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Full Length Research Paper

Effects of the fine recycled concrete aggregates on the concrete properties

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In this experimental study, the effects of the recycled fine recycled concrete aggregate (FRA) that was manufactured from concrete wastes on the concrete properties were investigated. In concrete mixtures, 0, 10, 20, 30, 40, 50 and 100% by weight FRA were used instead of river sand. Afterwards, unit weight and water absorption ratios and 28-day compressive strength were determined. According to the test results obtained, it was seen that FRA can be used up to 10 % ratio for producing C30 concrete, between 20-50% ratios for producing C25 concrete. Thus, environmental impacts and consumption of the natural resources can be significantly reduced by using recycled fine concrete aggregates in concrete applications.

Key words: Compressive strength, concrete, normal crushed aggregate, recycled fine concrete aggregate, waste concrete.

INTRODUCTION

As a construction material, concrete is not regarded to be environment friendly due to its adverse effects on the environment. Nevertheless, it remains to be a most commonly used construction material. Around 10 billion tons of concrete is consumed per year, which means a ton of concrete is consumed per person every year (Nagaraj, 1993).

This being the current situation, the concrete industry has to conform to sustainable development, predicting the future of concrete and developing necessary strategies concerning this issue. For instance, better durability and more efficient use of concrete should be aimed at. Indeed, today, aggregates make up nearly 55 to 80% of concrete volume. Put differently, if the concrete industry fails to utilize alternative aggregates in the future, around 8 to 12 billion tones of natural aggregates will be consumed as of year 2010 (Tu et al., 2006).

The environment will inevitably be degraded by such large consumption of natural aggregates unless suitable substitutes for natural aggregates are instantly resorted to. In spite of the fact that recycling of aggregates has long been possible in the concrete industry, the recycled material has never been effectively introduced. Actually, it is very uncommon to use recycled aggregates in structural constructions, but rather they are mostly used as fillers in road construction and in similar low-level applications. Such defects of the material as its large water absorption capacity and the elongated and angular shape play a role in its relatively unimportant place in the concrete industry (Tu et al., 2006).

That 90% of our time is spent in buildings or infrastructures (roads, highways, bridges, etc.) demonstrates that construction materials have a remarkable place in our lives. Indeed, the construction sector is significant in two ways. First, the materials in the sector make up 3 to 4% of the total production all over Europe, and it provides employment for millions of people. Along with its important place in economy, however, the construction sector is detrimental for nature as it exploits 50% of raw materials and 40% of total energy, as well as causing 50% of the total waste (Oikonomou, 2005). What is more, concrete obtained

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from debris wastes, that is, the waste concrete, leads to environmental pollution and economic losses. Several research projects aiming at the reutilization of the waste concrete are going on. The recycled concrete aggregate (RCA) proved to be a good substitute for aggregate in the concrete production (Topçu, 1997; Topçu and Şengel, 2004). In fact, the homogenous aggregate mixture is obtained from concrete construction, and it is not mixed with other materials (Kohler and Kurkowski, 1998).Therefore, RCA obtained from concrete wastes has proved even more effective than those prepared from debris materials. The RCA is grouped into two: fine and coarse (Topçu and Şengel, 2004). As Hansen and Narud (1983) reports, the quality of the RCA, which has high capability to adhere (bond) with the cement paste, is closely related to the quality of the waste concrete. Other studies also indicate that RCA has a smooth granulometry shape (Özturan, 1988); its specific gravity is lower and its water absorption rate value is higher than the natural aggregate (Hansen and Narud, 1983; Buck, 1973). To use RCA in concrete, its water absorption needs to be known, and it has to be truly cleaned from other materials (Topçu, 1997).

As the absorption of recycled aggregate increases, more water is needed to make concrete from recycled coarse aggregates and natural sand. This is to ensure the same rate of workability (Mukai and Koizumi, 1979; Ravidrarajah and Tam, 1985). The absorption capacity of recycled aggregates causes a decline in the concrete's workability especially when they are implemented in dry conditions. Thus, as Nealen and Schenk (1998) maintains, the recycled aggregates need to be saturated before use. In brief, the absorption capacity of the recycled aggregates, as well as their shape and texture, influences the workability of recycled aggregate concretes. The particular type of crusher used determines this (Rashwan and AbouRizk, 1997).

