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USING WASTE CONCRETE AS AGGREGATE

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ABSTRACT

When restrictions severely limit local access to concrete aggregate, broken pieces of waste concrete (WCA) are used as aggregate. Today environmental studies discussing the recycling and reuse of waste materials are gaining great importance. Using waste material which was obtained from razed buildings that was cleaned and later reduced to aggregate form, is considered an appropriate solution to environmental pollution. In this study, various mechanical properties of concretes were examined. These concretes were obtained with 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 %. From σ–ε diagrams modulus of elasticity, toughness, plastic and elastic energy capacities were calculated. In the concretes, it was observed that as the amount of WCA increases, density, compressive strength, modulus of elasticity and value of toughness decrease.

1. Introduction

One of the problems arising from continuous technological and industrial development is the disposal of waste materials. Various solutions have been sought out for this major enviromental problem and the best solution found is recycling. As is in the rest of the world, as a result of fast population growth and urbanization the construction industry is growing at a great pace in our country as well. Everyday old buildings are being knocked down and replaced with the new ones. The debris from these demolished buildings is thrown away, causing enviromental pollution, or is used as filling material. Today it has become really difficult to obtain concrete aggregate locally. Bringing aggregate from far away places increases the cost of concrete. Since control of waste materials pollution is increasingly important, it would be a good solution to use the debris from old buildings, after being cleaned, as concrete aggregate.

It is known that aggregates of waste concrete are used as boulderheads to prevent erosion and for floor filling material. In big projects like renewing highways and airfield runways using the waste concrete aggregates (WCA) not only reduces the cost of carrying away the old material but also reduces the transportation cost by building an aggregate producing center at the site. Sometimes in the city centers, after a devastating earthquake, it becomes necessary for many destroyed buildings to be knocked down and rebuilt. If the debris obtained from these razed buildings is reduced to proper size and used as aggregate, it is possible to reach a desired quality in the concrete to be used in rebuilding these houses. Thus an important problem of carrying the debris away and bringing in new aggregate can be eliminated. But to be able to do this, WCA should be upgraded to normal aggregate standards. However, for this purpose, it is necessary that this material be tested for grain size, specific gravity, density, water absorption, Los Angeles abrasion and crushing. Also WCA should be cleared of wood, brick and iron.

2. Properties of waste concrete aggregate

Concrete waste pollutes our world more and more everyday. Making use of waste concrete has been the subject of investigation for a long time (1,2,3). Concretes produced by Frondistou & Yannas (3) with recycled aggregate had 4-14 % lower compressive strength than normal concrete. Their modulus of elasticity are also 40 % lower. In their emprical studies Hansen & Narud (4) stated that WCA gave similar test results to natural aggregates. These researchers concluded that in concretes obtained from waste material the percentage of waste mortar which was stuck on natural material changed between 30 and 60 %, and that these mortars would affect the properties of concrete, elastisity, deformations like creep and shrinkage and, apart from water absorption of aggregate, the mixture needed 10 % more water. They also stated that workability showed a decrease in a very short time and slump loss was very fast.

Buck (5) is also one who conducted highly extensive research on this subject. He used WCA only for coarse aggregate but for fine aggregate he preferred natural sand. Using constant W/C (water/cement) ratio, he preferred samples with various specifications but in some specimens he used such additives as fly ash and water reducers. He did some freeze-thaw experiments and separately he investigated the effect of sulfhate. The results obtained by Buck can be stated as follows: WCA has low specific gravity and high water absorption. Using waste concrete, which has a compressive strength under 14 MPa, doesn't have an extreme effect on the strength of the new concrete. Using WCA has a great effect on the workability. The compressive strength of the concrete with WCA is at least 8 MPa lower and the W/C ratio is lower than normal concrete. Equal strength can be obtained by reducing W/C ratio. Small pieces of WCA can be used as fine aggregate without granulometric correction. If WCA is used as fine aggregate, then in relation to the natural sand, the need for cement increases 34-46 kg per 0.8 m^3 accordingly. The frost resistance of concrete containing recycled concrete, where chert gravel was the original aggregate, was increased by a factor of five or more in laboratory freezing and thawing tests. This is assumed to be the result of a reduction in frost susceptibility of the porous coarse aggregate particles. If the amount of sulfhate is controlled to prevent harms caused by sulfhate reactions, then inorganic and ametal waste obtained from razed buildings can be used as aggregate.

