Effects of Using Recycled Concrete as Aggregate on Physical and Mechanical Properties of Concrete

Fatih Ozalp[1], Halit Dilsad Yilmaz[1], Omer Faruk Aydin[1], Mustafa Kara[2], Yasemin Kilic[2]
[1]ISTON, Istanbul Concrete Elements and Ready Mixed Concrete Factories, Istanbul, 34940, Turkey
[2]TUBITAK Marmara Research Centre Materials Institute, Kocaeli, 41470, Turkey
Keywords: aggregate, mechanical properties, physical properties, recycled concrete.
Presenting author email: omerfarukaydin@iston.com.tr

Abstract

This paper analyses the maximum feasible replacement ratio of natural aggregate by recycled aggregates derived from C&D wastes and precast manufacturing sector wastes for concrete production. Three types of concrete mixtures were tested: concrete made entirely with natural aggregate as a control concrete and two types of concrete made with recycled fine and recycled coarse aggregate. Laboratory scale studies were divided into 2 parts. In the first section, recycled aggregates derived from C&D wastes were used for concrete production. The results showed that recycled aggregates loose and dry-rodded unit weight values were found lower than natural aggregates because of the porous structure of cement mortar. Water absorption values of recycled aggregates were found higher than natural aggregates. Natural aggregates, recycled coarse aggregates and recycled fine aggregates water absorption values were found 1-2 %, 8 % and 10 %, respectively. Mechanical strength test results showed that natural aggregate containing sample highest strength values, coarse and fine aggregate compared with each other, coarse recycled aggregate containing samples have high strength values than fine recycled aggregate containing samples. The rapid chloride ions permeability of the mixes increased as the recycled aggregate content increased. In the second section, recycled aggregates derived from precast manufacturing sector were used in concrete production. The test results showed that increasing in recycled aggregate replacement decreased strength values of concretes. Optimum recycled aggregate amount was determined 12.5 wt. %.

1. Introduction

Population growth and increased migration to big cities accelerate construction works in city centers in the world. In addition, necessity to demolish old buildings and rebuild new ones became important over time [1].

Using of recyclable aggregates provide that reduction of using raw materials which are taken from natural resources. Waste landfills, which occur as a result of disposing huge amount of rubbles after demolition activities, can be removed by this way [2].

In literature, there are many investigations about utilization of construction and demolition wastes as aggregate in concrete products. In all conducted studies, researchers indicate that crushed concretes, of which dimensions are reduced in concrete aggregate sizes by broken with different methods, have quite good grain shapes for production. Conducted experimental studies, it was determined that crushed old concrete aggregates and natural aggregates showed similar results. During crushing, old crushed concrete are separated in two different size as fine and coarse. While coarse parts are used as coarse aggregate for concrete, fine parts are not added to concrete because usually sand is used in this size [3].

Executed slump tests on fresh concretes showed that slump was decreased with increasing of crushed aggregates of old concretes ratios in concrete mixing. Slump value was calculated as 100 mm for mixtures which have same water/cement ratio in normal concrete; on the other hand this slump value was calculated as 75 mm for concretes which were produced with using 100 % waste concrete aggregate. This shows that 25 % slump reduction is occur in concretes produced with waste concrete aggregate. It can be attributed to high water absorption capacity of mortars which are directly presented in concrete aggregates. It is almost impossible to separate these mortars from waste crushed aggregates; therefore waste crushed concrete aggregates at fine sizes should not be used [4].

Topçu (1993) observed that fresh concrete slump value was decreased with increasing waste crushed concrete aggregates ratio in concrete mixtures; moreover this reduction ratio reached as 15-20 % value at the mixture with 100 % waste crushed concrete addition [1].

Nixon (1978) indicated that water absorption capacity of waste concrete aggregates had higher values than natural aggregates [5]. Turanlı (1998) explained that waste concrete aggregates used at which 15-30 mm sieve size, had water absorption ratio at 5.02 % [6]. Hasaba et al. (1981) found that coarse aggregate (5-25 mm) had water absorption capacity at 7 % independently of concrete quality [7]. Poon (2007) determined that water absorption values of coarse and fine recycled aggregates at between 3.17 % and 10.3 % ratio. These values are between 0.5 % and 1 % for natural aggregates [8].

