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Production of Lightweight Concrete by Using Construction Lightweight Wastes

Abstract- *This research covers the use of cellular lightweight concrete waste as recycled coarse aggregates to produce lightweight concrete. Various volume fractions of coarse aggregate (35%, 50%, and 75%) were used. The specimens were tested for compressive strength and density at age of 28-days. The compressive strengths for the resulting lightweight concrete with a density of (2131, 1826 and 1630) kg/m^3 were (24, 22.6 and 11.5) MPa, respectively. In addition, silica fume was utilized as a constant replacement ratio 6% of cement weight for mixes lightweight aggregate to enhance the compressive strength of such concrete.*

Keywords- *Lightweight concrete; Cellular concrete aggregates and Strength.*

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1. Introduction

Lightweight concrete has utilized in buildings for over 93 years [1]. Structural lightweight concrete has a density varied from 1440 to 1840 kg/m3 compared to normal weight concrete with a density was varied from 2240 to 2400 kg/m3. The compressive strength of concrete must be maximal than 17.0 MPa, for structural applications. Use lightweight concrete leads to decrease the size of columns, footings and less reinforcing steel due to the decrease of the dead load of the structure of the concrete. Structural lightweight concrete fits a larger fire-rated concrete structure [2]. A combination of fine lightweight aggregate and coarse lightweight aggregate or coarse lightweight aggregate and normal weight fine aggregate can be used to manufacture Lightweight concrete [2]. Some of the researchers have been used the lightweight aggregates that were produced from a variety of source materials including pumice, expanded shale, and clay [3, 4, 5 and 6]. The construction of lightweight waste is very useful to produce lightweight concrete, in addition, the environmental pollution would be reduced. The wastes producing from the construction and destruction of buildings, and civil works infrastructure that can be called waste construction [7]. Many researchers have conducted intensive studies [7, 8 and 9] on the utilize of construction wastes as recycled lightweight aggregates such as fractions of cellular concrete, porcelanite and sawdust. The results showed a decrease in density, compressive strength and splitting strength. Therefore, carbon fiber, silica fume, and other material were inserted to improve the compressive strength and splitting strength of lightweight concrete. Thanon Dawood and others [10] used the carbon fibers for strengthening the foamed concrete. They concluded that the compressive strength increased from 17.1MPa to 23.1 MPa when used of 1% of carbon fiber as a volumetric fraction. Ganesh Babu and SaradhiBabu [11] and González-Fonteboa and Martínez-Abella [12] investigated the use of polystyrene beads and destruction waste as the lightweight aggregate with the insertion of silica fumeat different ratios. The results showed a variation in the density of the concrete form1500 to 2000 kg/m3, with the corresponding to strengths varied from 10 to 21 MPa. The amount of strength earning for concretes shows an increase when increasing the ratios of silica fume. González Fonteboa, MartínezAbella [12] executed experiments to determine the density, grading, water absorption, flakiness index and shape index. Chen and Liu [13] concluded that the partially substituting fine and coarse aggregate by expanded polystyrene beads made to a density of 800–1800 kg/m3 and a compressive strength of 10–25 MPa. The Interconnection between the expanded polystyrene beads and cement was improved by fine silica fume and led to increasing the compressive strength. In addition, the drying shrinkage was improved by adding fiber of steel.

In this paper, the effect of using the cellular concrete waste as a recycled aggregate on the density, absorption, thermal conductivity, compressive, flexure, splitting strengths of concrete is studied by replacing coarse aggregate with different percentages of recycled cellular concrete keeping the silica fume ratio constant 6%.

For all mixes, compressive, flexure and splitting strengths were determined at age of 28 days.

