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The Effect of Using Recycled Concrete Aggregate and Treated Wastewater on the Properties of RC Beams

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ABSTRACT: *This paper studies the effects of replacing natural aggregate and tap water with recycled concrete aggregate and treated wastewater on the properties of the RC beams. The main objective of this research is to provide a scientific base for using recycled concrete aggregate and treated wastewater in concrete manufacturing. Also, this research aims to gain a better understanding of the properties of the concrete made with recycled concrete aggregate and treated wastewater to increase its efficiency. To achieve these objectives, an experimental program was conducted. The program consists of 2 phases; phase 1, which studies the properties of concrete manufactured with recycled concrete aggregate and treated wastewater, and phase 2, which studies the effects of using recycled concrete aggregate and treated wastewater on the properties of RC beams. The results showed that replacing natural aggregate and freshwater with recycled concrete aggregate and treated wastewater didn't affect the mechanical properties of concrete cubes significantly. Also, the RC beams were not affected by the change as well. However, for these results to be attained, it is necessary to use high-quality recycled concrete aggregate and treated wastewater.*
Keywords: *RC beams; recycled concrete aggregate; tap water.*

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I. INTRODUCTION

Nowadays, many old and deteriorated buildings are being demolished and replaced by new ones, causing an increase in demolition wastes [3]. This sudden increase has caused an environmental problem as the demolition wastes are usually disposed in landfills [4]. Moreover, these new buildings along with many new construction projects have increased the demand for the natural aggregate as it is the largest component in concrete [5]. Thus, creating a dilemma of wanting to persevere natural aggregate and wanting to construct new buildings. To solve these problems, one of the many suggested solutions was to find an alternative for the natural aggregate by recycling demolition wastes (recycled concrete aggregate) [6]. To produce recycled concrete aggregate, two-stage of crushing concrete is required, and then it is filtered from any contaminations like reinforcements, wood, paper, etc. However, this filtration process is not perfect as a large amount of mortar and cement paste will be still attached to the crushed concrete [7]. This caused the recycled concrete aggregate to have different properties and quality compared to natural aggregate [8]. One of the different properties is the increased water absorption, which affects the workability of the concrete [9-10]. To reach the desired workability without the use of admixtures, a huge amount of water has to be used. Moreover, millions of cubic meters of tap water are being used in manufacturing concrete. All of this impacts the environment negatively as the freshwater resources are diminishing. Therefore, an alternative for tap water is necessary. The number of impurities in the water has to be taken into consideration when choosing an alternative for tap water. Because if the number of the impurities in the water is excessive, then the properties of the concrete may be affected such as the strength, setting time, hardening, durability, and so much more. So, a wide range of tests has to be conducted first before choosing to see whether the impurities will affect the properties or not. Moreover, another thing to consider is that many specifications require that the water used for mixing concrete should be suitable for drinking. Taking all of these things into account, it was found that the tertiary treated wastewater is the most suitable alternative for freshwater. Even though the wastewater normally contains many impurities, suspended and dissolved solids, and micro-organisms, it goes through many biological treatments, advanced coagulation sedimentation, filtration, reverse osmosis, and nutrient removal. Also, other research found that there is no adverse effect on the mechanical properties and durability of the concrete when tertiary treated wastewater was used in mixing concrete. However, the strength of the concrete made with tertiary treated wastewater was slightly lower than the strength of concrete made with tap water, but it was still in the acceptable range. The experimental program, including consists of 2 phases; phase 1, which studies the properties of concrete manufactured with recycled concrete aggregate and treated wastewater, and phase 2, which studies the effects of using recycled concrete aggregate and treated wastewater on the properties of RC beams. The tested beams are simply supported on two sides with fixed dimensions 2000 x 300 x 150 mm. The studied parameters in this research are type, quantity of recycled coarse aggregate, type, quantity of mixing water and using admixtures, to evaluate the behaviour of using recycled concrete aggregate and treated wastewater on the properties of RC beams. General from the experimental results, it is found the recycled aggregate concrete with treated wastewater can successfully be used as structural concrete.

