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Effect of Additive of Expanded Polystyrene and Perlite on Some Mechanical Properties and Thermal Conductivity for Mass Concrete

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Abstract

In this research, the major problem of mass concrete (Differences in Temperature) was studied. Expanded polystyrene and perlite were added in different percentages to investigate the effects on some mechanical properties and thermal conductivity of concrete. Two stages of work were performed.
In first stage, reference mix was designed at proportion (1cement: 1.41sand: 2.72gravel) with (0.4) water cement ratio. Four tests were conducted, these tests including density, compressive strength, flexural strength and thermal conductivity through exponential equation depending on dry density. In the second stage, polystyrene beads and perlite were added as volumetric ratio with (10, 15, 20, 25, and 30) percentages to the original size of reference mix and conducted the tests and study their effects .The results showed a significant improvement in thermal insulation and reduced thermal conductivity (40 , 22) % by using (30) % of polystyrene and perlite respectively. The decreasing in some mechanical properties can be seen and this decreasing did not have serious effects on the design efficiency of the structure which conformed with the specifications.

Keywords: Mass Concrete, Mechanical Properties, Thermal Conductivity, Expanded polystyrene, Perlite.

تأثير إضافة البولي ستيرين التمددي والبيرلايت على بعض الخصائص الميكانيكية والموصلية الحرارية للخرسانة الكتلية

الخلاصة

تناول هذا البحث دراسة المشكلة الرئيسية للخرسانة الكتلية (الاختلافات في درجات الحرارة) . حيث تم إضافة مادتي البولي ستيرين التمددي والبيرلايت بنسب مختلفة وذلك للتحري عن تأثير هذه المواد على بعض الخصائص الميكانيكية والموصلية الحرارية للخرسانة، و أن العمل تم على مرحلتين، حيث تم في المرحلة الاولى استخدام خلطة مرجعية مصممة بنسب (1 إسمنت : 1.41 رمل : 2.72 حصى) وبنسبة ماء الى إسمنت (0.4) . أجريت أربعة فحوصات على الخرسانة وشملت الكثافة ومقاومة الانضغاط ومقاومة شد الانحناء وحساب الموصلية الحرارية بواسطة معادلة أسية تعتمد على الكثافة. وفي المرحلة الثانية، أضيفت حبيبات البولي ستيرين والبيرلايت بنسب حجمية (10 و 15 و 20 و 25 و 30) % الى الحجم الاصلي للخلطة المرجعية وأجريت عليها الفحوصات السابقة ودراسة تأثيراتها. أظهرت النتائج تقدم واضح في العزل الحراري عن طريق التقليل في الموصلية الحرارية بنسب (40 و 22) % عند استخدام (30) % من حبيبات البولي ستيرين والبيرلايت على التوالي . وتم ملاحظة النقصان الحاصل في بعض الخصائص الميكانيكية، وهذا النقصان ليس له تأثيرات قيمة على الكفاءة التصميمية للمنشأ وبما يطابق المواصفات.

الكلمات الدالة: الخرسانة الكتلية، الخصائص الميكانيكية، الموصلية الحرارية، البولي ستيرين التمددي، البيرلايت.

Introduction

Mass concrete can be defined as “any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from the hydration of the cement and attendant volume change to minimize cracking”. Thermal properties of concrete are significant in connection with keeping differential volume change at a minimum in mass concrete, extracting excess heat from the concrete, and dealing with similar operations involving heat transfer. These properties are specific heat, conductivity, and diffusivity [1].

At a construction site of a dam or a large-scale concrete structure like an electric power plant, concrete would be placed in large quantities. However, such concrete in large quantities placed at the same time, causes the temperature of the concrete to rise. It often reaches about 40-70°C because of the hydration heat of the cement. Because to such temperature rises thermal stress can be generated. These kinds of structures should be constructed paying attention to the generation of cracks due to thermal stress to make sure of its safety and serviceability [2].

Concrete mixtures can be designed to provide a wide range of mechanical and durability properties to meet the design requirements of a structure. The compressive strength of concrete is the most common performance measure used by the engineer in designing buildings and other structures. The compressive strength is measured by breaking cylindrical or cubic concrete specimens in a compression-testing machine [3].

Thermal conductivity is a specific property of a gas, liquid, or solid. The coefficient of thermal conductivity k is a measure of the rate at which heat (energy) passes perpendicularly through a unit area of homogeneous material of unit thickness for a temperature difference of one degree; k is expressed as Btu × in./(h × ft^2 × °F)[W/(m^{2}K)] [4].

