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Properties of concretes produced with waste concrete aggregate

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Abstract

An environmentally friendly approach to the disposal of waste materials, a difficult issue to cope with in today's world, would only be possible through a useful recycling process. For this reason, we suggest that clearing the debris from destroyed buildings in such a way as to obtain waste concrete aggregates (WCA) to be reused in concrete production could well be a partial solution to environmental pollution. For this study, the physical and mechanical properties along with their freeze–thaw durability of concrete produced with WCAs were investigated and test results presented. While experimenting with fresh and hardened concrete, mixtures containing recycled concrete aggregates in amounts of 30%, 50%, 70%, and 100% were prepared. Afterward, these mixtures underwent freeze–thaw cycles. As a result, we found out that C16-quality concrete could be produced using less then 30% C14-quality WCA. Moreover, it was observed that the unit weight, workability, and durability of the concretes produced through WCA decreased in inverse proportion to their endurance for freeze–thaw cycle.

Keywords: Waste concrete; Workability; Strength; Durability

1. Introduction

Waste concrete aggregate (WCA) is being increasingly used in concrete. We suggest that taking advantage of the debris of the buildings damaged in destructive earthquakes occurring in various places would be beneficial because it can produce good-quality concrete, provided that the debris are used in proper amounts as WCAs. In order to be used in concrete, such environmentally unfriendly pollutants as WCAs should be standardized in consideration with normal aggregate [1]. For this purpose, gravel size, specific gravity, water absorption ratio, Los Angeles abrasion, and crushing values should be determined, and these aggregates should be rid of such materials as wood, ceramics, iron, and so on [2]. WCAs are mostly used as protective barrier and ground-filling material against erosion. However, in such large-scale projects as rebuilding roads and runways, by using WCA, the cost of removal of the debris is automatically reduced. In addition, by establishing a center to use WCA near the sites of the aforementioned projects, high expenditures of new concrete productions can be avoided [3,4]. This application is increasingly gaining popularity in many countries.

2. Properties of WCAs

WCAs are crushed and ground by means of different methods so that they could be used as concrete aggregates. Through visual observations, many experts working in this area have so far agreed that WCAs make proper aggregates. Waste concrete can be crushed into fine and coarse aggregates [5]. In comparison with normal concrete, WCAs have a higher water absorption ratio but a lower specific gravity. Also, Los Angeles abrasion percentage and crushing values are much higher. The mortar percentage used in WCA obtained from crushed concrete of destroyed structures was determined via linear traverse method. It was 30% for gravel between 16 and 32 mm and 60% for gravel between 4 and 8 mm. It was concluded that WCA would contain as much as 40% of mortar, which would accordingly affect such deformation properties of WCAs as elasticity, creep, and shrinkage [6]. Workability of WCAs in concrete is quite a hard process, which is why water amount was increased to enhance workability [7]. Howev-

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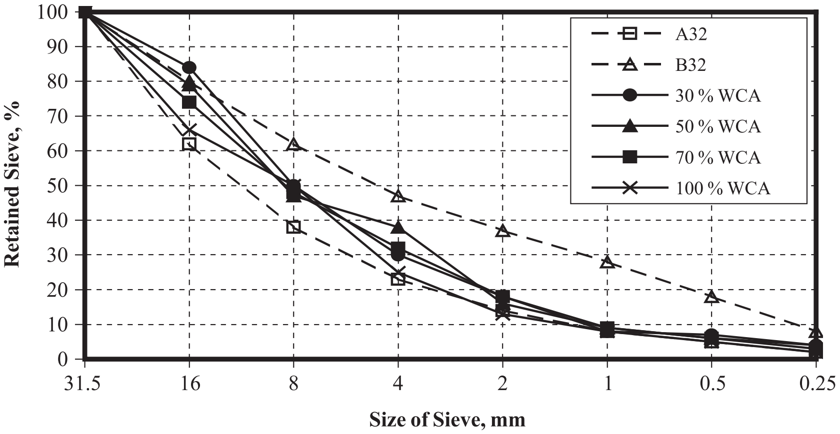

Fig. 1. Grading curve of WCAs.

er, it is inevitable that cement ratio will increase in proportion to water added. Therefore, it would be desirable to obtain finer aggregates in order for a proper workability [8,9].