When concrete made with 100% recycled coarse aggregate has a w/c ratio lower than the conventional concrete, it can have a higher compressive strength. However, when the w/c ratio is the same, the compression strength may be lower (Tavakoli and Soroushian, 1996). So as to achieve the conventional concrete's workability and compressive strength, it is necessary to add more cement to 100% recycled aggregate concrete. Hansen (1986) asserts that employing different qualities of recycled aggregate in concrete production manipulates the compressive strength variation coefficient. That is, any change in the production phase of concrete or in the properties of the constituents used is reflected on the strength of the concrete produced (Etxeberria et al., 2007).

There is no evidence of the negative impact of 20% untreated RCA on the fresh and hardened concrete (Acker, 1998). The workability of the fresh concretes with normal aggregates is similar to that of the fresh concretes with the RCA (Ravidrarajah and Tam, 1985). On the other hand, for the new concrete to reach the desired level of workability, it is essential to add chemical plasticizing agents to the new concrete (Zankler, 1999). Topçu and Şengel (2004) emphasizes that using more than 50% RCA in concrete mixture results in a decrease in the workability of the fresh concrete. Several research conclude that concrete mixtures obtained by RCA need more than 10% water, that the workability of the fresh concrete decreases quickly and the slump loss is relatively fast (Hansen and Narud, 1983b). Despite numerous studies on the use of RCA in producing high strength concrete (Limbachiya et al., 2000), it is suggested that RCA up to 30% be used (Durmuş et al., 2009).

In brief, the existing literature points to the fact that fine and coarse RCA have been used together in concrete mixtures. The present study focuses on RCA as fine aggregate, which was added in certain ratios into the concrete mixture and explores its physical and mechanical effects on the concrete.

MATERIALS AND METHODS

The mixes' constituents were ordinary Portland cement (OPC), water, natural river sand, crushed coarse aggregate and fine recycled fine aggregate (FRA) and superplasticizer.

Aggregates

Both natural river sand and FRA were used in this study. FRA was obtained from C30 concrete wastes, mostly generated during the concrete laboratory education. Concrete wastes were further crushed in the laboratory to produce FRA with particle size of less than 5 mm in diameter. Crushed coarse aggregate was also used in concrete mixtures with particle size of 20 mm in diameter.

Cement, water and superplasticizer

In this experimental study, OPC (CEM I 42.5) was used. Chemical composition and physical properties of the cement used are given in Table 1. The tap water water and superplasticizer chemical additive (SP) with a density of 1.20 ± 0.02 kg/L were used in these concrete mixtures.

Granulometry, specific gravity and water absorption tests on the aggregates entering into the concrete mixture were performed according to TS 3530 EN 933-1 "Tests for geometrical properties of aggregates-Part 1: Determination of particle size distribution-Sieving method", TS EN 1097-6 "Tests for mechanical and physical properties of aggregates-Part 6: Determination of particle density and water absorption" respectively (TSI, TS 3530 EN 933-1, 1999; TSI, TS 3529, 1980).

The concrete mixture was determined in conformity with the TS EN 206-1 "Concrete-Part 1: Specification, performance, production and conformity" standard. The concrete quality of the mixture was selected as C25/30 (TSI, TS EN 206-1, 2002). The concrete (0% FRA) prepared by using river sand and crushed course aggregate was considered as the control concrete (CC). Concrete specimens were prepared in conformity with the TS EN 12390-2 "Testing hardened concrete-Part 2: Making and curing specimens for strength tests" standard (TSI, TS EN 12390-2, 2002). The natural fine aggregate within the mixture was decreased by 0, 10, 20, 30,

Table 1. Chemical compounds and physical properties of cement.

Chemical compounds	(%)	Physical properties	%
SiO_2	21.01	Specific gravity (g/cm³)	3.12
Al_2O_3	5.39	Specific surface (Blaine) (cm²/g)	3350
Fe_2O_3	3.23	2 days compressive strength (Mpa)	21.0
CaO	62.11	7 days compressive strength (Mpa)	28.0
MgO	1.98	28 days compressive strength (Mpa)	42.0
Na_2O	0.21	Initial setting time (min)	157
K_2O	0.74	Final setting time (min)	235
SO_3	3.1	Soundness (mm)	1.0

Table 2. Properties of natural and recycled aggregates.

