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Employment of Brick Residue in the Production of a Lightweight Concrete

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ABSTRACT

The important way to obtain lightweight concrete with compressive strength, density, and thermal insulation properties that differ from normal concrete was by adding materials with cementitious properties to the concrete mix instead of cement or using lightweight aggregate. In most cases, the compressive strength of the lightweight concrete produced was less than that of normal concrete. The aim of this research was to conduct three main objectives. The first objective is to produce lightweight concrete with good compressive strength compared to the same type of concrete by adding chemical additives (Super-Plasticizer S.P and Carbon Powder C.P) to the lightweight concrete mix. The second objective is to recycle the residues of the local brick and use them as coarse aggregates in the production of lightweight concrete. The third objective is to increase the thermal insulation rate of concrete by adding the same r additive. The results were good, concrete was produced from this work with the lowest density (ρ) of up to (1810 kg/m^3) and the highest compressive strength of up to (31.240 MPa) when only carbon powder was added in certain proportions and the density of up to (1944 kg/m^3) and compressive strength of up to (31.946 MPa) when adding (Super-Plasticizer) to the same percentages of carbon powder. Compared to ordinary lightweight concrete without chemical additives, its density reaches (1894 kg/m^3) and compressive strength (24.848 MPa) at the age of 28 days. In addition, the thermal conductivity values reached about (0.507 W/m.^{o}C), compared to ordinary lightweight concrete (2.242 W/m.^{o}C).

Keywords: Lightweight aggregate, Lightweight concrete, Carbon powder, Super-plasticizer.

1- INTRODUCTION

Concrete is one of the important materials commonly used in the construction sector **(Habert et al., 2020; Naik, 2020).** Many new technologies and additives have been used to modify and improve concrete properties **(Nagrockiene et al., 2017; Han et al., 2017; Li et**

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al., 2022). It has been mentioned in the US concrete production roadmap 2030 **(Birgisson et al., 2010),** that aimed to improve the concrete performance until 2030 by using recycled and other additives materials. It has been added many of materials to concrete to modify its properties. These materials include silica fume, furnace slag **(Ozturk et al., 2020; Gupta, 2021),** and recycled rubber **(Li et al., 2019; He et al., 2021).** The lower density of lightweight concrete is considered an important engineering property that makes it a good alternative to normal concrete. The lightweight concrete had a density of approximately 80% of normal concrete **(Wu et al., 2017; Del Rey Castillo et al., 2020; Lee et al., 2021).** This lower percentage of density achieves an opportunity for cost savings in construction phases and design. The lower density leads to reduce from a dead load which may allow more beam spacing and fewer loads transmitted to the foundations and substructures with savings in support costs. Also, the lower density of lightweight concrete leads to cost savings due to easier handling and the potential to reduce shipping costs **(Elshahawi et al., 2021).** Another advantage during construction phases is that the lightweight concrete may allow the transfer of members that are too heavy for the crane capacity **(Liew et al., 2019, Lu et al., 2022)**. Therefore, lightweight concrete contributes to overcoming constructability issues as well as add to cost savings **(Sylva, 2002; Mohammed et al., 2021).** For many years, the lightweight aggregate has been used in structural concrete that was in North America where is used in the construction of concrete ships during World War I **(Rowland, 2018).** The lightweight concrete had a density of 1905 kg/m3 and compressive strength in a 28-day was 38.5 MPa **(Bader, 2015).** After several years, the lightweight concrete industry developed through the judicious selection of aggregates and precise proportions. This development led to the manufacture of semi-lightweight concrete with compressive strength ranging from 60-55 MPa **(Meir et al., 1995, Min, 2012; Hamada et al., 2021).**
The aggregate constitutes about 75% of the concrete volume. Using lightweight aggregate (LWA) in concrete production will contribute to producing lightweight concrete (LWC). Generally, the LWA are classified into two types; natural (diatomite, pumice, cinders, volcanic, etc.) and artificial (clay, expanded shale, perlite, sintered PFA, slate, etc.). LWC can easily be produced by using lightweight aggregates such as pumice or perlite aggregate **(Top et al., 2020; Hasan et al., 2021).** Recycling Normal brick as a coarse aggregate makes provision for sustainable concrete that uses the brick residue of construction and demolitions or from the remnants of the brick production industry **(Abbas, 2022).** The bricks, ceramics, and concrete become LWA, and any suspended metals can be removed and recycled as well. In addition, the recycled aggregate will contribute to reducing the economic impact of the concrete industry and reduce the need for normal aggregates. This, in turn, will reduce the negative impact on the environment from the aggregate extraction process. Also, the transportation process for the concrete aggregate will be reduced the project significantly **(Yazdanbakhsh et al., 2018; Wang et al., 2018).**
This work aims to produce lightweight concrete with good compressive strength compared to the same types of concrete. In addition to increasing the thermal insulation rate of this concrete produced by adding carbon powder to the lightweight concrete mix.

