

A PORTABLE FAST NEUTRON RADIOGRAPHY SYSTEM FOR NONDESTRUCTIVE ANALYSIS

Erol KAM^{1,*}, A. İskender REYHANCAN², Recep BIYIK³

^{1,*}Yıldız Technical University, Dep. of Physics Esenler Istanbul, Turkey, erolkam@hotmail.com

²Istanbul Technical University, Energy Institute, Sarıyer Istanbul, Turkey, iareyhancan@yahoo.com

³Turkish Atomic Energy Authority, Technology Development Dept. Küçükçekmece Istanbul, Turkey, recep.biyik@taek.gov.tr

Abstract

Depending on the neutron energy used, neutron radiography can be generally categorized as fast and thermal neutron radiography. Fast Neutron Radiography (FNR) with neutron energy more than 1 MeV opens up a new range of possibilities for a nondestructive inspection when the inspected object is thick or dense. Other traditional techniques, such as X-ray, gamma ray and thermal neutron radiography do not meet FNRs penetration capabilities in this area. Because of these distinctive features, this technique used in different industrial applications such as security (cargo investigation for contraband such as narcotics, explosives and illicit drugs), gas/liquid flow and mixing, radiography and tomography of encapsulated heavy shielded low Z compound materials. The FNR images are produced directly during exposure; the neutrons create recoil protons, the protons activate a scintillator screen, the images can be collected with a computer controlled charge –coupled device (CCD) camera and finally the picture can be saved on a computer for the image processing. The aim of this research is to set up a portable fast neutron radiography (FNR) system and to test it for use in nondestructive testing of different composite materials. Experiments were carried out by using fast portative neutron generator Thermo Fischer MP320.

Key words: Fast neutron, radiography, scintillator, recoil protons.

1 Introduction

Different radiography imaging techniques such as x, gamma, and neutron - graphy are well established techniques for the nondestructive testing (NDT) of materials. But FNR is relatively new and is currently under development [1]. Using this technique all materials such

as high density metals, loaded plastics, cadmium, lead, tungsten, concrete etc. could be analyzed. Compared to other techniques fast neutrons enable non-destructive testing of thicker object [2-5].

The FNR systems generally consist of three parts,

1. a neutron generator (must produce suitable neutron beam),
2. a converter or detector and,
3. a device to record the radiation intensity.

In fast neutron radiography systems, neutron generators are usually accelerator based which require a particle accelerator and a target. Proton or deuteron beam is accelerated to the desired energy and bombards the target material to produce fast neutrons by a nuclear reaction. In our study a sealed deuterium - tritium (DT) neutron source is used. Fusion of a deuterium and a tritium atom ($D + T$) results in the formation of a He-4 ion and a neutron with a kinetic energy of approximately 14.1 MeV [7].

A scintillation detector is used for FNR imaging as a converter or detector [3,8]. Fast neutrons are scattered by hydrogen nuclei and the recoil protons produced are absorbed in a scintillation plate. The scintillated product is in the visible wavelength range. Each neutron interaction with a scintillator may, therefore, be considered as a point-like light source producing rather significant number of optical photons [9]. At FNR systems neutron detectors work in an integrated mode, namely individual neutrons are not counted.

In this study we introduce a portable digital fast neutron radiography system and demonstrate some images of different composite materials to show efficiency of the system. Some other parameters of the systems which are used to describe the image, spatial resolution, contrast sensitivity, detective quantum efficiency, dynamic range, and temporal resolution will be discussed in another paper.

2 Description of the system

The FNR system is designed as shown in Fig.1. Aluminum sheets were chosen as the construction material of the optical box because of the short half - life activation of aluminum when it interacts with fast neutrons. The inner wall of the optical box was painted matt black

to prevent light reflections. The optical box system was exposed to light sources from outside to confirm that there is no light leakage into the box. After the light leakage tests the CCD camera was mounted.

An accelerator based portable neutron generator was used as a source (Thermo Scientific Fischer MP320) (Fig.2). The generator uses DT reactions and produces 14.1 MeV energetic neutrons with a $\sim 1 \times 10^8$ n/cm²/s flux at 80 kV terminal voltage, and a 60 - μ A ion beam current. In FNR systems scintillation screens (plastic or inorganic scintillators) are used [3,9,10]. Because of their sensitivity to fast neutrons, inorganic scintillators ZnS(Ag) were prepared (silver activated ZnS (% 30) granule size 20 μ m dispersed in polypropylene %70) with dimensions 27x27 cm and 2.4 mm thickness. The SEM (scanning electron microscope) image of the granules and the picture of the scintillator developed by us are shown in Fig. 3a and Fig. 3b, respectively. To record the image of a composite sample material subjected to neutrons a scintillator, a mirror at 45 degrees, and a CCD were used as depicted in Fig. 1. The mirror was necessary to avoid direct neutron irradiation of the CCD. Furthermore, additional shielding was required to protect from stray radiation. The lens of CCD focuses light on the chip and helps collect more light. We used Hamamatsu ORCA-BT-1024 G type, High Resolution, 1024x1024 pixel BT (Back Thinned) as our high cooling performance with 4-stage peltier cooled CCD digital camera. This very high resolution, back thinned, back illuminated million pixel CCD offers very high quantum efficiency over 90 % peak and broad sensitivity from UV to NIR the spectrum from 350 nm to 900 nm. Quantum efficiency is the measure of the effectiveness of an imager to produce electronic charge from incident lights. This is an especially important property when doing low-light-level imaging.

After the desired exposure time the obtained images need to be processed. There are a lot of software that can be obtained commercially or freely for this purpose. However, instead we wrote a computer software using Visual C#, which has simple interface and is easy to use, effective and fast. It runs only on Windows operating system and free. A zipped pack, containing the program, some examples and user manual can be obtained on request via e-mail from the authors. In our software we used LPGL and AForge.NET libraries. The program includes common image processing units like contrast change, gray tones, curves, brightness, threshold, filters (Median, Gaussain Blur, Gamma Correction, Sharpen, Adaptive smoothing etc.) and so on.

