Experimental Enhancement of the Thermal Conductivity for Mortar Concrete by Adding Polystyrene

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Abstract

This paper gives an experimental study for the thermal conductivity of mortar concrete material by adding polystyrene (styropr) as granules for different volume percentages (0%, 5% , 10% and 15 %). Polystyrene considered as a polymeric thermal isolative material. The specimens of 343 cm^3 are made with a mixing percentages of 22.72% cement, 68.18% sand and 9.1% water which they accredited according to the Iraqi standardization No. (5 /1984).

Tests are carried out in the laboratories of the engineering college – Karbalaa university to determine the thermal conductivity, compressive strength, porosity and the density for the specimens. The results showed that the polystyrene leads to decrease the thermal conductivity of the mortar concrete. The thermal conductivity of the (5%) polystyrene specimen is decreased by (2.6%), (10%) polystyrene specimen is decreased by (10.4%), and for the specimen of (15%) polystyrene is decreased by (20.28%).The compressive strength of the specimen is decreased by increasing the polystyrene percentages and this clearly appear in the 10% and the 15% specimens but it isn't exceed the permissible range according to the Iraqi standardization No. 5/1984 (compressive strength ≥ 23 Mpa).

المستخلص

يعطي هذا البحث دراسة عملية للموصلية الحرارية لمادة الكونكريت (مونة) بإضافة مادة البوليسترين (الستايروبر) على شكل حبيبات بنسب حجمية مختلفة (5% , 10% و 15 %). تعتبر مادة البوليسترين من المواد البوليمرية العازلة . تم تصنيع النماذج وبحجم 343 سم^3 وبنسب خلط (22,72%) سمنت , (68,18%) رمل و (9,1%) ماء وحسب المواصفة العراقية (1984/5) مع اضافة المادة العازلة بالنسب اعلاه للخليط.

اجريت الفحوصات في مختبرات كلية الهندسة جامعة كربلاء لقياس الموصلية الحرارية, مقاومة الانضغاط, النفاذية, والكثافة للنماذج المصنعة.

بينت النتائج ان اضافة مادة البوليسترين ادت الى نقصان الموصلية الحرارية لمادة الكونكريت. ان اضافة حجمية بنسبة (5%) من مادة البوليسترين قللت الموصلية الحرارية بنسبة (2,6%) واضافة (10%) من البوليسترين قللت الموصلية الحرارية بنسبة (10,4%) اما اضافة (15%) من البوليسترين فقد قللت الموصلية الحرارية بنسبة (20,28). لقد لوحظ ان مقاومة الانضغاط تقل بزيادة نسبة المادة المضافة وخصوصا بنسب (10 و 15) % ولكن دون ان تتجاوز الحد المسموح به لمادة الكونكريت وحسب المواصفة العراقية (1984/5) حيث (مقاومة الانضغاط ≤ 23 ميغا باسكال).

1. Introduction

Thermal conductivities for most polymers are on the order of 0.3 W/m.K^o. For these materials, energy transfer is accomplished by the vibration and rotation of the chain molecules. The magnitude of the thermal conductivity depends on the degree of crystallization of polymer with a highly crystalline and ordered structure will have a greater conductivity than the equivalent amorphous material. This is due to the more effective coordinated vibration of the molecular chains for the crystalline state. Polymers are often utilized as thermal insulators because of their low thermal conductivities. Like ceramics, their isolative properties may be further enhanced by the generation of small pores, which are ordinarily generated by foaming during polymerization (chemical process of forming a polymer). Foamed polystyrene (styropr) is commonly used [1].

Al-Sanea [2] found that the inclusion of a 5-cm thick molded polystyrene layer reduced the roof heat transfer load to one-third of its value in an identical roof section without insulation. Hernandez-Olivares et al. [3] studied mechanical and thermal properties of a composite material that is made of cork and gypsum; they found that cork-gypsum composite is characterized by both low thermal conductivity and low density. On the other hand, the mechanical properties of cork–gypsum composite are poor, and such a composite material was suggested for use in building applications as partitions. Mohsen and Akash [4] showed that large energy savings about (76.8%) can be achieved when polystyrene is used for both wall and roof insulations. Jubran et al. [5] investigated the use of Jordan Valley clay with addition of straw, chicken feather, human hair, cement and polystyrene as insulating materials. The percentage of insulating materials in the brick ranged from 2 to 20 %. They also found that the combined additives consisting of 10 % rock wool, 5% human hair and 5% cement gave the best thermal and mechanical properties. Jaber and Hammad [6] showed that adding thermal insulation system proved to be effective nearly 82% of the estimated required heating energy was saved by using thermal insulation of 0.057 m and about 7.2 m^2 of Trombe wall system where added and the payback period was less than 2 year. Awni Al-Otoom et al

[7] presented a new technology based on crystallization of the salt solution of sodium acetate, which can be produced via the reaction of acetic acid and sodium carbonate.

