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Behavior and Strength of Reinforced Recycled-Aggregate Concrete Beams

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Abstract -In recent years, the world was increasingly attacked by the environmental pollution caused by the wastes out of quarries, building materials industry and construction demolishing besides; the conservation of natural materials resources has become of a top priority in all production sectors. The construction industry faced this challenge and has pioneered the development of new techniques for the reuse of the waste materials that it generates. However, these problems could be partially solved by using these wastes after recycling as coarse aggregate in concrete manufacture. This research was conducted to investigate the behavior and strength of reinforced recycled aggregate concrete beams cast with construction demolition wastes as coarse aggregates under flexural load. The effect of using recycled aggregate (RA) as total or partial replacement of natural aggregate on the behavior of this beams was studied. The main variables of this research were the type of the recycled aggregates (RA) and the percentage of the replacing the dolomite aggregate by recycled aggregates. Among these wastes were ceramics, marble, cement bricks, red bricks and lightweight bricks. Ten beams were cast and tested with dimensions (10×15×120cm). The reinforced recycled aggregate concrete (RRC) beams were divided into two groups according to the percentage of the replacement of the natural aggregate (NA) by recycled aggregates. The performance of the beams was investigated in terms of the initial crack load, ultimate flexural load, load-deflection response, energy absorption capacity, ductility index, load-strain response and cracking patterns. Out of this research wide applications could be achieved in concrete industry in structural applications with special precautions and protection regulations.

Keywords:Demolition Wastes, Recycle, Recycle Concrete, Recycle Aggregates, Recycled Concrete and Reinforced Concrete Beam.

I. INTRODUCTION

Concrete is the world's most widely used material in the construction industry. Concrete is a composite material (a binder, water and aggregates). The aggregates comprise about 60% to 75% of the total volume of concrete. Not only can the aggregate limit the strength of concrete, but the aggregate properties also greatly affect the durability and structural performance of the concrete. The concrete was originally viewed as an inert and inexpensive material. In fact, the aggregate is not truly inert because its physical and sometimes chemical properties influence the performance of the concrete (1-4).

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Wastes' arising from industry is one of the largest waste streams all over the world. Thus, industrial waste has become a global concern that requires sustainable solution. In recent years, Construction and demolition waste can be used as recycled aggregate in construction (1-4). The recycling potentials of construction and demolition (C&D) waste has made it a target of interest and the main focus of waste management polices encouraging minimization, reuse, recycling, and valorization of the waste as opposed to its final disposal in landfills. Concrete recycling gains importance because it protects natural resources and eliminates the need for disposal by using the readily available concrete as an aggregate source for new concrete. This has significant environmental and economic impacts (5, 6). The use of recycled aggregate materials can reduce wastes to landfill and reduce consumption of natural material resources. The studies with respect to the applicability of recycled aggregate in concrete have been extensively conducted around the world. However, most researchers have focused on the mechanical properties of recycled aggregate concrete as replacement the natural aggregates (7- 21). Depending on the type of recycled aggregate and its strength, this kind of material might be used to produce concrete of comparable compressive strength to concrete made of natural aggregates as well as better fire resistance when crushed bricks and tiles are used (7-10). The improvements of the properties of recycle aggregate concrete using clay bricks as coarse aggregate with 100 % clay bricks replacement ratio were studied. The properties of the recycled concrete were improved by reducing the water/ cement ratio, increasing admixture/ cement ratio and using silica fume as a mineral admixture (13). Effects on concrete durability of using recycled ceramic aggregates and the mechanical behavior of non-structural concrete made with recycled ceramic aggregates were investigated. The thermal conductivity coefficient of such recycled concrete is lower than the thermal conductivity coefficient of concrete containing natural aggregate (14- 17). The effect of using marble powder as partial replacement of cement in concrete mixes and on the behavior and strength of RC slabs was studied. Using definite amount of marble powder as replacement of cement content increased the workability, compressive strength and tensile strength. Using marble powder enhanced also the structural performance of the tested slabs as it increased the stiffness and the ultimate strength compared to the control slabs without marble powder replacement (18). Many researchers investigated the applicability of producing structural concrete with recycled industrial waste (rubber or iron waste) as recycled aggregate and studied the flexural behavior of reinforced concrete beams (19). The recycled aggregate obtained from the construction and demolition wastes was used to manufacture concrete blocks which were used in pavements and floor slabs (20).

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II. RESEARCH SIGNIFICANCE

The main objective of this research is to establish the behavior and strength of reinforced recycled aggregate concrete beams with the replacement of the natural coarse aggregate by recycled aggregates. Recycled demolition wastes were used as replacement of natural dolomite as coarse aggregates with different ratios. The type of the demolition wastes taken into consideration were (ceramic, marble, red brick, cement brick and lightweight brick). The ratios of replacement were (25% and 100%) of the dolomite aggregate. The behavior of the investigated beams was studied with special attention to the initial crack load, ultimate flexural load, load-deflection curves, energy absorption capacity, ductility index, load-strain curves and crack patterns under flexural loading.

III. EXPERIMENTAL PROGRAM

III-1- Materials

Cement: The cement used was the ordinary portland cement (CEM I, 42.5 N) produced by the Suez cement factory. Its chemical and physical characteristics satisfied the requirements of the Egyptian Standard Specification (E.S.S. 4657-1/2009) [21].

Water: The water used for concrete mixing and curing was clean drinking fresh water free from impurities.

Fine Aggregates: The fine aggregates used in the experimental program was natural siliceous sand. Its characteristics satisfy the requirements of the (E.S.S. 1109/2008) [22]. It was clean and free from impurities with a specific gravity 2.65 and fineness of modulus 2.7.

Coarse Aggregates: The coarse aggregates used were dolomite and five different types of demolition wastes which included ceramic, marble, red bricks, cement bricks and lightweight bricks. The properties of the aggregates satisfied the requirements of the (E.S.S. 1109/2008) [22]. While the grading of all coarse aggregates followed the grading of (ASTM C33) [23]. The shape of the particles was irregular with a low percentage of flat particles. The fineness modulus was 6.64 and the maximum nominal size was 20mm.

