The Effect of Different Types of Recycled Coarse Aggregates on the Properties of Concrete

Gehad M. Mostasfa[1], Dr. Ahmed Abd El-azim A.[2], and Prof. Dr. Hany A. El-Ghazaly[3]
Faculty of Engineering, Fayoum University, Fayoum, Egypt

Abstract--- *The main purpose of this study is to investigate the effect of different types of recycled coarse aggregates on the properties of fresh and hardened concrete. The neutral aggregates and the five types of recycled coarse aggregates were used to produce twenty-one design mixes. The mixes are divided to three groups. Group (1) is obtained by replacing gravel coarse aggregate by recycled coarse aggregates (crushed concrete, crushed marble, crushed mosaic, crushed ceramic, and crushed bricks) at cement content = 300 kg/m³, W/C= 0.52 Group (2) is obtained by replacing natural coarse aggregate with the same recycled coarse aggregates at cement content = 350 kg/m³, W/C= 0.50. Group (3) is obtained by replacing natural coarse aggregate with the same recycled coarse aggregates at cement content = 400 kg/m³, W/C= 0.48. The experimental part of this study was carried out to cover the various properties of fresh and hardened recycled aggregates concrete. Twenty-one design mixes were needed for the parametric study. The effects of replacing gravel coarse aggregate on the fresh and hardened properties of concrete such as slump, density, compressive strength, splitting tensile strength, and flexural strength were investigated. Finally, the results showed that crushed recycled marble and crushed concrete are the best recycled aggregates to use in reinforced concrete. Crushed mosaic, crushed ceramic, and crushed bricks can be used in plain concrete but cement content must be increased.*

Keywords---*Fresh, hardened concrete, Recycled Aggregate, Coarse Aggregate, crushed.*

I. INTRODUCTION

The Effect of using coarse recycled aggregate instead of natural coarse aggregate have been studied previously [1-3]. The studies on the use of recycled aggregates have been going on several years. The results showed that recycled aggregates are unsuitable for concrete structures. Recycled aggregates are being employed practically only as base filler for road construction [4], when using up to 25% of recycled coarse aggregates in concrete, it is suitable for concrete structures. According to the different percentages of recycled coarse aggregates were used for the production of the four concretes, all of which had the same compressive strength [5]. Automatic mixing machine were used to produce the concretes, and the recycled coarse aggregates were used in a saturated surface dry state in order to control the effective workability and water cement ratio of the recycled aggregate concrete.

When natural coarse aggregate is replaced by recycled aggregate, the concrete could be considered as environment at friendly concrete for sustainable construction [6]. The type of crusher (laboratory, semi-industrial or industrial) does not have any major influence on the relative residual cement paste content. Additional crushing cycled aggregates could decrease the residual paste content. However, from an industrial point of view, this would generate additional economic and environmental costs [7].

The benefits of using recycled aggregate concrete include construction and demolition waste, and reducing demand on original aggregate sources [8]. Since aggregates make up 80% of concrete by mass, there is a chance for economic and environmental benefits in using recycled aggregate concrete (both coarse and fine aggregate) in structural applications [9]. In areas, such as Japan where sources are limited, the need to get alternative sources for aggregates is high. The recycling rate of concrete waste in Japan had reached 98% [10]. Three Main benefits are economic aspects, reducing environmental impacts and saving resources.

It is important and economically option to use recycled crushed concrete as aggregates. Manufactured RCA became more economical than virgin aggregate in terms of transportation costs and increased cost of landfilling construction and demolition debris [3]. And in some cases, recycled aggregates may be more economical due to reduced transportation distances and energy costs (Ministry of Natural Resources (M. N. R.), 2009) the total aggregate usage in Ontario, Canada was 184 million tones (M. N. R., 2010). This volume of resource attains an economic value $1.3 billion (M. N. R., 2010).

