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A Study of the Internal Defects of Auto bricks and Handmade Wire cut Red Clay Bricks Construction Materials by Using Neutron Radiography Technique

Shahajan Miah
(Department of Electrical and Electronic Engineering (EEE), Bangladesh University of Business and Technology (BUBT), Dhaka, Bangladesh)
Corresponding Author: Shahajan Miah, Email: miahsust@gmail.com

ABSTRACT:*Neutron radiography technique has been used for studying internal defects of various types of construction materials through optical density measurements of the samples. Two kinds of locally developed construction materials were used as samples in our experiment. They were Handmade Wire cut Red Clay Bricks and auto bricks construction materials. Tangential Neutron Radiography Facility of 3 MW TRIGA Mark-II research reactors was used to find internal defects in 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 auto bricks construction material are uniformly distributed. No voids or any inclusions in the materials have been observed in the radiograph. Neutron radiographic image of Handmade Wire cut Red Clay Bricks showed variable optical density values at different reference positions. 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. The heterogeneity of composition can lead to several issues like rain-water absorption and to damages. This also leads to deterioration of strength and susceptibility to damage from even minor environmental stress.*

Keywords: *Neutron Radiography, Optical density, Homogeneity, Internal Structure and defect.*

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I. INTRODUCTION

Neutron radiography, also known as n-ray radiography, is a very efficient tool to enhance investigations in the field of non-destructive testing. In this technique, a neutron beam penetrates the specimen to be studied. This beam is attenuated by the sample material depending on the material's neutron cross-section. The beam is then detected by an imaging device that outputs an image representing the macroscopic structure of the samples interior **[1].**The property of thermal neutrons, which makes them valuable for studying industrial components, is their high penetration through widely applicable on industrial materials such as steel, aluminum or zirconium. Neutrons are efficiently attenuated by only a few specific elements such as hydrogen, boron, cadmium, samarium and gadolinium. For example, organic materials or water attenuate neutrons because of their high hydrogen content, while many structural materials such as aluminum or steel are nearly transparent.

Neutron radiography is an advance technique for non-destructive testing of materials and is exact analogue of X-ray radiography. Therefore, NR has some special advantages in Nuclear, Aerospace, Ordnance and rubber & plastic industries. NR is a technique which gives enough information about heavy and light materials when X-rays andneutrons penetrate through light and heavy materials. X-rays are attenuated best by materials with large atoms and not well by small, light ones. This allows x-rays to pass through the water in a human body easily and attenuate in bones.

Conversely, neutrons move through high Z materials easily and are attenuated well by low Z materials, such as Hydrogen. Thus the two radiographic process using x-rays and neutrons are complementary to each other. **Fig 1:** shows penetration of X-Ray and Neutron through light and heavy materials.

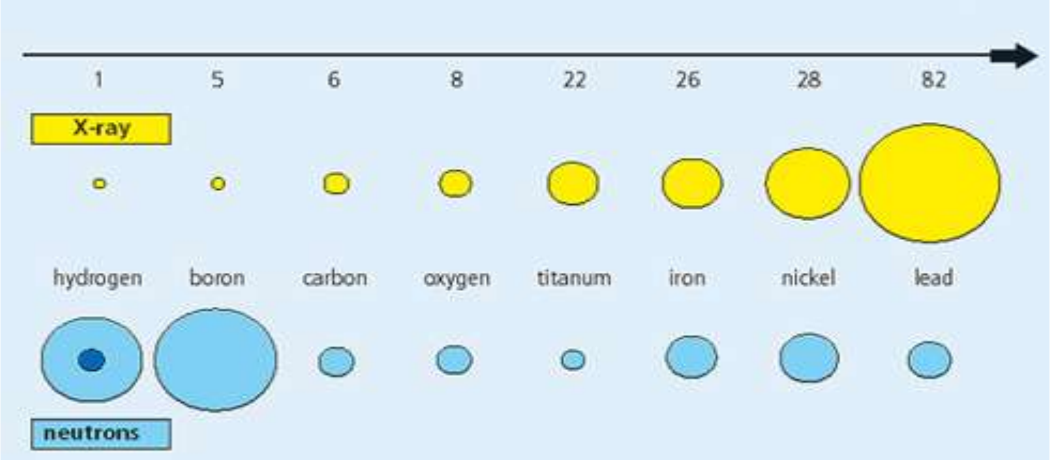

Fig 1: Penetration of X-Ray and Neutron through light and heavy materials.

