IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 21, Issue 2 Ser. 1 (Mar. – Apr. 2024), PP 28-34
www.iosrjournals.org

A Comparative Study Of Self-Compacted Lightweight Concrete Developed By Utilizing Local And Artificial Lightweight Aggregates

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Abstract:
This paper presents the development of structural self-compacted lightweight concrete made with local and artificial lightweight aggregates. The water/binder ratio that was used in concrete mixes was set to 0.4. Five mixes were prepared and adjusted by inserting micro-silica and fly ash as supplementary cementitious materials. The percentages of micro-silica and fly ash were 5% and 20%, respectively. Polypropylene fibers percentages of 0.125% and 0.11% were also added to the mixes to increase the tensile capacity and control both plastic and autogenous shrinkage of concrete. Leca and basaltic pumice (scoria) have been utilized as lightweight aggregates to achieve the minimum density of concrete and reducing its unit weight. The graduation, specific gravity, water absorption, and fineness modulus have been testified for two types of local fine aggregates, in addition to, the graduation, specific gravity, water absorption, particle shape, and surface texture of both types of lightweight coarse aggregate. The properties of hardened concrete such as compressive strength, and tensile strength have been examined and the properties of fresh concrete such as slump flow, and density have been measured.

Keywords: *Lightweight Concrete (LWC), Self-compacted Concrete (SCC), Self-Compacted Lightweight Concrete (SCLC), Micro Silica (MS), Fly ASH (FA), Polypropylene Fibers (PF), Scoria, Lecca.*

Date of Submission: 17-03-2024 Date of Acceptance: 27-03-2024

I. Introduction

The need for developing self-compacted lightweight concrete has become an aim for structural engineers to face architectural challenges due to the growth of population and limited areas for urban sprawl. skyscraper method of growth has been applied in many countries such as United States, Japan, China etc. Building vertically emphasizes improving the properties of concrete to be flowable, pumpable, workable, compactable, stable, and durable. Mazloom and Mahboubi [1] reported that Self-compacted concrete is classified such a high performance concrete that owns the properties of self-compacted concrete (SCC) and lightweight concrete (LWC).Cui et al. [2] mentioned that self-compacted concrete (SCC) is a type of concrete that can be consolidated by its own weight and flowing for filling up the available space without the need for vibration. Kılıç et al. [3] reported that the essential component for producing lightweight concrete and reducing its unit weight is by utilizing lightweight coarse aggregate i.e., pumice or perlite aggregate. Shafigh et al. [4] have stated the main four advantages of using lightweight concrete instead of traditional concrete which can improve the structural performance of buildings. Firstly, LWC has higher thermal properties than conventional concrete and can significantly reduce energy consumption in buildings. Secondly, LWC owns more resistance to fire and provide stronger protective coat for the reinforcement. Thirdly, LWC has higher thermal insulation than normal concrete due to its higher void ratio, and this can be useful for reducing the adverse effect of noise pollution in congested cities. Lastly, ACI 213 defines the density of structural lightweight concrete to be in the range of (1440 kg/m^3,1850 kg/m^3) and its compressive strength is more than 17.2 Mpa at 28 days. The reduced bulk density of SLWC resulted in decreasing the dead load of the structure, therefore, reduction in the size of structural components, reduction in reinforcement, decreasing the cost of labor and equipment, minimizing the use of materials, increasing the availability for constructing more floors at a given bearing capacity of soil, reduction in the geotechnical cost of building, accelerating soil stabilization, and accelerating the rate of construction by decreasing the time schedule of the project. Cui et al. [2] SCC enhances the homogeneity of the concrete and achieve excellent finishes in addition to avoiding the chances for honeycombs due to either over consolidation or lack of consolidation at the site. SCLC has more resistance for aggregate interlock during pumping than normal concrete and require less energy to be added to the system. SCLC has a lower noise level than ordinary concrete due to its self-compaction. SCLC has low segregation chances due to its high powder content which increases the fluid carrying capacity of the mortar phase. The main objective of this study is twofold. First, to develop structural self-compacted lightweight concrete by using local and artificial lightweight aggregate such as scoria and leca. Second, to investigate the effect of coarse aggregate types on the mechanical properties of the green mix.

