The Effect of Different Types of Aggregate and Additives on the Properties of Self-Compacting Lightweight Concrete

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Abstract

The major aim of this research is study the effect of the type of lightweight aggregate (Porcelinite and Thermostone), type and ratio of the pozzolanic material(SF and HRM) and the use of different ratios of w/cm ratio(0.32 and 0.35) on the properties of SCLWC in the fresh and hardened state. SF and HRM are used in three percentage 5%,10%, and 15% as a partial replacement by weight of cement for all types of SCLWC. The requirements of self-compatibility for SCC are fulfilled by using the high performance superplasticizer (G51) at 1.2liter per 100 kg of cement.

The values of air dry density and compressive strength at age of 28 days within the limits of structural lightweight concrete. The air dry density and compressive strength at age of 28 days for w/cm ratio(0.32) for SCLWC of Porcelinit aggregate are 1964 kg/m^3 and 29.57 MPa, respectively. The corresponding values for the SCLWC of Thermostone aggregate are 1820 kg/m^3 and 25.75 MPa, respectively. The results show that the HRM performance which is locally available is better than SF in production of SCLWC.

Keywords: Self-compacting lightweight concrete, porcelinite, thermostone, superplasticizer, silica fume, high reactivity metakaoline

المستخلص

إن الهدف الرئيسي من البحث هو دراسة تأثير نوع الركام الخفيف الوزن(البورسيلينايت و الثرمستون) ونوع ونسبة المادة البوزولانية (الميتاكاوؤلين عالي الفعالية والسليكا فيوم) واستخدام نسبتين مختلفتين من نسبة الماء إلى الاسمنت(0.32 و 0.35)على خواص الخرسانة خفيفة الوزن ذاتية الرص في الحالة الطرية والحالة الصلبة. استخدمت كل من السليكا فيوم والميتاكاؤولين عالي الفعالية بثلاث نسب 5%،10%،15% كاستبدال جزئي من وزن الاسمنت لكل نوع من أنواع الخرسانة خفيفة الوزن ذاتية الرص.

وقد تم تحقيق متطلبات الخرسانة ذاتية الرص باستعمال الملدن عالي الأداء بنسبة 1.2لترلكل 100كغم من الاسمنت لكل نوع من أنواع الخرسانة خفيفة الوزن ذاتية الرص. كانت قيم الكثافة الجافة ومقاومة الانضغاط بعمر 28 يوم ضمن حدود الخرسانة الإنشائية خفيفة الوزن فالكثافة الجافة ومقاومة الانضغاط بعمر 28 يوم ولنسبة ماء إلى إسمنت تساوي 0.32 لخرسانة ذات ركام البورسيلينايت خفيف الوزن ذاتية الرص كانت 1964 كغم\م^3 و29.57 ميكاباسكال على التوالي بينما كانت في الخرسانة ذات ركام الثرمستون خفيف الوزن ذاتية الرص 1820 كغم\م^3 و 25.75 ميكاباسكال على التوالي وقد بينت النتائج بأن أداء الميتاكاؤولين عالي الفعالية المتوفر محليا أفضل من أداء المضاف(السليكا فيوم) في إنتاج الخرسانة خفيفة الوزن ذاتية الرص.

1-Introduction

Lightweight concrete (LWC) is a concrete which by one means or another has been made lighter than conventional concrete. Using concrete with a lower density can, therefore, result in significant benefits in terms of load-bearing elements of smaller cross-section and a corresponding reduction in the size of foundations. Furthermore, with lighter concrete , the formwork needs to withstand lower pressure than would be the case with normal weight concrete, and also the total mass of material to be handled is reduced with a consequent increase in productivity. Concrete which has a lower density also gives better thermal insulation than ordinary concrete and possesses good fire and frost resistance(**Neville 2005).** Self-compacting concrete (SCC) represents one of the most outstanding advances in concrete technology during the last decade. Due to its specific properties ,SCC can contribute significantly to the quality of concrete structures and open up new fields for the applications of concrete. SCC describes a concrete with the ability to compact itself only by means of its own weight without the requirement of vibration, it fills all recesses , reinforcement spaces and voids even in highly reinforced concrete members and flows free of segregation nearly to a level balance. Self-compacting lightweight concrete is a new building material which combines the known advantages of lightweight concrete and self-compacting concrete. Lightweight concrete with self-compacting ability offers considerable benefits, from reducing the density of concrete and providing self-compacting properties.

The workability of self-compacting lightweight concrete (SCLWC) can be characterized by the following properties (**Badman 2003**)

1. Filling ability: the ability of SCLWC to flow under its own weight (without vibration) to fill completely all spaces within intricate formwork, containing obstacles, such as reinforcement.

2. Passing ability: the ability of SCLWC to flow through openings approaching the size of the mix coarse aggregate. such as the spaces between steel, reinforcing bars, without segregation or aggregate blocking. This property is of concern in those application that involve placement in complex shapes or sections with closely spaced reinforcement.

3. Segregation resistance (stability): the ability of SCLWC to remain homogenous during transportation , placing and after placement.