3 Some image examples

Several testing objects, being composed of different materials and shapes, were prepared . These are included plexiglas, plastics, aliminum, iron, cupper wire and concrete. Based on the radiographic images obtained, it can be said that the spatial resolution of our system is capable of resolving objects of at least 1.5 mm. The illustrations of the objects are given in the following;

The first tests of the imaging system were performed with a Plexiglas plate (90x90x20 mm) (Fig. 4a). Upon the plate holes with different radii and depths were formed. The radii and depths of the holes were between 5 to 12 mm and 5 to 15 mm, respectively. The numerical gray level of the plexiglass sample was determined and the values of the signal to noise ratio (SNR) are shown in Table 1. SNR is a measure used in science and engineering to quantify how much a signal has been corrupted by noise. It is defined as the ratio of signal power to the noise power corrupting the signal. A ratio higher than 1:1 indicates more signal than noise. The higher the ratio, the less obtrusive the background noise is. As seen in Fig. 4b and Table 1 the resolution of the system is pretty good and the contrast of the holes are clearly distinguished according to their sizes.

In another test to show the response of the radiographic system against different composite materials, materials with different shapes were collected together in a container. For this purpose a cylindrical aluminum block was placed on top of an upside down half- full adhesive gum tube and they were placed in an empty cylindrical container. Fig. 5a and Fig. 5b show normal and FNR image of the materials, respectively. The FNR system did not only distinguish different composite materials but also showed different contrast on the empty side of the half - full adhesive gum.

The other example is a lantern. The FNR image shows distinctly the different gray levels of the plastic case of the lantern, the copper wire, some metals, and the lithium battery (Fig. 6a and Fig. 6b).

The fourth image test shows the detection of iron sticks in concrete. Firstly, molds with two different shapes were prepared. One type consists of steel cylindrical tubes (6 cm in radius) and the other one is a triangular wood (30x40x50 cm) (Fig. 7a). Iron sticks with different

thicknesses and shapes were placed in steel molds. Then C30 - type concrete was poured. After waiting for the concrete to dry, samples were removed from the mold to take FNR images. Then images were taken and processed. Because iron and concrete have nearly the same neutron absorption coefficients, traditional imaging methods cannot distinguish the two satisfactorily. However, as depicted in Fig.7b, three iron sticks with different shapes could easily be seen in concrete in our case. Moreover, contrast difference of curves of the iron sticks and the nut parts are remarkably distinguished. The image of the triangle sample also has an important value (Fig.7c). The thickness of the triangular concrete block shown in the figure varies from 2 cms at the apex to 30 cms at the base. All of the iron sticks are seen in the FNR image. Fig. 7d shows gray levels of the iron sticks against pixel dimension. This result demonstrates that iron sticks and their thicknesses in concrete structures can be seen with nondestructive FNR techniques. This feature may especially be used to check the strength of historical buildings in a nondestructive way.

4 Conclusion

In this study we try to show some key features of the fast neutron radiography systems for the industrial applications. The results obtained in this study are important in terms of demonstrating the development of fast neutron radiography technique for portable use. At this point, it can be said that two basic parts of FNR need to be developed; commercially available turn-key D-T and D-D neutron generators and scintillation screens. Portable neutron sources that can be used for this purpose should be able to produce high neutron flux and scintillation screens with high light efficiency are required.

We have presented FNR images taken for materials with different compositions and also we showed that iron bars and thicknesses in concrete molds can be detected using portable neutron generator. At this point, if the works are developed, this system can be used construction sector for the purpose of control and inspection of buildings without destructive way.

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Table Captions

Table 1 The values of the signal to noise ratio (SNR) of plexiglass sample.

Figure Captions

Figure 1- Fast neutron radiography hardware.

Figure 2- Thermo Fischer MP320 portable neutron generator

Figure 3- a) The SEM image of the ZnS (Ag) scintillator

b) Scintillator screen (27x27 cm).

Figure 4- a) Plexiglas plate (upon which different holes with different radii and depths are formed).

b) FNR image of the plexiglas plate.

Figure 5- a) Normal image of the different composite materials

b) FNR image of different composite materials which was collected all together in a container.

Figure 6- a) Normal and b) FNR image of the lantern sample.

Figure 7- a) Molds with two different shapes were prepared, cylindrical and triangle

b) FNR image of the different thicknesses of the irons in concrete

c) FNR image of irons in triangle shaped molds

d) Gray levels of the iron rods against pixel dimension.

Table 1 The values of the signal to noise ratio (SNR) of plexiglass sample

Diameter	Depts		
	15 mm	10 mm	5 mm
12 mm	5,31	3,56	2,32
8 mm	5,20	3,39	2,10
5 mm	5,15	2,97	1,94

