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Effect of Expanded Perlite Aggregate Dosage on Properties of Lightweight Concrete

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ABSTRACT

In this paper, an experimental study was carried out in order to provide more data on the effects of expanded perlite aggregate (EPA) dosage on the compressive strength and thermophysical properties of lightweight concrete at different ages. The first part of this experimental study was devoted to the choice of the proper mixing procedure for expanded perlite concrete (EPC). Thereafter, six sets of cubic specimens and six sets of parallelepiped specimens were prepared at a water-to-cement ratio of 0.70 with varying replacement percentages of sand by EPA ranging from 0% to 80% by volume of sand. Compressive strength, thermal conductivity and thermal diffusivity were determined over curing age. Unit weights for the mixtures prepared varied between 560 and 1510 kg/m^3. Compressive strength was decreased when perlite content was increased. The test results indicated that replacing natural aggregate by EPA increased the thermal resistance of the lightweight concrete and consequently, improved thermal insulation.

KEYWORDS: Expanded perlite aggregate, Dosage, Lightweight concrete, Compressive strength, Thermophysical properties.

INTRODUCTION

Perlite is an amorphous volcanic glass that has relatively high water content (2-5%), typically formed by the hydration of obsidian (Mladenovic et al., 2004). It occurs naturally and has the unusual property of greatly expanding when heated sufficiently. It is an industrial mineral and a commercial product useful for its light weight after processing. Perlite is not a trade name, but a generic term for naturally occurring siliceous rock. The distinguishing feature which sets perlite apart from other volcanic glasses is that when heated to a suitable point in its softening range, it expands from four to twenty times its original volume (Chandra and Berntsson, 2002). This expansion is due to the presence of two to five percent combined water in the crude perlite rock. When quickly heated to above 1600°F (871°C), the crude rock pops in a manner similar to popcorn as the combined water vaporizes and creates countless tiny bubbles which accounts for the amazing light weight and other exceptional physical properties of EPA. This expansion process also creates one of perlite's distinguishing characteristics: its white color. While the crude rock may range from transparent light gray to glossy black, the color of EPA ranges from snowy white to grayish

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white. Since perlite is a form of natural glass, it is classified as chemically inert and has a pH of approximately 7.

Perlite is used in various areas such as construction materials. Because of perlite's outstanding insulating characteristics and light weight, it is widely used as a loose-fill insulation in masonry construction (Celik et al., 2013; ASTM C 330, 2009; ASTM C 332, 2009). In this application, free-flowing perlite loose-fill masonry insulation is poured into the cavities of concrete block where it completely fills all cores, crevices, mortar areas and ear holes (Topçu and Işıkdağ, 2007). In addition to providing thermal insulation, perlite enhances fire ratings, reduces noise transmission and is rot, vermin and termite resistant. Perlite is also ideal for insulating low temperature and cryogenic vessels, it has high-freeze-thaw resistance and fire protection capability (Yu, 2003; Mo and Fournier, 2007). When perlite is used as an aggregate in concrete, a lightweight, fire resistant, insulating concrete is produced that is ideal for roof decks and other applications. Perlite can also be used as an aggregate in Portland cement and gypsum plasters for exterior applications and for fire protection of beams and columns. Other construction applications include under-floor insulation, chimney linings, paint texturing, gypsum boards, ceiling tiles and roof insulation boards. EPA can also have pozzolanic activity and can be used as a mineral admixture when finely ground (Erdem et al., 2007; Urhan, 1987).

Industrial applications of perlite are very diverse, ranging from high performance fillers for plastics to cement for petroleum, water and geothermal wells. Other applications in construction are improving thermal and acoustic insulation properties. The reduction of the heat loss in buildings decreases the consumption of energy and reduces the cost of heating and cooling (ACI, 2002).

The main objective of this study is to provide more data on the effect of the incorporation of EPA on the compressive strength and thermal properties of lightweight concrete. EPA is very brittle; consequently, mixing lightweight concrete that is based on these aggregates must be carried out carefully to avoid crushing and therefore changing their size. In order to prevent the aforementioned phenomenon, three different procedures were tested. In this experimental study, the volume of sand will be dropped and replaced by the expanded perlite with a percentage ranging from 0% to 80% to obtain mixtures with different unit weights.

Compressive strength of the different mixtures was measured at the ages of 3, 7 and 28 days. We studied also the effect of EPA dosage on the thermal conductivity and on the thermal diffusivity of EPC at the age of 28 days. Finally, specific heat and thermal effusivity were also deducted.

