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ENGINEERING PROPERTIES OF SUSTAINABLE SELF-COMPACTING CONCRETE WITH CLAY BRICKS WASTE AGGREGATE

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ABSTRACT

The present study covers the use of different percentages (25, 50, 75 and 100%) of clay bricks waste as replacement by volume of coarse natural aggregates to produce sustainable self-compacted concrete (SCC). All mixes used containing 10% silica fume as a replacement by cement weight. The properties of SCC studied were, workability, fresh density, dry density, water absorption, compressive strength, splitting tensile strength, flexural strength, modules of elasticity and thermal conductivity. The results show that the flow ability, filing ability, and passing ability of self -compacted concrete through steel reinforcement are decrease with the increase of clay brick waste content. In addition, the segregation resistance decreases with the increase of clay brick waste content of SCC. The use of clay brick waste aggregate causes reduction in density, compressive strength, splitting tensile strength, flexural strength, modules of elasticity and thermal conductivity of SCC. The percentage reduction increases with the increase of clay bricks waste content in self-compacted concrete.

KEYWORDS: Self-compacted concrete, Sustainable, Clay bricks wastes.

1. INTRODUCTION

Huge quantities of clay brick wastes are generating around the world due to the large using of these materials in buildings. The best solutions of sustainable waste management are the ability to Reduce, Reuse and Recycling of this waste to the maximum as possible (Rao, 2014; Hussain and Chandak, 2015). The use of clay bricks in large quantities is observed all over the world in latest years which leads to an increase in clay brick waste materials. Clay brick contains many venomous chemicals, and thus clay brick pollutes air, water and soil. Recently, a significant attention has been given to use the clay brick wastes in concrete industry. One of the perfect solution for disposing clay brick wastes is to reuse clay brick wastes to produce new type of concrete, which it is ecological and economic benefits (Alamgir and Ahsan, 2007). There is a significant possibility for the use of clay brick wastes as coarse aggregate in concrete preparation. The incorporation of clay brick wastes in concrete can significantly improves some self-compacted concrete properties, as clay bricks have low density, and high heat capability (Siddique et al., 2013).

2. MATERIALS AND METHODS

2.1. Materials

Iraqi ordinary Portland cement Type I manufactured in the Najaf Governorate with trade mark of (kar) was used. It was stored in airtight plastic containers to avoid the exposure to atmospheric conditions. The results show that the cement used is corresponding with Iraqi standards No.5/1984 (Iraqi Standard- No. 5, 1984). Natural sand with maximum aggregate size of 4.75mm was used. The physical properties and sieve analysis indicate that the fine aggregate used is within the requirements of the Iraqi Standard No.45/1984 (Iraqi Standard- No. 45, 1984). The grading and sulphate content of the natural crushed coarse aggregate satisfy the requirements of Iraqi Standard No.45/ 1984 (Iraqi Standard- No. 45, 1984), with nominal maximum size of 12 mm. The water used for mixing and curing of self-compacted concrete was potable water. Also, admixture (superplasticizer) with a commercial mark of GLENIUM 54® was used. The recommended dosage by the manufacturer was in the range of 0.5-2.5 liters/100 kg of the cement. This type of admixture is free from chlorides and compatible with ASTM C494-04 type F (ASTM C494, 2007). Silica fume is used and satisfies the requirements of ASTM C1240-06 (ASTM C1240, 2006) limitation, its content is 10% as a parietal replacement of cement weight. Clay brick wastes were collected, crushed, washed and dried to have grading similar to that for natural coarse aggregate as shown in Fig. 1. The grading of clay brick waste aggregate used in this investigation is shown in Table 1. The physical and chemical properties of clay brick wastes are shown in Table 2.

a: Clay brick waste

b: Prepared clay brick waste

Fig. 1. Preparation of Clay brick Waste.

Table 1. Grading of Clay brick Waste Aggregate.

Sieve Size (mm)	Passing By Weight (%)	Limits of Iraqi Standard No. 45 / 1984 with (5-14)mm
14	100	90-100
12.5	100	-----
10	59.9	50-85
4.75	3.64	0-10

Table 2. Physical and Chemical Properties of Coarse Clay Brick Waste Aggregate Used in this Investigation.

