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خواص خرسانات الركام المعاد تدويره المنتجة في الكويت: دراسة حالة

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الخلاصة

تم صب واختبار إحدى وثلاثين خلطة خرسانية باستخدام خلطات مختلفة من الركام الخشن والناعم المعاد تدويره (المنتج في الكويت). وتتراوح مقاومة ضغط المكعب لتلك الخلطات بين 26-51 ميجاباسكال. وأظهرت الخلطات الخرسانية تشغيلية جيدة بسبب استخدام فوائق اللدونة. وتم استخدام اسمنت من النوع الأول طبقاً لمواصفات ASTM بدون مواد اسمنتية مساندة بحدود 295 إلى 509 كجم/ م^3 من الخرسانة كما تراوحت نسبة الأسمنت إلى الماء في تلك الخلطات بين 0.3 إلى 0.67 وكما تراوح معامل المرونة الذي تم تحديده تجريبياً بين 26 إلى 39 جيجاباسكال والذي يعتبر مؤشراً لخرسانة ذات نوعية جيدة. كما وصلت مقاومة الانحناء لتلك الخلطات حتى 6.2 ميجاباسكال. تمت متابعة تطور المقاومة لتلك الخلطات حتى 91 يوماً مع معالجتها بماء العذب وماء البحر والمعالجة في الهواء.

الخواص الهندسية لتلك الخلطات الخرسانية توضح أن الركام المنتج في الكويت من إعادة تدوير الخرسانة الناتجة من مخلفات الهدم يمكن استخدامه لإنتاج خرسانة إنشائية جيدة النوعية.

Characteristics of recycled aggregate concretes produced in Kuwait : a case study

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ABSTRACT

Thirty one concrete mixes made of various combinations of coarse and fine recycled aggregates (produced in Kuwait from demolition waste) were cast and tested. The possibility of producing structural grade concrete using the recycled concrete aggregates (RCA) produced in Kuwait has been investigated in this study. The cube compressive strength of these concretes was in the range from 26 to 51 MPa. The concretes produced exhibited good workability, due to the use of a proprietary super-plasticizer. ASTM Type I Portland cement, without any supplementary cementitious material, in the range of 295 to 509 kg/m^3 of concrete has been used. The water – cement ratio of these concretes varied between 0.3 to 0.67. The 28-day experimentally determined modulus of elasticity of the concretes ranged from 26 to 39 GPa, which is indicative of good quality concrete. The flexural strength of these concretes was found to be as high as 6.2 MPa. Strength development of these concretes, up to a period of 91 days, was monitored under continuous curing in tap water, in seawater and under air curing. The engineering characteristics of the concretes derived from this study suggest that the recycled concrete aggregates (RCA) produced from the demolition waste in Kuwait are capable of making good quality structural concrete.

Keywords: Compressive strength; flexural strength; modulus of elasticity; recycled aggregate concrete (RAC); structural concrete.

INTRODUCTION

There are environmental and economic concerns that arise for the continuous extraction of natural aggregates, production and land filling of demolition waste and haulage of these materials from the production to the construction and disposal sites. It makes both environmental and economic sense to recycle / reuse the demolished waste products, particularly crushed concrete and bricks, since it will reduce both the amount of primary aggregates extracted and waste (Chidiroglou *et al.,* 2008).

The utilization of recycled aggregates contributes to the production of green concrete and to increasing the sustainability of the construction industry. Waste arising from construction and demolition (C&D) constitutes one of the largest waste streams within the European Union and many other countries. Construction demolition waste has become a global concern that requires sustainable solution (Limbachiya *et al.,* 2004). In fact many governments throughout the world have now introduced various measures aimed at reducing the use of primary aggregates and increasing reuse and recycling, where it is technically, economically, or environmentally acceptable. For example, the British government has introduced a number of policies to encourage wider use of secondary and recycled concrete aggregate (RCA) (Limbachiya *et al.,* 2004).

Concrete demolition waste has proved to be an excellent source of aggregates for new concrete production. Many studies prove that concrete made with this type of coarse aggregates can have mechanical properties similar to those of conventional concretes and even high-strength concrete is nowadays a possible goal for this environmentally sound practice (Adjukiewicz & Kliszczewicz, 2002; Khatib, 2004; Evangelista & Brito, 2007).