Neutron Radiography (NR) is an imaging technique, which provides images similar to X-ray and Gamma-ray radiography. The advantage of neutron radiography is its ability to image very light elements (i.e. with low atomic numbers) such as hydrogen, water, carbon etc. In addition, neutrons penetrate very heavy elements (i.e. with high atomic numbers) such as lead, titanium etc. as well as distinguish between different isotopes of the same element. This makes neutron radiography an important tool for the studies of both radioactive and nonradioactive materials. NR is the photographic image of the internal structure of a substance obtained by using neutron. 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 analog or digital signals. NR is a non-destructive testing (NDT) technique, which is completely complementary to other NDT techniques, like X-ray or gamma ray radiography **[2, 3].**

Recently NR method has been applied to detect faults and to study water absorption properties of building materials **[4]**. A neutron radiography standard testing method for the moisture analysis was introduced by Peterka et al. **[5]** 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 **[6]** quality of leather and ceramics has been studied. Study of corrosion in aluminum has been reported by M.N. Islam et al. **[7]**. 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 **[8]**. Details of the parameters of the facility have been given in **[9].** A study of defects and water absorption behavior of jute products was reported by A.K.M. Azad Rahman et al. **[10]**. Study of the Internal Structure of Electronic Components RAM DDR-2 and Motherboard of Nokia-3120 by Using Neutron Radiography Technique was reported by Shahajan Miah et al. **[11].**

The following experiments have been carried out in the present study 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 in homogeneity 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 applicable for X-rays, gamma rays or neutrons

$$I = I_0 e^{-\mu x} \qquad \text{................................} \qquad (1)$$

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

$$\phi_s = \phi_0 e^{-N\sigma x} \quad \text{................................} \quad (2)$$

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.

II. EXPERIMENTALFACILITY

The experimental neutron radiography facility installed at the tangential beam port of 3 MW TRIGA Mark II reactors in the Institute of Nuclear Science and Technology, Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh. The neutron radiography facility consists of the following devices/equipment.

2.1. Bismuth Filter

In the NR facility at TRIGA reactor of BAEC a 15 cm long Bi filter in the tangential beam port is used to reduce the intensity of gamma ray significantly from the beam to prevent the unwanted fogginess in the radiographic image.

2.2. Cylindrical Divergent Collimator

A cylindrical divergent collimator made of 120 cm long aluminum hollow cylinder with 5 cm and 10 cm diameter at the inner and outer end, respectively, has been inserted in the tangential beam port to collimated neutron beam of the reactor. The advantage of the divergent collimator is that a uniform beam can be projected easily over a large inspection area. Collimators are required to produce a uniform beam and thereby produce adequate image resolution capability in a neutron radiography facility.

2.3. Lead Shutter

The outer end of the tangential beam tube is equipped with a lead-filled safety shutter and door to provide limited gamma shielding. The thickness of lead in the shutter is 24 cm and the diameter of the shutter is 33 cm.

2.4. Beam Stopper

A wooden box with dimension of 68 cm × 40 cm × 68 cm has been made with the attachment of four ball bearings on the bottom part of it for forward and backward movement in front of the tangential beam port. It looks a wooden box, which contains neutron-shielding materials like paraffin wax and boric acid in 3:1 ratio by weight for neutron shielding.

2.5. Sample and Camera Holder Table

There is a sample and camera holder table with both horizontal and vertical movement facility placed in front of the beam line.

2.6. Beam Catcher

To absorb transmitted and scattered neutron and gamma radiations a beam catcher with dimension 100 cm × 100cm × 85 cm has been placed behind the sample and camera holding table. A 30 cm × 30 cm × 30 cm hole has been made in the middle of the front face of the beam catcher which coincides with the central axis of the beam port. A 30 cm × 30 cm × 15 cm lead block weighing 125 Kg has been placed at the back side of the hole for gamma shielding. For neutron shielding a mixture of paraffin wax and boric acid has been used in the catcher. The total weight of the beam catcher is 968 Kg.