II. Used Materials

The materials used in experimental investigation include:

Cement

The cement that has been used in this study was Type I normal Portland cement from Yanbu cement company and had a specific gravity of 3.17 g/cm^3. The specific surface of Yanbu cement was 3450 cm^2/g and its initial and final setting times were 2.35 h and 3.01h, respectively. The cement properties conform to ASTM C 150 for type 1 cement and its chemical compositions are given in table 1.

Table 1: Chemical Composition of Cement, Fly Ash and Micro Silica (%)

Oxide composition	Cement (C)	Fly ash (FA)	Micro silica (MS)
SiO_2	20.20	60.420	89.2
LOI	1.80	0.43	3.260
CaO	63.42	0.181	0.057
Fe_2O_3	3.58	5.710	3.09
SO_3	2.91	0.364	0.461
MgO	2.45	0.798	0.663
K_2O	-	1.457	1.12
Na_2O	-	0.832	0.464
Al_2O_3	4.67	25.086	0.610

Fly Ash

The fly ash that has been used was type F and its source from India. The specific gravity of fly ash was 2.25 and its surface area was 3100 cm^2/g. SiO2 and SO3 content of the current fly ash are 60.42% and 0.364%, respectively. ASTM C-618 [5] requires that minimum SiO2 and maximum SO3 content of fly ash to be 40% and 3%, respectively. The chemical analysis that of fly ash is shown in table 1 and complies with the chemical requirements of ASTM C618 for fly ash.

Micro Silica

The utilized micro silica was from India as well. The specific gravity of micro silica was 2.43 and its surface area was 16*10^4 cm^2/g. the chemical composition of micro silica is illustrated in table 1 which complies with the chemical requirements of ASTM C1240 for silica fume.

Polypropylene Fibers

High performance micro–polypropylene fibers has been used in this study and their source was from Forsroc company. The main goals for inserting micro polypropylene fibers into mix were not only controlling the cracks resulted from plastic and autogenous shrinkage or increasing the tensile strength of the mix, however, the most important goal was to increase the cohesiveness and homogeneity of the mix. Banthia ,and Gupta [6] have proved in their research that the effectiveness of polypropylene fibers depends upon their lengths and diameters. The relation between the length and effectiveness is directly proportional where the relation of fibers diameter and their effectiveness is inversely proportional. The length of the fiber was chosen to be 12 mm to be suitable with the nominal maximum aggregate size. The properties of PF such as: specific gravity, alkali content, sulphate content, air entrainment, and many other properties are provided in table 2.

Table 2 : Properties of Polypropylene Fibers

Specific Gravity	0.91 g/cm^3
Alkali Content	Nil
Sulphate Content	Nil
Air Entrainment	Air Content of Concrete Will Not Be Significantly Increased
Chloride Content	Nil
Constituents	Virgin Polypropylene C3H6
Fiber Thickness	18 Micron
Min. Specific Surface Area	220 M^2/kg

Storage Life	Minimum 12 months from date of manufacture
Youngs Modulus	5500-7000 Mpa
Tensile Strength	350 Mpa
Melting Point	160 °C
Fiber Length	12 mm
Aggregate Size, Max	32 mm
Dosage	0.6/0.91 kg/m^3

Retarding Admixture

Since SCLC need to be mixed, transported, handled, and finished before the initial set, a great demand for using retarding admixtures to delay its initial set of and provide adequate time for dealing with it. Viscocrete RM-115 from Sika company was utilized in the mix. Sika defines its product as a polycarboxylate based superplasticizer developed particularly for use in ready mixed concrete to give extended slump retention and high strength development of high specification grade concrete mixes. It is suitable for use in concrete mixes incorporating pozzolanic materials such as GGBS, PFA, MS, and appropriate for the use in hot climatic conditions. The composition of RM-115, density, chloride ion content, and recommended dose from sika company are shown in table 3.

