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Research Article

A Study of the Internal Defects of Terrazzo and Engraved Construction Materials using Direct Film Neutron Radiography Technique

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Abstract: Neutron radiography technique has been utilized in the work for studying internal defects of various types of construction materials through optical density measurements of the samples. Two kinds of locally developed construction materials have been used as samples in the experiment. They are Terrazzo and Engraved construction materials. Tangential Neutron Radiography Facility of 3 MW TRIGA Mark-II research reactor is used here to find out the internal defects of the samples. From the observation of neutron radiographic images of the samples and variation of optical density at different positions, it revealed that the associated composites of Terrazzo construction material are uniformly distributed. No voids or any inclusions in the materials have been observed in the radiograph. The neutron radiographic image of Engraved construction material shows that the optical density values at different reference positions are different. The density at the central position of the image is different from its neighboring reference positions. Moreover, some voids are observed in the neutron radiograph of the material. This confirms that in this material the associated composites are not uniformly mixed and distributed during its fabrication. So, the fabrication of this construction material is relatively faulty. This faulty material may have several bad impacts while it is used as a construction material. It can absorb rainwater and thus may be damaged. Due to its structural disorder, its strength is deteriorated and may be damaged easily from even a very minor environmental turmoil.

Keywords: Neutron radiography, non-destructive testing, optical density

1. INTRODUCTION

Neutron radiography (NR) is an imaging technique, which provides images similar to X-ray and Gamma-ray radiography. Interactions of neutron with matter can be divided into scattering and absorption. Neutrons can detect light elements, which have large neutron absorption cross-sections like hydrogen and boron. The information provided by spatial and temporal beam attenuation is recorded on magnetic media via analogy or digital signals.

All radiographic methods, whether making use of X-rays, γ-rays or neutron beams are based on the same general principle that, radiation is attenuated on passing through an object (sample). The object under examination is placed in the incident radiation beam. The beam, which remains after passing through, enters a detector that registers the fraction of the initial radiation intensity that has been transmitted through each point of the object. Any inhomogeneity in the object or an internal defect (such as voids, cracks, porosity, inclusion, corrosion, etc.) will show up as change in radiation intensity reaching the detector.

Neutron radiography is a non-destructive

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testing (NDT) technique of testing the nuclear and non-nuclear materials as well as industrial products [1]. It concerns neutrons and radiography using neutron beam. Recently, NR method has been applied to detect faults and to study water absorption properties of building materials [2]. A neutron radiography standard testing method for the moisture analysis was introduced by Peterka et al [3] to the building industries in order to evaluate the properties, functions and the efficiency of their water protective agents against the penetration of water, water solution etc. In another study [4], quality of leather and ceramics has been studied. Study of corrosion in aluminum has been reported by Islam et al [5]. In the present study, the NR set up at the tangential beam port of the 3.0 MW TRIGA Mark-II research reactor of AERE, Savar, Dhaka, Bangladesh has been used. Details of the NR facility of AERE, Savar, Dhaka can be found in reference [6]. Details of the parameters of the facility have been given by Ahsan et al [7]. A study of defects and water absorption behavior of jute products was reported by Rahman et al [8].

The following experiments were carried out using direct film neutron radiography technique:

A) Determination of optimum irradiation time for the present sample.

B) Determination of defects in the samples through optical density variation measurements.

Any inhomogeneity in the object or an internal defect, e.g., void, crack, porosity or inclusion will show up as a change in radiation intensity reaching the detector, irradiation intensity varies after passing through an object under examination. This intensity variation obeys the general attenuation law [9] applicable for X-rays, gamma rays or neutrons

$$I = I_0 e^{-\mu x} \quad (1)$$

where,

I_0 = initial intensity of the incident beam,
I = intensity of the emergent beam from the object,
μ = attenuation coefficient,
x = thickness of the object.

When the radiation beam is neutron, the above equation can be written as

$$I = I_0 e^{-\mu x} \quad (2)$$

where,

ϕ_s = number of neutrons transmitted through the sample, n cm^{-2} sec^{-1},
ϕ_0= number of neutrons incident upon the sample cm^{-2} sec^{-1},
N = number of nuclei per cm^3,
σ = microscopic cross-section, cm^2,
x = thickness of the sample, cm.