The main objective of this work is to investigate the effect of the addition of some insulation materials with different weight percentages on the water absorption, compressive strength and the thermal conductivity of the mortar concrete. The objective of this arrangement besides lowering the thermal conductivity is to make the material has an emulation capability when it is marketing.

2. Theoretical considerations

The inside door temperature of building is affected by the three modes of heat transfer: convection, conduction and radiation. The major portion of heat is transmitted into the building by conduction mode through the walls in addition to heat losses by air leakage. The thermal conductivity for steady state condition of a single wall can be calculated by the following Fourier's law [8]:

$$q_x = -kA\, \partial T/\partial x \qquad (1)$$

Where $\mathbf{q_x}$ is the heat-transfer rate (W) and $\partial \mathbf{T}/\partial \mathbf{x}$ is the temperature gradient in the direction of the heat flow. The positive constant (k) is called the **thermal conductivity** (w/m.k) of the material, and the minus sign is inserted so that the second principle of thermodynamics will be satisfied. The composite walls involve several layers of different materials with different thermal conductivities. In the composite systems it is often convenient to work with Newton's law of cooling using the following equation:

$$qx = UA\, \Delta T \qquad (2)$$

In which U is the overall heat transfer coefficient ($W/K.m^2$) and represents the sum of all parallel and series thermal resistances and ΔT is the overall temperature difference. In this research work the thermal conductivity of concrete containing different weight percentages of insulating materials are experimentally determined and compared with thermal conductivity of the concrete which do not contain any insulating materials.

3. Materials equipment and experimental procedures

3.1 Materials

The materials used throughout this work are the typical ones used in manufacturing the ordinary concrete. These are cement, sand and water with the insulating material which are used and added in different weight percentages to the concrete. The insulation material was chosen to be ease of handling, low water absorption values, low cost and low thermal conductivity [9,10].

3.2 Equipment

The Hilton B480 Thermal Conductivity of Buildings & Insulating Materials Unit instrument shown in Figure (1) was used to measure the thermal conductivity of the different manufactured specimens. The apparatus consists mainly of an insulated fiberglass hinged enclosure. The base section of the closure contains the heat flow meter and the cold plate assembly which mounted on four springs. The plate is cooled with water to maintain it at constant temperature. The enclosure lid houses the electrically heated hot plate, which is electronically controlled for setting the required temperature. A computerized system is used to determine and display the measured values of thermal conductivity.

Figure (1). Hilton B480 instrument for measuring thermal conductivity of buildings & insulating materials.

The faces of the enclosure are insulated to ensure adiabatic boundary condition and to ensure that all faces of the specimen are not in direct contact with the hot and the cold plates. This thermal conductivity measuring method is a heat flow meter method which complies with the International Standard for steady-state measurement, ISO8301, [11].

The compressive strength of the different specimens was measured using the international testing machine shown in Figures (2) and (3) respectively, where the specimen was compressed between the upper and lower hubs of the machine until fracture of the specimen had occurred. The uncertainty average of the used machine was (± 0.1%).

Figure (2).ELE international testing machine.

Figure (3).The hubs of ELE international testing machine.

4. Experimental procedures

The experimental procedure begin with preparation of the dry concrete follow the same procedure used in preparation of the concrete, which is in accordance with the International Standards. The specimens were of the dimensions $7cm \times 7cm \times 7cm = 343\ cm^3$, and this is according to the Iraqi specification to measure the compressive strength. The insulating material (as shown in the Figure (4)) was added in different volume percentages during the preparation of the concrete specimens. The insulating material was added in the form of small granules of the polystyrene.

Figure (4). Granules of polystyrene.

Table (1) shows the weight of each material that the concrete specimen consist of and its percentage was.

Table (1) . Tabulation of each material and its percentage per specimen.