Table 3 : Properties of Retarding Admixture

Composition	Aqueous Solution of Modified Polycarboxylates, Co-Polymers
Density	~1.09 Kg/ L (+25 °C)
Chloride Ion Content	Nil
Recommended Dosage	0.7-1.5 % By Weight of Binder

Water-Reducing Agent

Superplasticizers help us increasing the powder content at a given water quantity without compromising the workability of the mix. Minimizing the water content in mixes will result by improving the mechanical properties of concrete such as its compressive, and tensile strength. Plastiment RP-150 from SIKA company has been used in mixes as a water reducer. According to SIKA PR-150 is a highly effective water reducing agent with controlled retardation over a wide dosage range and suitable for use in tropical and hot climatic conditions. The composition of RP-150, density, chloride ion content, and recommended dose from sika company are shown in table 4.

Table 4 : Properties of Water-Reducing Agent

Composition	Modified Lignosulphonate
Density	~1.135 kg/L (+25 °C)
Chloride Ion Content	Nil
Recommended Dosage	0.3-0.8 % By Weight of Binder

Fine Aggregate

Two types of fine aggregate have been proportioned and used in the mixes. The first one is called Al-bowatt sand or dune sand and its source from Al-bowatt which is a village on the outskirts of Al-Medina in the Kingdom of Saudi Arabia and located 40 km northwest of Medina. The second one is called Al-laith sand and its source from Al-Laith Governorate which is one of the governorates of Makkah Al-Mukarramah. The utilized fine aggregates in the mixes have been proportioned as 90% of dune sand and 10% of Al-laith. The main parameters that were controlling the proportioning processes were slum-flow and cohesiveness. The fineness modulus of dune sand was 3.08 and that is very effective for increasing the deformability of the mortar phase and achieving self-compaction of structural light weight concrete, however, the mix should be cohesive as well, as a result, 10% of Al-laith sand with a fineness modulus of 2.1 have been added to increase the cohesiveness of mixes and not affecting the workability of SCLC. ASTM C128 have been conducted on both types of fine aggregate and the results are shown in table 5.

Table 5 : Specific Gravity of Al-Laith and Al-Bowatt Sand

	Al-Bowatt Sand	Al-Laith Sand
Weight of S.S.D. Sample in Air (g)	500.00	500.00
Weight of Oven Dry Sample in Air (g)	493.30	477.00
Weight of Pycnometer Filled with Water (g)	692.25	692.25

Weight of Pycnometer Filled with Water + Sample (g)	1004.60	983.10
Absorption (%)	1.358	4.822
Sp. Gr. (Oven Dry)	2.629	2.281
Bulk Sp. Gr. S.S.D.	2.665	2.391
Apparent	2.726	2.562

ASTM C136 has been applied on both types of fine aggregates for determining their gradations, % moisture contents, fineness modulus, and % dust contents. The percentages of moisture and dust content in Al-laith sand were 4.88%,1.77% respectively where the percentages of moisture and dust content in Al-bowatt sand were 6.24%, and 2.31%. The gradation of al-laith and al-bowatt sand are illustrated in figures 6, and 7.

Table 6 : The Gradation of Al-Laith Sand

Sieve size	Wet, Retain	Retain %	Passing %	Limits
No. 4	0.00	0.00	100.00	95~100
No. 8	3.00	0.30	99.70	80~100
No. 16	25.00	2.51	97.49	50~85
No. 30	244.00	24.52	75.48	25~60
No. 50	848.00	85.23	14.77	10~30
No. 100	974.00	97.89	2.11	2~10
No. 200	995.00	100.00	0.00	0~5