A significant result obtained by Buck (6) another experiment is that the 90-day compressive strength of concretes produced with calcar together with silis aggregate has a lower strength than concretes produced with WCA having natural aggregate. In their studies, Hansen & Hedegard (7) investigated the effects of additives in original concrete on properties of newly-produced waste-aggregated concretes. The additives used were superplasticizer, air-entrainer, accelerator and retarder. Pieces of the original concretes were used as coarse aggregate in new concretes. The properties of the concretes were found to have been affected by the additives in waste concretes. Forster (8) argues that in concretes to be obtained with pieces of concrete into which air-entrained, the amount of air in the recycled material should be subtracted from the measured air and emphasizes that the amount of air in the concrete with recycled aggregate should be kept high.We can state the results obtained by Gluzge (9) as follows: new concrete will not be better than the concrete used as aggregate. Using fine pieces of concrete as sand increases the need for cement. When WCA is used its compressive strength is low and specific gravity is lower than normal aggregate. If the WCA is moistened before use, the cement factor can be reduced.For equal compressive strength, bending strengths of waste-aggregated concretes are greater than the normal ones. Although the hardening of mixtures with additives of waste is fast, their slump with vibration is good.

In 1948, Graf (10) investigated the recycling of building rubble. He wanted to show the effect of adding gypsum to rubbles in different sizes. The result of the experiment showed that there was great improvement with addition of 1.5 % SO_3. The maximum percentage of SO_3 to be allowed is 1 %. Thus pieces of gypsum should not be used without being separated from waste concrete. According to the results of the research conducted by Ploger (11) compressive strengths of the concretes produced with WCA and those of normal concrete show a resemblance to one another. Also no great changes were observed between water contents and specific gravities of the mixtures.

Turanlı (12) changed W/C ratios in mixtures of concrete he prepared with WCA. Then he made some comparisons in normal concretes he prepared with the same W/C ratio. The results obtained by Turanlı are stated as: in comparison with the normal concrete aggregate, densities of WCA concretes are low and water absorption and abrasion capacities are high. Slump of the concrete with WCA is greater than normal concrete. Although there isn't any great difference in terms bending strength, there is difference in their compressive strength and this difference is about 12 %. The static and dynamic elastic modulus of the concretes with WCA are lower than those of normal concrete. Drying shrinkage values of WCA are higher than normal ones. Özturan (13) stated that concrete aggregates have good shapes and grading but have low specific gravity and high water absorption capacities in comparation to normal concretes. He also claims that compression strength and modulus of elasticity of WCA depend on W/C ratio, and if the W/C ratio of the waste concrete is equal or lower, compressive strength and modulus of elasticity of the concrete with waste aggregate might have equal or higher values.

Hüseyinoğlu (14), used C 14 concrete as WCA.Specimens of experiment were devided into 5 groups and the differences between them are the percentage of concrete aggregate. These percentages are 0, 30, 50, 70 and 100 %. His aim was to obtain C 16 and C 20 quality concrete by using WCA. The results he concluded that the density of waste concrete is lower than sand and gravel. Water absorption of waste concrete is high, around 7 %. As the percentage of waste concrete in the mixture increases, there occurs some decreases in workability. In C 16 concretes, 20 % increase of waste concrete decreases the density 1.7 % and this is 0.8 % in C 20 concretes. Each 20 % increase in waste aggregate causes a decrease of 3.85 % in Schmidt hardness values. The average of decrease in compression strength is 5.7 % in both groups. Topçu (15), tried to get supporting concretes of C 16 and C 20 by adding C 16 pieces into aggregate in weight percentages of 15, 30, 50, 70 and 100 %. As a result, he found out that it was possible to get C 16 and C 20 qualities.