The Properties of Coarse Clay Brick Waste	**Test Results**	**Limits of the Iraqi specification No.45/1984**
Absorption (%)	20.3	----
Sulfate Content (SO_3) (%)	0.22	≤ 0.1
Density (kg/m^3)	1655	----

2.1.1. Concrete Mixing Procedure

Mixing of SCC was carried out in a rotary mixer with a capacity of $0.1m^3$. The mixing sequence was as following:

- The fine aggregate was added to the mixer with 1/3 amount of water and mixed for 1.5 minutes.

- The Portland cement and silica fume were added and then another 1/3 the amount of water was added and mixed for 3 minutes.
- Half the amount of coarse aggregate was added with the last 1/3 of water and 1/3 the dosage of superplasticizer and mixed for 1.5 minute then the mixture was left for 0.5 minute to rest.
- The remaining amount of coarse aggregate and Superplasticizer were added and mixed for 1.5 minutes. The mixture was then discharged, casted and cured.

This method was chosen according to the limitations of mixing taken by other researchers.

2.1.2. Preparation of Concrete Specimens

The steel molds were cleaned and lubricated to prevent adhesion with concrete after hardening. SCC mixes do not require compacting, so the mixes were poured into the tight steel molds (cubes, cylinders and prisms) until these molds were fully filled without any compaction. The molds were covered with polyethylene sheet for about 24 hours.

2.1.3. Concrete Mixes

The details of SCC mixes prepared in this investigation are shown in Table 3.

2.2. Experimental Tests

Different tests were carried out in this investigation including:

2.2.1 Fresh Properties Tests for SCC

Fresh properties of SCC were tested according to the procedure of European Guidelines (EFNARE) (EFNARC, 2005) and ACI237-07 (ACI 237-07, 2007) for testing fresh SCC. Three properties were achieved by conducting five tests, which were flow ability, passing ability, and segregation resistance. These tests are:

Slump Flow Test

This test is used to estimate the horizontal free flow of SCC in the absence of obstructions and to assess the flow ability and deformability of SCC according to (EFNARE) (EFNARC, 2005).

V- Funnel Test

The V-Funnel test is used to measure the filling ability of SCC and can be used to judge segregation resistance according to (EFNARE) (EFNARC, 2005).

L-Box Test

This test is used to estimate the filling and passing ability of SCC to flow through tight opening includes spaces between reinforcing bars and other obstructions without blocking or segregation according to (EFNARE) (EFNARC, 2005).

Column Segregation Resistance Test

It is used to estimate the resistance of self-compacting concrete to segregation according to ACI237-07 (ACI 237-07, 2007).

Fresh Density

The fresh density of self-compacted concrete was computed directly after mixing according to ASTM C 138M-01 (ASTM C138, 2015).

2.2.2 Hardened Concrete Tests for SCC

In hardened phase, the tests carried out for hardened SCC were:

Compressive Strength Test

This test was carried out on concrete cube specimens of 100 mm according to BS 1881: part116 (B.S.1881: Part 116, 1989).

Splitting Tensile Strength Test

The splitting tensile strength test was carried out on cylindrical specimens of 100 x 200 mm according to ASTM C496-07 (ASTM C496, 2015).

Modulus of Rupture Test (Flexural Strength)

The modulus of rupture test was carried out on concrete prismatic specimens (100 x 100 x 400 mm) to estimate the modulus of rupture under two point loads according to ASTM C78-02 (ASTM C78, 2015).

Oven Dry Density and Absorption Water Tests

Oven dry density and absorption of concrete were determined at 28 day age according to ASTM C 642 – 97 (ASTM. C642, 2015).

Ultrasonic Pulse Velocity Test

This test was determined at 28 day age according to ASTM C597 (ASTM C597, 2002).

Static Modulus of Elasticity

This test was determine at 28 day age according to ASTM C469 (ASTM C469, 2002).

Thermal Conductivity

This test was determine at 28 day age according to ASTM C-1113 (ASTM C- 1113, 2013).

Table 3. Details of Concrete Mixes Used in the Present Investigation.

