Production of Structural Light-Weight Aggregate Concrete Using Different Types of Iraqi Local Crushed Materials as Coarse Aggregate

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Abstract

This paper presents the experimental investigation for producing structural lightweight concrete using three types of lightweight aggregate from different sources of local natural, waste and recycled materials in Iraq and those compared to natural aggregate concrete.

In this investigation, the natural porcelanite rocks available in western desert of Iraq used as a coarse aggregate in the first mix. The second mix involving the pumice stone which is obtainable in northern Iraq used as a coarse aggregate. The third mix of structural lightweight concrete produced by using composite aggregates that is formed from 75% recycled of local Iraqi clay bricks and 25% from waste of themestone. All those mixes compared with natural aggregate concrete at the same mix proportions which included minerals and chemical admixtures.

In this research, fresh and hardened concrete properties were studied. In hardened concrete state, destructive and non-destructive tests were performed of 28 days.

From the work results, it can be concluded that the coarse lightweight aggregate of porcelanite, pumice and composite aggregates can be used instead of natural aggregate (gravel) to make structural lightweight concrete with densities of less than 2000 kg/m^3 and this less than the corresponding natural aggregates concrete by the range of (25%-27.4%) with cylinder compressive strength ranged between (25.3-36.1) MPa at 28 days.

Many relations were proposed to estimate some of mechanical properties of lightweight aggregate concrete. The ACI318**,** 2014 expression and some of other codes and literature of researches were used to compare with the proposed experimental relations.

Key Words: Structural Lightweight Concrete (SLWC), Porcelanite Rocks, Pumice Stone, Clay Brick, Thermestone, Non-destrictive Tests.

الخلاصه

تقدم هذه الدراسة التحري العملي لإنتاج خرسانة انشائية خفيفة الوزن باستخدام ثلاثة أنواع من الركام الخفيف الذي يمكن الحصول عليه من مصادر مختلفة من المواد الطبيعية والنفايات والمواد المعاد تدويرها في العراق ومقارنتها بالخرسانة الاعتيادية المصنوعة من الركام الطبيعي (الحصى).

استخدمت في هذه الدراسة صخور البورسلانيت الطبيعية المتوفرة في الصحراء الغربية في العراق كركام خشن في الخلطة الاولى. أما الخلطة الثانية فتحتوي على حجر الخفاف الذي يمكن الحصول عليه من شمال العراق. الخلطة الثالثة للخرسانة الانشائية خفيفة الوزن انتجت باستخدام مزيج من الركام الخشن الذي يتكون من 75٪ من الطابوق الطيني العراقي المحلي المعاد تدويره و 25٪ من نفايات الثرمستون. كل هذه الخلطات قورنت مع الخرسانة الاعتيادية المصنوعة باستخدام الركام الطبيعي (الحصى) باستخدام نفس النسب لمكونات الخلطة الخرسانية والتي تضمنت استخدام المضافات المعدنية والكيميائية.

في هذا البحث، تم دراسة خصائص الخرسانة في الحالتين الطرية والصلبة. وفي الحالة الصلبة للخرسانة تم اجراء الفحوصات الاتلافية واللااتلافية بعمر 28 يوم.

من نتائج هذه الدراسة، يمكن الاستنتاج بإمكانية انتاج خرسانة خفيفة الوزن انشائية بكثافة جافة اقل من 2000 كغم/م^3 واقل مما يقابلها من استخدام الركام الطبيعي بنسبة تتراوح بين (25% – 27.4%) وبمقاومة انضغاط للأسطوانة تتراوح بين (25.3–36.1) ميكا باسكال بعمر 28 يوما باستخدام صخور البورسلينايت، حجر الخفاف ومزيج من كسر الثرمستون والطابوق الطيني المحلي المعاد تدويره كركام خشن خفيف الوزن.

في هذه الدراسة تم اقتراح العديد من العلاقات لإيجاد بعض الخواص الميكانيكية للخرسانة خفيفة الوزن الانشائية. كما تمت مقارنة النتائج المختبرية والعلاقات المقترحة مع معادلات معهد الخرسانة الامريكي ACI318, 2014 وبعض الدراسات والبحوث السابقة.

الكلمات المفتاحية: الخرسانة الانشائية خفيفة الوزن، صخور البورسلينايت، حجر الخفاف، الطابوق الطيني، الثرمستون، الفحوص اللااتلافية.

1-Introduction

Concrete is one of the oldest material which is used in construction structures, in a wide range of forms and types, it is probably the most widely used building material in the world today.