2- MATERIALS AND EXPERIMENTAL WORK

This section includes the details of the materials and additives used in this work and the types of concrete mixtures, then the experimental tests of specimens. The laboratory work consisted of 54 (100 mm) cubes to measure the absorption, density, compressive strength and thermal conductivity at 7 and 28 days. The brick residue used as a lightweight aggregate

(LWA) instead of normal coarse aggregate to produce a lightweight concrete. All mixtures used the Ordinary Portland cement and normal fine aggregate. All the concrete mixtures are produced by mixing rate (1:2:3). The cube samples have been poured in 54 which include six specimens for every type of concrete mixes. These types were included normal concrete, lightweight concrete, lightweight concrete with super-plasticizer (S.P), lightweight concrete with different ratios of C.P, and lightweight concrete with (C.P and S.P). **Table 1** shows the types of concrete mixture with its code.

Table 1. The types of concrete mixture with its code.

Mixture details	Code	Mixture details	Code
Normal concrete	CN	Lightweight concrete with C.P 12%	C_{cL3}
Lightweight concrete	CL	Lightweight concrete with S.P and C.P 4%	C_{ScL1}
Lightweight concrete with C.P 4%	CcL1	Lightweight concrete with S.P and C.P 8%	C_{ScL2}
Lightweight concrete with C.P 8%	CcL2	Lightweight concrete with S.P and C.P 12%	C_{ScL3}

2.1 Materials

2.1.1 Cement

Ordinary Portland cement was used with all concrete mixtures. The cement has properties of a cohesive, adhesive, and is considered a binding material when it interacts with water, where it works to bind granular with each other. Cement tests, in this research, were conducted in the laboratories of the College of Engineering - University of Diyala, according to the Iraqi standard specifications for cement use **(Mohammed et al., 2018).**

2.1.2 Coarse Aggregate

Residue clay brick is used as a lightweight coarse aggregate in all mixtures to obtain lightweight concrete. The residue of the clay brick break is the remains of the brick factories and construction and demolition process or resulting from the demolitions that hit large areas of Iraq due to terrorist acts.
The following works were carried out before using it as a lightweight aggregate: -

1. Crush the brick pieces into small sizes manually by using a hammer to get the required sizes (9.5 mm maximum size).
2. The crashed brick was passed through the standard sieves according to **(ASTM C33, 2003; Concreate, 2017) Table 2**. The resulting absorption and specific gravity of the lightweight aggregate were (25%, 2.13 Kg/ m^3) respectively.

Table 2. The grading of crushed clay brick aggregate

Sieve size (mm)	% Passing	Limit of (ASTM C33, 2003)
25.0 - 4.75	100	95-100
19.0 – 4.75	94	90-100
12.5 - 4.75	52	40 - 80
9.5 - 2.36	16.5	5 - 40

3. The samples of crushed brick were washed to remove dust from its surface then immersed in water for 24 hours.
4. Finally, the surface of the crushed brick is wiped by a cloth in the laboratory and spread inside the lab to expose to air for a convenient time to be a saturated surface dry (SSD).

2.1.3 Fine Aggregate (Sand)

The natural source of fine aggregate is used from Al-Soddor quarries. The natural fine aggregate is used for all concrete mixtures in this work. The sieve analysis of fine aggregates is given in **Table 3**. This analysis according to **(ASTM C 33, 2003; Commitee, 2003; Tayeh et al., 2017; Ajagbe et al., 2018).** The resulting absorption and specific gravity of the lightweight aggregate were (2.63 kg/ m^3, 2.4%) respectively. The aggregates were washed and brushed in the laboratory for an appropriate period to be saturated surface and dry.