The attenuated neutron beam enters a detector that registers the fraction of the initial radiation intensity reaching the detector and is then recorded in the X-ray film. This is the principle of NR. The rate of depletion of the control rod material can also be detected by taking regular neutron radiographs. Irradiated TRIGA fuel elements could be used as object for all these experiments.

2. EXPERIMENTAL PROCEDURE

2.1 Pre-Irradiation Procedure

1. Sample collection/preparation
2. Loading the film and converter foil in the NR cassette
3. Setting the sample in the neutron beam

2.2 Sample Preparation/Collection

Some locally developed construction materials have been collected from the Concord Ready-Mix and Concrete Products Ltd, Gulshan, Dhaka. The names of these products are terrazzo construction product and Engraved construction product. Terrazzo building product is made from marble chips, marble dust and white cement. Engraved product is made from cement, sand and pigment.

2.3 Loading the Film and Foil in the NR Cassette

Gadolinium (Gd) metal foil of 25 μm thickness was used as converter in the NR cassette and Agfa structruix D4pDW industrial X-ray films were used as detector in our experiment. The films have emulsions in single side only. The sample and the NR camera were placed on their respective tables across the neutron beam. In this position the camera was placed just after the sample. The sample holder table was set at the optimum sample position from the reactor biological shielding assembly.

2.4 Irradiation of the Sample

To find out the optimum irradiation time of the sample a series of experiments were performed with different exposure time. To do these experiments the reactor was operated at 250 kW power level. Finally, we found the optimum irradiation/exposure time for the sample. From the observation of the final radiograph we found out the internal details such as cracks, voids, homogeneity of their compositions etc. of the sample.

2.5 Post-Irradiation

After irradiation of the sample, the irradiated film was separated from the NR camera in the dark room and then following procedures have been carried out to make the radiographic image of the irradiated samples:

2.6 Developing

Developing ensures latent image, which was produced during irradiation to visual one. The film was then immersed into the developer for some time and was then agitated into the developer horizontally without touching the beaker (which contains the developer chemicals).

2.7 Washing

For cleaning the developing chemicals, the film was washed in cool water for a few minutes.

2.8 Fixing

The developed film was immersed in the fixture chemicals to obtain the clear image.

2.9 Final washing

The silver compounds, which were formed during the fixing stage have to be removed, since they can affect the silver image at the later stage. For this reason the film was washed thoroughly in running water.

2.10 Drying

After the final washing, the films were dried by clipping it in a hanger and simultaneously flowing fresh air from the air cooler.

The neutron radiographic images of the sample show that the region in which the sample was at close contact on the neutron radiography cassette were light whereas, the backgrounds were comparatively dark. This is because more neutrons were attenuated by the test sample and allowing more neutrons to pass freely through the rest.

3. BASIC PRINCIPLE OF THE STUDY

The quality/homogeneity of an object depends on the proper distribution of the composite materials. In the present work we have studied the quality of the test samples by the densitometric measurements of the neutron radiographic images of the sample.

When neutron beams hits an absorber, some of them are absorbed and scattered while the rest pass through it. Attenuation of radiation in the object is the difference between the radiation intensity before and after passing through this object. It has been expressed mathematically in eqn. (1).

$$I = I_0 e^{-\mu x} \qquad (3)$$

where e=base of natural logarithms, x = thickness of the test object, μ = linear neutron attenuation coefficient, which depends on the atomic number and the density of the material. I and I_0 is the neutron intensity after passing the object and the neutron intensity incident on the object.

In this work, the term homogeneity means the uniformity in the distribution of the composite materials. The homogeneity of a material depends on the proper distribution of the composite materials. Measuring the optical density of the radiographic film background (without image), the optical density of the center point of the sample image, and at different reference levels of the radiographic image of the sample, one can comment about its homogeneity/inhomogeneity. The best homogeneity is ensured would constant optical density values at all places/levels.

The mathematical expression [10] for the optical density D, at a point of the film/image is given by:

$$D = \ln\left(\frac{A_0}{A}\right) \tag{4}$$

where, A_0 = response of densitometer without the image and A = response of densitometer with the image.