Mix Symbol	Silica Fume as a Replace by Weight of Cement, (%)	Clay Bricks as a Volumetric Replace to Natural Coarse Aggregate, (%)	Age (days)	Mix Proportion by Weight for The Reference Mix (R)
S.F	10	----	28	1:1.72:1.97 (Cement Sand: Gravel) Cement Content of 450 kg/m^3, w/c=0.38, HRWRA= 2.2 Liter /100kg Cement
25CL	10	25	28	
50CL	10	50	28	
75CL	10	75	28	
100CL	10	100	28	

3. RESULTS & DISCUSSION

3.1. Selection of Mix Proportions

The mix proportions used was 1:1.72:1.97 (cement sand: gravel), with cement content of 450 kg/m^3, and w/c ratio of 0.38. This self-compacting concrete mix was designed according to EFNARC (EFNARC, 2005), to obtain concrete with minimum compressive strength of 40 MPa at 28 day.

Several trial mixes were carried out to select the optimum dosage of high range water reducing admixture (HRWRA) that satisfies the standard limitations for workability of SCC. According to the manufacturer, the recommended dosage of HRWRA (GLENIUM 54®) is between 0.5 and 2.5 liters per 100 kg of cement (cementitious material). The experimental results in this study indicate that the optimum dosage of HRWRA is 2.2 liters per 100 kg of cement.

It can be seen that HRWRA leads to a significant improvement in compressive strength and causes a decrease in water cement ratio compared with the reference mix. This is attributed to the action mode of the superplasticizer, that when it is added to cement water system, the polar chain is adsorbed on the surface of cement particles. That gives strong negative charge around the grains lowering the inter particles attraction by an electrostatic mechanism and reduces the amount of water required to attain equal workability (Cement Admixtures Association, 2012).

Finally, 10% silica fume was used as a replacement to cement weight. The results indicate that the use of silica fume improves the flow ability, filing ability, and passing ability of self-compacted concrete through steel reinforcement.

The limits of EFNARC (EFNARC, 2005) and ACI237-07 (ACI 237-07, 2007) of SCC are given in Table 4, also the properties of self-compacted concrete mixes containing different dosages of superplasticizer and the properties of reference self-compacted concrete mix containing silica fume (10%) are given in Table 5. The relationship between the different dosages of HRWRA and compressive strength of SCC is shown in Fig. 2.

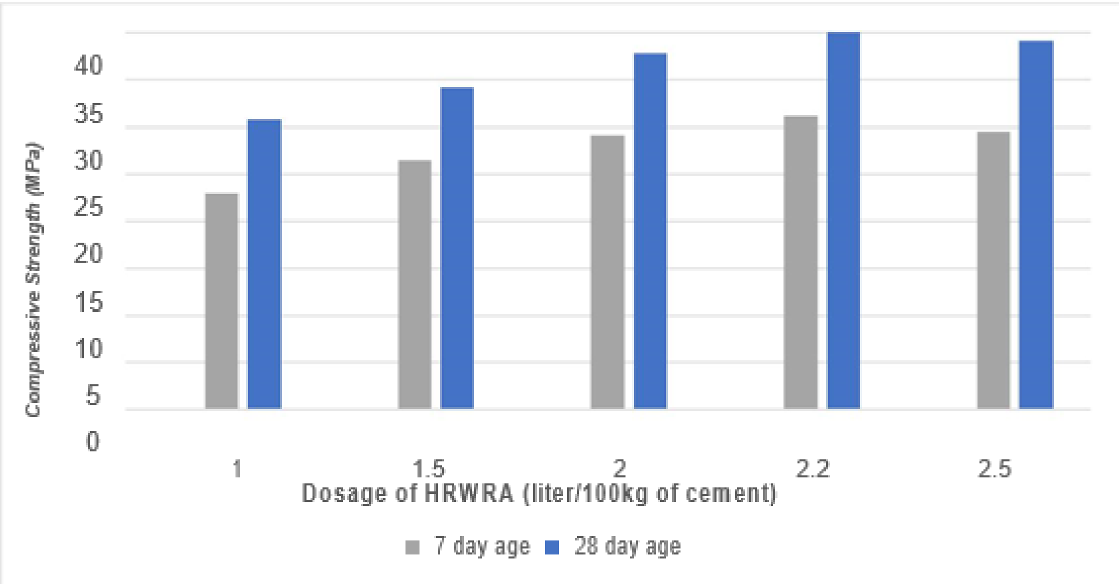

Fig. 2. Relationship between the Different Dosages of HRWRA and the Compressive Strength of SCC.