Some countries are now leading the way in recycling, with RCA taking more than a quarter of the market (Lay, 2009). Now in Kuwait, recycled concrete aggregates (RCA) in various sizes, both coarse and fine, are available in stockpiles which provide an incentive for concrete producer to use these aggregates in the design and production of concrete (EPIC, 2009). But the use of RCA has been so far limited, mainly to road sub base. This is due to the lack of standards and practice guidelines for its use. The authors have undertaken a systematic characterization of RCA and the concrete produced from it. The objective of the present study is to explore the possibility of producing structural grade concrete using the RCA. The unique feature of the research reported here is the utilization of 100% RCA, both coarse and fine in some mixes, and 100% coarse RCA in other mixes. The effects of up to 100% coarse RCA on a range of engineering and durability properties of concretes have been investigated. The ultimate objective is to set out some guidelines to facilitate the use of recycled concrete aggregate in the construction industry.

EXPERIMENTAL INVESTIGATIONS

The recycled coarse and fine aggregates used in this investigation were collected from the recycling factory – Environment Preservation Industrial Company (EPIC) in Kuwait (see Figure 1). The following tests have been performed on samples of coarse and fine aggregates.

i) Sieve Analysis

ii) Specific Gravity and Bulk Density

iii) Crushing Strength

iv) Absorption

The particle size distribution of the aggregates is shown in Figure 2. The fineness modulus for fine RCA is 2.39, which indicates a fine-to-coarse sand, whereas normal sand has a value of 2.57. The other physical characteristics are included in Table 1.

The higher absorption capacity of the RCA can be catered for using them in saturated surface dry (SSD) condition and adjusting the amount of mixing water accordingly. A lower value of the crushing strength of RCA will, however, limit the concrete strength, which can be achieved.

Fig. 1. Recycling of construction demolition waste in EPIC factory, Kuwait.

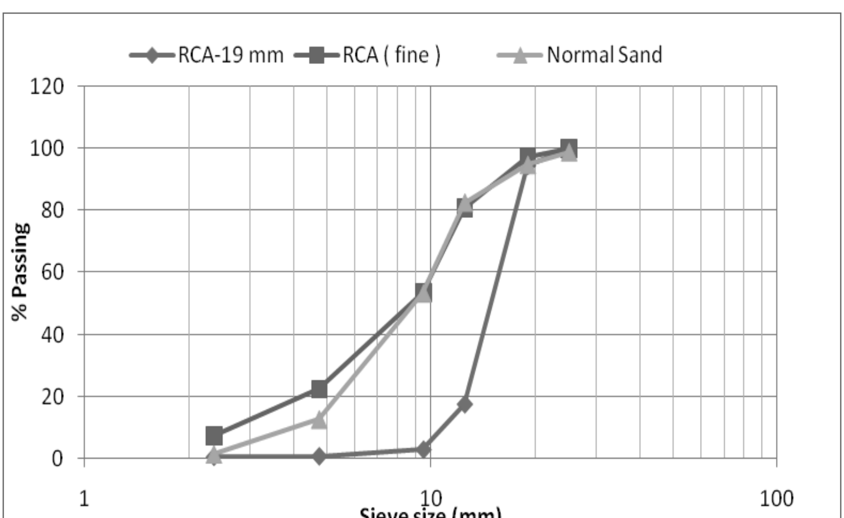

Fig. 2. Particle size distribution of aggregates used.

Table 1. Physical characteristics of the aggregates used.

Aggregate characteristic	RCA Coarse	RCA Fine	Virgin CA	Normal Sand
Specific Gravity	2.4	2.4	2.8	2.6
Crushing Strength (10% fine)-kN	121	--	332	--
Absorption (%)	4.1	6.2	0.8	2.0

Materials used

In this investigation, 31 concrete mixes were cast. Recycled coarse aggregates of maximum sizes 19 mm and 12.5 mm were used in SSD condition. Recycled fine aggregate as well as conventional fine aggregates were used for different mixes. A proprietary super-plasticizer (water reducing and retarding admixture) was used in mixes in order to improve workability at a lower water-cement ratio. The dosage of super-plasticizer (SP) was 5–6 l/m^3 of concrete in all the mixes. ASTM Type I Portland Cement was used. For mixing and curing, normal tap water was used. For a few mixes, seawater curing was employed to assess its effect on durability if any.