2. Materials and Mix Proportions

I. Materials

The cement used in mortar mixtures was Ordinary Portland Cement (OPC) produced by Sinjar Factory (Mosul). The chemical, mechanical and physical characteristics of ordinary Portland cement are shown in Table 1 and 2 such characteristics are confirmed to IQS: 5/1984 [14]. Silica fume (Sika Fume HR) was used at a constant replacement ratio of 6% of cement weight, the physical composition of silica fume are given in Table 3, the chemical composition is shown in Table 4 and agreeing to ASTM-C 1240 [15]. The fine aggregate was natural sand with a fineness modulus of 2.86 the sieve analysis for sand agreeing to ASTM C330/03 [16] and shown in Table 5. Natural coarse aggregate was used riverbed gravel obtained from River Tigris (Mosul/Iraq), the sieve analysis for gravel to ASTM C330/03 [16] and shown in Table 6. Cellular concrete wastes are used as a coarse aggregate by crushing these wastes, Figure 1 shows the crushed cellular concrete aggregates used in this study. The sieve analysis of coarse cellular concrete aggregates agreeing to ASTM C330 [17] and shown in Table 7. The bulk density and absorption capacity for the cellular concrete aggregates were 413 kg/ m^3 and 88.7% respectively these tests achieved according to ASTM C796 [18], tap water was used at a constant ratio 0.45%.

Table 1: Chemical Composition of Cement

Constituent	Portland cement % by weight	Limits of IQS: 5/1984 [14]
Lime (CaO)	62.55	-
Silica (SiO2)	21.52	-
Alumina (Al2O3)	5.6	-
Iron oxide (Fe2O3)	2.74	-
Magnesia (MgO)	3.23	≤ 5.0 %
Sulphur trioxide (SO3)	2.44	≤ 2.8
C3S	42.52	-
C2S	29.87	-
C3A	10.2	-
C4AF	8.33	-
Loss on ignition (L.O.I.)	1.5	≤ 4.0 %
Insoluble residue (I.R.)	0.4	≤ 1.5 %

Table 2: Physical Properties of Cements

Physical properties	Results	Limits of IQS: 5/1984 [14]
Initial setting time (minute)	80	≥ 45 minute
Final setting time (minute)	240	≤ 600 minute
Fineness (Blaine m^2/ kg)	310	≥ 230 (m2/ kg)
Soundness by Autoclave Method (%)	0.05	Not more than 0.8
Compressive strength (MPa) 3 days 7 days	 21 27	 ≥ 15 ≥ 23

Table 3: Physical Properties of Silica fume

Form	Agglomerated
Particles Color/ Appearance	Grey
Specific Gravity	2.20
Size of particles	0.1 μ
Dosage	2 - 10 % by weight of cement
Chloride content	Nil

Table 4: Chemical Composition of Silica fume

Constituent	Silica fume(SF) % by weight	Limits of ASTM-C 1240[15]
Lime (CaO)	0.89	-
Silica (SiO2)	91.3	≥% 85.0
Alumina (Al2O3)	0.66	-
Iron oxide (Fe2O3)	0.3	-
Moisture content	1.5	≤ % 3.0
Loss on ignition	2	≤% 6.0

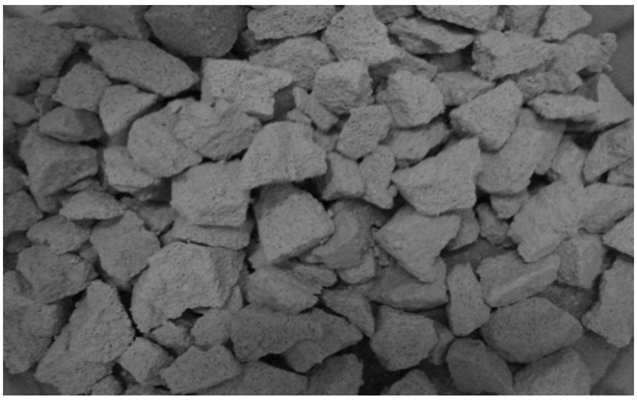

Figure 1: Crushed Cellular Concrete Aggregates

Table 5: Sieve analysis for sand

Sieve mm	% Passing	Limits of ASTM C330/03 [16]
9.5	100	100
4.75	96	95-100
2.36	91	80-100
1.18	77	50-85
0.6	38	25-60
0.3	9.8	5-30
0.15	2.6	0-10
pan	0	0

Table 6): Sieve analysis for gravel

Sieve mm	% Passing	Limits of ASTM C330/03 [16]
37.5	100	100
25	93	90-100
19	57.8	40-85
12.5	19	10-40
9.5	0	0-15
4.75	0	0-5
pan	0	0

Table 7: Sieve Analysis of Coarse Cellular Concrete Aggregates

Sieve designation	Percentage (Mass) Passing Sieves Having Square Openings % (ASTM C330) [17]	Percentage (Mass) Passing Sieves Having Square Openings %
25 mm	100	100
19 mm	90-100	91
12.5 mm		
9.5 mm	10-50	42
4.75 mm	0-15	0
2.36 mm	….	
1.18 mm	….	
300 mm	….	
150 mm	….	