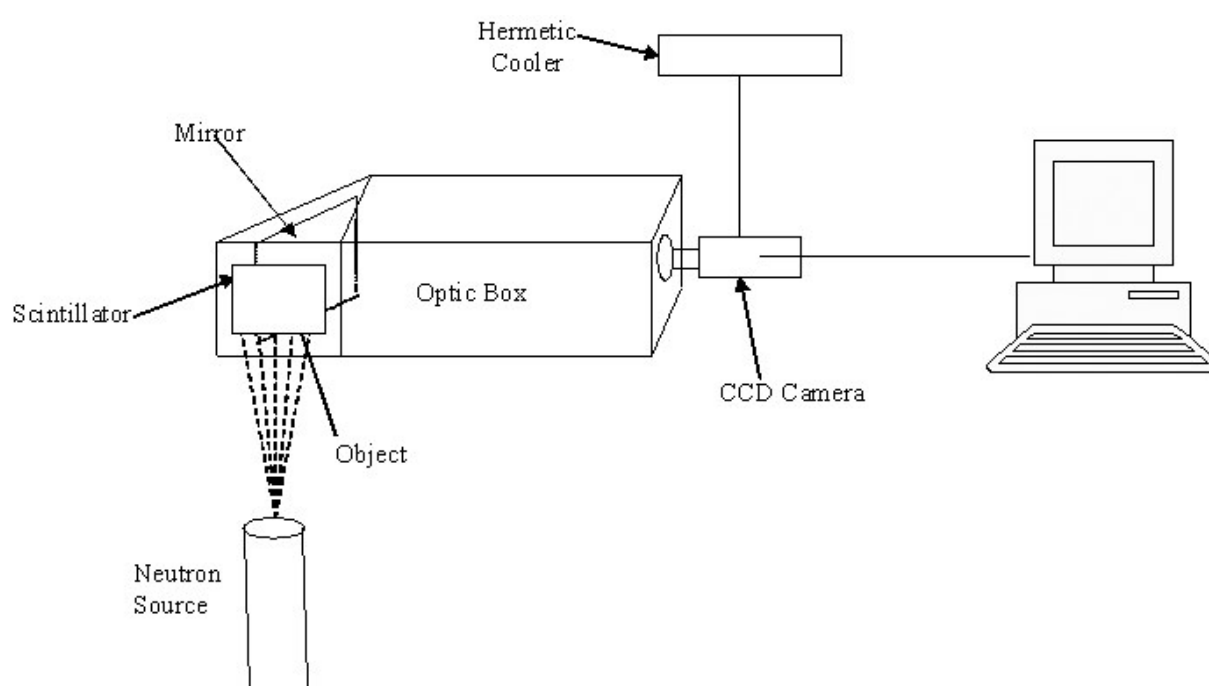


Fig. 1 Fast neutron radiography hardware

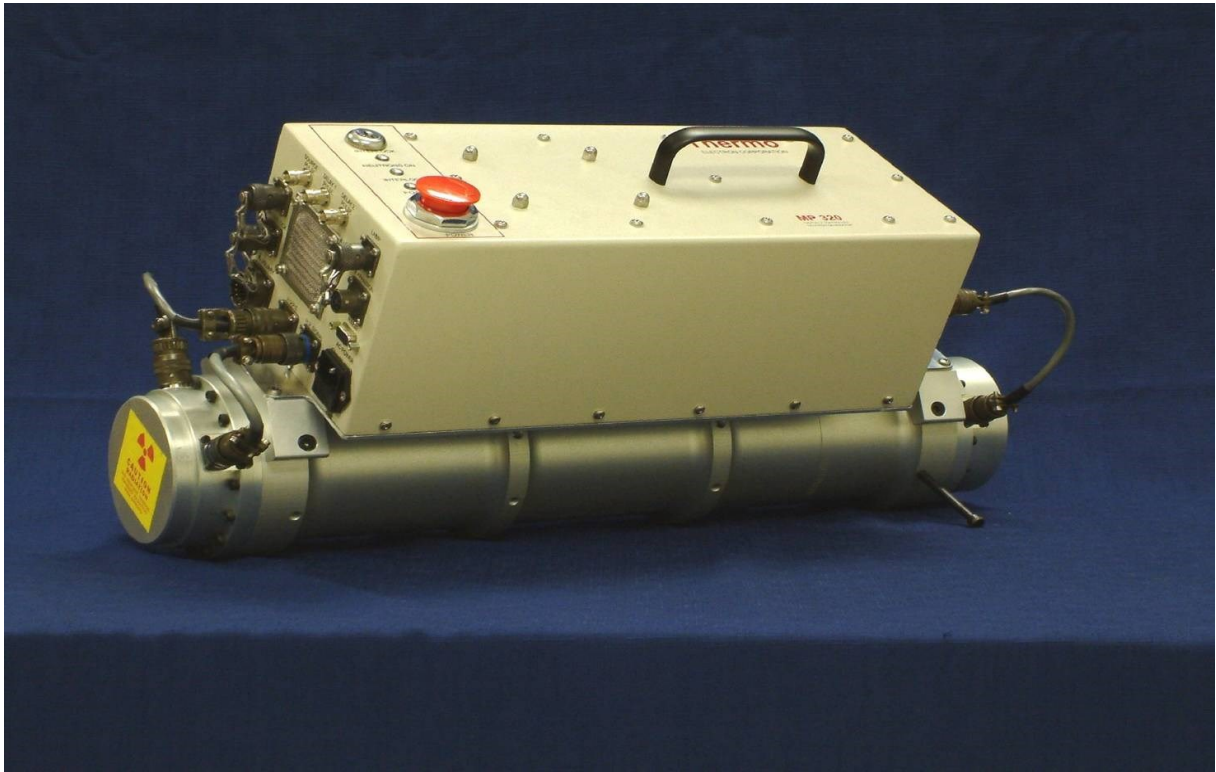


Fig. 2 Thermo Fischer MP320 portable neutron generator