II. EXPERIMENTAL PROGRAM

General

The aim of this research is to study the effect of recycled concrete aggregate and treated waste water reuse in RC beams properties by compare the basic properties of control concrete (concrete made with natural aggregate and fresh water) and the properties of concrete made with different contents of recycled aggregate and treated wastewater.

The experimental program consists of two phases, phase (I) contain seventy eight cubes, while phase (II) contain seven RC beams were made for testing of the listed properties of hardened concrete. Mixture proportions of the tested concrete types determined in accordance to the following conditions:

1. Same workability, same quantity of cement, same quantity of fine aggregate.
2. Variable type and quantity of coarse aggregate, variable type of mixing water.

Materials Properties

Cement

The cement used in this study was ordinary Portland cement (CEM I) 42.5R, purchased from Helwan Cement Company.

Fine and Coarse Aggregates

Fine aggregate (grain size 0/4 mm), - two types of coarse aggregate: natural aggregate and recycled concrete aggregate, grain sizes 4/8, 8/16 and 16/31.5 mm. Recycled concrete aggregate was produced by crushing of old concrete cubes used for compressive strength testing. The strength class of old concrete cubes was C25/32 nomenclature according to Eurocode 2 [3]. The primary crushing was done with a manual hammer. Crushed concrete particles were separated into standard fractions of coarse aggregate (4–8 mm, 8–16 mm and 16–31.5 mm).

Silica Fume

The silica fume used to improve the strength of normal concrete. It was supplied and added to the mix in a powder form (Sika 500s).

Superplasticizer

In order to improve the workability of normal concrete, superplasticizer in the form of a polynaphthalene sulphate-based admixture (conplast SP430) was used. When used, the superplasticizer content was kept constant at 1% of the cement mass. To keep the mixes' workability constant, with slump within the range 120 ± 10 mm, the w/c ratio was reduced in the mixes with superplasticizers to offset the latter's water reduction effect.

Water

Two types of water: fresh water and treated wastewater.

Concrete Compressive Strength

The average compressive strength of the normal / recycled concrete based on ECP 203-2020 [2] is 25 MPa and the average tensile strength is 2.60 MPa. The average yield strength of steel reinforcement is 400 MPa with a modulus of elasticity of 200 GPa (ECP 203-2020) [2] and the ultimate strength is 600 MPa. The mix composition of the studied normal / recycled concrete is shown in Table I & II.

Table 1: Experimental Program (Phase I) – Cubes

Samples Groups	symbol	cement	water		agg		sand	add	Notes
			N	T	N	R			
Group 1	N	400	265	-	1200	-	700	-	
Group 2	R25	400	265	-	900	300	700	-	
	R50	400	265	-	600	600	700	-	
	R75	400	265	-	300	900	700	-	
	R1	400	265	-	-	1200	700	-	
Group 3	W25	400	199	66	1200	-	700	-	
	W50	400	132.5	132.5	1200	-	700	-	
	W75	400	66	199	1200	-	700	-	
	W1	400	-	265	1200	-	700	-	
Group 4	A1	400	100	100	600	600	700	8 kg	2%of cement weight
	A2	400	120	120	600	600	700	4 kg	1%of cement weight
	S1	400	100	100	600	600	700	20 kg	5%of cement weight
	S2	400	120	120	600	600	700	40 kg	10%of cement weight