Ravindrarajah and Tam pointed out that there exists a similarity between the workability of the normal concretes and of the concretes with WCA [10]. They also reported that newly produced concrete had a higher fresh unit weight due to mortar with low density present in waste concrete. They determined that the mechanical properties of concrete with WCAs are lower than those of normal concrete aggregate. On the other hand, they determined the flexural strength of concrete with WCAs to be ± 15% in comparison with that of normal concrete. Gökçe et al. reported freeze–thaw cycles of concrete produced from WCAs with air content to be less durable [11]. They also reported that freeze–thaw durability of concrete produced from fine materials of WCAs was higher than that of concrete produced from normal sand. Salem and Burdette found that the 28-day compressive strength, using 14% and 28% fly ash, of recycled concrete decreased from 38.85 to 35.5 MPa (9% reduction) and of natural concrete decreased from 38.08 to 34.14 MPa (11% reduction). They also attributed the decrease in flexural strength to rough structure of WCAs [12]. Tavakoli and Soroushian observed that the flexural strength of concrete produced from WCAs are directly proportional with the w/c ratio [13]. Olorunsogo and Padayachee determined that, depending on the type of the mixture and curing period, an increase in the quantities of WCA results in a decrease in the durability of concretes with WCA [14]. Gomez-Soberon determined that there is a slight decrease in fresh unit weights of concretes with WCA [15]. Sagoe-Crentsil et al. [16] obtained a result similar to that of Hansen and Narud [17] wherein fresh unit weight values decreased. They also reported that the durability of concrete with WCAs were somewhat lower than that of normal concrete. In parallel with WCAs addition into new concrete, their durability decreased almost identically.

3. Experimental details

The aim of this study was to produce C16 (28-day cylindrical compressive strength of 16 MPa.) and C20 (28-day cylindrical compressive strength of 20 MPa) quality concrete with WCAs by crushing the natural C14 concrete specimens that are mentioned in Turkish Codes TS 500 (*Requirements for Design and Construction of Reinforced Concrete Structures*). In producing new concretes, in place of natural aggregates, 30%, 50%, 70%, and 100% of WCAs were added as coarse aggregates. Therefore, the purpose was to determine the optimum amount of WCA. Instead of normal aggregates, 30%, 50%, 70%, and 100% of WCAs

Table 1
Mixture proportions of concrete containing WCA

	W/C	C (kg/m^3)	W (kg/m^3)	S		G		WCA		Fineness modulus
				kg/m^3	%	kg/m^3	%	kg/m^3	%	
C16										
WCA 0%	0.639	327	209	901	50	914	50	–	–	4.78
WCA 30%	0.639	316	202	549	30	743	40	510	30	4.96
WCA 50%	0.635	310	197	370	20	564	30	860	50	5.07
WCA 70%	0.638	307	196	371	20	188	10	1205	70	5.12
WCA 100%	0.637	289	184	–	–	–	–	1764	100	5.40
C20										
WCA 0%	0.571	366	209	885	50	898	50	–	–	4.78
WCA 30%	0.570	354	202	539	30	730	40	501	30	4.96
WCA 50%	0.569	346	197	363	20	553	30	844	50	5.07
WCA 70%	0.571	343	196	365	20	185	10	1185	70	5.12
WCA 100%	0.570	323	184	–	–	–	–	1738	100	5.40