Self-weight of concrete construction represents a very large proportion of the total load on the structure, and there are clearly considerable advantages in reducing the density of concrete.

Nowadays, lightweight concrete (LWC) becomes one of the important materials in construction because of the practical and economic advantages of it.

The density of concrete can be reduced by replacing some of the solid material in the mix by air in three locations either cement paste, aggregate or between the coarse aggregate particles. One of these methods is replacing lightweight aggregate (LWA) either wholly or partially natural aggregate for both fine and coarse aggregate or for coarse aggregate only (ACI213R, 2003).

Lightweight aggregate concrete (LWAC) has been used successfully for structural purposes for many years everywhere the world, density and compressive strength are two important parameters of it, in many codes. ACI213R-03 defined structural lightweight concrete (SLWC) as having a twenty eight-days equilibrium density between 1120 kg/m^3 to 1920 kg/m^3 and having a minimum cylinder compressive strength equal to 17 MPa.

There are many types of aggregates available that are classed as lightweight and their properties cover wide ranges. In Iraq, little has been done on the use of LWC in structural members. Many researches has shown that there is an abundant supply of lightweight rock discovered in the Iraqi western desert that may be used to produce concrete of lower density; It is called porcelinite rocks. (**Al Barazanji, 2012**)

Since the production of manufactured LWA is more costly; therefore, in the present research it will be used natural porcelinite rocks with mineral and chemical admixtures to improve its properties concrete results. The cost of its material may, however, be very low because they are natural material and available in a wide areas in Iraqi western desert. On the other hand, the energy needed to crushing it is easy.

Pumice is an igneous stone which is created through volcanic outburst. It is a very light; made up of very small crystals, since they cool very quickly above the ground. The pumice texture is rough and has many cavities and hollows. This research studied the using of crushed pumice stones as a coarse lightweight aggregate.

In this country, thermestone and clay bricks, are widely used as masonry units. In the handling of these units during the building process; many of them are damaged because of its brittleness; also, during the demolition process of old building produce many of them. Therefore, the use of their recycled wastes in concrete is very necessary due to needed of light weight in structures and the environmental requirements. In the current research, the composition aggregates from demolition waste and recycled of local clay bricks at a specified ratio with thermestone waste are used to produce SLWC.

In the present experimental study, all types of LWA were used in conjunction with silica fume and high range water reducing admixture in order to produce good strength of structural lightweight aggregate concrete (SLWAC).

2-Objective of Research

This research attempts to investigate natural, waste and recycled local materials in Iraq as a coarse lightweight aggregate substitute for natural coarse aggregate in the production of SLWC.

The laboratory works include producing three different mixes of LWC by using natural crushed porcelinite rocks, crushed pumice stones and composition aggregates from waste of masonry units of bricks and thermestone as a coarse aggregate. These three types of lightweight concrete compared with natural weight aggregate concrete by wholly replacement of coarse aggregate in order to examine the differences.

After studying the fresh concrete properties, the destructive and non-destructive tests were performed on the hardened concrete for lightweight and normal weight concrete at 28 days which is including air dry density, compressive strength, splitting tensile strength, flexural tensile strength and modulus of elasticity and in non-destructive tests, ultrasonic pulse velocity and Schmidt hammer were conducted.

3- Experimental Program

3-1 Material Properties

3-1-1 Cement

Ordinary Portland cement (type I) was used under trade name Crista, the chemical analysis and the physical properties of it meet the requirements of Iraqi Standards (**IQS No. 5, 1998**)

3-1-2 Fine Aggregate

Al-Ukhaider natural sand of the zone two was used. The grading of this sand complies with the (**IQS No. 5, 1998**)

3-1-3 Coarse Aggregate

Crushed porcelinite were used as coarse lightweight aggregate (CLWA) for producing SLWC with a maximum nominal size of 12.5 mm. It was obtained by crushing manually porcelinite rocks available in the Iraqi western desert. It was separated by sieve analysis and recombined it to meet the grading according to (**ASTM C330, 2005**)

By the same manner that mentioned in the previous paragraphs of crushing and recombining method used for pumice stones, thermestone and bricks with the same maximum nominal size; Figure (1) shows the aggregate types used.

Figure (1) LWA Used

The recycled local bricks usually contain adherent residues of the cement paste in the holes, which makes its density higher therefore using thermestone with bricks is for the purpose of achieving the appropriate dry loose bulk density of lightweight aggregates comply to (**ASTM C29, 2003**) which must not exceed 880 kg/m^3 as stated in ASTM C330, 2005.