2.7. Biological Shielding House

The emitted neutron and the gamma rays are extremely dangerous for human body. This is why, to prevent these harmful rays to spread over the entire environment a biological shielding house has been built around the NR facility of the tangential beam port. It is made of special concrete containing cement, heavy sand (magnetite, limonite and ordinary sand) and stone chips in the ratio 1:3:3. Paraffin wax and boric acid in 3:1 ratio by weight were also used inside the biological shielding wall for neutron shielding. The width and height of the biological shielding wall of the facility are ≈ 3.0 ft and 6.5 ft, respectively. Details of the NR facility can be found elsewhere **[14, 15, 16].** The schematic diagram of the neutron radiography facility of 3 MW TRIGA Mark II Reactor, AERE, Savar, Dhaka is shown in **Fig 2**.

III. EXPERIMENTAL PROCEDURE

3.1. Pre-Irradiation Procedure

Before performing the irradiation of the experimental objects, the following steps were undertaken in the present experiment:

i. Sample collection/preparation.
ii. Loading the film and converter foil in the NR cassette.
iii. Setting the sample in the neutron beam

3.1.1.Sample Preparation/Collection

Some locally developed construction materials have been collected from the Concrete Products Ltd, Mirpur, Dhaka. The names of these products are Auto bricks construction product and Handmade Wire cut Red Clay Bricks construction product.

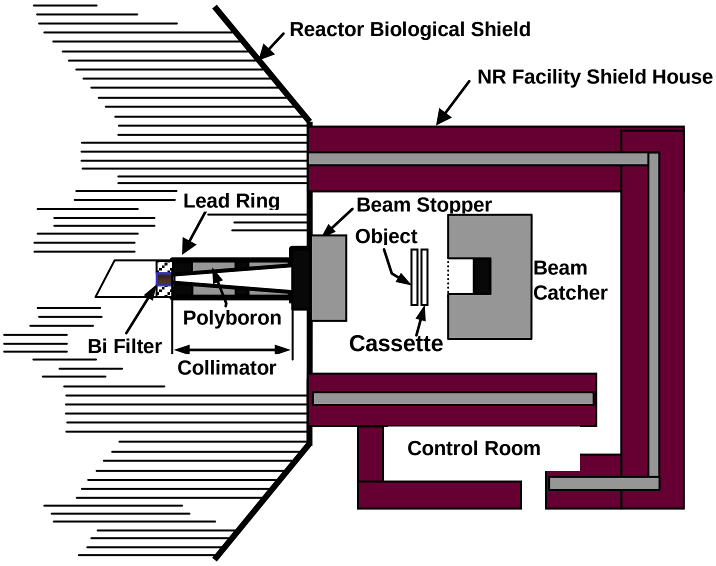

Fig 2: Schematic diagram of the neutron radiography facility.

3.1.2. Loading the Film and Foil in the NR Cassette

Gadolinium (Gd) metal foil of 25μm thickness was used as converter in the NR cassette and Agfa structruix D4DW 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.

3.1.3. 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 3 MW 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. Different steps after irradiation like film developing, washing. Fixing, washing and drying are described in detail elsewhere **[2, 4-8].** The neutron radiographic images of the sample show that the region in which the sample was at close contact on 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.

3.2. Post irradiation Procedure

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

a. Developing
b. Washing
c. Fixing
d. Final washing
e. Drying

All of these above processes are discussed individually bellow in brief:

3.2.1. Developing

Developing conditions differ from film to film. When irradiation of the samples was done we brought out the film from the NR cassette for developing in the dark room. Developing ensures latent image, which was produce during irradiation to visual one. The film was than emerge into the developer for some time and was then agitated into the developer horizontals without touching the beaker (which contains the developer chemicals). We have used Kodak D -19 developer in the developing. The time of developing till the image is visible depends on the film and the temperature of the developer. Longer development time generally yields faster film speed and slightly more contrast. The manufacturer's recommendations should be followed in choosingthe development time. When the temperature of the developer is higher or lower, development time must be changed. In present experiment we developed the films in the developer for 5 minutes at temperature 22^0 C.

3.2.2. Washing

For cleaning the developing chemicals, the film was washed as necessary. After completion of the development, the activity of the reaming developer in the emulsion should be neutralized. This was done by rinsing the developing films with vigorous agitation in the flowing water for one minute.