EXPERIMENTAL STUDY

Experimental Program

The first part of this experimental study was devoted to the choice of the proper mixing procedure for EPC. Thereafter, six sets of nine cubic specimens (100 mm x 100 mm x 100 mm) and six sets of three parallelepiped specimens (270 mm x 270 mm x 40 mm) were prepared by varying the proportion of EPA with a percentage ranging from 0% to 80% by volume of sand. The values (15, 30, 45, 60 and 80) indicate the proportion of EPA by substitution of the volume of sand. The Normal Concrete (without EPA) and the Expanded Perlite Concrete were respectively designated as NC and EPC. Figure1 shows 6 cubic and 6 parallelepiped specimens having different EPA proportions.

The composition of the different mixtures is presented in Table 1.

Effective water/cement ratio was 0.70 and was kept constant in all mixtures. The slump values were between 8 and 16 cm. This high water to cement ratio is due to the high water absorption and high porosity values of EPA (Topçu and Işıkdağ, 2007). To obtain workability more than 16 cm slump, a super plasticizer (SP) was used in all of the mixtures.

Table 1. Composition of the NC and EPC specimens

Designation of mixture	W/C	EPA			Cement [kg]	Water [kg]	Sand		SP* [kg]
		%	[m^3]	[kg]			[kg]	[m^3]	
NC	0.70	0	0	0	300	210	1420	1	3.00
EPC15	0.70	15	0.150	10.5	300	210	1207	0,850	3.00
EPC30	0.70	30	0.300	21	300	210	994	0,700	3.00
EPC45	0.70	45	0.450	31.5	300	210	781	0,550	3.00
EPC60	0.70	60	0.600	42	300	210	568	0,400	3.00
EPC80	0.70	80	0.800	56	300	210	284	0,200	3.00

* superplasticizer used to increase the workability of concrete.

Table 2. Shape, dimensions and number of tested specimens

Test	Shape of specimens	Dimensions of specimens	Standard
Compressive strength	Cubic	100 x 100 x 100 mm	EN 12390-3
Thermal conductivity	parallelepiped	270 x 270 x 40 mm	NF EN ISO 8990
Thermal diffusivity	parallelepiped	270 x 270 x 40 mm	NF EN ISO 8990

The cubic specimens were used to determine compressive strength of the mixtures at the ages of 3, 7 and 28 days. The other parallelepiped specimens were used to determine thermal conductivity and thermal diffusivity of the different mixtures at the age of 28 days by the boxes method. Finally, specific heat and thermal effusivity were predicted from the thermal conductivity and the thermal diffusivity data.

Test specimens were kept in their molds. After 24 h, they were removed from the molds and subjected to water curing at 20°C. At the correspondent age, the specimens were taken out and kept in laboratory conditions until testing time. Table 2 shows the shape and dimensions of the test specimens as well as adopted Standard test methods.

Materials Characteristics

Expanded Perlite Aggregate (EPA)

The perlite rock is imported from Turkey. However, its expansion process is carried out in Tunisia. EPA contains 70–80% silicon dioxide and 12–16% alumina. Other components are sodium oxide, potassium oxide, ferro oxide, manganese oxide, titan oxide and sulfide (Topçu and Işıkdağ, 2007). The physical properties of EPA are given in Table 3.

Table 3. Properties of expanded perlite aggregate

Color	White
pH	7
Melting point	1200 °C
Specific heat	0.20 kcal/kg °C
Rough density	70 kg/m^3
Thermal conductivity	0.040 W/m.K
Compression strength in the compacted condition	0.10–0.40 MPa
Water absorption	30-40 (%, V/V)
Porosity	70-85 %
Size (mm)	2 - 4
Sound insulating (125 Hz)	18 dB

Note: The physical properties of EPA are provided by the Tunisian Society “PERLA INDUSTRIES” (http://www.perla-group.com.tn/)

Cement

The cement used was a CEM I 32.5 in conformity with Tunisian Standard NT 47.01produced by the Cement Company of GABES. It has an absolute density of 3.10 g/cm^3 and a Blaine specific surface of 380 m²/kg.

Sand

The sand used is a natural sand 0/5 with a fineness modulus of 2.51 and bulk density of about 1.42 g/cm^3. The fineness modulus of the natural sand was performed in accordance with the requirements of NF EN 12620 (NF EN 12620, 2004).

Admixture

The employed admixture was an SP used to increase markedly the workability of concrete according to the requirements of NF EN 934-2. The dosage was 1% by weight of cement. Its physicochemical characteristics are given in Table 4.

