Production of Structural Lightweight Concrete Using Recycled Crushed Clay Brick Aggregates

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Abstract

The reuse of construction and demolition wastes, especially crushed clay bricks (CCB), represents a major contribution to the environment. Due to the nature of clay bricks, it can be considered as source of fine and coarse aggregate to produce structural lightweight concrete (LWC).

In this paper, the clay brick is crushed into the sizes of fine and coarse aggregate for concrete aiming to produce structural lightweight concrete. On achieving the targeted concrete properties, the physical and mechanical properties of the obtained concrete are studied.

The results indicated that lightweight concrete can be produced by utilizing CCB as coarse and fine aggregate. Limited combination of CCB and natural aggregate can yield structural LWC, which can be used in structural purposes. The attained LWC mixes have lower modulus of elasticity, higher permeability and lower strength than the corresponding control concrete mixes.

Keywords:

Lightweight concrete;Compressive strength;Permeability;Modulus of elasticity.

1. Introduction

The lightweight concrete (LWC) is beneficial to the environment as it reduces dimensions and dead weights of structure. LWC density ranges between 300 to 1840 kg/m³ compared to normal weight concrete density of approximately2500 kg/m³. For lightweight concrete to be used in structural applications, it should have density between 1440 kg/m³ to 1850 kg/m³ and minimum strength of 17.2 MPa, according to (ACI-213R-87) [1].

In addition to structural LWC characteristics, which make itpreferable and distinctive, it is produced for achieving similar strength compared tothat of normal weight concrete to be valuable for using in construction field. Recently the world is becomingmore interested in achieving clean and healthy environment, and finds an appropriate method for disposal of wastes which cause harmful effects on the environment. These wastes are induced by construction materials production processes, demolition sites and natural disasters [2].

During the last decades, it was observed that the wastes from construction and demolition sectors constitute large volume and this volume increased year after year. Demolition waste was about 180 million tons in EU countries per year [3]. In addition, the industry of brick manufacturing, which produce sizable amount of rejected fired- brick and these units may be broken and cause environmental pollution [4]. In the United States, the construction and demolition waste production per year was represented as 136 million tons by the Environmental Protection Agency [5]. Therefore, many researchers studied the effect of using these local wastes in production of concrete to reduce their harmful effect and to get concrete with good characteristics with reduced cost.

Researchers started to study the possibility for recycling wastes from construction demolishing which represented in crushed brick to produce LW concrete. It is reported that fine CCB obtained from waste products (e.g. demolished masonry) possess Pozzolaniccharacteristics and can be used as supplementary cementitious materials in concrete. [6, 7]

Yang [8] studied the possibility of using recycling concrete aggregate (RCA) and crushed clay brick (CCB) in concrete as replacement by natural aggregate to control the side effect of these waste. Topcu [9] carried out experimental studies on concrete specimens with varying replacement percentages of Recycled Concrete Aggregate up to 100% by weight. Test results showed that the density of concrete decreased as the waste concrete materials were increased, but the difference in density was not as large as those in water absorption.Limbachiya [10] found that recycling concrete aggregate (RCA) content from 7% to 9% achieved lower relative density and twice higher water absorption compared to concrete containing Natural Aggregate in the saturated surface dry state.

Bektas [11] examined the effects of recycled fine powder clay brick, used as replacement of fine aggregate, in mortar, which was used to replace 10% and 20% (by weight) of the river sand in two mixes. Heapproved that the compressive strength was not affectedwhen using 10% and 20% of fine powder aggregate brick as a sand replacement. But, mortar with 20% fine powder aggregate reduced the Alkali silica reactivity as compared with the reference mortar with no replacement of fine powder brick.

Ali [12] used the powder crushed brick (PCB) with 5%, 10%, 15%, 20% and 25% as a cement replacement in mortar. Results indicate that the presence of powder clay brick as a partial replacement of cement by weight reduces the mortar compressive strength. Mortar that contains the highest cement replacement by PCB (25%) exhibits about 28.2% reduction in 28-day compressive strength with respect to the control mortar.

