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Study of Water Uptake into Expanded Polystyrene (EPS) Aggregate Poly Brick Using Neutron Radiography Technique

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ABSTRACT— A powerful non-destructive testing (NDT) technique is adopted to study water penetrating height, water absorption, initial rate of absorption (IRA) and incremental water intrusion area in EPS sample. The measurement of gray value/optical density of the neutron radiographic images of the wet sample are used. From this measurement it is found that water absorption behavior of EPS poly brick is capillary in shape at different immersion time, the IRA is very low for the first 5 minutes compare to 10-20 minutes immersion time, water uptake height is 1.2 to 6.03cm, incremental intrusion area increasing slowly with immersion time. Lightweight expanded polystyrene (EPS) brick products that have been used in engineering applications including blocks, wall panels, floor and roof panels, cladding panels and Intel's.

Key Words: neutron radiography, gray value, water penetrating height, EPS aggregate poly, IRA, incremental water intrusion area.

1 INTRODUCTION

EXPANDED polystyrene (EPS) geofoam is a light weight material that has been used in engineering applications since at least the 1950s. Its density is about a hundredth of that of soil. It has good thermal insulation properties with stiffness and compression strength comparable to medium clay. It is utilized in reducing settlement below embankments, sound and vibration damping, reducing lateral pressure on sub-structures, reducing stresses on rigid buried conduits and related applications. Expandable polystyrene is the raw material or resin used for the molding of expanded polystyrene, EPS, geofoam. Polymers are long chain molecules in which one to three basic units, monomers, are repeatedly linked over and over in a process called polymerization [1]. Other studies have used EPS beads to design thermal insulator composites made with foamed cement pastes as a matrix, using granules of EPS as filler, along with additives to prevent segregation and improve adherence [2]. EPS has also been used for the manufacture of gypsum and plaster plates and panels [3] with the plaster matrix reinforced with polypropylene fibers in the manufacture of industrial components [4] and with mixtures of fly ash and metakaolinite to obtain light inorganic polymeric materials (light geopolymers) [5].

The radiography technique is normally nothing but exposing some objects to an X-ray, gamma-ray, neutron beam and some other types of radiation and then attenuated outgoing beam from the object is passed through a special type of photographic film to form images of an object. Neutron Radiography (NR) technique has, in recent years, emerged as a useful and complementary technology for radiation diagnoses. It is now routinely used in industrial quality assurance and in support of selected research and development activities. NR is the photograph of the internal structure of a substance obtained by using neutron. It is a powerful tool for non-destructive inspection of industrial materials and thus works as a complementary technique of X-ray radiography [5-12]. NR uses the basic principle of radiography where a beam of radiation is modified by an object in its path and the emergent beam is recorded in a photographic film (detector). The atoms of the object material scatter or absorb the radiation and so the beam reaching the detector shows an intensity pattern representative of the internal structure of the object [13-14].

Environmental concerns have been raised in some parts of the world where coal is the main power generating sources and where bricks are also the main building material. Most of the scientist believes that fly ash on its own can be an excellent raw material for brick making. This has now been proven and a patent is taken for the manufacture of bricks from fly ash [15]. Compressive strength and water absorption are two major physical properties of brick that are good predictors of bricks ability to resist cracking of face [16]. Water absorption is

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a measure of available pore space and is expressed as a percentage of the dry brick weight. It is affected by properties of clay, method of manufacturing and degree of firing. Water absorption capacity of the brick affects the surface finishing of the brick-laid wall [17-19]. Ancient technologists and archaeological material researchers have employed standard techniques such as X-ray radiography, X-ray diffraction (XRD), scanning electron microscopy (SEM), and neutron activation analysis (NAA) to study structure and composition of ceramic materials [20-21]. The aim of the present work is to determination of the water penetrating height at different immersion time, water absorption behavior/water penetrating behavior, IRA measurement and incremental water intrusion area in the EPS aggregate brick samples using neutron radiography technique.

2 EXPERIMENTAL FACILITY

A beam of thermal neutron having energy 0.025eV is used in this experiment. This is the most suitable energy of neutron for NR experiment. In the present study the homogeneity, presence of internal defects, cracks, voids in the special type of brick samples a well established NR facility [22-23] of BTRR (Bangladesh Atomic Energy Energy Triga Research Reactor) is used. The NR facility consists of bismuth filter, cylindrical divergent collimator, lead shutter, beam stopper, sample and camera holder table, beam catcher and a biological shielding house which is made of special concrete containing cement, heavy sand (magnetite, ilmenite and ordinary sand) and stone chips in the ratio 1:3: 3, paraffin wax and boric acid in 3:1 ratio by weight for neutron shielding.

