Research Article

Zena K. Abbas*, Ahlam A. Abbood and Raghad S. Mahmood

Producing low-cost self-consolidation concrete using sustainable material

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Abstract: The disposal of the waste material is the main goal of this investigation by transformation to high-fineness powder and producing self-consolidation concrete (SCC) with less cost and more eco-friendly by reducing the cement weight, taking into consideration the fresh and strength properties. The reference mix design was prepared by adopting the European guide. Five waste materials (clay brick, ceramic, granite tiles, marble tiles, and thermostone blocks) were converted to high-fine particle size distribution and then used as 5, 10, and 15% weight replacements of cement. The improvement in strength properties is more significant when using clay bricks compared to other activated waste ceramics and granite tiles. The percentage increases to 11.59% at 28 days for compressive strength when using 10% replacement of cement weight. The ability to produce eco-SCC with less cement content and lower cost consumption is encouraged, although the enhancement in strength is not high since the waste can be disposable. While the percentage reduction in the strength of SCC mixes containing marble tile or thermostone block powder increases with the replacement of cement weight with a greater need for superplasticizer justification, we recommend using 5% as a replacement by weight of cement with an insignificant retardation of strength. Finally, there is a good relationship between compressive strength and ultrasonic pulse velocity and between tensile and flexural strength with a high R^2.

Keywords: self-consolidation concrete, clay brick powder, ceramic tile, granite tile, marble waste powder, thermostone block

* **Corresponding author: Zena K. Abbas,** Civil Department, College of Engineering, University of Baghdad, 10071, Baghdad, Iraq, e-mail: dr.zena.k.abbas@coeng.uobaghdad.edu.iq
Ahlam A. Abbood: Civil Department, College of Engineering, University of Baghdad, 10071, Baghdad, Iraq, e-mail: ahlam.ali@coeng.uobaghdad.edu.iq
Raghad S. Mahmood: Civil Department, College of Engineering, University of Baghdad, 10071, Baghdad, Iraq, e-mail: raghad.s@coeng.uobaghdad.edu.iq

1 Introduction

Increasing the quantities of waste in the modern world led to a series of environmental problems [1,2]. Therefore, many researchers and academicians try to solve this problem by recycling these materials differently, such as in building construction [3]. Moreover, some waste materials can be replaced or added to the concrete mix according to the study approach [4–6].

Green building construction is eco-friendly, recyclable, healthy, and a good way to reduce the impact on environmental and human health [7–9].

Because of the high amount of emission of carbon dioxide (CO_2) in the cement production process, minimizing the use of cement products in the concrete mix is another good way to reduce pollution and acquire clean environment air. Besides, it can reduce the construction cost by recycling waste and cement content by repayment with high-fineness particle size waste material [10].

The use of supplemental cementitious materials in a finely powdered solid as a replacement for the cement in concrete was studied by converting the waste materials to powder. Chemical reactions and physical effects between them and hydrating cement led to a modified paste microstructure [11,12]. The high-fineness waste material may improve the concrete's fresh state, mechanical properties, and durability.

The selected waste can be in the form of pozzolana that conforms to ASTM C618. It can react chemically with calcium hydroxide to produce essential silica gel that enhances concrete strength and microstructure-density filling [13,14]. Pozzolanic nano–micro particle size in the concrete mixture is one of the most recent novelties in the concrete mix design. The micro–nano particle size has a large surface area relative to its particle size, which gives it more spatial properties than other materials [4]. These nanomaterials can be pronounced as particle dimensions at least 1–100 nm [15].

The self-consolidation concrete (SCC), which can be named compacted, offers spatial properties, such as rapid replacement, consumption time, and the high ability to flow easily in the case of congested reinforcement and with no need for the mechanical vibration proses [16–20]. These can be achieved by increasing the paste content with a low water/powder ratio, which means a high cement content [21].

Our study focuses on presenting a new type of SCC that provides:

1. Reducing cost by adopting the use of recycling waste to high-fineness material can be used as cement replacement by weight.
2. Clean the environment by reducing cement consumption and waste disposal.