Table 8: Concreter mix proportions

Index	Cement kg/m^3	Water kg/m^3	Percentage of cement weight replacement % by silica fume	Sand kg/ m^3	Percentage of coarse aggregate replacement (%)by volume of recycle cellular concrete aggregates	Coarse aggregate kg/m^3
A1	405.5	174	0	608.3	0	1216.7
A2	405.5	174	6	608.3	35	791
A3	405.5	174	6	608.3	50	608.3
A4	405.5	174	6	608.3	75	304

II. Mix proportions

Details of the mix proportions for the concrete containing different levels of cellular concrete aggregates are given in Table 8. The control mix was cast using normal aggregate without using silica fume (0% SF) with mix proportion (1: 1.5: 3: 0.45) by weight. While the other mixes were designed by substituting part of the coarse aggregates with coarse cellular concrete aggregates at three different replacement levels on a volume-for volume basis (according to the volumetric fraction). The percentages of coarse cellular concrete aggregates replacements were 35%, 50%, and 75%. The silica fume was added to the three mixes that have coarse cellular concrete aggregates with a constant value of replacement 6% by weight of cement.

3. Casting, Curing and Testing of Concrete Specimens

For each concrete mixture, three 150 × 300 mm concrete cylinders were used to test the splitting strength according to ASTM C496 [19], testing of bulk density and moist density for different concrete mixes according to ASTM C567 [20], and the absorption test for all mixes are achieved according to ASTM C642 [21]. Testing of the flexural strength of the specimens was conducted on three 100×100×400 mm samples in accordance with to ASTM C78 [22]. Also, three 150 mm cubes were used to test the compressive strength according to British standard BS 1881: Parts 116 [23]. The specimens were taken away from moulds 24 hours after casting and were put in the water at 23± 2°C. The compressive strength, flexural strength and splitting strength samples were tested at age of 28 days. Each strength value was the average of strength for three specimens.

4. Results and Discussion

I. Bulk density, moist density, and rate of absorption:

The density reduced by increasing the percentage of cellular concrete aggregate, various volume fractions of replacing the natural coarse aggregate (35%, 50% and 75%) by cellular concrete aggregate lead to decrease the bulk density by (14%, 26.3% and 34.2%) respectively as shown in Table 9 and Figure 2. This reduction in density is due to the fact that cellular concrete aggregate is lighter than the natural coarse aggregate. Also, the replacing led to increasing the rate of absorption from 62.9% to 291.4% as shown in Table 9 and Figure.3, due to the higher capacity of absorption of cellular aggregate than the natural coarse aggregate. Figure 4 and Figure 5 denote that the moist density of concrete is larger than the bulk density for the same mix and the amount of difference between bulk density and moist density is increased by decreasing the bulk density for all mixes due to high water absorption capability of cellular aggregate.

Table 8: Concreter mix proportions

Index	Cement kg/m^3	Water kg/m^3	Percentage of cement weight replacement % by silica fume	Sand kg/ m^3	Percentage of coarse aggregate replacement (%)by volume of recycle cellular concrete aggregates	Coarse aggregate kg/m^3
A1	405.5	174	0	608.3	0	1216.7
A2	405.5	174	6	608.3	35	791
A3	405.5	174	6	608.3	50	608.3
A4	405.5	174	6	608.3	75	304

Table 9: Effect of replacing the natural coarse aggregate by recycle cellular concrete coarse aggregate on bulk density, moist density and absorption

Index	Bulk density kg/m^3	Saturated surface dry(SSD) density kg/m^3	Decrease in Density (%)with respect to A1	Rate of absorption (%)	Increase in absorption percentages (%) with respect to A1
A1	2479	2567	….	3.5	….
A2	2131	2252	14	5.7	62.9
A3	1826	1997	26.3	9.4	168.6
A4	1630	1854	34.2	13.7	291.4