The thermal conductivity can be influenced by the material's chemical composition and molecular structure. Material with simple chemical composition and molecular structure has higher thermal conductivity than the complex. The thermal conductivity of solid matter is higher than that of air. Therefore, the higher the porosity is, the lower the thermal conductivity will be. In this aspect, not only the porosity matters, but also the size, distribution, shape, and connectivity of the pores. Materials in damp conditions have higher thermal conductivity [5].

Concrete temperature rising from the hydration of cement in roller compacted concrete (RCC) dams, coupled with the low conductivity of concrete can induce a high thermal gradient along the interior mass and the exterior surface of the dam. The interior restraints, due to this thermal gradient and the external restraints, such as foundation restraint, during the cooling of the dam can cause significant thermal stresses, which are sufficient for cracking [6].

The objectives of this study is to determine the effect of addition expanded polystyrene beads and construction perlite on mechanical properties (compressive & flexural strengths) of mass concrete and thermal properties (thermal conductivity) that can be determine by exponential equation according to ACI 122R-02, and determine the possibility of improving the thermal insulation in mass concrete so that it does not exceed the minimum compressive strength and reduce the temperature difference between the center and the concrete surface, In addition to assessing the role of construction perlite and also expanded polystyrene materials in reducing the thermal conductivity as well as their suitability for use, especially in mass concrete and other construction works that require thermal insulation in general . And also determine the effectiveness and suitability of these materials for environmental and climatic conditions.

Experimental Work

Materials

Cement

Ordinary Portland Cement Type I (Badoosh factory) which satisfy to the Iraqi Specifications was used [7] .

Fine Aggregate

Rough natural sand in accordance with Iraqi standard specifications (45:1984) [8], was used. The specific gravity 2.63 and fineness modulus 3. Its particle size shown in Table (1).

Coarse Aggregate

River gravel round shape was used; it has nominal maximum aggregate size of 37.5mm and specific gravity 2.7, sieve analysis was performed and Table (2) shows the results of the sieve analysis; it is found compatible to the Iraqi standard specifications (45:1984)[8].

Water

Tap water which has good drink water properties was used in all mixes.

Table 1. Sieve analysis of sand

Sieve Size		Weight (%) Passing	Total Limits (%) Passing
ASTM (in.)	B.S. (mm)		
No. 4	4.75	82.2	89 – 100
No. 8	2.36	67.1	60 – 100
No. 16	1.18	57.4	30 – 100
No. 30	600µ	42.1	15 – 100
No. 50	300µ	10.6	5 – 70
No. 100	150µ	1.6	0 – 15

Table 2. Sieve analysis of gravel

Sieve Size		Weight (%) Passing	Total Limits (%) Passing
ASTM (in.)	B.S. (mm)		
2.0	50	100	100
1 ½	37.5	94	90 – 100
3/4	19	65	35 – 70
1/2	12.5	50	25 – 55
3/8	9.51	32	10 – 40
No. 4	4.75	3	0 – 5

Expanded polystyrene

Polystyrene beads Spherical shape was used as shown in Figure (1). Its diameter (2-5) mm, density (20 - 50) Kg/m³ and thermal conductivity (0.031 - 0.047) W/m.˚k used as volumetric ratio added to the total volume of mix [5].

Fig. 1. Polystyrene beads

Construction Perlite

Expanded perlite, honey-comb like or bubble-like, white or grayish-white granules as shown in Figure (2), is made by calcining the natural perlite. It is a high-efficient heat insulating material, and has the advantages of light weight, good performance in low temperature, better hygroscopicity, better chemical stability, incombustibility, corrosion resistance, and easy application, etc. In construction, expanded perlite is widely utilized in exterior protected construction, low-temperature insulation equipment, thermal equipment, and also sound-absorbing products and having (0.06-0.17) W/m.˚k thermal conductivity at high temperature. Tables (3 and 4) show the chemical composition and sieve analysis respectively, and having density (60 – 150) Kg/m³ [5].

Fig. 2. Construction perlite

Table 3. The Chemical composition of perlite

Typical Elemental Analysis	
SiO_2	33.8
Al_2O_3	7.2
K_2O	3.5
Na_2O	3.4
Fe_2O_3	0.6
Ca_2O_3	0.6
MgO	0.2
Trace	0.2
O_2 (by difference)	47.5
Net Total	97.0
Bound water	3.0
Total	100.00
All analyses are shown in elemental from even through the actual forms present are mixed glassy silicates. Free silica may be present in small amounts, characteristics of the particular ore body. More specific information may be obtained from the ore supplier involved.	