Hansen & Narud (1983) explained that old crushed concrete aggregates have lower specific gravity, higher water absorption and higher Los Angeles abrasion percentage. In this study, Los Angeles abrasion loss value was found as 22.4 % for recycled aggregates (16-32 mm) obtained from high strength standard concrete, while this value was found as 41.4 % for recycled aggregates (4-8 mm) obtained from low strength standard concrete [3]. Hasaba et al. (1981) determined absorption loss value as 24.6 % for waste aggregates (5-25 mm) obtained from high strength concrete [7]. It is emphasized that Los Angeles abrasion value should not be higher than 50 % in the aggregates used for concrete production and should not be higher than 40 % in the aggregates used for road construction at ASTM C-33 'Standard Specification for Concrete Aggregates' [9].

In the study performed by Günçan (1995), it was determined that compressive strength of concrete decreased with increasing waste crushed concrete ratio in the mixture. After research conducted, it was indicated that waste crushed concrete aggregate should not be used at high level in especially carrier concretes. Although strength reduction is evaluated as negative, researchers is specified that required strength values can be achieved with keeping waste crushed concrete ratio at a certain level [4].

Nixon (1978) explained that concretes which are produced from waste concrete aggregates have 20 % lower compressive strength than normal concrete [5]. BCSJ (1978) from Japan indicates that compressive strength reduction value can be as 14-32 % [10]. In the study conducted by Wesche and Schulz (1982), concrete samples having same water/cement ratio were produced with using old concrete coarse aggregate and two types natural aggregate. After the experimental study, elasticity modulus of concretes produced with old crushed concrete aggregates was decreased as 19 % in proportion to normal concretes [11].

Buck (1977) indicated that waste crushed concrete aggregates have more porous structure because of mortar containing; this situation can increase freeze-thaw resistance [12]. Mukai (1979) found fresh unit weights of concretes produced with waste concrete aggregates as 2020-2210 kgm^{-3}. This value is 85-95 % of normal concrete. For this reason, it is specified that the concretes produced with waste concrete aggregates have higher air content than normal concretes [13].

Rodriguez et al. (2016) explore the possibility of using recycled mixed aggregates (RMA) in the preparation of precast non-structural concretes. To that end different percentages of natural aggregate were replaced by RMA in non-structural elements (25, 50, 75 and 100%). Contents of cement, water, and the dosages commonly used by companies were unchanged by the introduction of RMA. The paving blocks, curbstones, and hollow tiles prepared were tested for 360 days. The stability of the tested properties confirmed the possibility of using these wastes on an industrial scale satisfying the standard requirements. However, the surface of terrazzo with RMA is not as good as that prepared with natural aggregate [14].

Bravo et al. (2015) studied durability performance of concrete with recycled aggregates (RA) from construction and demolition waste (CDW) from various locations in Portugal. To better understand the experimental results, the characteristics of the various aggregates (natural and recycled) used in the production of concrete were analyzed in detail. The composition of the RA was determined and various physical tests of the aggregates were performed. 33 concrete mixes with RA from different CDW recycling plants were evaluated in order to understand the influence that the RA's collection point, and therefore their composition, has on the characteristics of the concrete mixes produced. Both coarse and fine RA was used to determine the influence of their size on concrete's performance. The analysis of the durability performance allowed concluding that the use of RA is highly detrimental. This is mostly true when fine RA are used. The carbonation resistance is the property most affected by the use of RA, leading to increases in the carbonation depth between 22.2 % and 182.4 % for the various RA types. However, the most influencing factor is by far the RA's composition [15].

Bravo et al. (2016) studied the mechanical performance of concrete with recycled aggregates (RA) from construction and demolition waste (CDW) from various locations in Portugal. First the characteristics of the various aggregates (natural and recycled) used in the production of concrete were thoroughly analyzed. The composition of the RA was determined and several physical and chemical tests of the aggregates were performed. In order to evaluate the mechanical performance of concrete, compressive strength (in cubes and cylinders), splitting tensile strength, modulus of elasticity and abrasion resistance tests were performed. Concrete mixes with RA from CDW from several recycling plants were evaluated, in order to understand the influence that the RA's collection point, and consequently their composition, has on the characteristics of the mixes produced. The analysis of the mechanical performance allowed concluding that the use of RA worsens most of the properties tested, especially when fine RA are used. On the other hand, there was an increase in abrasion resistance when coarse RA was used. In global terms, the use of this type of aggregates, in limited contents, is viable from a mechanical viewpoint [16].

