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# PHYSICAL AND MECHANICAL PROPERTIES OF CONCRETES PRODUCED WITH WASTE CONCRETE

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**ABSTRACT**

Because of the damage they do to buildings, natural disasters such as earthquakes produce large amounts of waste concretes. Carrying waste materials away from the disaster site causes financial and environmental problems, so people try to recycle the waste concretes as aggregate in order to prevent these problems. Using waste material that was obtained from razed buildings and then was cleaned and later reduced to aggregate form is considered an appropriate solution to environmental pollution. In this study, various physical and mechanical properties of concretes were examined. These concretes were produced by the addition of C 16 (28-day compressive strength of 16 MPa) pieces as aggregate in weight percentages of (referred to total aggregate) 0, 30, 50, 70, and 100%. In the concretes, it was observed that as the amount of WCA increases, density, workability, Schmidt hardness, ultrasound velocity, and compressive strength decrease. © *1997 Elsevier Science Ltd*

## Introduction

For years people have been trying to keep the environment clean. Scientific studies provide us with information on how we can maintain the natural balance of life, and recycling has a primary role in these studies. As a result of natural disasters or increasing population and urbanization, great amounts of waste materials are produced. These waste materials include iron, wood, glass, aluminium, ceramics, PVC, and concrete. To make the recycling of these various materials productive, we should first separate them according to their types. But that is impossible to manage simply through manpower; complex recycling centers need to be established. These facilities should be constructed in places that receive heavy damage after natural disasters or that cannot find enough materials to produce less capital than the other costs.

Our research on using waste concrete as aggregate (WCA) has been conducted for many years. WCA was being used just as a filling material before. Then it came to be used as aggregate as a result of comprehensive studies on erosion control. It is first necessary to clean, cut into pieces, and sieve according to standards in order to produce waste concrete as

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aggregate; after that, the material's conformity should be tested by making some experiments on it.

## Waste Concrete Aggregates (WCA) and Concretes

### Densities of the WCA

Hansen and Narud (1) found that dry-surfaced concrete has a density between 2340 $kg/m^3$ (4–8 mm) and 2490 $kg/m^3$ (16–32 mm). For ordinary concretes, these values are between 2500 $kg/m^3$ (4–8 mm) and 2610 $kg/m^3$ (16–32 mm). These values are not connected with the quality of the original concrete. Narud (2), explained from his own studies that the density of the fine aggregate that was produced from original concrete had a ratio of 0.70 water-cement is 2279 $kg/m^3$. Otherwise, according to a report by BCSJ (3) in Japan, the density of dry-surfaced waste concrete is between 2120 $kg/m^3$ and 2430 $kg/m^3$, and the density of the waste fine aggregate concrete is between 1970 $kg/m^3$ and 2140 $kg/m^3$. Turanlı (4) pointed out that the density of waste concrete sized 15–30 mm is 2410 $kg/m^3$ and the density when the outer surface is dry is 2510 $kg/m^3$. Topçu (5) uses the density in his studies as 2470 $kg/m^3$.

### Water Absorption of the WCA

Nixon (6), one of the first to study this subject, compared waste concrete aggregate and natural aggregate and found that waste concrete aggregate gives higher values of absorption capacity. Hasaba et al. (7) found as the result of the measurement, which is detached from the original concrete quality, that the aggregate sized 5–25 mm has an absorption capacity about 7%. Hansen and Narud (1) found 8.7% absorption capacity for the material that is 4–8 mm in size and found 3.7% for the material that is 16–32 mm in size. Kreijger (8) gives the idea according to the result of his own studies that there is a parabolic connection between WCA absorption and density. For example, 2400 $kg/m^3$ density is 3.8% absorption rate; 1900 $kg/m^3$ is 9.7% absorption rate; 1700 $kg/m^3$ is 12.8% absorption rate; and 1300 $kg/m^3$ density is 22.2% absorption rate value. According to the WCA standards in Japan, if the absorption capacity of WCA is more than 7% for coarse dimensional materials and more than 13% for fine dimensional materials, it is not recommended to use it in the production of concrete. The research published by BCSJ (3) pointed out that the absorption ratio is between 3.6–8% for coarse aggregate and 8.3–12.1% for fine aggregate. Turanlı (4) explained that the absorption is 5.02% for the WCA that is 15–30 mm in size. Topçu and Şengel (10) found that the fineness modulus is 5.50, density is 2470 $kg/m^3$, and the water absorption in 30 min is 7%.