Table 7 : The Gradation of Al-Bowatt Sand

Sieve Size	Wet, Retain	Retain %	Passing %	Limits
No. 4	29.80	4.07	95.93	95 ~100
No. 8	120.10	16.39	83.61	80 ~100
No. 16	360.70	49.22	50.78	50~85
No. 30	460.90	62.90	37.10	25~60
No. 50	630.50	86.04	13.96	10~30
No.100	653.70	89.21	10.79	2~10
No. 200	732.80	100.00	0.00	0~5

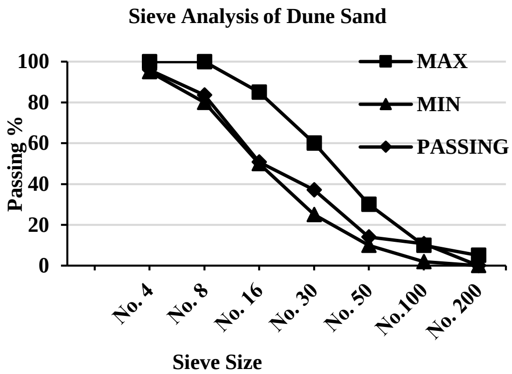

Fig. 1 : Al-Laith Sand Sieve Analysis

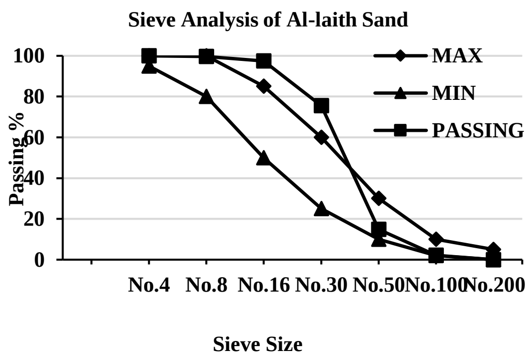

Fig. 2 : Dune Sand Sieve Analysis

The fineness modolus of the gradation that combines 90% of dune sand and 10% of Al-laith sand was 3.01 and its dust and mositure content percentages were 6.12%,and 2.05% . Fig.3 and table 9 show the gradation of mixed sand that have been used in the mixes.

Table 8 : The Gradation Of 90% of Dune Sand and 10% Of Laith Sand

Sieve Size	Wet, Retain	Retain %	Passing %	Limits
No. 4	46.00	6.08	93.92	95~100
No. 8	128.56	17.00	83.00	80~100
No. 16	248.78	32.90	67.10	50~85

No. 30	463.08	61.23	38.77	25~60
No. 50	654.80	86.58	13.42	10~30
No.100	729.78	96.50	3.50	2~10
No. 200	756.28	100.00	0.00	0~5