Table 3. The sieve analysis of fine aggregates

Sieve size (mm)	% Passing	Limit of ASTM (ASTM C33, 2003)
9.5	100	100
4.75	97	95-100
2.36	90	80-100
1.18	78.2	50-85
0.6	30	25-60
0.3	12	5-30
0.15	8.7	2-10

2.1.4 Chemical Additives

In this work, two types of chemical additives were used (Super-Plasticizer S.P and Carbon Powder C.P). High-performance super plasticizing admixture Conplast SP 430 which is sulphonate naphthalene polymers from Fosroc, Fars Iran Limited which conforms with BS EN 934 **(EN 934-2, 2009)** and with ASTM C494 **(ASTM C494, 2005)** was used for this investigation.
There is a various weight ratio of these additives were used with the lightweight concrete mixtures. To obtain the best ratio of S.P, experimental mixtures carried out on three weight ratios of S.P (5, 10, and 15 %). The ratio (15%) of cement weight was chosen which gave a good result in terms of compressive strength. This ratio of S.P was used as a fixed ratio with all the mixtures that contained the S.P. For C.P, three fixed ratios were used (4, 8, and 12%). These ratios were once used with LWC only, and the second time used with LWC and S.P as given in **Table 1**.

2.2 Mix Details

There are eight concrete mixtures in this work. The purpose of designing these mixtures is to obtain a suitable mix of concrete **(Ali, 2018),** which is lightweight, has good compressive strength, and has good thermal insulation. The reference mixture used normal fine and coarse aggregate with an expected density of about 2300 kg/ m^3. The other mixtures were designed to have different results in density and compressive strength.

The mixing ratios were (1:2:3) while maintaining the proportion of cement (1), and fine aggregate (2) for all concrete mixtures, and using natural coarse aggregate for the reference mix only. As for the rest of the mixtures, the lightweight coarse aggregate was used, with different percentages of (carbon powder) and (Super-plasticizer). The amount of (w/c) ratio equal (0.55) was used with many experimental mixtures to get the ideal ratio for every mix, as given in **Table 4**.

Table 4. Properties of the prepared mixtures are cement (1), fine aggregate (2), and W/C (0.55%).

Mix. Code	Coarse aggregate	Lightweight aggregate	Carbon powder	Super-plasticizer
C_N	3	___	___	___
C_L	___	3	___	___
C_{cL1}	___	3	0.04	___
C_{cL2}	___	3	0.08	___
C_{cL3}	___	3	0.12	___
C_{ScL1}	___	3	0.04	0.015
C_{ScL2}	___	3	0.08	0.015
C_{ScL3}	___	3	0.12	0.015

2.3 Laboratory Tests

All the laboratory tests were carried out for the concrete produced by the normal aggregates and the lightweight aggregate (break clay brick) with the ratios of chemical additives (S.P and C.P).

2.3.1 Compressive Strength

The compressive strength test was performed on all the concrete mixtures normal, lightweight concrete, and lightweight concrete with chemical additives. Six concrete samples were cast for each type of concrete mix with a dimension of (100 * 100 * 100 mm) by three cubes per age of (7, 28) day test. The results of the test are given in **Table 5.** The test method was according to the British Standard **(Herki, 2020)**

Table 5. Results of compressive strength and dry density for concrete mixes

Mix. Code	Compressive Strength MPa.		Dry Density (γd) Kg/m³
	7 days	28 days	
C_N	37.581	41.363	2330
C_L	28.688	24.848	1894
C_{cL1}	22.499	31.240	1908
C_{cL2}	15.941	26.068	1860
C_{cL3}	12.125	20.033	1810
C_{ScL1}	30.123	31.946	2000
C_{ScL2}	26.950	30.450	1976
C_{ScL3}	26.627	26.143	1944

2.3.2 Dry Density

The weight unit (dry density, γd) of all the concrete samples was calculated by weighing the dry models inside the dry oven using a sensitive weight scale and determining their size, as given in **Table 5.**

2.3.3 Absorption

The absorption test was carried out according to the British standard **(Fabbri et al., 2019; Dawood et al., 2021; Abid et al., 2022)** for 7 age**.** The specimens were weighed after immersing in water at 24 hours and weighed after drying by an electric oven at a temperature of more than 100 ° C until their weight was stable. As given in **Table 6.**

Table 6. Results of absorption test for concrete mixes.