Sabai et al. (2013) investigated recycling of C&D waste into building material in Tanzania. Eight C&D waste samples were collected from C&D building sites, transported to the recycling site, crushed, and screened (sieved) to get the required recycled aggregates. Natural aggregates were also used as control. The physical and mechanical results showed that recycled aggregates were weaker than natural aggregates. However, chemically they were close to natural aggregates and therefore suitable for use in new concrete block production. In the production process, each experiment utilized 100% recycled aggregates for both fine and coarse portions to replace natural aggregates. The results showed that the blocks produced with 100% recycled aggregates were weaker than those with natural aggregates. However, the results also showed that there is a possibility of recycling the C&D waste into building material because 85% of the tested concrete block specimens from recycled aggregates achieved a compressive strength of 7 N/mm^{-2}, which is defined as the minimum required load bearing capacity in Tanzania [17].

2. Material and method

The used materials are natural coarse aggregates (NCA), natural fine aggregates (NFA), coarse demolition aggregates (CDA) and waste aggregates (WA).

In this study, fine (0-5 mm) and coarse crushed stone (12-22 mm) was used as a natural aggregate. Two different kinds of recycled aggregates (CDA and WA) with various grain sizes (0-8 mm, 12-22 mm) are used. CDA aggregates are the outline of the construction and demolition wastes having 10-16 MPa strength based on concrete, tile brick waste. WA aggregates are the waste of prefabricated concrete products having 35-45 MPa strength such as concrete pipe, curb stone products. CEM I 42.5 R cement type was used, also.

3. Results and discussion

Granulometric properties of aggregates are given in Table 1. The physical properties of recycled fine and coarse CDA and WA aggregates are summarized in Table 2, Table 3 and compared with natural aggregates.

Specific gravity and Blaine surface area of CEM I 42.5 R was 3.15 gcm^{-3} and 4015 cm^{2}g^{-1}, respectively. The composition of cement is given in Table 4.

Table 1. Granulometry of aggregates.

Sieve Sizes (mm)	**CDA (0-5 mm) Passing (%)**	**CDA (12-22 mm) Passing (%)**	**WA (0-8 mm) Passing (%)**	**WA (12-22 mm) Passing (%)**
31.5	100	100	100	100
16	100	81	100	93
8	100	9	96	12
4	95	2	65	1
2	80	1	46	0
1	46	1	32	0
0.5	27	0	22	0
0.25	11	0	14	0
0.125	7	0	10	0
0.063	6	0	8	0

Table 2. Physical properties of recycled coarse aggregates.

Physical Properties	**NCA (12-22 mm)**	**CDA (12-22 mm)**	**WA (12-22 mm)**
Tight unit weight (kgm^{-3})	1597	1461	1583
Loose unit weight (kgm^{-3})	1413	1354	1392
Apparent specific gravity (kgm-3)	2721	2663	2690
Water absorption (%)	0.8	7.8	6.2
Ultra-fine thin material content (%)	0.56	1.1	0.65
Flatness index (%)	9	12	8
Los Angeles abrasion (%)	22.7	37.5	31.9

Table 3. Physical properties of recycled fine aggregates.

Physical Properties	NFA (0-5 mm)	CDA (0-5 mm)	WA (0-8 mm)
Tight unit weight (kgm^{-3})	1845	1436	1823
Loose unit weight (kgm^{-3})	1620	1274	1540
Apparent specific gravity (kgm^{-3})	2720	2670	2681
Water absorption (%)	1.1	10.2	6.4
Fineness modulus	3.52	3.90	3.71
Methylene blue	1.0	1.0	1.1
Water content (%)	1.20	0.69	1.05
Ultra-fine thin material content (%)	10.95	5.23	9.74
Sand equivalent (%)	76	65	72
Organic material	*	*	*

**Lighter than reference*

Table 4. Composition of cement (%).