Table 4. Limits of EFNARC and ACI237-07 of SCC.

SCC Tests	Limits of Specifications
Slump Flow (mm) Class (SF3)*	$\geq$ 740 mm $\leq$ 900 mm
V-Funnel (sec.) Class (VF2)*	$\geq$ 7 sec. $\leq$ 27 sec.
L- Box Class (PA2)*	$\geq$ 0.75
Column Segregation Resistance (%) **	>10

* Limits of EFNARC 2005 (EFNARC, 2005) [9]

** Limits of ACI237-07 (ACI 237-07, 2007) [10]

Table 5. Properties of Several Self-Compacted Concrete Mixtures.

	L- Box Class (PA2)	Dosage of HRWRA (liter/100kg of Cement)	w/cm	Slump Flow (mm) Class (SF3)	V- Funnel (sec.) Class (VF2)		Sieve Segregation Resistance Class (SR2)	Compressive Strength (MPa) 7 days	Compressive Strength (MPa) 28 days
	----	1	0.38	457	32	0.68	9.7	22.9	30.7
(1:1.72:1.97) Cement:	----	1.5	0.38	574	28	0.72	12.4	26.4	34.2
Sand : Gravel with	----	2	0.38	767	19	0.77	13.1	29.1	37.8
Cement Content of	----	2.2	0.38	782	11.5	0.78	12.6	31.1	42.2
450 kg/m3	----	2.5	0.40	811	19.7	0.75	11.2	29.5	39.1
	10	2.2	0.38	794	9.5	0.8	16.2	37.75	48.74

*** Replacement by weight of cement**

3.2. Workability

The test results in Table 6 illustrate that the slump flow decreases, the filling time increases, and the speed of passing of fresh self-compacted concrete thought reinforcement bars decreases with the inclusion of clay brick waste aggregate.

This is because the water absorption of clay brick wastes is high compared with the natural coarse aggregate. On the other hand, the segregation resistance (S.R) of fresh concrete is decreased with increasing the percentage of plastic wastes as a replacement by volume of coarse natural aggregate.

3.3. Fresh Density

Generally, the results in Table 6 show a reduction in the fresh density with the increase of clay bricks waste content compared with the reference mix (without clay brick wastes). This is due to the low density of clay brick wastes 1611 kg/m3 compared with the density of coarse natural aggregate 1753 kg/m^3. The percentage reduction increases with the increase of clay brick wastes content in concrete.

3.4. Oven Dry Density and Water Absorption

Table 6 shows a significant reduction in dry density for SCC specimens containing clay brick waste; this is due to the low density of clay brick wastes compared with the density of coarse natural aggregate. The percentage decrease increases with the increase of clay brick wastes content in concrete. On the other hand, the water absorption for self-compacted concrete increases with increasing the percentage of clay brick wastes in concrete.

This is due to the shape of clay brick aggregate that leads to increasing the continuous path between pores and increases porosity. Also, the low density of clay brick waste leads to unsuitable compaction then more pores is formed.

The water absorption for all self-compacted concrete specimens with clay bricks waste is ranged from 1.69% to 2.29% that is less than 10%. This displays the good quality of all SCC mixes prepared in this investigation (Neville, 2011).

3.5. Compressive, Splitting Tensile, Flexural Strengths, Ultrasonic Pulse Velocity and Static Modulus of Elasticity

The effect of different percentages of clay brick wastes as a replacement by volume of coarse aggregate (25%, 50%, 75%, and 100%) on compressive, splitting tensile, flexural strengths, ultrasonic pulse velocity (UPV) of SCC at 28 day age are shown in Table 6. The compressive strength or UPV, splitting tensile and flexural strengths of SCC specimens containing different percentages of clay brick wastes decreases compared with the reference specimens (without clay brick wastes).

The percentages reduction in the compressive strength of SCC with 25%, 50%, 75% and 100% are 7.42%, 15.2%, 16.9%, and 22.67 % respectively relative to SCC specimens without clay brick waste aggregate.