Crushed Dolomite: well graded crushed dolomite was used with a maximum nominal size 20mm, a specific gravity of 2.62, fracture modulus of 16.5% and water absorption of 0.8%.

Recycled Aggregates: included crashed ceramic tiles, marble, cement bricks, red bricks and lightweight sand bricks. The crushed aggregate particles were obtained from bulk products using a hand hammer, so that the maximum nominal size did not exceed 20mm. The grading of the aggregate was controlled to obtain well graded aggregate. Tests were conducted to evaluate the specific gravity, fracture modulus and water absorption and Table (1) summarizes these results.

Admixtures: A high rang water reducer (HRWA) was used to adjust the consistency of the mixes. It meets with the requirements of (ASTM C494 (type A and F)) [24]. The admixture is a brown liquid having a density of 1.18 kg/liter at room temperature. The amount of HRWA was 1.0 % of the cement by weight in all mixes.

Reinforcing Steel Bars: The steel bars used were produced from the Ezz Al Dekhila Steel Factory– Alexandria. Its mechanical and physical characteristics satisfy the Egyptian Standard Specification (E.S.S. 262/2011) [26].

High Tensile Steel deformed steel bars of 10mm. diameters 10mm. were used as main reinforcement, with yield stress of 410 MPa. and tensile strength of 615 MPa.

Mild steel bars of 8 mm diameter were used for stirrups and stirrups hangers with yield stress of 250 MPa. and tensile strength of 365 MPa.

Table (1): Properties of the Recycled Aggregates Used

Recycled Aggregates	Specific Gravity	Fracture Modulus %	Water Absorption%
Ceramic	2.31	21.2	5.6
Marble	2.63	22.3	1.0
Cement Bricks	2.39	26.9	4.4
Red Bricks	1.66	40.9	7.5
Light Sand Bricks	0.94	100.0	50.0

III- 2- Concrete Investigation

The experimental program conducted in this study was performed in the laboratory of testing building materials at the Faculty of Engineering, Menoufia University, Egypt [17]. The concrete mixes were designed and cast according to (E.C.P. 203/2007) [22]. The concrete mixes contained a cement content of 400 kg/m3. The ratio of course to fine aggregate, the water to cement ratio and the admixtures to cement ratio were 2:1, 40% and 1% respectively. The mixes investigated in this research are shown in Table (2).

Table (2): Proportions of the Concrete Mixes Used

Mixes	Dolomite	Ceramic (%)	Marble (%)	Bricks			Fracture Modulus of C.A. (*)%
				Cement (%)	Red (%)	Lightweight (%)	
D1	**100**	------	------	------	------	------	**16.49**
C100	----	**100**	------	------	------	------	**21.21**
C25	**75**	**25**	------	------	------	------	**17.7**
M100	-----	------	**100**	------	------	------	**22.3**
M25	**75**	------	**25**	------	------	------	**17.94**
B100	-----	------	------	**100**	------	------	**26.9**
B25	**75**	------	------	**25**	------	------	**19.1**
R100	-----	------	------	------	**100**	------	**40.91**
R25	**75**	------	------	------	**25**	------	**22.6**
L25	**75**	------	------	------	------	**25**	**37.37**

*C.A. = Coarse Aggregate.

III-3- Reinforced Concrete Beams Investigation

The mixes in table (2) were used to cast ten reinforced concrete beams with dimensions 10× 15 ×120 cm. The beams were reinforced with 2Ø6 stirrups, 2 Ø 8 and 2 ∅ 10 as upper and lower reinforcements, respectively.

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The beams tested to determine the performance and behavior of reinforced recycled concrete beams with the replacement of the natural coarse aggregate by recycled aggregates. They were designed according to the Egyptian code of practice (E.C.P. 203/2007) [26]. After casting, the specimens were covered with wet burlap in the laboratory at 24ºC and 68% relative humidity. The specimens were demoded after 24 hours and wrapped with damp cloth till they were tested. Description and detailing of the tested beams are shown in Table (3) and Figures (1&2).

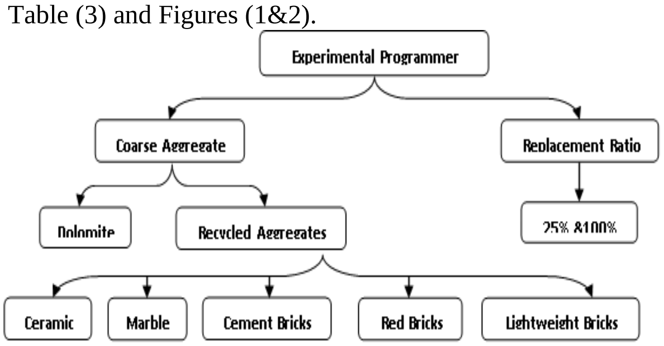

Figure (1): Flow Chart of the Experimental Work Program

Table (3): Details of Beam Samples Used		
Beams	**Concrete mix**	**Fcu. (*) (MPa)**
BD	D1	42
BC1	C100	33
BC2	C25	40
BM1	M100	31
BM2	M25	39
BB1	CB100	26
BB2	CB25	37
BR1	R100	17
BR2	R25	31
BL2	L25	20

* Fcu.= Concrete compressive strength at 28 days using 150mm. cubes.