Properties	Amount (%)
SiO_2	19.8
Al_2O_3	4.9
Fe_2O_3	2.8
CaO	63.7
MgO	1.4
SO_3	2.2
Na_2O equivalent	0.24
Chloride (Cl^-)	0.07
Loss on ignition loss	3.4

The concrete mixtures are summarized in Table 5. C25/30 and C30/37 class concretes are produced in experiments. The water/cement ratios are set 0.55 and 0.40 for ready concrete and zero slump mixtures, respectively. Polycarboxylate based super plasticizer was used as 1.8 % and 1 % replacements of cement in ready concrete and zero slump concrete mixtures, respectively. Super plasticizer solid material amount is 30 % and unit weight is 1.1 gcm^{-3}.

Table 5. Concrete mix proportions (kgm^{-3}).

Material	Concrete Class	
	C25/30	C30/37
Cement (kg)	300	360
Sand (kg)	490	480
Crushed stone powder (kg)	465	465
Crushed stone No1 (kg)	480	670
Crushed stone powder No 2 (kg)	485	290
Concrete slump	S4	Zero slump

In the first part of the study, S4 slump concretes were produced for ready mixed concrete. In the second part of the study, zero slump concretes were produced for paving stone, curb stone, concrete and reinforced concrete pipe products. In ready concrete and zero slump concrete design, concrete classes were defined as C25/30 and C30/37. C25/30 concrete class mixtures were prepared both CDA and WA aggregates and slump classes are defined as S4.

In order to observe the effects of the CDA and WA addition, CDA was used as 20 wt. % and WA was used as 12.5 wt. %, 25 wt. % and 50 wt. % replacement of natural aggregate for S4 slump ready concrete designs. In concrete designs 3 different ways were applied such as only displacement of fine aggregate, coarse aggregate and equal combination of fine and coarse aggregates.

In the sample code, the displacement rate was defined as 2-digit number, fine aggregate displacement coded as "F", coarse aggregate displacement as "C", the displacement along the fine and coarse aggregates as "FC" and normal (reference) concretes as "reference".

In zero slump concrete designs, only CDA aggregate displacement was performed with 15 wt. % substitution rate. In these mixtures, coarse aggregate displacement coded as "C" and fine aggregate displacement was coded as "F" (Table 6).

Table 6. Concrete compositions.

Series	Concrete Class	Slump	Aggregate Type	Substitution Ratio (%)		Mix notation
				Fine	Coarse	
I	C25/30	S4	-	-	-	Control
	C25/30	S4	WA	-	12.5	WA12C
	C25/30	S4	WA	12.5	-	WA12F
	C25/30	S4	WA	25	-	WA25F
	C25/30	S4	WA	-	25	WA25C
	C25/30	S4	WA	25	25	WA50FC
II	C25/30	S4	-	-	-	Control
	C25/30	S4	CDA	10	10	CDA20FC
	C25/30	S4	CDA	-	20	CDA20C
	C25/30	S4	CDA	20	-	CDA20F
III	C30/37	Zero Slump	-	-	-	Control
	C30/37	Zero Slump	CDA	15	-	CDA15F
	C30/37	Zero Slump	CDA	-	15	CDA15C

Compressive strength: A compressive strength value of concrete is determined by testing of 150mm x 150 mm x 150 mm size of concrete cubes at 28 days. The relationship between compressive strength and replacement ratio of WA and CDA is shown in Table 7. It was found that compressive strengths of WA and CDA concretes at 28^{th} days are lower than control and the maximum reduction is 76 % for WA concrete and 80 % for CDA concrete.

Splitting Tensile Test: The splitting tensile tests are performed on 150 mm x 150 mm x 150 mm cube specimens according to the TS EN 12390-6 standard as shown in Table 8.

Rapid Chloride Permeability Test: The resistance of concrete against chloride penetration was obtained by applying the rapid chloride ion permeability test according to ASTM C1202-05 standards. The total charge passed through the WA and CDA are given in Table 9 and 10. As presented in Table 9, the rapid chloride permeability of the concretes produced with the 12.5 wt. % containing coarse or fine WA aggregates are slightly higher than control concrete in moderate permeability class. The rapid chloride permeability values of the concrete increased within the increasing in aggregate content. For example, For the WA25C concrete, the rapid chloride permeability is about 1.79 times higher than control concrete in high permeability class.

Table 7. Compressive strength results of cube specimens.