Table 4. Physicochemical characteristics of the SP

Density	pH	Na_2OEq (%)	Dry extract (%)	Cl^-
1.06 ±0.01	4.5 à 6.5	≤ 1%	28.0 à 31.0	≤ 0.1%

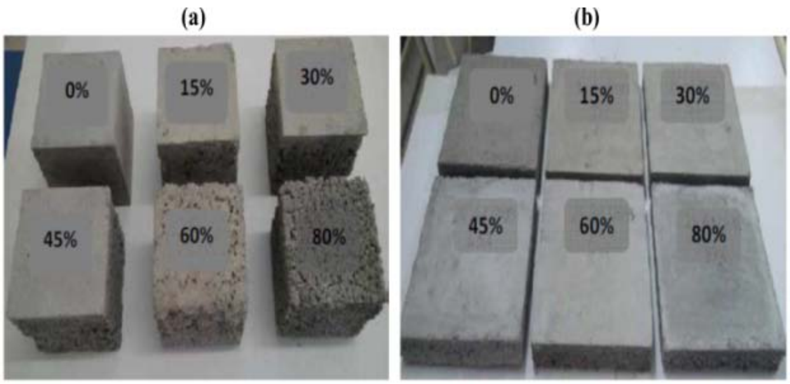


Figure (1): Cubic specimens (a), parallelepiped specimens (b)

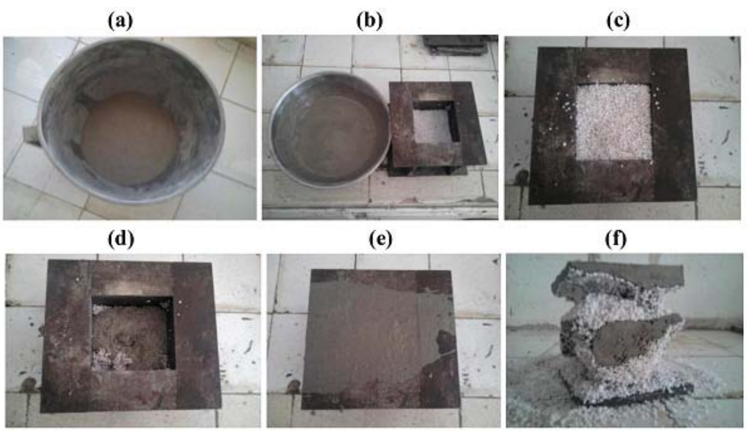


Figure (2): Steps of the second procedure of mixing

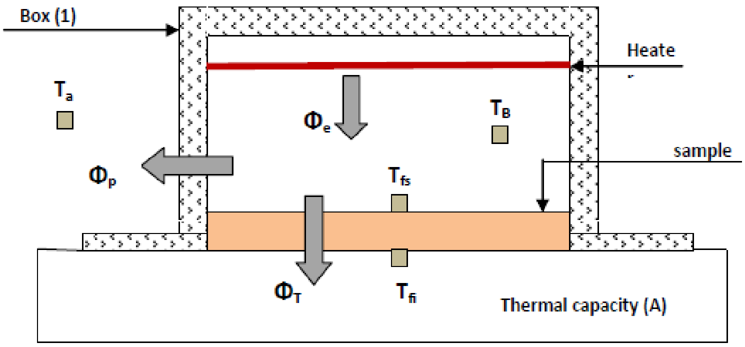


Figure (3): Thermal conductivity testing apparatus

Table 5. Comparison of the three mixing procedures

Photos of EPC80 specimens		
Procedure n°1	**Procedure n°2**	**Procedure n°3**
		
Mixing procedures' results		
- Crushing of the majority of perlite particles due to mixing. - Change in grain size of EPA due to friability. - Stiffness of the mixture. - Very high density.	- Heterogeneity of the specimen.	- Homogenization of the specimen. - Presence of EPA in the mixture without changing dimensions. - Very low density.

Mixtures

EPA is very brittle; consequently, mixing lightweight concrete that is based on these aggregates must be carried out carefully to avoid crushing and therefore changing their size. We tried three different procedures in order to prevent the aforementioned phenomenon.

Procedure n°1:

The first procedure consisted of mixing lightweight concrete in a mixer with a vertical rotation axis. The steps of this procedure were:

1- Sand, cement and EPA were mixed until homogenization.
2- Water mixed with SP was added and the mixture

was mixed until complete homogenization.

3- The mold was filled by the mixture.
4- The specimen was removed from the mold after 24h.

Procedure n°2

To avoid the problem of changing the size of grains of expanded perlite particles, a second procedure was tested. The steps of this procedure were:

1- Sand and cement were mixed until homogenization (Figure 2 (a)).
2- Water mixed with SP was added and the mixture was mixed until complete homogenization (Figure 2 (b)).
3- The mold was filled by EPA (Figure 2 (c)).
4- The mortar (very fluid) was poured into the mold (Figure 2 (d,e)).
5- The specimen was removed from the mold after 24h (Figure 2 (f)).