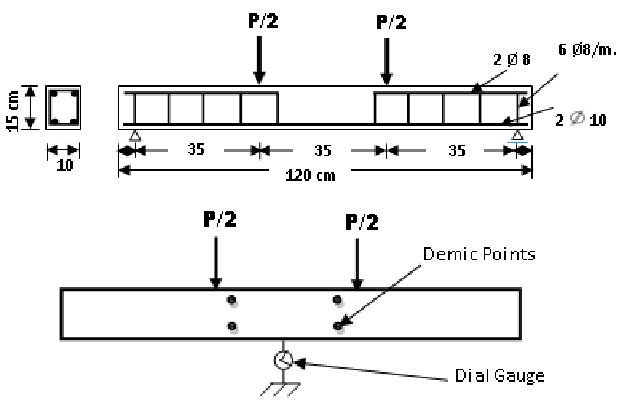

Figure (2): The Details of the Tested Reinforcement Beams

IV. NALYSIS AND DISCUSSION OF THE TEST RESULTS

IV-1- Loads

IV-1-1 Initial Cracking Loads

Table (4) and Figure (3) show the initial cracking load for the recycled aggregate reinforced concrete beams tested using different recycled aggregates (crushed ceramic, marble, cement brick, red brick and lightweight brick) as coarse aggregate. The results show that the initial cracking load for the control beam was 10 KN. with regard of the beams cast with recycled aggregate are decrease in the initial cracking load was found and consistent with the increased in the percentage of recycled material. Using recycled aggregate ceramic as a course aggregate showed that the initial cracking loads were decreased for beams BC2 and BC1 by about 40 and 60%, respectively compared to the control beam. This decreasing was according to increasing the replacement ratio of the natural coarse aggregate by recycled aggregates. Using crushed cement brick and marble showed that the initial cracking loads were decreased for beams BM1, BM2, BC1 and BC2 by about 40% compared to the control beam. Using crushed red brick showed that the decreasing of the initial cracking loads were 60% for beams BR1 and BR2 compared to the control beam. Using crushed lightweight brick as a recycle aggregate showed that BL2 the initial cracking loads were decreased by 40% compared the cracking load to the control beam.

IV-1-2 Ultimate Loads

Figure (3) and Table (4) show the ultimate loads for the recycled reinforced concrete beams. The ultimate load for the control beam was 33.5 KN. The type and the percentage of recycled aggregate affected the ultimate load. The ultimate load was decreased by increasing the percentage of recycled aggregate. Using ceramic as a recycled aggregate showed that the ultimate load were decreased by 10.8 % and 14.3 % for BC2 and BC1, respectively, compared with the ultimate load for the control beam, The ultimate load for beams BM2 and BM1 decreased by 11% and 14.6%, respectively compared to the control beam. Using cement bricks as a recycle aggregate showed that the ultimate load were decreased by about 13.4 % and 17.3% for beams BC2 and BC1, respectively, compared to the control beam and decreased by 16.4% and 24.1% for BR2 and BR1, respectively. Using lightweight bricks as recycled aggregate showed that the ultimate loads were decrease by 19.4% for BL2 compared to the control beam. The recycled aggregate concrete beam BC2 showed 25% improvement in the ultimate load compared with the beam cast with the natural coarse aggregate. The ceramic recycled aggregates recorded the highest strength comparing to the other recycled concrete mixes. Increasing of the recycled aggregate ratio increased the decreasing of the ultimate load.

IV-1-3 Flexural Serviceability Load

The Flexural serviceability load was calculated from the load-deflection curves. It is defined as the load corresponding to deflection equal to the span of the beam (1000 mm) divided by (constant = 250) according to E.C.P. [26]. Table (4) and Figure (5) show the comparison of all recycled concrete beams with the control beam. The ratio of serviceability load to the ultimate load was 77.31% for the control beam and this ratio was between 80.36 % & 96.5% for recycled aggregate concrete beams.

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The serviceability load was increased by about 4% & 3% for beams BM2 and BM1, respectively compared to the control beam and it was decreased from 3.3% to 16.25% for other recycled aggregate concrete beams compared to control beam. Figure (7) represents the values of the first cracking load, serviceability load and ultimate load for all the tested beams.

Table (4): Test Results for All Test Specimens

Beams	Initial Crack Load (KN)	Serviceability Load (KN)	Ultimate Load (KN)	Initial Crack Load / Ultimate Load %	Serviceability Load / Ultimate Load %	Maximum Deflections (mm)	Energy Absorption (KN×mm)	Modulus of Toughness $\times10^{-5}$ (KN /mm^2)	Ductility Ratio	Max. Compressive Strain $\times10^{-5}$ (mm)	Max. Tensile Strain $\times10^{-5}$ (mm)
BD	10	26.5	33.5	29.85	77.31	22	630.54	3.50	33.0	215	4175
BC 2	6	25.2	29.9	20.07	85.28	20.2	524.33	2.91	40.5	180	1400
BM 2	6	27.5	29.8	20.13	92.62	13.58	337.76	1.88	9.3	109	558
BB 2	6	25.6	29	20.69	87.59	17.15	423.17	2.35	15.5	165	680
BC 1	4	24	28.7	13.94	84.69	22	549.43	3.05	33.2	127	1788
BM 1	6	27.3	28.6	20.98	96.50	14.9	363.06	2.02	8.9	241	1036
BR 2	4	22.2	28	14.29	80.36	28.5	716.34	3.98	13.4	213	890
BB 1	6	24	27.7	21.66	86.64	26.4	652.15	3.62	20.9	209	1035
BL 2	6	22.5	27	22.22	83.33	18.42	423.11	2.35	22.6	185	798
BR 1	4	24	25.4	15.75	94.49	13	276.47	1.54	28.3	237	371