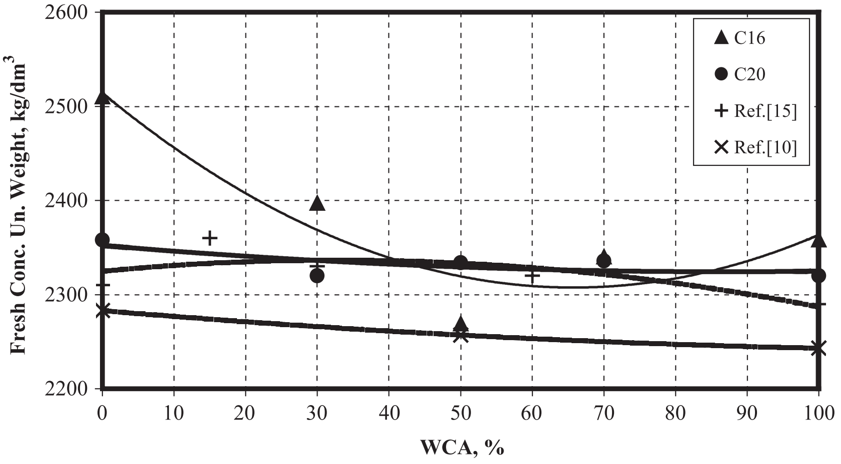

Fig. 2. Variation of fresh concrete unit weights with WCA content.

were used in normal concrete mixtures. The grading curve of aggregates is presented in Fig. 1. WCAs were obtained by crushing cylindrical concrete specimens of C14 quality produced in advance and then sieving them using a mesh square of 31.5 mm. The fineness modulus of WCAs was 5.50, unit weight 2470 kg/m^3, loose unit weight 1160 kg/m^3, and water absorption 7% (30 min). Sand (S) from the Sakarya River in Osmaneli was added into concrete together with WCAs. Gravel (G) was used along with sand as coarse aggregate. The fineness modulus of sand was 3.81, unit weight 2660 kg/m^3, loose unit weight 800 kg/m^3, and water absorption 1.5% (30 min). As for gravel, fineness modulus was 5.74, unit weight 2700 kg/m^3, and loose unit weight 1700 kg/m^3 [5].

ASTM C 150 Type I, blended Portland cement (C) produced in Eskisehir Cement Mill was used in concrete production. Sand and gravel percentages were separately calculated for each WCA percentage during preparation process of aggregate mixture so that grading curve would remain between A32 and B32 (see Fig. 1). Concrete mixing ratio of aggregates were determined using reference curves A32 and B32 referred by TS 707 (*Method for Sampling of Aggregates for Concrete Reducing Samples to Testing Size*), whose reference is ASTM D-75, ASTM C-702, and the sieve system TS 706 (*Aggregates for Concrete*) (Turkish codes). A test was made for every mixture in accordance with TS 3529 (*Test Method for Determination of the Unit Weight of Aggregates for Concrete for Aggregate Unit Weight*) and TS 3526 (*Test Method for Specific Gravity and Water Absorption of Aggregates for Concrete*), whose reference are ASTM C 127 and ASTM C 128 for density. The grading curve of concrete mixture used in the experiment is given in Fig. 1. Percentages and proportions of materials used in mixtures are presented in Table 1. Total water content was determined using $E = \alpha(10 - k)$ equation. In this formula, k indicates the fineness modulus and α indicates the coefficient of sand and gravel for plastic consistency. Accordingly, w/c ratios were separately calculated for each admixture, and these are presented in Table 1. WCAs underwent a saturation process adding as much water as the WCAs could absorb 30 min before they were used in mixtures [18]. Fresh unit weight, slump, and flow-table tests were carried out for newly produced concrete, and then three ∅ 15 × 30-cm cylindrical specimens and two 10 × 10 × 50-cm prismatic specimens were obtained.

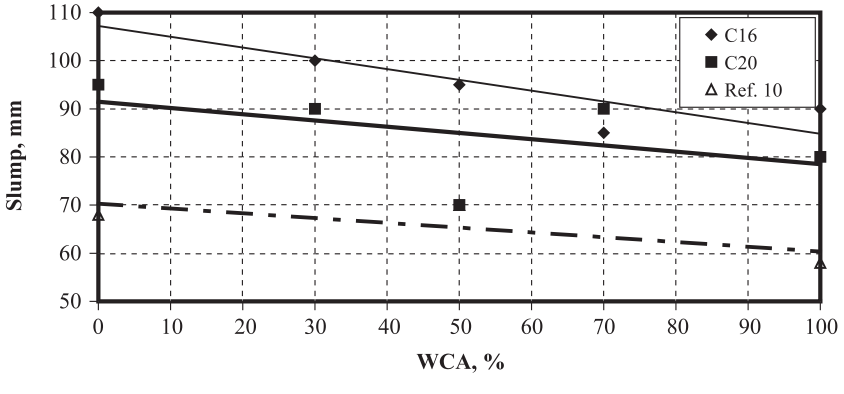

Fig. 3. Variation of slump with WCA content.