Procedure n°3

The steps of this procedure were:

1- Sand and cement were mixed until homogenization.
2- Water mixed with SP was added and the mixture was mixed until complete homogenization.
3- EPA was added at once and mixed in a minimum of time until complete homogenization of the mixture.
4- The mixture was poured into the mold.
5- The specimen was removed from the mold after 24h.

Choice of Mixing Procedure

The results of comparison of the three mixing procedures are shown in Table 5. According to the results, only procedure n°3 led to a homogenous mixture. The hardened mixture has a very low density. Finally, procedure n°3 was approved and the mixtures obtained were suitable and satisfactory.

TEST PROCEDURES

Cube Compressive Strength

The test of compressive strength was carried out on specimens of cubic shape of 100 mm side in accordance with the requirements of EN 12390-3 (NF EN 12390-3, 2009). The specimens were placed between two plates of a hydraulic press equipped with a ball. The specimens were subjected to compression without increasing impact, speed of constant stress, up to rupture. The compressive strength was calculated from the maximum force and the surface of the specimen.

Thermophysical Properties Measurement

Thermal Conductivity Measurement

The thermal conductivity of the mixtures was determined using parallelepiped specimens in accordance with the requirements of NF EN ISO 8990 (NF EN ISO 8990, 1996).

For measuring the thermal conductivity, the “boxes method” has been used (El-Bakkouri, 2004; Cerezo, 2005).

The measurement principle of the thermal conductivity using box 1 is presented in Figure 3.

According to Eq. (1), we can deduce the expression of the thermal conductivity:

$$\lambda_{\exp} = \frac{e}{S.\left(T_1 - T_2\right)}\left[\frac{U^2}{R} - C.\left(T_B - T_a\right)\right] \quad (1)$$

Thermal resistance R_{th} is deduced from the measurement of thermal conductivity by the following expression:

$$R_{th} = \frac{e}{\lambda_{\exp}} \quad (2)$$

Thermal Diffusivity Measurement

The principle of the experimental measurement method is to emit a heat flux, for a few seconds, by means of the lamp, on one face of the sample, and then the thermal diffusivity is evaluated from the temperature variation of the non-irradiated face of the sample (Figure 4). Using Degiovanni model based on the method of part-time (Taoukil et al., 2012), the thermal diffusivity is given as follows:

$$\alpha = \frac{\alpha_{1/2} + \alpha_{2/3} + \alpha_{1/3}}{3} \quad (3)$$

where:

$$\alpha_{1/2} = e^2 \left[\frac{0.761 t_{5/6} - 0.926 t_{1/2}}{(t_{5/6})^2} \right] \quad (4)$$

$$\alpha_{2/3} = e^2 \left[\frac{1.150 t_{5/6} - 1.250 t_{2/3}}{(t_{5/6})^2} \right] \quad (5)$$

$$\alpha_{1/3} = e^2 \left[\frac{0.617 t_{5/6} - 0.862 t_{1/3}}{(t_{5/6})^2} \right] \quad (6)$$

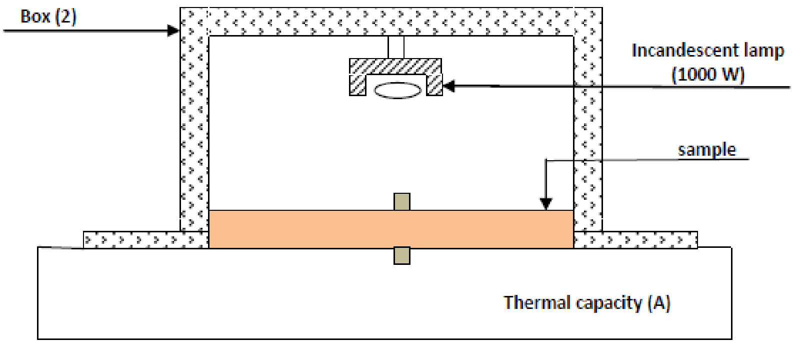


Figure (4): Thermal diffusivity testing apparatus

Table 6. Thermal conductivities of different types of lightweight concrete (W/m.K)

Lightweight concrete	Cellular concrete	Expanded clay concrete	Expanded perlite concrete
$500 \leq \rho$ [kg/m^3] ≤ 1100			
0.17- 0.32	0.23 - 0.32	0.21 - 0.43	0.13 - 0.35

Note: Comparison between thermal conductivity of the tested EPC with that of other types of lightweight concrete (Jiri et al., 2009; Xiang et al., 2011).