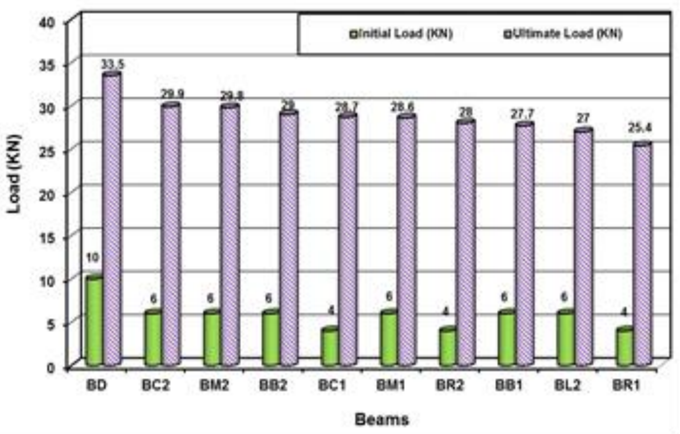

Figure (3): Initial& Ultimate Loads for All Beams

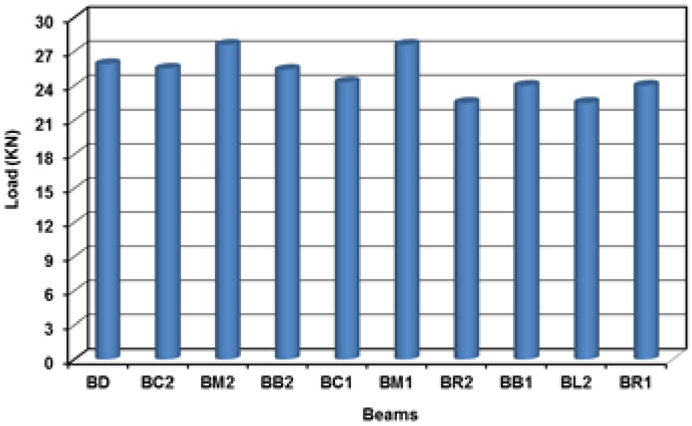

Figure (4): Serviceability Load for All Beams

IV-2- Deformations of Reinforced Concrete Beams

Measuring the deformations for all the investigated beams included the deflections at the center and the longitudinal compression and tensile strain in the constant moment region. The measured deformations for each beam and the corresponding loads up to ultimate load are given in Table (4) and Figures (5 to 12).

IV-2-1 Deflection

The behavior of all beam passed through three stages. The first stage was the elastic stage, in which the load-deflection relationship was linear as load was proportion to deflection values. It ended once the first crack emerged. The second stage was the crack propagation stage in which the load-deflection relationship was nonlinear. The third stage was the failure stage. Figures from (5) to (12) show the load deflection curves at different stages of loading and the maximum deflection for the tested beams. Figure (5) shows the maximum deflection for all the tested beams. From the results, the behavior of the recycling aggregate concrete beams was the same as the normal concrete beam. Figures (6, 7) show the effect of recycled aggregate types on the load-deflection responses with (25% and 100%) replacement of the natural coarse aggregate. At load 10 KN., the deflections were increased by (54.54%, 75.76%, 86.36, 115.15% and 118.18%) for the beams (BC2, BM2, BB2, BR2 and BL2), respectively compared to the control beam. Figure (7) shows the comparison of the load deflection curve between different types of recycled aggregate for 100% replacement of the natural coarse aggregate by recycled aggregates. The deflections were increased by 103%, 65.15%, 93.94 and 89.4% for the beams BC1, BM1, BB1 and BR1, respectively compared to the control beam. Figures (8 to 12) show the effect of the recycled aggregate ratio (25% and 100%) on the load-deflection response for the tested beams. At ultimate load of each beam, the deflection was increased for beams (BB1 & BR2) by (1.4% & 10.6%), respectively compared to the control beam, and this deflection was decreased by 9.7%, 26.5%, 26.6%, 35.3%, 45.6%, 55% and 57.5% for beams BC1, BC2, BL2, BB2, BM1, BM2 and BR1, respectively compared to the control beam.

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At the collapse load, using ceramic aggregate of 25% replacement ratio showed that the maximum deflection was decreased by 8.2% for beam BC2 while, it wasn't changed for beam BC1 compared to the control beam. Using marble showed that the maximum deflection decreased by 32.27% and 38.27% for beams BM1 and BM2, respectively compared to the control beam. Using cement brick showed that the maximum deflection increased by 20% for beam BB1 and it was decreased by 22% for beam BB1 respectively compared to the control beam. Using red brick showed that the maximum deflection was increased by 29.5% for beam BR2 and it was decreased by 41% for beam BR1, respectively compared to the control beam. The maximum deflection decreased by 16.27% for beam BL2 compared to the control beam. However the increase in maximum deflection was due to the reduction of the stiffness of the beams. Increasing the recycled aggregate ratio decreased the stiffness of the beams and increased the deflections of the tested beams at the same load levels.

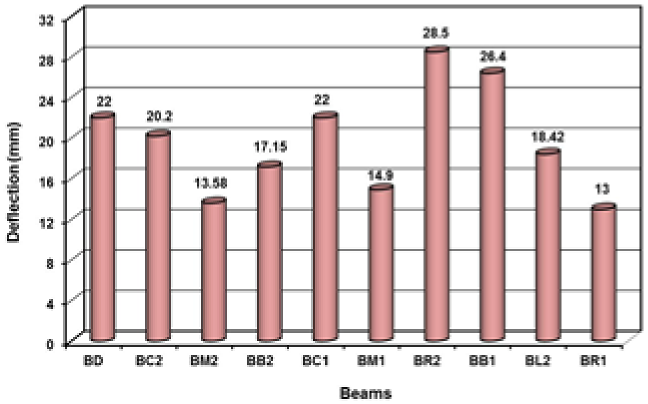

Figure (5): Maximum Deflections for All Beams

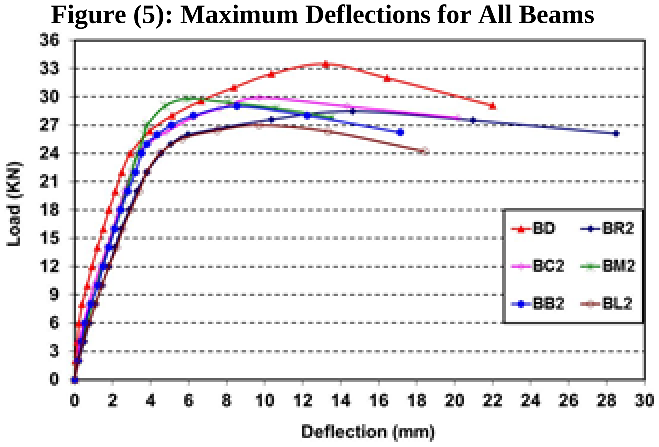

Figure (6): Load Deflection Curve for Beams with 25% Recycle Aggregates & Control Beam