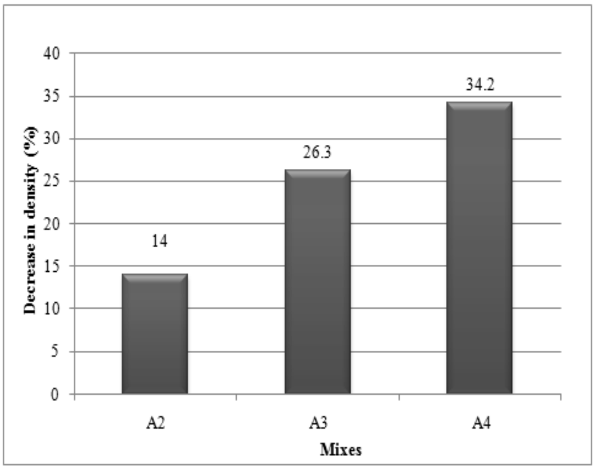

Figure 2: Drop in density (%) of the mixes that have volume fractions of replacing (35%, 50% and 75).

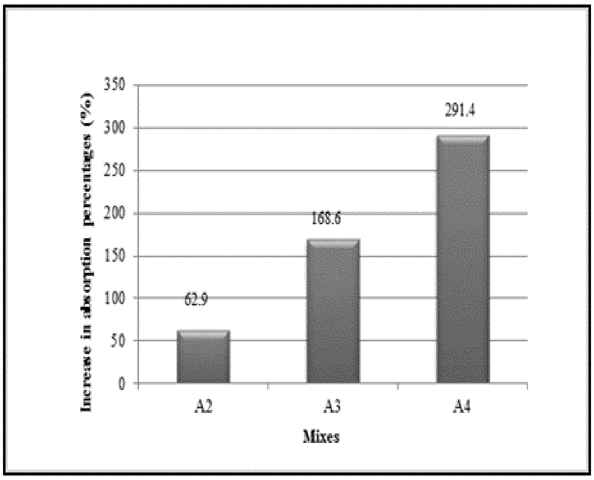

Figure 3: Increase in absorption capacity (%) of the mixes that have volume fractions of replacing (35%, 50% and 75%).