### Los Angeles Abrasion of the WCA

Hansen and Narud (1) found the LA abrasion loss value is 22.4% for the aggregates that were produced from high-strength original concrete sized 16–32 mm and 41.4% value for aggregates sized 4–8 mm. These LA values are facing one another 0.24 and 0.38 according to L100/L500. Otherwise BS aggregate crush values are 20.4% and 28.2%, respectively. Hasaba (7) found this value to be 23.0% for the WCA sized 5–25 mm, which were produced from the high-strength concrete, and 24.6% for the WCA at the same size, which was

TABLE 1
Changes in LA abrasion values with the compressive strengths

| Concrete Specimen Code | C | A | B | E | F | D |
|---|---|---|---|---|---|---|
| Compressive, Strength MPa | 15 | 16 | 21 | 30 | 38 | 40 |
| Los Angeles Abrasion Loss Ratio, % | 28.7 | 27.3 | 28.0 | 25.6 | 22.9 | 20.1 |

produced from low-strength concrete. BCSJ (3) did some abrasion tests on coarse aggregates produced from 15 different concretes that seperated differently and had different strength values. At the end of the research he found that the LA abrasion loss changed between 25.1% and 35.1%. Also, Yoshikane (11) who did the same tests, proved that this is an openly inverse proportion. The values found by Yoshikane are presented in Table 1.

According to ASTM C-33 "Standard Specification for Concrete Aggregates," the LA abrasion value should be less than 50% for the aggregate that will be used to produce concrete, and should be less than 40% for the aggregate will be used to make roads. According to British Standard 882, 1201, Part 2, 1973, "Specifications for Aggregates from Natural Sources," the abrasion value for the aggregate will be used in the surface of the pavement.

## Workabilities of the Concretes Produced with WCA

Rasheeduzzafar and Khan (12) obtained research data using several mixtures that concretes made of WCA lower the workability of concrete. Mukai (13) determined, as a result of his experiments using WCA and natural sand, that to catch the same slump value 10 $dm^3/m^3$ or 5% water should be used. Otherwise, if the mixture includes both coarse and fine WCA, then these values become 25 $dm^3/m^3$ and 15%. Similar results were found by Buck (14), Frondistou–Yannas (15), Malhotra (16), and Hansen and Narud (1). Topçu (5) found a reduction of slump values in the concrete by raising the extent of WCA in the mixture. Also, the reduction in 100% WCA-added concrete mixtures reaches 15–20%.

TABLE 2
Compressive strength values for different mixtures produced by Hansen and Narud

| Series | H | H/H | H/M | H/L | M | M/H | M/M | M/L | L | L/H | L/M | L/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 56.4 | 61.2 | 49.3 | 34.6 | 34.4 | 35.1 | 33.0 | 26.9 | 13.8 | 14.8 | 14.5 | 13.4 |
| 2 | 61.2 | 60.7 | | | 36.0 | | 36.2 | | 14.5 | | | 13.6 |
| 3 | 58.5 | 60.6 | | | 33.2 | | 36.0 | | 15.0 | | | 12.8 |

H, high-strength concrete (W/C = 0.40); M, medium-strength concrete (W/C = 0.70); L, low-strength concrete (W/C = 1.20); H/M, high-strength concrete produced with medium-strength; L/H, low-strength concrete produced with high-strength concrete WCA.