Fractional change in the image density of the neutron radiograph can be represented by ΔD and the expression can be written as,

$$\Delta D = \left(\frac{D_c - D_n}{D_c}\right) \tag{5}$$

where D_c = Average optical density of the total radiographic image and D_n = Optical density at different positions of the radiographic image.

The optical density of the neutron radiographic images of the sample have been measured by a digital densitometer (Model – 07 - 424, S - 23285 Victorian, USA). Densitometric data of the optical density of the radiographic image of the sample tiles are given in Table 2.

4. RESULTS AND DISCUSSION

To calculate the optimum irradiation time for the two samples, the samples were irradiated for different time intervals at reactor power 250 kW. The optimum irradiation time was found out to be 45.0 ±3.7 minutes for both the samples. The results are shown in Table 1. The radiographs of Terrazzo and Engraved tile samples are shown in Fig. 1(a) and Fig. 1(b), respectively. The optical density of the neutron radiographic images of the samples were measured by a digital densitometer (Model – 07-424, S-23285 Victorian Inc., USA). Densitometric data of optical density of the radiographic image of the sample is shown in Table 2.

Table 1. Optimum irradiation/exposure time of the objects.

Construction material	Irradiation time (Minute)	Optimum irradiation time (Minute)
Terrazzo	60.0 50.0 40.0 45.0	45.0 ±3.7
Engraved	60.0 50.0 40.0 45.0	45.0±3.7

Table 2 Densitometric data for Terrazzo and Engraved building materials.

Construction material	Optical density at the centre	Average density (D_c)	Optical density at different positions (D_n)	Fractional change in image density $\Delta D = (D_c - D_n) / D_c$
Terrazzo	2.54 2.54 2.54 2.53 2.53 2.54	2.537±0.002	2.54 2.54 2.54 2.55 2.54 2.54 2.54 2.55 2.54	0.001 0.001 0.001 0.005 0.001 0.001 0.001 0.005 0.001
Engraved	2.48 2.48 2.48 2.48 2.48 2.47	2.478±0.001	2.48 2.50 2.47 2.52 2.49 2.44 2.50 2.44	0.000 0.009 0.003 0.017 0.005 0.015 0.009 0.015

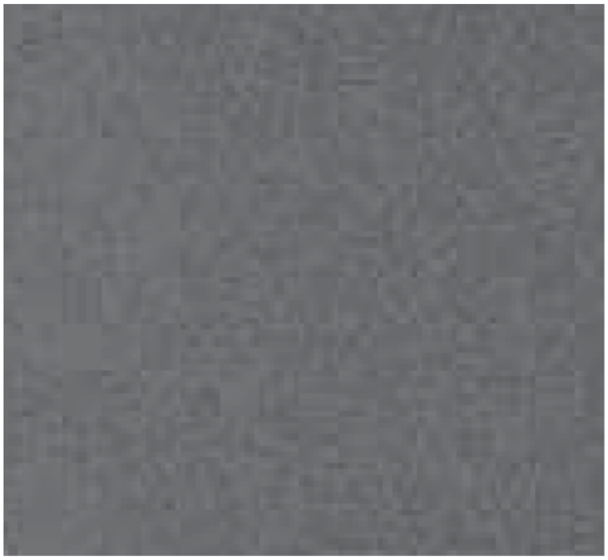

Fig. 1(a). Neutron radiographic image of a Terrazzo tile.

Fig. 1(b). Neutron radiographic image of an Engraved tile.

The Terrazzo tiles are usually used in the floor of buildings. The radiograph of Terrazzo is almost clear which shows that the mixture of the constituent elements of the sample is quite uniform. The densitometric data also proves the uniformity in mixing the constituent elements in the Terrazzo material. From experience in handling the radiographic films, we can conclude that the quality of Terrazzo tiles is good. From the radiograph of the Engraved construction materials it seems that the sample was not perfectly homogeneous. From the densitometric data it may be concluded that mixing of the constituent elements in the Engraved tiles is not uniform. The quality of the Engraved tiles should be improved further by mixing the constituent elements in a much better and improved way. The samples were dipped into water for 24 hours and then radiographs were taken but no absorption of water was seen in the radiographs. The reason was that the tiles were coated by water resistant porcelain type materials.

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