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PROPERTIES OF LIGHT WEIGHT FOAMED CONCRETE MADE WITH VERY FINE LOCAL SAND

Md. Nahid Hossain[*1], Abu Zakir Morshed[2], Mostafizur Rahman[3] and Md. Sakib Ul Hafiz[4]

[1]Graduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh, email: hossainmdnahid64@gmail.com
[2]Professor, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh, email: azmorshed@ce.kuet.ac.bd
[3]Sr. Manager, RCC LAB LTD., Dhaka, Bangladesh, email: raju.kuet@gmail.com
[4]Graduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh, email: sakibhafiz16@gmail.com

***Corresponding Author**

ABSTRACT

Foamed concrete has become a very well-known material that has excellent thermal insulation properties. Foamed concrete offers benefits such as decreasing the dead weight of a structure and it decreases high temperature related problems. The scope of this project was to compare the concrete physical, mechanical and thermal properties between normal weight concrete and foamed concrete by using different percentages of pea-gravel, local sand, foam and admixture. Four batches of concrete cylinders were made for determination of density, water permeability, rapid chloride permeability and compressive strength. Densities of foamed concrete varied from 1404 kg/m^3 to 1459 kg/m^3 with different percentages of pea-gravel where density of normal weight concrete was found 2330 kg/m^3. Compressive strength was found 17.7 and 22 MPa at 7 and 28 days respectively for normal weight concrete. The compressive strength of foamed concrete was varying from 4.3 to 6 MPa and 6 to 8 MPa at 7 and 28 days, which is lower than normal weight concrete by 66-74% and 63-72% respectively. The compressive strength of foamed concrete was gradually decreasing with increasing pea-gravel content. Water permeability and rapid chloride permeability of foamed concrete with different percentages of pea-gravel were gradually decreasing with increasing pea-gravel content, which is higher than normal weight concrete. Two slab specimens were made from each batch for testing of thermal insulation performance under specified range (35^{0}C to 50^{0}C) of temperature. The bottom surface temperature was varying from 35^{0}C to 50^{0}C where the top surface temperature of normal weight concrete, 0%, 10% and 20% pea-gravel foamed concrete were varying from 26.2^{0}C to 40.8^{0}C, 26^{0}C to 37.8^{0}C, 27.5^{0}C to 36.8^{0}C and 26^{0}C to 35.8^{0}C respectively. The foamed concrete with 20% pea-gravel shows the better insulation performance than the other types of slab.

Keywords: *Foamed concrete, Thermal properties, Density, Permeability, Compressive strength.*

1. INTRODUCTION

Bangladesh is a tropical country with average monthly temperature of 30°C to 40°C in summer season. Thermal movements occur due to high temperature changes, which could destroy building formations and contents. Keeping buildings with low temperature variation helps in maintain the integrity of building formations and contents. This can be obtained through the proper use of thermal insulation, which also increase the lifetime of building structures. The term thermal insulation is defined as a material or combination of materials that when properly applied, obstruct the rate of heat flow by conduction (heat flow through a material by molecular contact), radiation (heat transfer by the movement of particles with an alteration in their heat content) and convection (heat transfer by electromagnetic waves with the help of a gas or vacuum (Zahari et al., 2009). Due to high thermal movements many problems occur on the top floor of the building. These problems are summertime high energy demand, air conditioning costs, air pollution and greenhouse gas emissions, heat-related illness and mortality and uncomfortable for the users. So the main concern of this study is to reduce the high temperature of the top floor of the building. There are many insulating materials and techniques available for the purpose of reducing high temperature on the top floor of the building. From the last decades, foamed concrete has become a popular material for thermal insulation in buildings (Zahari et al., 2009). Foamed concrete primarily consists of a cement based mortar mixed with at least 20% of volume of air. Foamed concrete offers benefits such as decreasing the dead weight of a structure which economies the design of supporting structures including the walls and foundation of lower floors (Amarnath & Ramachandrudu, 2017). It was used in trench reinstatement, bridge abutment, void filling, roof insulation, road sub base, wall construction, tunneling etc. In this study, the thermal insulating properties of foamed concrete made with locally available very fine sand was investigated. Besides, the physical and mechanical propeties were also investigated. The physical properties were assessed in terms of it density, water permeability and rapid chloride permeability. Mechancial property was assesed in terms of its compressive strength at 28 days and thermal insulating property was evaluated by uni-directional heat flow by creating an artificial environment.