2 Materials

Tables 1 and 2 list the properties of ordinary Portland cement (OPC)/R 42.5. The properties of fine aggregate/natural sand (Zone 2 grading)-F.A and crushed coarse aggregate (14-5) mm-C.A, according to Iraqi stander (IQS) 45/1988, are listed in Table 3. Note that Structuro 520 (a superplasticizer) is issued by the producer and complies with ASTM C494/15 types A and F according to the manufactured sheet. All tests were carried out by the Building Research Center.

Figure 1 shows the steps for preparing the waste material, while the marble powder waste was collected from the workshop of tile marble. Table 4 presents the chemical analysis and the physical properties specification requirements adopting by ASTM C618-15 for class N [25].

3 SCC mixture, fresh properties, casting and curing

Laboratory trials for the initial mix composition, which was adopted according to the European guidelines [21], recommend the reference mix with a specified compressive strength of more than 40 MPa (standard cylinder) at 28 days, which contains only cement as a powder. Five waste materials were used as cement weight replacements

Table 1: Chemical composition of the OPC/R 42.5 cement

	Oxide content (%)							
	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	LOI	IR
Results-OPC	63.02	19.97	6.05	3.18	2.19	1.89	2.69	0.4
IQS No. 5-19 [22]	—	—	—	—	≤2.8	≤5.0	≤4.0	≤1.5
ASTM C150-17 [23]	—	—	—	—	≤3.0	≤6.0	≤3.0	≤0.75

Table 2: Physical properties of the OPC/R 42.5 cement

	Blaine surface (m^2/kg)	Autoclave soundness (%)	Setting time (Vicat's method) (min)		Compressive strength (MPa)			
			Initial setting	Final setting	2 days	3 days	7 days	28 days
Results	393.5	0.02	130	215	21	21.5	27	43.5
IQS No.5-19 [22]	≥280	≤0.8	≥45	≤600	≥20	—	—	≥42.5
ASTM C150-17 [23]	≥260	—	≥45	≤375	—	≥12	≥19	—

Table 3: Properties of the F.A and C.A

	Specific gravity	Absorption (%)	SO_3 content (%)	Material passing sieve 75 µm (%)
Results-FA	2.6	0.85	0.28	3.6
IQS No. 45-FA [24]	—	—	≤0.5	≤5
Results-CA	2.62	0.25	0.02	1.5
IQS No. 45-CA [24]	—	—	≤0.1	≤3.0

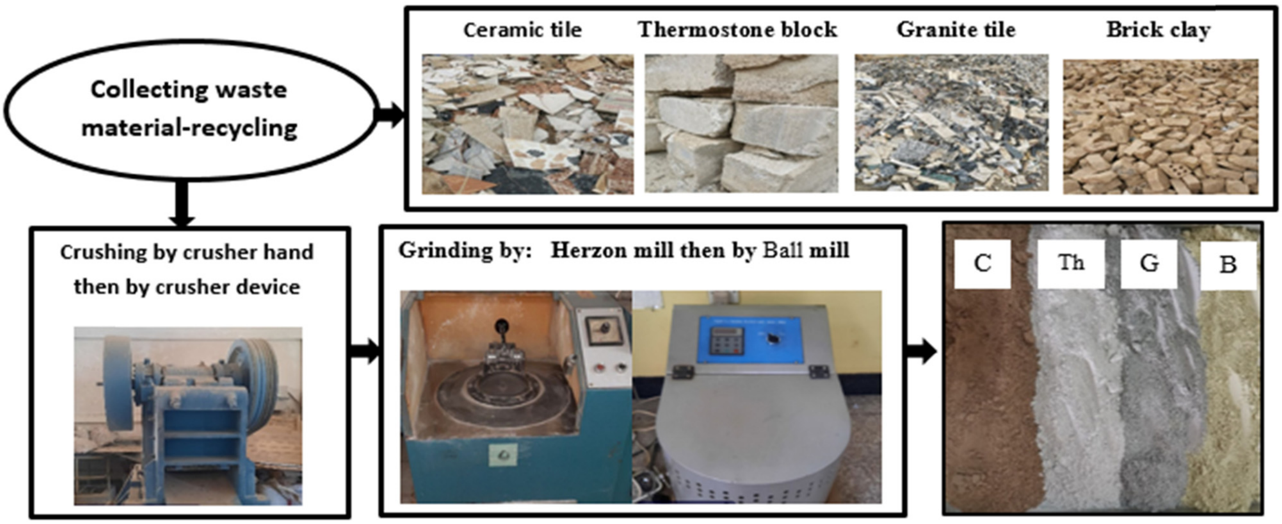

Figure 1: Preparing the waste material.