Table 2: Experimental Program (Phase II)-RC Beams

Group of samples	Symbol	Cement	Water		Aggregate		Sand	Add (S.P) (S.F)	Notes
			N	T	N	R			
Group 1	N	400	220	-	1200	-	700	-	Reference Beam
Group 2	R50	400	220	-	600	600	700	-	50% CRA
	R100	400	220	-	-	1200	700	-	100% CRA
Group 3	A1	400	100	100	600	600	700	8 kg	2%of cement weight (Super plasticizer)
	A2	400	120	120	600	600	700	4 kg	1%of cement weight (Super plasticizer)
Group 4	S1	400	100	100	600	600	700	20 kg	5%of cement weight (Silica fume)
	S2	400	120	120	600	600	700	40 kg	10%of cement weight (Silica fume)

Phase I

The type and quantity of coarse aggregate were varied in the following way:

1. The first concrete mix had 100% of natural coarse aggregate (R0), control mixture,
2. The second concrete mix had 75% of natural coarse aggregate and 25% of recycled coarse aggregate (R25),
3. The third concrete mix had 50% of natural coarse aggregate and 50% of recycled coarse aggregate (R50),
4. The fourth concrete mix had 25% of natural coarse aggregate and 75% of recycled coarse aggregate (R75),
5. The fifth concrete mix had 0% of natural coarse aggregate and 100% of recycled coarse aggregate (R100),

The type and quantity of tap water were varied in the following way:

1. The first concrete mix had 100% of tap water (R0), control mixture,
2. The second concrete mix had 75% of tap water and 25% of treated wastewater (W25),
3. The third concrete mix had 50% of fresh water and 50% of treated wastewater (W50),
4. The fourth concrete mix had 25% of tap water and 75% of treated wastewater (W75),
5. The fifth concrete mix had 0% of tap water and 100% of treated wastewater (W100),

As all the other variables were kept constant, this research enabled us to determine the influence of the coarse recycled aggregate and treated wastewater amount (0%, 25%, 50%, 75, and 100%) on tested concrete properties. The following properties of concrete were selected for testing:

1. Compressive strength fc (at 7 and 28 days),
2. Flexural strength (at 28 days).

Seventy two cubes and seven RC beams were made for testing of the listed properties of hardened concrete.

Phase II

Phase II was included 4 groups with 7 beams.

Group (1), Control beam (N).

Group (2), Recycled aggregate concrete beams (50%, 100%).

Group (3), Concrete beam with super plasticizer 1%, 2% of cement weight and 50% replacement of treated water and recycled aggregate.

Group (4), Concrete beam with super plasticizer 5%, 10% of cement weight and 50% replacement of treated water and recycled aggregate(50%N.A&50%RCA),(50%F.W&50%T.W).

The seven reinforced concrete beams are divided into 4 groups, a control group with natural aggregate and tap water and other groups with recycled concrete aggregate and treated wastewater. The RC beam study having a total length (L = 2000 mm), overall depth (h= 300 mm) and width (b = 150 mm). The RC beams are reinforced with 2 Ø 10 as top reinforcement, 2 Ø 16 as bottom reinforcement and with stirrups Ø 8@100mm as show in Figure 1.

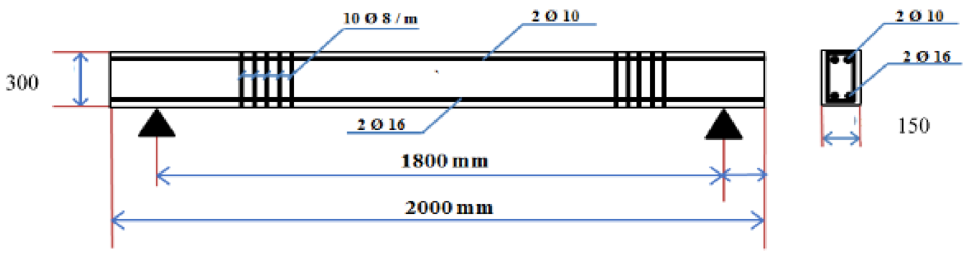

Figure1: RC Beam Dimensions and Reinforcement Details

Test Set-up

Compressive tests were done by using a compression testing machine with a capacity of 2,000 kN. The load was measured by using a 2,000-kN-capacity load cell. The loading was applied through the displacement control method at a rate of 0.005 mm/s. The overall view of the compressive test setup is shown in Figure 2.