3 EXPERIMENTAL PROCEDURES

3.1.1 Collection and preparation of the sample

Portland cement, aluminum powder, sand were collected from local market. Portland cement of ASTM type CEM II is used to prepare EPS brick sample. The expanded polystyrene (EPS) collected from local market is used in making poly block i.e., EPS aggregate brick sample.

3.1.2 Portland cement

The chemical composition and some other characteristics (in weight percent) of the Portland cement are as follows: CaO-63.58%, SiO2- 20.44%, Al2O3- 5.34%, Fe2O3- 4.0%, Loss on ignition-1.10%, Insoluble residue- 0.07% and Moisture content-0.5%. The standard test-properties of the Portland cement used as binder in the experiment are evaluated following ASTM standard methods. It is found that initial setting time of the cement is 2 hr, final setting time 3 hr, fineness 0.068% and average compressive strength 19 MPa. For creation of large number of air gap in the brick carbonic acid gas was used.

3.1.3 Sand

Particle size of the fine aggregates is in the range of $0.15 \le x \le 4.75$ mm, about 50% of the fine aggregates are with sizes $4.75 > x \ge 0.9$ mm, the specific gravity, fineness of modulus is 2.6 and 2.5 0, respectively and the maximum EPS aggregates size of 4.75 mm were used.

Both types of bricks are made using the traditional method known as 'hand-molding' and dried in air (usually in the sun/environment) until they were strong enough for use and light weight bricks (also called lightweight blocks). Brick are produced in numerous types, materials, and sizes which vary with region and time period, and are produced in bulk quantities.

Finally both the samples are polished manually by using series paper, cement block, diamond cutter and was dried at day light/dryer machine at 65ºC until to get the constant weight. The actual size, shape and weight of final sample are $11.75 \times 11.5 \times 7.297 cm^3$, rectangular in shape and weight 811.0gm.

Sample Expandable polystyrene is the raw material or resin used for the moulding of expanded polystyrene, EPS, geofoam. Polymers are long chain molecules in which one to three basic units, monomers, are repeatedly linked over and over in a process called polymerization [1].

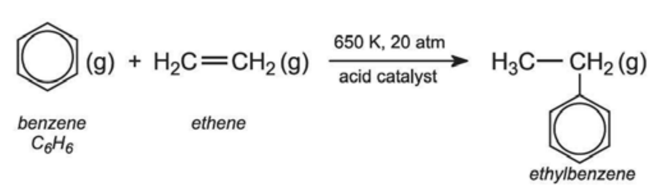
3.1.4 Chemical Reaction of Producing Polystyrene [24]

First step: The manufacture of ethyl benzene from benzene

Benzene vapor and ethane are mixed and passed over an acid catalyst, at 650 K and 20 atm pressures:

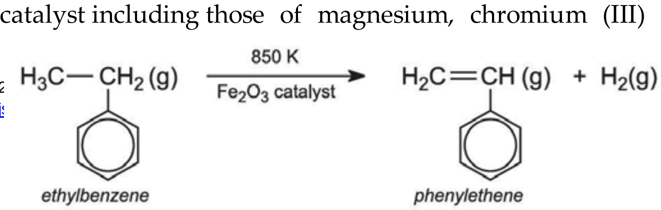
This is an example of a Friedel-Crafts reaction. The acid catalyst now used is a zeolite, ZSM-5, an aluminosilicate.

Second step: The manufacture of phenylethene (styrene)



from ethyl benzene

Ethyl benzene vapor is mixed with excess steam and passed over heated iron (lll) oxide. Other metal oxides used as the catalyst including those of magnesium, chromium (III) and



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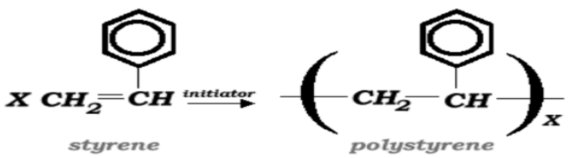
zinc, usually coated on carbon or alumina. It is dehydrogenated:

Third step: The polymerization of phenylethene (styrene) to get polystyrene



3.1.5 Loading converter foil and film in the NR-cassette

A thin converter (gadolinium metal foil of 25 μm thickness) was placed at close contact with the emulsion surface of the X-ray industrial film. The loading of the X-ray industrial film (Agfa structurix D_4DW) into the NR cassette (18 cm x 24 cm) is a simple procedure [25] which requires a darkroom.