1-1 Development of Self-Compacting Concrete

For several years beginning in 1983, the problem of the durability of concrete structures was a major topic of interest. To make durable concrete structures, sufficient compaction by skilled workers is required. However, the gradual reduction in the number of skilled workers in construction industry has led to a similar reduction in the quality of construction work. One solution for the achievement of durable concrete structures, independent of the quality of construction work, is the use of self-compacting concrete, which can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction (**Ouchi 1999).**

1-2 The methods for achievement self-compatibility

Okamura and ouchi (2003) have employed the following methods to achieve self-compatibility:

1-limited aggregate content;

2- low water-powder ratio;

3- Use of superplastizer.

They found also that the highly viscous paste is also required to avoid the blockage of coarse aggregate when concrete flows through obstacles, High deformability can be achieved by the employment of a super plasticizer, keeping the water-powder ratio to a very low value. They have also found that the frequency of collision and contact between aggregate particles can increase as the relative distance between the particles decreases and then internal stress can increase when concrete is deformed, particularly near obstacles. They have concluded that the energy required for flowing is consumed by the increased internal stress, resulting in blockage of aggregate particles. Limiting the coarse aggregate content to a level lower than normal, which is effective in avoiding this kind of blockage.

1-3Structural lightweight concrete (SLWC)

The (American Concrete Institute) (**ACI 213R-91)** defines the structural lightweight concrete as a concrete which (a): has a minimum compressive strength at 28 days of 17.2MPa,(b): has a corresponding air-dry unit weight in a range of 1440 to 1850 kg/m^3 and (c): consists of all lightweight aggregate LWA or a combination of LWA and normal weight aggregates.

Al-Rawi(1995) has studied the properties of Porcelinite lightweight aggregate to produce LWC. 18 mixes in various mix proportion are prepared without using any admixture. Cement content was between 272 - 687kg/m^3 and water/cement ratios ranged between 0.65-1.6.The lightweight concrete used in this investigation can offer a compressive strength up to 32MPa with an air dry density of 1815 kg/m^3 at 28 days.

1-4 Self-Compacting Lightweight Concrete (SCLWC)

Self-compacting lightweight concrete (SCLWC) is a new high-performance building material, which combines the well-known advantages of lightweight concrete with those of self-compacting concrete (SCC).

Kobayashi (2001) has examined the characteristics of SCC in fresh state with artificial lightweight aggregate (LWA).Whereas, the artificial LWA has lower water absorption ratio than ordinary LWA because of its tight surface structure, and can be used for concrete mixing without pre-wetting procedure. Another advantage of this aggregate is its spherical shape that is expected to increase fluidity of concrete. The results show that SCC with this aggregate has higher self-compactability than that with crushed stone, while the deformation rate of concrete is very small. Segregation between the aggregate and mortar, however, tends to be large because of larger difference of specific gravity between them than in the case of ordinary self-compacting concrete with crushed stone. Increase in unit mass of the lightweight aggregate does not affect so much on self-compactability of concrete.

2- Objective of the research

The main objective of this study is to investigate the effect of the following variables on the properties of SCLWC in the fresh and hardened states:

1. type of lightweight aggregate by using porcelinite and waste crushed Thermostone aggregate.

2. type of mineral admixtures by using silica fume (SF) and high reactivity metakaoline (HRM).

3. Water cement ratio by using two values of 0.32 and 0.35.

Results of this research will provide information about the rheological and mechanical properties of self-compacting lightweight concrete. High performance superplasticizer (Glinume 51) is used as chemical admixture in this study. In this study, the self-compatibility tests (Slump flow, V-Funnel, L-Box, U-Box) were performed on the fresh concrete for each mix of SCLWC. Air dry density at 28 days, compressive strength and splitting tensile strength at 7,28,90 day tests are conducted. 28 concrete mixes are investigated in fresh and hardened state. A total of 252 concrete cubes of 150 mm, 252 concrete cylinders of 150×300 mm, are cast, cured and tested for this study.

3- Experimental work

3-1 Materials

- **Cement**

AL-Shemalia ordinary Portland cement manufactured in Kingdom of Saudi Arabi (KSA) is used in this research. the results of the chemical analysis and physical properties of the cement indicate that the available cement is conformed to the Iraqi Specification as shown in **Table 1**and **Table2** (Chemical and Physical properties of cement are performed by the State Company of Geological Survey and Mining.)

- **Water**

potable water is used as a mixing water for all concrete mixes.

- **Sand**

Al-Ekhaider sand of 4.75 mm maximum size is used as fine aggregate in concrete mixes the results of the chemical analysis and physical properties of the sand indicate that the available sand is conformed to the Iraqi Specification as shown in **Table 3.**(Chemical and Physical properties of sand are performed by the State Company of Geological Survey and Mining.)

- **Coarse aggregate**

- **Porcelinite Aggregate**

Crushed stone Porcelinite has been used as coarse aggregate in this study with max. size 9.5 mm

- **Thermostone Aggregate**

Thermostone aggregate is considered as one of the industrial residual which is accumulated during industrial process of Thermoston blocks. it used with max. size 9.5 mm.