Wesche & Schulz (16), compiled some earlier results. They reported that compressive strength of the recycled aggregate concretes is 10 % lower than the compressive strength of the natural aggregate concretes. This value was reported between 8-24 % by Ravindrarajah & Tam (2). Wesche & Schulz (16), produced recycled aggregate concrete made with the same water-cement ratio and coarse recycled aggregates containing two different natural aggregates. As results, they found up 19 % lower modulus of elasticity for recycled aggregate concretes compared to the modulus of elasticity of conventional control concretes. Zagurskij & Zhadanovskij (17) and BSCJ (18) found between 10 % and 30 % lower modulus of elasticity of recycled aggregate concrete made with coarse recycled aggregate and natural sand, compared with the original control concretes. If recycled concrete aggregates are made instead of both of coarse and fine aggregates modulus of elasticity of the recycled aggregate concrete is 25 to 40 % lower compared to the modulus of elasticity of the corresponding original control concretes.

Hansen & Boegh (19) report that both dynamic and static modulus of elasticity reduce between 14 and 28 % for recycled aggregate concrete. Hansen & Boegh found the modulus of elasticity of a recycled aggregate concrete that consisted of a low quality crushed mortar to be 45 % lower than the modulus of elasticity of a corresponding control concrete made with conventional aggregates. Gerardu & Hendriks (20) found 15 % lower modulus of elasticity for recycled aggregate concrete made with coarse recycled aggregate and natural sand compared with corresponding original concrete. If the recycled aggregate concrete is also used instead of fine aggregate, the value of reduction is observed 40 %. Hansen (21), prepared second state-of-the-art report which is research the developments of this subject from 1945 to 1985. There is not enough information in this state-of-the-art report and some other publications (1, 27) about σ–ε diagrams, elastic and plastic energy capacities and toughnesses of these concretes. So experimental research results given here might be a key study.

3. Experimental studies

Waste concretes used in experiments were obtained from C 16 concrete specimens brought from neighbouring constructions. These specimens were first broken into middle size pieces by

Table 1. Mix designs of concretes and characteristics of fresh concrete.

WCA (%)	C (kg)	W (kg)	A_0 (kg)	A_1 (kg)	A_2 (kg)	A_3 (kg)	WCA (kg)	δ (kg/m³)	Slump (mm)	Fineness Modulus
0	315	190	522	355	444	444	-	2370	100	4.94
30	310	185	430	270	270	270	532	2267	95	6.02
50	300	180	345	180	180	180	894	2259	80	6.19
70	285	170	258	90	90	90	1262	2245	80	6.34
100	285	170	-	-	-		1780	2235	75	5.84

the help of a sledge hammer and than into smaller pieces in a jaw crusher, jaws being 31.5 mm. Specific gravity of WCA (8-31.5 mm) is 2450, bulk loose dry density 1161 kg/m^3, 30-minute water absorption 7 %, specific gravity of sand used A_0 (0-4 mm) is 2500, bulk loose dry density 800 kg/m^3, 30-min. water absorption 1.5 % and modulus of fineness 2.16. As coarse aggregates three types of crushed stone were used; A_1 (4-8 mm), A_2 (8-16 mm) and A_3 (16-31.5 mm). Specific gravity of these crashed stones is 2500, bulk loose dry density 1600 kg/m^3, 30-min. water absorption 1.5 % and modulus of fineness is 5.04, 6.10, 7.00, respectively.