Concretes cast

Different mixes of 25, 30, 35, 40, 45 and 50 MPa nominal cube strength were designed using–Huge's Approach. Some of the mixes were made with both recycled coarse and fine aggregates, while others were made with recycled coarse and normal fine aggregate. Some mixes were cast by replacing 50% recycled fine aggregate with normal sand. Two mixes were cast with virgin coarse aggregates, one with normal sand. Mixes are designated by the target strength of 25, 30, etc followed by 'RR' or 'RN'. In RR mixes both coarse and fine aggregates are recycled (Mixes 1−6). RN mixes are cast with recycled coarse aggregates and 'normal' sand. Mixes where fine aggregate are a 50:50 combination of both normal and recycled sand are designated by RN0.5. Finally, the mixes with only normal aggregates are designated by NN or NR. The mix quantities, in kg, used to produce a cubic metre of various concretes are included in Table 2.

During casting of concrete, the slump, air content and density have also been determined. The essential data and the strength results on all the concretes tested are included in Tables 2, 3, 4 and 5.

The first endeavour of this study was to explore the capacity of the recycled concrete aggregates produced in Kuwait to cast concretes of varying strength which can be eventually used for different applications. Preliminary trials indicated that the recycled concrete aggregates would be of adequate compressive strength to produce RAC strength up to 50 MPa.

Initially it was decided to design mixes using both recycled coarse and fine aggregates. Mixes in this series used stockpile containing 19 mm maximum nominal size aggregates. The first 6 mixes (1–6) in Table 2, designated as RR, belong to this group.

The second group of five mixes (7–11) in Table 2 used 'normal' sand instead of recycled fine aggregates. The third group of concretes, 12–17 in Table 2, used recycled coarse aggregates from both 19 mm and 12.5 mm stockpile, 50% each with normal sand. Mixes 12 and 17 were cast without super-plasticizer.

Mixes 18 to 22 in Table 2 were cast using recycled coarse aggregate with 50% normal sand and 50% recycled fine aggregates. All mixes used coarse aggregates of size 19 mm and 12.5 mm stockpile, 50% each, except mixes 19 and 21, which used only 19 mm aggregates.

Table 3 shows the characteristics of the concretes tested. Table 4 includes strength under continuous water curing, seawater curing and continuous air curing. The slump, air content, w/c ratio used and the total cement content in a given batch of concrete are also included in the table. Nine additional mixes, as in Table 5, were cast to evaluate the flexural strength and the modulus of elasticity.

Table 2. Mix quantities (kg/m^3) for the concretes cast.

Mix No.	Designation	Cement	Water	RC Coarse	RC Fine	Sand
1	25 RR	295	195	1210	622	-
2	30 RR	311	196	1045	620	-
3	35 RR	371	211	1045	601	-
4	35 RR	440	224	1045	533	-
5	40 RR	440	194	1045	533	-
6	30 RR	345	231	1001	682	-
7	35 RN	440	139	1045	-	579
8	40 RN	371	148	1045	-	653
9	40 RN	440	169	1045	-	579
10	40 RN	440	161	1045	-	579
11	45 RN	440	155	1045	-	579
12	40 RN	371	211	1045	-	653
13	45 RN	440	144	1045	-	579
14	50 RN	475	144	1045	-	579
15	50 RN	509	176	1042	-	512
16	50 RN	425	147	1045	-	653
17	50 RN	425	208	1045	-	653
18	30 RN0.5	311	139	1045	310	337
19	45 RN0.5	371	155	1045	299	326
20	45 RN0.5	371	150	1045	299	326
21	50 RN0.5	440	164	1045	266	290
22	50 RN0.5	440	162	1045	266	290
23	30 RR	345	193	1001	682	-
24	40 RR	440	178	1045	533	-
25	40 RN	371	133	1045	-	653
26	50 RN	425	147	1045	-	579
27	30 RN0.5	311	168	1045	310	337
28	45 RN0.5	371	143	1045	299	326
29	50 RN0.5	425	147	1045	265	290
30	40 NR	371	171	1045	-	-
31	50 NN	440	167	1210	598	579

Table 3. Characteristics of fresh and hardened concrete.