2. METHODOLOGY

2.1 Materials

Portland cement was used as binder. Local sand having FM of 0.72 was used at fine aggregate. Pea-gravel passing 3/8 in. and retained on No.8 ASTM standard sieve was used as coarse aggregate for light weight concrete while stone chips (12.5 mm nominal maximum size) was used as coarse aggregate in normal weight concrete. Foaming agent (conplast f297)was used to produce foam which was required to produce Light weight concrete (LWC) and polyethylene foam (PE foam) was used to insulate the box which was used for thermal insulation test. Water reducing and plasticizing admixture (Sika) was used to produced flowable concrete.

2.2 Determination of Material Properties

ASTM standard test methods were followed to determine the unit weight, voids content, specific gravity, absorption, moisture content, gradation and fineness modulus of aggregates.

2.3 Preparation of Normal Weight Concrete

Normal weight concrete (NWC) was made to serve as a reference batch to compare its characteristic parameters to that of the foamed concrete. A mix design for C22 grade NWC was prepared following ACI mix design procedure. The ratio of Cement : Fine Aggregate : Coarse Aggregate (by mass) was 1: 1.42 : 2.95 and the water-to-cement ratio (w/c) was kept as 0.54 by mass. The mix proportion is shown in Table 1.

2.4 Preparation of Foamed Concrete

The main constituents of foamed concrete are foam, water, admixture, cement and fine aggregate. The fine aggregate was replaced by 10% and 20% pea-gravel to produce more light weight concrete. For foam generation, the foaming agent and admixture was mixed with water in a bucket. Then the whole solution was stirred by using a drill machine to produce foam. Finally, the cement and sand were added in the bucket and rotated the mixture to produce light weight foamed concrete. The mixing was continued until a homogeneous concrete mass was produced. The mixing procedure of foamed concrete is shown in Figure 1. The dry-weight proportions of concrete mix designs for NWC and foamed concrete (FC) with different percentage of pea-gravel are shown in Table 1.

Figure 1: Mixing procedure of foamed concrete

Table 1: Mix Proportions for Normal Weight Concrete (NWC) and Foamed Concrete (FC) **(Kg/m^3)**

Batch ID	**Water**	**Cement**	**CA**	**FA**	**Pea-Gravel**	**Foaming Agent**	**Admixture**
NWC	216	400	1180	569	_	_	_
FC-0-PG	200	400	_	200	_	1.714	0.400
FC-10-PG	200	400	_	179.93	22.15	1.714	0.400
FC-20-PG	200	400	_	159.84	44.30	1.714	0.400

2.5 Specimen Preparation

Figure 2: Cylindrical and slab specimens

Four batches of concrete were made; among which one batch was for reference NWC and three batches for foamed concrete, where the fine aggregate was replaced by 0%, 10% and 20% pea-gravel and named as FC-0-PG, FC-10-PG and FC-20-PG, respectively. Concrte cylinders of 100 mm dia. and 200 mm height were made from each batch and were used to determine density, compressive strength and permeability of concrete. In addition, 2 slab specimens were made from each batch for testing of thermal insulation performance. The cylindrical and slab specimens are shown in Figure 2.

2.6 Determination of Density

The density of concrete is a measurement of concrete's solidity. A higher or lower density of concrete end product is dependent on the mix proportion of the constituent materials. After demolding the cylindrical mold, the mass, diameter and height of the specimen was taken both for normal weight concrete and foamed concrete. Then, the density was calculated by dividing the mass by the volume of the specimen.

2.7 Determination of Compressive Strength

Compressive Strength of concrete is one of the most important and significant properties. The compressive strength of concrete cylinders was measured by applying continuous compressive load by using universal testing machine over the cylinder until failure occurs. Test method ASTM C39 was followed to determine the compressive strength of cylindrical concrete specimens.