From previous researches, the main advantages of using crushed brick aggregates are reducing the density of concrete, reducing natural aggregate consumption and improving environment. The disadvantages of using recycling crushed brick in concretecan be summarized in its high porosity,high absorption rate and variations in properties due to variation in brick properties.

The main objective of this study is to investigate the possibility of utilization crushed clay brick as coarse and fine aggregates to produce structural lightweight concrete.

2. *Experimental program*

The testing program consisted of 32 concrete mixtures tested for physical and mechanical properties. The aim of the testing program was to achieve concrete mixes accepted by ACI-213R [1] as a structural LWC. Then, thephysical and micro properties of the achieved mix were studied.

2.1 Materials

Ordinary Portland cement type (CEM I, 42.5 N) complying with ESS (1-4756) [13] was used in all mixes. The used cement was produced by Sinai Cement Company. Table 1 shows the chemical composition of the used cement.

Natural siliceous well graded sand with fineness modulus of 2.65 and crushed limestone having nominal maximum size of 19 mm was used in control mixes. Crushed clay bricks (CCB) were used as coarse and fine aggregates according to their size. Clay bricks were crushed manually using a steel hammer, then grouped to three sizes namely; from19 mm to 12.5 and from 12.5 mm to 9.50 mm for use as coarse aggregate and less than 4.75 mm for use as a replacement range of 20-100% of sand. Table 2 presents the physical properties and the grading of the used aggregates.

Silica fume was also used as cement replacement material. The used silica fume was supplied from EVACO Company and its specific gravity was 2.3 and BET surface area equal to 20 m^2/g, Table 1 shows its chemical composition. Air entraining Agent (AEA) was needed in some mixes in order to reduce the density of concrete by making air bubbles in the specimen and improving workability. The usual dose of AEA was 0.6% to cement weight.

Table 1: Chemical compositions of cement and silica fume.

Chemical Composition, %	Cement	Silica fume
Silicon dioxide (SiO2)	20.38	96.4
Iron dioxide (Fe2O3)	3.93	1.44
Aluminum oxide (Al2O3)	4.78	0.914
Calcium oxide (CAO)	62.85	0.013
Magnesium oxide (MgO)	1.95	0.383
Sulfur trioxide (SO3)	2.18	-
Loss on ignition (L.O.I)	2.68	1.04
Insoluble residue	0.69	-

Table 2: Grading and physical properties of aggregates

Sieve size, mm	% Passing			
	Natural aggregate		Crushed brick	
	Crushed lime stone	siliceous Sand	Coarse (CCB)	Fine (CCB)
25	100	-	100	
19	95.9	-	95	
12.5	34.8	-	55	
9.5	1.7	-	21	
4.75	-	99	9	100
2.36	-	96	-	85
1.18	-	82.3	-	56
0.6	-	48.5	-	31
0.3	-	9.5	-	20
0.15	-	3.1	-	9.5
Physical properties				
Max. Nominal Size, mm	19.0	-	19.0	-
Fineness Modulus	-	2.65	-	3.2
Bulk density , t/m^3	1.82	1.74	0.91	-
Apparent specific gravity	2.70	2.63	2.05	2.10
Absorption Capacity, %	0.9	1.65	11.8	15.6
Los Anglos,%	26.4	-	35.6	-

2.2 Mix proportion

To reach suitable structural LWC concrete mixes, three groups of mixes were investigated. The first group was concrete mixes with *W/C* ratio of 0.55 with different ratios of fine and coarse CCB aggregate. As the resulting mixes did not attain the required results, further mixes were cast using a reduced *W/C* equal to 0.45. Nevertheless, more modifications were necessary to fulfill ACI-213R [1] limits of structural lightweight concreteand another mixes were castwith *W/C = 0.40* and cement content 400 kg/m³ to attain SLWC but it doesn't be noted in this research due to its incompliance to the SLWC requirements. Group 3 mixes were then selected by changing the percentages of (Natural/ CCB) fine and coarse aggregates. The mix proportions of the tested concrete mixes are shown in Tables (3), (4) and (5). High Range water Reducer (HRWR) was employedin mixes to maintain a suitable workability of 150±25 mm slump.