Table 4. Sieve analysis of perlite

Sieve Size	(mm)	Weight % Passing
No. 4	4.75	100
No. 8	2.36	85 – 100
No. 16	1.18	40 – 85
No. 30	600µ	20 – 60
No. 50	300µ	5 – 25
No. 100	150µ	0 – 10

Mix Proportion, Mixing and Curing

Mix design with (ACI 211.1- 91)[9] was performed depending upon the compressive strength, workability and nominal maximum aggregate size and the proportions were listed in Table (5). The reference mixture compared with mixes containing polystyrene beads and perlite materials, the expanded polystyrene beads were added to the mixture as volumetric ratio to the total volume of the reference mixture with proportions (10, 15, 20, 25, and 30) % respectively and forming five mixes with these proportions. The previous proportions are repeated by using construction perlite as shown in Table (6). The dry cement, aggregate and polystyrene beads or perlite were mixed without water till it became homogeneous; then water was mixed with homogeneous dry mixes and casting in steel molds (150) cubic mm for compressive strength and (150*150*750) mm for flexural strength.

In this study, eleven mixes were casted taking six samples for each test. After 24 hr. samples were removed from molds and cured in normal water (23 °C) temperature for (7 & 28) days.

Table 5. Mix proportion of concrete constituents by (ACI 122R-02)

Constituents	Water	Cement	Sand	Gravel
Weights (kg/m³)	175	437.5	617.24	1190.25
Percentages (%)	0.4	1	1.41	2.72

Table 6. Composition of mixes

Materials	Water (kg/m³)	Cement (kg/m³)	Sand (kg/m³)	Gravel (kg/m³)	Polystyrene (%) of total volume	Perlite (%) of total volume
Mix (1) reference	175	437.5	617.25	1190.25	---	---
Mix (2)	175	437.5	617.25	1190.25	10	---
Mix (3)	175	437.5	617.25	1190.25	15	---
Mix (4)	175	437.5	617.25	1190.25	20	---
Mix (5)	175	437.5	617.25	1190.25	25	---
Mix (6)	175	437.5	617.25	1190.25	30	---
Mix (7)	175	437.5	617.25	1190.25	---	10
Mix (8)	175	437.5	617.25	1190.25	---	15
Mix (9)	175	437.5	617.25	1190.25	---	20
Mix (10)	175	437.5	617.25	1190.25	---	25
Mix (11)	175	437.5	617.25	1190.25	---	30

Testing Program

1. Density according to(ASTM C138/C 138M-01a)[10].
2. Compressive strength for (7 & 28) days, according to (BS. 1881:part 116)[11].
3. Flexural strength for 7 and 28 days, according to (ASTM C78-02) [12].
4. Thermal conductivity depending upon the oven-dry density of concrete according to (ACI 122R – 02)[4].

Results and Discussions

Density (Unit Weight)

The densities of the concrete with and without insulation materials (polystyrene beads & perlite) are shown in Table (7). Figures (3 & 4) show the comparison between the densities (fresh, air-dry, and oven-dry) of normal concrete and the concrete that contains the percentages of polystyrene beads and perlite.

From results, the densities of concrete containing polystyrene beads are less than the densities of concrete with perlite because the density of polystyrene is less than the density of perlite as mentioned in materials properties.

Table 7. Densities of concrete

Mix No.	Fresh density (kg/m^3)	Air-dry density (kg/m^3)	Oven-dry density (kg/m^3)
1. Reference Concrete	2500	2465	2442
2. 10 % Polystyrene addition	2375	2356	2301
3. 15 % Polystyrene addition	2290	2263	2215
4. 20 % Polystyrene addition	2195	2183	2170
5. 25 % Polystyrene addition	2130	2114	2090
6. 30 % Polystyrene addition	2065	2050	2032
7. 10 % Perlite addition	2390	2335	2311
8. 15 % Perlite addition	2348	2319	2298
9. 20 % Perlite addition	2300	2287	2268
10. 25 % Perlite addition	2280	2250	2239
11. 30 % Perlite addition	2224	2195	2171