Series	Mix notation	Compressive Strength (28th days) (MPa)	Change (%)
I	Control	34.0	100
	WA12C	33.2	97
	WA12F	30.7	90
	WA25C	29.3	86
	WA25F	28.9	85
	WA50FC	26.0	76
II	Control	36.4	100
	CDA20C	31.0	85
	CDA20FC	29.5	81
	CDA20F	29.3	80
III	Control	37.8	100
	CDA15C	36.8	98
	CDA15F	33.3	88

Table 8. Splitting tensile strength results of cube specimens.

Series	Mix notation	Splitting Tensile Strength (28 days) (MPa)	Change (%)
I	Control	3.9	100
	WA12C	3.8	97
	WA12F	3.6	92
	WA25C	3.5	90
	WA25F	3.3	85
	WA50FC	3.1	79
II	Control	3.7	100
	CDA20C	3.4	92
	CDA20F	3.2	81
	CDA20FC	3.2	81
III	Control	4.6	100
	CDA15C	4.3	93
	CDA15F	4.1	89

Table 9. Rapid Chloride Permeability Classes for WA.

Series	Mix notation	Chloride permeability charge passed (Coulombs)	Permeability class (ASTM C1202)
I	Control	2698	Moderate
	WA12C	3442	Moderate
	WA12F	3811	Moderate
	WA25C	4816	High
	WA25F	5550	High
	WA50FC	6122	High

In Table 10, it is seen that concretes produced with the fine and coarse CDA aggregates have higher values than control concretes. Compared to the permeability of the control concrete, the increment in the aggregate content is significantly affect the chloride permeability charge and permeability class, also.

Table 10. CDA Rapid Chloride Permeability Classes for CDA.

Series	Mix notation	Chloride permeability charge passed (Coulombs)	Permeability class (ASTM C1202)
II	Control	2865	Moderate
	CDA20FC	4876	High
	CDA20F	4931	High
	CDA20C	5225	High
III	Control	2525	Moderate
	CDA15C	2761	Moderate
	CDA15F	2863	Moderate

4. Conclusion

The aggregate characterization test results showed that, 2 different recycled aggregates as CDA and WA, obtained from C&D waste and prefabricated concrete products, tight and loose unit weights are lower than natural aggregates. This is due to the reason of back stuck around the recovered aggregates form in the hollow cement slurry. Recycled aggregates water absorption values showed great differences with natural aggregates. The water absorption values for natural aggregates, recycled aggregates from C&D waste and prefabricated concrete products are around 1-2 %, 10 % and 6 %, respectively. Usage of the aggregates having high water absorption in concrete negatively affects strength and durability properties because of increasing water requirement of concrete. Laboratory scale concrete samples rapid chloride permeability values are found higher than reference concrete. Los Angeles abrasion results of coarse aggregates are determined higher than natural aggregate. High abrasion value is not preferred particularly pavement and road surface field applications. It may be subject to corrosion may lead to fall service life of concrete. Both of two recycled aggregates sand equivalent, methylene blue, flatness and organic material results are similar with natural aggregates. Recycled aggregates unit weight values are lower than natural aggregates; moreover, concretes prepared with recycled aggregates unit weight values are also lower than control group as expected.

28^{th} days compressive strength results of ready mixed concrete shows that 50 wt. %, 25 wt. % and 12 wt. % WA aggregate replacement instead of natural aggregate decreases strength values as 24 %, 15 % and 6 %, respectively. On the other hand, 20 wt. % CDA aggregates usage decreases strength values meanly 18 %. For zero slump concrete design, 20 wt. % replacement decreases strength value as 8 %. Also, it was found that coarse aggregates increased strength values more than fine aggregates.

Both ready mixed concrete and zero slump series prepared with recycled aggregates showed that different displacement ratios with natural aggregate affects splitting tensile strength properties. In ready mixed concretes made with WA aggregates, 12 wt. %, 25 wt. % and 50 wt. % replacement ratios decreased strength values as 5 %, 13 % and 20% approximately. CDA aggregates usage in 20 % replacement ratio in ready mixed concrete decreased strength values meanly 14 %.

In zero slump experiments, 15 wt. % replacement reduced compressive strength values approximately 8 %. Both of two concrete class results showed that, strength values of coarse aggregate containing concrete samples were found higher than strength values of fine aggregate containing concrete samples.