3.2.3. Fixing

The developed film was immersed in the fixture chemicals to obtain the clear image. We have used Kodak unfix powder as a fixer in the experiment. The time of fixing depends on the film and temperature of the fixer. The manufacturer recommendations should be followed in choosing the fixing time. In the present work, the films were immersed for 5 minutes at 22^0C.

3.2.4. Final Washing

The silver compounds, which were formed during the fixing stage, must be removed, since they can affect the silver image at the later stage. For this reason the film must be washed thoroughly in running water. The duration of washing will depend upon the temperature of the water used. A chart of temperature and required washing time is shown in **Table 1**. In the present work, the film was washed in the running water for 15 minutes at room temperature.

Table 1: Table for washing time of the films at different temperature

Temperature	**Required time**
5^0C-12^0C	30 min
13^0C-25^0C	20 min
25^0C-30^0C	15 min
Above 30^0C	10 min

3.2.5. Drying

After the final washing, the films were dried by clipping it in a hanger and simultaneously flowing fresh air from the air cooler. Basically, drying condition differs from film to film. It is a function of type of film, temperature, humidity, flow of air etc. The above mentioned procedures were repeated for every experiment.

IV. BASIC PRINCIPLE OF THE STUDY FOR THE SAMPLE

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 centre point of the sample image, and at different reference levels of the radiographic image of the sample, one can comment about its homogeneity. The reference points are selected in such a way that almost whole sample is covered when optical densities are measured at these reference points. The best homogeneity is ensured if constant optical density values at all places/levels. The mathematical expression **[14, 15]** for the optical density, D, at a point of the film/image is given by:

$$D = \ln\left(\frac{A_0}{A}\right) \qquad (3)$$

Here, A_0 = response of densitometer without the image and A = response of densitometer with the image. Fractional change in image density of neutron radiograph can be represented by ΔD and the expression can be written as,

$$\Delta D = \left(\frac{D_c - D_n}{D_c}\right) \qquad (4)$$

Where, D_c = Average optical density of the total radiographic image and D_n = Optical density at different positions of the radiographic image. We have measured the optical density, of the neutron radiographic images of the sample 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 below.**

V. RESULTS AND DISCUSSION

Table – 2: Optimum irradiation/exposure time of the objects.

Samples	**Irradiation time (minute)**	**Optimum irradiation time (minute)**
Auto Bricks	60 50 40 45	45
Handmade Wire cut Red Clay Bricks	60 50 40 45	45

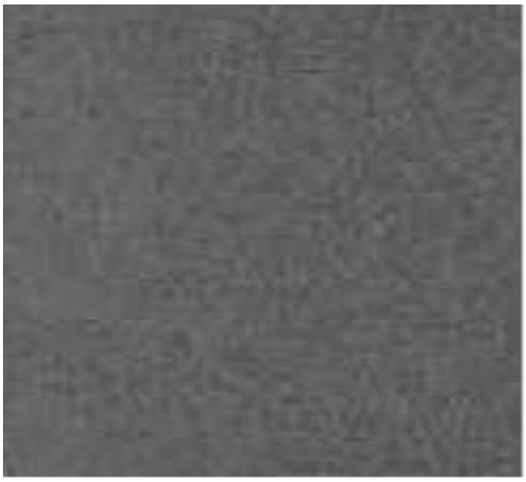

Fig 3(a): Neutron Radiographic Image of Auto bricks.

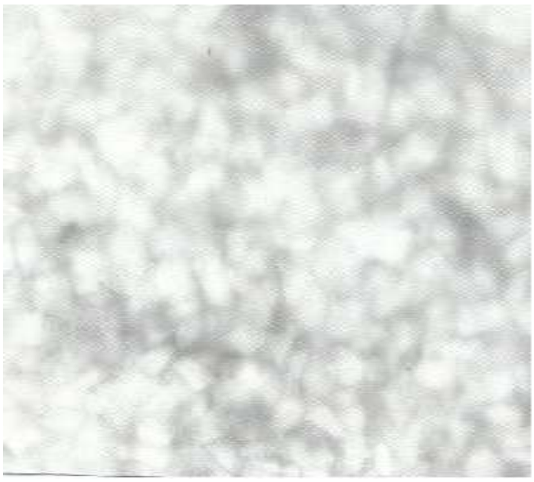

Fig3(b): Neutron Radiographic image of Handmade Wire cut Red Clay Bricks.