Mixes were cast in 150 mm steel cubes, kept for 24 hoursand covered by water tight sheets. After 24 hours of casting, concrete cubes were kept in standard water curing tank till the time of testing. The air content of the fresh concrete mixes was determined by ITC Air meter and the compressive strength were tested by ELE 2000 KN compressiontesting machine.

Water flow characteristics as represented by sorptivity were determined according to ASTM C1585 -04[14].

Table 3: Concrete mixes proportions (Group 01)

W/c =0.55								
Mixes	Cement (Kg/m³)	SF (Kg/m³)	Fine CCB (Kg/m³)	Sand (Kg/m³)	Lime stone(Kg/m³)	Coarse CCB (Kg/m³)	Water (Kg/m³)	HRWR %
MC55	350	0.0	0.0	800	1000	0.0	195	0.0%
M0	350	0.0	0.0	800	0.0	760	195	2%
M20	350	0.0	130	636	0.0	760	195	2%
M40	350	0.0	260	475	0.0	760	195	2%
M60	350	0.0	383	320	0.0	760	195	2%
M80	350	0.0	510	160	0.0	760	195	2%
M100	350	0.0	638	0.0	0.0	760	195	2%
SM20	315	35	130	636	0.0	760	195	2%
SM40	315	35	260	475	0.0	760	195	2%
SM60	315	35	383	320	0.0	760	195	2%

Table 4: Concrete mixes proportions (Group 02)

W/C=0.45									
Mixes	Cement (Kg/m³)	SF (Kg/m³)	Fine CCB (Kg/m³)	Sand (Kg/m³)	Lime stone (Kg/m³)	Coarse CCB (Kg/m³)	Water (Kg/m³)	HRWR %	AEA %
MC45	400	0.0	0.0	800	1000	0.0	180	1.0%	0.0%
CM0	400	0.0	0.0	800	0.0	760	180	2.5%	0.6%
CM20	400	0.0	130	636	0.0	760	180	2.5%	0.6%
CM40	400	0.0	260	475	0.0	760	180	2.5%	0.6%
CM60	400	0.0	383	320	0.0	760	180	2.5%	0.6%
SCM20	360	40	130	636	0.0	760	180	2.5%	0.6%
SCM40	360	40	260	475	0.0	760	180	2.5%	0.6%
SCM60	360	40	383	320	0.0	760	180	2.5%	0.6%

Table 5: Concrete mixes proportions (Group 03)

W/C=0.45									
Mixes	Cement (Kg/m³)	SF (Kg/m³)	Fine CCB (Kg/m³)	Sand (Kg/m³)	Coarse CCB (Kg/m³)	Lime stone (Kg/m³)	Water (Kg/m³)	HRWR %	AEA %
CM60/20	400	0.0	383	320	610	200	180	2.5%	0.6%
SCM60/20	360	40	383	320	610	200	180	2.5%	0.6%
CM60/40	400	0.0	383	320	455	400	180	2.5%	0.6%
SCM60/40	360	40	383	320	455	400	180	2.5%	0.6%

3. Results and analysis

3.1 Fresh concrete properties

3.1.1 Air content

The results of Air content (by Air meter) are represented in Figure (1).it can be noted that increasing in replacement levels of sand by fine CCB leads to increase in Air content.The percentage of increasein air content is related to percentage of replacement for fine CCB. It is also noted that mixes containing 10% of silica fumes (SM20, SM40 and SM60) have higher values of air content than the same mixes M20, M40 and M60, without silica fume (SF).This behavior of silica fume to increase of Air content in lightweight concrete is agreed with Chung [15].