Mix. Code	**Dry Density (γd) kg/m³**	**Absorption %**
C_N	2330	3.9
C_L	1894	10.5
C_{cL1}	1908	11.0
C_{cL2}	1860	11.4
C_{cL3}	1810	11.8
C_{ScL1}	2000	7.9
C_{ScL2}	1976	7.8
C_{ScL3}	1944	7.6

2.3.4 Thermal Conductivity

A thermal Conductivity test was carried out for all concrete mixtures to compare the thermal conductivity of lightweight concrete specimens with the reference mix **(Aljubori et al., 2018**). The thermal conductivity is measured by Hot Disk Thermal Constants analyzer 6.1 Beta 37. Two circular pieces with a thickness of 10 mm and a diameter of 50 mm were used to test the thermal conductivity for each type of concrete mix. The thermal conductivity for all mixes is given in **Table 7**.

Table 7. Results of thermal conductivity test for concrete mixes.

No.	**Mix. Code**	**Dry Density (γd) kg/m³**	**Thermal conductivity W/m.°C**
1	C_N	2330	3.958
2	C_L	1894	2.242
3	C_{cL1}	1908	2.33
4	C_{cL2}	1860	2.239
5	C_{cL3}	1810	0.507
6	C_{ScL1}	2000	3.371
7	C_{ScL2}	1976	3.265
8	C_{ScL3}	1944	3.146

3. RESULTS AND DISCUSSION.

The ratios of carbon powder added to lightweight concrete mixtures made from brick residue have an effect on the specific weight of concrete as given in **Table 5**. It is clear, the specific weight (SW) decreases by (4.5%) with (12%) from carbon powder. Also, the SW increase (2.5%) when using S.P. This is expected because the specific weight of carbon powder is less than the specific weight of aggregates and cement. The increase (2.5%) when using S.P. because the S.P. acts as an auxiliary to increase the strength of the stacking between the concrete particles. The compressive strength of all concrete mixtures given in **Table 5**, shows that the Compression strength increases by (20%) when carbon powder is used by (4%), and (22%) when using the same ratio with S.P. at age 28. This shows that when using the lowest ratios of carbon powder leads to more homogeneity of the concrete material which gives greater strength. The thermal conductivity of different concrete mixtures is given in **Table 7**. The conductivity was reduced by (22%) when using carbon powder by (12%). This result is logical because the conductivity is directly proportional to the density, where the density decreases with an increase of carbon powder. In the same case, when using S.P. with Carbon Powder. The thermal conductivity was obtained for all the concrete mixers as shown in **Figs. 1 to 8**. In the end, lightweight concrete produced from the brick residue of construction demolition then improves the properties of this concrete in terms of compressive strength, density, and thermal conductivity. The best result was when the carbon powder was added by 12% for the density and thermal conductivity, while the best result of compressive strength was when the carbon powder was by 4%.

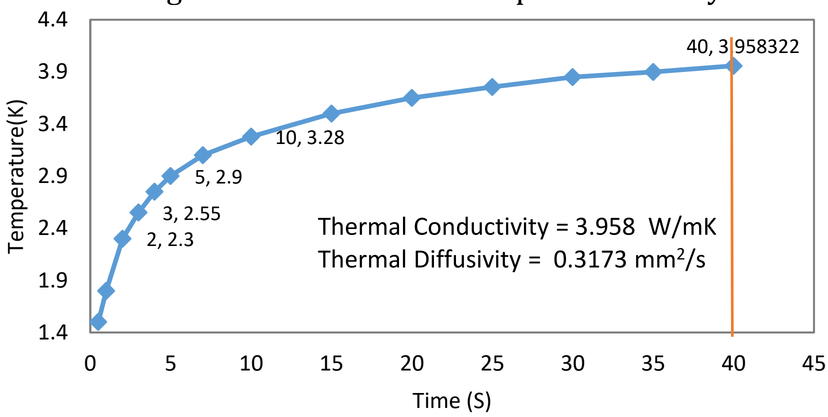

Figure 1. Thermal conductivity test for sample (C_N)