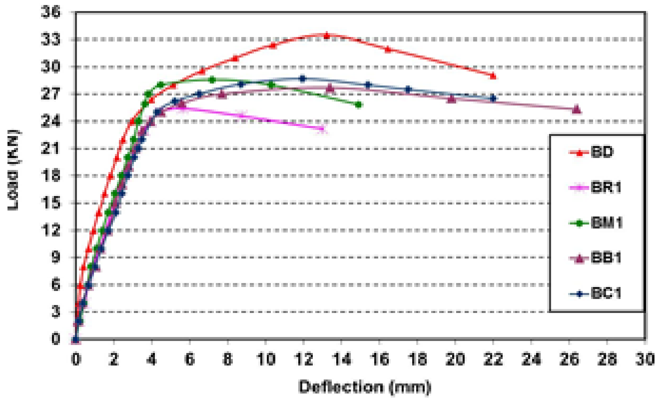

Figure (7): Load Deflection Curve for Beams with 100 % Recycle Aggregates & Control Beam

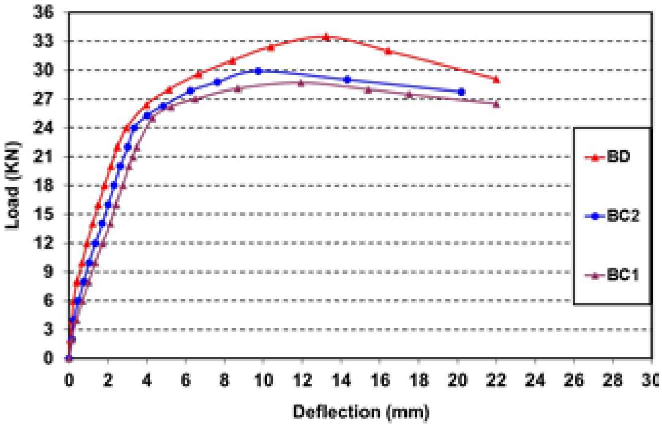

Figure (8): Comparison of Load Deflection Curve for Beams Using Ceramic as Aggregates & Control Beam

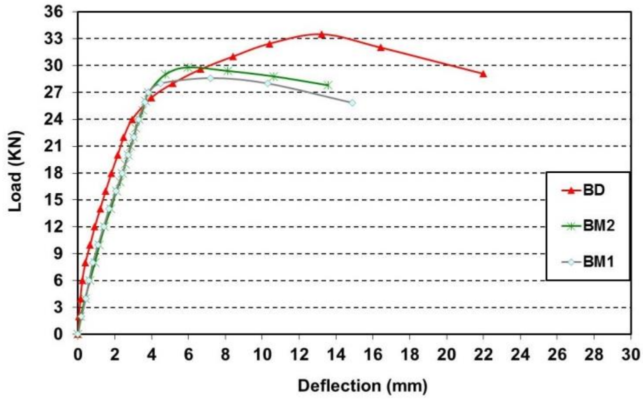

Figure (9): Comparison of Load Deflection Curve for Beams Using Marble as Aggregates & Control Beam

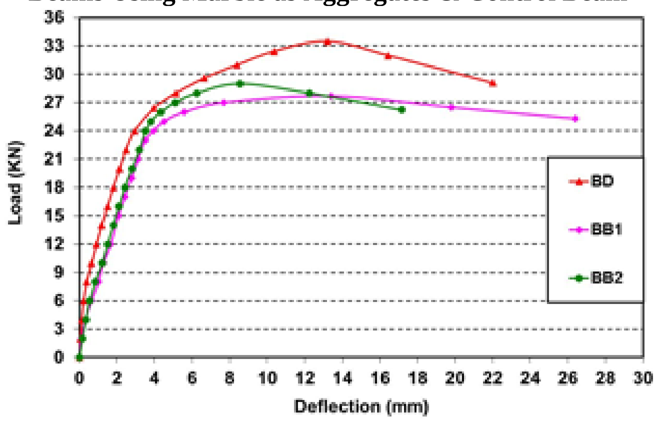

Figure (10): Comparison of Load Deflection Curve for Beams Using Cement Bricks as Aggregates & Control Beam

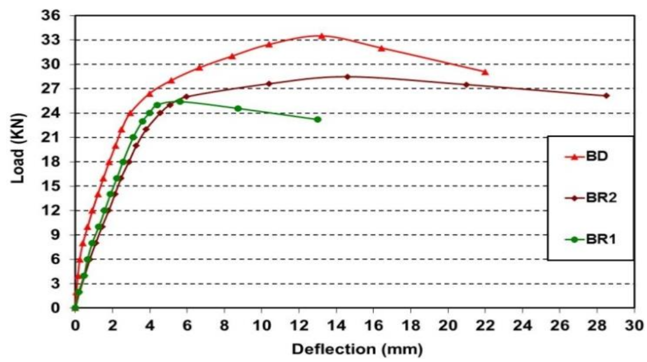

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Figure (11): Comparison of Load Deflection Curve for Beams Using Red Bricks as Aggregates & Control Beam

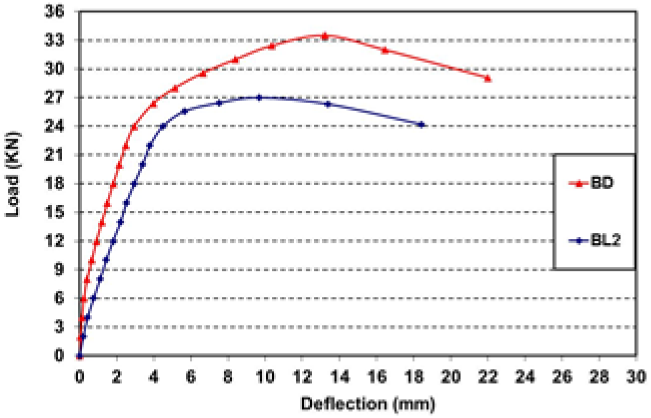

Figure (12): Comparison of Load Deflection Curve for Beams Using Lightweight Bricks as Aggregates & Control Beam

IV-2-2 Ductility Ratios

The ductility of the beam can be expressed based on the deflection of the beam, according to E.C.P [22] and ACI Committee 363[27]. The ductility ratio is defined as $\mu = \Delta\mu / \Delta y$. where $\Delta\mu$ is the maximum deflection at the ultimate load of beam. Δy is the beam deflection when longitudinal reinforcement yielded. Table (4) and Figure (13) show that the higher ductility was occurred by using ceramic as recycled aggregates. The ductility ratio μ was increased by 22.7% and 0.6% for beams BC2 and BC1, respectively compared to the control beam. Increasing the percentage of ceramic decreased the ductility ratio. However the ductility ratio was decreased by 14.2%, 31.5%, 36.7%, 53.0%, 59.4%, 71.8% and 73.0% for beams BR1, BL2, BB1, BB2, BR2, BM2 and BM1, respectively compared to the control beam. Increasing the percentage of recycled decreased the ductility ratio.