Material	Material's weight per specimen gm / specimen	The material weight percentage
Cement	185	22.72 %
Sand	555	68.18 %
Water (H_2O)	74	9.1 %

The insulation added as a volume percentage, where the polystyrene has a low density and these percentage listed in Table (2). For example it was evaluated as ($0.05 \times 343 = 17.15\ cm^3$).

Table (2). Tabulation of Insulation volume added for each Specimen type .

Specimen type	Insulation volume(cm^3) Per specimen
0% Insulation	0.0
5% Insulation	17.15
10% Insulation	34.3
15% Insulation	51.45

The experimental work of the project was carried out in the laboratories of engineering college of Karbalaa university begin with the specimens making process. Mixing process was done by putting the cement and sand then they mixed manually properly , finally the mixture is made by adding the water with overturning it to have a homogenous mixture for four minutes as mentioned in the Iraqi standardization, as shown in Figure (5). In case of adding the insulation the cement , sand and the specified percentage of the granule of insulation (polystyrene) are putted and then mixed manually for the same period.

Figure (5). The mixing process.

Vibrating machine device is also used to ensure a good distribution of the mixture in the mold and expel the air (Figure (6)).

Figure (6). The Vibrating machine.

Finally, after pull out the specimen mold from the vibrating device, it is putted in an optimum condition box as shown in Figure (7) with specified condition (dry bulb Temperature = 21.4 ^{o}C **&** relative humidity = 88%), to reach the maturation case (7days). Figure (8) shows the specimens after the process.

Figure (7) .The optimum conditions box.

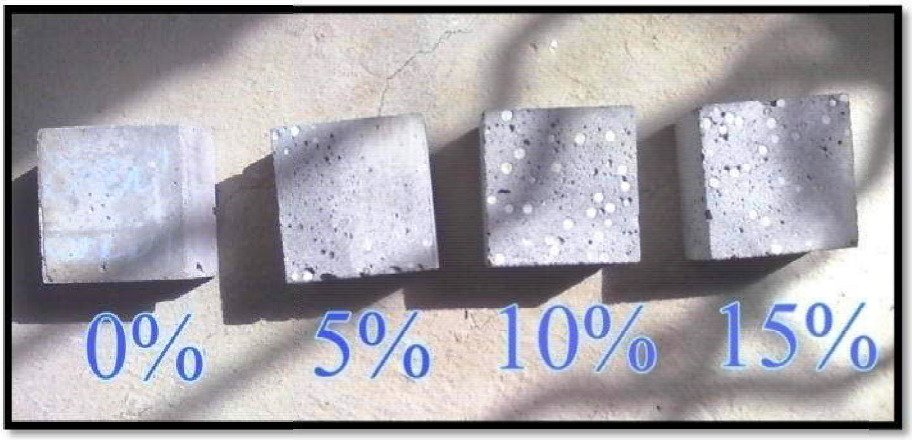

Figure (8).The specimens after the process .

5. Results and discussion

The compressive strength is measured directly by the ELE International testing machine for each specimen and the results are listed in Table (3). The readings still in the permissible range according to the Iraqi standardization number (5/1984) for the mortar concrete at maturation for 7 days which it is (compressive strength $\geq$ 23 Mpa).

Table (3). Tabulation of the compressive strength for each specimen.

Specimen type	Compressive strength (Mpa)
0 % Insulation	33.29
5 % Insulation	31.18
10 % Insulation	26.05
15 % Insulation	23.88

The density of each specimen is calculated by knowing the masses and the reduction in the mass for all specimens and the porosity is evaluated as:

$$\% \; porosity = \frac{void \;\; volume}{total \;\; volume} \times 100 \qquad (3)$$

$$= \frac{(m_t - m_s)}{V_s \rho_w} \times 100$$

The masses after the specimens immersed appeared as:

$m_{t\,(0\%)}$ = 813 gm, $m_{t\,(5\%)}$ =799 gm, $m_{t\,(10\%)}$ = 769 gm, $m_{t\,(15\%)}$ = 747 gm

therefore the results are tabulated in Table (4) for the constant specimens volume of (343 cm^3).

Table (4). Tabulation of the specimens masses and its reduction with calculated density and porosity.