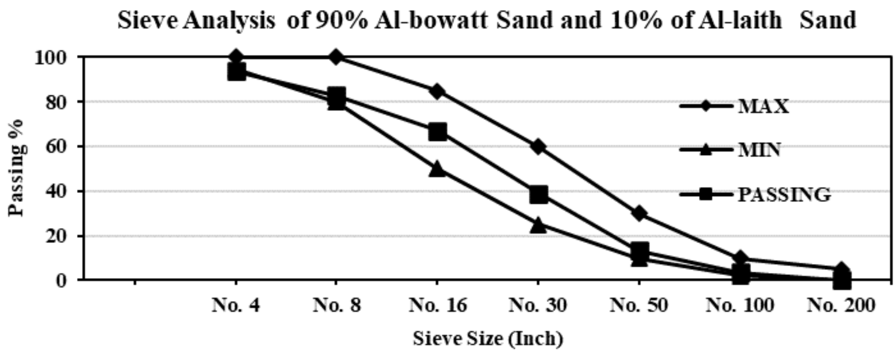

Fig. 3 : Sieve Analysis of 90% Al-Bowatt and 10% of Al-Laith Sand

Scoria Coarse Aggregate

Crushed basaltic pumice (scoria) has been used as lightweight aggregates due to its high porosity and low density for producing self-compacted lightweight concrete. The source of scoria was locally from Al- Medina Al- Munawara and two sizes of aggregate have been used 1/2 and 3/8 inch, respectively. Teymen et al. [7] showed in their research that the size (nominal maximum aggregate size) of scoria coarse aggregate has an important impact on the mechanical properties of lightweight concrete. scoria has angular shape, and its surface texture is rough and that will produce a strong relation between the mortar phase and aggregate, hence, improving the mechanical properties of the mix. the density of 3/8-inch scoria was 1730 kg/m^3 where the density of 1/2 inch scoria was 1690 kg/m^3 because of its higher void ratio as a nominal aggregate size have increased. the gradation of both sizes of scoria aggregate have been tested and is shown in fig.4, and 5.

Table 9 : The Gradation of 3/8 Scoria Coarse Aggregate

Sieve size	Wet, Retain	Retain %	Passing %
1/2 in	50.00	7.33	92.67
3/8 in	643.20	94.29	5.71
No. 4	682.12	100	0

Table 10 : The Gradation of 1/2 Scoria Coarse Aggregate

Sieve size	Wet, Retain	Retain %	Passing %
3/4 in	0.00	0	100
1/2 in	50.00	7.33	92.67
3/8 in	643.20	94.29	5.71
No. 4	682.12	100	0

Fig. 4 : Sieve Analysis of 1/2 Inch Scoria

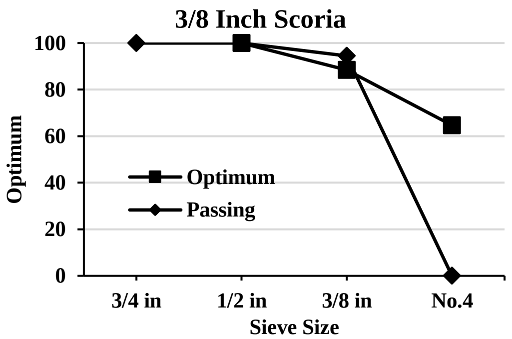

Fig. 5 : Sieve Analysis of 3/8 Inch Scoria

ASTM C127 have been conducted on scoria aggregates and the results of bulk dry specific gravity, bulk saturated surface-dry specific gravity, apparent specific gravity, and % of absorption is shown in table 12 for both sizes of coarse aggregate

Table 11 : ASTM C127 For All Types of Coarse Aggregate

	Bulk Dry Sp. Gr (g)	Bulk SSD Sp. Gr (g)	Apparent Sp. Gr (g)	Absorption (%)
Scoria 3/8 Inches	1.61	1.84	2.09	12.50
Scoria 1/2 Inches	1.59	1.85	2.14	14.05
Leca	0.57	0.71	0.81	19.72

Leca Coarse Aggregate

Ahmad et al. [8] leca stands for lightweight expanded clay aggregate and is defined as a lightweight aggregate produced by heating the clay to about 1200 ° c in a rotary kiln. Slurry gases expand by thousands of small bubbles that created during heating. Rashad [9] has shown the effectiveness of leca in multiple construction applications such as: production of lightweight blocks , structural backfill against foundations, concrete precast….etc. The density of leca aggregate was 955 kg/m^3 and its properties such as: bulk dry specific gravity, bulk saturated surface-dry specific gravity, apparent specific gravity, and % of absorption are shown in table 10. ASTM C136 has been conducted to determine many properties such as: % dust content, % moisture content, and the gradation which is illustrated in fig.5.

Table 12 : The Gradation of Leca

Sieve size	Wet, Retain	Retain %	Passing %
3/4 in	0.00	0	100
1/2 in	108.50	10.91	89.1
3/8 in	500.00	50.28	49.7
No. 4	994.50	100	0

