



EFFECT OF FILLER FROM RECYCLED CONSTRUCTION WASTE ON PROPERTIES OF SELF-COMPACTING CONCRETE IN FRESH AND HARDENED STATES

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Abstract: Construction waste is becoming a growing concern in the modern world. Waste recycling reduces the need for landfills and preserves natural resources. This paper investigates the possibility of using construction waste in self-compacting concrete. Fillers of various particle sizes were prepared by grinding several types of waste directly without any sorting or separation. Eighteen mixtures of concrete were prepared by varying the types and proportions of fillers and other additives, and they were tested for workability in fresh state, compressive strength, and dynamic modulus of elasticity after 7 and 28 days of hardening. Eventually, the mixtures were also tested for water absorption. Results indicated that fresh concrete samples did not meet all the requirements of self-compacting concrete, and therefore guidelines were proposed for improving the composition of concrete.

Keywords: self-compacting concrete; filler; construction waste; workability of SCC; dynamic modulus of elasticity; strength

UTJECAJ PUNILA OD RECIKLIRANOG GRAĐEVINSKOG OTPADA NA SVOJSTVA SAMOZBIJAJUĆEG BETONA U SVJEŽEM I OČVRSLOM STANJU

Sažetak: Gomilanje građevinskog otpada postaje sve veći problem modernog svijeta. Recikliranjem građevinskog otpada smanjuje se potreba za odlagalištima i čuvaju se prirodni izvori materijala. U radu je ispitana mogućnost primjene građevinskog otpada kao punila za samozbijajuće betone. Mljevenjem otpada različitog porijekla pripremila su se punila različitih veličina čestica. Na 18 mješavina ispitana je obradivost u svježem stanju, tlačna čvrstoća i dinamički modul elastičnosti na očvrslom betonu kod starosti od 7 i 28 dana, te vodoupojnost. Uzorci svježeg betona nisu zadovoljili sve uvjete za samozbijajući beton te su dane smjernice za poboljšanje sastava betona.

Ključne riječi: samozbijajući beton; punilo; građevinski otpad; obradivost SCC; dinamički modul elastičnosti; čvrstoća



1 INTRODUCTION

There are numerous reasons for recycling of construction waste, the most important ones being the preservation of non-renewable mineral resources and environment protection. Rapid urban development not only reduces the number of suitable landfills but also increases the waste from demolished buildings. Waste from new constructions, renovations, and demolitions consists of wood, concrete, glass, brick, copper wire, insulation, and other materials [1-3]. These are mostly (up to 90%) inert and non-degradable materials for reuse or recycling. Waste containing paints, solvents, and various chemicals or that contaminated with asbestos is considered to be potentially hazardous [4].

Waste separation is a major concern in recycling, considering that minimal processing is preferred for efficient waste handling. A concrete waste can be reused directly without any additional processing for applications in hard standing, bank protection, noise barriers and embankments, and road construction [5]. In general, a material recycled from a construction waste can be used as an additive in new asphalt-concrete mixtures and various types of concrete [6].

Using recycled aggregates in a new construction is a common subject of research [7-12]. Kamal et al. [13] examined the properties of a self-compacting concrete mixture containing recycled aggregates such as crushed red bricks and ceramics instead of dolomite. Ravindrarajah [14] classified concrete waste into two categories: contaminated and free-from-contamination. Recycled aggregates need to be cleaned prior to use in new constructions, and their quality depends on the source material (waste) and method of recycling.

The amount of a powdered component required to prepare a self-compacting concrete mixture is 380–600 kg/m³, according to EFNARC [15, 16]. Most of this component is cement, the production of which is characterized by high energy consumption and a large amount of CO₂ emission [17]. Extensive research is underway to replace part of the cement with a suitable additive such as silica fume, fly ash, stone dust, metakaolin, or any recycled material. Sighn et al. [18] used brick powder, marble powder, and VMA (viscosity modifier) to improve the workability and other properties of self-compacting concrete. A team of experts from Algeria University [19] studied the impact of fine clay on the properties of self-compacting concrete. The effect of ground brick as a filler or an aggregate material on the properties of self-compacting lightweight concrete was investigated in [20]. The authors concluded that a filler with a size of less than 0.04 mm in combination with other additives improves the compressive strength of a concrete mixture.

This paper examines the possibility of using the fillers obtained by grinding a construction waste as an additive to a self-compacting concrete mixture.