The grading and physical properties of Porcelinite and Thermos tone aggregate conform to the requirements of the **ASTM C330** as shown in **Fig. 2** and **Table 4** respectively. (Physical properties of Porcelinite and Thermestone are performed by the State Company of Geological Survey and Mining) **. Table (4a)** indicate the sieve analysis of coarse aggregate.

- **Chemical Admixture**

A high performance concrete superplasticizer Glinume 51 (G51) is used in this research as chemical admixture .G51 complies with **ASTM C494 Types A and F**

- **Mineral admixture**:

- **Silica fume (SF)**

The chemical analysis of SF was used in this research conforms to the chemical requirements of **ASTM C1240** as shown in **Table5** and **Table 6.**

- **High Reactivity Metakaoline(HRM)**

The chemical analysis of HRM was used in this research conforms to the chemical requirements of **ASTM C618** respectively as shown in **Table 7** and **Table 8**. (Chemical analysis of HRM and SF are performed by the State Company of Geological Survey and Mining)

3-2 Design of Concrete Mixes

The design of SCLWC mixes is performed to produce structural lightweight concrete conforms to the requirements of structural LWC, according to **ACI Committee 213** In the same time, the mix deign of SCLWC must satisfy the criteria of filling ability, passing ability and segregation resistance. The mix design method of SCC used in the present study is according to **EFNARC 2005**, Two series are used throughout this research, Porcilinite aggregate is used as a coarse aggregate in the first series, Thermostone aggregate is used as a coarse aggregate in the second series. Two w/c ratios (0.32 and 0.35) are adjusted for each mix and The optimum dosage of GLINUME51(G51) (1.2 liter per 100 kg of cement) For all mixes, cement content is 500 kg/m^3 , fine aggregate is 590 kg/m^3 and coarse aggregate is 620 kg/m^3. The optimum dosage of GLINUME51(G51) (1.2 liter per 100 kg of cement) is obtained from several trail mixes incorporating G51,by increasing the dosage of the admixture gradually ,and fixed the w/cm ratios (0.32and 0.35) to ensure the self-compactability as shown in **Fig.1**.

3-3 Mixing of concrete

The Porcelinite and Therrmostone aggregate is used in saturated surface dry (SSD) ,which is recommended by the **ACI committee 211-2** . In this study the method of **Emborg2000** is used in the mixing of reference concrete (LWC) and self-compacting lightweight concrete. This method includes the following steps for reference concrete:

1.The dry quantity of fine aggregate is mixed with 1/3 of mixing water for 1 minute.

2.The quantity of cement with 1/3 of mixing water is added to the mix and the mixture is mixed for about 1 minute.

3.The quantity of coarse aggregate plus 1/3 of mixing water+1/3 of the dosage of the admixture are added to the mix and the mixture is mixed for about 1 minute after that leave the mixture to rest for 1.5 minute.

4. The remained dosage of the admixture is added to the mix and the mixture is mixed for about 1.5 minute.

For mixing the SCLWC the same steps as shown above except before adding the quantity required of cement, the required quantity of mineral admixture (S.F or HRM) is added by the weight of cement and mixed with the cement only for about 15 second to disperse all the particles of mineral admixture(S.F or HRM) throughout the cement grains.

3-4 Testing of concrete

❖ **Testing of Fresh Concrete**

- Slump test was used to determine the workability for reference concrete. This test is performed according to **ASTM C143**.
- Slump Flow Test, V-Funnel test, L-Box Test and U-Box Test were used to characterize the properties of SCLWC (filling ability, passing ability and segregation resistance these tests were performed according to **EFNARC 2002** and **EFNARC 2005**.

❖ **Testing of Hardened Concrete**

- **Compressive Strength**: The compressive strength test is carried out on 150mm cubes This test was performed according to **BS1881:part 116** The specimens are tested at ages of 7,28 and 90 days and in each age the average of three specimens are adopted.
- **Splitting Tensile Strength**: The splitting tensile strength test is performed according to **ASTM C496** ,150×300 mm cylindrical concrete specimens are used. The specimens are tested at age of 7,28 and 90 days and in each age the average of three specimens has been adopted
- **Hardened Unit Weight (28 Days Air Dry Density):** This test is used to determine the air dry density of concrete mixes Cubes specimens of 150mm are used in this test at age of 28 days the test is performed according to **ASTM C567**.

4- Properties of Fresh SCLWC

- **Slump Flow**: The results of Slump flow test ranged between 657- 712 mm for SCLWC mixes produced from Porcelinite aggregate and range between 679--769 mm for SCLWC mixes produced from Thermostone aggregate. These results are within the acceptable criteria for SCC and indicate also excellent deformability and filling ability without any segregation ,bleeding and blocking.

