopic cross section. The values of the neutron attenuation coefficient obtained in the present experiment (GdHC/2DS and BNHC/SDM) are in good agreement with the macroscop-

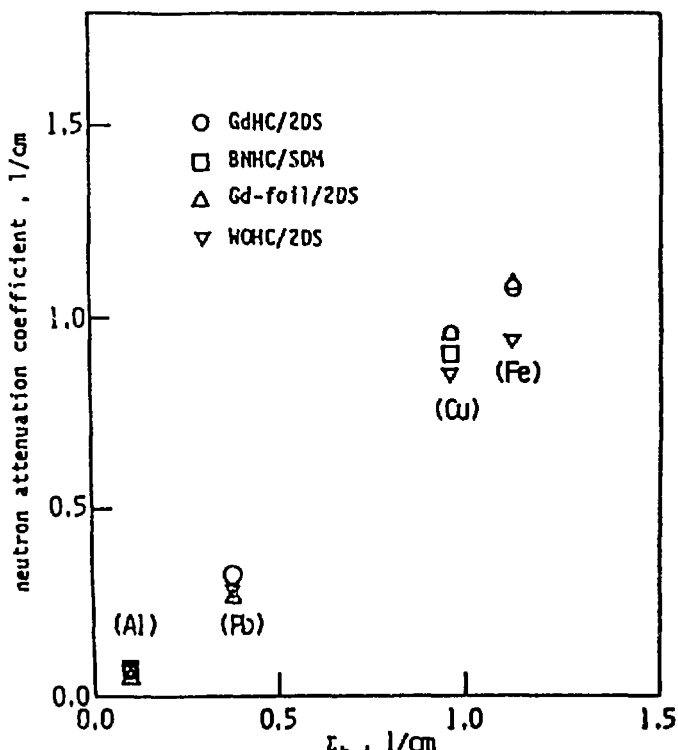


Fig. 2 Relation between neutron attenuation coefficient and macroscopic cross section of metals by various NR systems.

ic cross section data[9]. The published data by Kobayashi method[4] are in a good agreement with the present results. The present BNHC/SDM data are somewhat low compared to the GdHC/2DS) values because of the rather low neutron absorbing capability of the boron coating honeycomb. And the present data by conventional method were appreciably low compared to those by honeycomb collimator methods due to the scattered neutron effect.

Quantitative Neutron Computed Tomography by Television Method

Experiments on the quantitative neutron radiography and the computed tomography were conducted by using the television method in the thermal neutron radiography facility(TNRF-2) at the JRR-3M(Table 2).

Table 2. Specification of JRR-3M TNRF-2

Neutron flux	1.5 x 10^8neutron/cm^2sec
Collimator ratio (L/D)	150 (7350mm / 50mm)
Cd ratio of gold	more than 100
(Neutron/gamma ray) ratio	62.5n/$cm^2\mu$Sv

Fig.3 shows the typical relations between the neutron attenuation ratio ($\ln(I/I_o)$) and the thickness of the iron step with and without Gd honeycomb collimator. The curves with and without honeycomb collimator show a linear relation in a thickness range from 0 to 2cm. The neutron attenuation coefficient is 0.94cm^{-1} and 0.81cm^{-1} for GdHC and WOHC cases, respectively. The total cross section of iron is 1.12cm^{-1} [9]. This indicates that the influence of the scattered neutrons was appreciably decreased. Using