2 EXPERIMENTAL PART

2.1 Materials and methods

Table 1 shows a list of 18 mixtures of self-compacting concrete prepared using cement (CEM II/A - LL 42,5 R) of 360 kg/m³ and crushed limestones with fractions of 0–4, 4–8, and 8–16 mm. The grain-size distribution curves of the mixtures of the three fractions and the cumulative curve are shown in Figure 1.

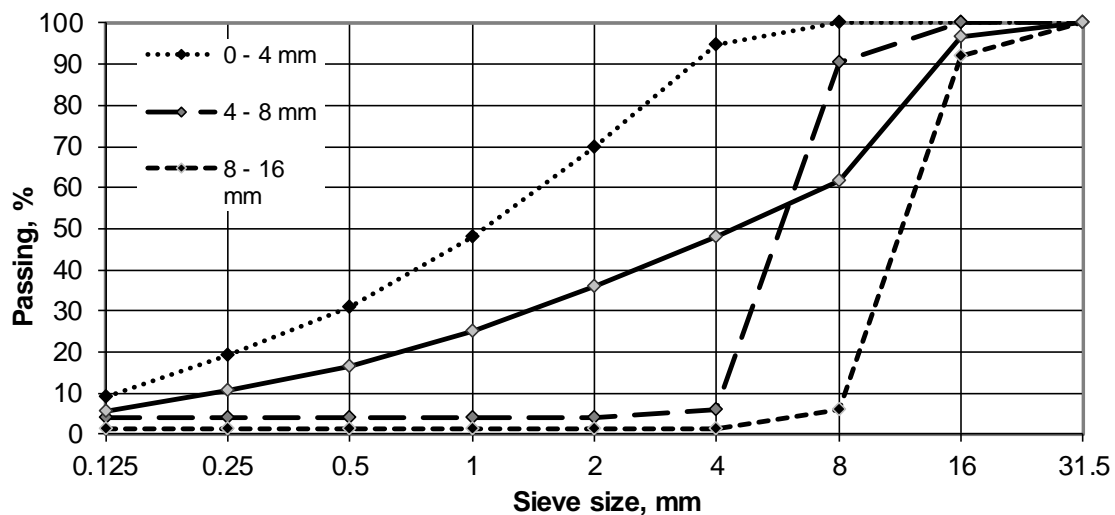


Figure 1 Grain-size distribution curves of aggregate fractions and self-compacting concrete

Two types of superplasticizer on polycarboxylate ether base of an amount of 1% of the binder by weight were added. The concrete mixtures differ from one another in respect of the additives and fillers. Three types of additives, each measuring 10% of cement by weight, were used: silica fume (SF), fly ash (FA), and metakaolin (M). Fillers commercially available in the market and/or the ones obtained by recycling were used. The commercially available fillers considered for this study were:

P1—concrete filler prepared by a cement plant by finely grinding a concrete surface using a machine, with a specific surface area of 7891 cm²/g (Blaine method), a density of 2.45 g/cm³, and a percentage passing of 71% through a sieve with a mesh of 0.032 mm.

P2—stone dust of a density of 2.7 g/cm³ and a percentage passing of 86% through a sieve with a mesh of 0.032 mm.

Fillers prepared in the laboratory were:

F1—filler obtained by grinding the rubbles of a demolished masonry structure. It consists of concrete, brick, mortar, styrofoam, glass, tiles, and other similar materials, as shown in Figure 2 (left). The unsorted waste was ground in a ball mill and then sieved through a mesh of 0.04 mm, in accordance with the recommendations in [20]. Its density was 2.20 g/cm³, and specific surface area was 10603 cm²/g (Blaine method).



Figure 2 Material for preparation of filler F1 (left) [21] and F32 — fraction 0.063–0.125 mm (right) [22]



F2—filler obtained by grinding concrete elements in a ball mill and sieving the powder subsequently through a sieve with a mesh of 0.04 mm. Its density was 2.40 g/cm³ and specific surface area was 9679 cm²/g (Blaine method).

F3—fillers of different fractions obtained by grinding concrete test cubes and sieving the resultant powder: F31 particles <0.063 mm, F32 of 0.063–0.125 mm (Figure 2, right), F33 of 0.125–0.25 mm, F34 of 0.25–0.5 mm, and F35 fraction comprising all particles <0.5 mm.