Instrumentation

In order to record the beams vertical deflection, three vertical dial gages with 0.01 mm accuracy were used for vertical measurements were used under beams at the mid span as well as the two thirds of the span between the two supports as shown in Fig. (3). the mid-span tensile steel strain (S1) was measured by one electrical strain gauge of 20-mm length and 120-Ohm resistance.

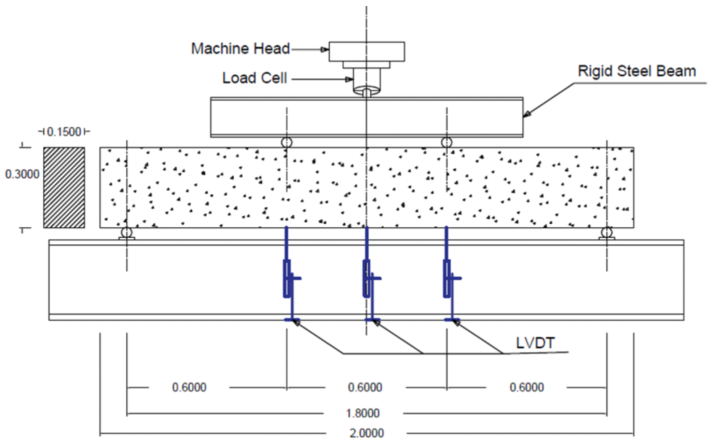

Figure 2: Test Set-up

Figure 3: Dial Gauges Positions

Test Procedures

Compressive Strength Test
The compressive strength of the concrete was determined by testing three 150 mm size cubes at ages 7 and 28 days for each mix. The test was carried out according to ECP 203-2020 [2] using a compressive machine with capacity of 2,000 KN.

Flexural Strength Test
This flexural strength test for reinforced beams, the flexural strength test was carried out on (150 mm x 300 mm x 2000 mm), using a simple beam with four-point load.

III. RESULTS

Compressive Strength and Flexural Strength

This experimental program is conducted in order to study the behavior the flexural behavior of reinforced recycled concrete beams. In the present experimental investigation, the following tests were carried out namely: compressive strength and flexural strength. Tests for normal and recycled concrete have been attempted over the concrete specimens such as cubes and beams respectively. The recycled with varying percentages of 0%, 25%, 50%, 75% and 100% percentages of total aggregate/water content were used for recycled concrete. For each recycled percentages of total aggregate/water content, 6 cubes. Totally 78 cubes were cast with locally available admixture are taken for testing in this investigation. Totally 7 RC beams for 28 days were used for finding flexural strength. The four series of tests have been carried out as show in Tables 3, 4 and Figures 4, 5, and 6. The figure 4 clearly show that, on average, the relative strengths of 96, 93, and 92 % in compression and 89 to 81 % in flexure are attained when the aggregate replacement ratio is varied from 0.25 to 0.75 for the mix cases under investigation. For an aggregate replacement ratio of 1.0, the corresponding mean values are 88% which are comparatively low. Similarly, the figure 5 (bar charts) show that, on average, the relative strengths of 88, 86 and 83 % in compression are attained when the water replacement ratio is varied from 0.25 to 0.75 for the mix cases under investigation. For a water replacement ratio of 1.0, the corresponding mean values are 81% which are comparatively very low. The reference mix had compressive strength (f_{cu}) of 27 MPa (no admixture), 31.65 MPa (Super plasticizer) and 35.25 MPa (Silica fume). The addition of superplasticizers and silica fume led to compressive strength increases up to 17% and 30% respectively, were used.