Sieve size (mm)	Fine aggregate		Sieve size(mm)	Coarse aggregate
	River sand	FRA		
	% passing			% passing
4.76	100.00	100.00	19.10	19.10
2.38	87.10	80.00	12.70	92.50
1.19	64.00	51.70	9.53	62.00
0.59	41.10	35.20	4.76	0.00
0.297	21.80	13.30	Absorption (%)	0.26
0.149	8.60	5.40	Specific gravity (kg/m^3)	2.69
0.074	0.50	3.10		
Absorption (%)	1.22	4.28		
Specific gravity (kg/m^3)	2.65	2.31		
Material finer than 75 µm (%)	0.40	1.20		

40, 50 and 100%, the FRA was used in place of it. In concrete mixtures, SP was used as 1.2% of the cement quantity. The maximum aggregate size in the concrete mixtures was 20 mm. Effective water amount in each concrete type was kept constant. The ratio of water/cement (w/c) was fixed as 0.53. Cement quantity and SP ratio were taken as constant in the concrete mixtures. SP was added to mixing water by weight of cement. Laboratory type mixer was used in the production of concrete. The concrete mixtures were prepared by using the following procedure: First, FRA, river sand and coarse aggregates were placed in the mixer along with the water for 10 min. The water placed in the mixer was that indicated in Table 3, 75% of the total absorption water of aggregates. This procedure was used to ensure that aggregates absorbed part of the water and that the pores were at least partly saturated. Additionally, this guaranteed that aggregate surface was wet when cement was added. Afterwards cement was added to the mixer. This procedure ensures that a large quantity of cement particles will adhere to aggregate, thus causing a good connection between cement paste and aggregates. After, the water and superplasticizer were premixed and added within 10 s. The total mixing time was about 15 min. Slump test were carried out on the fresh concrete batches. All concrete mixtures were produced in conformity with the pump concrete slump value, 16 to 18 cm. The fresh concrete was cast into steel moulds and compacted by vibration to obtain test specimen in laboratory with the temperature of 23±2°C and a relative humidity of 50 to 55%. For each concrete mixture, three 100 mm cubes specimens were cast. The specimens were taken out from the steel moulds 24 h later and cured for 28 days until the time of testing.

Slump test on the fresh concrete produced were conducted in conformity with the TS EN 12350–2 "Testing fresh concrete- Part 2: Slump test" standart (TSI, TS EN 12350–2, 2002. The cubic specimens produced were kept in the standard curing pool with a temperature of 23±2°C until the testing day. 28 day compressive strength, water absorption and specific gravity tests on these specimens were performed in accordance with the TS EN 12390-3 "Testing hardened concrete-Part 3: Compressive strength of test specimens" and TS 3624 "Test Method for determination the specific gravity the absorption water and the void ratio in hardened concrete" standards, respectively (TSI, TS EN 12390-3, 2003; TSI, TS 3624, 1981).

EXPERIMENTAL RESULTS AND DISCUSSION

Results for the granulometry of the river sand and the FRA are given in Table 2. As seen in the table, there is a similarity between the grain size distribution of the normal fine crushed aggregate and that of the FRA.

Properties of fresh concrete

The quantities of the materials entering into concrete

Table 3. Mixture proportions of concrete containing FRA (kg/m^3).

Mix type	FRA replaced (%)	Cement	Water	River sand	FRA	Coarse aggregate	SP
CC	0	350	185	1050	0	860	4.1
FRA10	10	350	185	946	105	860	4.1
FRA20	20	350	185	840	210	860	4.1
FRA30	30	350	185	735	315	860	4.1
FRA40	40	350	185	630	420	860	4.1
FRA50	50	350	185	525	525	860	4.1
FRA100	100	350	185	0	1050	860	4.1

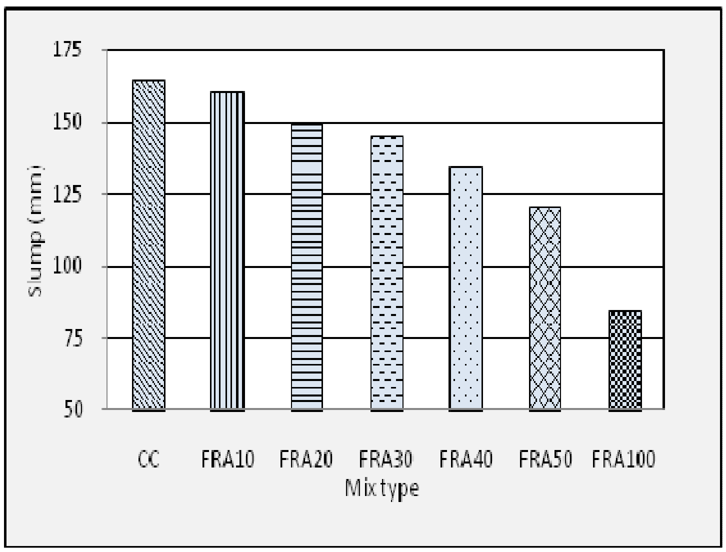

Figure 1. Effect of FRA on slump of concrete.

mixture prepared by the crushed coarsa aggregate and the FRA are given in Table 3.