The proportion of filler for the first mixture (M1) was determined by the CBI method, where the minimum volume of paste was determined based on the minimum void criteria and blocking criteria [23] and the same proportion was adopted for all other mixtures. The starting water-cement ratio was 0.51; however, the amount of water was adjusted for the workability and visual stability of the mixture.

Table 1 Compositions and markings of mixtures

Composition Mixture	Cement kg	w/c	w/c**	Additive		Filler		Aggregate			Admixture Kg
				type	kg	type	kg	0–4 mm	4–8 mm	8–16 mm	
M1	360	0.51	0.46	SF	36	P1	92.88	810.45	161.57	649.47	3.96*
M2	360	0.51	0.61	FA	36	P1	92.88	810.45	161.57	649.47	3.96
M3	360	0.51	0.59	FA	36	P1	46.44	810.45	161.57	649.47	3.96
						F2	46.44				
M4	360	0.51	0.53	FA	36	F2	92.88	810.45	161.57	649.47	3.96
M5	360	0.51	0.55	FA	36	P1	69.66	810.45	161.57	649.47	3.96
						F2	23.22				
M6	360	0.51	0.58	FA	36	F1	92.88	810.45	161.57	649.47	3.96
M7	360	0.51	0.60	FA	36	P1	46.44	810.45	161.57	649.47	3.96
						F1	46.44				
M8	360	0.51	0.61	FA	36	P1	69.66	810.45	161.57	649.47	3.96
						F1	23.22				
M9	360	0.51	0.60	SF	36	P2	69.66	810.45	161.57	649.47	3.96
						F2	23.22				
M10	360	0.51	0.55	SF	36	F31	92.88	810.45	161.57	649.47	3.96
M11	360	0.51	0.59	SF	36	F32	92.88	810.45	161.57	649.47	3.96
M12	360	0.51	0.58	SF	36	F33	92.88	810.45	161.57	649.47	3.96
M13	360	0.51	0.61	FA	36	F33	92.88	810.45	161.57	649.47	3.96
M14	360	0.51	0.59	M	36	F33	92.88	810.45	161.57	649.47	3.96
M15	360	0.51	0.64	SF	36	F33	46.66	810.45	161.57	649.47	3.96
						F34	46.44				
M16	360	0.51	0.66	SF	36	F35	92.88	810.45	161.57	649.47	3.96
M17	360	0.51	0.63	FA	36	F35	92.88	810.45	161.57	649.47	3.96
M18	360	0.51	0.61	M	36	F35	92.88	810.45	161.57	649.47	3.96

* other type of superplasticizer

** actual water-cement ratio

The samples of the mixtures were tested for workability in fresh state using the methods such as the V-funnel, T500, slump-flow, J-ring, and L-box, and the sample stability was visually inspected. Subsequently, the samples were embedded in 15-cm cube-shaped molds. After 24 h, the samples of the concrete mixtures were extracted from the molds and cured in water at 20 ± 2 °C during the test period. After 7 and 28 days, the dynamic modulus of elasticity and compressive strength were determined using three samples from each mixture, and the remaining samples were dried at room temperature to constant weight and tested for water absorption.

2.2 Test results of fresh concrete

Table 2 shows the results of concrete testing in fresh state.



Table 2 Results of fresh concrete testing

Method Mixture	V-funnel		T500		Slump-flow		J-ring		L-box	
	s	class	s	class	mm	class	PJ	class	PL	class
M1	88.93	-	3.17	VS2	520	-	40	-	0.00	-
M2	3.19	VF1	0.74	VS1	485	-	41.25	-	0.46	-
M3	4.24	VF1	0.91	VS1	505	-	43.75	-	0.37	-
M4	5.91	VF1	1.23	VS1	565	SF1	31.25	-	0.41	-
M5	3.15	VF1	0.92	VS1	630	SF1	31.25	-	0.67	-
M6	3.65	VF1	0.62	VS1	590	SF1	35	-	0.43	-
M7	3.45	VF1	0.94	VS1	607.5	SF1	33.75	-	0.59	-
M8	6.9	VF1	1.26	VS1	677.5	SF2	32.5	-	0.59	-
M9	9.26	VF2	0.73	VS1	640	SF1	36.25	-	0.38	-
M10	24.31	VF2	3.63	VS2	465	-	69.5	-	0.08	-
M11	15.47	VF2	3.28	VS2	445	-	45	-	0.00	-
M12	18.19	VF2	2.12	VS2	525	-	36.25	-	0.06	-
M13	11.53	VF2	0.69	VS1	735	SF2	27.5	-	0.71	-
M14	18.81	VF2	0.66	VS1	622.5	SF1	36.25	-	0.13	-
M15	12.37	VF2	0.46	VS1	607.5	SF1	37.5	-	0.44	-
M16	12.19	VF2	0.46	VS1	610	SF1	26.25	-	0.35	-
M17	15.56	VF2	0.88	VS1	690	SF2	26.25	-	0.73	-
M18	10.31	VF2	0.41	VS1	690	SF2	15	-	0.46	-