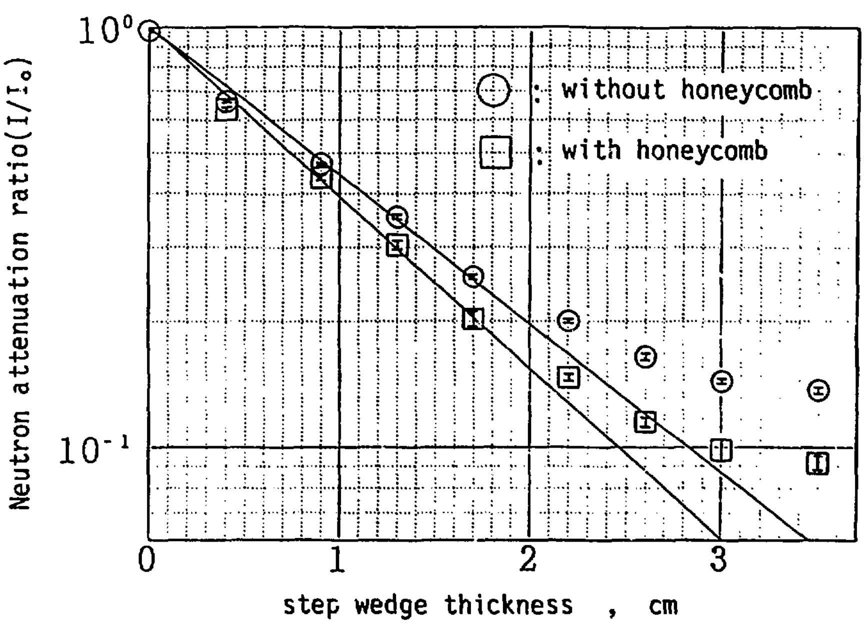


Fig.3 Relation between neutron attenuation ratio(I/I_o) and step wedge thickness of iron with and without Gd honeycomb collimator by neutron television method.

the neutron television system, data set of the neutron radiography projections for the computed tomography were obtained by CT principle as illustrated in Fig. 4. The data set was recorded with video tape. The digital images converted from the video were used for the shading correction of the projection images of the honeycomb by making a relation of ((projection of sample with honeycomb)/(projection of honeycomb)). The normalized projection data were obtained without the effects of the scattered neutrons, beam profile and honeycomb. The reconstruction calculation of the computed tomography from the normalized image data set was done at the Nagoya Computer Center.

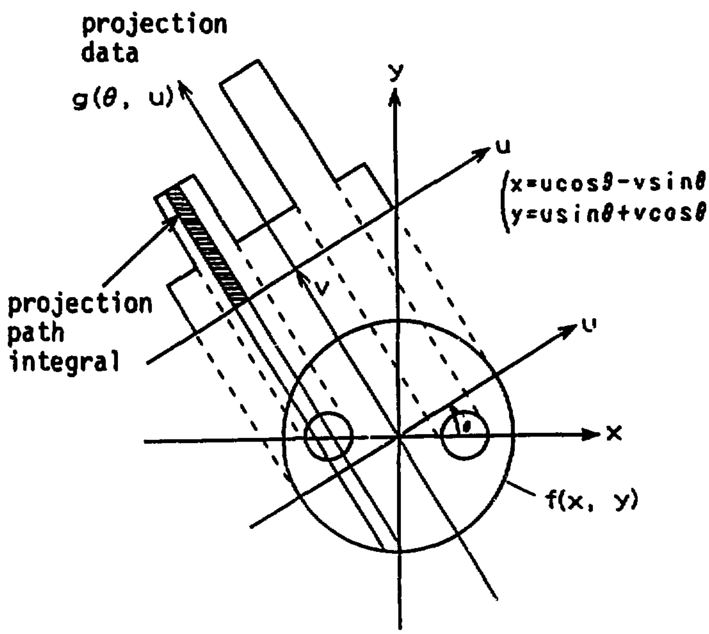
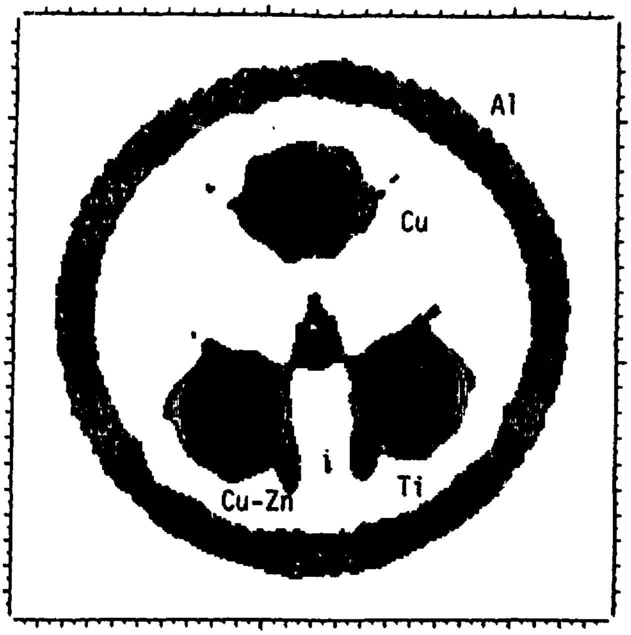