The air content of the fresh concretes produced varies between 1.8% and 2.5%. It was observed that the air content was increased as the FRA quantity in the concrete mixture raised. There was a linear relationship between the FRA quantity and the air content. However, the air content varies according to the aggregate size and cement quantity; it was required not to exceed 6% for the concrete used in the study (Neville, 1996). It was seen that the air quantity of all the concrete mixtures conforms to the prescribed value.

Unit weight values of fresh concretes produced changes between 2.350 and 2.510 kg/dm^3. The unit weight value decreased as the FRA quantity in the concrete mixture was increased. The reason of this was that the specific gravity of the FRA was lower than that of the normal fine aggregate and increasing air content of the fresh concrete. For concretes in which the normal aggregate was used, the unit weights of the fresh concretes produced varies between the values of 2200 to 2450 kg/m^3 (Erdoğan, 2003). So, it can be said that all of the concretes produced are in the concrete quality with normal weight.

Test results for the slump obtained from the fresh concrete specimens are shown in Figure 1. Slump values of the fresh concrete varies between 85 to 165 mm. The slump of FRA concrete mixes was decreased with an increase in FRA content probably due to the shape, texture and dust content of the crushed sand when compared to river sand. This result is similar to that of Cabrera and Donza (1997). No relationship can be established between slump and increase in the FRA quantity in the concrete mixture.

Properties of hardened concrete

Test results for the unit weight, water absorption and compressive strength of the hardened concretes are given in Figures 2, 3 and 4.

As seen in Figure 2, unit weight values of the hardened concretes vary between 2.30 and 2.41. The unit weight of the concrete decreased as the FRA quantity in the

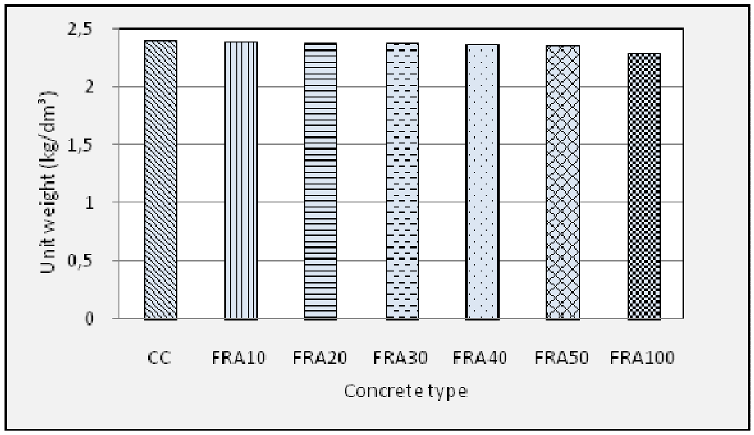

Figure 2. Effect of FRA on unit weight of hardened concrete.

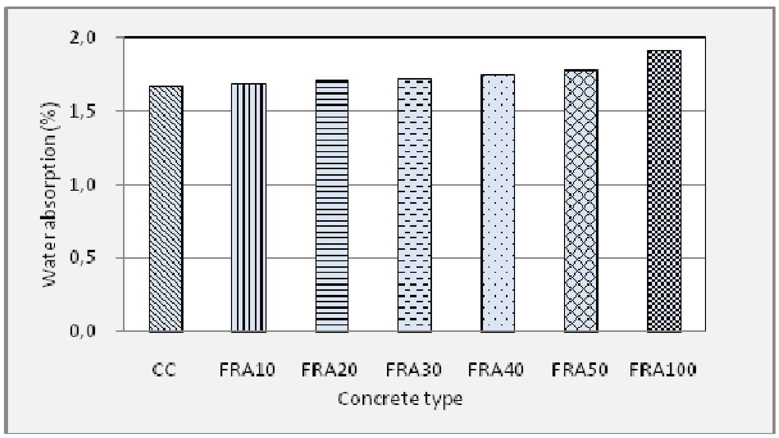

Figure 3. Changes of water absorption of concrete type.