3.1.6 Placing of sample and the NR-cassette

The sample is placed in close contact with the NR cassette on the sample holder table. The NR cassette is placed on the cassette holder table. Both of NR cassette and sample are placed in front of the neutron beam.

3.1.7 Immersion procedure and obtained NR images of wet EPS brick

The expanded polystyrene brick is placed in a plastic pan and a constant 2.0 cm height of water level is maintained at every immersion time of both the samples. The water level is observed very carefully and adds extra water to maintain water level at 2 cm during each immersion time. After time of interest (TOI) such as 5, 10, 15 and 20 minutes the EPS brick is pick up from the pan and extra water of outside the samples are removed by using the tissue paper and then wet EPS poly brick is placed on the sample holder table in front of the neutron beam to irradiate the wet EPS sample.

3.1.8 Obtained radiographic images

To obtain the neutron radiographic images of these samples the following procedures are completed.

Irradiation: After putting the sample on the sample holder table the neutron beam was disclosed by removing the wooden plug, lead plug and beam stopper from the front side of the collimator.

Developing: Development is an image processing technique by which the latent image recorded during the exposure of the material is converted into a silver image [26]. Developing process is completed at 20-22^{o}C for 07 minutes.

Fixing: The fixation solution will dissolve the unexposed silver-halide crystals leaving only the silver grains in the gelatin. The fixing is completed within a 05 minutes and control the fixture temperature at 20-22^{o}C.

Washing: In between developing and fixing the radiographic film, it is necessary to wash for 1 minute at flowing tap water.

Final washing: The silver compound was formed during the fixing stage must be removed, since they can affect the silver image at the latter stage. For this reason the film must be washed thoroughly in flowing tap water for 15 minutes (min) after completion of developing and fixing process.

Drying: After final washing, the films were dried by clipping in a hanger at fresh air/or in a drying cabinet.

4 MATHEMATICALFORMULATION

The neutron radiographic image represents the attenuating behavior of thermal neutron beam due to dry/ wet sample. Attenuation of thermal neutron beam is mainly due to scattering and absorption interactions of neutrons with atomic nuclei. This attenuating response for dry sample can be written [27] as:

$$I = I_0 e^{-\mu_s t_s} \quad (1)$$

Here I and I_0 are the attenuated and incident neutron intensities respectively, μ_s is the attenuation coefficient of the samples and t_s is the corresponding thickness.

For wet sample the above equation can be written as follows:

$$I' = I_0 e^{-(\mu_s t_s + \mu_w t_w)} \quad (2)$$

Where I' the attenuated neutron intensity of is wet sample, μ_w is the attenuation coefficient of water and t_w is the thickness of the water absorbed by the sample.

From equations (1) and (2) the thickness of the absorbed water by the samples can be calculated as follows:

$$t_w = -\ln(I'/I)/\mu_w \quad (3)$$

The gray value /neutron intensity of the radiographic images of the sample is changed with the increase of water absorbed by the samples. The attenuated neutrons beam enters the detector that resists the fraction of initial radiation intensity that has been transmitted by each point of the object and is then recorded by the radiographic film i.e. image detector.

4.1 Optical density measurement

The neutron intensity before reaching the brick sample (object) is different from the intensity of the neutron after passing through the sample(s). The relationship between these two intensities is expressed through the equation (1). On the other side of the film, a light sensor (photocell) converts the penetrated light into an electrical signal. A special circuit performs a logarithmic conversion on the signal and displays the results in density units. Actually, optical density is the darkness or opaqueness of a transparency film and is produced by film exposure and chemical processing. An image contains areas with different densities that are viewed as various shades of gray.

4.2 Gray value

The visual appearance of an image is generally characterized by two properties such as brightness and contrast. Brightness refers to the overall intensity level and is therefore influenced by the individual gray-level (intensity) values of all the pixels within an image. Since a bright image (or sub image) has more pixel gray-level values closer to the higher end of the intensity scale, it is likely to have a higher average intensity value. Contrast in an image is indicated by the ability of the observer to distinguish separate neighboring parts within an image. This ability to see small details around an individual pixel and larger variations within a neighborhood is provided by the spatial intensity variations of adjacent pixels, between two neighboring sub images or within the entire image. Thus, an image may be bright (due to, for example, overexposure or too much illumination) with poor contrast if the individual target objects in the image have optical characteristics similar to the background. At the other end of the scale, a dark image may have high contrast if the background is significantly different from the individual objects within the image, or if separate areas within the image have very different reflectance properties. An image that contains pixels with brightness values spread over the entire intensity scale is likely to have better contrast than the image with pixel gray-level values located within a narrow range. The relationship between the intensity spread at the pixel level and the overall appearance of an image provides the basis for image enhancement by gray-level transformation. The terms gray value and intensity are used synonymously to describe pixel brightness.

