Investigating the Ability of producing Sustainable Blocks using Recycled Waste

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ABSTRACT

The primary objective of this study is to manage price market items in the construction of walls for affordable structures with load-bearing hollow masonry units using the ACI 211.1 blend design with a slump range of 25-50 mm that follows the specification limits of IQS 1077. It was difficult to reach a suitable cement weight to minimum content (economic and environmental goal), so many trail mixtures were cast. A portion (10-20%) of the coarse aggregates was replaced with concrete, tile, and clay-brick waste. Finally, two curing methods were used: immersion under water as normal curing, and water spraying as it is closer to the field conditions. The recommendation in IQS 1077 to increase the curing period from 14 to 28 days was taken into account. The results proved that the compressive strength of the blocks of cured immersion under water increased by 2.63%-0.63% and 5.12%-7.88% for 10% and 20% concrete waste aggregates, decreased by 0,3.84% and 4.22%,6.41% for 10% and 20% tile waste aggregates, and decrease by 5.71%-6.10% and 12.1%-11.4% for 10% and 20% brick waste aggregates, respectively at 14 and 28 days, and beams that were cured by spraying performed a little worse than those immersed under water.

Keywords-concrete waste aggregates; mosaic-tiles waste aggregates; clay-brick waste aggregates; load bearing hollow block; sustainable block

I. INTRODUCTION

One of the most important investigations for cost saving and pollution reduction is the use of demolishing waste as recycled construction material [1-3]. The idea of green concrete, an eco-friendly substitute, is a creative way to lessen the harmful environmental effects of conventional construction methods. Green concrete reduces carbon emissions connected with concrete manufacturing and improves the effective use of natural resources by including recycled materials in its composition [4-7]. To manufacture high-quality concrete, it is possible to replace up to 20% of the river sand with volumetric waste brick, and up to 10% of the cement with nano-brick powder [8]. Clay brick aggregates (AB) can be reused as coarse aggregates and clay brick powder (PB) can substitute cement by [9-11]. Crushed tile waste has been also used as coarse aggregates in varying proportions, the most successful being 25% [12]. Concrete masonry units (hollow blocks) were taken into consideration for the production of an ecologically friendly carrier using recycled waste materials, and stronger, more affordable, and lighter blocks were produced in [13-15] The ability to create carrying load masonry units that meet the IQS 1077/1987 standard type A using the ratio 1:3.2:2.5 of cement: sand: coarse aggregates with slump ranging between 25 and 50 mm was studied in [8].

II. MATERIAL CHARACTERIZATION

The mixture composition of the blocks was:

- Ordinary Portland Cement (OPC) grad R42.5, in accordance with [16]. Its physical and chemical properties are shown in Tables I and II.
- Fine aggregates (sand - zone2) in accordance with [17] were utilized (Table III). Their chemical and physical test results are presented in Table IV.
- Natural coarse aggregates (C.N), concrete- waste aggregates (C.C), mosaic-tiles waste aggregates (C.T), clay-brick waste aggregates (C.B) (single size 10mm), that conform to the Iraqi requirements [17] as presented in

Table VI were used. The rating test results are presented in Table V.

- The water for curing and mixing was conformable with the Iraqi requirements [18].

TABLE I. OPC PHYSICAL TEST RESULTS

Physical properties	Test result	[16] requirements
Fineness (Blaine method) m²/kg	386	≥280
Initial setting (min)	165	≥45
Final setting (min)	260	≤600
Soundness (autoclave method), %	0.12	≤0.8
Compressive strength (MPa) at 2 days	28	≥20
Compressive strength (MPa) at 28 days	46	≥42.5

TABLE II. CHEMICAL COMPOSITION AND MAIN COMPOUNDS OF CEMENT

Oxide composition and chemical properties	Test result	[16] requirements
Lime (CaO)	61.90	-
Silica (SiO_2)	20. 50	-
Alumina (Al_2O_3)	4.90	-
Iron oxide (Fe_2O_3)	3.55	-
Magnesia (MgO)	4.35	≤ 5%
Sulfate (SO_3)	2. 50	≤ 2.8% for C3A >3.5%
Loss on Ignition (L.O.I.)	1.35	≤ 4%
Insoluble residue (I.R.)	0.95	≤ 1.5%
Main Compounds (Bogue's equation)		
Tri calcium silicate (C_3S)	53.77	-
Di calcium silicate (C_2S)	18.72	-
Tri calcium aluminate (C_3A)	7.10	-
Tetra calcium aluminate - ferrite (C_4AF)	10.43	-