Specific Heat

The specific heat (C_p) represents the heat amount required to raise the temperature by one degree of a mass unity of a material. More heat energy is required to increase the temperature of a substance with high specific heat capacity than when using a low specific heat capacity material. Dividing heat capacity by the body's mass yields a specific heat capacity, which is no longer dependent on the amount of material but on the type of material and on the temperature.

The specific heat is determined from measurements of the thermal conductivity and diffusivity by using the following relation (NF EN ISO 7345, 1996):

$$C_P = \frac{\lambda_{\exp}}{\rho . \alpha_{\exp}} \quad (7)$$

Thermal Effusivity

The thermal effusivity is the property that fixes the interfacial temperature when a contact is formed between two material objects initially at different temperatures. This parameter is a measure of the material's thermal impedance or its ability to exchange heat with the environment. In conclusion, thermal effusivity characterizes the transient thermal behavior that occurs when two materials are brought into contact with each other.

The thermal effusivity is defined by using the following expression (NF EN ISO 7345, 1996):

$$b = \left(\rho.C_P.\lambda_{\exp}\right)^{\frac{1}{2}} \qquad (8)$$

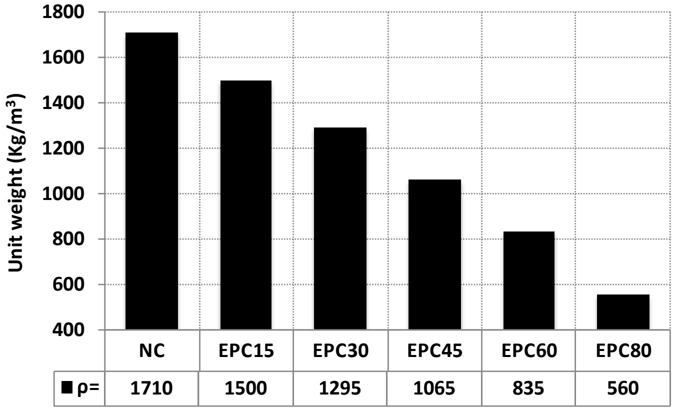


Figure (5): Effect of EPA dosage on the unit weight of the EPC

EXPERIMENTAL RESULTS AND DISCUSSION

Effect of EPA Dosage on the Unit Weight of EPC

The unit weights of samples were measured at right after 28 days of curing. It can be seen from Figure 5 that the unit weight of concrete was decreased with an increase in the EPA proportion. While the unit weight of control samples that contain 0% EPA was 1710 kg/m^3, the unit weights of those made up of 15, 30, 45% 60 and 80% of EPA replacement were respectively 1500, 1295, 1065, 835 and 560 kg/m^3. This decrease in unit weight is due to the low bulk density of EPA (0.07 g/cm^3), which is lower than that of river sand (1.42 g/cm^3).

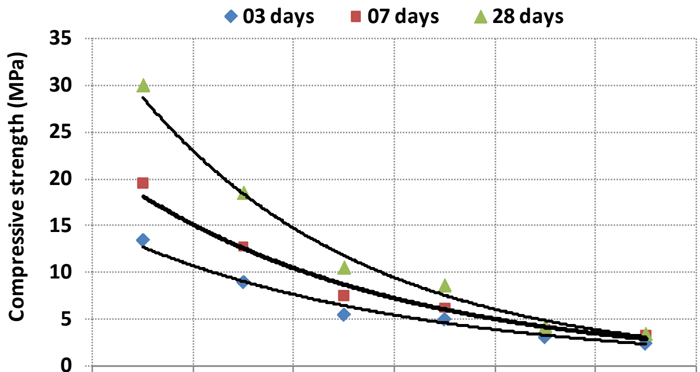
Finally, because of the unit weights of all tested EPC mixtures varied between 560 and 1500 kg/m^3, the EPC has its place in the category of insulation lightweight concrete (ASTM C 332, 1999).

Effect of EPA Dosage on the Compressive Strength of the EPC

The results of Figure 6 show the compressive strength values for concrete mixtures at all levels of EPA replacement at the ages of 3, 7 and 28 days. It can be observed that the compressive strength values decrease with an increase in EPA content from 0% to 80%. This decrease in compression strength is due to the lower strength and porosity of perlite (Torres and Garcia-Ruiz, 2009; Lo et al., 2007). It is also due to the highly crushable behavior of EPA on loading (Jamei et al., 2011).