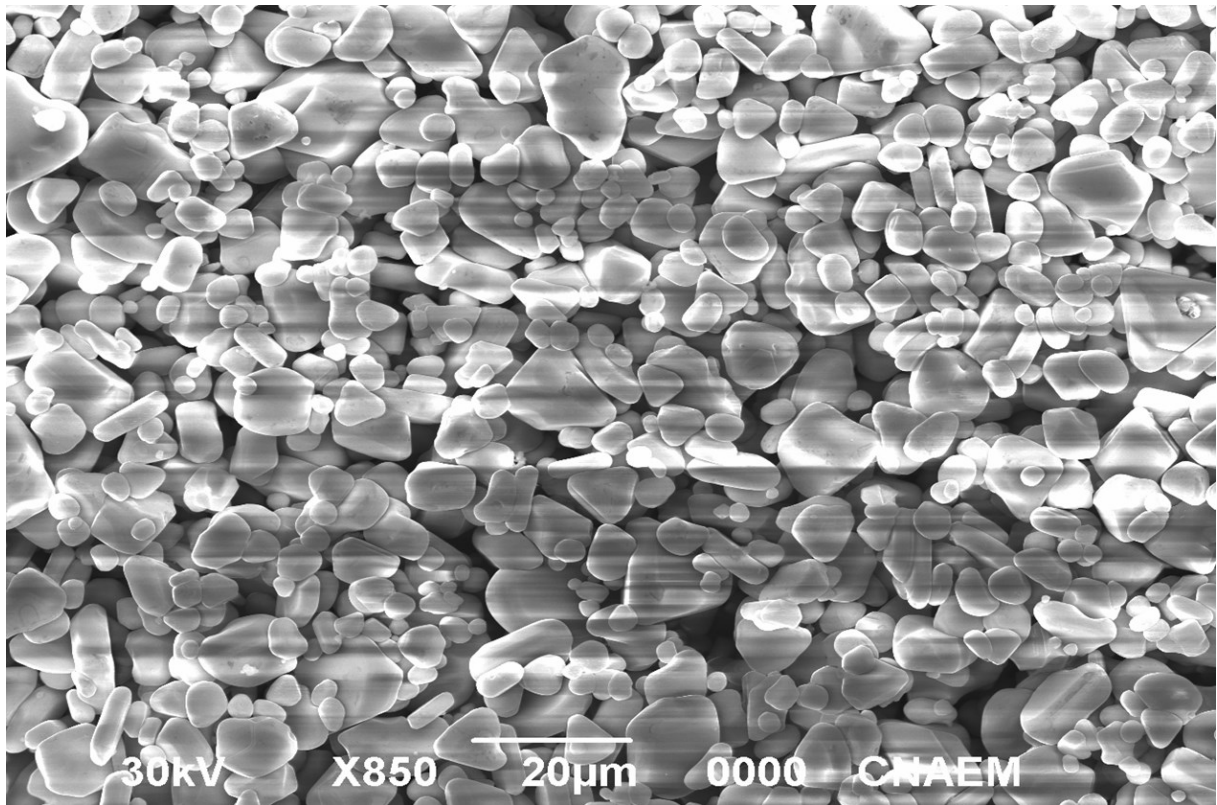


Fig. 3a The SEM image of the ZnS (Ag) scintillator

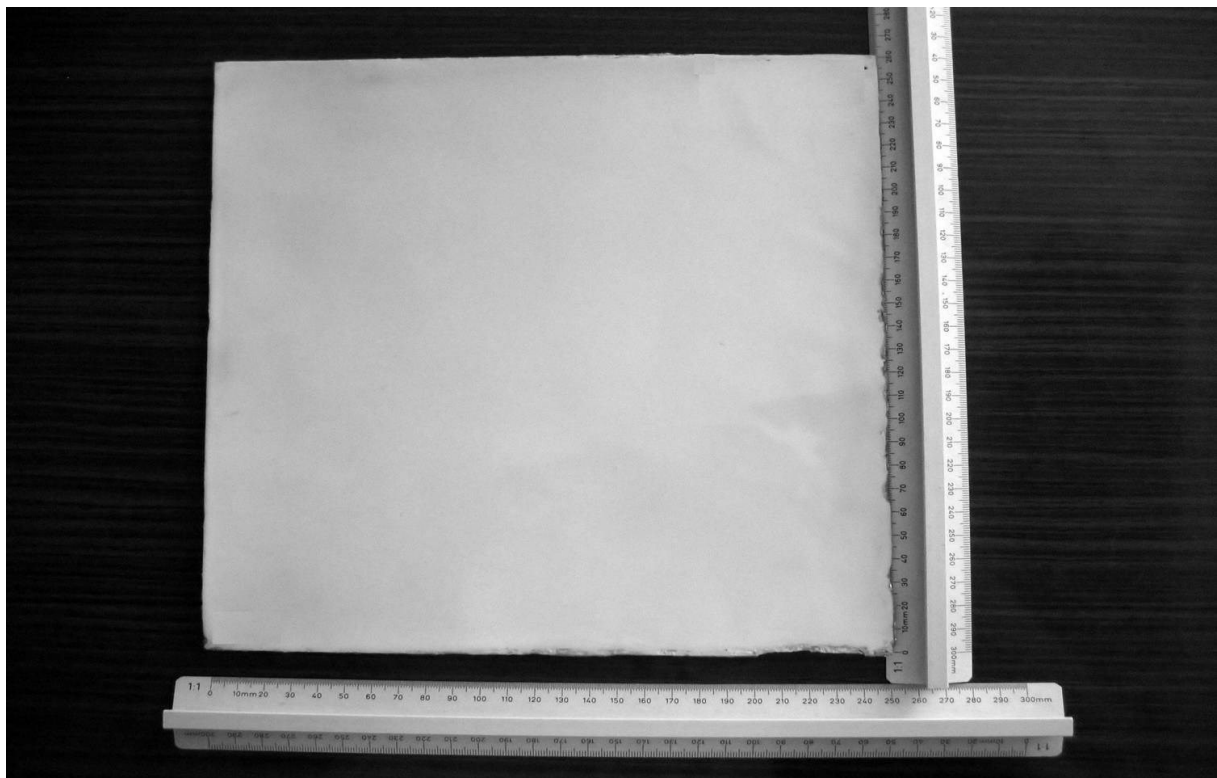


Fig. 3b Scintillator screen (27x27 cm)