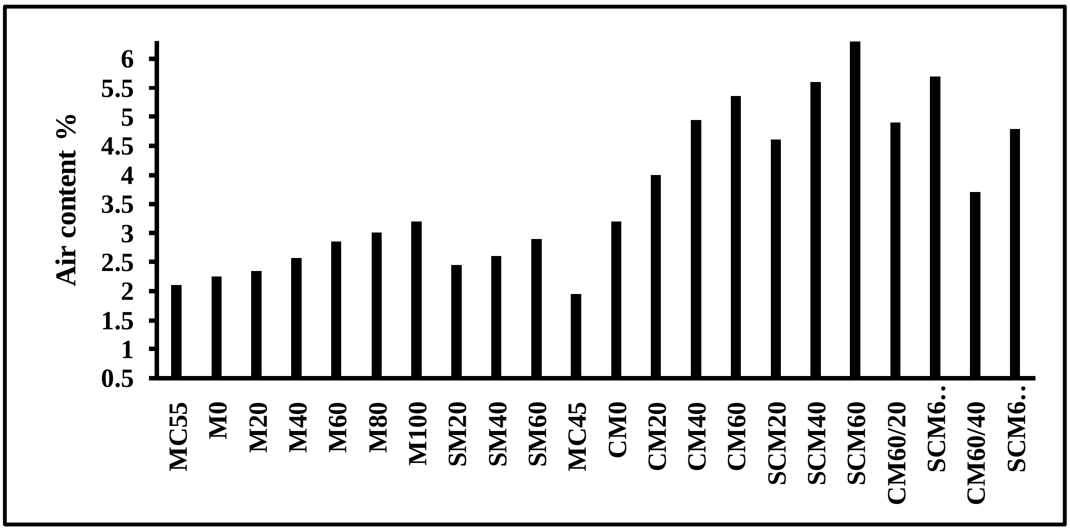

Figure (1): Air content results of LWC for groups (01), (02) and (03)

3.2 Hardened properties

3.2.1 Compressive Strength and splitting strength

From Figures (2 to 4) it can be generally concluded that increasing the percentage of fine crushed clay bricks replacing the natural siliceous sand reduced concrete strength. This can beattributed to the reduced strength of the CCB aggregate as well as the lower bond between the matrix and the fine CCB particles. This result coincided with the conclusions of Debieb[2], and Ali [12] and contradicted with Mohammed[16].Similar conclusions can be drawn for splitting strength as represented in Figure (7). This is previously reported by Chi Sun [17] who approved that the use of fine CCB and coarse CCB decreased the splitting strength. Kummutha [18] also concluded the previous results when used fine crushed clay brick as partial replacement ranged from 20% to 100% of natural sand. Using AEA further reduced both compressive and splitting strength.

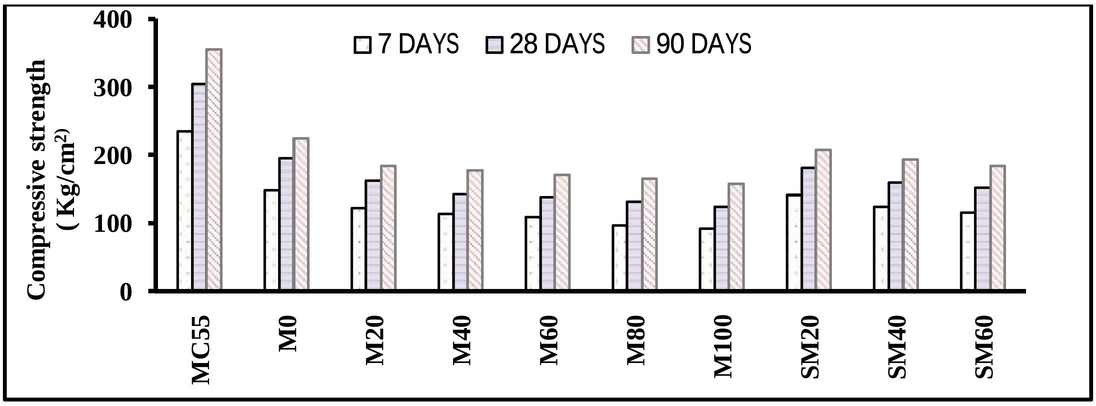

Figure (2): Compressive strength results for group (01) mixes.