The first mixture M1 (Figure 3, right) did not satisfy the tests, and therefore another type of superplasticizer was selected. Other mixtures exhibited better leakage time; however, they could not satisfy the J-ring and L-box tests (Figure 4). The fillers obtained by grinding concrete cubes (M10–M18) increased the concrete leakage time compared to other mixtures (M2–M9). The mixtures M1–M3 and M10–M12 did not exhibit the minimum required spreading of 550 mm (Figure 3, left). The mixtures with fly ash, metakaolin, and F3-type filler of slightly larger particles exhibited the best workability according to the slump-flow method. In the case of M3 and M10, thixotropic effect was observed when the mixing was interrupted (Figure 5).



Figure 3 Mixture M10 (slump-flow) [22] and M1 (L-box) [21]



Figure 4 Testing of mixture M17 by J-ring method [22]



Figure 5 Mixtures M3 and M10 [21, 22]

2.3 Test results of hardened concrete

2.3.1 Dynamic modulus of elasticity

The samples of concrete mixtures were tested for dynamic modulus of elasticity (expressed as below) after hardening (aging) for 7 and 28 days, which are hereinafter called as 7-days and 28-days, respectively, for the sake of simplicity:

$$E_{din} = \frac{v^2 \rho (1 + \mu)(1 - 2\mu)}{1 - \mu} \quad (1)$$

where

v — mean ultrasonic wave speed [m/s]

ρ — concrete density [kg/m^3]

μ — Poisson coefficient, $\mu = 0.2$

Figure 6 shows the test results of 7-days and 28-days. In the case of 28-days, M1 exhibits the highest values, while M1–M9 exhibit higher values than M10–M18. The differences in values of 7-days and 28-days are not significant, while M10–M17 exhibit higher values for 7-days as compared to 28-days. It is possible that there was a change in the humidity of the cubes during the measurement, affecting the transit time of ultrasonic speed.