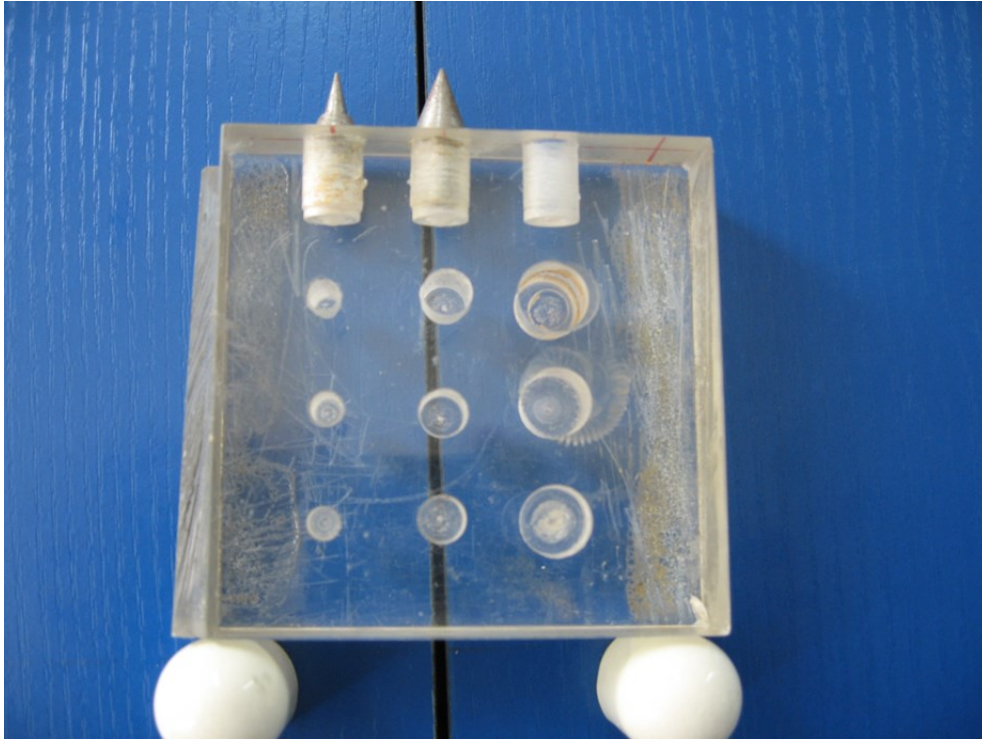


Fig. 4a Plexiglas plate (on which holes with different radii and depths are formed)