Table 4: Properties of waste-recycled materials

	Oxide content (%)							Physical tests		
	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	LOI	Strength activity index (%)	Specific gravity	Particle size distribution
Brick powder	58.25	12.46	5.25	20.20	0.0	1.69	2.15	97.8	2.85	92 nm
Granite powder	45.25	18.25	7.25	15.38	0.25	0.44	1.75	78.5	2.75	0.54 µm
Ceramic powder	50.15	15.85	8.92	16.75	0.35	0.45	2.35	88.2	2.65	0.60 µm
Thermostone powder*	20.82	10.95	3.25	64.55	0.32	1.22	8.55	—	2.15	0.38 µm
Marble powder*	4.35	6.75	1.15	67.25	0.11	0.15	16.56	—	2.22	0.48 µm
ASTM C618-15, Type N [25]	$SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70$			—	≤4%	—	≤10%	≥75% at 7 days	—	—

*Inert or semi-inert material.

by 5, 10, and 15%. Hence, the superplasticizer dosages were 1.4, 1.6, and 2.0 L/100 kg of cement, respectively, to achieve the fresh properties of SCC. The filling and passing ability were checked by slump flow, V funnel, and L-box to recommend the mix proportion, as shown in Figure 2. Table 5 presents the mixture content and fresh tests results for all SCC mixture.

After producing the SCC mixture and checking the fresh tests, the specimens were molded in cubic molds of 100 mm, cylinder molds of 150 mm × 300 mm, and prism molds of 100 mm × 100 mm × 400 mm for compressive, splitting, and flexural tests, respectively. A vibrating bench was done in two layers of cubes (10–12 s) adopting the British stranded 1881:Part 108:1983 [26], while the cylinders were compacted in three layers, and prisms had two layers adopting the ASTM C192-11 [27]. All specimens were smoothed in surfaces and covered with a nylon page for approximately 24 h and then cured in a tap water chamber until the test ages, as shown in Figure 3.

4 Experimental lab tests

For mechanical properties, three experimental tests were done: the ASTM C39/C39M [29] and the ASTM C496/C496M-11 [31] cover the determination of compressive strength and splitting tensile strength, respectively, of a cylindrical concrete size of 150 mm × 300 mm. The ASTM C78/C78M [32] can be adopted to test the flexural strength of concrete using simple beam size 100 mm × 100 mm × 400 mm with third-point loading and, finally, the ultrasonic pulse velocity (UPV) test according to ASTM C597 [30], as shown in Figure 4.

Table 5: SCC mixture and fresh tests

Mix ID	Sand = 775 kg/m^3, Crushed gravel = 850 kg/m^3, W/P = 0.34	Cement + powder (kg/m^3)	Superplasticizer (L/100 kg cement)	Slump flow—SF2 (mm)	Viscosity class—VS2/VF2		L-box PA2 (H2/H1) for 3 bars
	Description of the used powder in the mix				T500 (s)	V funnel (S)	
				660–750	>2	9–25	≥0.8
Ref	Cement	500	1.1	670	4.2	10.0	0.95
B5	Cement + 5% brick	475 + 25	1.4	695	4.0	12.0	0.92
B10	Cement + 10% brick	450 + 50	1.6	688	3.8	11.0	0.90
B15	Cement + 15% brick	425 + 75	2.0	675	4.2	10.5	0.95
C5	Cement + 5% ceramic	475 + 25	1.4	695	4.1	12.2	0.92
C10	Cement + 10% ceramic	450 + 50	1.6	701	4.1	9.8	0.88
C15	Cement + 15% ceramic	425 + 75	2.0	705	4.2	9.5	0.85
G5	Cement + 5% granite	475 + 25	1.4	747	3.9	9.4	0.85
G10	Cement + 10% granite	450 + 50	1.6	735	3.7	9.3	0.90
G15	Cement + 15% granite	425 + 75	2.0	690	3.6	11.2	0.91
Th5	Cement + 5% thermostone	475 + 25	1.4	680	4.1	10.5	0.87
Th10	Cement + 10% thermostone	450 + 50	1.6	725	3.9	9.5	0.85
Th20	Cement + 15% thermostone	425 + 75	2.0	715	3.8	9.8	0.88
M5	Cement + 5% marble	475 + 25	1.4	680	3.8	10.8	0.9
M10	Cement + 10% marble	450 + 50	1.6	688	4.2	11.0	0.85
M15	Cement + 15% marble	425 + 75	2.0	678	4.1	10.7	0.82