IV-2-3 Energy Absorption

The energy absorption of a beam can be expressed based on deflection of the beam. The energy absorption was defined it as the toughness of mid span deflection. This may be calculated as the entire area under the load deflection curve. Figure (14) shows that the energy absorption recorded values of beam BB1 and BR2 was higher than the energy absorption of the control beam by 3.5% and 13.6%, respectively. The other recycled beams showed smaller than the energy absorption of the control beam. The energy absorption increased by increasing the replacement of recycled aggregates ratio of recycled aggregate concrete beams.

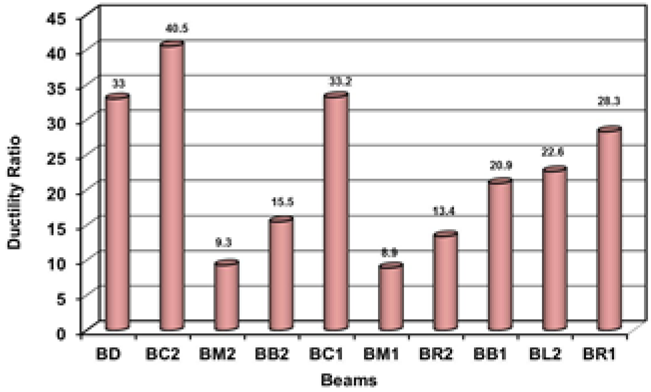

Figure (13): Ductility Ratio for All Beams

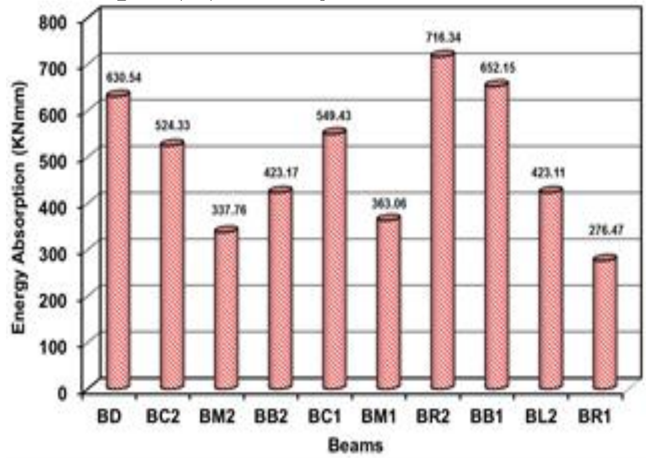

Figure (14): Energy Absorption for All Beams

IV-2-4 Strain Values

Figures (15) to (24) show the relation between the load and both the tensile and compressive strain curves for the tested beams. Test results indicated that the values were affected by the type of demolition wastes (ceramic, marble, red brick, cement brick and lightweight brick) and the ratio of replacement (100% and 25%) of the dolomite aggregate. Results indicated also that the values of the strains decreased by increasing both the replacement of normal aggregates by recycled aggregates and the ratio of this replacement.

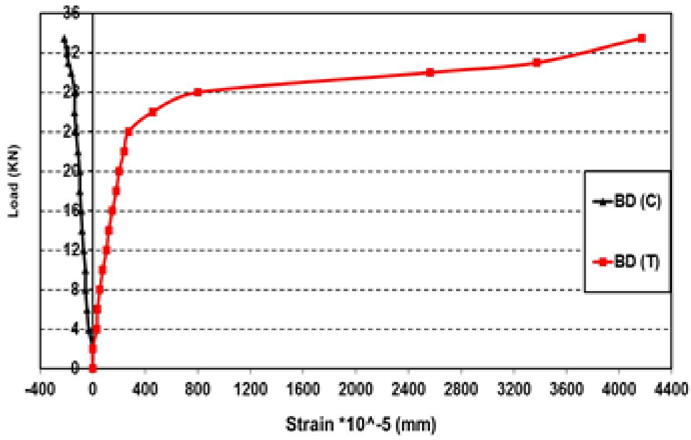

Figure (15): Load Strain Curve for Control Beam (BD)

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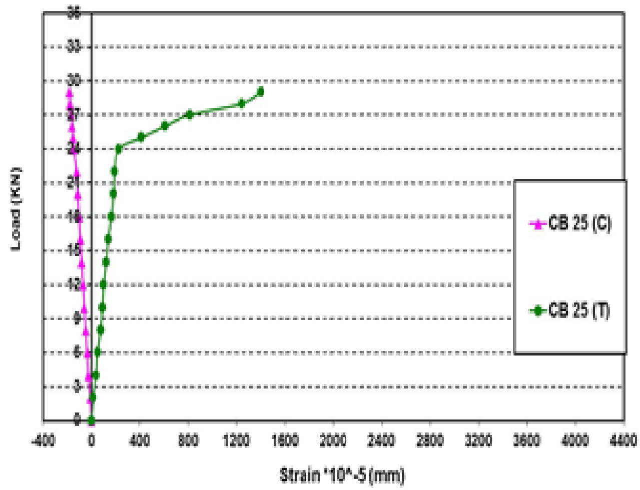

Figure (16): Load Strain Curve for Beam (BC2)