The percentages reduction in the splitting tensile strength of SCC with 25%, 50%, 75% and 100% are 16.51%, 19.93%, 24.61%, and 26.48% respectively relative to SCC specimens without clay brick waste aggregate.

The percentages reduction in the flexural strength for SCC with 25%, 50%, 75% and 100% are 7.42%, 7.7%, 16.24%, 22.8%, and 28.2% respectively relative to SCC specimens without clay brick waste aggregate.

This reduction in the compressive strength or UPV, splitting tensile and flexural strengths are attributed to the reduction in adhesive strength between the surface of particles of clay brick waste and the cement paste. Also, it is due to the mismatch of particles size and shape between natural and partials of clay brick waste aggregate. The smooth surface of the clay brick waste particles may cause a weak bonding strength between clay brick waste waste and the cement paste (Kinda et al., 2010).

In addition, the natural aggregate is stronger than clay brick aggregate, and as the most strength of concrete is from the strength of aggregate because approximately three quarters of the volume of concrete is occupied by aggregate (Zongjin, 2011).

The relationship between clay brick waste content and the compressive strength of SCC is shown in Fig. 3.

3.6. Static Modulus of Elasticity

The effect of different percentages of clay brick wastes as a replacement by volume of coarse aggregate (25%, 50%, 75%, and 100%) on static modulus of elasticity of SCC at 28 day age are shown in Table 6. The percentages reduction in the static modulus of elasticity of SCC with 25%, 50%, 75% and 100% are 17.26%, 31.15%, 39.22%, and 49.66% respectively relative to SCC specimens without clay brick waste aggregate.

The reduction in modulus of elasticity can be attributed to the lower modulus of elasticity of clay brick waste particles compared with natural coarse aggregate. Also, the low bond between the cement paste (matrix) and clay brick waste aggregate can also contribute to this drop (Saikia and De. Brito, 2013). According to Jones and Facaroau (cited by (Rahmani et al., 2013)) the modulus of elasticity is affected by type of aggregate, since the deformation produced in the concrete specimens is partially related to the elastic deformation of the aggregate. Therefore, the partial replacement of natural aggregate by clay brick wastes aggregate implies that the modulus will be gradually decrease since the clay brick has less static modulus than the natural coarse aggregate and will deform at lesser stress compared with natural aggregate.

3.7. Thermal Conductivity

The effect of different percentages of clay brick wastes as a replacement by volume of coarse aggregate (25%, 50%, 75%, and 100%) on thermal conductivity of SCC at 28 day age are shown in Table 6.

It can be observed a considerable reduction in thermal conductivity with the increase in clay brick waste aggregate content. This is due to the formation of huge amount of cavities in the structure of concrete containing clay bricks waste aggregate. Porosity is one of the factors affecting the thermal conductivity of concrete and enclosed pores reduce the conductivity due to the low thermal conductivity of air (Semiha et al., 2013).