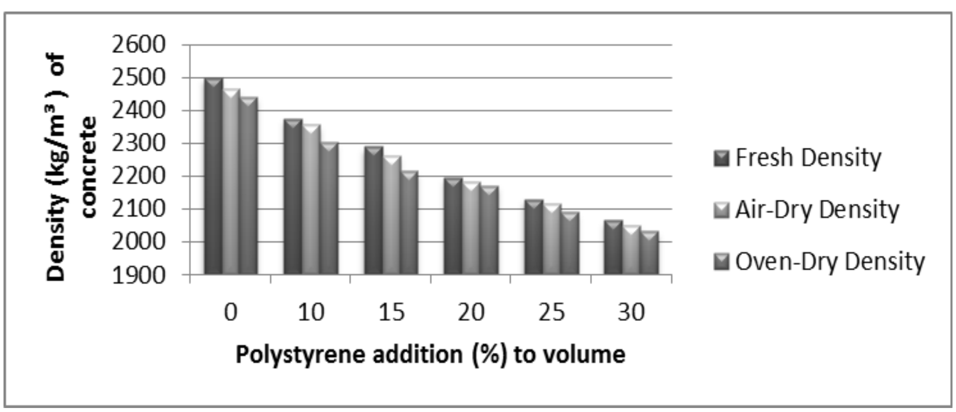

Fig. 3. Densities of concrete with polystyrene addition

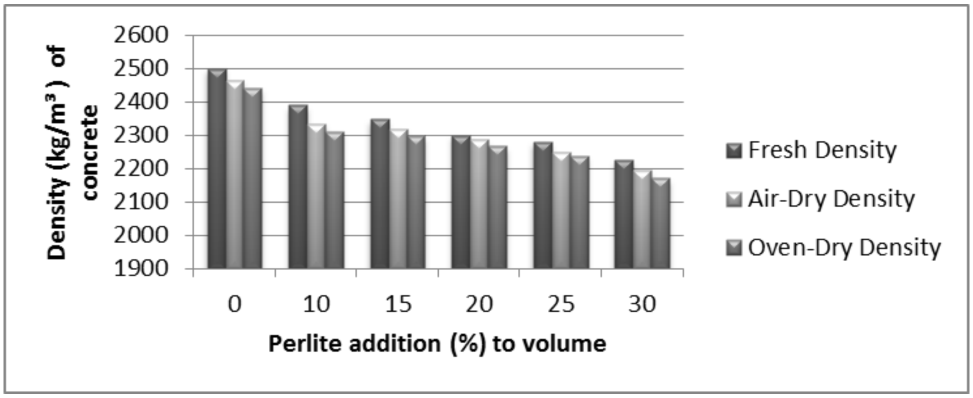

Fig. 4. Densities of concrete with perlite addition

Compressive Strength

The compressive strengths of concrete with and without insulation materials are shown in Table (8) and represented in Figures (5 & 6). From results it is shown that the compressive strength reduced with addition of insulation materials (polystyrene beads & perlite), but the compressive strengths reduced by using polystyrene beads larger than the reduction that is caused by using perlite because the perlite is stronger than the polystyrene beads in interlocking among concrete constituents because perlite represents a type of lightweight aggregate.

Table 8. Compressive strengths of concrete

Mix No.	Compressive Strengths (MPa)	
	7-Days	28-Days
1. Reference Concrete	33.80	41.30
2. 10 % Polystyrene addition	28.47	37.76
3. 15 % Polystyrene addition	24.81	35.41
4. 20 % Polystyrene addition	23.92	29.20
5. 25 % Polystyrene addition	22.02	26.19
6. 30 % Polystyrene addition	19.01	26.04
7. 10 % Perlite addition	35.04	38.42
8. 15 % Perlite addition	30.02	36.08
9. 20 % Perlite addition	28.01	30.96
10. 25 % Perlite addition	25.32	30.00
11. 30 % Perlite addition	23.47	29.36