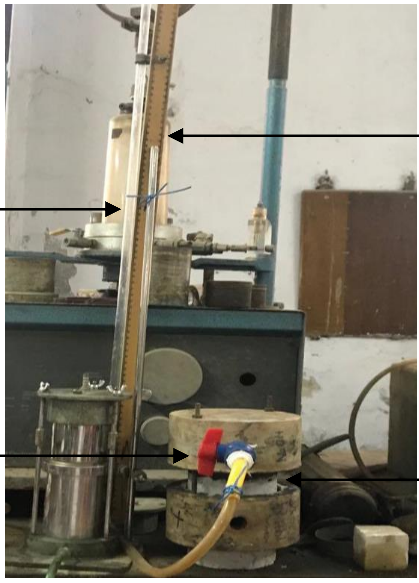

Figure 3: Experimental setup for permeability test

2.8 Determination of Water Permeability

Permeability is defined as the property that regulate the rate of flow of a fluid into a porous solid. Cylindrical specimens from each batch were sliced to a thickenss of 5 cm by a concrete saw so that the test specimens ended up with a disk of 5 cm height and 10 cm diameter. The specimens were made saturated surface dry before placing in the test column, which was connected with a standpipe or burette. A 100 cm height scale was also attached with the standpipe. The standpipe was filled with water in such a manner that all the air bubbles were removed from the standpipe. Then the test started by allowing water to a desired level to flow through the sample. The time required for change in water level in the standpipe from an upper limit to a designated lower limit was recorded. The test was performed at the age of 7 and 28 days curing and it was continued for 10 hours. Figure 3 shows the experimental setup for permeability test.

2.9 Rapid Chloride Permeability Test (RCPT)

The capability of concrete to prevent the intrusion of invasive elements like chloride ions is key to the durability of reinforcing steel in concrete. To determine the resistance of concrete against chloride penetration, this test was done according to ASTM C1202. Two specimens at the age of 7 and 28 days were taken from each batch and a 50mm thick slice was made from the center of the specimen by a concrete saw. Subsequently, the specimens were setup into two Plexiglas half cells and sealed using M-seal. To perform this test filter paper with 100 No. sieve and two stainless steel bars were placed at two ends of the test specimen. Those two bars acted as an anode and cathode, respectively. Each half-cell contained a reservoir filled with a solution of 0.3N NaOH at positive side and 3.0% NaCl at negative side. Both cells were subjected to a 60-volt DC voltage through the specimen's 50 mm longitudinal section for a duration of 6 h. Changes in voltage and current were measured by using a multimeter at every 30 min. The recorded values were adjusted by converting the charge passed through the diameter of the test specimens (100 mm) to the equivalent charge passed through a standardized diameter (95 mm). The schematic diagram of RCPT test is shown in Figure 4.

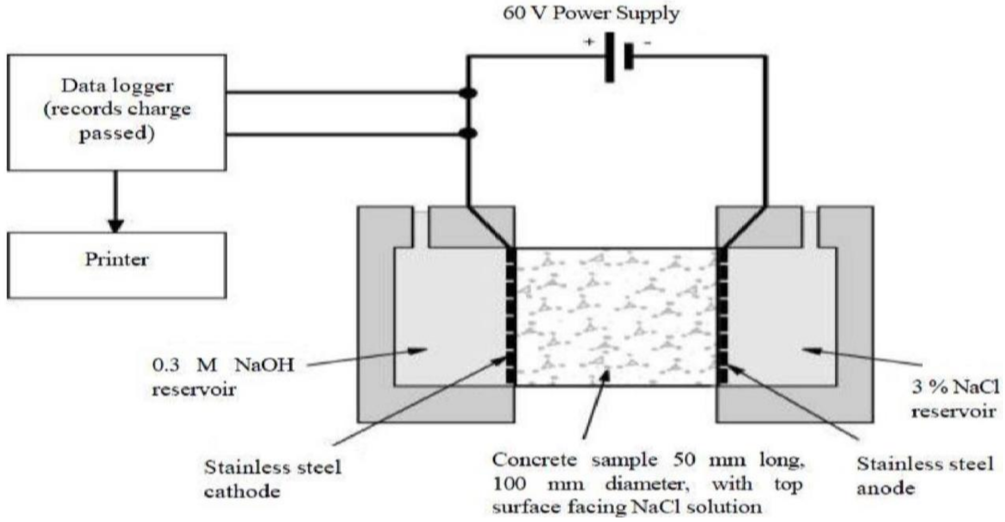

Figure 4: Schematic diagram for RCPT test

2.10 Experimental Setup for Testing of Thermal Insulation Performance of Slab

Two small scaled boxes were prepared with wooden pieces of 1 in. thickness having dimensions of 16 in. × 16 in. × 15.5 in. (L × W × H). Inner side the box was insulated by using polyethylene foam so that it acts as an airtight box. Inside the box, 2 in. width wooden bits were used to hold up the slab specimen. Two19 mm dia. holes in two boxes were made for the passage of wires of heater and sensors. A heater was placed inside of the box to produce heat. A sensor was attached with the bottom of the slab which is connected with the heater on/off switch, which helped to maintain the definite temperature (35 to 50^{0}C) inside the box automatically. For each temperature, this test procedure was run for 4.5 hours in order to stabilize the input temperature. Three DHT22 temperature sensors were attached on the other face of the slab and another box was placed over it to insulate the output side. The sensors were connected with a computer by the help of an Arduino and breadboard to measure the temperature of the top surface of the slab automatically. Average value from the three sensors were counted. This test was performed after 28 days curing of slab specimen. The experimental setup for thermal insulation test as shown in Figure 5.