Mix No.	Designation	W/C	Slump (mm)	Air content (%)	Cube compressive strength (MPa)		
					7 day	28 day	91 day
1	25 RR	0.66	110	2	21.5	27.5	28
2	30 RR	0.63	140	2.2	25	32	38
3	35 RR	0.57	90	1.9	28.5	35	40
4	35 RR	0.51	200	2	31	34.5	40
5	40 RR	0.44	200	2	33	39	45
6	30 RR	0.67	120	2.2	23	32	34
7	35 RN	0.316	90	2	37	36	50.5
8	40 RN	0.4	140	1.3	35	42.5	36
9	40 RN	0.385	100	1.9	26	39	46
10	40 RN	0.366	120	1.8	42	44	45
11	45 RN	0.353	160	1.6	40.5	45	N/A
12*	40 RN	0.569	90	1.8	18	26	28.5
13	45 RN	0.328	105	1.8	35	48.5	48
14	50 RN	0.304	100	2.2	42	49.5	N/A
15	50 RN	0.346	70	2.4	47	51	52.5
16	50 RN	0.346	110	1.9	46.5	51.5	51
17*	50 RN	0.49	40	2	30	36.65	36
18	30 RN0.5	0.446	80	1.7	32	35.5	44.5
19	45 RN0.5	0.419	80	2	32	47	52
20	45 RN0.5	0.404	110	2.6	36.5	41	46
21	50 RN0.5	0.372	70	2	30	49	45
22	50 RN0.5	0.369	75	2.5	46	50	48

N/A: Result not available, as 91 days test was not performed for some mixes

* The two mixes cast without super-plasticizer.

Table 4. Compressive strength development of concretes under different curing regimes.

Mix No.	Designation	W/C	Cement (kg/m^3)	Slump (mm)	Air Content (%)	Cube Strength (MPa)					
						Normal curing (days)		Seawater curing (days)		Without curing (days)	
						28	91	28	91	28	91
5	40 RR	0.405	440	180	1.5	39	45	41	34	48.5	43.5
6	30 RR	0.561	345	77	3.1	32	34	32	31.5	28	29.5
8	40 RN	0.358	371	105	2.6	42.5	36	32	41	23.5	35
16	50 RN	0.346	425	175	1.5	51.5	51	53	44	36	41
18	30 RN0.5	0.541	311	140	2.6	32	34	28	29.5	28	27.5
19	45 RN0.5	0.386	371	90	2.5	47	52	47	45	45.5	40.5
21	50 RN0.5	0.345	425	105	2.1	51.5	51	44.5	46	53.5	46
30	40 NR	0.462	371	110	1.6	N/A	N/A	43.5	49	33	39.5
31	50 NN	0.379	440	72	2.1	N/A	N/A	51	62.5	43	55

N/A: Result not available

Table 5. Flexural strength and E values of concretes.

Mix No.	Designation	28 day Flexural Strength (MPa)	Density (kg/m^3)	28 day Comp. Strength (MPa)	E – Experimental (GPa)	E–Values as per AS 3600 (GPa)	E–Values as per ACI 318 (GPa)
1	50RN	5.8	2342	53	35.6	35.5	34.4
2	40RN	5.6	2332	32	33.4	27.4	26.8
3	30RR	5.2	2225	32	29.1	25.5	26.8
4	45RN0.5	5.5	2309	47	34.6	32.7	32.4
5	40RR	5	2320	41	24.2	30.8	30.3
6	50RN0.5	4.5	2361	44.5	26	32.9	31.6
7	30RN0.5	3.7	2274	28	27.9	24.7	25
8	50NN	5.2	2526	51	39.2	39	33.8
9	50NR	6.2	2458	43.5	33.3	34.6	31.2

Curing regimes

All the mixes in Table 2 were cured in water tanks stored in temperature controlled rooms. The temperature in the control room was maintained at 23 ± 2º C. This curing regime has been designated as Normal curing. The seawater cured specimens were, immediately after de-moulding, stored in tanks filled with seawater which were placed outside the control room. Air-cured specimens were placed outside the control room on the roof of the laboratory. Unfortunately, the temperature and the ambient humidity of these specimens have not been recorded. This, however, did not affect the qualitative comparison between different curing regimes.