In the composite aggregate, it was used the ratio of composition (25% thermestone and 75% bricks) according to the result of hardened density and cylinder compressive strength comply to ACI213R-03 to meet the best result.

The CLWA was soaked in water for one day then spreaded inside the laboratory to get the Saturated Surface Dry (SSD) condition.

Al-Nebai natural coarse aggregate were used with the same maximum nominal size of CLWA. Some of physical properties for all coarse aggregate types are illustrated in Table (1) and shown in Figure (2).

Table (1) Some of Physical Properties of Aggregate*

Aggregate Type	Dry Loose Bulk Density kg/m^3	Absorption (%)
Porcelinite	814	31.2
Pumice	720	36.8
Bricks	874	26.9
Thermestone	247	42
Natural Gravel	1632	0.87

* This tests performed according to ASTM C 29-03

Figure (2) Tests Procedures of Aggregate

3-1-4 Silica Fume

Sika Fume®-HR was used in this study meeting the requirements of (**ASTM C1240, 2005**).

3-1-5 Superplasticizer

The Egyptian product from company of Sika known as " Sikament 163" is a high range water reducing concrete admixture; used in this study. It is conformed to (**ASTM C494, 2005**)

3-1-6 Water

For mixing concrete and for curing of it tap water was used.

3-2 Mix Proportions

LWC are generally depended on their density; SLWAC is defined as a concrete having an oven-dry density of less than 2000 kg/m^3 and having cylinder compressive strength in excess 17 MPa at twenty two days.

After many trial mixes were done according to (**ACI211. 2, 1998**); depending on the previous researchers with several changes to meet the limit of density and compressive strength for SLWC.

To study the effect CLWA types, all mixes have the same mix proportions. The mix by weight was 1 : 1.163 : 1.21 for cement, sand and coarse aggregates; respectively. The water cement ratio was equal to 0.35 and cement content was 430 kg/m^3. The Superplasticizer was used at 3% weight of cement and Silica Fume was about 4%.

First mix used natural crushed porcelinate rocks as coarse aggregate, namely, (M-PR). The second mix used crushed pumice stones as CLWA, namely, (M-PS). In the third mix the CLWA consists of 25% thermestone and 75% bricks, namely, (M-TB).

Finally, Theses three mixes are compared with the fourth mix concrete used wholly normal weight aggregate (gravel) instead of CLWA, namely, (M-G).

3-3 Mixing, Casting, Curing and Concrete Testing of Specimens

According to (**ASTM C192, 2005**), all molds were poured with concrete and cured as shown in Figure (3). In testing of fresh properties of concrete, the slump test was conducted depending on (**ASTM C143, 2005**) and the fresh density test was performed in accordance with [**ASTM C567, 2005**].

The destructive tests of hardened concrete were performed after 28 days of curing, air dry density test was performed according to (**ASTM C567, 2005**). The cylinder compressive strength of concrete ($f_{c'}$) was tested depended on (**ASTM C39, 2005**) while, the cube compressive strength of concrete (f_u) was tested according to (**BS 1881 − part 116, 2002**).

The splitting tensile strength (f_{sp}) was determined depending on (**ASTM C496, 2004**) while the flexural strength (f_r) test was performed on concrete prisms of dimensions (100×100×400) mm based on (**ASTM C78, 2002**). The static-elastic modulus is determined from testing procedure in (**ASTM C469, 2002**).

Figure (3) Casting and Destructive Tests Procedures of Specimens

In non-destructive tests, ultrasonic pulse velocity (UPV) test was doe based on (**ASTM C597, 2006**). The rebound hammer (RN) (Schmidt hammer) test was performed according to (**ASTM C805, 2006**) as shown in Figure (4).

Figure (4) Non-Destructive Tests Procedures of Specimens

4- Experimental Results and Discussion

The fresh and hardened properties at 28 days age; are presented in Table (2). Some of relationships between concrete properties with respect to cylinder compressive strength are illustrated in Table (3)

Table (2) Fresh and Hardened Properties of Concrete

Mix Symbol	Fresh Properties		Hardened Properties							
			Hardened Density Kg/m^3	Non-Destructive Tests		Destructive Tests				
				RN	UPV km/sec	Compressive Strength MPa		Tensile Strength MPa		Modulus of Elasticity GPa
	Slump mm	Fresh Density Kg/m^3				$f_{c'}$	f_{cu}	f_{sp}	f_r	E_c
M-PR	160	1998	1905	36.9	3.83	28.5	33.9	2.27	2.88	20.1
M-PS	140	1978	1888	38.5	3.52	36.1	43.3	3.11	3.95	24.2
M-TB	145	1972	1869	35.7	3.31	25.3	29.9	2.08	2.39	19.8
M-G	180	2443	2381	43.2	4.91	39.4	48.4	3.7	4.9	27.6