Table 3: Experimental Results (Phase I)-Cubes

Group	Specimen	Avg. compressive strength at 7 days	Avg. compressive strength at 28 days	Redaction or increasing %
Group 1	N	237	270	-
Group 2	R25	235	260	-4 %
	R50	230	252	-7 %
	R75	220	250	-8 %
	R100	211	240	-12%
Group 3	W25	201	239	-12 %
	W50	195	232	-14 %
	W75	189	226	-17 %
	W100	166	220	-19%
Group 4	A1	238	346	+28%
	A2	230	287	+6 %
	S1	302	360	+33%
	S2	307	345	+27%

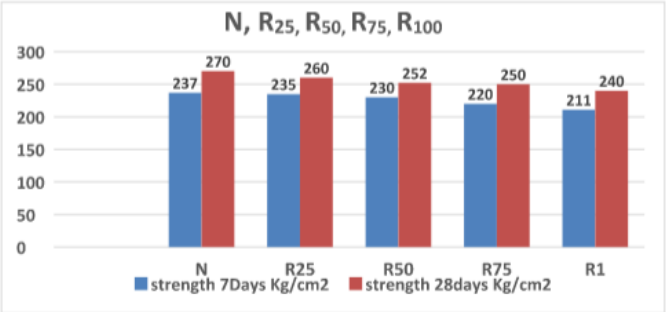

Figure 4: Compressive Strength at 7 days & 28 days (Group 2 Aggregate replacement)

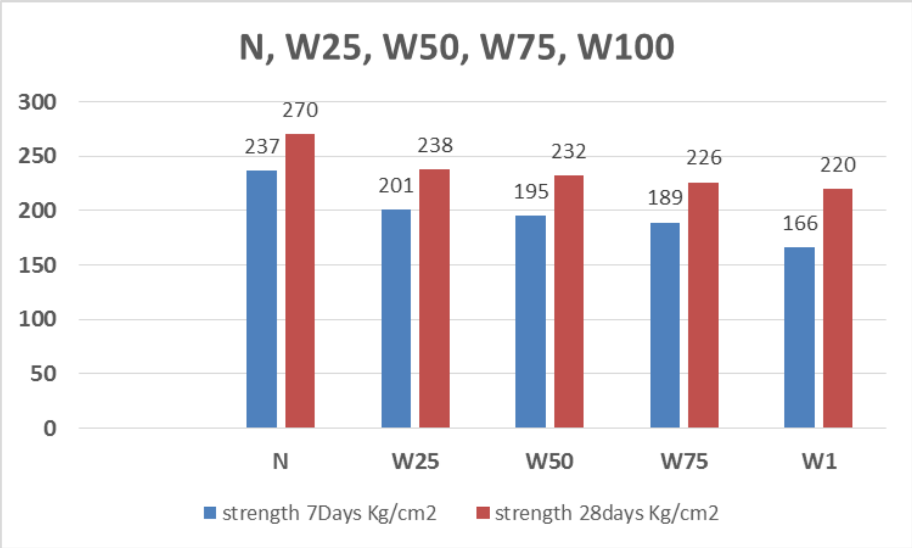

Figure 5: Compressive Strength at 7 days & 28 days (Group 3 Water replacement)

Load Testing of Reinforced Concrete Beams

Tested concrete types (N, R50 and R100) were used for producing RC beams (beams R0, -R50 and R100). Three beams with a length of 2.0 m and rectangular cross section of 15/30 cm were prepared for flexural testing. Figure 1. The failure load was calculated for the-N beam. Stresses in concrete and reinforcement, deflections and characteristic cracks width were calculated. Calculated values for the beam with referent concrete beam N -R0 are shown in Table 4.

Table 4: Stresses Values for Cross-Section in the Middle of the Beam.