SF2: slump flow class 2 ranging (660–750 mm) suitable for many normal applications (e.g. walls, columns); VS2/VF2: Viscosity VS or VF (measure of the speed of flow); PA2: passing ability class 2 for structures with a gap of 60 mm to 80 mm.

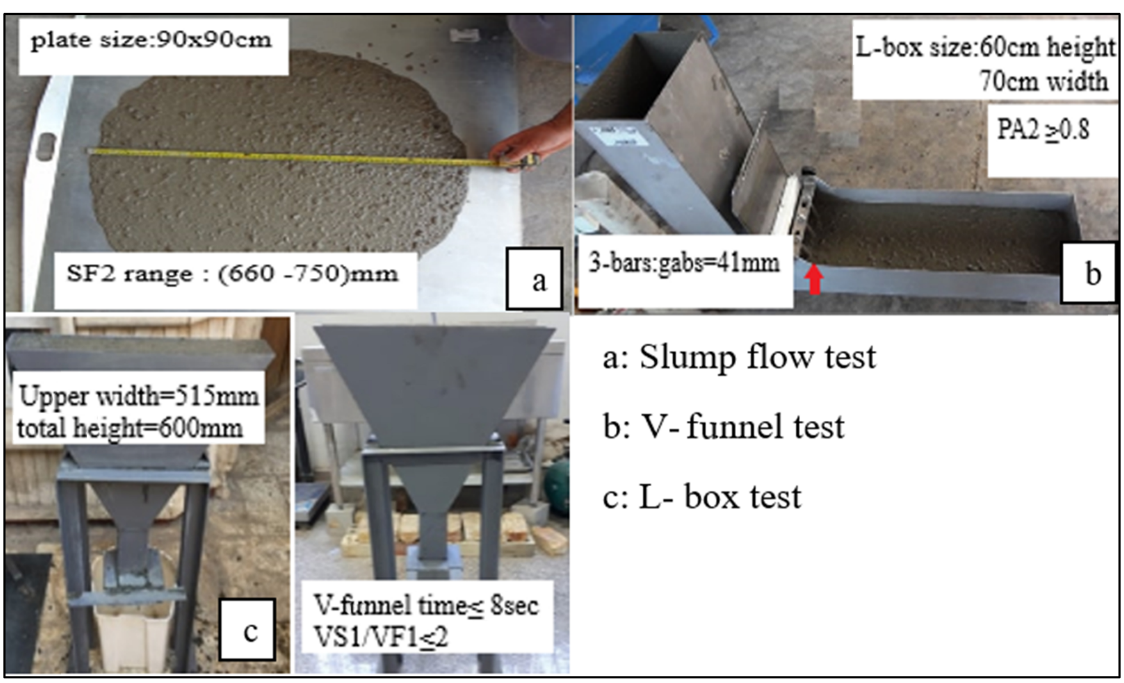

Figure 2: Fresh properties test according to the European guidelines for SCC [21].

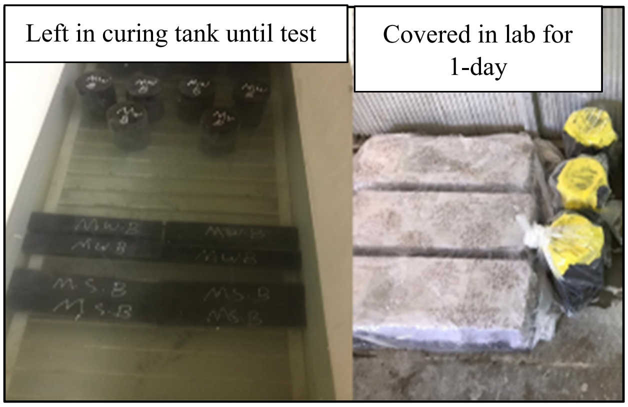

Figure 3: Curing samples.