TABLE III. GRADING TEST OF FINE AGGREGATES (SAND)

Sieve size (mm)	Passing%	[17] requirements
10	100	100
4.75	97	90– 100
2.36	83	75 – 100
1.18	68	55 – 100
0.6	46	35– 59
0.3	16	10– 30
0.15	2	0 – 10

TABLE IV. CHEMICAL AND PHYSICAL TESTS OF SAND

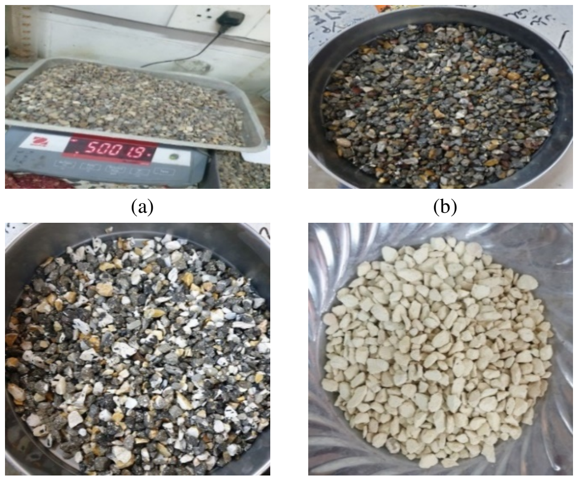
Property	Test result	[17] requirements
Sulfate content, %	0.18	≤ 0.5
Specific gravity	2.58	-
Fineness modulus, %	2.8	-
Dry rodded density, kg/m³	1694	-
Absorption, %	0.8	-

TABLE V. AGGREGATE CHEMICAL AND PHYSICAL TESTS

Aggregate Type	SO_3	Specific gravity	Impact value, %	Abrasion, %	Crushing value, %	Dry rodded density, m³/kg	Absorption, %
C.N	0.02	2.62	14.4	17.4	17.77	1620	0.7
C.C	0.03	2.61	13	17	16.3	1263	4
C.T	0.08	2.67	16.4	20.3	19.6	1337	7.3
C.B	0.04	2.2	35.2	22.5	37	995	21

TABLE VI. GRADING TEST OF NATURAL COARSE AGGREGATES AND CRUSHED WASTE AGGREGATES

Sieve size (mm)	Passing (%)				[17] requirements
	C.N	C.C	C.T	C.B	
14	100	100	100	100	100
10	97	95	96	97	85 - 100
4.75	12	13	16	14	0– 25
2.36	1.0	4.8	5	4	0-5



(a) (b) (c) (d)

Fig. 1. Crushed coarse aggregate single size 10 mm. (a) C. N, (b) C.C, (c) C.T, (d) C.B.

III. NORMAL CONCRETE AND BLOCK MIXTURES

The ACI 211.1 was adopted for concrete mix design. The required compressive strength equal to 20 MPa was adopted for the control mixture. We tried to reduce the required compressive strength to 15 MPa (18.75 MPa per cub) in order to lower cement weight for economic and environmental reasons. Sustainable waste from demolished buildings was used as volume coarse aggregate replacement.

- Cement density for all mixes was 300 kg/m³, except for M15 mix, which equals to 262 kg/m³.
- Sand density for all mixes was 995 kg/m³, except M15 mix with 1015 kg/m³.
- Coarse aggregates content of M20, M15 was equal to 745 kg/m³, for 10% replacement it was 671kg/m³, and for 20% replacement it was 596 kg/m³.
- C.C replacement content of 10% of C.N equals to 58 kg/m³, and 20% equals to 116 kg/m³.
- C.T replacement content of 10% of C.N equals to 61.48 kg/m³, and 20% equals to 122.9 kg/m³.
- C.B replacement content of 10% of C.N equals to 45.75 kg/m³, and 20% equals to 91.51 kg/m³.
- Water content was 207 kg/m³ for all mixes and the water-cement ratio (w/c) of MR20 was 0.69 and of M15 was 0.79.
- The reduction rate to get dry to semi-dry mixture was 3-5%.