Controller of heater DHT22 temperature sensor

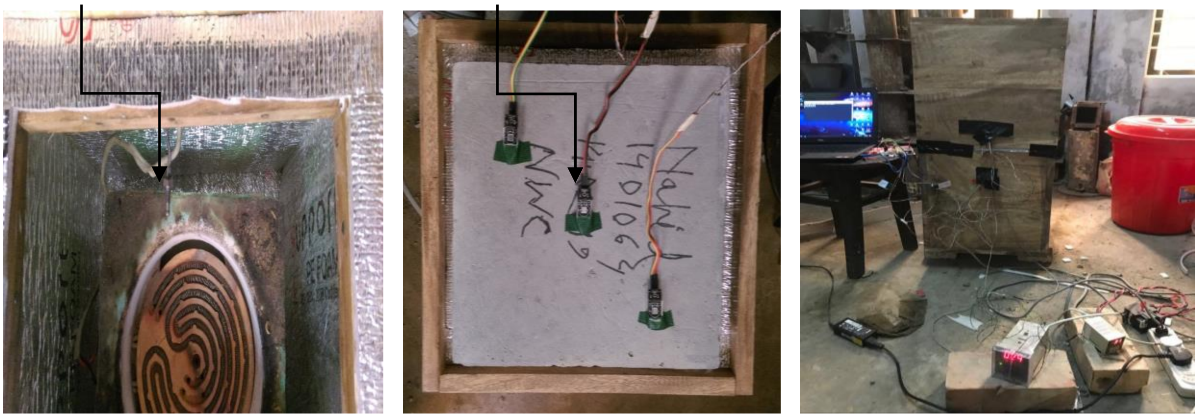

Figure 5: Experimental setup for thermal insulation

3. RESULTS AND DISCUSSIONS

3.1 Test Results for Materials Properties

The material properties for coarse aggregates (CA), fine aggregates (FA) and pea-gravel were determined according to ASTM standard procedures and those are shown in Table 2. The gradation curve for both CA and Pea-Gravel is shown in Figure 6.

Table 2: Physical Properties of Aggregates

Types of materials	FA	CA	Pea-Gravel
Bulk density (kg/m^3)	1412	1530	1542
Bulk specific gravity, G_{sb}	2.40	2.66	2.65
Water absorption (% by weight)	3.60	2.20	2.67
Moisture Content (% by weight)	3.00	1.50	0.70
Voids (% by volume)	41	43	41
Fineness Modulus (FM)	0.72	-	-