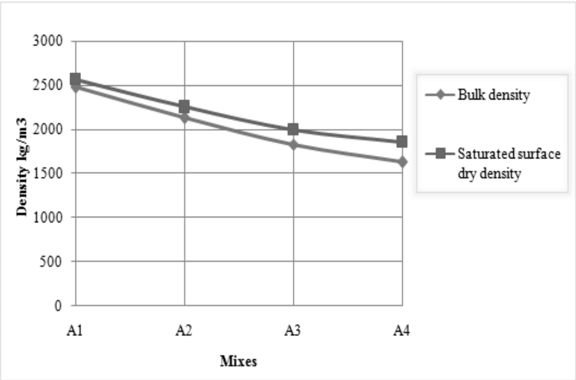

Figure 4: Density for all mixes

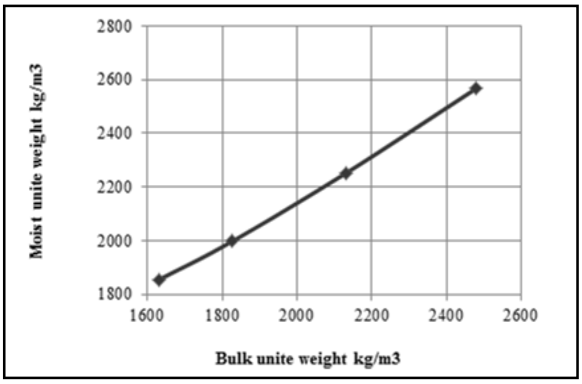

Figure 5: Relationship between bulk density and moist density for all mixes

II. Compressive strength

The compressive strength results of all mixes, are abridged in Table 10. For the different mixes the 28-day compressive strength varied from 11.5 MPa to 33.5 MPa. The important factor affected the strength is percentage replacement of natural coarse aggregate with cellular concrete aggregate. Figure 6 shows the diversity of compressive strength with cellular concrete aggregate replacement percentages where the compressive strength values at constant ratio 6% of SF have been plotted for the three cellular concrete aggregate replacement percentages in addition to the control mix (0% replacing cellular concrete aggregate) (0% SF).The percentages of losing strength with respect to the control mix for 35%, 50% and 75% of cellular concrete aggregate replacements are 21.1%, 32.4%, and 65.7% respectively. In spite of use the SF with a constant value (6%) in all mixes except the control mix the results denote that compressive strength decrease when increasing the percentage replacements of cellular concrete aggregate because the strength of cellular concrete that used as coarse aggregate is lighter than the natural coarse aggregate and the percentage of additional SF is not enough to compensate of strength reducing that caused by replaced the natural coarse aggregate with cellular concrete aggregate. Figure 7 shows the relation between the bulk density and compressive strength of all mixes of concrete. This graph demonstrates the trend of increasing strength with increasing density for concrete. The specimen A3 gives the best result for compressive strength and density because the compressive strength for this specimen 22.6 MPa is greater than 17 MPa that make it be used for structural applications [2] and the density for this specimen (1826 kg/m3) is within the lightweight concrete ranges of 300 to 1850 kg/m3 as defined by Neville[24]. Figure 8 depicts a cube during the compression test.

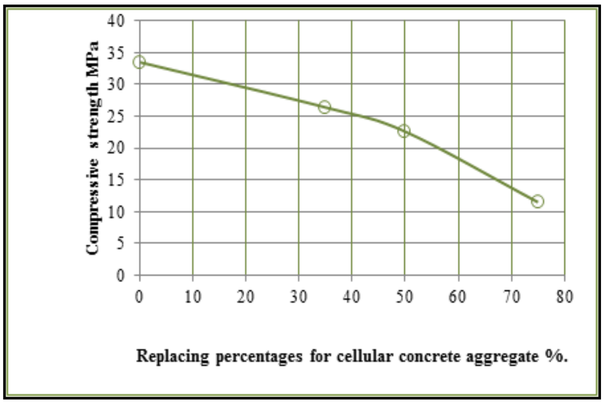

Figure 6: Relationship between compressive strength and percentage replacements of cellular concrete aggregate

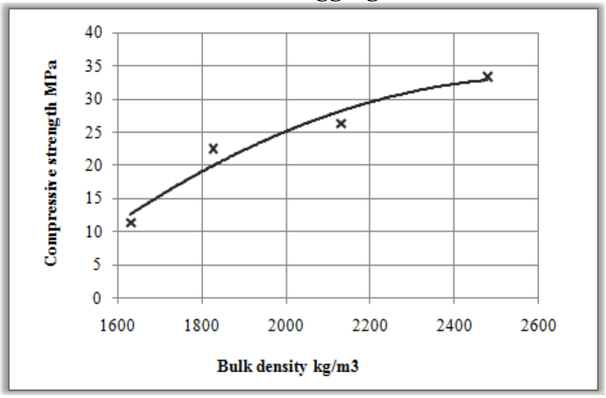

Figure7: Relationship between the bulk density and compressive strength

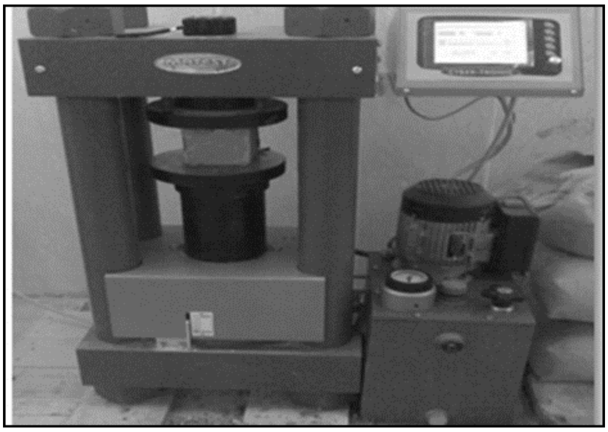

Figure 8: A cube during the compressive strength test

Table 10: Compressive strength, splitting strength, flexural strength and Thermal Conductivity of concrete for specimens used at age 28 day