The results also reveal that the compressive strength values increased as the curing period increased from 3 to 28 days. The compressive strength reached 70% of its final value at the age of three days, and then it grew slowly until the age of 28 days.

Lightweight concretes can be classified into different groups based on their unit weights and compressive strengths. The mixture produced using 15% EPA has a compressive strength of 18.5 MPa and can be classified as a structural lightweight concrete (ASTM C 330, 2005). However, due to the lower compressive strengths, mixtures containing more than 15% EPA can be classified as insulation lightweight concretes (ASTM C 332, 1999).

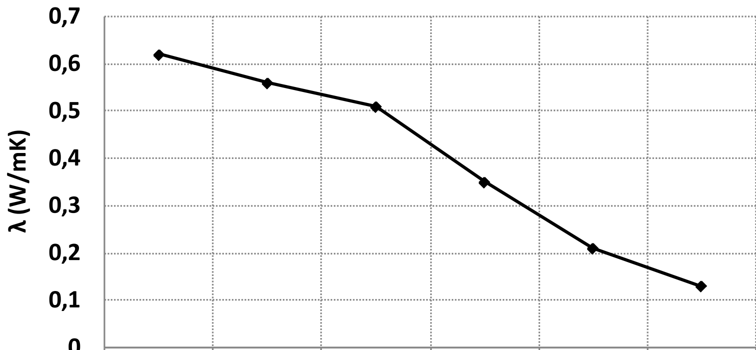


	NC	EPC15	EPC30	EPC45	EPC60	EPC80
03 days	13,5	9	5,5	5	3,1	2,4
07 days	19,5	12,7	7,5	6,2	3,8	3,2
28 days	30	18,5	10,5	8,6	4,2	3,4

Figure (6): Effect of EPA dosage on compressive strength of the EPC at ages of 3, 7 and 28 days

Effect of EPA Dosage on the Thermal Conductivity of the EPC

Thermal conductivity was determined experimentally on specimens having a parallelepiped shape with dimensions 270 mm x 270 mm x 40 mm. All the specimens were tested in oven-dry condition (Khan, 2003). The values of thermal conductivity of different specimens obtained experimentally by the box method are shown in Figure 7.



	NC	EPC15	EPC30	EPC45	EPC60	EPC80
λ =	0,62	0,56	0,51	0,35	0,21	0,13

Figure (7): Effect of EPA dosage on thermal conductivity of the EPC at the age of 28 days

According to the results presented in Figure 7, the percentage of EPA replacement has a considerable influence on the thermal conductivity of EPC. For the replacement percentages of 15%, 30%, 45%, 60% and 80%, the reductions of the thermal conductivity were 9.6%, 17.7%, 43.5%, 67.7% and 79% compared to the control specimens.

These thermal conductivity values of all tested mixtures were used for calculating thermal resistance of specimens using Eq. (1). The thermal resistance values of all specimens are presented in Figure 8. The results show that the increases in the thermal resistance were 10.8%, 21.76%, 77.2%, 195.8% and 378% compared to the control specimens. This increase in thermal resistance is due to the porosity of the material which decreases gradually when the concrete is heavy (Demirbog and Gul, 2003). The improvement in thermal resistance allows for energy efficient buildings able to keep actual energy consumption low whilst decreasing the loss of heat from a building during winter and minimizing the entry of heat during the summer months. In fact, the incorporation of EPA in lightweight concrete provides a continuous, unbroken layer around the building envelope and ensures airtight walls with the highest energy rating performance.

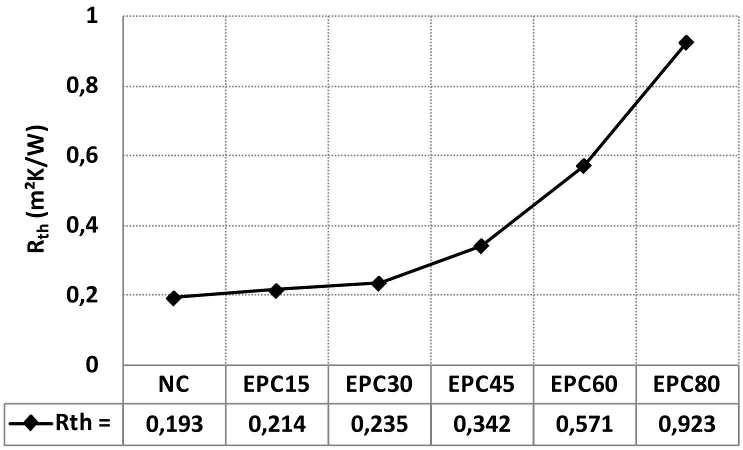


Figure (8): Effect of EPA dosage on thermal resistance of EPC at the age of 28 days (e =12cm)

Replacing normal aggregate by EPA reduced the thermal conductivity of the mixtures and improved the thermal resistance. This improvement was relatively low for the replacement ratios of 15% and 30%, but it was remarkable for the other ratios. This can be explained by the thermal conductivity of EPA (0.040 W/m.K) which is less than that of the natural sand (1.50 W/m.K). In fact, thermal conductivity of concrete was decreased with decreasing the thermal conductivity of aggregate (Bastianl, 1982).