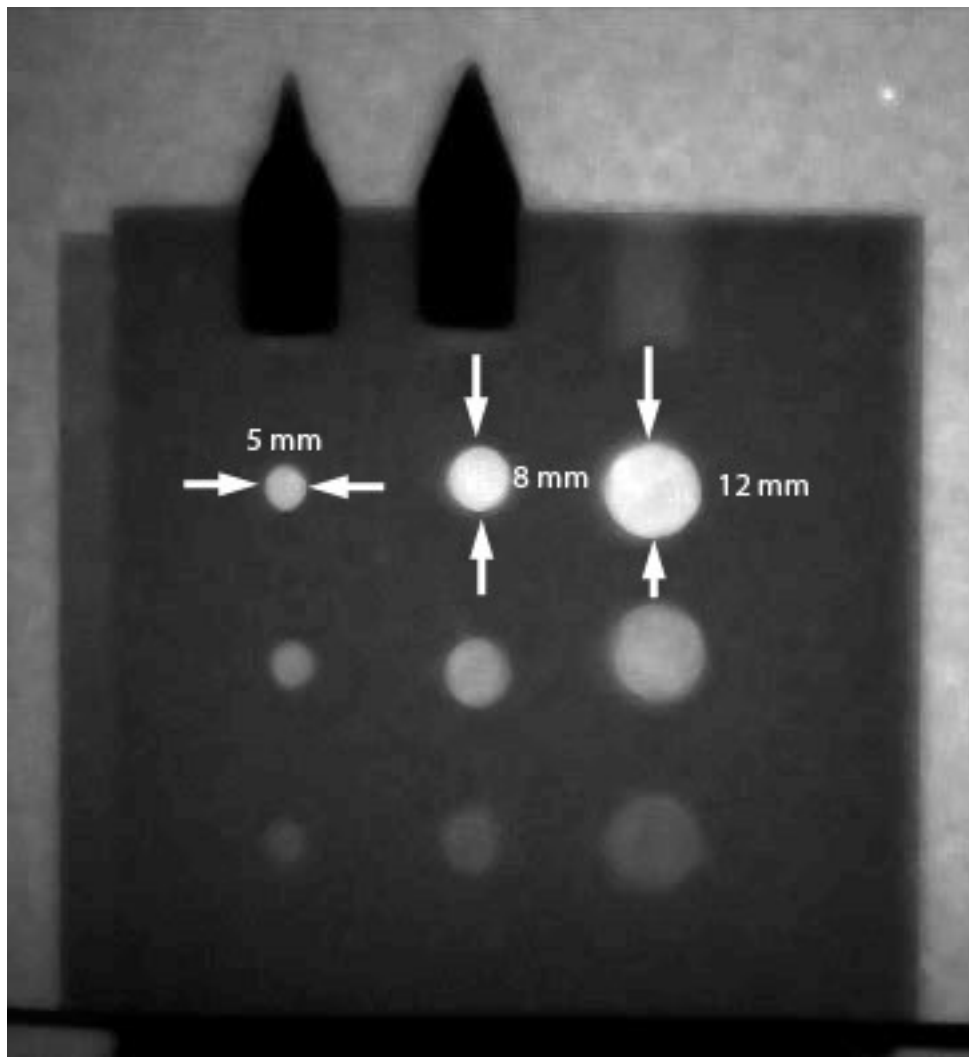


Fig. 4b FNR image of the plexiglass sheet

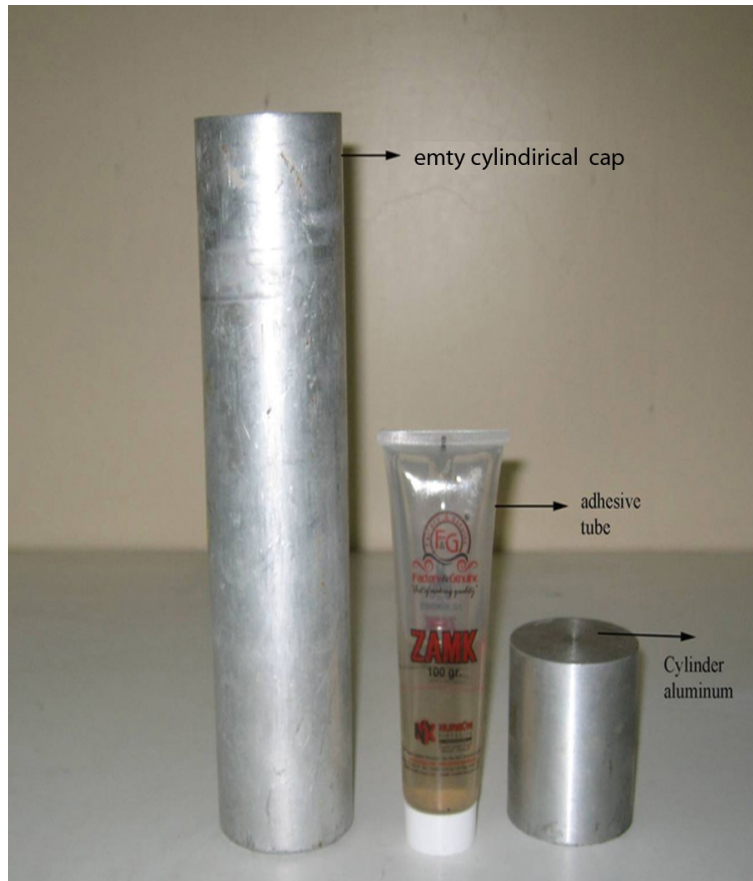


Fig. 5a Picture of different composite materials

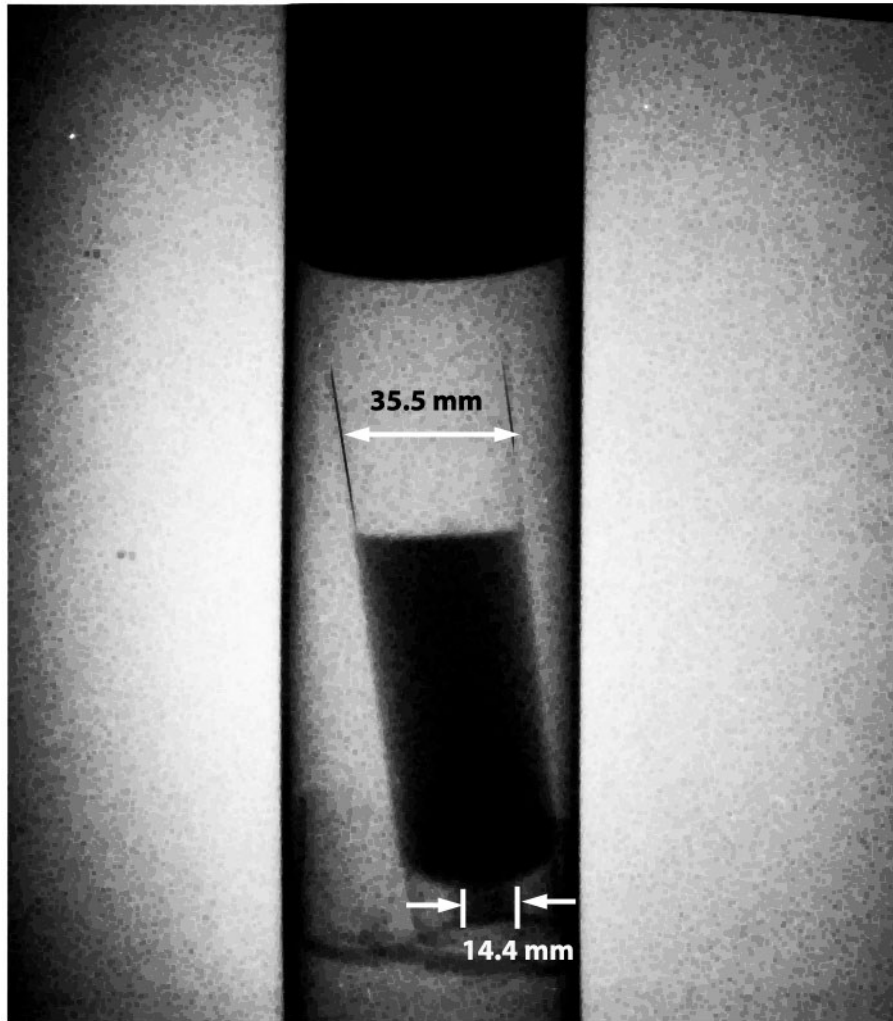


Fig. 5b The FNR images of different composite materials collected all together in a container