Table (3) Relationships between Some of Mechanical Properties

Mix. Symbol	$f_{cu}/f_{c'}$	$f_r/\sqrt{f_{c'}}$	$f_{sp}/\sqrt{f_{c'}}$	$E_c/\sqrt{f_{c'}}$	$E_c/\gamma^{1.5}\sqrt{f_{c'}}$
M-PR	1.189	0.539	0.425	3765	0.0452
M-PS	1.199	0.657	0.518	3345	0.0491
M-TB	1.182	0.475	0.414	3936	0.0487
M-G	1.228	0.780	0.589	4397	0.0378

4-1 Slump and Fresh Density

All concrete mixtures had been same proportions for cementations material content (cement and mineral additive), fine and coarse aggregate, water content and superplasticizer in order to comparison study between three types of LWA from side and with natural aggregate (gravel) from the other side.

The highest slump of the LWC mixtures, 160 mm, was for M-PR containing porcelinate; the lowest value of 140 mm was obtained for M-PS, incorporating pumice; this is due to the nature of surface texture and microstructure of pumice aggregate that reflected on the water demand for the mix to get a suitable workability as shown in Table (2). The slump of normal concrete mixture M-G was 180 mm which is had the higher value between all mixtures; this is explained by the smooth and solid surfaces of the gravel.

As expected according density of aggregate, the lowest value of fresh density for LWC mixtures is 1972 Kg/m^3 for M-TB while the M-PR have the higher fresh density. The porcelinite material have the inner pores are connected to each other and retain water for a certain period after removing them from the process of soaking which works as a sponge while the stone pumice has wide open cracks, which retain water quickly and lose it quickly and this is reflected later on the values of fresh densities and the nature of the fabric of the solid stone pumice the water is not absorbed.

4-2 Hardened Density and Compressive Strength

Results of air dry density for LWC mixtures are below 1900 kg/m^3 comply to the limits of many codes for SLWAC. M-TB mixture give the lowest value of hardened density with lowest value of compressive strength while M-PS mixture have the highest value of compressive strength at hardened density about 1888 Kg/m^3. M-PR mixture have the highest density with cylinder compressive strength equal to 28.5 MPa.

The average values of its density of LWC is lower than it in normal weight concrete at the same mix proportions by about 26.2%. Figure (5) shows the effect of LWA types on cylinder compressive strength compared with natural aggregate. Pumice aggregate concrete gives cylinder compressive strength higher than it in porcelinite aggregate concrete by about 26.67%. The lowest value of compressive strength for M-TB mixture is due to the lower strength of thermestone compared with others of LWAs.

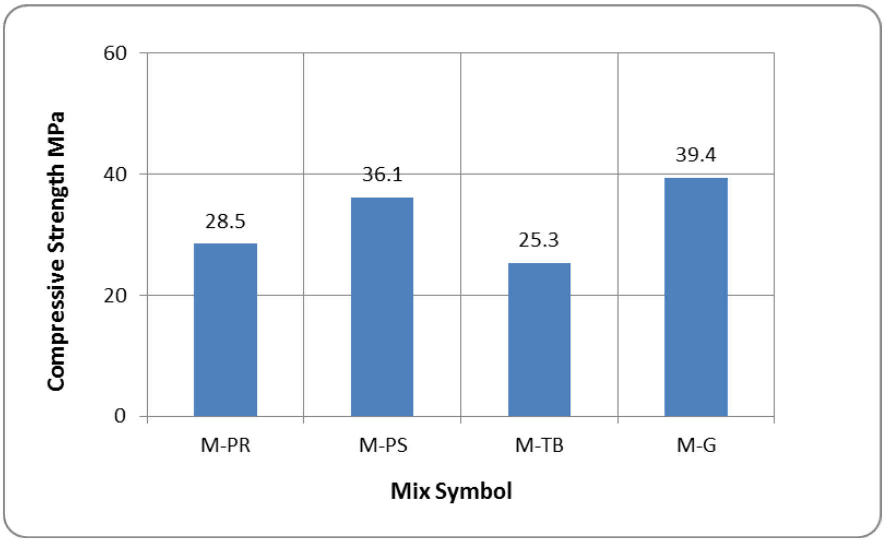

Figure (5) Cylinder Compressive Strength vs. Aggregate Type

For the range of LWC strength studied, it can be seen that higher the compressive strength, the higher is the value of the ratio of cube to cylinder compressive strengths; as shown in Figure (6).