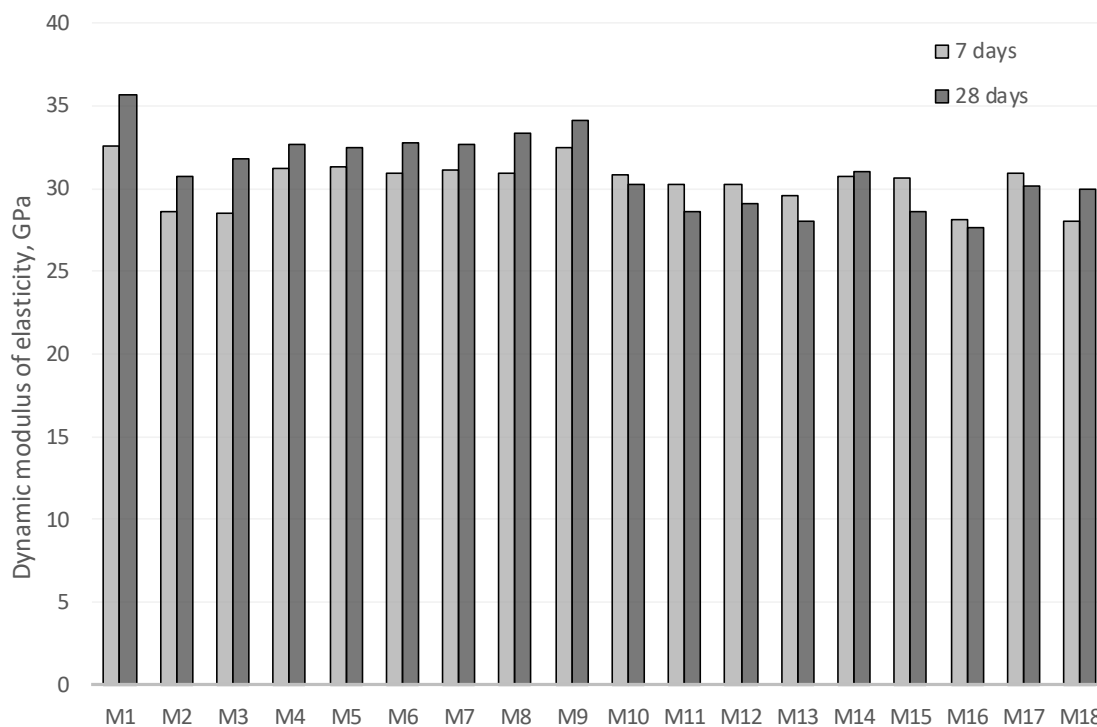


Figure 6 Dynamic modulus of elasticity after 7 and 28 days

2.3.2 Compressive strength

The results of compressive strength for 7-days and 28-days are shown in Figure 7. The values for 28-days are observed to be above 50 MPa.

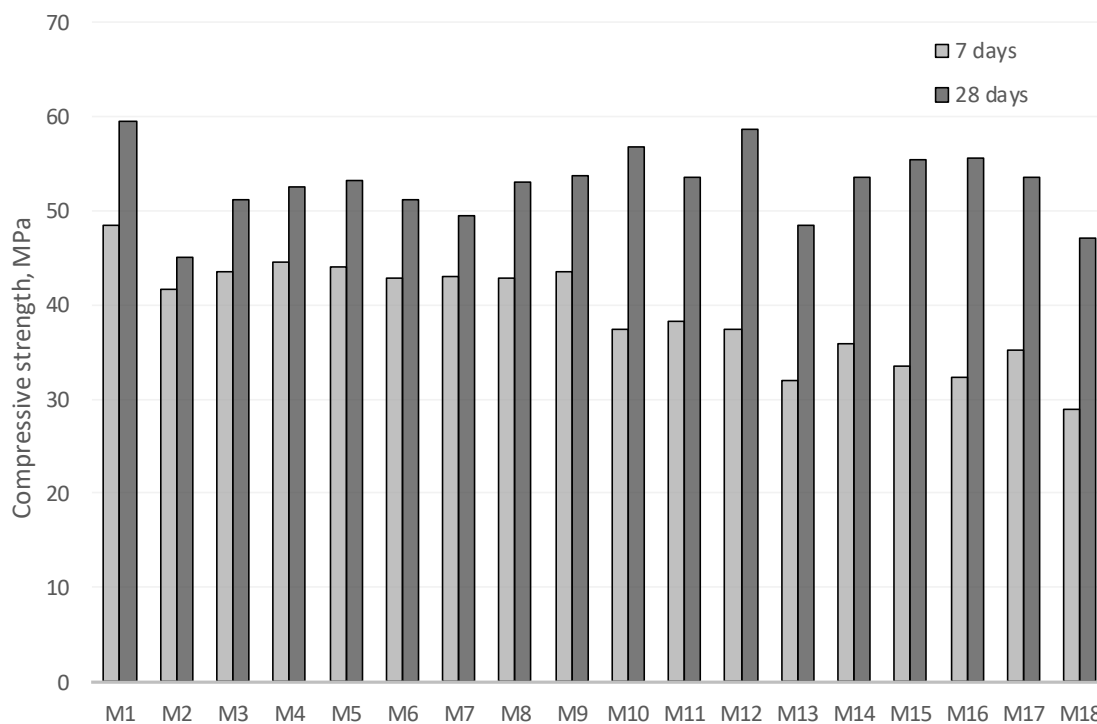


Figure 7 Compressive strength after 7 and 28 days



M1 attained the best compressive strength in the case of 28-days, followed by M12, M10, M16, and M15, in decreasing order. It is observed that these are silica-fume mixtures with fillers of recycled concrete (P1 and F3). Since M1 did not meet the requirements of workability of self-compacting concrete, the strength would probably have been much better if it were prepared as a standard concrete, under the influence of vibration, as inferred from the appearance of the sample (Figure 8). Mixtures with F3-type filler exhibit higher strength increase after 7 days. This strength increase is up to 42% in relation to 28-day strength (M16).

Mixtures with unsorted waste or filler F1 exhibit closely similar values of compressive strength. The values would probably have been higher if they were prepared with silica fume. The highest and lowest values were achieved for the mixtures with commercial filler P1, and the difference in the values was attributed to the additive (silica fume versus fly ash) and amount of water added.



