Neutron Radiography with Kyoto University Research Reactor (IV) Defect Detection in Plastics, Fine Ceramics and Metals

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Neutron Radiography with Kyoto University Research Reactor (Ⅳ) Defect Detection in Plastics, Fine Ceramics and Metals

Yukio TSUJII*, Ryoich TANIGUCHI**, Masatoshi FUJISHIRO*
Tadashi TSUJIMOTO***, Kenji YONEDA***, and Ken-ichi OKAMOTO***

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We are carrying out the standardization of image indicators in neutron radiography to detect the defects in various materials and composites with high sensitivity. Investigation was made of the relationship between the number of detected holes (*H*) by the ASTM sensitivity indicator (ASTM E545-81 Edition) and the detected minimum diameter (*D*) by authors' indicators (wires type indicators with nylon wires, and those with steel wires) on radiographs to evaluate the radiographic image quality. The *H* value 6 of the ASTM indicator corresponded to the *D* value 75 μm of the *nylon-wire type indicator* (NWI) and to 150 μm of the *steel-wire type indicator* (SWI), and the *H* value 3 of the ASTM indicator corresponded to 130 μm of the NWI and to 250 μm of the SWI. Fault sensitivities for plastic and steel plates were calculated from the *D* values. The results are also given as the relationship between the fault sensitivities and the values of the *H* of the ASTM sensitivity indicator.

1. Introduction

The progress of neutron radiography technique is eagerly desired in industry because of its high inspection ability for mixtures consisting of metal and hydrogenous materials such as explosives, plastics and metal composites and nuclear spent fuel. In the neutron radiography, the characteristics of the neutron beam and the radiographic image quality are generally evaluated with the "*Beam Purity Indicator* (BPI)" and the "*Sensitivity Indicator* (SI)" approved by ASTM[1-4].

The standardization of image indicators for neutron radiography is being carried out with Kyoto University Research Reactor (KUR). This paper describes the relationship between *the number of detected holes* (*H*) *by the ASTM E545-81 SI* and *the minimum diameter* (*D*) *detected by authors' indicators* for mixtures of plastics, fine ceramics

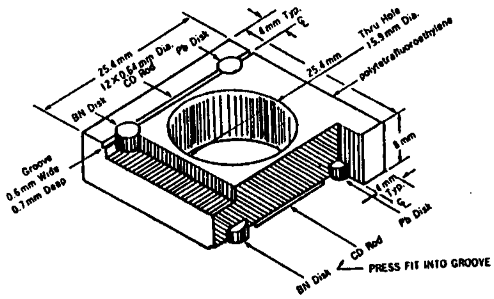
* Research Center of Radiation, Research Institute for Advanced Science and Technology.
** Department of Fundamental Science, Institute for Advanced Science and Technology.
*** Research Reactor Institute, Kyoto University.

and metals.

2. Experimental and Results

The study of evaluation method for image quality in neutron radiographs has been carried out with KUR. In this experiment, E—2 hole in KUR was chosen as the exposure place. The neutron flux there is about $1.2 \times 10^6\, n/cm^2/sec.$[4]

At first, the characteristics of neutron beams and the radiographic image quality were evaluated by the indicators described in ASTM E545 "Determining Image Quality in Direct Thermal neutron Radiography Testing". There are two types of the indicators in the ASTM E545, (1) a device for measuring the comparison of beams (BPI), and (2) a device for the sensitivity of details visible on neutron radiograph (SI). Their structures and details are shown in Figs. 1 and 2. The BPl is composed of a



Polytetrafluoroethylene
Cadmium 99.999% pure
Lead 99.999% pure
BN-Boron nitride
UCAR Grade HBN
Note—Pb and BN disks are 4mm in diameter and 2mm thick.

D_1: density under the lower boron nitride disk
D_2: density under the upper boron nitride disk
D_3: density under the lower lead disk
D_4: density under the upper lead disk
D_5: backgraund film density in the center of the hole
D_6: film density through the teflon body.

Thermal neutron content-C

$$\% C = D_5 - (\text{higher value of } D_1 \text{ and } D_2) / D_5 \times 100$$

Scatterd neutron content-S

$$S = D_1 - D_2 / D_5 \times 100$$

Gamma content-r

$$r = D5 - (\text{lower value of } D_3 \text{ and } D_4) / D_5 \times 100$$

Pair production contribution

$$P = D_2 - D_4 / D_5 \times 100$$

Fig. 1 ASTM Beam Purity Indicator, BPI.