V-Funnel: The values of flow time (TV) range between 9.8-12.4 sec and 6.4-11.5 sec for SCLWC mixes produced from Porcelinite aggregate for w/cm ratio 0.32 and 0.35 respectively. The values of flow time (TV5) range between 10.6-15.2 sec and 8.5-14.5 sec for SCLWC mixes produced from Porcelinite aggregate for w/cm ratio 0.32 and 0.35 respectively.. Values of flow time (TV) range between 6.5-11.5 sec and 6-10.5 sec for SCLWC mixes produced from Thermostone aggregate for w/cm ratio 0.32 and 0.35 respectively. Values of flow time (TV5) range between 7.8-13.7 sec and 7.4-12.8 sec for SCLWC mixes produced from Thermostone aggregate for w/cm ratio 0.32 and 0.35 respectively. These results are within the acceptable criteria for SCC(**EFNARK 2002**).

L-Box: The results of L-Box test blocking ratio (H2/H1) range between 0.8-0.94 for all mixes of SCLWC. These results are within the acceptable criteria for SCC and indicate that the mixes have excellent passing ability.

- **U-Box:** The results of U-Box test filling height (H1–H2) range between 12-28 mm for all mixes of SCLWC. These results are within the acceptable criteria for SCC.

5- Hardened Concrete Properties

- **Compressive Strength:** The results of compressive strength test for all concrete mix in this study at 28 days are higher than 17 MPa, the minimum required strength recommended by **ACI-213** for structural LWC.
At early ages (7 days) (see **Fig3**) for the same w/cm ratio the compressive strength for all concrete mix of SCLWC containing SF is higher than concrete mix of SCLWC containing HRM and reference mix The contribution of silica fume to the early strength development (up to 7 days) is through improvement in packing and the interface zone with aggregate (**Neville 2002**) While for HRM, the dilution effect of it, when is used as a partial replacement for cement. The concrete mixture will also experience some effect of the removal of cement from reacting system and that affecting the early compressive strength (**Justice 2005**) For this reason, all concrete mixes of SCLWC containing HRM give compressive strength at 7days less than the compressive strength of reference concrete at the same age. At 28 and 90 days (see **Figs. 3**) for the same w/cm ratio the compressive strength for all concrete mixes of SCLWC containing HRM was higher than concrete mix of SCLWC containing SF.

This is due to high pozzolanic activity of HRM if compared with SF(P.A.I for SF=108%, for HRM=140%) as HRM the major components responsible for the pozzolanic reaction are alumina and silica (**Advanced Cement Technology 2002**) From the chemical composition of HRM used in this study, the sum percentage of alumina(AL_20_3) and silica(SIO_2) is 91.17%, more than the percentage of amorphous silica (SIO_2) in SF which is responsible for the pozzolanic reaction(**ACI234R-96**) (SIO_2=87.45% for SF used in this study). The pozzolanic reaction take place between the components mentioned above in pozzolanic material (SF and HRM) and calcium hydroxide CH formed during the hydration process. This leads to the cementations compound which is produced from the reaction of HRM more than the cementations compound which is produced from the reaction of SF and this leads to densification of the concrete matrix resulting in a considerable increase in strength ,and reduction in permeability. Besides, the pore-size and grain-size refinement processes associated with pozzolanic reaction can effectively reduce the microcraking and strengthen the transition zone (**Mehta et al 2006**).

- **Splitting Tensile Strength:** Due to the usage of mineral admixtures(SF and HRM), chemical admixtures (Glinume 51) , in addition to the self- compactability, an improvement to the ITZ is expected. Consequently, good results of tensile strength are expected**. Figs(4)** show that at early ages (7 days) and for the same w/cm ratio splitting tensile strength of SCLWC mixes containing SF is higher than SCLWC mixes containing HRM and reference mixes. This is due to the physical effect of silica fume and the ability of the extremely fine particles of silica fume to be located in very close proximity to the aggregate particles, that is, at the aggregate-cement paste interface, and this allows to the cement particles packing tightly against the surface of the aggregate, and this leads to strengthen the ITZ. A contributing factor is the fact that silica fume because of its high fineness, reduces bleeding so that no bleed water is trapped beneath coarse aggregate particles. Consequently, the porosity in the ITZ is reduced then splitting tensile strength increased (**Neville 2002**) . Due to the dilution effect of HRM when it is used as a partial replacement of cement, splitting tensile strength at 7 days of SCLWC mixes containing HRM is less than reference mixes (LWC) . At 28,90 days and for the same w/cm ratio **Figs(4)** show that the splitting tensile strength of SCLWC mixes containing HRM is more than SCLWC mixes containing SF, this because of high pozzolanic activity of HRM if compared with SF as shown in pervious section. The pozzolanic reaction strengthen the transition zone through processes of pore size and grain size refinement ,thus reducing the microcracking of concrete. in addition the well and uniform dispersion of cement and particles of mineral admixture (HRM and SF) by the action of superplasticizer (Glinume 51) leads to a great improvement in tensile strength (**Mehta et al 2006**)(**Druta 2003**).