Results obtained from the Eco-Costs/Value Ratio Model developed by Hendriks and Jansen [11] prove the benefits of using concrete with recycled aggregates. Hendriks and Janssen [12] found out that the lower transportation cost of processed waste concrete aggregates might be the incentive that promoted the use of recycled aggregates in the U.S.

although a large part was still only suitable as backfill or construction base.

II. MATERAILS USED

In this experimental study cement, sand, and different types of recycled coarse aggregates (crushed concrete, crushed marble, crushed mosaic, crushed ceramic, and crushed bricks) were used. Properties of sand and recycled coarse aggregates used are shown in table (1) and table (2).

Table (1): Properties of Sand

Properties	Measured Values	Specification Limits
Specific gravity	2.55	2.5-2.7
Volume weight (t/m^3)	1.52	1.4-1.7
Fineness modulus	2.57	2-2.73
Percentage of dust and fine material (by weight)	1.4%	<3% by weight

Table (2): Properties of Coarse Aggregates

Properties	Aggregate Type					
	Gravel	Crushed Concrete	Crushed Marble	Crushed Mosaic	Crushed Ceramic	Crushed Bricks
Specific gravity	2.57	2.5	2.62	2.22	2.12	2.00
Max. size (mm)	37.5	37.5	37.5	31.5	37.5	31.5
Bulk density (t/m^3)	1.57	1.47	1.62	1.24	1.15	1.11
% Absorption	0.90 %	6.19%	0.40%	8.97%	10.62 %	12.83 %

III. MIX PROPORTIONS

The mix design and testing program was conducted in accordance with Egyptian code and ASTM standards. Twenty-one mixes containing different percentages of water, cement, and different types of recycled coarse aggregates were designed as shown in Table (3). In Group (1), the cement content was 300 kg/m^3 and (W/C) = 0.52. While, in Group (2), the cement content was 350 kg/m^3 and (W/C) = 0.50, and Group (3), the cement content was 400 kg/m^3 and (W/C) = 0.48**.** For each mixes 6 cubes (150x150 mm), 3 Cylinders (150x300 mm), and 3 beams (150x150x750 mm) were pouring. Concrete samples were cured in water until testing.

IV. TEST PROGRAM

The slump test is used to measure the consistency of fresh concrete. It was carried out according to ASTM C143. The compressive and splitting tensile strengths of hardened concrete were determined using compression testing machine having 2000 KN capacity. The loading rates applied in the compressive and splitting tensile tests were 0.6 and 0.03N/mm^2/sec respectively. The compressive strength was measured by using cubes (150x150 mm) at the ages of 7, and 28 days while the tensile splitting strength was only measured by using cylinder (150x300 mm) at 28 days. For the flexural strength of hardened concrete, beam specimens of size 150x150x750 mm were used. The specimens were placed in UTM and tested for flexural strength. The loading

Table (3): Mix Proportions of Concrete Mixes

Mix No.	Group No.		Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Aggregate (kg/m^3)		Type of Aggregates
M1	1	M1-1	156	300	631	1262		Gravel
	2	M1-2	175	350	601	1202		
	3	M1-3	192	400	573	1146		
M2	1	M2-1	156	300	619	1239		Crushed Concrete
	2	M2-2	175	350	590	1180		
	3	M2-3	192	400	562	1124		
M3	1	M3-1	156	300	639	1278		Crushed Marble
	2	M3-2	175	350	609	1218		
	3	M3-3	192	400	580	1160		
M4	1	M4-1	156	300	571	1142		Crushed Mosaic
	2	M4-2	175	350	544	1087		
	3	M4-3	192	400	518	1036		
M5	1	M5-1	156	300	552	1105		Crushed Ceramic
	2	M5-2	175	350	526	1053		
	3	M5-3	192	400	502	1003		
M6	1	M6-1	156	300	530	1060		Crushed Bricks
	2	M6-2	175	350	505	1010		
	3	M6-3	192	400	481	962		
M7	1	M7-1	156	300	594	594	594	Crushed (Concrete & Mosaic)
	2	M7-2	175	350	566	566	566	
	3	M7-3	192	400	359	359	359	

rates applied was 0.06 N/mm^2/sec, as shown in figure (1). The average results of three samples were calculated for all tests.