Table – 3: Densitometric data for Auto bricks and Handmade Wire cut Red Clay Bricks constructions materials.

Samples	**Optical density at the centre**	**Average density (D_c)**	**Optical density at the different positions (D_n)**	**Fractional change in image density □ D = (D_c - D_n) / D_c**
Auto Bricks	3.88 3.68 3.58 3.53 3.76	3.68	3.68 3.68 3.66 3.68 3.68	0.000 0.000 0.000 0.004 0.000
Handmade Wire cut Red Clay Bricks	3.66 3.46 3.64 3.46 3.64	3.57	3.57 3.61 3.59 3.65 3.59	0.000 0.008 0.004 0.016 0.004

Table- 4(a) Densitometric data at different levels for the radiographic image of Auto bricks.

Different level	**Optical density**					
1	3.88	3.90	3.91	3.88	3.88	3.85
2	3.67	3.61	3.68	3.66	3.61	3.68
3	3.58	3.51	3.63	3.61	3.51	3.53
4	3.53	3.52	3.64	3.64	3.53	3.47
5	3.76	3.89	3.73	3.68	3.73	3.71

Table- 4(b) Densitometric data at different levels for the radiographic image of Handmade Wire cut Red Clay Bricks

Different level	**Optical density**					
1	3.68	3.71	3.66	3.73	3.80	3.85
2	3.46	3.46	3.46	3.43	3.50	3.55
3	3.82	3.58	3.64	3.46	3.35	3.40
4	3.34	3.46	3.46	3.30	3.36	3.36
5	3.61	3.83	3.64	3.66	3.66	3.54

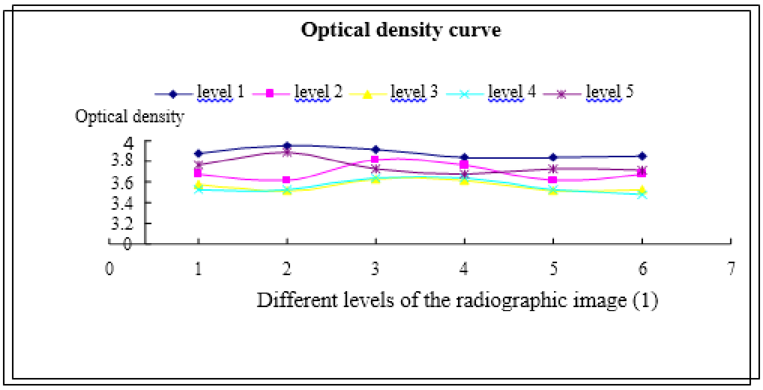

Fig 4(a): Optical density differences at different levels of the film background and the radiographic image of the Auto bricks.