- **Hardened Unit Weight (28 day air dry density):** The results show that the 28 days air dry density for concrete mixes produced from Thermostone aggregate conform to the requirement of **ACI 213** for structural LWC. The 28 days air dry densities for concrete mixes produced from Porcelinite aggregate more than 1850 kg/m^3 ,but they are below 2000 kg/m^3 . However all concrete mixes in this study conform to the requirement of structural lightweight aggregate concrete, according to British specification which limits the maximum density of structural lightweight concrete to 2000 kg/m^3.
  The 28 days air dry densities for SCLWC mixes containing HRM more than SCLWC mixes containing SF(see **Fig. (5)**). This is due to the highly pozzolanic activity of HRM if compared with SF. The Cementation compound that results from the pozzolanic reaction of HRM is more than the cementation compound that result from pozzolanic reaction of SF, and this leads to an increase in cement gel and density.
  From **Fig.(5)**. The results show that the 28 days air dry densities of all SCLWC mixes are more than reference concrete mixes (LWC), this behavior can be ascribed to the pozzolanic reaction of mineral admixture(HRM and SF) in SCLWC mixes. The pozzolanic reaction leads to an increase in cement gel (the cementation compounds), it also leads to the densification of concrete matrix and the transition zone through the processes of pore-size and grain-size refinement(**Mehta et al 2006**).

6- Conclusions

1. It is possible to produce SCLWC by using two types of locally available porcelinite or thermostone as coarse lightweight aggregate, high performance superplasticizer (Glinume51)

and highly active pozzolanice materials (HRM and SF).

2. Results of this investigation indicated that locally available HRM performs better than SF in produced SCLWC.
3. The SCLWC mixes produced from Porcelinite aggregate showed considerable improvement in all mechanical properties compared with SCLWC mixes produced from Thermostone aggregate.
4. at 28 days There is a positive relationship between the air dry density and compressive strength and the percentage of the added pozzolanic material and the compressive strength of the SCLWC mixes.
5. There is no significant increase in all mechanical properties of SCLWC mixes for w/cm ratio 0.32 if compared with SCLWC mixes for w/cm ratio 0.35.
6. There is no significant increase in all mechanical properties of SCLWC mixes for w/cm ratio 0.32 if compared with SCLWC mixes for w/cm ratio 0.35.
7. The values of air dry density and compressive strength for SCLWC mixes produced from Thermostone aggregate at 28 days are within the requirements limits of structural LWC. At 28 days, the air dry density ranges between 1710-1820 kg/m^3 and 1688 -1795 kg/m^3 for w/cm ratio 0.32 and 0.35 respectively. The compressive strength ranges between 20.14 -25.75 MPa and 19.89 -25.21 MPa w/cm ratio 0.32 and 0.35 respectively. For reference concrete (LWC) the 28 days air dry density falls between 1683 and1653 kg/m^3 and the compressive strength falls between 18.50 and 17.88 MPa for w/cm ratio 0.32 and 0.35 respectively. the splitting tensile strength at 28 days ranges between 2.55 -3.09 MPa and 2.35 -2.89 MPa for w/cm ratio 0.32 and 0.35 respectively. For reference concrete (LWC), the splitting tensile strength at 28 days falls between 2.44 and 2.19 MPa for w/cm ratio 0.32 and 0.35 respectively.
8. The values of air dry density and compressive strength for SCLWC mixes produced from Porcelinite aggregate at 28 days are within the requirements limits of structural LWC. At 28 days, the air dry density ranges between 1907-1964 kg/m^3 and 1844-1944kg/m^3 for w/cm ratio 0.32 and 0.35 respectively. The compressive strength ranges between 24.12 -29.57 MPa and 22.22 -27.89 MPa w/cm ratio 0.32 and 0.35 respectively. For reference concrete (LWC) the 28 days air dry density falls between 1890 and 1823 kg/m^3, and compressive strength falls between 21.76 and 20.5 MPa for w/cm ratio 0.32 and 0.35 respectively. The splitting tensile strength at 28 days ranges between 3.17 - 3.77MPa and 2.84 -3.27 MPa for w/cm ratio 0.32 and 0.35 respectively. For reference concrete (LWC), the splitting tensile strength at 28 days falls between 2.91 and 2.69 for w/cm ratio 0.32 and 0.35 respectively.

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List of Abbreviations

CH	Calcium Hydroxide
C-S-H	Calcium Silicate Hydrate
G51	Glinume 51
HRM	High Reactivity Metakaoline
ITZ	Interfacial Transition Zone
LWA	Lightweight Aggregate
LWC	Lightweight Concrete
PAI	Pozzolanic Activity Index
Ref.	Reference
SCC	Self-Compacting Concrete
SCLWC	Self-Compacting Lightweight Concrete

SSD	Saturated Surface Dry
SF	Silica Fume
w/cm	Water to Cementitous Material Ratio
TV5	Flow time of V- funnel test after 5 minutes

Table (1) Chemical composition and main compounds of cement

Oxide composition	**% by weight**	**Limits of Iraqi Specification no.5 / 1984**
SIO_2	19.59	Not available
Fe_2O_3	3.53	Not available
AL_2O_3	4.63	Not available
Cao	61.58	Not available
Mgo	2.75	5.0(max)
SO_3	2.74	2.8(max)
Loss on ignition	1.64	4.0(max)
Insoluble residue	0.78	1.5(max)
Lime saturation factor	0.95	0.66-1.02
Main compounds (Bogue's equation)% by weight of cement		
C_3S	57.78	Not available
C_2S	12.89	Not available