CHARACTERISTICS OF THE CONCRETES PRODUCED

Workability

The water/cement ratio used in this study varied between 0.3 to 0.7 and the slump varied from 70 to 200 mm. It can be seen in Tables 3 and 4 that for mixes with 440 kg/m^3 cement, even lower water/cement ratios produced more workable mixes (Mix Nos. 7, 9, 10, 11, 13). The concretes made were easy to handle and compact. The use of the super-plasticizer certainly helped to achieve better workable concretes at relatively low water content. All concretes loose slump with time due to the process of ongoing hydration. It was observed that most of the mixes lost about 50 mm slump in the first 30 minutes after mixing. This suggests that temperature monitoring is important while casting concrete.

Compressive strength

All researchers report a loss in compressive strength when RCA is used as a direct replacement of natural aggregate at the same w/c ratio. Values differ but losses in strength of up to 10% are common when RCA is used as the sole aggregate, with respect to concrete made with only comparable natural virgin aggregates (Dhir, 2009). This study has used the RCA's in mix designs. The loss in strength due to replacing virgin aggregates with RCA was not evaluated.

The reasons for the loss in strength is usually associated with : i) the weaker interfacial transition zone between aggregate and mortar, due to the aggregate having a coat of weak mortar already attached (Otsuki *et al.*, 2003; Etxeberria *et al.,* 2006) and ii) this attached mortar raising the porosity of the concrete (Gomez-Soberon, 2002; Scanchez & Guiterrez, 2009). Put simply, the resultant bond between coarse RCA and mortar is not as strong as is in virgin aggregates. In order to overcome some of these problems, as already mentioned, most mixes were cast with a super-plasticizer.

Compressive strength development of concretes made with 100% RCA

Concretes of this series, with both coarse and fine RCA, were made using 295 to 440 kg of cement for a cubic metre of concrete. The water-cement ratio used varied between 0.44 to 0.67. Concrete made with cement content less than 300 kg/m^3 did not show any change in strength between 28 and 91 days (Mix 1). This could be due to the weakening of the interface between the cement paste and aggregate. These results suggest that up to 300 kg/m^3, cement hydrated sufficiently in the first 28 days and there was not an over abundance of cement to keep hydrating beyond 28 days and hence develop extra strength. The maximum strength achieved by using 100% recycled aggregates is about 40 MPa. In other words, the recycled coarse and fine aggregates are capable of producing 40 MPa compressive strength concrete.

Compressive strength development in concretes made with 19 mm RCA and normal sand

When recycled fine aggregate was replaced by normal sand, the potential to develop compressive strength of the concrete was enhanced. For example, Mixes 3 and 8 are comparable in terms of total cement content of 371 kg/m^3 of concrete. The replacement of recycled sand by the normal sand managed to lower the w/c ratio and hence enhance the strength for the same slump. Again, there does not seem to be an appreciable development in strength of this series of concrete between 28 and 91 days. The long term strength seems to be limited by the amount of cement and the strength capacity of the recycled coarse aggregates as well. Using a higher cement content of 440kg/m^3, a maximum strength of 45 MPa was achievable (see Mix 11).

Strength development in concretes made with 19 and 12.5 mm RCA and normal sand

The use of both 19 mm and 12.5 mm stockpiles of aggregates on equal weight basis with normal sand has further enhanced the strength potential of these concretes compared to those using 19 mm aggregates only. This is attributed to the more desirable packing of the resultant aggregate solid skeleton (compare Mixes 10 and 13). However, there is no appreciable increase in strength between 28 and 91 days (only 2.9% increase) even with a considerable higher amount of total cement (see Mix 15 with 509 kg/m^3 of cement). This does indicate that the use of coarse recycled concrete aggregate in combination with normal sand tested in this study can produce concrete of no more than 50 MPa compressive strength.

Two mixes in this series were cast without super-plasticizer (Mixes 12 and 17). Similar mixes cast with super-plasticizer (Mix 12 with 8, and Mix 17 with 16) clearly indicates that, the w/c ratio had to be increased to maintain workability, which decreased the strength considerably (38.8% reduction for Mix 12, and 28.8% reduction for Mix

17 in 28-day strength). This suggests that the use of super-plasticizer in the recycled aggregate concrete will play a vital role.