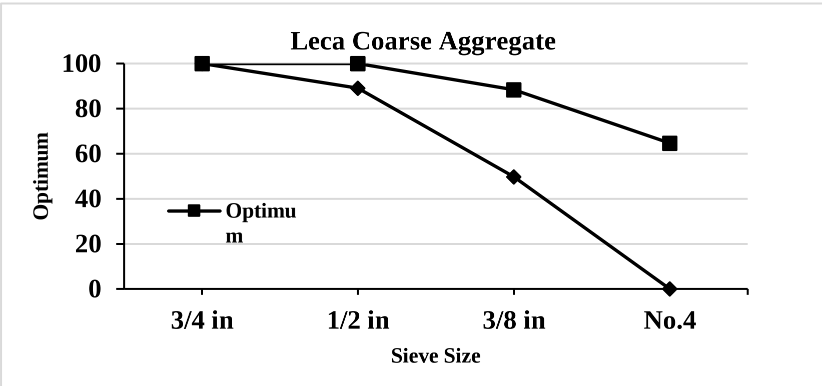

Fig. 6 : Sieve Analysis of leca

III. Conclusion

This study investigated the differences in the nonmechanical, and mechanical properties of self-compacted lightweight concrete made with local and artificial lightweight aggregates. The properties such as: density, oven dry specific gravity, saturated surface dry specific gravity, apparent specific gravity, % absorption, % dust content, % moisture content, gradation, fineness modulus, surface texture, shape characteristics and slum flow have been examined. The compressive and split tensile strength test at 7 and 28 days of curing have been tested as well. Following conclusion can be drawn based on these experimental results:

- The fineness modulus of fine aggregates has an incredible influence on the workability of concrete.
- Experimental observations showed that the minimum value of fineness modulus for achieving self-compaction of concrete (slump flow greater than 650 mm) is 2.95.
- There should be some percentages of fine sand with low fineness modulus to achieve the cohesiveness and not reducing the workability, so the mix can be homogenous and that will have a noticeable result on the mechanical properties of concrete.
- The percentages of inserting fine aggregates which have a lower fineness modulus than 2.1 should not exceed 20% (from experimental works) by the total volume of sand in the mix due to the massive reduction of workability which will result by not achieving SCC.

- The percentages of inserting polypropylene fibers have three stages. The first stage is from 0.01% up to 0.015% which has a positive effect on the workability of the mix. The next stage is from 0.015% up to 0.0.02% which result by decreasing the workability, but it is not noticeable. The third stage is by inserting more than 0.02%, therefore, a massive and noticeable reduction in the workability of the mix would be obtained.
- The main advantages of polypropylene fibers are not only controlling either plastic or Autogenous shrinkage and increasing the tensile capacity but increasing the cohesiveness and homogeneity of the mix. It is the most important point because if we are not able to fix some certain properties of fine aggregate such as: % absorption in Al-laith sand we will decrease the percentage of fine aggregate which has a low fineness modulus from the total mix of fine aggregate by using % of polypropylene fibers and conclude with the same homogeneity.
- Surface texture and shape characteristics had a major influence on the mechanical properties of the mix. Angular shapes and rough texture provided strong bonds between the scoria aggregate and mortar which resulted in larger value of average compressive and tensile strength than leca because of its soft texture and round shapes.
- Leca coarse aggregate can occupy large volume and has small specific gravity (less than 1), however, the use of leca should be limited to the minimum volume of mixed coarse aggregates due to its shape properties.
- The major role of leca coarse aggregate is to justify and control the density of the mix without affecting adversely its mechanical properties.
- Structural -self compacted lightweight concrete can be produced with a reduction of dead loads up to 31.5% compared to normal concrete by combining leca and scoria lightweight aggregate. This could be done through multiple stages such as: studying the properties of cement paste containing menial admixtures, identifying the maximum volume of fine aggregates by determining the mortar tendency of blocking, optimizing mortar carrying capacity, determining the maximum volume of coarse aggregate with low probabilities of segregation and aggregates interlock, and investigating the optimum proportions of leca and scoria which produce the minimum density of the mix and the maximum mechanical strength simultaneously.

Acknowledgement

The authors wish to express their sincere thanks to the guide Dr.Mohammad Ismeail and Dr. Mohammad Laissy of Civil Engineering Department for their kind support and valuable guidance.