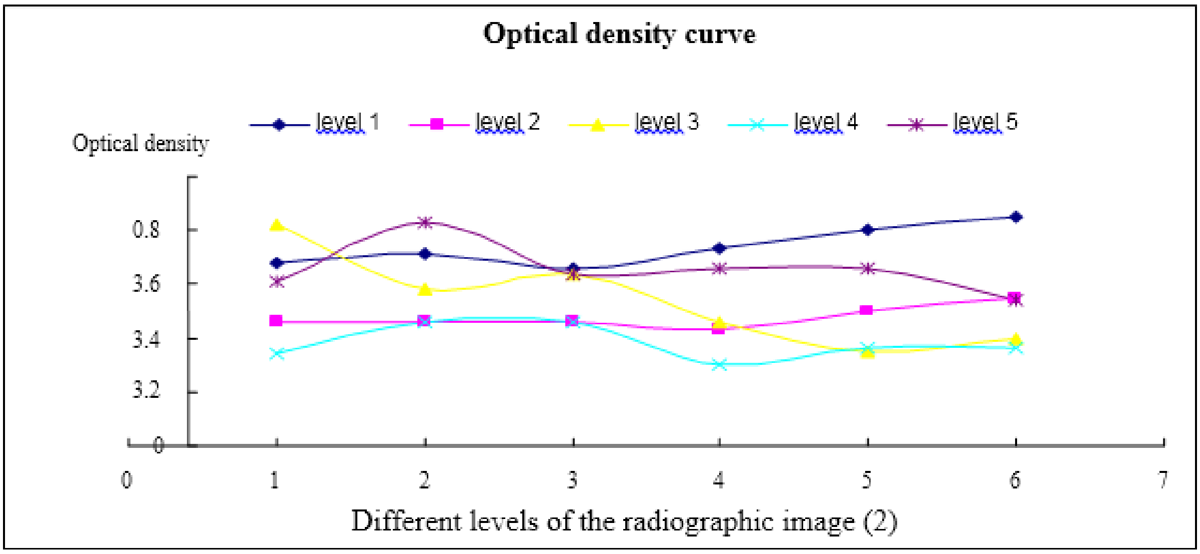

Fig 4(b): Optical density differences at different levels of the film background and the radiographic image ofthe Handmade Wire cut Red ClayBricks.

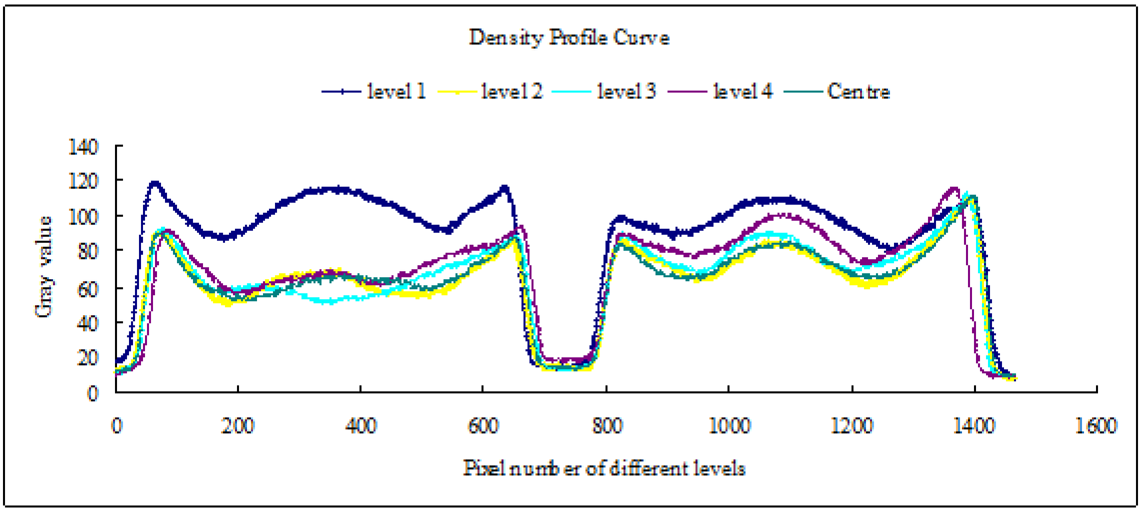

Fig 5: Pixel number of different levels

VI. CONCLUSION

Auto bricks have been used from the ancient time and are still used enormously in modern construction in everywhere. The radiograph of Auto bricks is almost clear which shows that the mixture of the constituent elements of the sample is quite uniform. The densitometry data also proves the uniformity in mixing the constituent elements in the Auto bricksmaterial. From experience in handling the radiographic films we can conclude that the quality of Auto bricksis good. From the radiograph of the Handmade Wire cut Red Clay Bricks 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 Handmade Wire cut Red Clay Bricks is not uniform. The quality of the Handmade Wire cut Red Clay Bricks should be improved further by mixing the constituent elements in a much better and improved way.

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Shahajan Miah was born on 11/11/1988 in Sylhet, Bangladesh.He completedhis B.Sc (Hon's) and Masterof Science (M.S) in Physics from Shahjalal University of Science and Technology (SUST), Sylhet, Bangladesh. Currently, heserving as a Lecturer in Physics under Department of Electrical andElectronic Engineering (EEE) at Bangladesh University of Business and Technology (BUBT), Dhaka, Bangladesh. He published more than 4 papers in different journals. Contact email is miahsust@gmail.com.

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