Index	Coarse aggregate replacement with recycled cellular concrete aggregates (%)	Silica fume (SF)%	Compressive strength MPa	Splitting strength MPa	Flexure strength MPa	Thermal conductivity w/m. k
A1	0	0	33.5	2.8	6.4	1.6
A2	35	6	26.4	2.1	4	1.03
A3	50	6	22.6	1.9	3.6	0.7
A4	75	6	11.5	1.4	2.7	0.55

III. Splitting strength

The results in Table 10 show that the splitting strength decrease when increasing the percentage of replacements of cellular concrete aggregate, Figure 9 displays the diversity of splitting strength with the cellular concrete aggregate replacement percentages. The loss of splitting strength is almost like a loss of compressive strength. The percentages of losing strength with respect to the control mix for 35%, 50%, and 75% cellular concrete aggregate replacements are 25%, 32.1%, and 50%, respectively. The relation between the splitting strength and compressive strength of all mixes of concrete are shown in Figure 10.

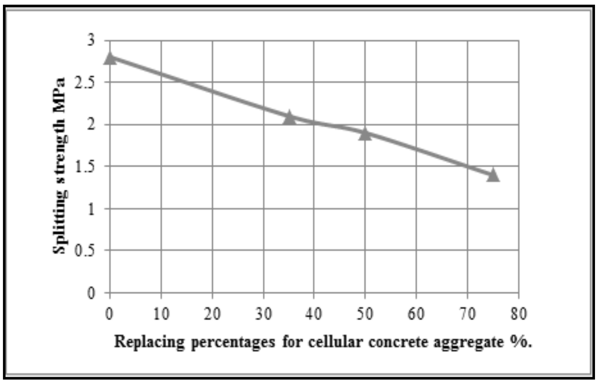

Figure 9: Relationship between splitting strength and percentage replacements of cellular concrete aggregate

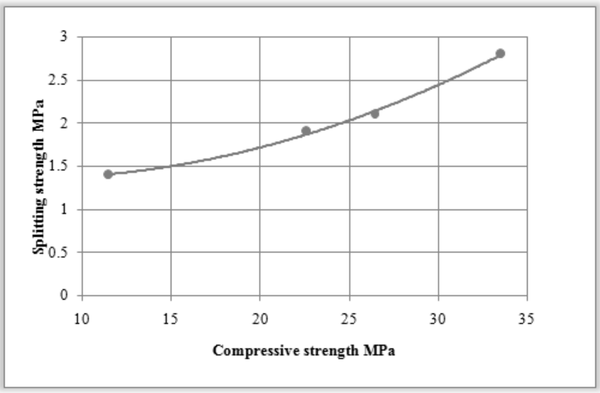

Figure 10: Relationship between the splitting strength and compressive strength

IV. Flexural strength

The flexure strength of all mixes are explained in Table 10. Figure 11 shows the diversity of flexure strength with the cellular concrete aggregate replacement percentages. There is an obvious loss in flexure strength due to cellular concrete aggregate replacement

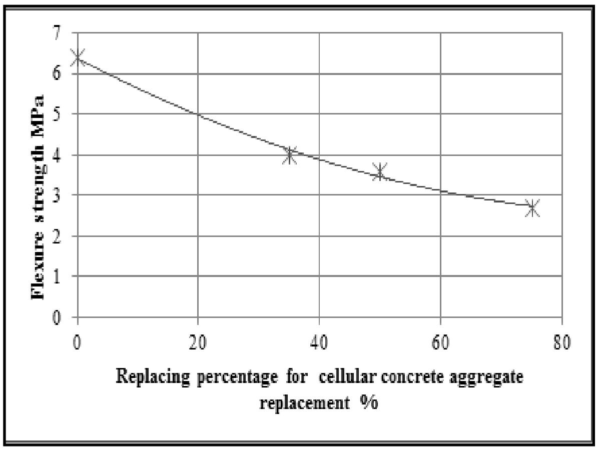

Figure 11: Relationship between flexure strength and percentage replacements of cellular concrete aggregate