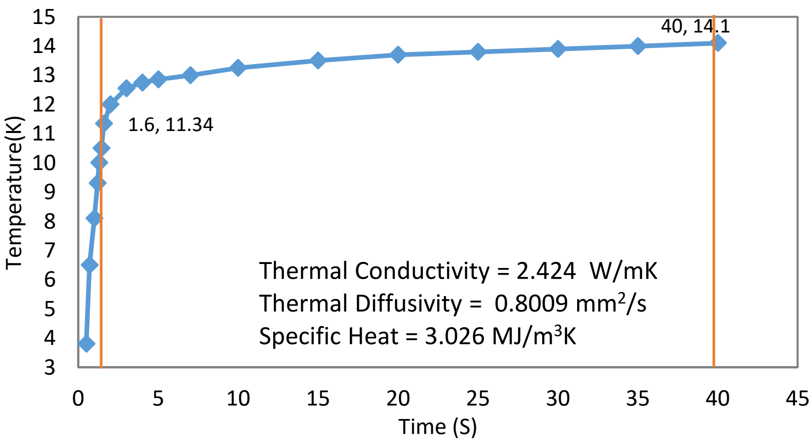

Figure 2. Thermal conductivity test for sample (C_L).

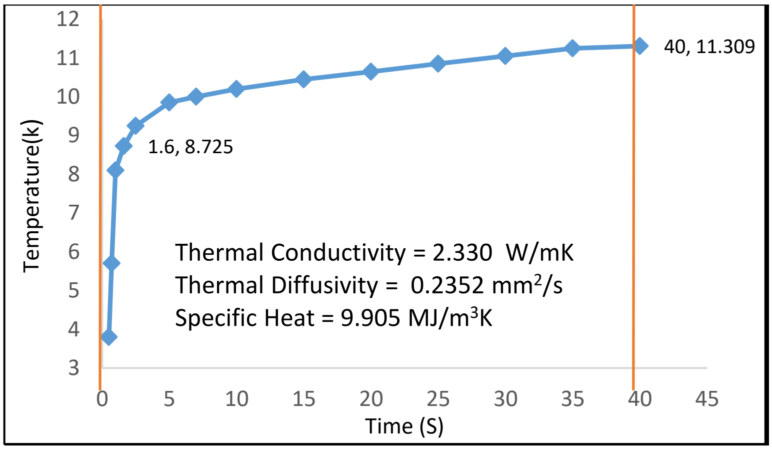

Figure 3. Thermal conductivity test for sample (C_{cL1})

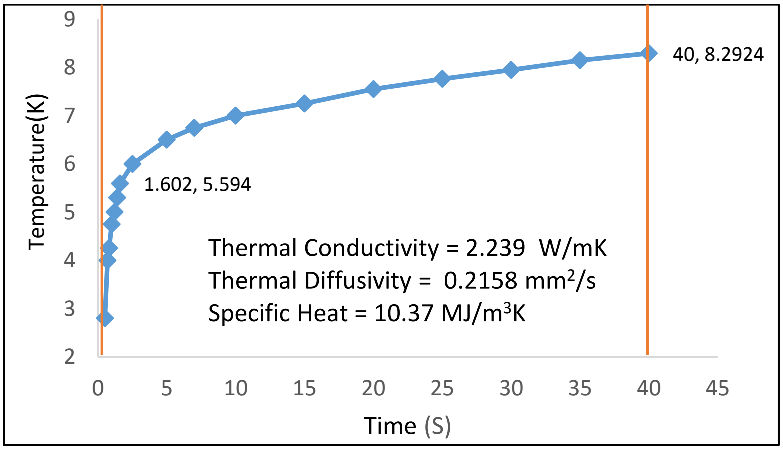

Figure 4. Thermal conductivity test for sample (C_{cL2})