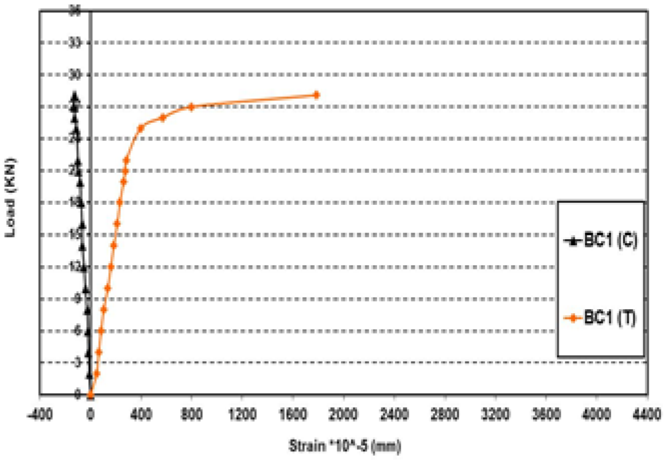

Figure (17): Load Strain Curve for Beam (BC1)

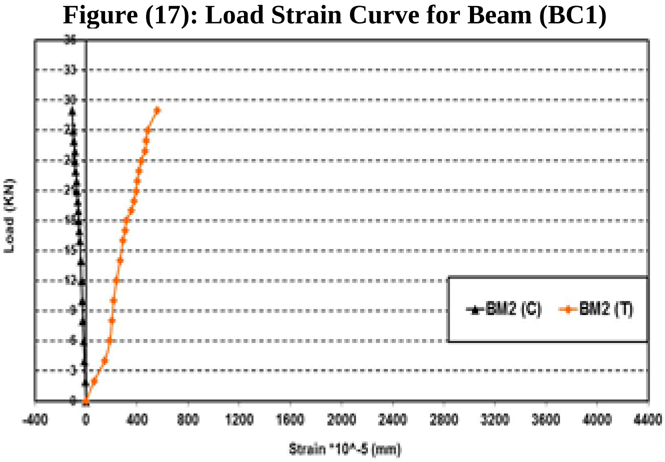

Figure (18): Load Strain Curve for Beam (BM2)

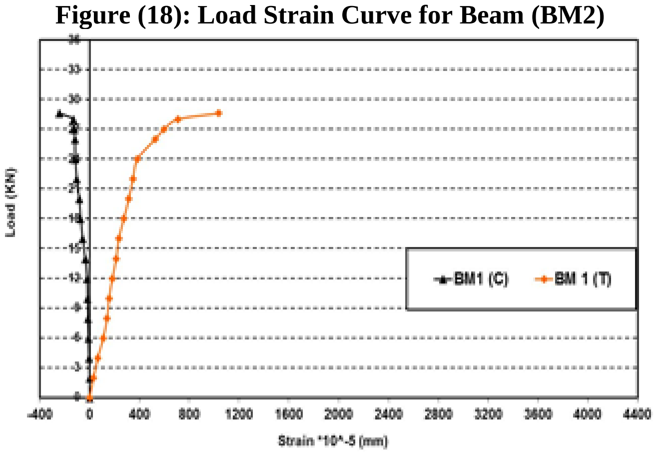

Figure (19): Load Strain Curve for Beam (BM1)

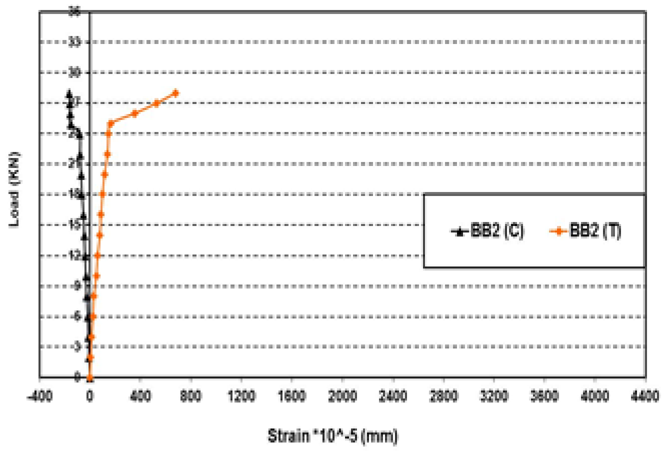

Figure (20): Load Strain Curve for Beam (BB2)

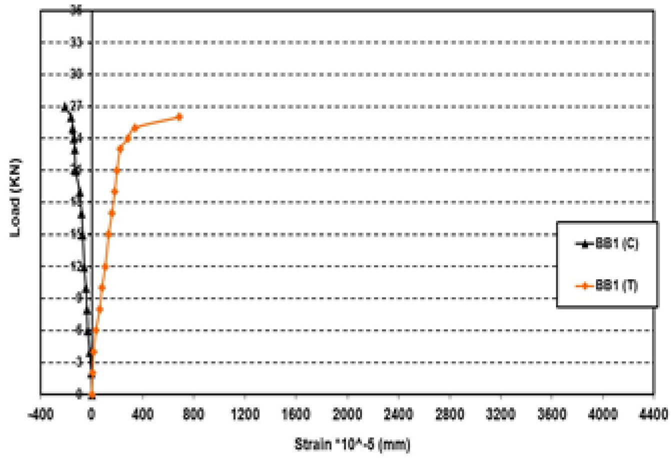

Figure (21): Load Strain Curve for Beam (BB1)

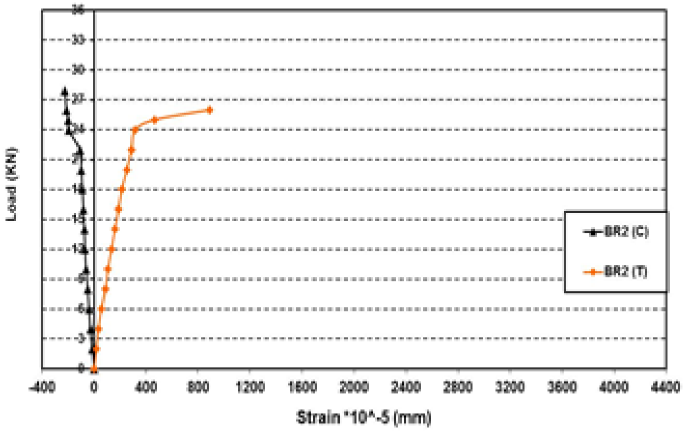

Figure (22): Load Strain Curve for Beam (BR2)