IV. CURING CONCRETE MASONRY UNITS (BLOCKS)

The blocks were covered with plastic sheet to prevent water evaporation for 24 hours. Two types of curing were followed:

- Normal curing by immersing the hollow blocks in curing tanks until the ages of test (14 and 28 days), according to [19].
- Spray of water two times per day at 7:00 am and 2:00 pm until testing age.

V. TESTS AND RESULTS OF NORMAL CONCRETE

After curing, we conducted the tests (compressive strength test according to [20], splitting tensile strength according to [21], and flexural strength according to [22]). The results are presented in Figure 2.

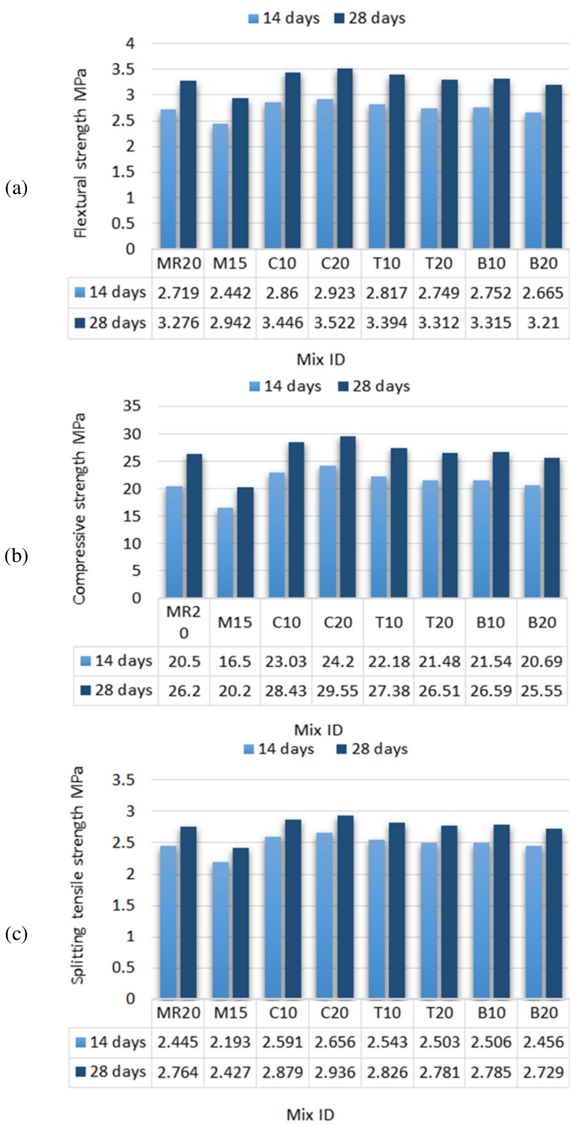


Fig. 2. Results strength of normal concrete.

VI. SIZE RANGE OF CONCRETE MASONRY UNITS

The size ranges of the blocks at 14 days were taken according to Iraq guide No. 32. The limitations of [23] (length 400 ± 3, width 200 ± 3, high 200 ± 3, web ≥ 20, shall ≥ 20) were followed (Figure 3).

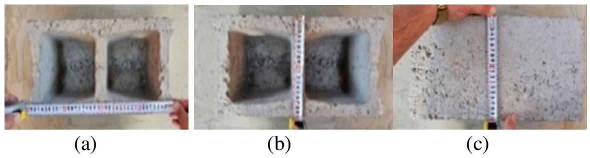


Fig. 3. Dimensions measurement of concrete masonry units. (a) Length, (b) width, (c) height.

VII. CONCRETE MASONRY UNITS ABSORPTION TEST RESULTS AT 14 AND 28 DAYS

The absorption tests were conducted according to the specifications of [23, 24]. The results are shown in Figure 4.