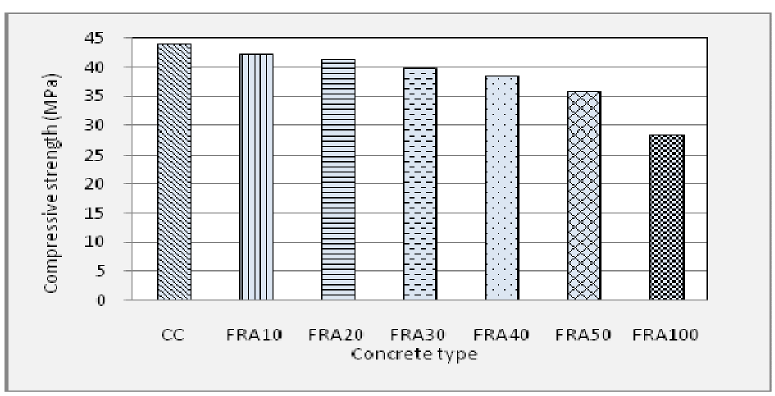

Figure 4. Effect of FRA concrete on compressive strength of concrete.

concrete mixtures went up. The reason of this was that specific gravity of the FRA used instead of the normal fine crushed aggregate was lower and air content ratio was increased as the FRA quantity in the concrete mixtures increased. All of the concretes produced by using the FRA are included in the normal concrete quality according to TS EN 206-1 (TSI, TS EN 206-1, 2002).

Water absorption ratio values of the hardened concretes varied between 1.67 and 1.92%. The water absorption rate values increased as the FRA quantity in the concrete mixtures rose. The reason of this was that the FRA used in the concrete mixture has a higher water absorption ratio (Hansen and Narud, 1983).

Compressive strength values for the hardened concretes varied between 28.50 to 44.10 MPa. The highest compressive strength was obtained as 44.10 MPa for the CC among the concretes manufactured. The compressive strength decreases as the FRA quantity in the concrete mixture raised. The interfacial transition zone, composed of the recycled aggregate and the cement matrix, is the weakest phase in recycled aggregate concrete because of the the higher porosity and absorption capacity of recycled aggregate (Poon et al., 2004). In the course of vibration, the water absorbed by the recycled aggregate particles can be transferred to the cement matrix. This process creates cement matrix, which has a relatively high w/c ratio, and poorer interfacial bonds between the aggregate and the cement paste (Poon et al., 2004).

In comparison with the CC, the concretes produced by using the FRA show lower strength by 4.3% for 10 FRA, 5.9% for 20 FRA, 9.8% for 30 FRA, 12,7% for 40 FRA, 18.6% for 50 FRA and 35.4% for 100 FRA. This case indicates that there is an opposite relationship between the compressive strength and the FRA quantity. This result is similar to the study conducted by Khatib (2005).

Concretes were designed according to the characteristic strength and desired to reach to the target strength. Target strength for C30/35 concrete quality was required to be 36/43. The characteristic strength must be 35 MPa since 150 mm cubic specimen was used in the study. Except for 100 FRA, all produced concretes were met the required characteristic compressive strength. 20, 30, 40 and 50 FRA specimens have strengths less than the target strength.

According to TS 5893 ISO 3893; 10 FRA concretes are included in the C30/35 concrete quality, 20, 30, 40 and 50 FRA concretes are included in the C25/30 concrete quality, in terms of the characteristic and the target strength (TSI, TS 5893 ISO 3893, 1999).

CONCLUSIONS AND SUGGESTIONS

The results obtained from the research can be summarized as follows:

(a) When aggregate granulometry was compared, the normal crushed aggregate and the FRA show a harmonious granulometry.
(b) Water absorption ratio of the FRA was obtained as higher than the water absorption ratio of the normal crushed fine aggregate.
(c) Water need and air content values for the fresh concrete were increased and the unit weight values decrease as the FRA ratio in the concrete mixture increase.
(d) Specific gravity and compressive strength values for the hardened concretes decrease and the water absorption rate went up as the FRA ratio in the concrete mixture grown.
(e) The highest and the lowest compressive strengths were respectively obtained from 10 and 100 FRA concretes among all the concretes produced by using the FRA.
(f) According to the test results obtained, the FRA can be used up to 10 % ratio for producing C30 concrete, between 20 to 50% ratios for producing C25 concrete.
(g) Use of the waste aggregate in the new concrete as the recycled concrete aggregate reduces the environmental pollution as well as providing an economic value for the waste material.
(h) Usage of recycled aggregates can not only preserve the finite raw materials, but also reduce energy consumption and overall construction costs.

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