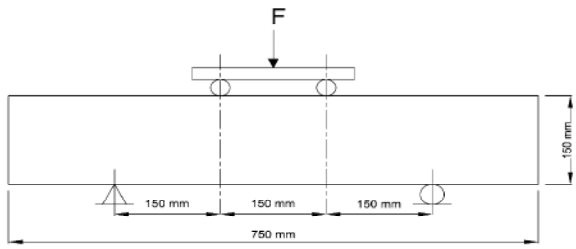

Fig.(1): Flexural Strength Test

V. RESULTS AND DISCUSSION

Results of slump test, density, compressive strength, splitting tensile strength, and flexural strength for twenty-one mixes of concrete were calculated. Table (4) shows these results.

A.SLUMP

The slump for the seven types of recycled coarse aggregates and cement content with different (w/c) ratio is shown in Figure (2). It is observed that slump for crushed bricks concrete has the highest values (159, 168, and 179 mm), and crushed marble concrete has the lowest values (35, 41, and 52 mm) as compared to gravel concrete values (45, 62, and 85mm).

Table (4): Results of Slump, Compressive Strength, Split Tensile Strength and Flexural Strength Tests for Recycled Coarse Aggregates Concrete

Mix No.	Group No.		Slump (mm)	Density (t/m^3)	Compressive Strength at 7 days (kg/cm^2)	Compressive Strength at 28 days (kg/cm^2)	Splitting Tensile Strength at 28 days (kg/cm^2)	Flexural Strength at 28 days (kg/cm^2)	Type of Aggregates
M1	1	M1-1	45	2.407	158	208	23.1	33.8	Gravel
	2	M1-2	62	2.439	190	252	24.9	35.5	
	3	M1-3	85	2.485	235	303	29.0	37.8	
M2	1	M2-1	70	2.298	152	195	18.0	20.1	Crushed Concrete
	2	M2-2	88	2.310	180	242	21.8	32.1	
	3	M2-3	112	2.311	230	275	25.7	37.1	
M3	1	M3-1	35	2.537	215	242	24.5	34.6	Crushed Marble
	2	M3-2	41	2.591	231	261	26.7	37.7	
	3	M3-3	52	2.624	252	314	29.8	41.5	
M4	1	M4-1	75	2.275	145	171	16.2	27.5	Crushed Mosaic
	2	M4-2	83	2.215	172	218	20.6	30.2	
	3	M4-3	90	2.226	194	235	22.9	34.6	
M5	1	M5-1	152	2.151	105	155	15.2	22.0	Crushed Ceramic
	2	M5-2	161	2.177	131	184	19.8	26.3	
	3	M5-3	168	2.211	170	203	21.7	30.1	
M6	1	M6-1	159	2.097	99	146	15.0	20.7	Crushed Bricks
	2	M6-2	168	2.153	117	171	17.3	23.9	
	3	M6-3	179	2.207	134	185	20.5	26.9	
M7	1	M7-1	55	2.273	146	192	18.2	30.8	Crushed (Concrete & Mosaic)
	2	M7-2	72	2.218	169	238	21.3	32.7	
	3	M7-3	103	2.146	198	270	25.7	35.8	

B.DENSITY

The density of concrete for the seven types of recycled coarse aggregates and cement content with different (w/c) ratio is shown in Figure (3). It is observed that density for crushed bricks concrete has the lowest values (2.097, 2.153, and 2.207 t\m^3), and crushed marble concrete has the highest values (2.537, 2.591, and 2.624 t\m^3) as compared to gravel concrete values (2.407, 2.439, and 2.485 t\m^3).

C.COMPRESSION STRRENGTH

The results of compressive strength test at 7 days for the seven types of recycled coarse aggregates and cement content with different (w/c) ratio is shown in Figure (4). It is observed that compressive strength at 7 days for crushed bricks concrete has the lowest values (99, 117, and 134 kg\cm^2), and crushed marble concrete has the highest values (215, 231, and

252 kg\cm^2) as compared to gravel concrete values (158, 190, and 235 kg\cm^2).