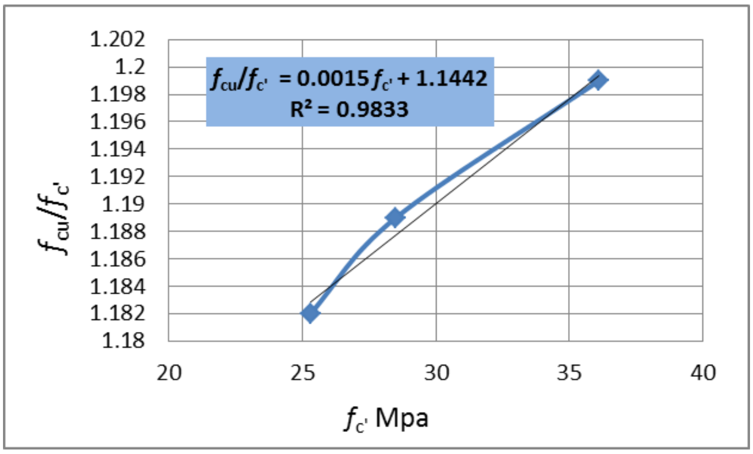

Figure (6) Cube/Cylinder Compressive Strength vs. Cylinder Compressive Strength

It appears in Table (3) that, the proportion between cube and cylinder compressive strength ($f_{cu}/f_{c'}$) for LWC ranges between (1.182–1.199) and about 1.228 for normal weight concrete is lower than 1.25 by **[Neville and Brooks, 2002]** for normal weight and normal strength concretes.

By applying Excel software as shown in Figure (7) , the linear expression ($f_{c'} = 0.8064 f_{cu} + 1.1773$) can be used to obtain the cylinder compressive strength of SLWAC.

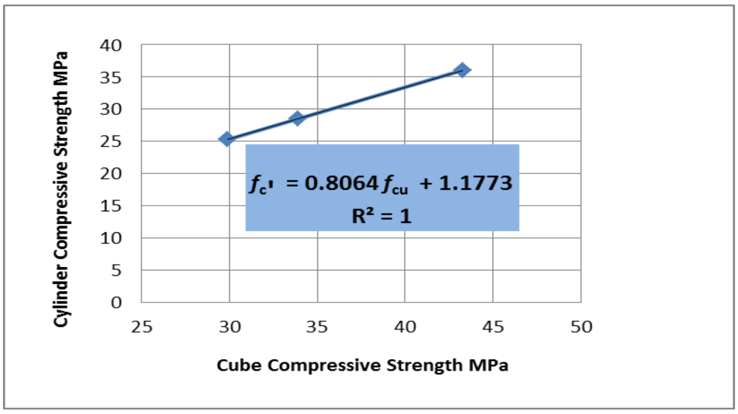

Figure (7) Relation Between Cylinder and Cube Compressive Strength of SLWAC

4-3 Tensile Strength

The splitting and flexural tensile strength of LWC ranged between (2.08 – 3.11 MPa) and (2.39 – 3.95 MPa), respectively. As expected, the tensile strength (splitting and flexural) of LWC increases with increase in compressive strength as shown in Table (4).

The pumice texture is rough and has many cavities and hollows and the shape is angular; these properties possibly improved the interfacial bond, so resulting in a higher splitting and flexure tensile strength comparison with other types of LWAs used.

The use of natural gravel instead of LWA increased the splitting and flexural tensile strength by about 48.6% and 59.6%; respectively when compared with average value for LWA concrete; it can also be seen that the percentage of increased of flexural tensile strength is more than splitting tensile strength. This can be explained by the fact that the gravel resist the progress of the cracks that are formed under flexure test with increasing load over LWAs because it is stronger.

The ratio of flexural tensile strength to cylinder compressive strength as shown in Table (3) for M-PS, M-TB and M-PR is overestimates by about 24.7%, underestimates by about 10.9% and almost the same when compared with the proposed relation by (**ACI318, 2014**) $f_r/\sqrt{f_{c'}} = 0.527$ ($\lambda = 0.85$ for sand LWC). This is due to the nature and the strength of CLWAs used.

Figure (8) compares proposed equation of splitting tensile strength and cylinder compressive strength with the formula of ACI318**,** 2014, it can be concluded that the differences between them resulted from the reduction factor of density λ which used in ACI318/14.