Fig. 6a Normal lantern sample

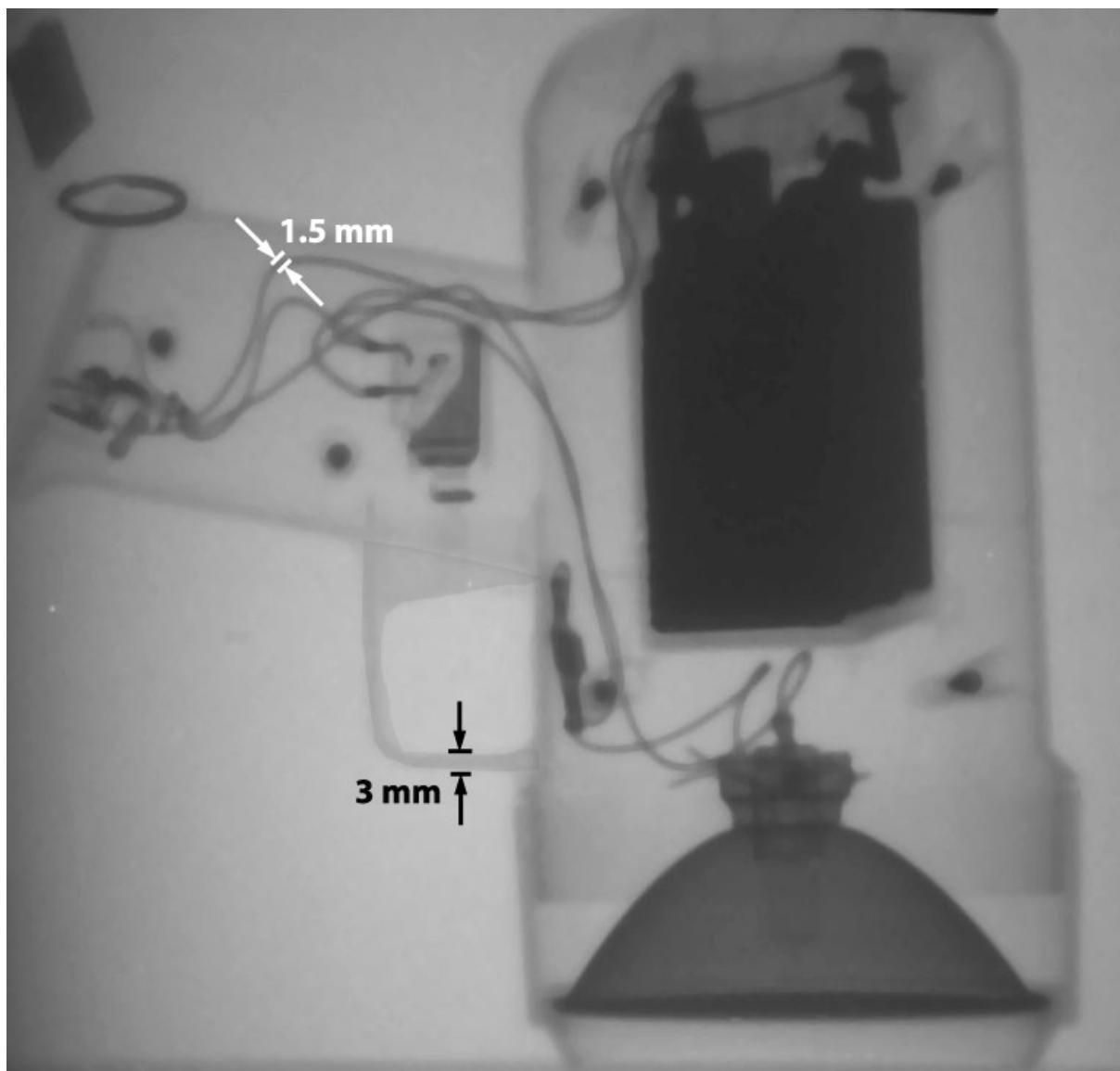


Fig. 6b FNR image of the lantern sample

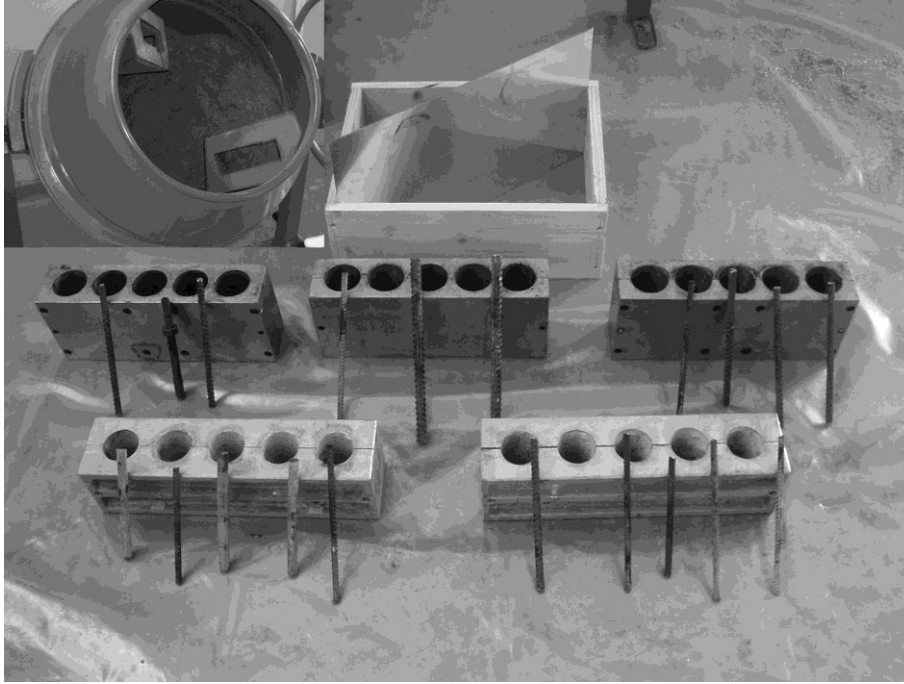


Fig 7a Molds with two different shapes, cylindrical and triangular

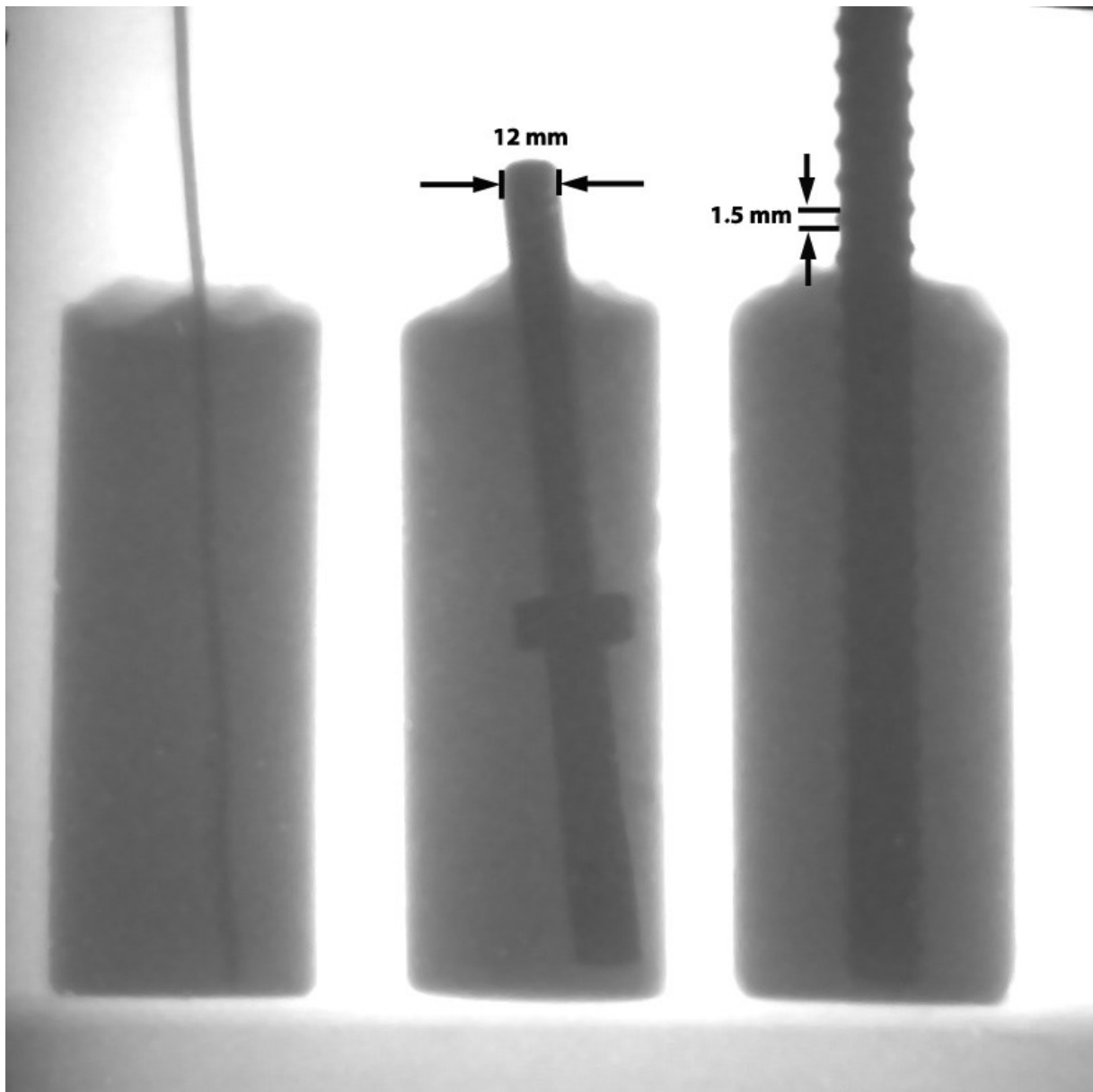