Compressive Strength development in concretes made with both normal and recycled sand

Concretes made with 19 mm recycled aggregates and 50% normal sand and 50% recycled fine aggregate (FA) again have considerably enhanced strength than concretes made with 100% recycled FA (compare Mix 3 with 19, and Mixes 4, 5 with 22). Concretes made with 50 : 50 FA's are as good as those with 100% normal sand.

Except Mixes 19 and 21, all other mixes were cast with coarse aggregate of 19 and 12.5 mm size in equal proportion. This further improved the compressive strength development. Again, the maximum compressive strength achievable using these recycled concrete aggregates appears to be 50 MPa. The results do establish that using normal practices, the recycled concrete aggregates from the present source can produce 50 MPa concrete.

Figure 3 shows a plot of water-cement ratio versus compressive strength (28-days) of the concretes produced. The data points plot close to the typical 28-day strength curve (Mehta & Monteiro, 2006) based on Abram's water-cement ratio rule. A straight line best fit is drawn through the plotted points for comparison. This suggests that Abram's water – cement ratio is applicable to the concretes produced using recycled concrete aggregates. In addition, the graph shown in Fig. 3 can be used to design concrete mixes of strength between 25 to 50 MPa using the recycled concrete aggregates produced by the EPIC factory.

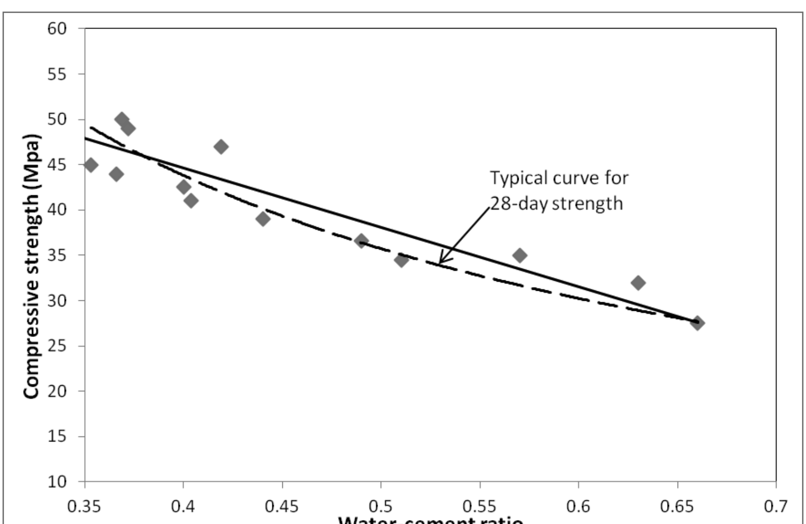

Fig. 3. Variation of compressive strength for RCA concrete with w/c ratio.

Effect of seawater curing and lack of curing on compressive strength development

As mentioned earlier, nine mixes shown in Table 4 were cast for durability evaluation of recycled aggregate concretes as well as compressive strength development under different curing regimes. One set of sample cubes was kept in normal tap water for curing, a second set in seawater and the third set was only air cured after de-moulding. The cubes were tested for 28 and 91 days strength. On the overall, it can be observed from the strength results in Table 4, that seawater curing or air curing have not appreciably decreased the strength compared with continuous water cured specimens. It is expected that Chlorides present in seawater can accelerate the early strength development but the long term strength (say 91 days) decreases (Neville, 1995). This seems to hold true for Mixes 5, 6, 16 and 19 in Table 4, where upto 5 % increase in early strength was observed. As expected, air curing decreases the process of strength development, and the 91 day strength of all the air cured specimens given in Table 4 is less than the corresponding strength of the tap water cured concrete. The extent of loss in strength, of course, depends on the severity of the ambient humidity and temperature. The strength results do indicate that air cured concretes made using recycled concrete aggregate have not been overly affected. Of course, all concretes have got to be properly cured to reduce the extent of shrinkage and shrinkage induced cracking and to avoid subsequent durability problems.