Figure 8 Samples of mixtures M1 and M8 [21]

2.3.3 Absorption

The samples dried to a constant weight at room temperature were exposed to water only on one side. The change in weight was measured after 2, 4, 8, 15, 30, 45, 60 min, and 4 and 24 h. The change in the amount of absorbed water (g) in relation to the initial weight of the sample is plotted with time (s) for M1–M18 in Figure 9.

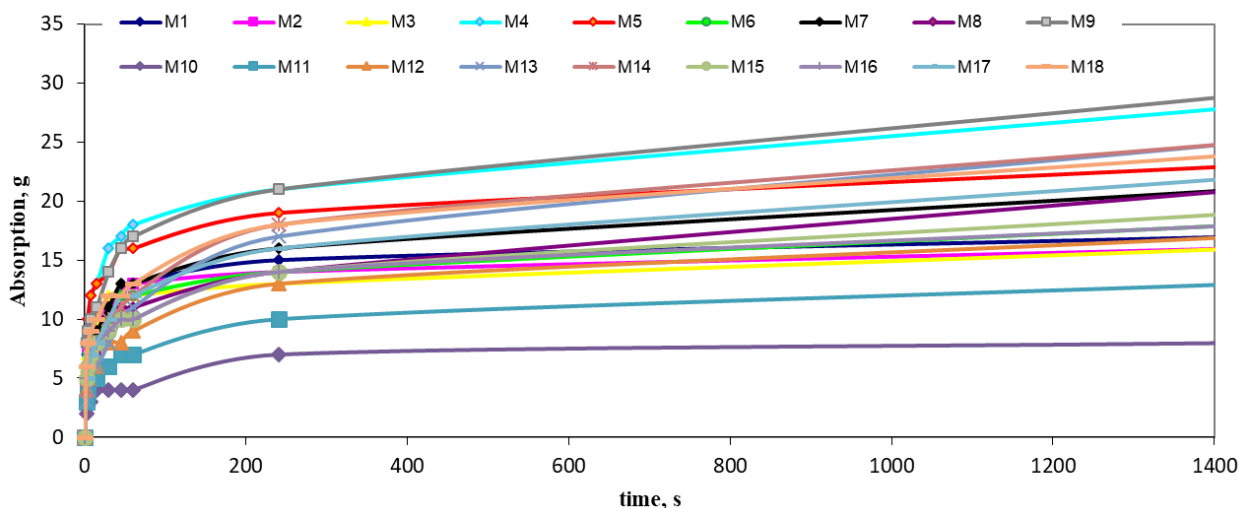


Figure 9 Absorbed water (g) in samples M1-M18 during 24 h



The least water absorption is observed in M10 and M11, which are the mixtures with silica and filler particles (of concrete cubes) smaller than 0.063 mm and in the range of 0.063–0.125 mm. The mixtures with the highest change in weight are M9, M4, and M5, prepared with F2-type filler formed by grinding concrete elements. The combination of P2-type (stone dust) and F2-type fillers in M9 exhibited the worst results, considering that the weight increased by 0.37% in relation to the initial sample weight after 24 h. Mixtures with mixed waste exhibited intermediate values.

3 DISCUSSION ON RESULTS

The test results of the mixtures indicate that the fresh state of concrete, the inability to overcome the obstacles, is the major issue, while the size of spreading is a concern in a few cases. Table 3 [15] proposes the measures to improve various features of concrete. For example, it proposes to increase the water content in the concrete as a solution to reduce the viscosity.

Table 3 Possible corrective actions from identified faults [15]

Possible improvement	Effect on:				
	Viscosity too high	Filling ability	Passing ability	Segregation resistance	Strength
<i>increase water content</i>		+	+	-	-
<i>Increase paste volume</i>		+	+	+	+
<i>increase superplasticizer</i>		+	+	-	+
Yield value too high					
<i>increase superplasticizer</i>		+	+	-	+
<i>increase paste volume</i>		+	+	+	+
<i>increase mortar volume</i>		+	+	+	+
Rapid loss of workability					
<i>use different superplasticizer</i>		?	?	?	?
<i>exchange filler for cement</i>		?	?	?	?
Blockage					
<i>reduce maximum aggregate size</i>		+	+	+	-
<i>increase paste volume</i>		+	+	+	+
<i>increase mortar volume</i>		+	+	+	+

“+” indicates better results with respect to concrete properties, - indicates poorer results with respect to concrete properties, and “?” means that the impact on concrete properties cannot be predicted.