Fig. 7b The FNR images of iron sticks with different thicknesses in concrete

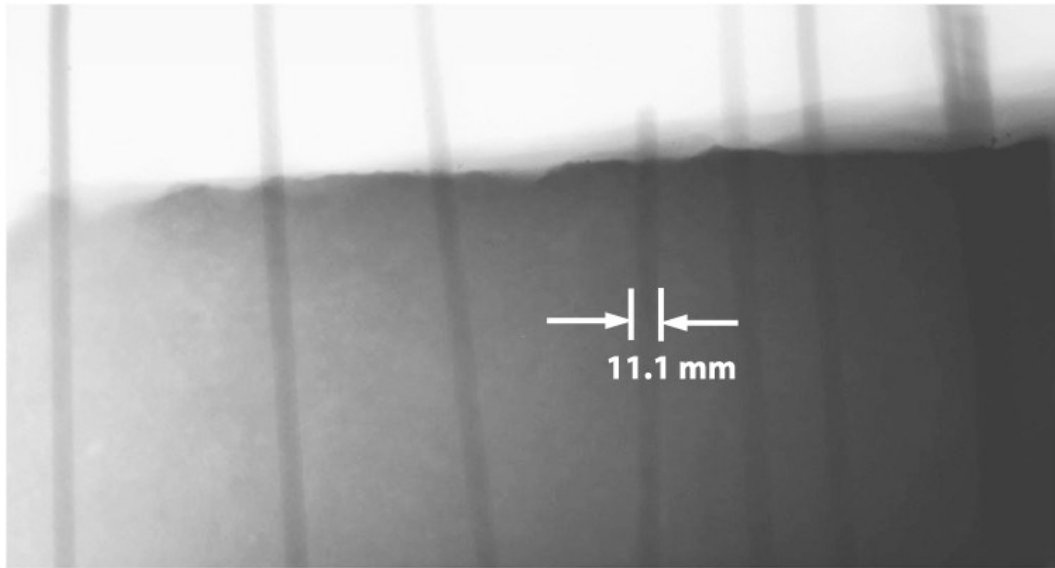


Fig. 7c The FNR images of iron sticks in triangular concrete block

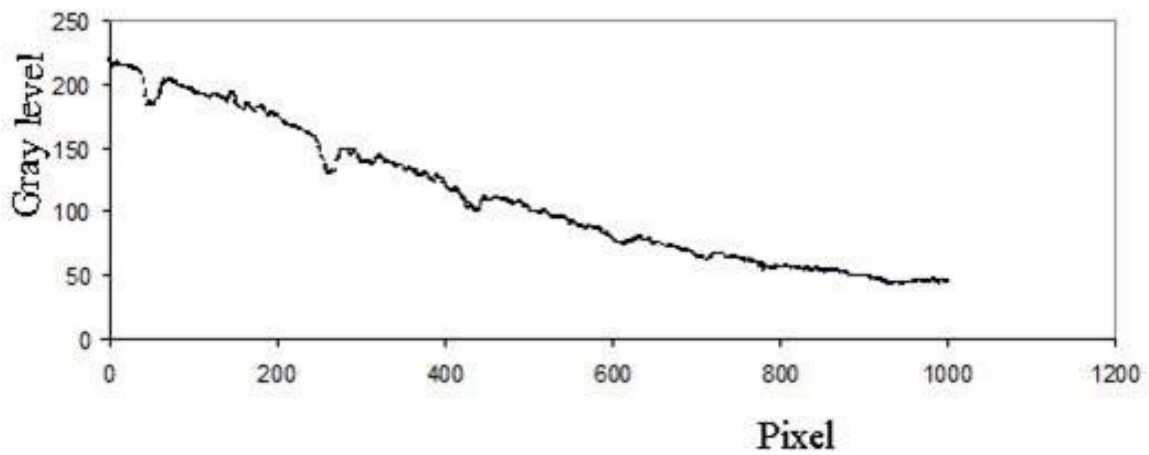


Fig. 7d Gray levels of the iron rods against pixel dimension