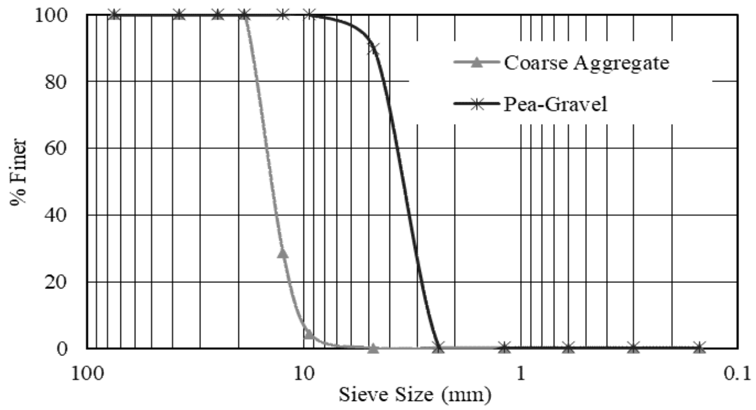

Figure 6: Gradation Curve for Coarse Aggregate and Pea-Gravel

3.2 Physical Properties of Concrete

3.2.1 Density

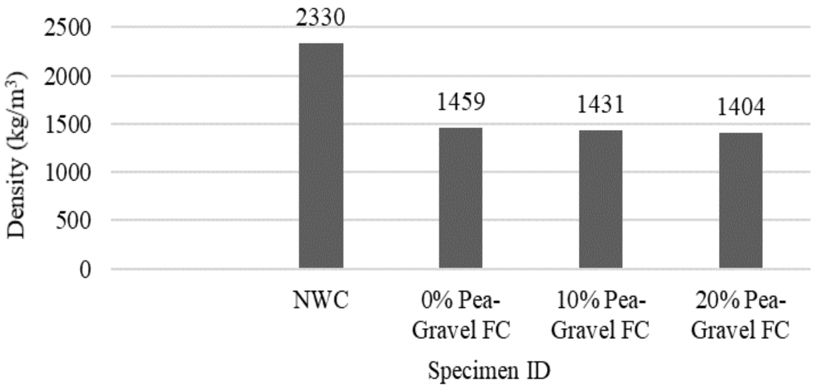

Figure 7: Comparison of Density of NWC and Foamed Concrete

Figure 7 shows the variation of the density of normal weight concrete (NWC) and foamed concrete (FC) with the different percentage of pea-gravel. It is seen that the density of foamed concrete with different percentage of pea-gravel varies from 1404 to 1459 kg/m^3 and the density of normal weight concrete is 2330 kg/m^3. The density ranges of light weight foamed concrete belongs to 400 to 1600 kg/m^3 (Ramamurthy et all., 2009). The obtained results reside inside the range of light weight foamed concrete. The density of normal weight concrete is greater than foamed concrete. It also shows that the density of foamed concrete reduced gradually with the increase in pea-gravel content. The main function of fine aggregates is to fill up the voids between the coarse aggregates. The density of foamed concrete decreases as voids in concrete increase with the increase in pea-gravel content.

3.2.2 Water Permeability

Figure 8 shows the variation of the coefficient of water permeability of normal weight concrete (NWC) and foamed concrete (FC) with different percentage of pea-gravel. The permeability range for foamed concrete lies between 10^{-8} to 10^{-10} cm/s (Sulaiman, 2011). The obtained values are not within the acceptable ranges for foamed concrete. Figure shows that the permeability of foamed concrete is higher than normal weight concrete and it gradually increases with the increase in pea-gravel content due to decrease in density of concrete. It also shows that the permeability of concrete decreases with the increase in the age of concrete.