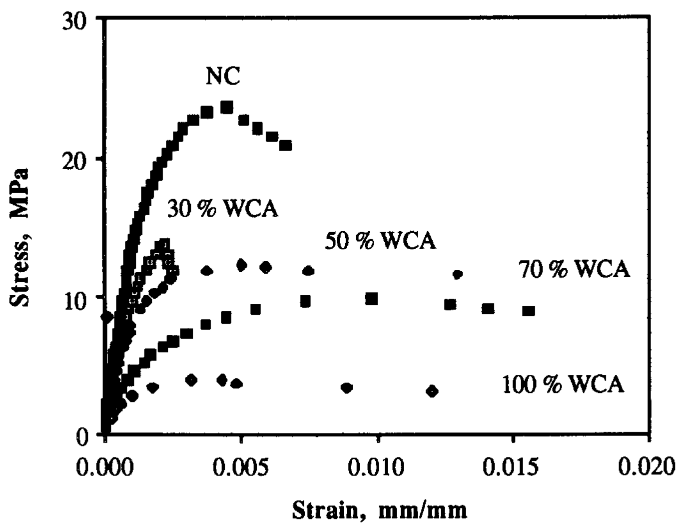

Figure 1. σ–ε diagrams of 28-day old normal and WCA concretes

The cement used in experiment was ASTM C 150 Type I Portland cement (28-day compressive strength of 32.5 MPa). WCA and natural aggregate used were wet. Since waste concrete is apt to soak more water than normal one, some manupulations were made in calculations. W/C ratio was kept constant at 0.6. As sample moulds cylinder of r=15, H=30 cm in size were used. Mixtures of samples and some of the values measured are given in the Table 1. Mixtures were divided into five groups. The main variable that creates the difference among these five groups is the amount of the WCA used. The percentages of WCA within the whole aggregate are 0, 30, 50, 70 and 100 %. Three cylinders were moulded in each group, we tried to keep the slump around 100 mm. In placement vibration table was used. All specimens were cured in water at 20 °C for 28-days after demolding.

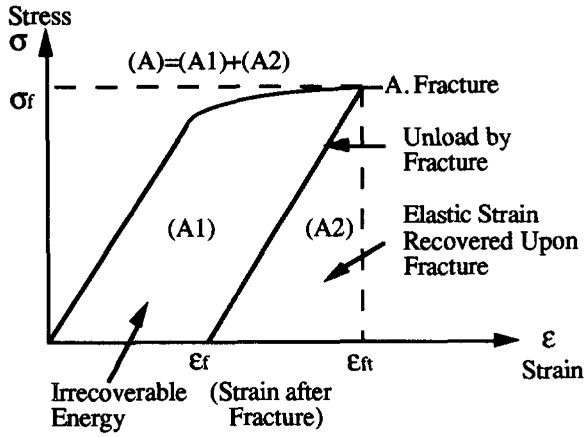

Figure 2. Determination of elastic and plastic energy capacities.

In order to get information diagrams on concrete specimens of 7 and 28-day old, a compressor and sensitivity of (1/100 mm) comparator were used. To be able to measure the deformation a frame was placed around the sample. The distance between the two constant points on the frame was 150 mm. After placing the sample, for every increase of 1 ton on the press scale, every value read on the comparator which was on the frame was noted. Then from these P-l data, were calcu-

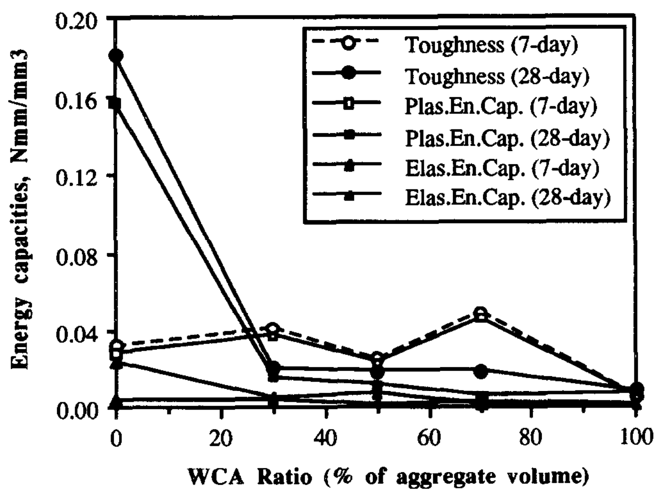

Figure 3. Changes in toughness, plastic and elastic energy capacities with the amount of WCA.

lated and deformation diagrams were plotted. Because of their similarity with 7-day only those of 28-day concretes are given in Fig. 1. With the help of diagrams plotted according to 7 and 28-day data of the samples of each group values of modulus of elasticity, toughness, plastic and elastic energy capacities were found (Fig. 3). The method of calculation is shown in Fig. 2.

4. Conclusion

The density of concrete made with WCA shows opposite properties with the normal one. It's density is less than normal concrete. The workability of WCA is low and could be explained by the high water absorption of WCA. As the amount of the WCA in the mixture is increased, the compression strength is less and the modulus of elasticity is less than the normal ones at about 80 %. With the increase of WCA amount in mixture the values of toughness, plastic energy capacity and elastic energy capacity decreases.