5 Discussion of the experimental lab results

All SCC mixes conform to the European guide limits [15] for fresh properties that conform to passing and filling ability with resistance to segregation. Table 6 lists all test results for compressive strength, UPV, and tensile and flexural strength for different SCC mixes.

Figures 5–7 show the strength properties of the SCC mix that contains high-fineness waste-recycled powder with pozzolana activity (clay brick, ceramic tile, and granite tile) and the reference mix, while the SCC mixture contains inert or semi-inert waste-recycled as a powder

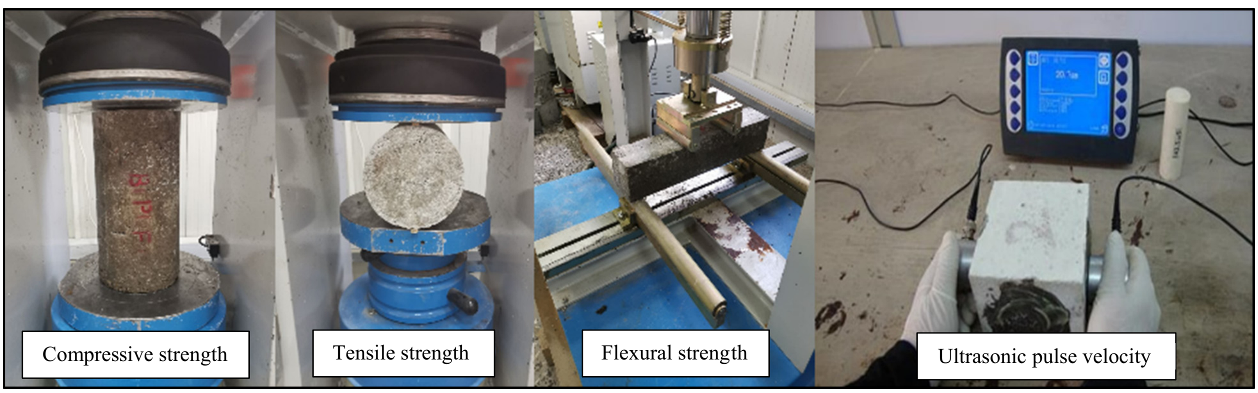

Figure 4: Experimental hardened lab tests.

Table 6: Experimental lab tests for different SCC mixture

Mix ID	Dry densit[1] 28 days (kg/m^3)	Compressive strength[2] (MPa)			UPV[3] (km/s)			Tensile strength[4] (MPa)			Flexural strength[5] (MPa)		
		7 days	28 days	90 days	7 days	28 days	90 days	7 days	28 days	90 days	7 days	28 days	90 days
Ref	2,355	33.9	41.4	46.4	4.175	4.335	4.442	3.20	3.60	3.75	3.82	4.38	4.47
B5	2,385	35.7	43.5	48.7	4.221	4.376	4.495	3.28	3.69	3.84	3.94	4.54	4.60
B10	2,450	37.1	45.2	51.7	4.265	4.395	4.535	3.39	3.81	3.96	3.79	4.34	4.43
B15	2,465	35.1	42.8	47.9	4.176	4.365	4.455	3.26	3.66	3.81	3.75	4.28	4.38
C5	2,365	34.0	41.5	46.9	4.178	4.338	4.425	3.22	3.62	3.77	3.84	4.40	4.48
C10	2,435	35.1	42.8	49.1	4.197	4.352	4.458	3.30	3.71	3.85	3.73	4.26	4.36
C15	2,455	33.2	40.5	46.5	4.168	4.311	4.405	3.21	3.61	3.75	3.75	4.27	4.38
G5	2,360	33.8	41.2	46.8	4.165	4.318	4.425	3.22	3.62	3.76	3.78	4.32	4.42
G10	2,428	34.9	42.6	47.7	4.195	4.352	4.445	3.25	3.66	3.80	3.70	4.34	4.33
G15	2,435	33.5	40.8	45.7	4.165	4.305	4.412	3.18	3.58	3.72	3.67	4.16	4.28
M5	2,370	32.8	40	44.8	4.145	4.295	4.388	3.15	3.54	3.68	3.60	4.04	4.20
M10	2,365	31.6	38.5	43.1	4.125	4.265	4.355	3.09	3.47	3.61	3.53	3.95	4.13
M15	2,325	30.5	37.2	41.7	4.112	4.238	4.338	3.04	3.42	3.55	3.64	4.11	4.26
Th5	2,360	32.4	39.5	44.2	4.145	4.265	4.375	3.13	3.52	3.66	3.56	4.02	4.16
Th10	2,350	31.0	37.8	42.3	4.121	4.227	4.342	3.06	3.44	3.58	3.50	3.96	4.09
Th20	2,315	29.9	36.5	40.9	4.172	4.217	3.577	3.01	3.38	3.52	3.82	4.38	4.47