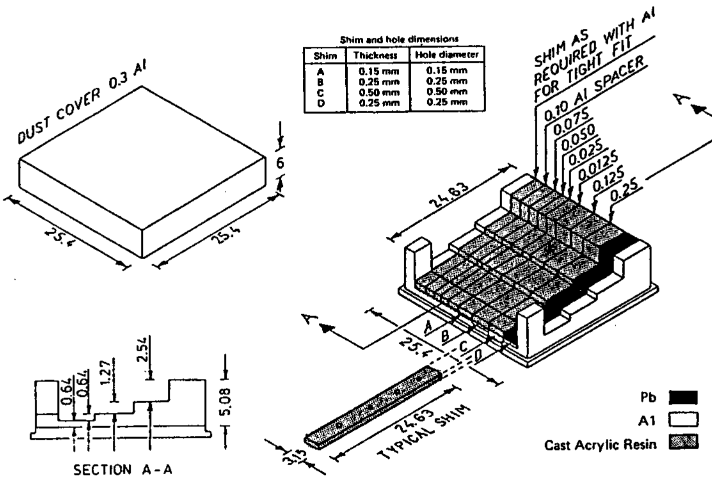


Fig. 2 ASTM Sensitivity Indicator, SI.

block of boron nitride. By densitometric measurements of radiographic images with it, the neutron-beam components are determined. The ASTM SI is constructed by a combination of complex step wedges consisting of PMMA with five different thicknesses, a Pb wedge, PMMA shims having graded holes, and Al spacers with different thicknesses shown in Fig. 2. The sensitivity of neutron radiographs is determined by the *H* value, and Al spacers with different thicknesses between the complex step wedges are used as the gap gauge to evaluate the direction of neutron beams. Also the radiographic image quality is evaluated by Table 1. The characteristics of image quality in radiographs are generally determined by the combination of the converter and the sensitivity of the film.

Table 1 Permitted Values by ASTM E545-81 Edition

	BPI				SI	
Category	*NC*	*S*	*r*	*P*	*H*	*G*
Ⅰ*	65	5	3	3	6	6
Ⅱ*	60	6	4	4	6	6
Ⅲ*	55	7	5	6	5	5
Ⅳ	50	8	6	6	4	5
Ⅴ	45	9	7	7	3	5

*For Categories Ⅰ, Ⅱ, and Ⅲ, the 0.25 mm hole must be visible at all lead thicknesses.

The *NC*, and *S* indicate the ratios of thermal and scattered neutrons to incident beams estimated using the film density obtained by BPI in neutron radiograph, respectively. The *r* and *P* indicate the ratios of gamma-ray and electron consittuents to incident beams. The *H* is the number of holes detected by ASTM SI, and the *G* is the number of Al spacer gaps detected by ASTM SI in neutron radiograph.

The authors developed new sensitive indicators[7] to obtain better fault sensitivity in neutron radiographs of composites of plastics, fine ceramics, and metals.[5,6] The new indicator consists of two kinds of indicators. One of them is the nylon-or steel-wire type indicator with different 7-diameter and 45mm-length wires, and the other is the bacillus type indicator having 30 nylon wires with the same diameter and the same length. In this experiment, the authors fixed the combination of the converter and the sensitivity of films, and then the ASTM SI and authors' indicators were used for the standardization of image indicators. For steel and plastics samples investigation was made of the relationship between the H value of the ASTM SI and the D value of wire type indicators.

Figure 3 shows the relationship observed. One of the two lines in Fig. 3 represents the relationship obtained by the *nylon-wire indicator* (NWI) and the ASTM SI, and another by the *steel-wire indicator* (SWI) and the ASTM SI. In these rediographs, three kinds of indicators were set on the surface of a film without sample. In Fig. 3, the H values 6 of the ASTM SI corresponds to the D value 75 μm of the NWI and to the D value 150 μm of the SWI; the H value 3 of the ASTM SI corresponds to the D value 130 μm of the NWI and to the D value 250 μm of the SWI.

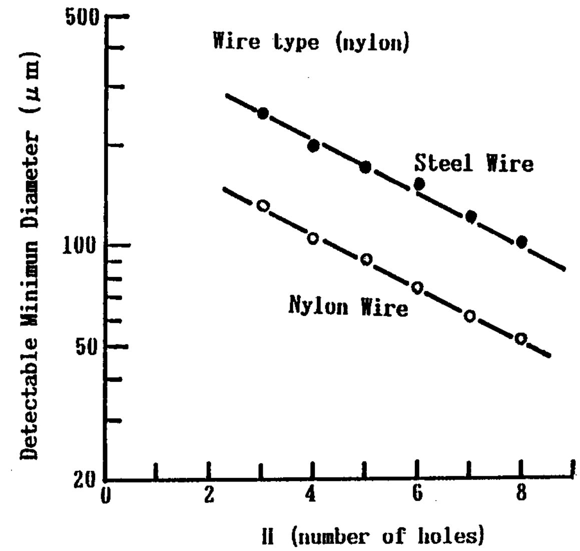


Fig. 3 Relationship between the detected minimum diameters by the NWI and the SWI and the number of holes (H).