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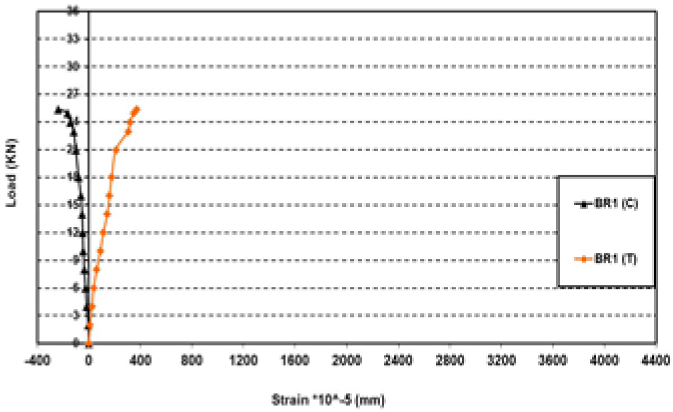


Figure (23): Load Strain Curve for Beam (BR1)

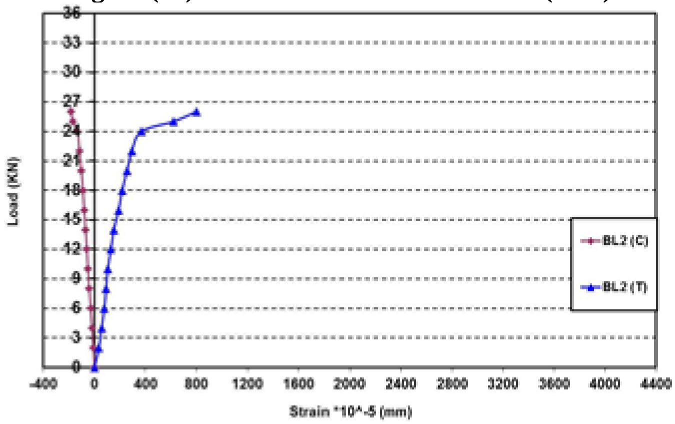
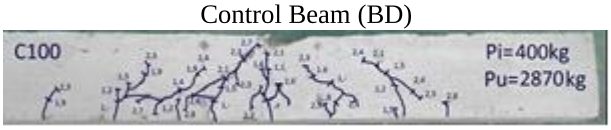


Figure (24): Load Strain Curve for Beam (BL2)

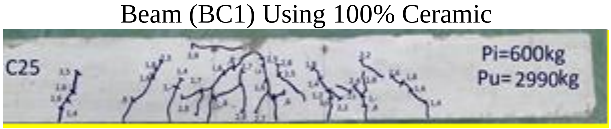
IV-3- Crack pattern

Figure (25) shows the cracking patterns recorded at different stage of loading and up to failure load for the tested beams. The cracking behavior and modes of failure of the tested beams were flexure ductile failure. All beams cracked in the early stages of loading in the maximum moment region within the middle third of the beam. Those fine flexure cracks propagated upwards with loading and were followed by cracks near the supports. Failure took place due to flexure in all beams as planned.

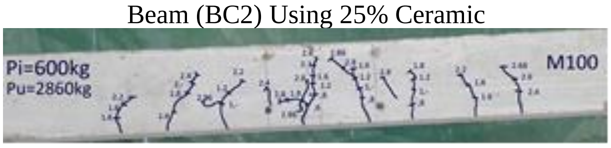
Control Beam (BD)



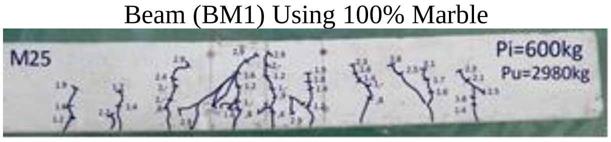
Beam (BC1) Using 100% Ceramic



Beam (BC2) Using 25% Ceramic

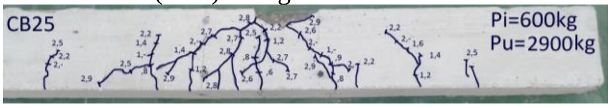


Beam (BM1) Using 100% Marble



Beam (BM2) Using 25% Marble

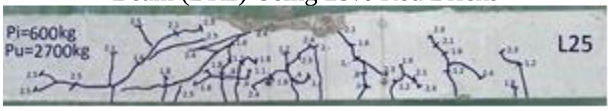
Beam (BB1) Using 100% Cement Bricks



Beam (BB2) Using 25% Cement Bricks

Beam (BR1) Using 100% Red Bricks

Beam (BR2) Using 25% Red Bricks



Beam (BL2) Using 25% Lightweight Bricks

Figure (29) Cracking Load for Tested Beams

V. CONCLUSION

Out of the pervious investigations carried out in the field of recycled aggregate concrete and the experimental work carried out in this research, the following conclusions could be driven:

A. Recycling of wastes out of quarries, industry and building demolitions has become of great importance due to environmental and economic considerations.

B. Among the most common wastes used after recycling as concrete coarse aggregate are ceramic, marble, crushed concrete, cement bricks, red bricks and lightweight bricks. Due to their limited mechanical and physical properties, they were mainly suggested for plain concrete applications such as bricks, road pavement blocks, street side waves … etc.

C. Using such wastes in casting reinforced beams with concrete mixes as partial or total replacement for natural dolomite coarse aggregate showed that:

1) All beams cast with the different types of recycled aggregate concrete taken into consideration in this research showed higher deflections, less ductility index, less stiffness, less initial cracking loads and less carrying capacity in compression with those beams cast with natural dolomite aggregate.

2) The affect on the behavior and strength was less for partial replacement (25%) than the total replacement (100%).

3) The nearest strength and behavior under loading to the beam cast with natural dolomite aggregate were for these casts with partial replacement with ceramic particles.

4) Beams cast with (100%) red bricks showed smallest initial cracking loads and ultimate strength and the highest deflection, longitudinal strain.

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5) Although the strength and the behavior under loading of those beams cast with natural dolomite, the strength and the behavior of these beams cast with the different types of recycled aggregates showed that it can be used for reinforced concrete structures with light line loads as sheds unccesaple slab, fiancés…etc.
6) More investigations should be carried out with regard to the durability and protection against sever conditions.

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