By comparing the thermal conductivity of the EPC with that of other types of lightweight concrete having the same unit weight (Table 6), EPC finds its place in the category of insulation lightweight concrete (ASTM C332, 1999).

Effect of EPA Dosage on the Thermal Diffusivity of the EPC

Thermal diffusivity was determined experimentally on specimens having a parallelepiped shape with the box method. Figure 9 presents the results of the thermal diffusivity measurements. According to the results presented in Fig. 9, replacing normal aggregate by EPA reduced the thermal diffusivity and hence improved the thermal insulation of the concrete. For example, the lightweight concrete with 45% and 60% EPA replacement produced respectively a 17.23% and 27.15% reduction in thermal diffusivity compared to the control specimens.

According to Figure 7 and Figure 9, the reduction of thermal conductivity reduced thermal diffusivity; this may be offset by the reduction in density necessary to achieve lower thermal conductivity. The thermal diffusivity of specimens decreased with decreasing density. Hence, the incorporation of EPA into the lightweight concrete, via its reduction in density, decreased its thermal diffusivity. Air entrainment might have also contributed to reduce the thermal diffusivity of all the mixtures. For example, the lightweight concrete with 30% EPA produced 18% reduction in thermal conductivity and also produced 12% reduction in thermal diffusivity compared to the control specimens.

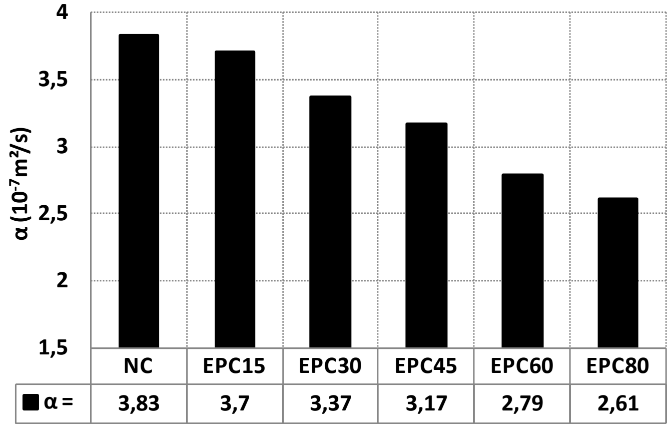


Figure (9): Effect of EPA dosage on thermal diffusivity of the EPC at the age of 28 days

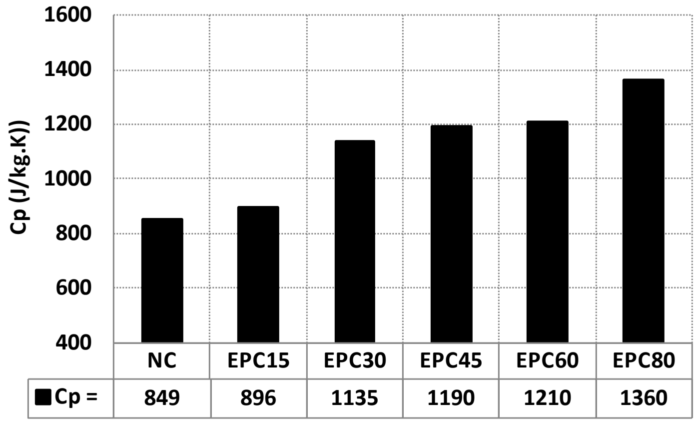


Figure (10): Effect of EPA dosage on specific heat of the EPC at the age of 28 days