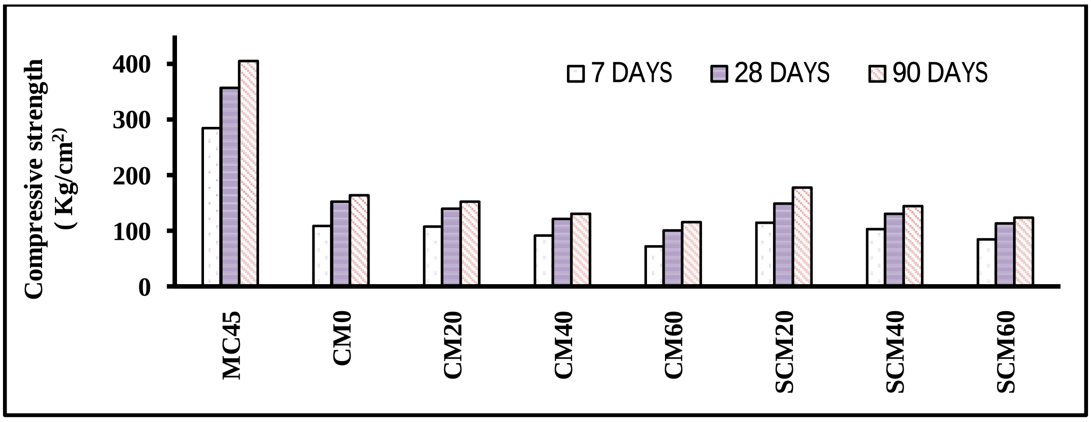

Figure (3): Compressive strength results for group (02) mixes.

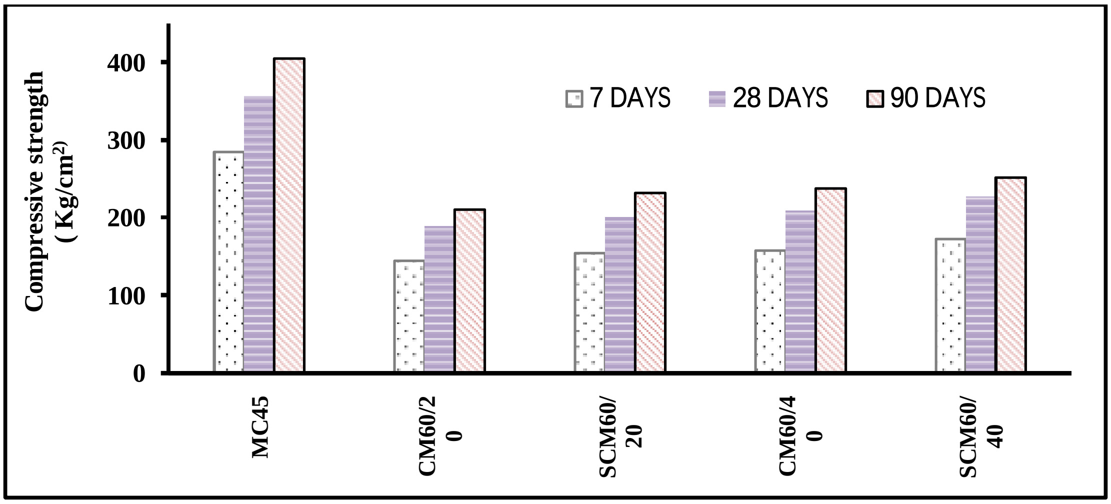

Figure (4): Compressive strength results for group (03) mixes.