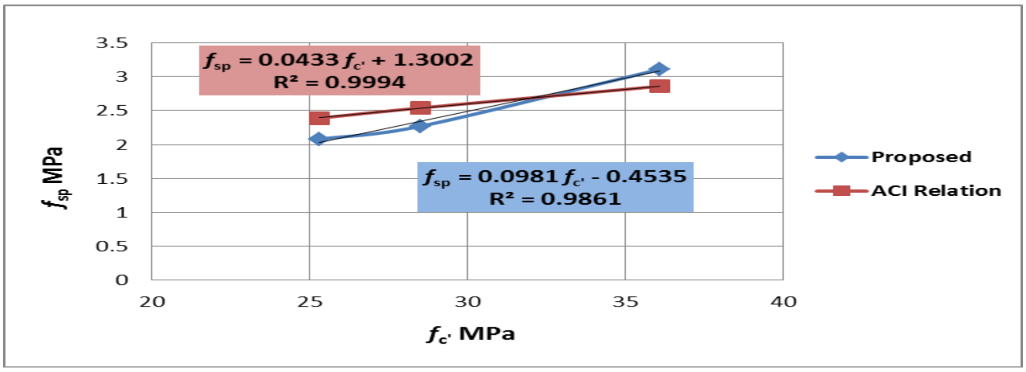

Figure (8) Relationship between Splitting Tensile Strength and Compressive Strength

The relation between splitting tensile strength and square root of cylinder compressive strength for mixture used gravel is close to the value of ACI318, 2014. However, the splitting tensile strength of natural aggregate concrete overestimates by about 5.2% compared with the ACI318**,** 2014.

4-4 Modulus of Elasticity

Concrete modulus of elasticity depends on the modulus of elasticity of its ingredients and their proportions in the mix. These include the aggregate type, the concrete compressive strength and the concrete density.

Due to the significant differences in the lightweight aggregate stiffness for a given particle density, it is more easy to relate the modulus of elasticity, for each type of LWA used in the present research with its square root of compressive strength only, once $E_c/\sqrt{f_{c'}}$ and; again with density $E_c/\gamma^{1.5}\sqrt{f_{c'}}$ as shown in Table (3) to compare with the corresponding values in ACI318**,** 2014.

Generally, as is known, the modulus of elasticity of LWC is directly proportional to the compressive strength and density of concrete. However, it can be noted in Table (3) that the relative proportion depends not only on the compressive strength with/without density of the concrete but also on the strength and stiffness of the aggregate used.

This is evident in pumice mixture M-PS; although it is had the higher modulus of elasticity and higher compressive strength, the ratio of $E_c/\sqrt{f_{c'}}$ is the lowest value than other types of LWAs used in M-PR and M-TB concrete by about 12.6% and 17.7%; respectively. On the other hand, the M-G concrete gives underestimated value of modulus of elasticity $E_c = 4397\sqrt{f_{c'}}$ when compared with ACI318/14 relation for normal concrete $E_c = 4700\sqrt{f_{c'}}$ (by about 6.9%).

A ratio relating with the modulus of elasticity as a function of its density and compressive strength $E_c/\gamma^{1.5}\sqrt{f_{c'}}$ that have been calculated in Table (3) gave overestimate values for all LWAC types by about (5.1%-14.2%) and underestimate value for normal concrete by about 13.8% when compared with their instance of ACI318/14; $E_c(GPa) = \left(\rho^{1.5} 0.043\sqrt{f_{c'}}(MPa)\right)\times 10^{-3}$; ρ = (1440 - 2480) kg/m^3.

Table (4), illustrate the comparisons between the predicted values of the modulus of elasticity using the relations derived by (**BS 8110: 2, 1985**), (**CEB: FIP, 1998**), and (**Chinenkov *et. al.*, 1980**) as a function of its density and compressive strength with experimental and proposed values. Figures (9) illustrated the formulae proposed that linked the modulus of elasticity with cylinder or cube compressive strength which used in Table (4).

It can be seen that the values resulted by the mentioned literature codes or researchers is lower than values providing by experimental work, while, the values resulted by proposed relation is higher than experimental values because of density is not included within the proposed equations.