5 RESULTS AND DISCUSSION

5.1 Determination of Water Penetrating Height at Different Immersion Time

Water penetrating/rising behavior of the EPS brick sample at different immersion time such as 5, 10, 15, 20 minutes is shown in Fig. 1 From these graph it is observed that due to 5-15 minutes immersion water rises in upward direction as like as capillary equally through the all but at one corner it shows slightly variation compare to other places. The height of water up take is 1.2-3.9cm, 3.42-5.34cm, 4.47-5.91cm and 5.22-6.03cm for 5min, 10min, 15min and 20min immersion time, respectively. From the above investigation it shows that at first 5-10 minutes the water uptake through the whole sample is very higher than that of 15 and 20 minutes.

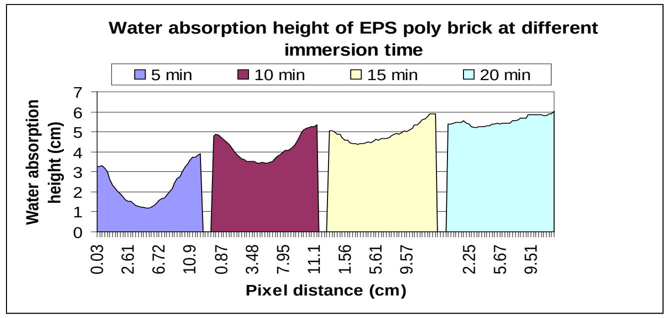


Fig.1

5.2. Water penetrating behavior

During the manufacturing time if the clay mixture absorbs more water, brick exhibits a larger pore size, resulting in a lower density. Depending on the H_2O absorption time of brick, observe differences in capillary absorption [28]. From the present investigation it shows that the water rising/penetrating behavior through the EPS poly brick samples is almost capillary type for 5-15 minutes immersion and for 20 minutes immersion it looks same at the middle and at the both edges. The resulting shape/behavior of the penetrating water through the brick sample is shown in Fig. 2.

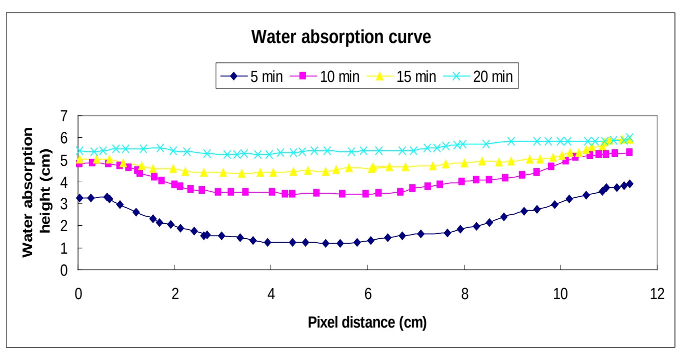


Fig. 2

5.3. Determination of Initial Rate of Absorption (IRA)

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It is the measurement of the absorption rate that water is absorbed by a porous solid. It is related to the durability, porosity, pore size distribution and water absorption. It is sometimes called rising damp. The quantity, sizes and connection of pores influence the absorption rate of the brick. The IRA is reported in units of gm/(30 in^2 min) [29]. In the present case IRA is measured in units of (gm/cm^3)/min. Sanders et al. [29] described three stages of capillary absorption. IRA stage is one of them. The results of IRA measurement for EPS poly styrene brick sample is shown in Fig. 3. In that case the initial rate (first 5 minutes) of absorption is very low which indicates that the EPS poly brick is less porous.