References

1. Nixon, P.J., Materials and Structures, Research and Testing. Vol. 11, No.65. Sep.-Oct. 1978, pp. 371-378.
2. Ravindrarajah, R., Loo, Y. H. and Tam, C. T., Magazine of Concrete Research, Vol. 37, No. 130, March, 1985, pp. 29-38.
3. Frondistou-Yannas, S., ACI Journal, Proc., Vol. 74, No.8, Aug. 1977, pp. 373-376.
4. Hansen, T.D. and Narud, H., ACI, Concrete International, Design and Construction, Feb. 1983, pp. 79-83.
5. Buck, A.D., ACI Journal, Vol. 74, No. 5, May 1977, pp. 212-219.
6. Buck, A.D., Highway Research Record, No.430, Highway Research Board, 1973, pp.1-8.
7. Hansen, T.C. and Hedegard, E., ACI Journal, Jan.-Feb. 1984, pp. 21-26
8. Forster, S.W., ACI, Concrete International, Design and Construction, Oct. 1986, pp.34-40.
9. Gluzge, P.I., Gidrotekhnic-heskoye Stroitel' stvo (Moskow), No.4, Apr. 1946, pp.27-28, (in Russian). Also, brief English summary in Engineer' s Digest, Vol. 7, No. 10, 1946, p.330.
10. Graf, O., Die Bauwirt-schaft (Wiesbaden), Jan.-Mar. 1948. Also, Translation No.73-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Jan. 1973.
11. Ploger, R. R., MS Thesis, Cornell University, Ithaca, 1947.
12. Turanlı, L., Turkish Chamber of Civ. Eng., Technical Congress Declarations Book, Nov. 1993, pp.119-132., (In Turkish).
13. Özturan, T., İ.T.Ü. Faculty of CE, Constructions of Materials Seminars, 1988, İstanbul, Turkey, (In Turkish).
14. Hüseyinoğlu, S., BS. Thesis Anadolu University, Faculty of Engineering and Architecture, Department of CE, 1992, Eskişehir, Turkey, (In Turkish).
15. Topçu, İ.B., Turkish Civ. Eng. XII. Tech. Cong., Chamber of Civ. Eng., pp. 511-522, 1993, Turkey, (In Turkish).
16. Wesche, K. and Schulz, R.R., Beton aus aufbereitetem Altbeton, Technologie und Eigenschaften, Beton 32 (1982), No. 2, pp. 64-68, No. 3, pp. 108-112.
17. Zagurskij V.A. and Zhadanovskij B.V., Special Technical Report. Research Institute for Concrete and Reinforced Concrete (GOSSTROY), Moskow, 1985, (english translation available from European Demolition Association), Wassenaarseweg 80, 2596 CZ, Den Haag, the Netherlands.
18. BCSJ., Building Contractors Society of Japan, Committee on disposal and reuse of concrete construction waste, Summary in Concrete Journal, Japan, Vol. 16, No. 7, July 1978, pp. 18-31 (in Japanese).
19. Hansen, T.C. and Boegh E., ACI Journal, September-October 1985.
20. Gerardu, J.J.A. and Hendriks, C.F., Rijkswaterstaat communications No. 38, the Hague, 1985.
21. Hansen T.C., Second state-of-the-art report, Developments 1945-1985; Materiaux et Constructions 19 (1986), No. 111, pp. 201-246.
22. Ivany, G., Lardi, R. and Eßer, E., Forschungsberichte aus dem Fachbereich Bauwesen der Universitat-Gesamthochschule Essen, Heft 33, pp.1-91, Essen 1985.
23. Civieltechnisch Centrum Uitvoering Research en Regelgeving (CUR): CUR-Rapport 125, Zoetemeer (Netherlands), September 1986.
24. Hilsdorf, H.K., Forschungsgesellschaft fur Straßen- und Verkehrswesen, Koln, Schriftenreihe der Arbeitsgruppe Betonstraßen, Heft 17, Kriechbaum-Verlag, August 1986.
25. Schmidt, M, Straße und Autobahn 37 (1986), No.12, pp. 540-546.
26. Rahlwes, K., Vortrag Deutscher Betontag 1991.
27. Krass, K., Betonwerk + Fertigteil-Technik 60 (1994), No. 1, pp. 103-108.