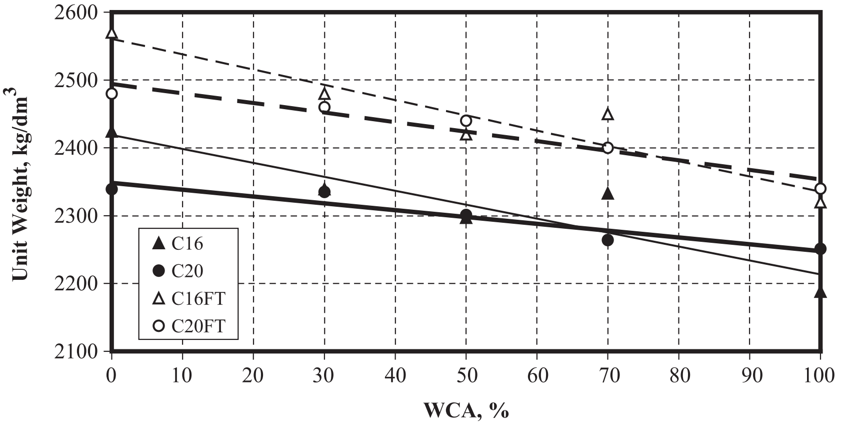

Fig. 4. Variation of unit weights with WCA content.

It is essential that concretes should have the workability feature. For this reason, a fresh concrete experiment was carried out, complying with TS 2871 (*Measuring the Consistency of Concrete by the Method of Slump Test*), whose reference is ASTM C 143-90 standards. Afterward, experiments of undamaged Schmidt hardness in hardened concretes were carried out, apart from damaged experiments with compressive and flexural strength. Unit weight, Schmidt hardness, and compressive and flexural strengths were tested after 28 days. As for specimens exposed to freeze–thaw cycles, they underwent repeated cycles of freeze–thaw first for 8 h at – 20 °C and then for 16 h at 20 °C for 8 days altogether. Test results of fresh and hardened concrete specimens as well as of those obtained after freeze–thaw cycles appear in Figs. 2–7.

4. Experimental results and discussion

4.1. Evaluation of fresh concrete experiment results

Fig. 2 shows that fresh unit weight decreased in concrete with WCA. Specific gravity of WCAs was far lower than that of normal crushed aggregates. The reason for such a decrease is the cohesive mortar with lower specific gravity existing on the surface of these aggregates. Fresh concrete specimen tests were carried out to determine workability of concrete with WCAs. The results obtained showed that workability decreased in parallel to an increase in the proportion of WCAs. The decrease amount between natural concrete and concrete with 100% of WCAs was nearly 15–20%, the reason is that the water absorption ratio of mortar over WCAs was much higher. Relations between change in unit volume ratio of WCAs and slump values are presented in Fig. 3. Besides, fresh unit weight of concrete with WCAs was found to decrease consistent with the results of Ref. [19].

4.2. Evaluation of hardened concrete experiment results

It was determined that as the proportion of WCA admixtures increased, unit weight decreased in hardened concrete with WCAs. While the unit weight of concrete containing 50% of WCAs was 2301 kg/m^3, the unit weight of concrete with whole WCAs was 2251 kg/m^3. Concretes produced with WCA proved to be 6% lighter than con-