Fig. 4 Schematic view of NR projection for computed tomography.

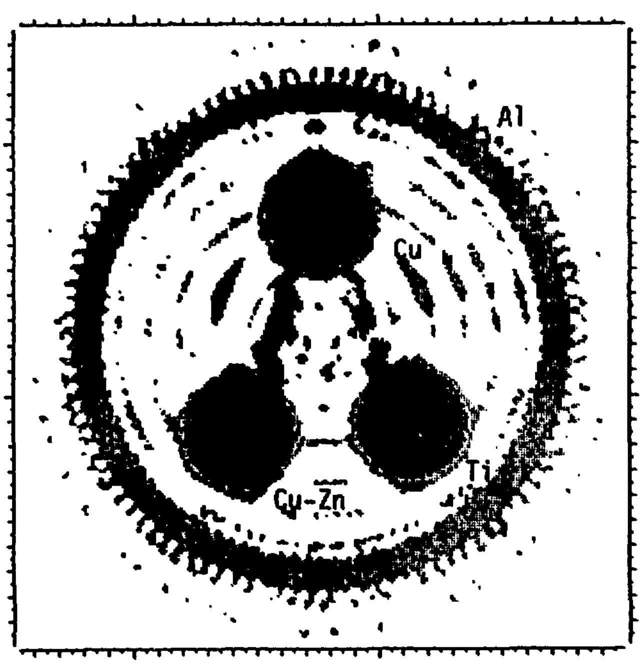
Fig. 5 shows typical neutron computed tomography (CT) images of metal cylindrical columns (Cu, Cu-Zn, Ti and Al): a) is without Gd honeycomb and b) with Gd honeycomb. CT image with HC contained some artifact due to imperfect elimination of the honeycomb image, compared to without honeycomb. Fig. 6 shows the relation between computed tomography value (CT-value) and total cross section of various metals for with and without honeycomb collimator, obtained by the proposed quantitative neutron radiography method. It reveals clearly that the quantitativeness of the CT-value of with honeycomb is very high.

Advanced Developing System

A digital electronic imaging systems of the cooled Plasma-Coupled Device (PCD) had been developed for improving the image dynamic range[10]. Further development has been just progressing by using a high precision cooled Charge-Coupled Device (CCD) camera[11,12]. The cooled CCD camera image of metal step wedges with Gd-coated aluminum honeycomb collimator of the



a) CT image of cylindrical metals without honeycomb collimator



b) CT image of cylindrical metals with honeycomb collimator

Fig. 5 Reconstruction images by computed tomography with and without honeycomb collimator