The results of compressive strength test at 28 days for the seven types of recycled coarse aggregates and cement content with different (w/c) ratio is shown in Figure (5). It is observed that compressive strength at 28 days for crushed bricks concrete has the lowest values (146, 171, and 185 kg\cm^2), and crushed marble concrete has the highest values (242, 261, and 314 kg\cm^2) as compared to gravel concrete values (208, 252, and 303 kg\cm^2).

Relation between compressive strength at 28 days and compressive strength at 7 days for the twenty-one mixes with different types of recycled coarse aggregates is shown in Figure (6). It is observed that:

F_{cu} at 7 days ≈ 0.7823 f_{cu} at 28 day

Where: $f_{cu=}$ compressive strength

D.SPLITTING TENSILE STRRENGTH

The results of splitting tensile strength test at 28 days for the seven types of recycled coarse aggregates and cement content with different (w/c) ratio is shown in Figure (7). It is observed that splitting tensile strength for crushed bricks concrete has the lowest values (15.0, 17.3, and 20.5 kg\cm^2), and crushed marble concrete has the highest values (24.5, 26.7, and 29.8 kg\cm^2) as compared to gravel concrete values (23.1, 24.9, and 29.0 kg\cm^2). Relation between splitting tensile strength and compressive strength for the twenty-one mixes with different types of recycled coarse aggregates is shown in Figure (8). It is observed that:

$f_t \approx 0.0978\ f_{cu}$

Where: f_t = splitting tensile strength.

E.FLEXURAL STRRENGTH

The results of flexural strength test at 28 days for the seven types of recycled coarse aggregates and cement content with different (w/c) ratio is shown in Figure (9). It is observed that flexural strength for crushed bricks concrete has the lowest values (20.7, 23.9, and 26.9 kg\cm^2), and crushed marble concrete has the highest values (34.6, 37.7, and 41.5 kg\cm^2) as compared to gravel concrete values (33.8, 35.5, and 37.8 kg\cm^2). Relation between flexural strength and compressive strength for the twenty-one mixes with different types of recycled coarse aggregates is shown in Figure (10). It is observed that:

$f_f \approx 0.1407\ f_{cu}$

Where: f_f = flexural strength

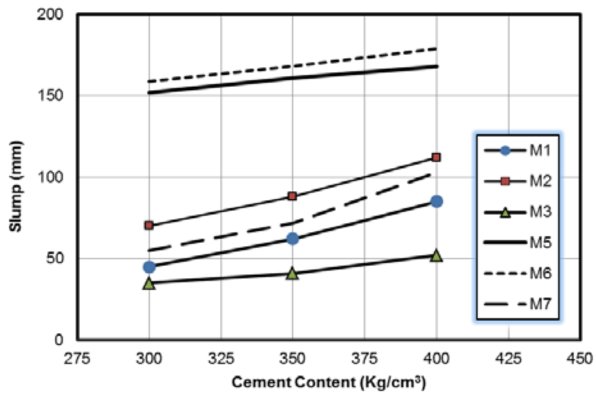

Fig.(2): Relation between Cement Content and Slump for Different Types of Recycled Coarse Aggregates Concrete

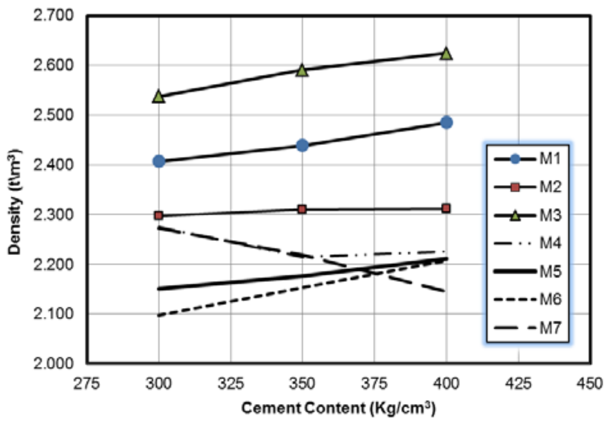

Fig.(3): Relation between Cement Content and Density for Different Types of Recycled Coarse Aggregates Concrete