Specimen type	Mass (gm)	%Reduction in mass	Density gm / cm^3	Porosity %
0 % Insulator	809	0.0	2.358	1.166
5 % Insulator	794	1.854	2.315	1.457
10 % Insulator	761	5.933	2.218	2.332
15 % Insulator	737	8.899	2.149	2.915

The effect of the volume addition of insulating material on thermal conductivity of the concrete specimens is shown in Figure (**9**). It can be seen from this figures that, for all the tested concrete specimens, as the volume percentages of insulator increases the thermal conductivity decreases where the overall density of the specimens decreases and the results of the thermal conductivity of each specimen are listed in the Table (5). However, the decreasing rate is more pronounced for the insulating percentage of (15%).

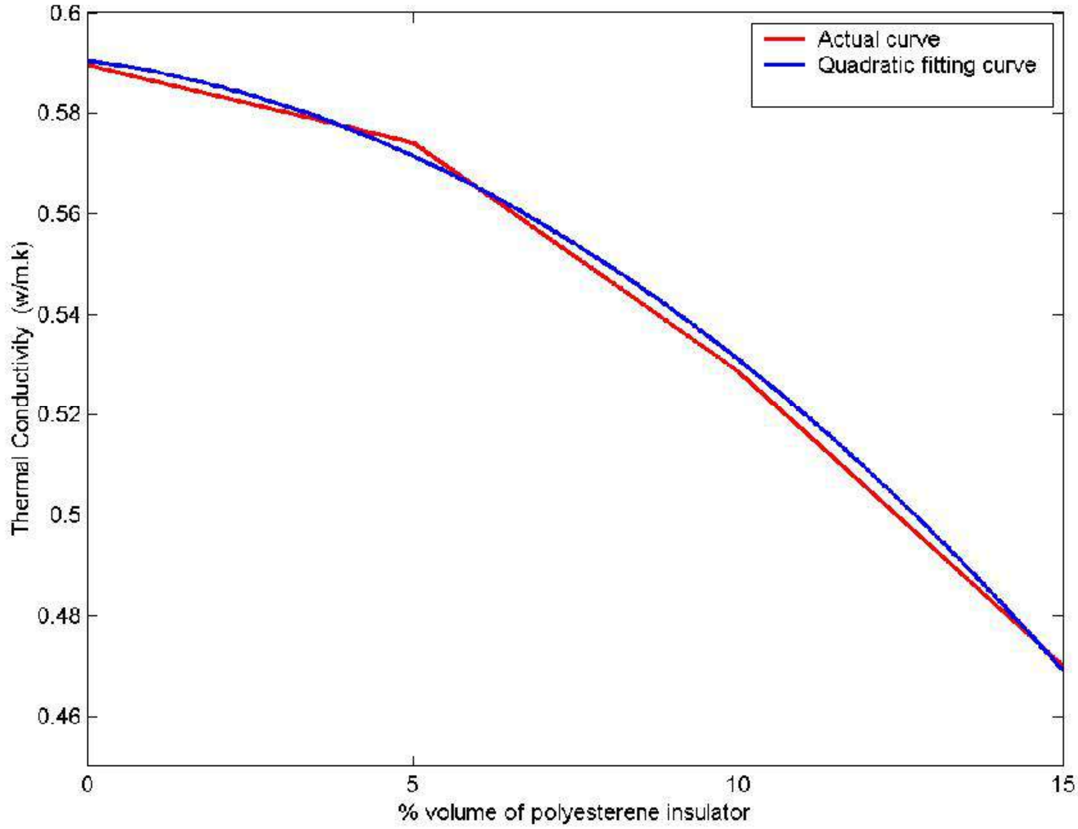

Figure (9). The relation between the thermal conductivity and the % volume of Polystyrene insulator.

Table (5). Tabulation of the Thermal Conductivity and the Percentage of Reduction .

Specimen type	Thermal conductivity (W/m.K)	Reduction of Thermal Conductivity (%)
0 % Insulator	0.5896	0.0
5 % Insulator	0.5742	2.6
10 % Insulator	0.5286	10.4
15 % Insulator	0.47	20.28

6. Conclusions

It can concluded that the addition of a reasonable percentage of the Polystyrene (5-15)%, resulted in reduction of water absorption, decrease in the compressive strength and pronounced decrease in thermal conductivity. The most effective Polystyrene percentage in reducing thermal conductivity of concrete is found to be (15%) which is lead to reduce the thermal conductivity by (20.28%) with the permissible strength limit of (compressive strength ≥ 23 Mpa). The maximum porosity percent is in the case of (15%) addition being (2.915%) and the minimum porosity percent is in the case of (5%) addition (1.457%).

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