1: According to BS 1881-114:1983 [28], 2: According to ASTM C39/C39M-17b (L/D = 2) [29] 3: According to ASTM C597-16 [30], 4: According to ASTM C496/C496M-11 [31], 5: According to ASTM C78/C78M-16 [32].

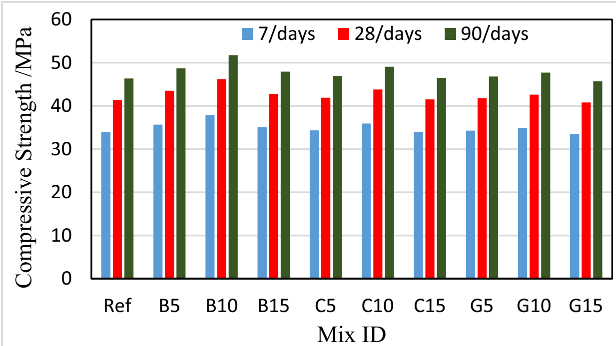

Figure 5: Compressive strength for Reference mix and pozzolanic SSC mix.

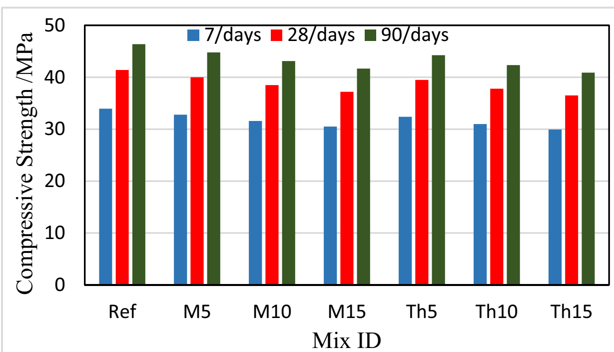

Figure 6: Compressive strength for Reference mix marble and thermostone SCC.

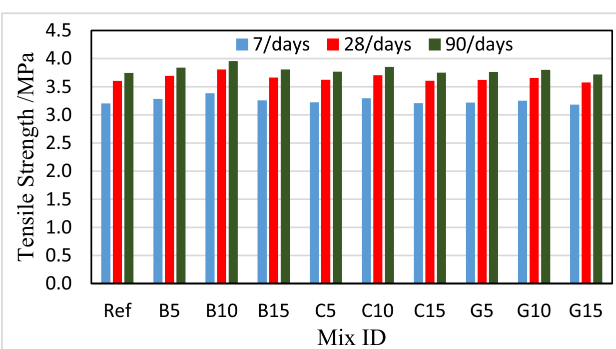

Figure 7: Tensile strength for Reference mix and pozzolanic SSC mix.

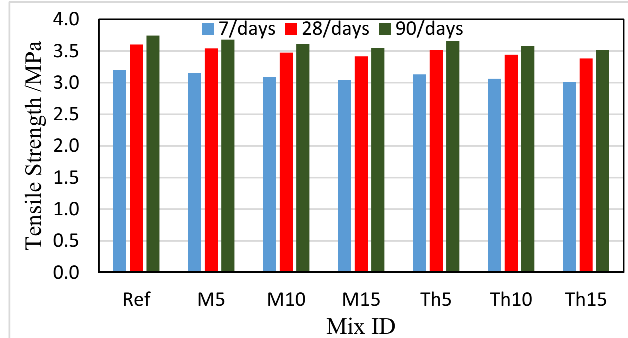

Figure 8: Tensile strength for Reference mix marble and thermostone SCC.