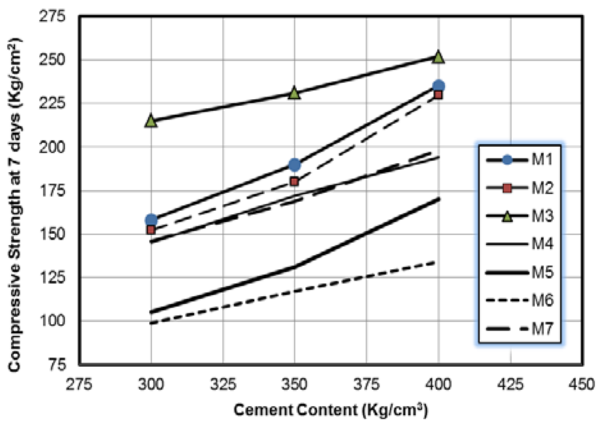

Fig.(4): Relation between Cement Content and Compressive Strength at 7days for Different Types of Recycled Coarse Aggregates Concrete

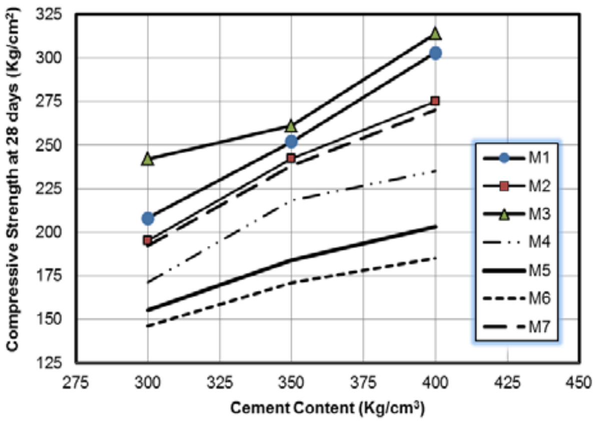

Fig.(5): Relation between Cement Content and Compressive Strength at 28 days for Different Types of Recycled Coarse Aggregates Concrete

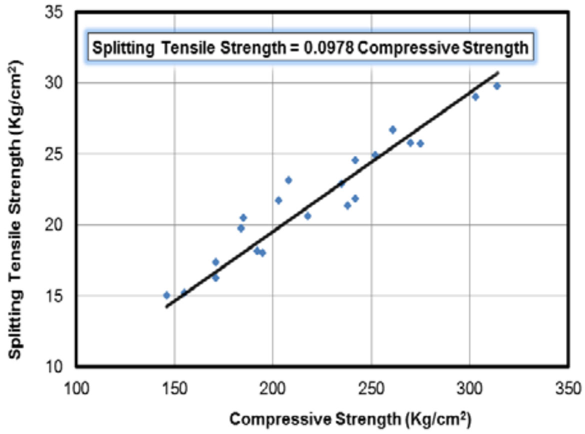

Fig.(8): Relation between Compressive Strength at and Splitting Tensile Strength for Recycled Coarse Aggregate Concrete

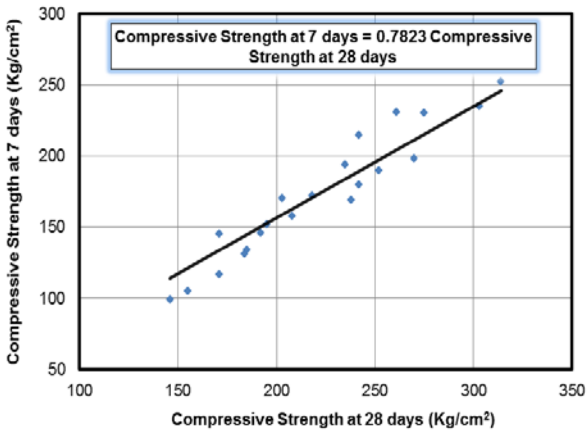

Fig.(6): Relation between Compressive Strength at 7 days and 28 days for Recycled Coarse Aggregate Concrete