C_3A	6.31	More than 5%
C_4AF	10.73	Not available

Table (2) Physical properties of cement

Physical property	Test result	Limits of Iraqi Specification no.5/1984
Specific surface area (blaine method), m²/kg	240	230 (min)
Setting time (vicate's method) Initial setting, hrs:min Final setting, hrs:min	1:00 6:00	00:45 (min) 10:00 (max)
Compressive strength, mpa 3 days 7 days	17.6 26.8	15.00 (min) 23.00 (min)
Autoclave expansion, %	0.5	0.8 (max)

Table (3) Chemical and physical properties of sand

Property	Test result	Limit of Iraqi Specification no .45/1984
Specific gravity.	2.54	Not available
Absorption, %	2.97	Not available
Dry loose unit weight, kg/m³	1587	Not available
Sulphate content as so_3,%	0.07	0.5(max)
Material finer than 75µm, %	2.6	5.0(max)

Table(4) Physical properties of the Porcelinite and Thermostone aggregate

Aggregate	Porcelinite	Thermostone
Sspecific gravity	1.52	1.14
Absorption, %	32.85	53.6
Bulk density(dry loose), kg/m³	765*	560*

***within the limits of ASTM C330 (880 kg/m³ max.) for coarse aggregate.**

Table (4a) Sieve analysis of coarse aggregate(Porcelinite and Thermestone)

Sieve size (mm)	Cumulative passing %	Cumulative passing%(Limits of ASTM C330)
12.5	100	100
9.5	95	80-100
4.75	30	5-40
2.36	11	0-20
1.18	0	0-10

Table (5) Chemical analysis of SF

Oxide composition	Oxide content %
SIO_2	87.45
AL_2O_3	0.35
Fe_2O_3	1.17
Mgo	2.4
Cao	1.25
SO_3	0.91
L.O.I	3.78
Na_2O	1.37

Table (6) Chemical requirements of SF according to ASTM C I240

Oxide composition	S.F.	Limits of ASTM C1240
SiO_2,min.,%	87.45	85.0
Loss on ignition, max %	3.78	6.0

Table (7) Chemical analysis of HRM

Oxide composition	Oxide content %
SiO_2	54.88
AL_2O_3	36.29
Fe_2O_3	1.4
Mgo	0.21
CaO	0.38
SO_3	0.21
L.O.I	2.47
Na_2O	0.66

Table (8) Chemical requirements of HRM according to ASTM C 618

Oxide composition	HRM	Pozzolan class N
SiO_2 + AL_2O_3 + Fe_2O_3, min. %	92.57	70
SO_3, max. %	0.21	4
Loss on ignition max	2.47	10

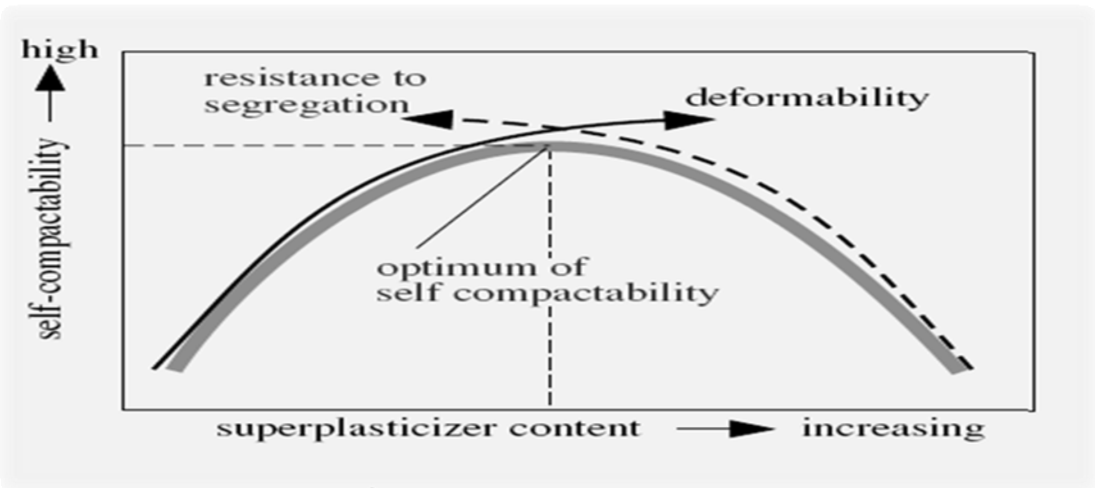

Fig. (1) Illustrative figure of self-compactability(Shindoh et al 2003)