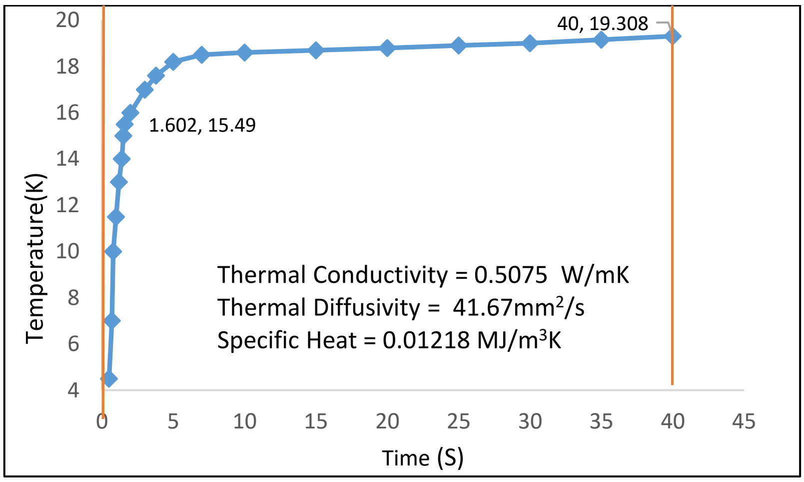

Figure 5. Thermal conductivity test for sample (C_{cL3}).

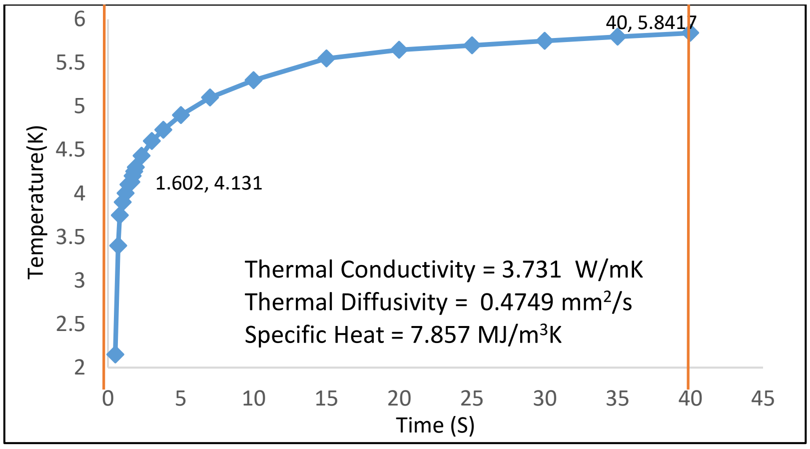

Figure 6. Thermal conductivity test for sample (C_{ScL1}).

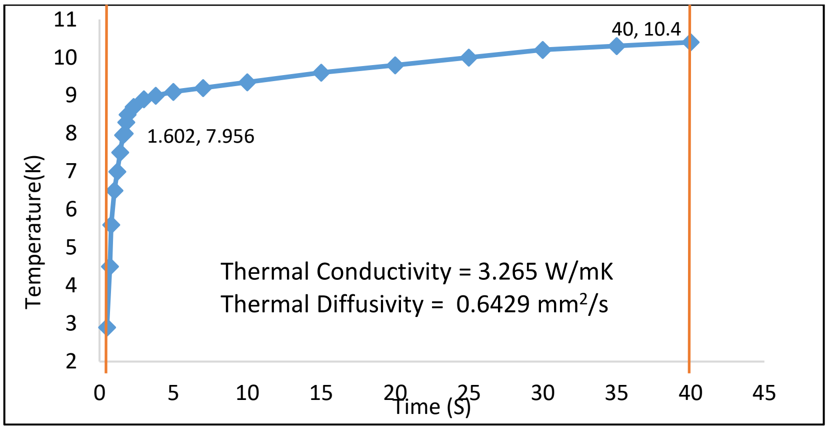

Figure 7. Thermal conductivity test for sample (C_{ScL2}).

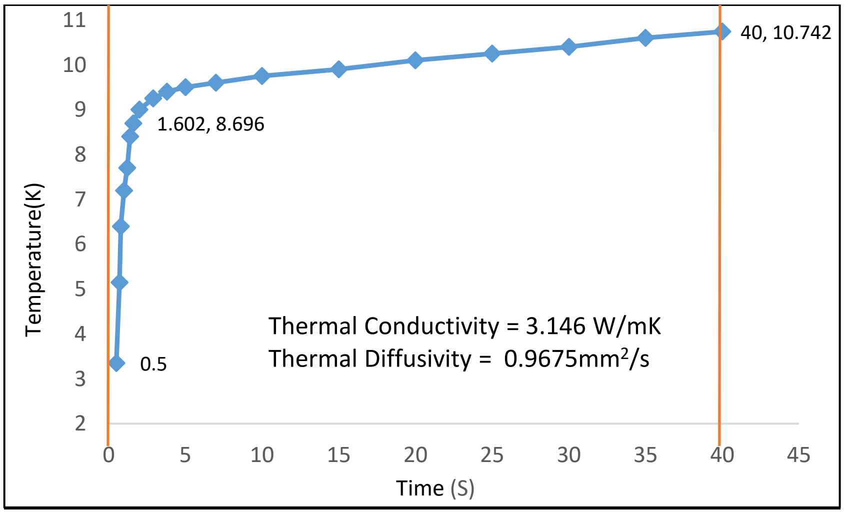

Figure 8. Thermal conductivity test for sample (C_{ScL3}).