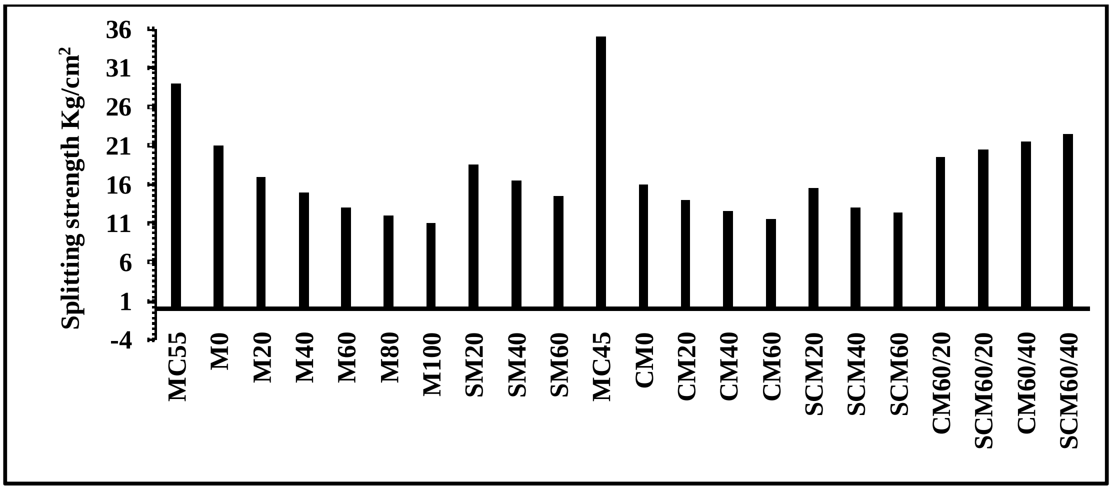

Figure (5): splitting strength results for groups(01), (02) and (03)

3.2.2 Relation between Wet and Air-dry density

From Figure (6), it can be noticed that the increase in fine crushed clay brick content led to decrease in the fresh and Air dry density up to 19%. This reduction of density is due to the lower density of the used CCB aggregate compared to normal aggregate, and the reduction in density rises by the increase of the replacement level of CCB in the mix. Use of Air entraining admixture further reduces the fresh and Air dry density by values up to

25%.It should be also noted that only mixes CM60/20 and SCM60/20 that satisfy the strength and density requirements of structural LWC as per ACI-213R [1].

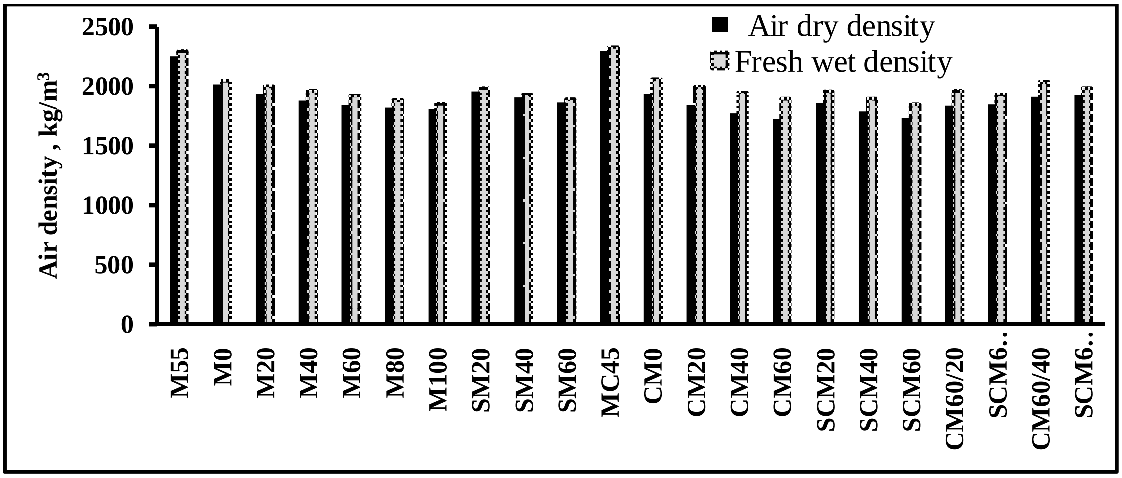

Figure (6): Relation between concrete Wet and Air dry density for groups (01), (02) and (03)

3.2.3 Stress-Strain curve

Stress-strain curves were computed using strain gauges mounted on one side of the specimens and recorded bydata acquisition system (data logger) for selected mixes which are represented in Table 6. The values of experimentally measuredmodulus of elasticity were estimated by the chord modulus method ASTM – C469 [19] from the stress-strain curves.