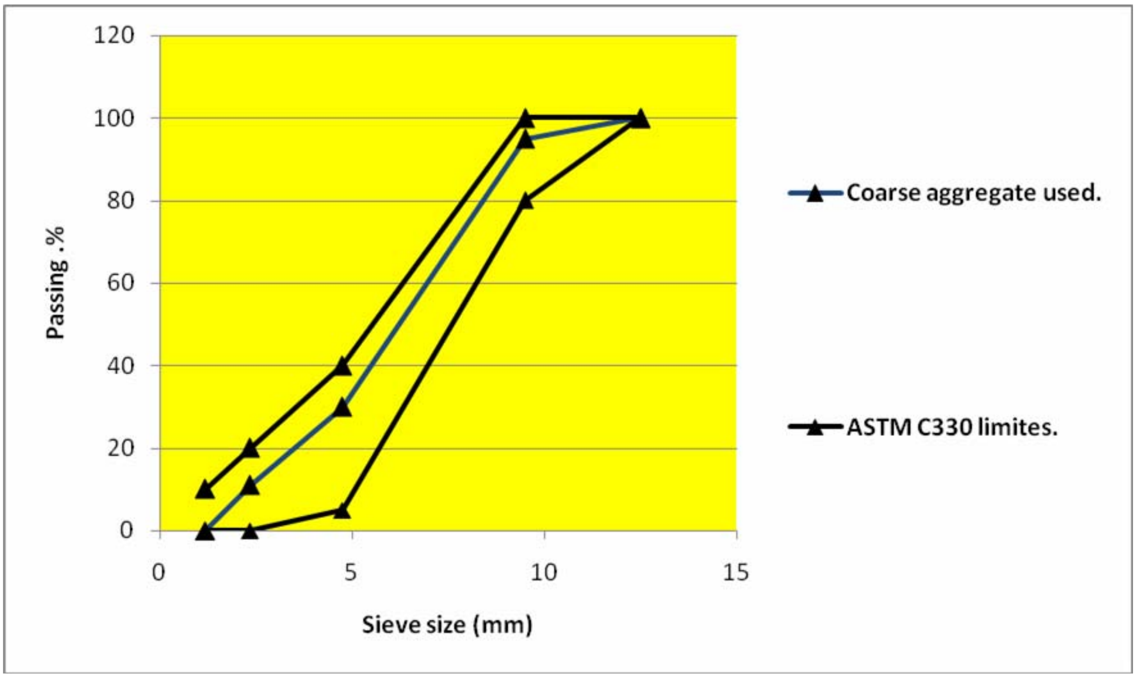

Fig. (2) Grading curve of coarse aggregate (Porcelinite and Thermoston)

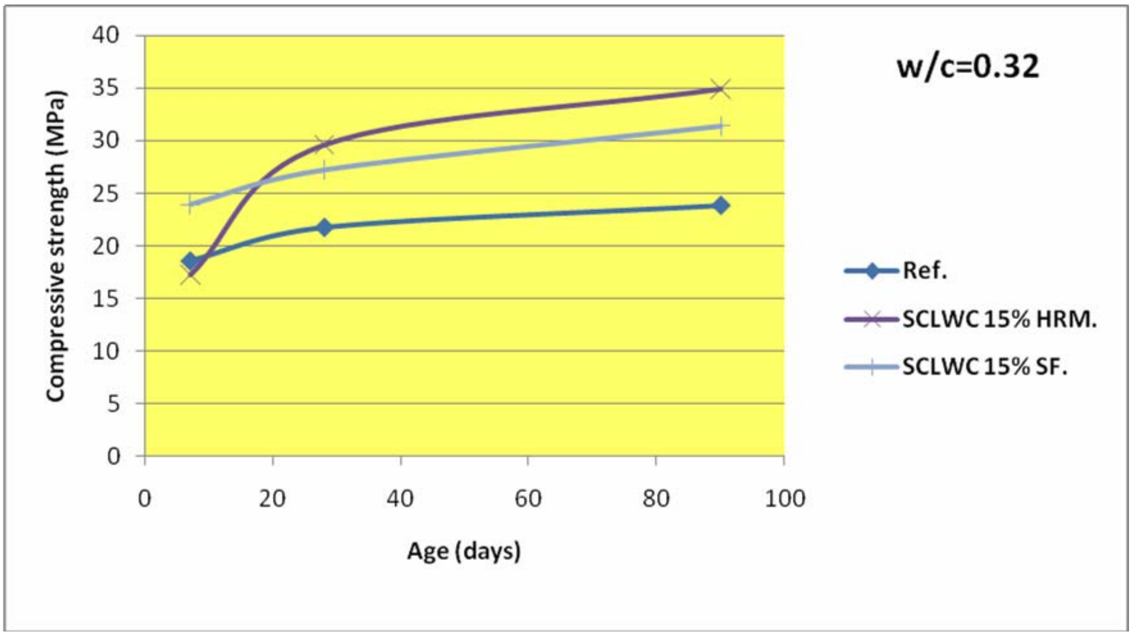

Fig. (3) Compressive strength development with age for Ref. concrete and SCLWC that containing 15% HRM and 15% SF for concrete mixes produced from porcelinite aggregate. for w/cm ratio (0.32)