TABLE 3
Compressive strength values for different mixtures produced by BCSJ

| Water/Cement | With natural coarse and fine aggregate (original concrete) | Waste concrete coarse aggregate and 100% natural sand | Waste concrete coarse, 50% waste, and 50% natural sand | Waste concrete coarse and 100% waste fine aggregate |
|---|---|---|---|---|
| 0.45 | 37.5 | 37.0 | 34.0 | 30.0 |
| 0.55 | 28.9 | 28.5 | 25.0 | 21.5 |
| 0.68 | 22.0 | 21.0 | 17.5 | 13.0 |

## Compressive Strengths of the Concretes Produced with WCA

Buck (14) used the WCA instead of the coarse aggregate. For a fine aggregate he preferred to use natural sand, and also he used a constant W/C ratio for the specimens to be compared. In some of his specimens, there were additions such as fly ash, retarder, and superplasticizer. He also tested for the strength of aggregate freeze-thaw and workability properties in his study. As a result, he pointed out that WCA has a low unit weight and high absorption capacity

Also, the compressive strength of WCA doesn't decrease much, in contrast to normal concrete. In Buck's freeze-thaw experiments, it is seen that WCA is stronger than normal concrete under conditions of freeze-thaw cycling. Nixon (6), explained that the compressive strength of WCA decreases 20% or sometimes more when compared to normal concrete. BCSJ (9) explained that in Japan this decreasing rate may be between 14–32%; Gerardu and Hendriks (17) and Topçu (18) proved that the compressive strength will be at about 80–95% of normal concrete if it is produced with WCA and natural sand. Hansen and Narud (1) concluded that by using the W-C ratio it is possible to match the compressive strength quality of the concretes produced by natural aggregates. The compressive strength values found by BCSJ (9) are given in Table 3.

## Experimental Studies

C 16 concrete specimens were used in the studies, and jaw crushers adjusted 31.5 mm were used in order to make the concretes in suitable aggregate size. The crushed waste concretes were sieved to prepare them for producing. They weren't cleaned from other materials because the WCAs were produced by using concrete test specimens in our laboratory. Before the production of concrete specimens, some research was done on the WCAs. As a result, it was found that the density of WCA is 2450 kg/m$^3$, unit weight is 1161 kg/m$^3$, and the water absorption in 30 min is 7%. The surface of the WCA is rough and porous, and its shape is angled because of debris. Sand with the unit weight 800 kg/m$^3$ and density 2500 kg/m$^3$ is used instead of fine aggregate. As a coarse aggregate, WCA with 2500 kg/m$^3$ density and 1600 kg/m$^3$ unit weight and ASTM C 150 Type I Portland cement (28-day compressive strength of 32.5 MPa) were used. The W/C ratio was kept constant at 0.60 in mixtures. Specimens were seperated in 5 groups. The percentages of WCA within the whole aggregate were 0, 30, 50, 70, and 100% by weight. For workability of fresh concrete, the slump test was conducted. As specimen moulds, cylinders of r = 15, H = 30 cm were used. Three specimens

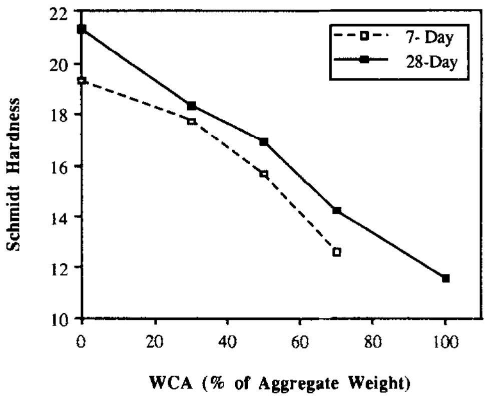


FIG. 1.
Changes in Schmidt hardnesses with the amount of WCA.

were prepared for each group. Each specimen was consolidated using a vibrating table. All specimens were cured in water at 20°C for 7 and 28 days after demoulding. After the curing time, unit weight, ultrasound velocity, Schmidt hardness, compressive strength, and impact tests were conducted on these specimens.