CONCLUSIONS

Use carbon powder to improve the lightweight concrete properties produced from local brick residues.

1. Using a carbon powder ratio of 12% wt. of the used cement has improved the insulation properties and decreased the density, but the compression strength decreased somewhat. However, when using 4% wt. of the used cement, the compressive strength increases significantly.
2. It is recommended to use a low ratio of carbon powder about (4%) when interested in compressive strength and a higher ratio of about (12%) when attention to density and thermal conductivity.
3. In addition, the carbon powder is affected by high temperatures, so be careful when using carbon with concrete in high temperatures.

NOMENCLATURE

Symbol	Description	Symbol	Description
C.P	Carbon Powder	Γd	Dry Density, Kg/m^3
S. P	Super-Plasticizer	K	Thermal Conductivity, W/m.°C
SSD	Saturated surface dry	ρ	Density, kg/m^3

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Credit Authorship Contribution Statement

Sultan N. Alkarawi: Writing – review & editing, Writing – original draft, Experimental work.
Hutheifa J. Al Azzawy: Writing – review & editing, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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توظيف بقايا الطابوق في إنتاج الخرسانة خفيفة الوزن

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الخلاصة

نظرا للتطور في مجال التقنيات الجديدة لإنتاج الخرسانة .هذا التطور ادى إلى إنتاج عدة أنواع من الخرسانة مع خصائص مقاومة الانضغاط والكثافة والعزل الحراري تختلف عن الخرسانة العادية. وقد تم الحصول على هذه الخصائص من خلال عدة طرق. ومن أهم هذه الطرق إضافة مواد ذات خواص إسمنتية إلى الخلطة الخرسانية بدلاً من الأسمنت أو استخدام الركام الخفيف بدلاً من الركام الخشن والناعم. وفي معظم الحالات كانت مقاومة الانضغاط للخرسانة المنتجة أقل من الخرسانة العادية . ثلاثة أهداف رئيسية من إجراء هذا البحث .الهدف الأول هو إنتاج خرسانة خفيفة الوزن ذات مقاومة انضغاط جيدة مقارنة بنفس النوع من الخرسانة عن طريق إضافة مضافات كيميائية أخرى (Super-Plasticizer S.P and Carbon Powder C.P) إلى خليط الخرسانة خفيفة الوزن .الهدف الثاني: إعادة تدوير بقايا الطابوق المحلي واستخدامها كركام خشن بدلاً من الركام العادي في إنتاج الخرسانة خفيفة الوزن .الهدف الثالث هو زيادة معدل العزل الحراري للخرسانة عن طريق إضافة (مسحوق الكربون) إلى الخلطات الخرسانية. وكانت النتائج جيدة, تم إنتاج الخرسانة من هذا العمل باقل كثافة تصل الى (1810 كجم/م^3) واعلى مقاومة انضغاط تصل الى (31.240 ميجاباسكال) عند اضافة فقط (Carbon powder) بنسب معينة, وكثافة تصل الى (1944 كجم/م^3) ومقاومة انضغاط تصل الى (31.946 ميجاباسكال) عند اضافة (Super-Plasticizer) لنفس نسب (Carbon powder). مقارنة بالخرسانة العادية خفيفة الوزن بدون إضافات كيميائية والتي تصل كثافتها (1894 كجم/م^3)، ومقاومة انضغاط (24.848 ميجاباسكال) عند عمر 28. بالإضافة إلى ذلك، بلغت قيم التوصيل الحراري حوالي (0.507 واط/م.س) مقارنة بالخرسانة العادية خفيفة الوزن (2.242 واط/م.س).

الكلمات المفتاحية: الركام خفيف الوزن, الخرسانة خفيفة الوزن, مسحوق الكاربون, الملدنات المتفوقة.