Figures 4a and 4b show the relationships between the D value of the NWI and SWI and the thicknesses of plastic sample plates. To obtain these relationships, the NWI and SWI were set on the source side surface of a test sample and the ASTM SI on the films. The parameter attached to each line of these figures represents the H value of the ASTM SI. The followings can be seen from these figures: For the plastic plates of thicknesses from 1 to 8mm, the D value of the NWI is from about 90 to 210 μm when the *H* value is 6, and is from about 170 to 370 μm when the *H* value is 3. However, the *D* value of the SWI larger for the same thicknesses of the plastic plates; it is from 170 to 350 μm when the *H* value is 6, and is from 280 to 600 μm, when the H value is 3.

Figures 5a and 5b show the relationship between the *D* value of the NWI and the thicknesses of steel plates, and the same relationship between the *D* value of the SWI for the steel plates, against the *H* value of the ASTM SI as the parameters.

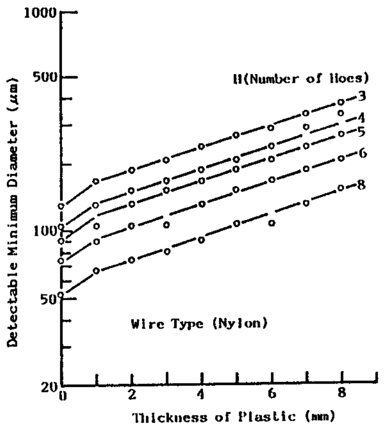


Fig. 4a Relationship between the detected minimum diameters by NWI and the thicknesses of plastic plates, against the *H* by the ASTM SI as parameters.

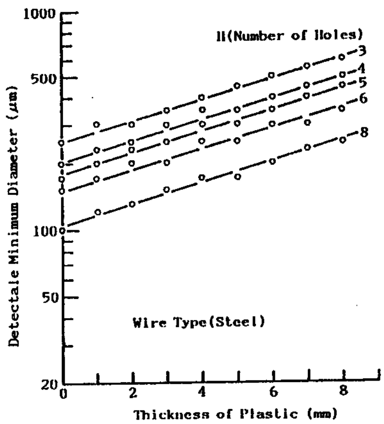


Fig. 4b Relationship between the detected minimum diameters by the SWI and the thicknesses of plastic plates, against the *H* by the ASTM SI as parameters.

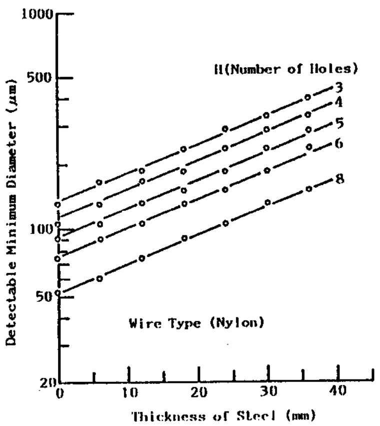


Fig. 5a Relationship between the detected minimum diameters by the NWI and the thicknesses of steel plates, against the *H* by the ASTM SI as parameters.

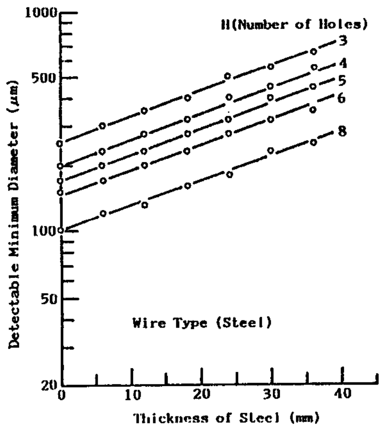


Fig. 5b Relationship between the detected minimum diameters by the SWI and the thicknesses of steel plates, against the *H* by the ASTM SI as parameters.

3. Conclusion

In this work study was made of the relationship between the H value of the ASTM SI and the *D* value of authors' indicators. In the case of NWl the *D* value is usually smaller than the *D* value of the SWI for each *H* value of the ASTM SI.

Fault sensitivities for plastic or steel plates were calculated from the *D* values of the NWI and SWI given in Figs. 4a, 4b, 5a and 5b. The relationship between the fault sensitivities and the *H* values of the ASTM Sl are summarized as follows: When the *H* value of the ASTM Sl is 6, *the value of fault sensitivity* (FS) obtained by the NWI was from about 2.5 to 9% and from about 4.4 to 17% by the SWI for the plastic plates of thicknesses from 1 to 8 mm; for the steel plates of the thicknesses from 6 to 36 mm, the *FS* value was from about 0.7 to 1.5% by the NWI and from about 1 to 2.8% by the SWI. When the *H* value was 3, the *FS* value was from about 4.6 to 17% by the NWI and from about 7.5 to 25% by the SWI for the plastic plates of thicknesses from 6 to 8 mm; for the steel plates of the thicknesses from 6 to 36 mm, the *FS* value was from about 1.7 to 2.8% by the NWI and from about 1.8 to 5% by the SWI.

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