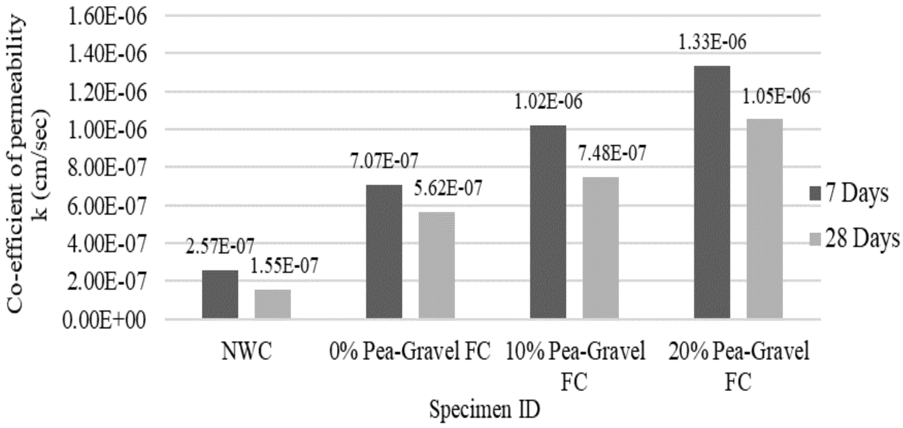

Figure 8: Comparison of Water Permeability of NWC and Foamed Concrete

3.2.3 Rapid Chloride Permeability

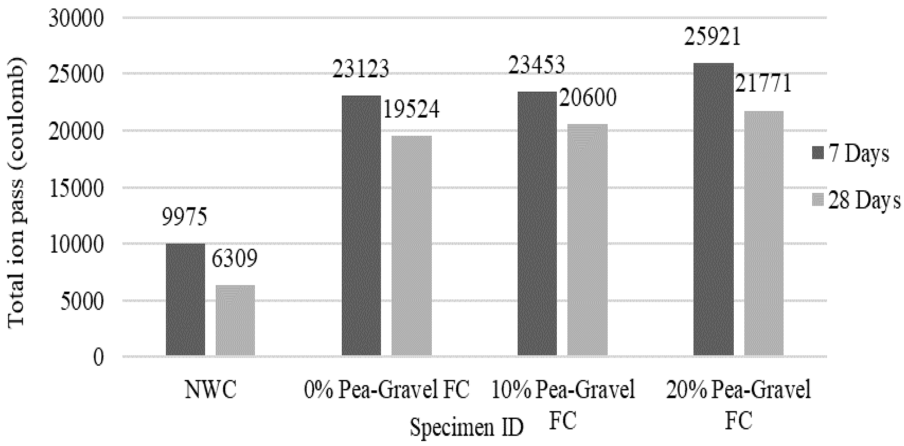

Figure 9: Comparison of Rapid Chloride Permeability of NWC and Foamed Concrete

Figure 9 shows the variation of Rapid Chloride Permeability of normal weight concrete (NWC) and foamed concrete (FC) with different percentage of pea-gravel. It is seen that the total charge passed varied from 23123 to 25921 coulomb and 19524 to 21771 coulombs at 7 and 28 days respectively for foamed concrete with different percentage of pea-gravel. On the other hand, the total charge passed for normal weight concrete ranged between 9975 and 6309 coulombs at 7 and 28 days respectively.

The results show that the total ion passed through foamed concrete was much higher than that of the normal weight concrete and it gradually increased with the increase in pea-gravel content due to increase in percentage of voids in concrete. It is obvious from Figure 9 that due to progressive hydration of cement chloride ion permeability decreased with the age of concrete for both NWC and LWC.

3.3 Mechanical Properties of Concrete

3.3.1 Compressive Strength

The results of compressive strength for normal weight concrete and foamed concrete with different percentage of pea-gravel are shown in Figure 10. It shows that the compressive strength of foamed concrete is less than normal weight concrete and it gradually decreases with increase in pea-gravel content. The target compressive strength of normal weight concrete was 22 MPa at 28 days. The obtained compressive strength of normal weight concrete is 17.7 and 22.0 MPa at 7 and 28 days respectively. Figure shows that the compressive strength of foamed concrete with different percentage of pea-gravel varied from 4.7 to 6 and 6.3 to 8 MPa at 7 and 28 days, which is lower than normal weight concrete by 66-74% and 63-72% respectively. The compressive strength range of foamed concrete lies between 0.5 to 10 MPa (Sulaiman, 2011). These obtained values are within the acceptable ranges for foamed concrete. The test results indicate that this type of concrete is suitable for non-structural purposes such as thermal insulation of roof, void filling etc.

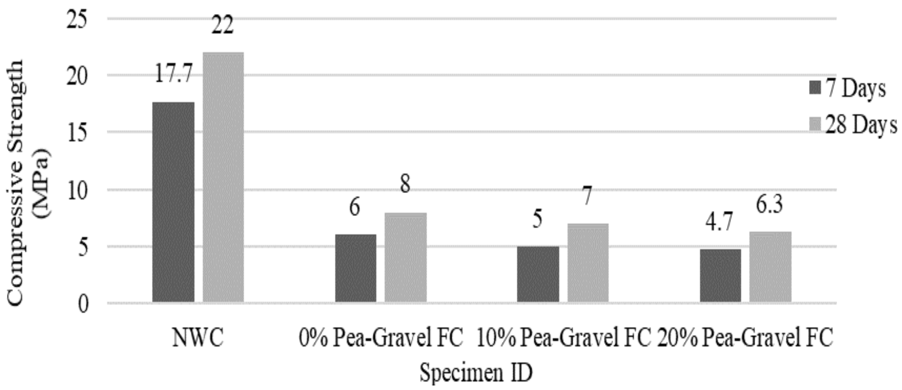

Figure 10: Comparison of Compressive Strength of NWC and Foamed Concrete

3.4 Thermal Insulation Performance of Slab

For thermal insulation test of slab specimen, the temperature at bottom of the enclosed area was created artificially from 35^0C to 50^0C at an interval of 5^0C. Then the top surface temperature of the slab was measured at an interval of 10 min. The variation of top surface temperature with respect to time for bottom temperature 35^0C, 40^0C, 45^0C and 50^0C is shown in Figure 11, Figure 12, Figure 13 and Figure 14 respectively. It shows that the thermal insulation behavior of foamed concrete slab with different percentage of pea-gravel is better than normal weight concrete slab. For foamed concrete the thermal insulation behavior gradually increased with increasing pea-gravel content due to lower density. If the density of a specimen is lowered, then better thermal insulation performance of this specimen can be achieved (Zahari et al., 2009). The results show that the top surface temperature of normal weight concrete slab varies from 26.2^0C to 32.8 ^{0}C, 26.5^0C to 35.8^0C, 28.3^0C to 37.7^0C and 28.8^0C to 40.8^0C respectively, when the bottom surface temperature is varies from 35^0C to 50^0C. The results also show that the top surface temperature of foamed concrete slab with different percentage of pea-gravel varies from 26^0C to 37.8^0C, 27.5^0C to 36.8^0C and 26^0C to 35.8^0c respectively for different bottom surface temperature. The starting temperature of different slab specimens varies due to the variation of the room temperature. During testing, the room temperature varies from 26^0C to 29^0C, so that the starting temperature is not same for all slab specimens. From this figure it is seen that the 20% pea-gravel foamed concrete shows better result in thermal insulation test than other foamed and normal weight concrete.