## Test Results and Evaluation

### Evaluation of Fresh Concrete Test Results

In the research on concrete mixtures including WCA, it is seen that slump values decrease whereby the WCA increases. The slump value is 100 mm if there is no WCA in it. If there is, then the slump value is 75 mm. The most important reason for this is that WCA has a high absorption ratio. The water in the mixture decreases because of the cement paste debris, and the workability of the mixture decreases also. Additional research has been done on the unit weights of the fresh concretes. Although the measured unit weight is 2370 kg/m$^3$ in normal concrete, the unit weight is 2235 kg/m$^3$ in concrete including WCA. This decline is directly connected with the fact that the unit weight of the WCA is lower than the normal aggregate.

### Evaluation of Hardened Concrete Test Results

At the end of the unit weight tests on the hardened concretes, it was seen that unit weight decreases when the WCA increases. According to the surface hardness of the concrete, Schmidt hammer tests were made in order to observe compressive strength. It was observed that the concrete surface hardness values decreased if the WCA increased in the mixture. The Schmidt hardness value 21.3 in normal concretes changes to 11.6 in WCA. It shows that there is also a decreasing in concrete strength (Fig. 1).

Specimens also underwent an ultrasound velocity test. It was made on specimens aged 28 days. It does not give certain clues about strength but helps to determine the concrete quality. The ultrasound velocity value is 69–70 μs for normal concrete in laboratories, but this value

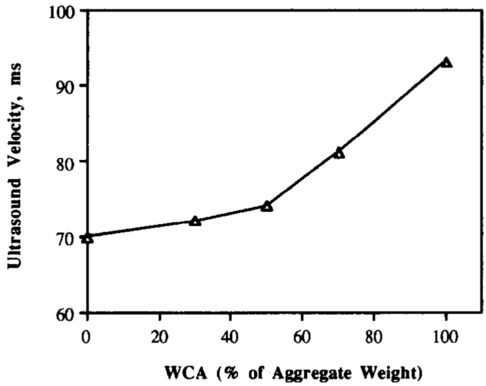


FIG. 2.
Changes in ultrasound velocitiy with the amount of WCA.

is 92–93 μs for WCA, and it shows that the air voids become wider in the concrete and the strength of the concrete decreases.

This decrease with the presence of WCA is shown in Figure 2. The most important test on the specimens is the compressive strength test. These tests were made on specimens aged for 7 and 28 days. At the end of this test the results were obtained but it is seen that the compressive strength of WCA decreases, especially if the WCA ratio is above 50% in the mixture there become important decreases.

Another test for hardened specimens is the impact test. A special device was used in order to make this test. Clyindrical concrete specimens were put on it and a constant weight was brought down from a certain height onto the specimen 10 times. The damages after this impact tried to be mended. In normal concrete the damage depth is 20–30 mm and in concrete including WCA the damage depth is 100–130 mm. The most important reason is the weak cement paste debris in the concrete. It affects the interbalance of the concrete under impact effect.

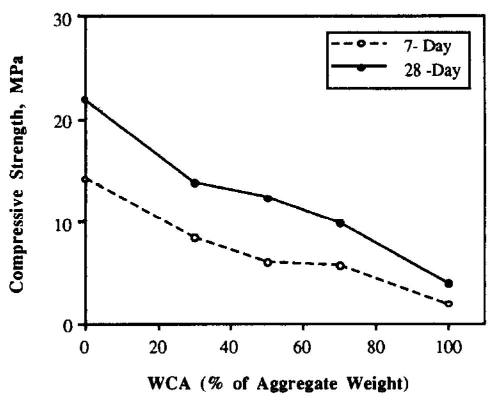


FIG. 3.
Changes in compressive strength with the amount of WCA.

## Conclusion

At the end of our research, the values we obtained show that we can use WCA if it is necessary. Also, it is necessary to test the waste concretes before using them in producing concrete. When using WCA for producing high-strength concrete, it is especially a must to know the absorption capacity and the approximate strength of the WCA. Otherwise, abrasion loss values should be known when the WCA is used in places that are exposed to abrasion. Before using the WCA it should be cleaned from the other materials carefully.

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