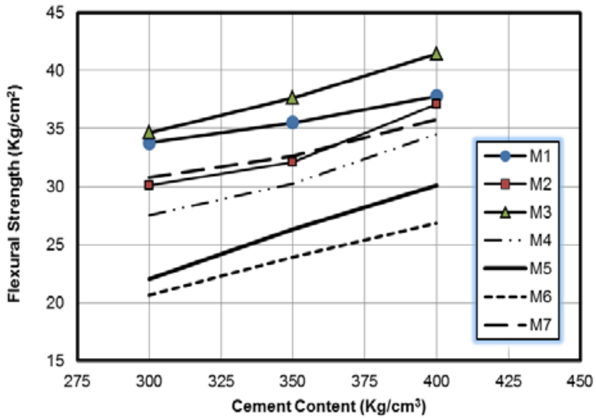

Fig.(9): Relation between Cement Content and Flexural Strength for Different Types of Recycled Coarse Aggregates Concrete

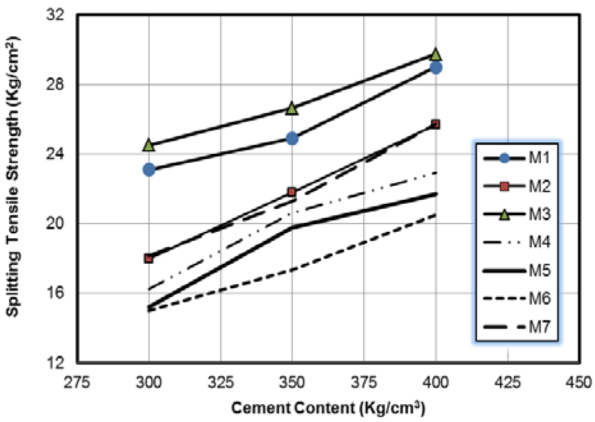

Fig.(7): Relation between Cement Content and Splitting Tensile Strength for Different Types of Recycled Coarse Aggregates Concrete

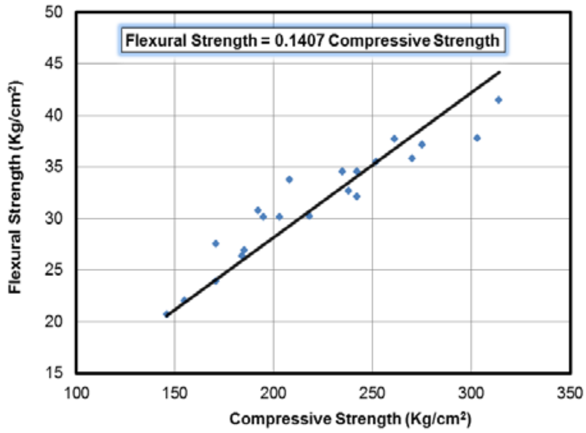

Fig.(10): Relation between Compressive Strength and Flexural Strength for Recycled Coarse Aggregate Concrete

VI. CONCLUSION

Based on the experimental results presented in this paper, the main conclusions are as the follows:

1- Slump of recycled coarse aggregates concrete is greater than natural coarse aggregate for all mixes except for crushed marble. As a result of increasing water cement ratio in the mix due to increase the absorption of recycled aggregates. Increase the content of cement increased value of slump.

2- Density of gravel concrete is greater than all recycled concrete mixes (crushed concrete, crushed mosaic, crushed ceramic and crushed bricks) except for crushed marble concrete mix.