Rapid chloride permeability rates decreased with decreasing of recycled aggregates displacement ratio. Permeability is not affected from dimensional displacement ratios. As a result, increasing of recycled aggregate usage instead of natural aggregate negatively affects mechanical and durability properties of concrete.

When WA and CDA aggregates evaluated together, it can be said that strength loss values of WA containing concretes was found lower than CDA containing concrete strength values in the same replacement ratio according to the reference. This situation is attributed to the high compressive strength and low water absorption properties of WA aggregates.

Acknowledgements

This study was supported within ‘‘Construction and Demolition Wastes Recycling and Determination of Utilization Criteria” project. Project owner is Ministry of Environment and Urbanization, Substructure and Urban Transformation Services General Management. Project coordinator is TUBITAK Marmara Research Centre. The contributor institutions are ISTON Incorporated Company, ISTAC Incorporated Company, ISFALT Incorporated Company and AKCANSA Cement Industry and Trading Incorporated Company.

References

[1] Topçu, İ.B.: Beton kırıklarının agrega olarak kullanıldığı betonlar. In: Türkiye İnşaat Mühendisliği XII. Teknik Kongresi Bildiriler Kitabı TMMOB İnşaat Mühendisliği Odası, Ankara, pp. 511-522 (1993)

[2] Muller, C.: Requirements on concrete for future recycling. Technical University of Aachen, Germany (1999)

[3] Hansen, T.C., Narud, H.: Strength of recycled concrete made from crushed concrete coarse aggregate. ACI Concrete International Design and Construction, pp. 79-83, Germany (1983)

[4] Günçan, N.F.: Eski beton kırığı agregalı betonların fiziksel ve mekanik özellikleri. Osmangazi University Institute of Science Master Degree Thesis, p.44, Eskişehir (1995)

[5] Nixon, P.J.: Recycled concrete as an aggregate for concrete. First State of Art Report RILEM TC-37-DRC Materials and Structures (RILEM), pp.371-378 (1978)

[6] Turanlı, L.: Atık betonların yeni betonda kaba agrega olarak kullanılması, Hazır Beton Dergisi, İstanbul (1998)

[7] Hasaba. S., Kawamura. M., Torijik, K., Takemoto, K.: Drying shrinkage and durability of the concrete made of recycled concrete aggregate. Translation of The Japan Concrete Institute, pp. 55-60, Japan (1981)

[8] Poon, C.S.: Management of construction and demolition waste. Waste Management, 27, 159-160 (2007)

[9] ASTM C 33: Standard specification for concrete aggregates. ASTM International, West Conshohocken, PA (2016)

[10] BCSJ: Study on recycled aggregate and recycled concrete aggregate. Building Contractors Society of Japan, Committee on Disposal and Reuse of Concrete Construction Waste, Summary in Concrete Journal, pp.18-31, Japan (1978)

[11] Wesche, K., Schulz, R.R.: Beton aus aufbereitetem altbeton, tecnologie und eigenschaften, Beton 32, pp.108-112, France (1982)

[12] Buck, A.D.: Recycled concrete as a source of aggregate. ACI Journal, 212-219, England (1977)

[13] Mukai, T.: Study on reuse of waste concrete for aggregate of concrete. In: Japan-Us Cooperative Science Programme Energy and Resources Conservation in Concrete Technology, San Francisco (1979)

[14] Rodriguez, C., Parra, C., Casado, G., Minano, I., Albaladejo, F., Benito, F., Sanchez, I.: The incorporation of construction and demolition wastes as recycled mixed aggregates in non-structural concrete precast pieces. Journal of Cleaner Production, 127, 152-161 (2016). doi:10.1016/j.jclepro.2016.03.137

[15] Bravo, M., Brito, J., Pontes, J., Evangelista, L.: Durability performance of concrete with recycled aggregates from construction and demolition waste plants. Construction and Building Materials, 77, 357–369 (2015)

[16] Bravo, M., Brito, J., Pontes, J., Evangelista, L.: Mechanical performance of concrete made with aggregates from construction and demolition waste recycling plants. Journal of Cleaner Production, 99, 59-74 (2016)

[17] Sabai, M.M., Cox, M.G.D.M., Mato, R.R., Egmond, E.L.C., Lichtenberg, J.J.N.: Concrete block production from construction and demolition waste in Tanzania. Resources, Conservation and Recycling ,72, 9–19 (2013)