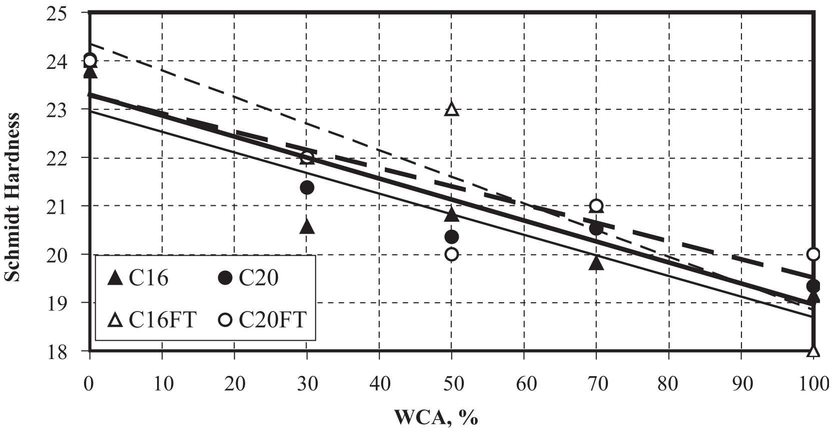

Fig. 5. Variation of Schmidt hardness with WCA content.

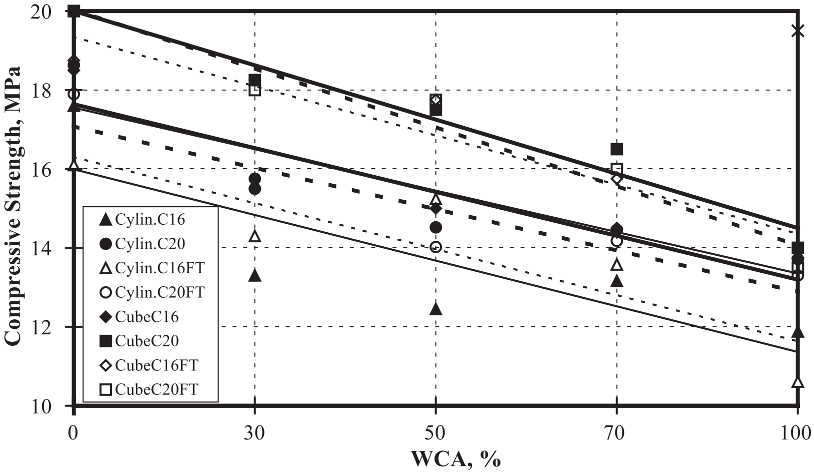

Fig. 6. Variation of compressive strength with WCA content.

cretes with normal aggregates. As a result of freeze–thaw cycles, there was a decrease of as much as 1%. This was attributed to small particles caused by the freeze–thaw cycles of the experiments. Relations between WCAs percentages and unit weights, as well as unit weights after exposure to freeze–thaw cycles, are presented in Fig. 4. While Schmidt hardness values were 23–24 in normal concrete, it decreased as much as 19 in concrete with WCAs. The fact that Schmidt hardness results of concrete exposed to freeze–thaw cycles were either almost identical to or a little higher than those of normal concrete suggested that freeze–thaw cycles had little effect on Schmidt hardness of newly produced concrete. The results obtained are presented in Fig. 5 [5].

Cylindrical and cubic compressive strengths of concrete with WCA were calculated separately for C16- and C20-quality concrete. Compared with normal concrete, cylindrical compressive strength values decreased by as much as 33% and 23.5% in C16- and C20-quality concrete, respectively. Test results of cubic specimens exposed to freeze–thaw cycles showed that strength was only a little high for C16-quality concrete but remained almost same in C20-quality concrete. Therefore, it could be concluded that freeze–thaw cubic compressive strength remained unchanged. Relations between WCAs percentages and cylindrical and cubic compressive strengths are presented in Fig. 6. As for flexural strength, it increased to 2.65 MPa in normal concrete but decreased to 2.30 MPa in concrete with a 100% of WCAs (13%). In concrete specimens, 27% was of C20 quality. Furthermore, it was concluded that freeze–thaw cycles had little effect on flexural strength. Relations between flexural strength and WCAs percentages are presented in Fig. 7. Regression and correlation coeffi-