Table 6 shows that modulus of elasticity of LWC is lower than that of normal concrete. The decrease in experimentally measured modulus of elasticity for lightweight mixes than the control mix MC45 is thought to be due to the decrease in concrete density, the use of porous aggregates and weaker concrete. Itis also noted that the values of evaluated modulus of elasticity for lightweight mixes are much lower but closer to the values of modulus of elasticity which is calculated from the ACI – 318 considering concrete density (presented by equation Eq.1 in the text).

Table 6: Modulus of elasticity of hardened concrete.

Mixes	Experimental (E_c),N/mm²	Air density,kg/m³	(E_c),* N/mm²	(E_c),** N/mm²
MC45	21,615	2290	25,183	26,290
CM20°	6050	1840	11,153	16,166
CM40	2318	1775	10,046	15,368
SCM20°	7610	1856	11,910	17,041

$E* = Wc^{1.5} \times 0.043 \times \sqrt{fc''}$ Using ACI Formula …..Eq.01

$E** = 4400 \times \sqrt{f_{cu}}$ Using ECP Formula …..Eq.02

° Data terminated after failure of strain gauge.

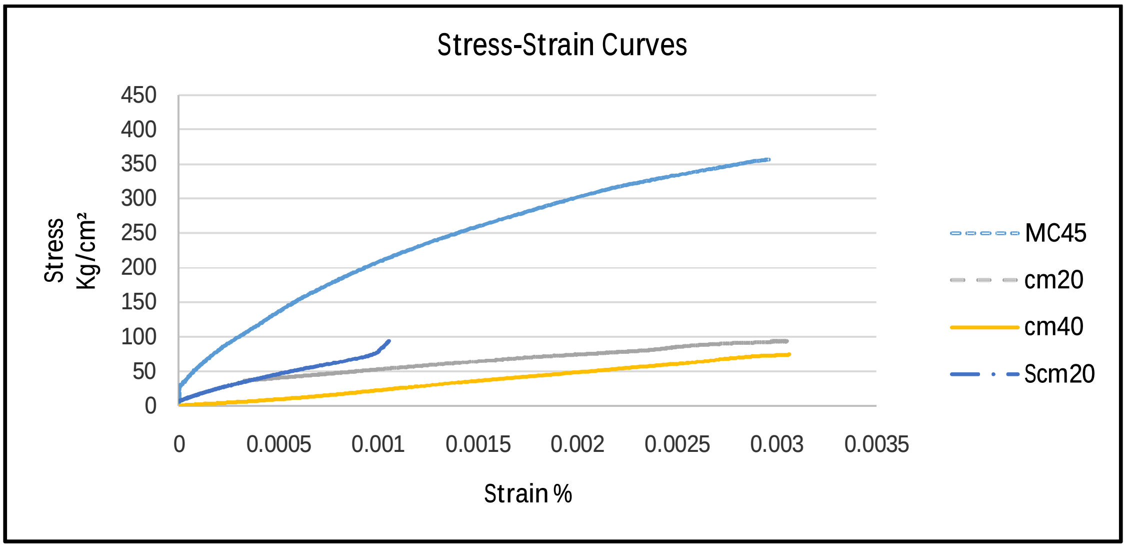

Figure (7): Stress -Strain curve for previous mixes

It is recommended, from this research, that the modulus of elasticity of concrete produced by CCB aggregates to be estimated as follows;

$$E_{CCB} = E_{ACI} \times (A - B) \times C \qquad \text{….. Eq. 03}$$

E_{CCB} = Modulus of elasticity for air entrained CCB concrete (N/mm²);

E_{ACI} = Modulus of elasticity estimated by ACI – 318 Formula (N/mm^2);

A= 0.74 × % replacement of Coarse CCB;

B= 1.3 x % replacement level of Fine CCB; and

C= 1.185 + % replacement level of Silica Fume.