An analysis of the composition of fresh concrete according to the values recommended by EFNARC (Table 4) indicates that the volume ratio of water to powdery component deviates from the recommended values except for M1 that exhibits all the parameters within the recommended values but lacks the property of self-compacting concrete. As the water content has already exceeded the recommended limit in a few mixtures, a measure to increase the water content is not applicable. Similarly, the amount of superplasticizer cannot be increased as it is already at a maximum level. However, there is a possibility to add a viscosity modifier or change the type of superplasticizer, which is one of the recommendations as inferred from Table 3.



Table 4 EFNARC parameters and actual mixture values [16]

Parameter/ Typical range	Coarse aggregate (kg/m ³)	Fine aggregate weight/ total aggregate (%)	Volume of paste (L/m ³)	Mass of powdery component (kg)	Water (kg)	v/p water/powdery component (vol.)
Mixture	750-1000	48-55	300-380	380-600	150-210	0.85-1.10
M1	817.4	50	312	488.9	164.5	0.97
M2	817.4	50	312	488.9	219	1.29
M3	817.4	50	312	488.9	212	1.25
M4	817.4	50	312	488.9	189	1.11
M5	817.4	50	312	488.9	197	1.16
M6	817.4	50	312	488.9	210	1.24
M7	817.4	50	312	488.9	216	1.27
M8	817.4	50	312	488.9	219	1.29
M9	817.4	50	312	488.9	217	1.29
M10	811.0	50	312	488.9	197.9	1.16
M11	811.0	50	312	488.9	211	1.24
M12	811.0	50	312	488.9	208.8	1.23
M13	811.0	50	312	488.9	218.2	1.28
M14	811.0	50	312	488.9	211.4	1.24
M15	811.0	50	312	488.9	230.5	1.36
M16	811.0	50	312	488.9	236.6	1.39
M17	811.0	50	312	488.9	225.6	1.33
M18	811.0	50	312	488.9	217.9	1.28

Furthermore, Table 3 indicates that increasing the volumes of paste and mortar is a possible measure to eliminate blockage and thereby affect the workability favorably. As the volume of paste is closer to the lower recommended limit, it is possible to increase the amount of powdered component. If silica, fly ash, or metakaolin of an amount of 10% of cement by weight is added, the amount of cement could be increased by 50–100 kg per m³ of concrete, and the quantity of powdered component would remain within the recommended limits. Increasing the amount of cement is expected to increase the compressive strength of concrete positively.

4 CONCLUSION

Disposal of waste, especially construction waste, is a serious concern in the modern world. Waste recycling requires dedicated equipment, while waste separation is a time-consuming and expensive process. This paper investigates the possibility of using construction waste directly without any sorting or separation. Accordingly, in this study, the waste is ground, and the sieved powder is used to prepare concrete mixtures of various compositions that include different types of additives and fillers. The tests conducted on the concrete mixtures lead to the conclusions as follows:

- The mixtures did not qualify for the tests on blockage of self-compacting concrete; therefore, it is recommended to increase the amount of cement, add a viscosity modifier, and change the type of superplasticizer. This measure is expected to ensure better workability of concrete.
- Mixtures with additives such as fly ash and metakaolin and a filler of a large particle size exhibit better results in respect of slump flow.
- The best compressive strength is obtained by combining silica fume and recycled concrete.
- The finest particles of the ground concrete cubes increase the 7-day strength to a larger extent as compared to the 28-day strength. It is recommended to examine the samples after 90 days in order to explore the possibility of increasing the strength.
- Samples made of silica and filler particles of concrete cubes smaller than 0.063 mm and in the range of 0.063-0.125 mm exhibit significantly less absorption than other samples.
- A filler obtained from mixed construction waste does not deviate from the other results.

Samples of concrete mixtures are tested in laboratories on a daily basis for compressive strength. The tested samples are disposed as construction waste. The hardened concrete mixtures prepared with silica fume and the

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fillers obtained by grinding concrete cubes exhibit good results. Even if the proposed changes in the composition of concrete would not improve the workability and quality of self-compacting concrete, the compressive strength achieved in this study clearly indicates that the filler can be used as an addition to ordinary concrete. It is expected that vibration will help improve the final characteristics of concrete, which can be determined by simple studies.

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