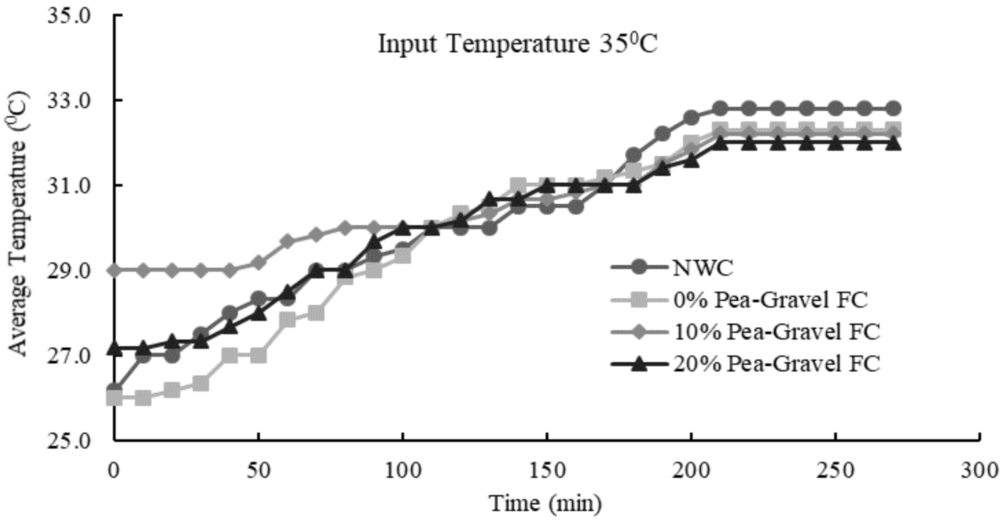

Figure 11: Comparison of Temperature Variation with Time of NWC and Foamed Concrete

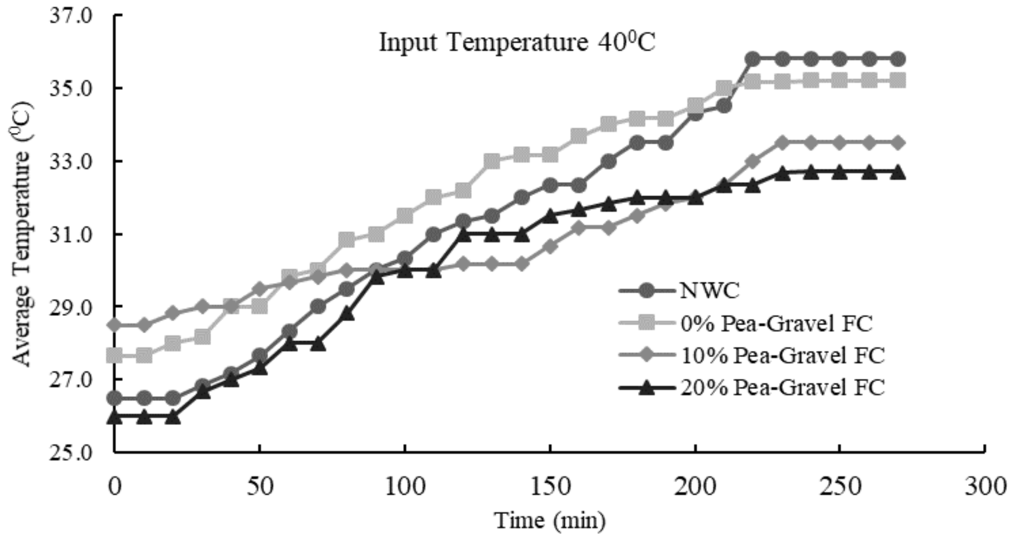

Figure 12: Comparison of Temperature Variation with Time of NWC and Foamed Concrete