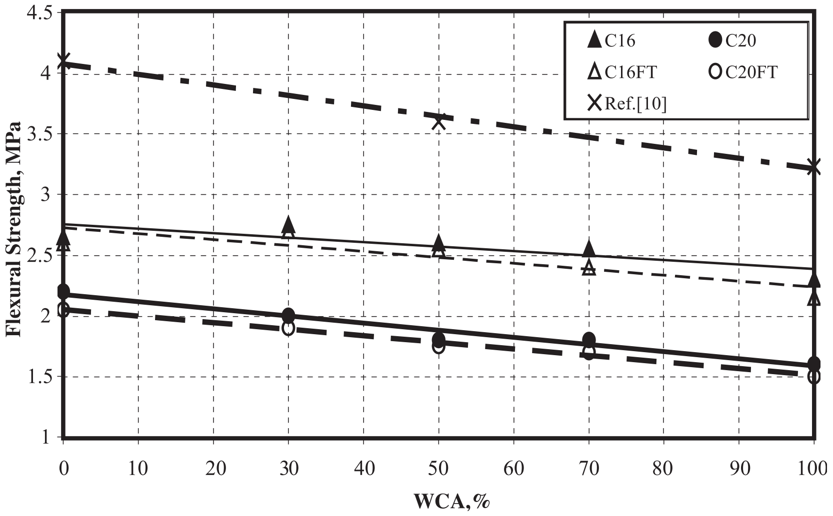

Fig. 7. Variation of flexural strengths with WCA content.

Table 2
Regression equations and correlation coefficients of concretes produced with WCA

	Regression equation	R^2
Fresh unit weight		
C16	$y = 0.048x^2 - 6.283x + 2514$	.860
C20	$y = 0.004x^2 - 0.642x + 2352$	.529
Slump		
C16	$y = 0.2241x + 84.793$	.788
C20	$y = 0.25x + 72.5$	.906
Unit weights		
C16	$y = -2.0552x + 2419$	.838
C20	$y = -1.0034x + 2348.2$	.909
C16FT	$y = -2.2586x + 2560.9$	.894
C20FT	$y = -1.4138x + 2494.7$	.941
Schmidt hardness		
C16	$y = -0.0426x + 22.955$	.832
C20	$y = -0.0434x + 23.296$	.864
C16FT	$y = -0.0552x + 24.359$	.833
C20FT	$y = -0.0379x + 23.297$	.745
Compressive strength		
C16 (cubic)	$y = -1.05x + 18.6$	.829
C20 (cubic)	$y = -1.375x + 21.375$	.957
C16 (cylindrical)	$y = -1.158x + 17.152$	.653
C20 (cylindrical)	$y = -1.111x + 18.749$	.821
C16FT (cubic)	$y = -1.25x + 20.6$	.908
C20FT (cubic)	$y = -1.5x + 21.55$	.945
C16FT (cylindrical)	$y = -1.17x + 17.476$	.773
C20FT (cylindrical)	$y = -1.052x + 18.136$	.840
Flexural strength		
C16	$y = -0.0037x + 2.7553$	.705
C20	$y = -0.0059x + 2.1731$	.958
C16FT	$y = -0.0049x + 2.7257$	.765
C20FT	$y = -0.0054x + 2.0516$	.989

cients are presented in Table 2. As could be assumed from tables, WCAs decreased workability, strength, and durability of concrete produced with WCAs [6].

5. Conclusions

The specific gravity of WCAs was lower than that of normal crushed aggregates. The reason for this was thought to be the fact that there was a certain proportion of mortar over these aggregates. Water absorption ratio was found to be much higher compared with that of normal crushed aggregates. This was also attributable to mortar over these aggregates. Compressive strength decreased in both control concrete and concrete with WCAs in parallel to w/c ratio. However, compressive strength decreased in proportion to low w/c ratio in concrete with WCAs. We suggest that recycling WCAs in concrete production raises the problem of workability. In particular, concrete with more than 50% WCAs experiences workability problem more. In light of all these, it seems possible to produce concrete of C16 quality, unless exceeding 30% using recycled C14 concrete aggregates. It was mentioned earlier that using WCAs decrease workability of fresh concrete. In conclusion, recycling WCAs in concrete production may help solve a vital environmental issue apart from being a solution to the problem of inadequate concrete aggregates in concrete.

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