3- Compressive strength at 7 days for gravel concrete is greater than all recycled concrete mixes (crushed concrete, crushed mosaic, crushed ceramic, crushed bricks, and crushed (concrete and mosaic)) by average 4%, 12%, 30%, 40%, and 12%, except for crushed marble concrete mix where the compressive strength is greater than gravel concrete by average 20%.

4- Compressive strength at 28 days for gravel concrete is greater than all recycled concrete mixes (crushed concrete, crushed mosaic, crushed ceramic, crushed bricks, and crushed (concrete and mosaic)) by average 7%, 18%, 29%, 34%, and 8%, except for crushed marble concrete mix where the compressive strength is greater than gravel concrete by average 7%.

5- Compressive Strength at 7 days ≈ 0.7823 Compressive Strength at 28 day.

6- Splitting tensile strength at 28 days for gravel concrete is greater than all recycled concrete mixes (crushed concrete, crushed mosaic, crushed ceramic, crushed bricks, and crushed (concrete and mosaic)) by average 15%, 22%, 26%, 31%, and 18%, except for crushed marble concrete mix where the splitting tensile strength is greater than gravel concrete by average 5%.

7- Splitting Tensile Strength ≈ 0.0978 Compressive Strength

8- Flexural strength at 28 days for gravel concrete is greater than all recycled concrete mixes (crushed concrete, crushed mosaic, crushed ceramic, crushed bricks, and crushed (concrete and mosaic)) by average 17%, 14%, 27%, 33%, and 7%, except for crushed marble concrete mix where the flexural strength is greater than gravel concrete by average 6%.

9- Flexural Strength ≈ 0.1407 Compressive Strength

10- Crushed recycled marble and crushed concrete are the best recycled aggregates to use in reinforced concrete. Crushed mosaic, crushed ceramic, and crushed bricks can be used in plain concrete but cement content must be increased.

VII. REFERENCES

[1] Correia, J. R., de Brito, J., and Pereira, A. S., " Effects on Concrete Durability of Using Recycled Ceramic Aggregates," Materials and Structures, 2006.

[2] Etxeberria, M., Va´zquez, E. A., and Barra, M, " Influence of Amount of Recycled Coarse Aggregates and Production Process on Properties of Recycled Aggregate Concrete," Cement Concrete Res 37:735–742, 2007.

[3] Poon, C., Shui, Z., Lam, L., and Kou, S, "Influence of Moisture States of Natural and Recycled Aggregates on the Slump and Compressive Strength of Hardened Concrete," Cem. Concr. Res 34(1):31–36, 2004.

[4] Meyer C., " The Greening of the Concrete Industry,". Cem. Concr. Compos, 2009.

[5] M. Etxeberria E A. R. Marı E. E. Va´zquez, "Recycled aggregate concrete as structural material," Materials and Structures (2007) 40:529–541.

[6] Knoeri, C., Sanyé-Mengual, E., and Althaus, H., "Comparative LCA of Recycled and Conventional Concrete for Structural Applications," The International Journal of Life Cycle Assessment, 18(5), 909-918, 2013.

[7] Yang, J., and Jiang, G., " Experimental Study on Properties of Pervious Concrete Pavement Materials," Cem. Concr. Res 33:381–386, 2003.

[8] De Juan MS, Gutie´rrez PA (2009), "Study on the Influence of Attached Mortar Content on the Properties of Recycled Concrete Aggregate," Const. Build Mater 23:872–877.

[9] Abbas, A., and others, "Environmental Benefits of Green Concrete," EIC Climate Change Technology, 2006 IEEE, Ottawa, Canada, 1-8.

[10] Mehta, B. , "Reducing the Environmental Impact of Concrete," Concrete International, Oct 2001, 61-66.

[11] Dosho, Y. ,"Development of a Sustainable Concrete Waste Recycling System Application of Recycled Aggregate Concrete Produced by Aggregate Replacing Method," Journal of Advanced Concrete Technology, Japan Concrete Institute, 5(1), 27-42, 2007.

[12] Hendriks, C., and Janssen, G., "Use of Recycled Materials in Construction," Materials and Structures, 36: 604–608, 2003.