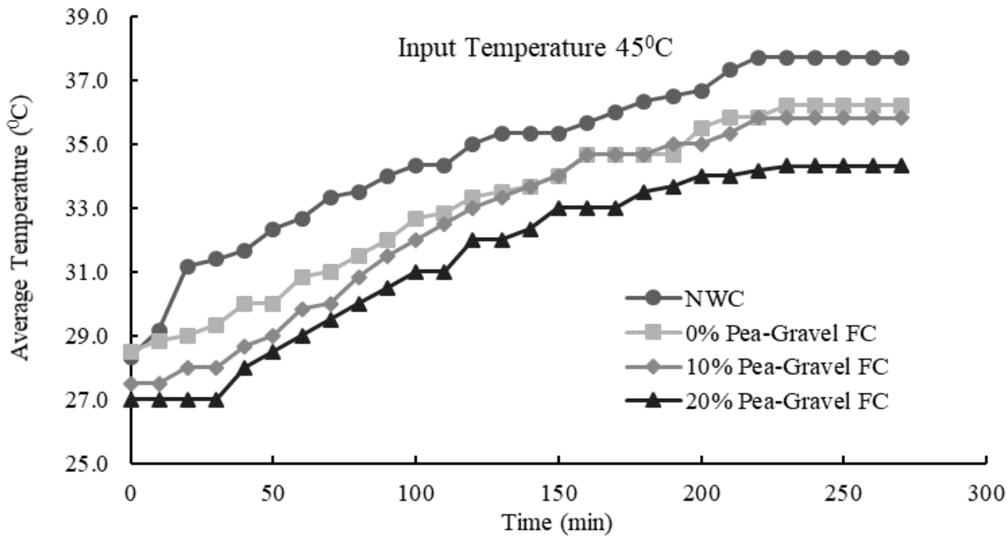

Figure 13: Comparison of Temperature Variation with Time of NWC and Foamed Concrete

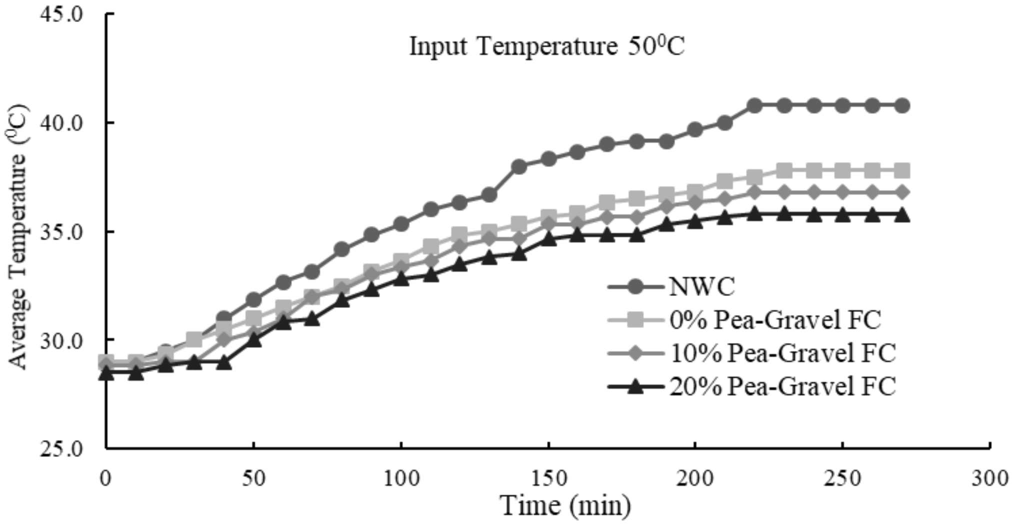

Figure 14: Comparison of Temperature Variation with Time of NWC and Foamed Concrete

4. CONCLUSIONS

The important findings based on the experimental results are summarized below:

- The density of normal weight concrete is higher than foamed concrete with different percentage of pea-gravel. The density of foamed concrete with different percentage of pea-gravel are gradually decreases with increasing pea-gravel content.
- The water permeability and rapid chloride permeability of foamed concrete with different percentage of pea-gravel is higher than normal weight concrete and it is gradually increased with increasing pea-gravel content.
- The compressive strength of normal weight concrete is close to target strength (24 MPa). But the compressive strength of foamed concrete with different percentage of pea-gravel is lower than the normal weight concrete and it is gradually decreased with increasing pea-gravel content.
- During insulation test, temperature of top surface of slab for normal weight concrete was found 26.2^0C to 40.8^0C, when the bottom surface temperature varies from 35^0C to 50^0C.
- For 0%, 10% and 20% pea-gravel foamed concrete, the temperature variation of top surface was found 26^0C to 37.8^0C, 27.5^0C to 36.8^0C and 26^0C to 35.8^0C respectively.
- The thermal insulation property of foamed concrete was gradually increased with increasing pea-gravel content due to decrease in density.

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