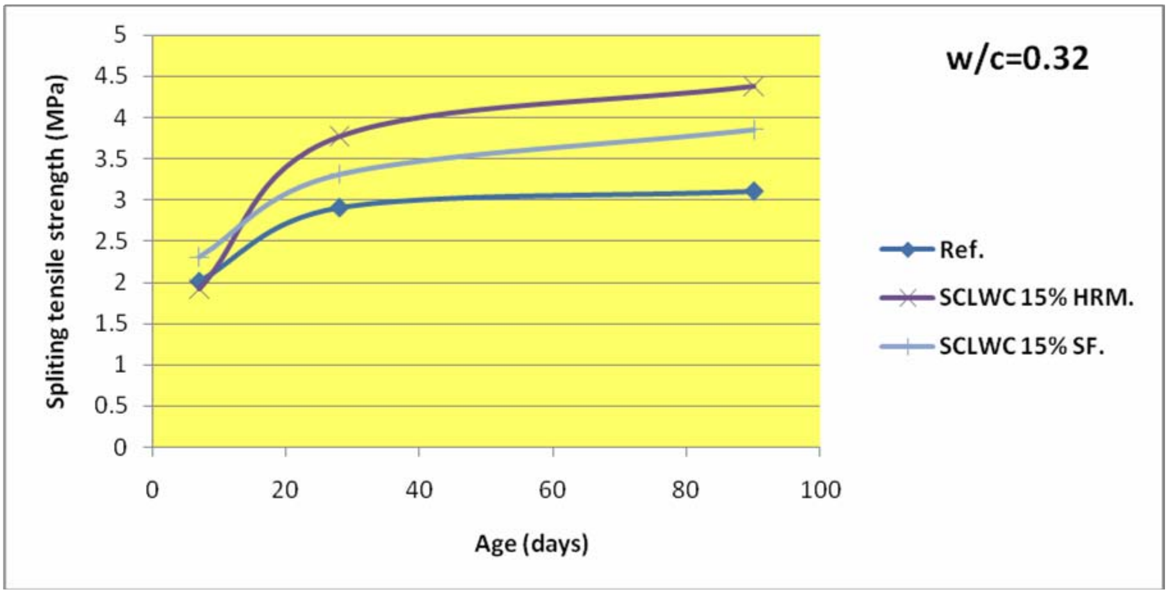

Fig. (4) Splitting tensile strength development with age for Ref. concrete and SCLWC that containing 15% HRM and 15% SF for concrete mixes produced from porcelinite aggregate for w/cm ratio (0.32)

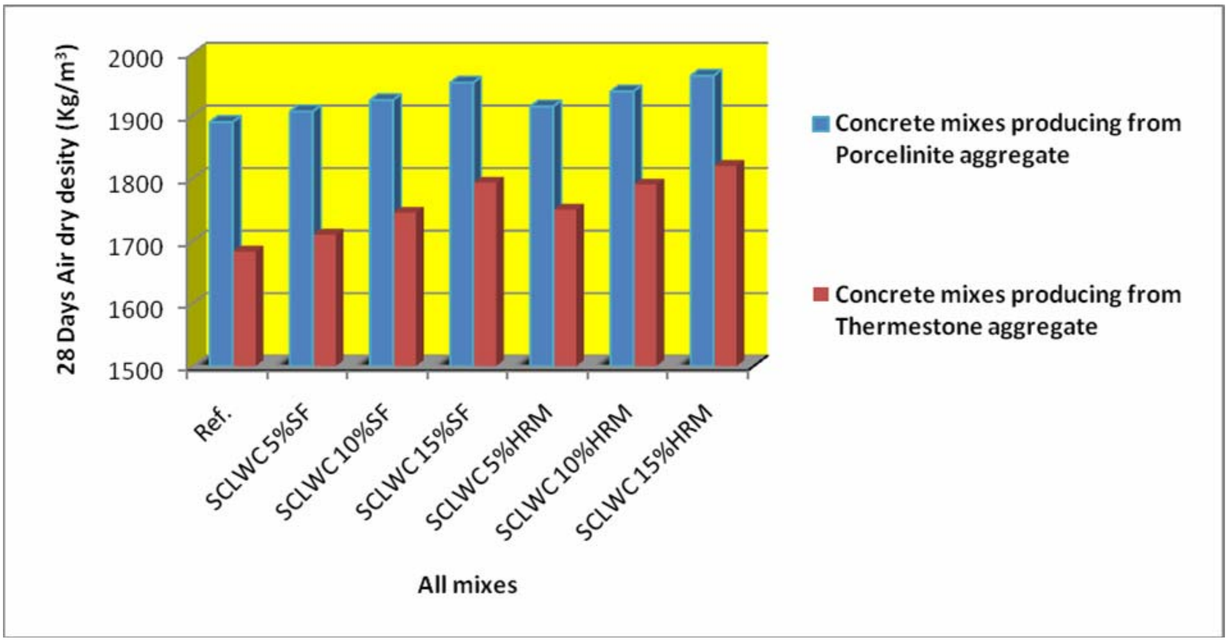

Fig. (5) 28 days air dry density for all concrete mixes for w/cm ratio (0.32)