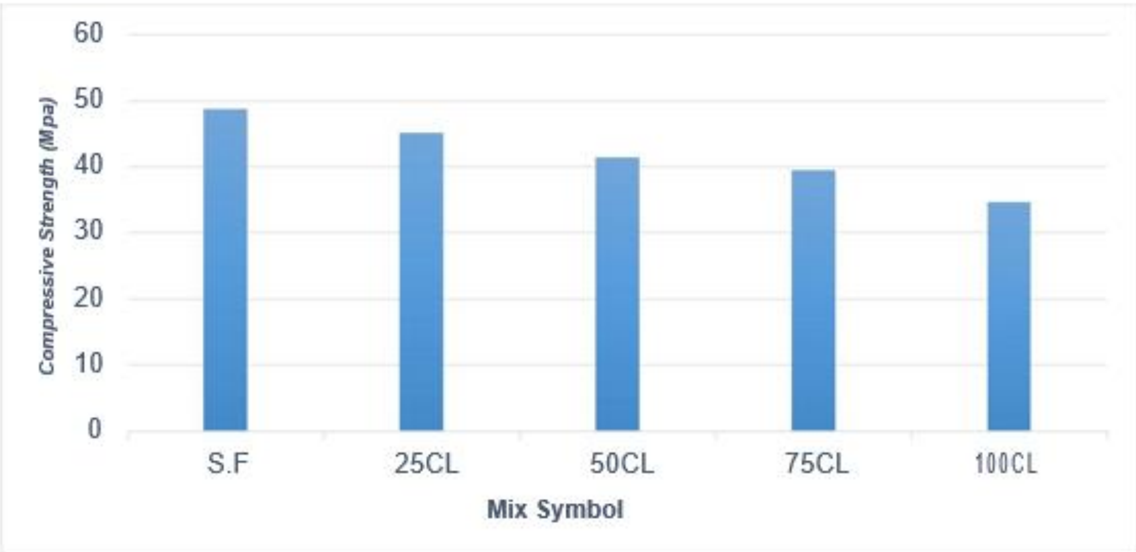

Fig. 3. Relationship between Clay Bricks Wastes Content and the Compressive Strength of Self-Compacted Concrete.

Table 6. Water Absorption, Fresh density, Oven Dry Density, Compressive, Splitting Tensile, Flexural strengths, UPV, Static Modulus of Elasticity and Thermal Conductivity of Different self- compacted Concrete Mixes.

Mix Symbol		S.F	25CL	50CL	75CL	100CL
SCC Tests	Slump (mm)	794	782	771	764	753
	V-funnel (sec.)	9.5	11	14.7	18.2	20.1
	L-box	0.79	0.78	0.78	0.77	0.77
	S.R (%)	3.5	4.1	5.7	6.5	8.4
Fresh Density (kg/m^3)		2362	2347.5	2318.1	2243.2	2201.1
Oven Dry Density (kg/m^3)		2285.5	2195.7	2097.7	2048	1947
Water Absorption (%)		1.1	1.69	1.97	2.09	2.29
Compressive Strength (MPa)		48.74	45.12	41.33	39.5	34.69
UPV (km/sec)		5.12	4.78	4.63	4.46	4.18
Splitting Tensile Strength (MPa)		3.21	2.68	2.57	2.11	2.01
Flexural Strength (MPa)		3.51	3.24	2.94	2.32	2.18
Static Modulus of Elasticity (MPa)		47.32	39.15	32.58	28.76	23.82
Thermal Conductivity (w/m.k)		2.15	1.87	1.72	1.54	1.36

4. CONCLUSIONS

1- Clay brick waste with maximum size of 12mm can be used as a replacement by volume of natural coarse aggregate in SCC.

2- The slump flow diameter decreases as the content of coarse clay brick waste aggregate increased in SCC mix. On the other hand, The V-funnel flow time increases with increasing clay brick wastes content in concrete.

3- L-box ratio and the segregation resistance decrease as the content of coarse clay brick waste aggregate increased in SCC mix. The values for the reference SCC mix are 0.79 and 16.2% respectively, while for SCC mixes with different contents of clay brick waste aggregate are in the range of 0.78-0.77 and 14.3-10.3 % respectively. The percentage decrease increases with the increase of clay brick wastes content in SCC.

4- The compressive, splitting tensile, flexural strengths, ultrasonic pulse velocity (UPV), Static modulus of elasticity and thermal conductivity for mixes containing clay brick wastes in different percentages (25%.50%, 75%, and 100%) as a replacement by volume of natural coarse aggregate in SCC are decreased. The compressive, splitting tensile and flexural strengths, ultrasonic pulse velocity (UPV), Static modulus of elasticity and thermal conductivity for SCC with 100% natural coarse aggregate are 48.74, 3.21, 3.51 MPa, 5.12 km/sec, 47.32 MPa and 2.15 w/m.k respectively, while for mixes with different contents of clay bricks waste aggregate are in the range of 45.12-34.96, 2.68-2.01,3.24-2.18 MPa, 4.78 - 4.18 km/sec , 39.15-23.82 and1.87-1.36 w/m.k respectively. The percentage decrease increases with the increase of clay brick wastes content in SCC.

5- The use of clay brick waste in different percentages (25%.50%,75%,and 100%) as a replacement by volume of natural coarse aggregate in SCC mixes significantly reduces the fresh, and dry density compared with the reference SCC mix (without clay bricks waste). The percentage decrease increases with the increase of clay bricks waste content in concrete.

6- SCC specimens containing different content of clay brick waste show an increase in water absorption compared with the reference SCC concrete (without Clay bricks waste).

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