Table (4) Comparison Study For Modulus of Elasticity

Mix Symbol	Experimental E_c GPa	Proposed		BS 8110-2/85 $E_c = (20 + 0.2 f_{cu})(\frac{\rho}{2400})$ GPa	CEB-FIP/98 $E_c = 9.5(\frac{\rho}{2400})^2 f_{c'}^{\frac{1}{3}}$ GPa	Chinenkov, et al / 80 $E_c = 0.00313\rho f_{cu}^{\frac{1}{3}}$ GPa
		E_c & $f_{c'}$	E_c & f_{cu}			
M-PR	20.1	19.8	19.8	16.9	18.3	19.3
M-PS	24.2	24.2	24.3	17.7	19.4	20.8

M-TB	19.8	20.1	20.2	15.8	16.9	18.2

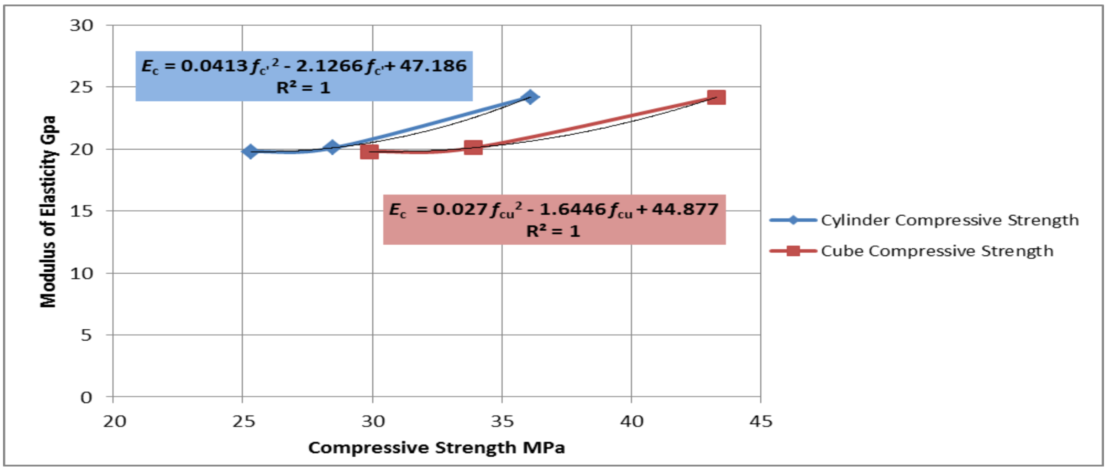

Figure (9) Relationship between Modulus of Elasticity and Compressive Strength

The replacement of CLWA with gravel in M-G mix resulted in an increase in the modulus of elasticity by amount of 29.2% as average value for the same mixing percentages used. The percentage of increasing the modulus of elasticity by about 37.3%, 14% and 39.4% when compared with porcelinite, pumice and composition aggregate (25% thermestone and 75% bricks), respectively.

In LWC, the pumice aggregate gave the higher value of modulus of elasticity than other LWAs by about 20.4% and 22.2% when compared with porcelinite and composition aggregate, respectively. This is due to the different in strength of aggregate type used.

4-5 Non-Destructive Tests

4-5-1 Rebound Number (RN) Test (Schmidt Hammer)

The RN test was performed for (150×300 mm) cylinders by taking two faces in the longitudinal direction, while (150) mm cubes test by taking six faces in three directions and (100×100×400 mm) prisms test by taking two faces in the longitudinal direction and three locations for each face in other two directions for all concrete types; in the same locations which UPV test were performed later.

According to specifications, more than (10) readings per specimens should be taken. It is suggested that the highest and lowest reading should be discarded. Conversion graphs are provided with the instrument to indicate a measure of compressive strength with the reading obtained from the test hammer scale.

This test was performed on all faces of specimens, the results indicate that all faces gives approximately same results which are ranged between (35.7-38.5) for LWAC and about 43.2 for normal concrete as shown in Table (2).

The RN value of normal concrete that used gravel is higher than it in LWAC by about 16.8% as average value. The RN value for pumice concrete M-PS is higher than them in M-PR and M-TB by about 4.3% and 7.8%. These results show that the hammer depends mainly on the compressive strength of the concrete and therefore on the strength of the aggregates used.

4-5-2 Ultrasonic Pulse Velocity (UPV) Test

The UPV test for concrete is based on measuring the travel time over a known path length of a pulse of ultrasonic compression waves. In present study, it was performed after RN test.

The control specimens of (150×300 mm) cylinders test by taking one reading in the longitudinal direction, while, (150) mm cubes test by taking one reading in three directions and (100×100×400 mm) prisms test by taking one reading in the longitudinal direction and three reading in other two directions then take average values.