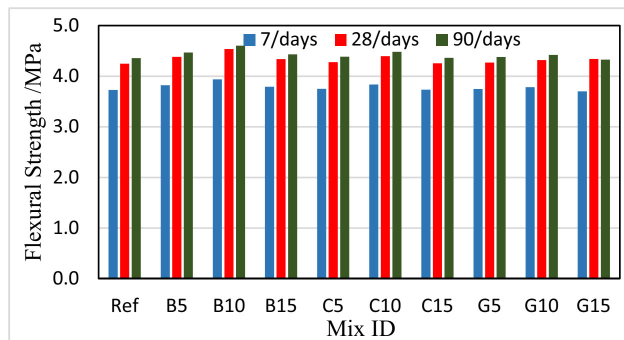

Figure 9: Flexural strength for Reference mix and pozzolanic SSC mix.

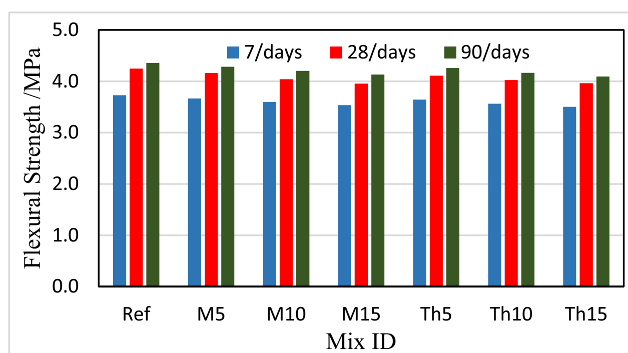

Figure 10: Flexural strength for Reference mix marble and thermostone SCC.

(marble tile and thermostone blocks) and the reference mix, as shown in Figures 8–10.

The improvement in strength properties is more significant when using clay brick compared to other activated waste materials (ceramic and granite tile). That behavior may be attributed to its high-strength activity index (97.8%), and a particle size distribution of 94 nm can be prepared [4]. Apart from that, the pozzolanic behavior can provide more strengthening gel contributing to the reaction between calcium hydroxide and active fine silica [33,34]. The use of ceramic tile powder instead of cement weight by 10% showed an enhancement in compressive strength up to 5.8% at 28 days [35,36]. Hence, removing waste can be recommended without a doubt of retardation of strength when converting that waste-recycled material to such a fine particle size [4,16]. While the

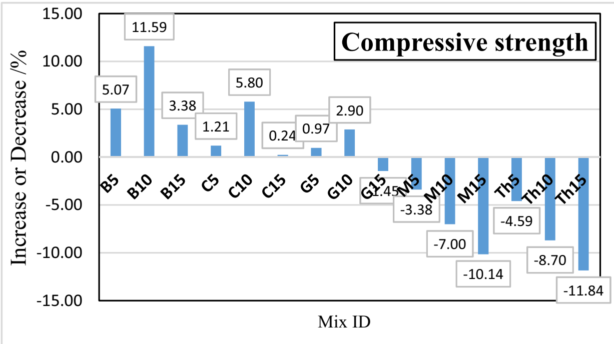

Figure 11: Variance in compressive strength for different mixes compared to the reference SCC.

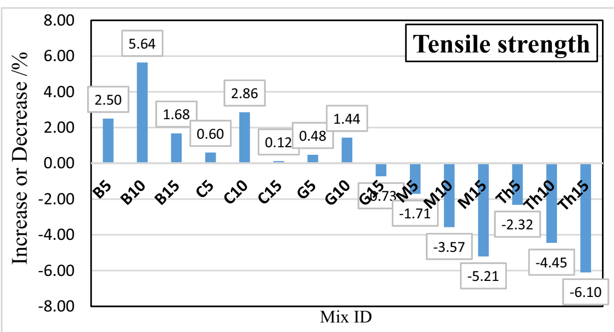

Figure 12: Variance in tensile strength for different mixes compared to the reference SCC.