However, it's recommended to conduct more researches to verify this proposed equation.

3.2.4Structural lightweight concrete mixes:

For lightweight concrete mixes to be considered structural, it should satisfy strength and density according to the ACI-213R[1] requirement. Therefore, mixes CM60/20 and SCM60/20 with *W/C=0.45* and 20% of coarse CCB which replaced by crushed lime stone. These mixes CM60/20 and SCM60/20 achieved comparable compressive strength with values of 189 and 201 kg/cm^2 and splitting strength 19.5 and 20.5 kg/cm^2 respectively.

3.3 Fluid transport properties

3.3.1 Sorptivity

The incorporation of fine CCB to replace the sand hasreverse effect on the surface permeability of the concretebecause of the presence of the porous aggregate which creates more voids in the concrete structure and raise the surface absorption, Zong [19].

Sorptivtiy is calculated from Eq.04 as follows;

$$S = I \times t^{-0.5} \qquad \text{.....Eq. 04}$$

Where,

I = Mass of absorbed water per unit area (gm); and

T = Time (sec).

S= sorptivity ($gm/cm^2.s^{-0.5}$)

Form Figure 8, it's showed that the increasing of fine CCB as replacement instead of sand, led to increase the values of sorptivity and also, SLWC mixes have higher values of sorptivity compared with the control mix.

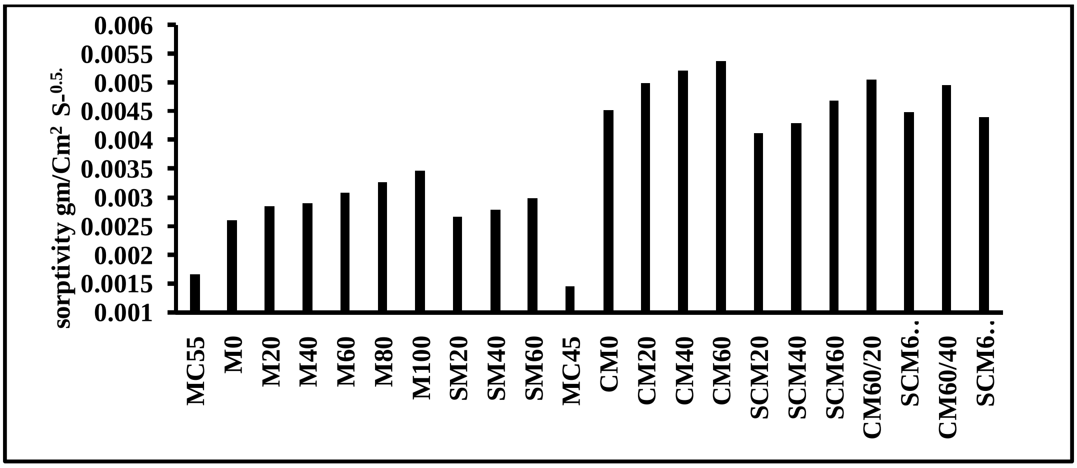

Figure (8):Sorptivity test resultsfor stages (01), (02) and (03)

5. Conclusions

The followings conclusions could be obtained as follows:

1- Increasing the percent of fine and coarse CCB in concrete mix, led to decreased density, reduced compressive, splitting strength and lower modulus of elasticity.

2- Incorporation of fine and coarseCCBcould reduce the fresh and Air dry density of concrete up to 19% and 20% respectively without use of AEA. Using AEA reduced the air dry density up to 25%.

3- Usingof Air entraining admixture with suitable CCB concrete mixesis essential to achieve structural lightweight concrete.

4- Only mixes CM60/20 ad SCM60/20 are consideredas structural LWC having compressive strength of 189 kg/cm², 201 kg/cm², air dry densities of 1836 kg/m³ and 1848 kg/m³ respectively.

5- The produced structural lightweight concrete has higher permeability and consequently needs more protection for improved durability.

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