Beam	Load (kN)	Stress reinforcement (MPa)	Deflection (mm)	Crack width (mm)
N	160	530	8	2
R50	143	500	9	2
R100	130	480	10	2
A1	150	520	8	2
A2	164	535	8	3
S1	158	530	10	2
S2	165	540	10	3

Table 5: Experimental Results (Phase II)-Beams

Group	Beam	Cracking Load P_{cr} (KN)	Ultimate Load P_U (KN)	(P_U/P_U Control)	(P_{cr}/P_u) %
Group 1	N	40	160	-	25
Group 2	R50	39	143	89%	27
	R100	38	130	81%	29
Group 3	A1	40	150	94%	26
	A2	75	164	1.02%	46
Group 4	S1	80	158	99%	50
	S2	65	165	1.03%	40

For the purpose of comparing beam behavior during loading, the calculated deflections of beam - R0 and measured deflections of all remaining beam types are presented in Table 4. In the elastic area all tested beams have similar deflection, which means that for appropriate load level the quantity of coarse recycled concrete aggregate has no significant influence on the beam behavior. According to test results, concrete beam strength (ultimate load) depends on the content of used recycled aggregate. With increasing of recycled aggregate content up to 100%, beam strength (ultimate load) is decreasing up to 19 %.

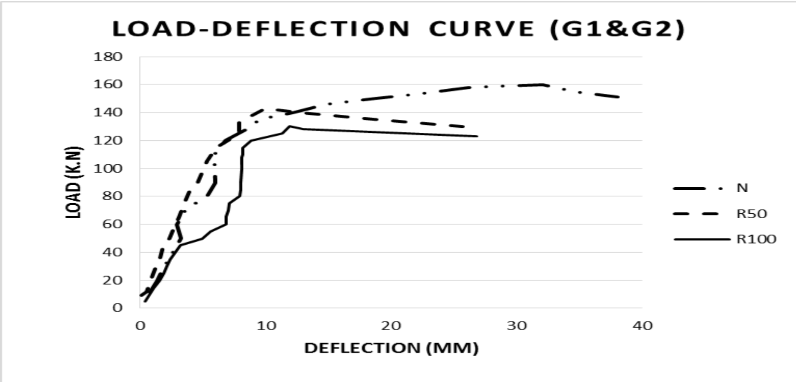

Figure 6: Load-Deflection Curve (Group 2)

Deflections of tested beams depend on the quantity of used aggregate in the elastic area-similar deflections were registered. However, in the post elastic area, with increasing quantity of coarse recycled aggregate the deflection value increased. The deflection increase compared to deflection of the -R0 beam is 12% for the -R50beam and 25% for the -R100 beam for the service load level. The main reason for such behavior of the tested beams is a lower modulus of elasticity of concrete types R100 and R50 in comparison to referent concrete R0.

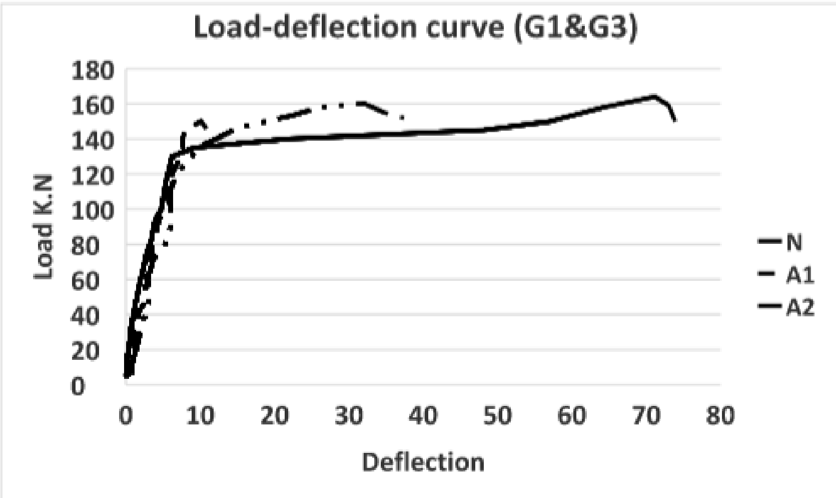

Figure 7: Load-Deflection Curve (Group 3)