Results of tests indicate that there are similar UPV value with different shape of control specimens (cubes, cylinders and prisms) for each type of LWAC and normal concrete. This means that the UPV test not dependent on the shape of specimens tested for any type of concrete. But, the UPV test for LWAC is affected by path length more than normal concrete; the UPV values for prism specimens are anomalous when using path length equal to 400 mm. therefore, neglect its results from the calculate of average values that shown in Table (2).

The results of UPV test for LWAC and normal concrete cubes and prisms in direction and in anti-direction of casting are also indicate approximately similar values results, this shows the good homogeneity and good compact of concretes.

The UPV test results of All types of LWAC range between (3.31 – 3.83 km/sec). While, 4.91 km/sec for normal concrete. As an average, the UPV results of LWAC are lower than that result for NWC by about 38.3%, this is due to the difference in properties of coarse aggregate and therefore on concrete density.

The UPV result of porcelinite LWC, is higher than the results of pumice and composition aggregate (25% thermestone and 75% bricks), by about 8.8% and 15.7%, respectively. This means that the density is the main factor effected on UPV results more than compressive strength.

This test aimed at developing a method of combined use of both the non-destructive tests (Schmidt rebound number and Ultrasonic pulse velocity) for assessment the concrete quality with greater accuracy. Figure (10) illustrates the relations between RN value and cylinder compressive strength and UPV value and density for LWAC used different types of CLWA within the mechanical properties range of current study.

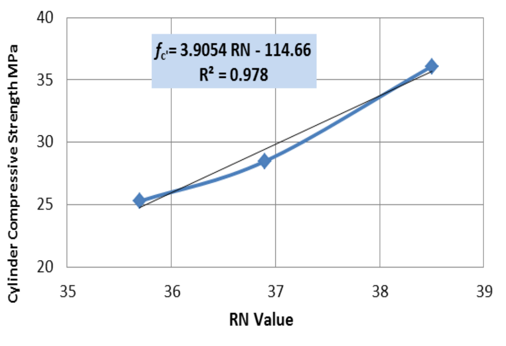

Figure (10-A) RN VS. Cylinder Compressive Strength

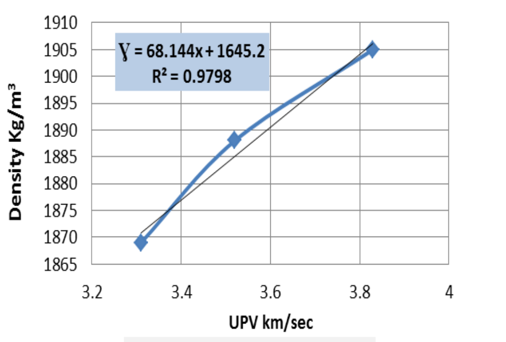

Figure (10-B) UPV VS. Density

Figure (10) Relationship between RN vs. $f_{c'}$ and UPV vs. Density

5- Conclusions

1- The structural lightweight aggregate concrete with density of less than 2000 kg/m^3 and with cylinder compressive strength ranged between (25.3-36.1) MPa at 28 days can be produced with the use of waste, recycled and natural local materials in Iraq such as (porcelanite rocks, pumice stones, recycled local Iraqi clay bricks and waste of themestone) as light weight coarse aggregate with cementitious materials content of 430 kg/m^3 in addition to use minerals admixtures and super plasticizers.

2- Composite aggregate (25% thermestone and 75% bricks) concrete gave the lowest value of hardened density (1869 Kg/m^3) with the lowest value of cylinder compressive strength (25.3 MPa) while Pumice aggregate concrete have the highest value of cylinder compressive strength (38.5 MPa) at a hardened density about (1888 Kg/m^3) and porcelinite concrete have the highest density (1905 Kg/m^3) with cylinder compressive strength equal to (28.5 MPa).

3- The pumice aggregate concrete gave the higher value of modulus of elasticity than other LWAs by about 20.4% and 22.2% Also, it gave the higher splitting and flexure tensile strength by about (37% and 37.2%) and (49.5% and 65.3%) when compared with porcelinite and composition aggregate, respectively. This is due to the difference in strength of aggregate type used, on the other hand, the pumice texture is rough and has many cavities and hollows and the shape is angular; these properties possibly improved the interface bond

4- In lightweight aggregate concrete, it is necessary to relate the density with the derived equations between mechanical properties for more accuracy when compared with formulae of ACI318, 2014.

5- The RN value of normal concrete that used gravel is higher than it in LWAC by about 16.8% as average value. While, the UPV results of LWAC are lower than that result for NWC by about 38.3%, this is due to the difference in properties of coarse aggregate and therefore on concrete density.

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