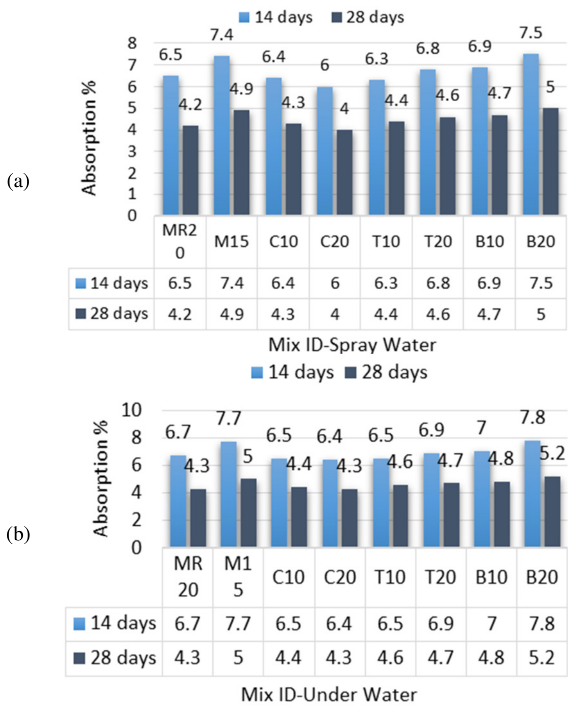


Fig. 4. Water absorption results of different concrete masonry unit mixtures. (a) Spraying curing, (b) water immersion curing.

VIII. COMPRESSIVE STRENGTH TEST RESULTS

According to [24], the blocks were put between two boards of wood using a compressive strength test equipment, with an appropriate load speed applied up to half of the predicted maximum load, followed by a continuous speed application for the 1-2 minutes. The results are shown in Figure 5 and Table VII.

TABLE VII. COMPRESSIVE STRENGTH RESULTS

Block	Compressive strength-Under Water (MPa)						Compressive strength-Spray Water (MPa)					
	14-days			28-days			14-days			28-days		
	Class	each block	Av. 3 block	Class	Each block	Av. 3 block	Class	each block	Av. 3 block	Class	Each block	Av. 3 block
BMR20	A	7.4	7.4	A	7.9	7.8	A	6.9	7.2	A	7.7	7.45
		7.5			7.4			7.5			7.1	
		7.3			8.1			7.2			7.4	
BM15	B	6.5	6.5	A	6.9	7.1	B	5.8	5.5	B	6.1	6.25
		6.7			7.3			5.2			6.5	
		6.3			7.1			5.6			6.2	
BC10	A	7.7	7.6	A	7.9	7.85	A	7.2	7.4	A	6.9	7.5
		7.3			7.4			7.6			7.8	
		7.8			8.1			7.4			7.8	
BC20	A	7.9	7.8	A	7.8	7.95	A	7.4	7.5	A	7.9	7.6
		8.1			8.3			7.5			7.8	
		7.4			7.6			7.6			7.1	
BT10	A	7.2	7.4	A	6.9	7.5	A	6.9	7.2	A	7.5	7.3
		7.6			7.9			7.5			7.1	
		7.4			7.7			7.2			7.4	
BT20	A	7.3	7.1	A	7.3	7.3	B	6.9	6.8	A	7.2	7.25
		7.1			6.9			7.1			7.2	
		6.9			7.9			6.5			7.4	
BB10	A	7.3	7	A	7.3	7.2	B	6.6	6.8	A	7.4	7.1
		6.8			7.5			7.0			7.1	
		6.9			6.8			6.9			6.9	
BB20	B	6.7	6.6	A	7.9	7	B	6.4	6.2	B	6.4	6.4
		6.8			7.2			6.1			6.7	
		6.4			7.9			6.2			6.2	

(a)

(b)