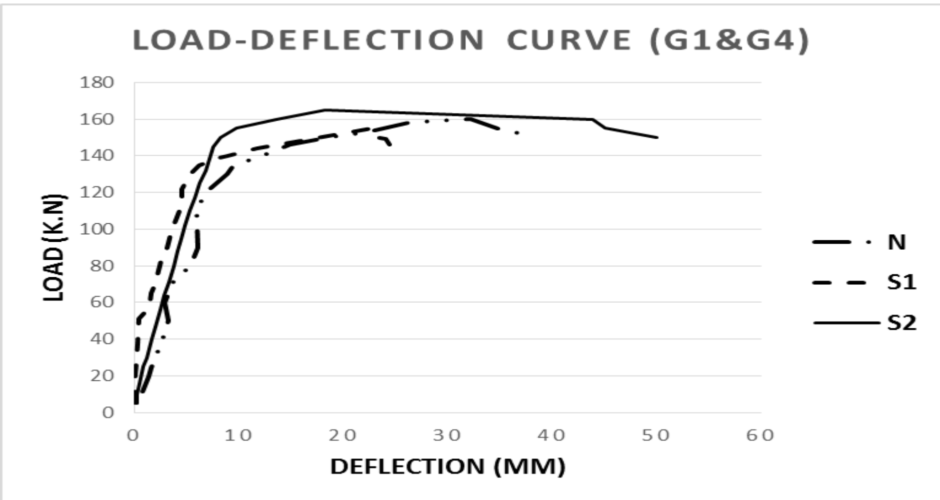

Figure 8: Load-Deflection Curve (Group 4)

IV. DISCUSSION AND CONCLUSION

On the basis of our test results, the following conclusions are made.

- Recycled aggregate concrete is a sustainable solution to reduce environmental impact by reducing the amount that must be disposed of, thus reducing the demand for natural aggregates.
- Recycled aggregate concrete can successfully be used as structural concrete.
- Flexural strength of recycled aggregate concrete is lower than that of virgin concrete.
- Flexural strength of recycled aggregate concrete can be increased by using admixtures.
- Beams made with the recycled aggregate concrete show wider cracks at lower spacing.
- Mid span deflection of recycled aggregate concrete beams is larger than that of normal concrete. However, it is within the permissible limit according to the concern codes.
- Test results showed that up to 25 % coarse RCA had minor effect on the compressive strength of concrete, but thereafter this reduces with an increase in RCA content. This was observed consistently for concrete mixes tested at 7 and 28 days.
- The differences in the ultimate load of beams failed in flexure, made of NAC and RAC with admixtures (regardless of the replacement ratio of natural with coarse recycled aggregate) with the same reinforcement ratio, are negligible.
- The general trends observed indicate that coarse RCA can be used in a range of normal-strength concrete mixes with satisfactory engineering properties, namely compressive strength, flexural strength, and modulus of elasticity.
- The optimum level of using recycled concrete aggregate on structural elements must not exceed 25% of the used aggregate.
- Moreover, it is important to recognize that there is a need to introduce new standards for recycled aggregates and demonstrate that these materials can be used successfully in practice, under a range of exposure conditions.
- Regardless of the type of mixing water (DW or TDW), there is a continuous increase in the concrete compressive strength. However, the compressive strength growth rate is water type dependent.
- Using treated domestic wastewater (TDW) as mixing water led to a reduction in the compressive strength. The relative strength index indicates that using TDW as mixing water for concrete production led to a significant reduction in the compressive strength by up to 19%.
- This study has shown that TDW is a potential alternative for fresh water in the concrete industry. Therefore, the current guidelines for treated domestic wastewater reuse should be revised by the governmental authorities to encourage the use of TDW as a substitute for fresh water in concrete production.

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