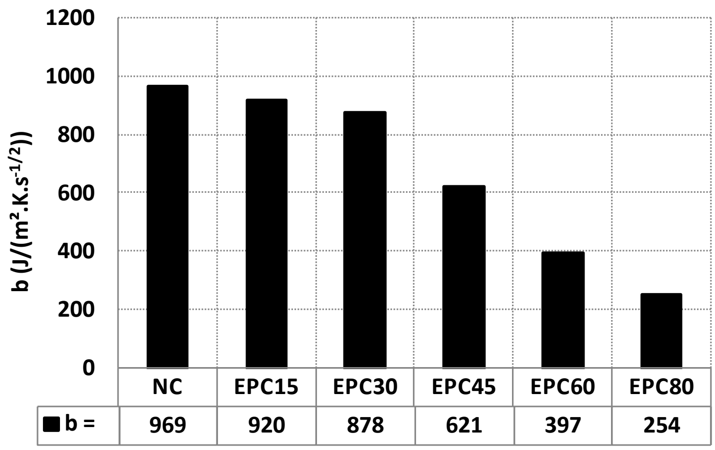


Figure (11): Effect of EPA dosage on thermal effusivity of the EPC at the age of 28 days

Finally, the decrease of thermal diffusivity improves the thermal insulation of lightweight concrete. This improvement can be explained by the rate at which heat travels by conduction through a body: more the value of thermal diffusivity is low, more the time is important for the heat front to cross the thickness of the wall.

Effect of EPA Dosage on the Specific Heat of the EPC

The specific heat of the specimens was determined by calculation using Eq. (7) that combines thermal conductivity, density and thermal diffusivity into one value conforming to the requirements of NF EN ISO 7345, 1996. According to the results shown in Figure 10, the specific heat of specimens was increased with decreasing density and can reach a value of 1360 J/Kg.K for a percentage of 80% EPA. The thermal conductivity and specific heat varied in the opposite directions. For example, lightweight concrete with 80% EPA produced 79% reduction in thermal conductivity and also produced 60% increase in specific heat compared to the control specimens.

Effect of EPA Dosage on the Thermal Effusivity of the EPC

The thermal effusivity of the specimens was determined by calculation using Eq. (8) that combines thermal conductivity, density and heat capacity into one value. It is a relevant thermophysical parameter for modeling heat exchanges in thermal treatment process. The results of Figure 11 show the effect of the percentage of EPA replacement on the thermal effusivity of concrete. The values of thermal effusivity of concrete specimens are limited between 254 and 969 ($J/m^2.Ks^{-1/2}$) according to the percentage of EPA. More the material is dense, its thermal effusivity increases and the speed with which the surface temperature warms decreases.

It is clear that the values of the thermal effusivity were significantly decreased with increasing percentage of EPA. In fact, thermal effusivity of materials remains a thermal characteristic that cannot, under any circumstances, replace the insulation quality. It cannot improve the comfort of winter, but can reduce indoor summer temperatures, during the day, absorbing the influx of unwanted heat. Conversely, thermal effusivity can reduce the temperature drops at night by releasing the stored heat in the day.

CONCLUSIONS

The present paper has presented results of the experimental investigation of the effect of EPA dosage on the compressive strength and thermophysical properties of EPC. Thermal conductivity of the specimens was determined by the boxes method. Thereafter, the same device was used for measuring thermal diffusivity. Thermal resistance, specific heat and thermal effusivity were also deducted.

According to the experimental results, the following conclusions have been drawn:

1- A mixing procedure was performed without crushing of the majority of EPA due to mixing, keeping their size.

2- The unit weight of concrete can be significantly reduced by replacing natural aggregate by EPA to as low as 560 kg/m^3. Consequently, the compressive strength was considerably decreased especially for mixtures containing 45% or more.

3- Thermal conductivity of the mixture is substantially reduced by replacing normal aggregate by EPA. The results also reveal that thermal conductivity of EPC is lower than the one of the other types of lightweight concrete having the same unit weight.

4- The contribution of EPA to reducing thermal conductivity of semi-lightweight concrete was superior to that of other LWA of similar density.

5- The incorporation of EPA into lightweight concrete decreased its thermal diffusivity and hence improved its thermal insulation.

6- The specific heat of specimens increased with increasing the percentage of EPA.

7- The values of thermal effusivity were significantly decreased by increasing the percentage of EPA.
8- The findings of the present work indicated significant positive contribution of EPC to thermal properties of semi-lightweight concrete.

Nomenclature

T_1	Temperature of upper face	°C
T_2	Temperature of lower face	°C
T_a	Ambient temperature	°C
T_B	Temperature of the box	°C
R_{th}	Thermal resistance	m²K/W
S	Surface of the sample	m²
e	Thickness of the sample	m
R	Resistance	Ω
C	Overall heat transfer coefficient	W/m²K
U	Potential difference	V
C_p	Specific heat	J/kg.K
b	Thermal effusivity	$J/m^2.K.s^{-1/2}$
R_C	Compressive strength	MPa
α	Thermal diffusivity	m²/s
λ	Thermal conductivity	W/mK
ρ	Unit weight	kg/m^3
Φ	Heat flux	W

Acknowledgments

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