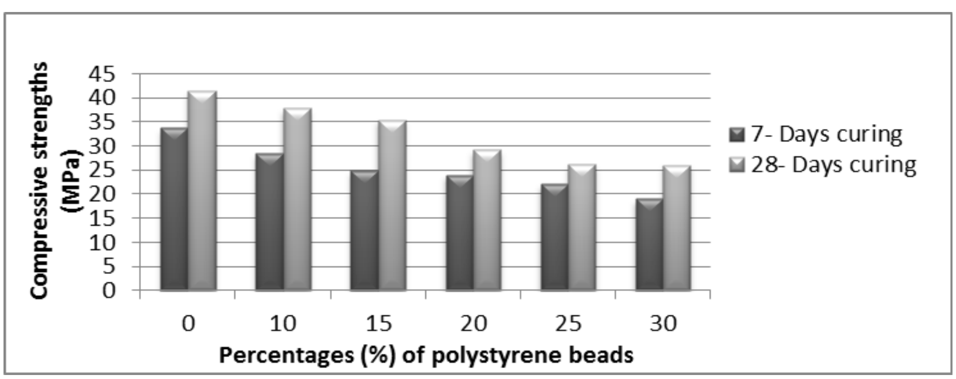

Fig. 5. Compressive strengths of concrete with polystyrene addition

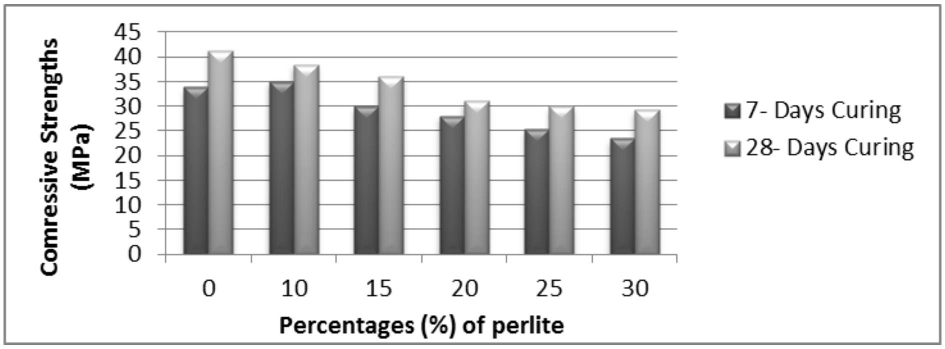

Fig. 6. Compressive strengths of concrete with perlite addition

Flexural Strength

Flexural strengths of concrete are shown in Table (9) and represented in Figures (7 & 8). The results showed that the strengths of concrete containing polystyrene are better than that with perlite for the same causes in compressive strength.

Thermal Conductivity

Depending upon the density of concrete, thermal conductivity was calculated by an exponential equation according to (ACI 122R – 02) [4], where the thermal conductivity coefficient (**kc**) is dependent on types of aggregate used in concrete mixture. By using insulation materials (expanded polystyrene & construction perlite) with different proportions, the oven-dry densities of concrete reduced by increasing insulation materials. Thermal conductivity **(kc)** is calculated by Equation (1):

$$\mathbf{kc = 0.072e^{0.00125d}} \qquad \text{(1)}$$

Where $\mathbf{kc}$ = Thermal conductivity coefficient in (S.I. units), and **d**= oven-dry density in (kg/m^3).

Thermal conductivities of the concrete are shown in Table (10) and represented in Figure (9). The results showed that the thermal conductivity is reduced about 40 % and 22 % when added 30% of polystyrene beads and perlite to the total volume of mix respectively.

Table 9. Flexural strengths of concrete

Mix No.	Flexural Strength (MPa)	
	7-days	28-days
1. Reference Concrete	5.84	7.24
2. 10 % Polystyrene addition	5.56	6.95
3. 15 % Polystyrene addition	5.35	6.42
4. 20 % Polystyrene addition	4.62	5.64
5. 25 % Polystyrene addition	4.42	5.26
6. 30 % Polystyrene addition	3.67	5.03
7. 10 % Perlite addition	6.07	6.98
8. 15 % Perlite addition	5.51	6.55
9. 20 % Perlite addition	5.37	6.06
10. 25 % Perlite addition	4.80	5.66
11. 30 % Perlite addition	4.62	5.32