As seen in Table 4, Mixes 2 and 8 with 100% recycled sand developed higher compressive strength than Mix 3 with 100% normal sand. Further studies are to be conducted on application of recycled sand in structural concrete. By comparing Mixes 4 and 9, it can be seen that the strength development in recycled aggregate concrete and normal concrete are very similar.

Modulus of elasticity (E)

Modulus values have been determined both experimentally and calculated from the results of strength and density. Cylinders of 150×300 mm size were used to determine the E values. Modulus of elasticity was calculated to Australian Standard AS 3600-2009 using the formula $E = \rho^{1.5} * (4.3 \text{ X } 10^{-6} f_c^{1/2})$

where ρ = density of concrete (kg/m^3);

f_c = compressive strength at 28 days (MPa), and

E = Modulus of elasticity (GPa).

The modulus of elasticity was also calculated using ACI 318 equation,

$E \text{ (in GPa)} = 4.73 \sqrt{f_c}$

where fc is the compressive strength at 28 days (MPa).

The cylinders were tested for modulus of elasticity according to ASTM C469-02 at 28 days, after curing in tap water. The values of E obtained and calculated are listed in Table 5.

The experimentally determined values of E for all the recycled concretes vary approximately between 24 to 39 GPa. These results suggest that these concretes are sufficiently stiff and further these values are similar to those of virgin aggregate concretes. The variation of E with the concrete compressive strength are similar to those of the virgin aggregate concrete (Neville, 1995). Figure 4 shows the variation of E with compressive strength. Plots of E-values calculated as per AS 3600 and ACI 318 equations are also included in Figure 4. The experimental E-values are slightly higher than those of ACI 318 equation, but follow a similar pattern. However, the E-values determined are very close to the E-values calculated by AS 3600 equation, as six out of nine specimens showed a good correlation of 0.97.

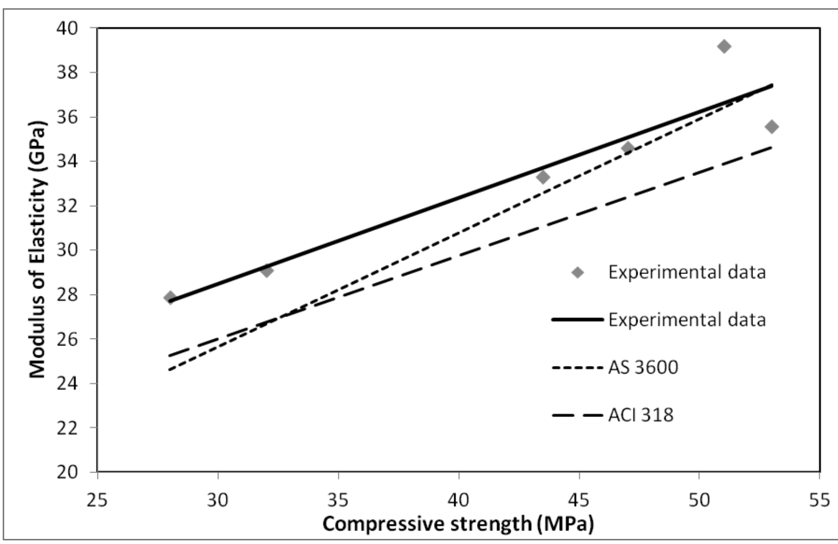

Fig. 4. Modulus of elasticity versus compressive strength relationship for RCA concrete (experimentally determined corresponding to those from AS and ACI equations).

Analysis of flexural strength

Concrete beams of size 100×100×500 mm were cast and tested for flexural strength according to ASTM C 78-02 after 28 days of tap water curing. As indicated in Table 5, the results show that RCA gave equal performance to that of natural aggregate concrete (compare flexural strength of 50RN, 50NN and 50NR mixes).

Figure 5 shows the plot between flexural strength and compressive strength of some concretes tested in this investigation. The relationship shown is very similar to that between the flexural strength and the compressive strength of concretes made with virgin aggregates (Neville, 1995). For the concretes plotted in Fig. 5, the flexural strength is about 12% of the compressive strength which again is similar to that reported for normal aggregate concretes (Neville, 1995). Further, the variation of flexural strength showed a reasonably good correlation of 0.78 with the compressive strength for the plotted specimens. However, this correlation is only an approximation, because the relationship between flexural and compressive strengths is affected by the mix components and their proportions (ASTM, 2006).