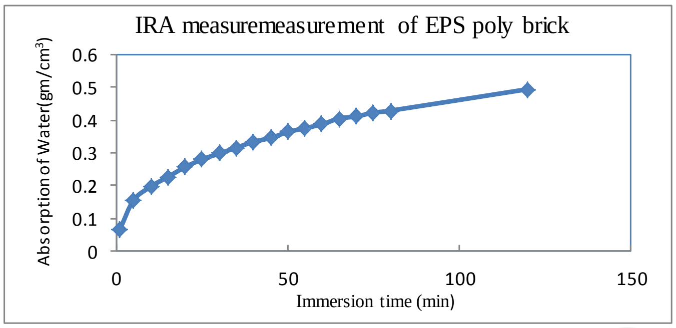

Fig. 3

5.4. Observation of incremental water intrusion area

The incremental intrusion area means the unexpected water absorbed area during immersion period of the respective sample. Fig. 4a to Fig. 4d is the neutron radiographic images of the EPS poly brick sample for 5 min., 10 min., 15 min. and 20 min. immersion into water, respectively. It shows that growing of incremental intrusion area with immersion time is slow. But absorption of water due to 15 and 20 minutes immersion is slightly differ but rising rate is very small compare to first 5 minutes immersion. It shows that growing of incremental intrusion area with immersion time is slow. The relation of incremental intrusion area of the sample at different immersion time is directly related to the IRA. Many authors [3o-31] studied that water absorption/rising depends on submersion time, firing temperature and firing time. Few authors [32] investigated that when the mixture absorbs more water, brick exhibits a larger pore size, resulting in a lighter density. The specific relationship between the shades of gray or density and exposure depends on the characteristics of the film emulsion and the processing conditions.

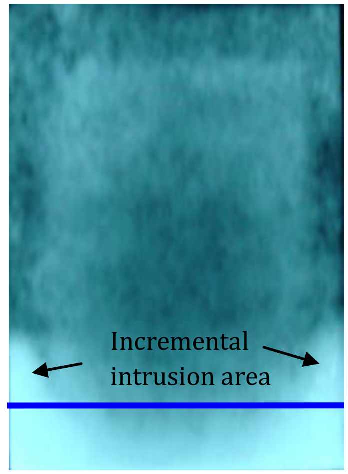

Fig. 4a

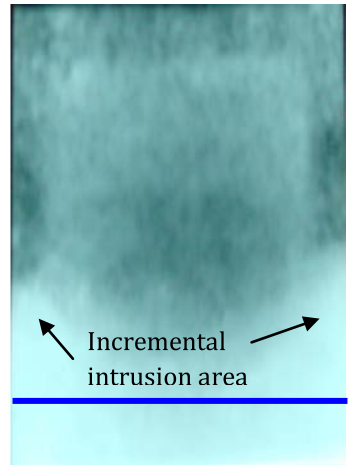

Fig. 4b

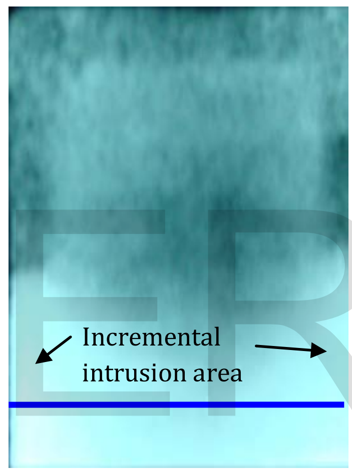

Fig. 4c

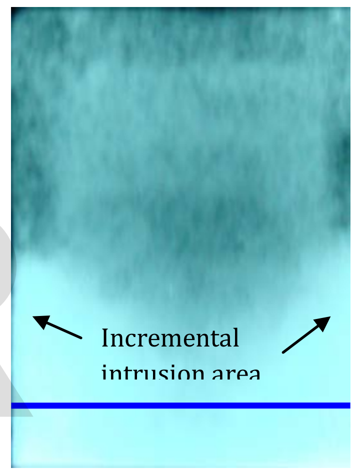

Fig. 4d

Expanded polystyrene (EPS) geofoam is a lightweight material that has been used in engineering applications since at least the 1950s. EPS concrete is designed for consumers who are environmentally conscious. It helps reduce at least 30% of environmental waste, decrease over 50% of greenhouse radiation and over 60% integrated energy of the surface of bricks. EPS bricks are totally inorganic and are incombustible. If some plastics are added to the raw materials, it is possible to increase the volume of the voids by controlled procedures. By increasing the volume of the empty spaces, the weight of the bricks is reduced. This causes specific properties, e.g. increased thermal resistance in the end product. Another advantage of lightweight bricks is reduced transportation costs.

EPS concrete blocks reduce one–fifth of the weight of concrete and produced is easily handled sizes. EPS bricks are very airy thus allowing more diffusion of water, reducing humidity of the building. EPS concrete products are not affected by harsh climatic condition and will not degrade under normal atmospheric condition. It's reducing the using of top soil.

6 CONCLUSION

The high demand for cheap building materials has lead brick making, an age old tradition, to thrive. EPS products include blocks, wall panels, floor and roof panels, cladding panels and Intel's. EPS based waste packaging material can provide light weight properties to the modified concrete, which is significant for floating structure and where light weight material is recommended. The industry is growing rapid in Asia due to strong demand in housing and commercial space. Thus for poor water absorption behavior and light weight poly bricks materials can be used as building materials in external wall.

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