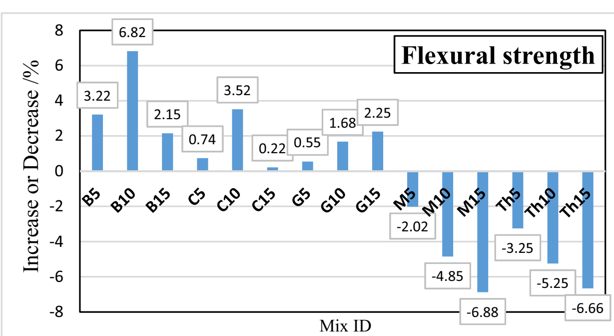

Figure 13: Variance in flexural strength for different mixes compared to the reference SCC.

percentage reduction in strength of SCC mixtures containing marble or thermostone powder increases with a high replacement of cement weight up to 15%, take into consideration the superplasticizer justification [37]. This behavior was expected when using inert or semi-inert materials as replacements for cement. The use of the low percentage of thermostone powder (5%) in the SCC

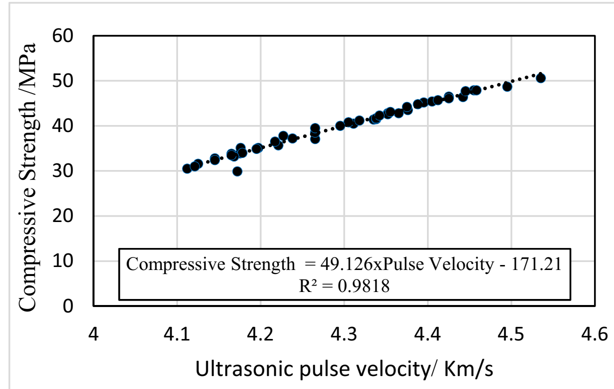

Figure 14: Statistical relation between the UPV and compressive test.

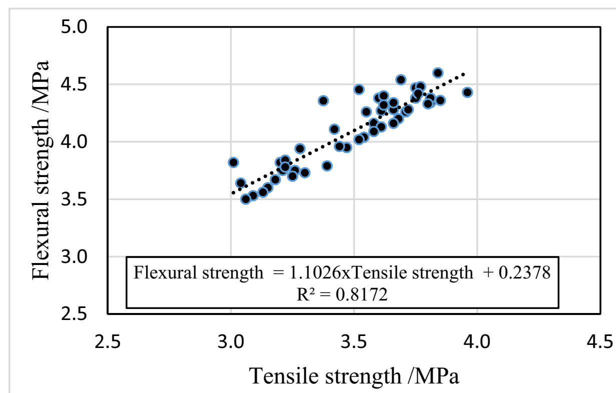

Figure 15: Statistical relation between tensile and flexural strength.

mixture showed a low decrease in compressive strength and was within the required design. Note that the variance in strength properties between reference mix and other mixes containing powder waste materials at 28 days is shown in Figures 11–13.

The good compatibility relation between compressive strength and UPV shown in Figure 14 considers that it is less significant to change the type of waste material since the replacement from the weight of cement. Finally, a good correlation between tensile and flexural strength is shown in Figure 15.

6 Conclusions

1. The compressive strength of the SCC mix containing 10% waste-recycled brick powder as a replacement for cement weight showed the highest percentage increase, up to 11.59% at 28 days compared to the reference mix.

2. Partially replacing cement weight with 10% of ceramic tile high-fineness powder showed an improvement in compressive strength up to 5.8% at 28 days.
3. The ability to use disposal brick or ceramic with a high-fine particle size of up to 15% of cement weight without affecting the strength of the SCC mixture.
4. Granite tile powder can be used safely up to 15% as partial replacement of cement weight with little compressive strength improvement equal to 1.68 and 2.25% at 28 and 90 days, respectively, in SCC.
5. The possibility of using (marble tile or thermostone blocks) waste instead of 5% cement weight with a slight reduction of 2.02 and 3.25%, respectively, at 28 days in SCC.
6. The 10 and 15% replacement cement weights by (marble tile or thermostone blocks) waste led to a considerable reduction in compressive strength, up to approximately 7% at 90 days.

Conflict of interest: Authors state no conflict of interest.

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