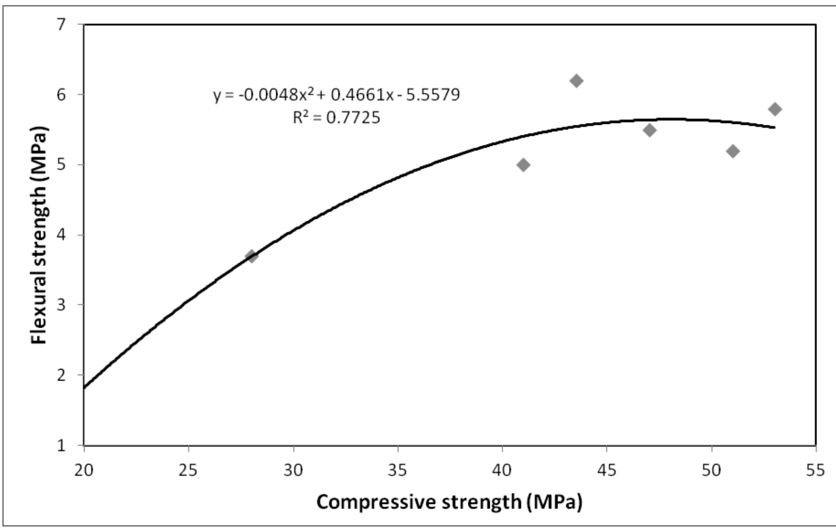

Fig. 5. Variation of flexural strength with compressive strength for RCA concrete.

APPLICATION OF RECYCLED CONCRETE AGGREGATES IN STRUCTURAL CONCRETE

Internationally, the properties of recycled aggregate concrete have been established and demonstrated through several experimental and field projects. It has been concluded that RCA can be readily used in construction of low rise buildings, concrete paving blocks and tiles, flooring, retaining walls, approaching lanes, sewerage structures, sub base course of pavement, drainage layer in highways and dry lean concrete (DLC) etc.

Recycling and reuse of construction demolition waste is the appropriate solution to the environmental problems caused due to the dumping of enormous quantity of debris and the substantial depletion of natural resources. Most researchers also report that a certain proportion of coarse RCA can be added to natural aggregate without any effect on performance, a conservative value of 20 % by mass is adopted in BS 8500-2.

LIMITATIONS

Generally, there was not appreciable increase in compressive strength between 28 and 91 days, even with a considerable higher amount of total cement (see mix 18 with 509 kg/m^3 of cement). This indicates that the continued curing after 28 days weakens the porous mortar attached to aggregates and thus prevent further enhancement of strength. If this is the case, the RCA used may not be suitable for wet environment applications.

There are a few standards and specifications currently in use for recycled aggregates, and where they are allowed, it is a standard practice to subject recycled concrete aggregates to the same rules as natural aggregates. This tends to be an obstacle to their greater use. However, standards have been introduced in Europe by CEN (largely based on the composition of the recycled aggregates – BSEN 12620) and in Japan (based on a combination of performance related properties and combination).

Although, it is environmentally and economically beneficial to use RCA in construction, the current legislation and experience are still lacking. Lack of awareness, guidelines, specifications , standards, data base of utilization of RCA in concrete and lack of confidence in engineers, researchers and user agencies is major cause for poor utilization of RCA in construction.

CONCLUSIONS

The results of this study can be summarized as:

i) Structural concretes of 25 to 50 MPa cube compressive strength can be produced using the recycled coarse (100%) and fine aggregate produced locally in Kuwait. The aggregates' other physical characteristics like particle density, bulk density, surface texture, particle size distribution and absorption are suited to some concrete production.

ii) The compressive strength values in the range of 35 to 50 MPa, the modulus of elasticity values 24 to 39 GPa and flexural strength 3.7 to 6.2 MPa suggest that recycled aggregate concrete produced can be used in structural applications. Nonetheless, the durability characteristics need to be ascertained before actual application of these concretes.

iii) The seawater curing or air curing have not appreciably decreased the strength compared with continuous water cured specimens, though an increase in early strength development and decrease in long term strength was observed in case of seawater cured specimens.

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