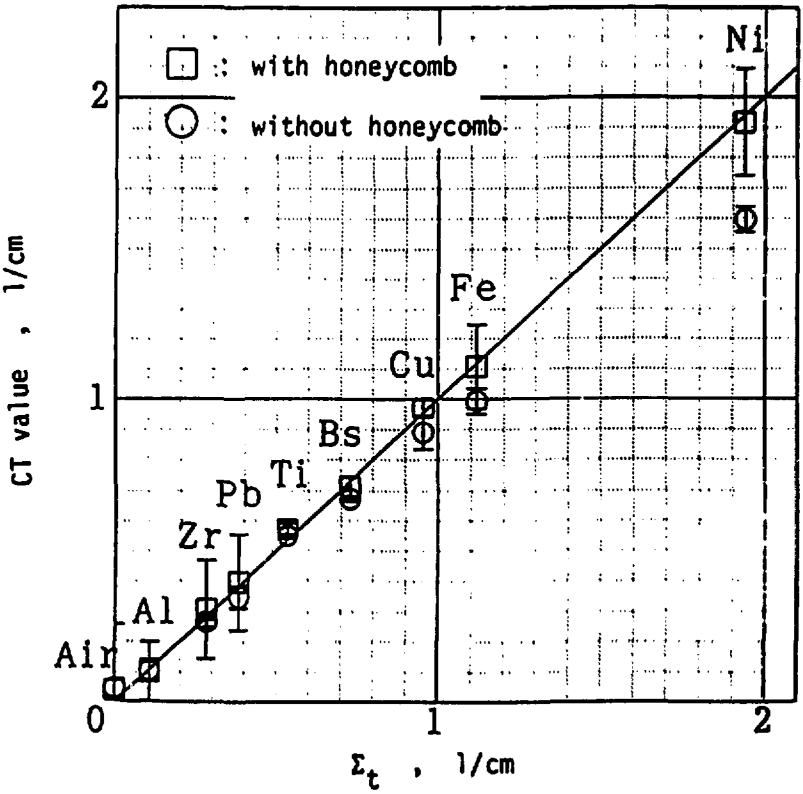


Fig. 6 Relation between computed tomography value (CT-value) and total macroscopic cross section of varoius metals with and without honeycomb collimator

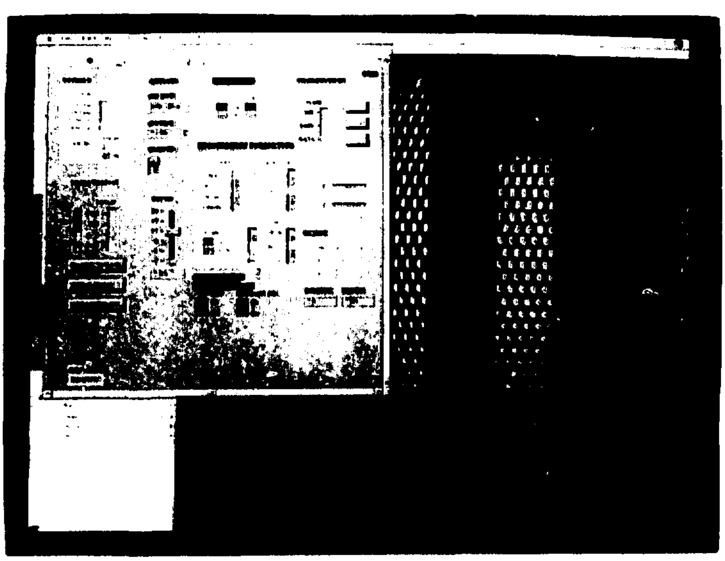


Fig. 7 Cooled CCD camera image of metal step wedges with Gd-coated aluminum honeycomb collimator

preliminary test was shown in Fig. 7[12]. In order to eliminate the image of the honeycomb collimator, on the other hand, a micro-honeycomb collimator is now developing by gadolinium coating of ceramics micro-honeycomb with capillary diameter of 6 microns and length of 500 microns. By combining the micro-honeycomb collimator with the two digital imaging devices above-mentioned, highly quantitative neutron radiography and computed tomography systems will be established in very near future.

CONCLUSION

Through this investigation, following conclusion was obtained. A new quantitative neutron·radiography and computed tomography by using a neutron absorbing honeycomb collimator has been proposed and verified experimentally. Boron nitride and gadolinium coated aluminum honeycomb collimators were fabricated and applied experimentally for the elimination of the scattered neutrons from the object materials. The attenuation coefficients and computed tomography (CT) values of various materials are evaluated to be consistent with the macroscopic cross section. This indicates that the new neutron radiography method using the neutron-absorbing honeycomb collimator for the elimination of the scattered neutrons improves the quantitativeness of the neutron radiography and computed tomography.

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