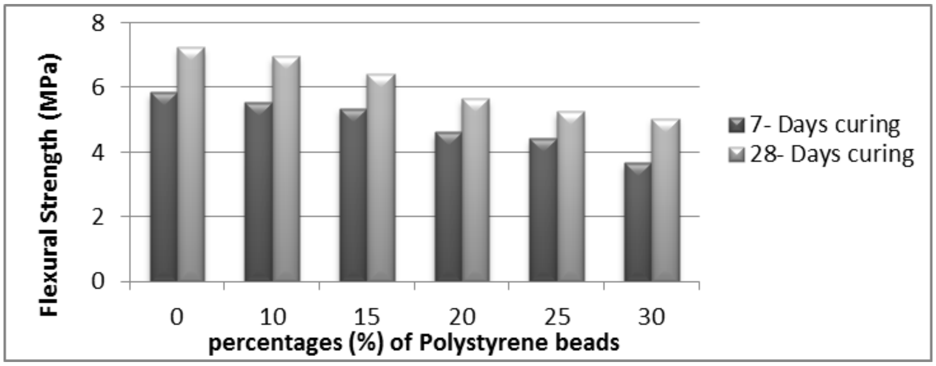

Fig. 7. Flexural Strengths of concrete with polystyrene addition

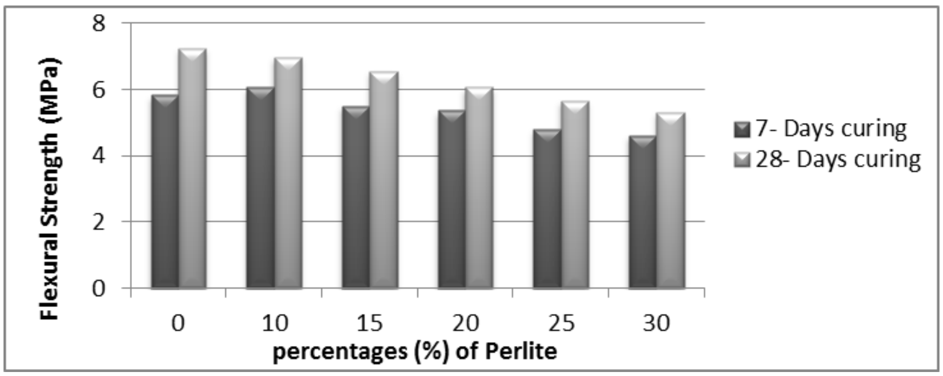

Fig. 8. Flexural Strengths of concrete with perlite addition

Table 10. Thermal conductivities of concrete

Mix No.	Thermal Conductivity (W/m˚K)
1. Reference Concrete	1.524
2. 10 % Polystyrene addition	1.278
3. 15 % Polystyrene addition	1.148
4. 20 % Polystyrene addition	1.085
5. 25 % Polystyrene addition	0.982
6. 30 % Polystyrene addition	0.913
7. 10 % Perlite addition	1.379
8. 15 % Perlite addition	1.318
9. 20 % Perlite addition	1.268
10. 25 % Perlite addition	1.251
11. 30 % Perlite addition	1.188

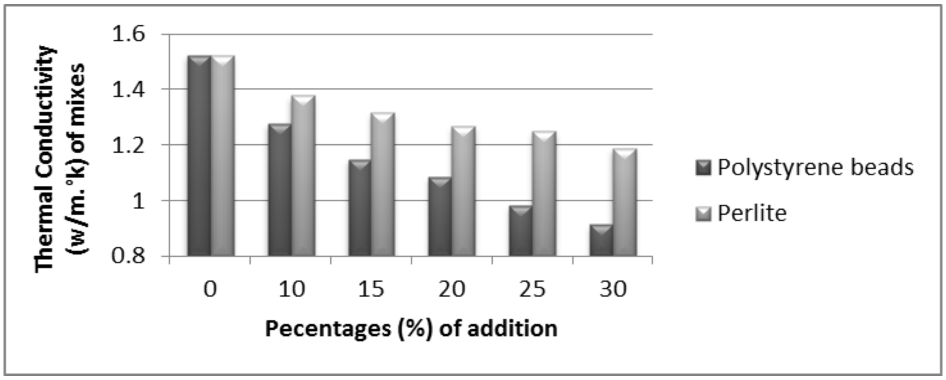

Fig. 9. Thermal Conductivities of concrete with & without insulation materials

Conclusions

From results of tests, it was concluded that:

- The density of concrete is reduced about (17 & 11) % by using (30) % of expanded polystyrene beads and construction perlite respectively to the total mix .
- The density of concrete containing polystyrene beads is less than that containing perlite .
- The compressive strength reduced approximately (37 & 29) % at age of 28-days by using (30) % of expanded polystyrene beads and construction perlite respectively to the total mix .
- The flexural strengths are reduced about (30 & 27) % at age of 28-days by using (30) % of expanded polystyrene beads and construction perlite respectively to the total mix.
- Reducing the thermal conductivity to (40 & 22) % when used (30) % of expanded polystyrene beads and construction perlite respectively to the total mix.

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