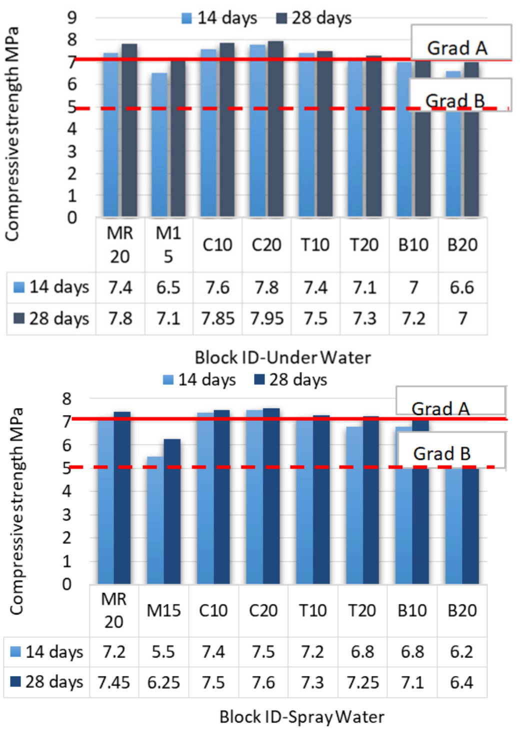


Fig. 5. Compressive strength results for different concrete masonary unit mixtures. (a) Spraying curing, (b) water immersion curing.

IX. DISSCUSION

This research studied the production of load masonry units according to the ACI 211.1 with minimum cost by reducing cement weight. M20 can be our reference mixture of the production block grade A, while when we tried to reduce cement content to 262 kg/m^3, the production block converted to grade B.

Fig. 6. Compressive strength test of concrete masonry units.

The main results of this study are:

- Compressive strength increased by 8.52% and 12.80% for 10% and 20% concrete waste substitution, increased by 4.52% and 1.24% for 10% and 20% tile waste substitution, and increased by 1.55% and decreased by 2.57 for 10% and 20% brick waste substitution, at 28 days.
- Splitting tensile strength increased by 4.21% and 6.20% for 10% and 20% concrete waste substitution, increased by 2.23%, and 0.61% for 10% and 20% tile waste substitution,

and increased by 0.10% and decreased by 1.30 for 10% and 20% brick waste substitution, at 28 days.

- Flexure strength increased by 5.20% and 7.52% for 10% and 20% concrete waste substitution, increased by 3.64% and 1.10% for 10% and 20% tile waste substitution, and increased by 1.23%, and decreased by 20.1 for 10% and 20% brick waste substitution, at 28 days.
- The positive acquired results for concrete with tile coarse aggregates partial volume substitution are due to the good bonding between the cement paste and the surface texture of waste C.A for 10 and 20% substitution. The 10% substitution of bricks gave almost the same results with the reference mixture and 20% replacement initiated the strength reduction.
- Adopting M20 as reference mixture led to the production of block grad A according to IQS1077 at 14 days.
- All sustainable production blocks using 10% or 20% substitution of C.A by concrete or tile waste were grad A for both types of curing (water immersing and water spraying). The same stands for using 10% brick waste for under water curing while it converted to grad B for spray water curing. The 20% substitution of brick waste produced grad B at 14 days for both types of curing and was improved to grad A after 28 days of immersing in water.

X. CONCLUSION

The environmental advantages of using waste materials as aggregate replacements in concrete blocks is the reduction in the existing solid waste and the reduction in the consumption of natural resources typically utilized as aggregates. Additionally, because different types of waste have different qualities, it is possible to make concrete blocks that function better than the expected and adhere to norms. The consideration of substitute waste may lead to the following conclusions:

- There is the ability to manufacture load-bearing masonry units in accordance with ACI 211.1 mix design standards using 1:3.2:2.5 cement: sand: coarse aggregate ratio with 25-50 mm slump limit that conform to criterion type A [23].
- All results show block improvement with age from 14 to 28 days, and the BB20-class B improves to BB20-class A, so increasing the age of curing is recommended.
- We adopted MR20 for best results and satisfactory to produce a concrete block with class A, since M15 may lead to class B or failed blocks as indicated by our experiment results.
- Water spraying was compatible with under water curing with less compressive strength results. We should take into consideration that B15 changed its class from A to B, which shows the importance of curing for 28 days.

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