Figure 12: Shows a A4 beam after flexural strength test

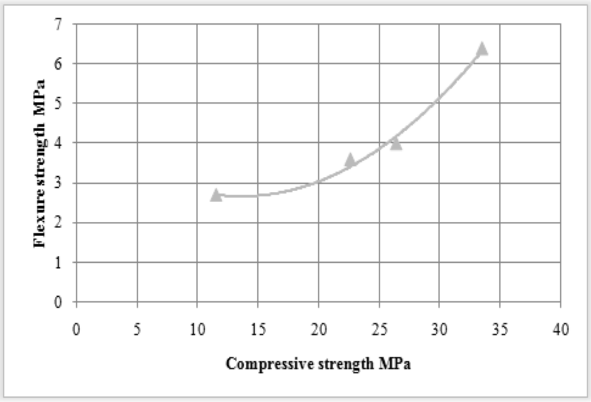

Figure 13: Relationship between the flexure strength and compressive strength

V. Thermal conductivity

It has been developed in several ways to compute the thermal conductivity of concrete. The determination of thermal conductivity of concrete is usually accrued according to ACI Committee 523[25] by the equation (1). When test data are not ready these calculated evaluations are useful. This equation is often interrelated to dry density of concrete as a function of the logarithm of kc

$$kc = 0.072 \times e^{0.00125 \times d} \quad (1)$$

Where:
kc: thermal conductivity in w/m k
d: dry density in kg/m^3
As a result, the various volume fractions of replacing the natural coarse aggregate (35%, 50%, and 75%) by cellular concrete aggregate leads to decrease the thermal conductivity from (35.4%, 56%, and 65 %) respectively as shown in Table 9 and Figure14.

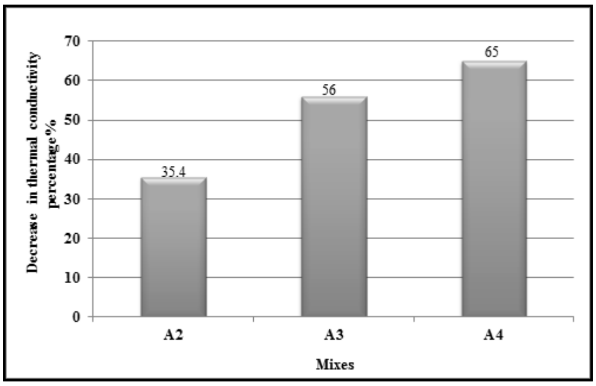

Figure14: The Drop in thermal conductivity (%) of the mixes that have volume fractions of replacing (35%, 50% and 75%)

5. Conclusions

Through the experimental work carried out in this study, the following conclusions were reached:

1. The successful application of structural demolished elements lightweight can be used in structural lightweight concrete to improve green construction environment such as decreasing the wastes trade on site and keeping dust level at the construction site to the minimum.
2. The use of cellular concrete aggregate instead of natural coarse aggregate leads to decrease the density by (14%, 26.3 and 34.2%) and increase the rate of absorption by (62.9%,168.6% ,and 291.4%) with difference percentages depends on the percentages of replacing (35%, 50%, and 75%) respectively.
3. The replacing natural coarse aggregate (35%, 50%, and 75%) by cellular concrete aggregate leads to decrease the compressive strength because the strength of cellular concrete that used as coarse aggregate is lighter than the natural coarse aggregate, the percentages of losing strength with respect to the control mix are 21.1%, 32.4%, and 65.7% respectively. Although uses the SF with a constant value (6%) in all mixes except the control mix.
4. Various volume fractions of replacing the natural coarse aggregate (35%, 50%, and 75%) by cellular concrete aggregate lead to decrease the splitting strength by (25%, 32.1%, and 50%) respectively.
5. The percentages of variation in flexure strength for 35%, 50% and 75% cellular concrete aggregate replacements percentages with respect to the control mix are 37.5%, 43.8%, and 57.8%, respectively, that is means the natural coarse aggregate replacement leads to decrease of flexure strength.
6. The trend in the flexure strength loss and splitting strength loss for three different cellular concrete aggregate replacement percentages in addition to the control mix are almost similar to that in compressive strength.
7. The thermal conductivity is decreased when increasing the percentage replacements of cellular concrete aggregate, the percentages of losing thermal conductivity with respect to the control mix for 35%, 50%, and 75% cellular concrete aggregate replacements are (35.4%, 56%, and 65%) respectively.

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