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Lightweight Concrete Cast Using Recycled Aggregates

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Abstract Lightweight concrete (LWC) has been successfully used since the ancient Roman times. It has gained its popularity due to its lower density and superior thermal insulation properties. LWC can significantly reduce a dead load of structural concrete elements compared to normal weight concrete. Concrete cast using recycled aggregates considered as green concretes as their positive impact on the environment. This research conducted to study the efficiency of obtaining structural LWC cast using recycled aggregates as coarse aggregates. In this research, the main variables are; type of recycled coarse aggregates used *(crushed light brick, crushed glass, and crushed red brick compared to dolomite)*, the dosage of Lightweight aggregate used *(ADDIPOR-55" as 0, 10, 20 and 30% of coarse aggregate volume)*. The investigated physical properties included the unit weight and slump values as well as the main mechanical properties of hardened concrete in terms of compressive, tensile, flexural, and bond strengths.

Keywords Lightweight concrete, Lightweight aggregate, Recycled aggregates

1. Introduction

In recent years, the demand for structural lightweight concrete increased at several applications of modern constructions. This was owing to many advantages such as lower density results in a significant benefit in terms of load-bearing elements of smaller cross sections and reduction in the size of the foundations [1]. The aggregates considered the former of concrete, which is, actuates about 75% of concrete volume. Using lightweight aggregate (LWA) in the concrete industry contributes to producing the lightweight aggregate concrete (LWAC). LWA are broadly classified into two types; natural (pumice, diatomite, volcanic cinders, etc.) and artificial (perlite, expanded shale, clay, slate, sintered PFA, etc.). Lightweight concrete can easily be produced by utilizing lightweight aggregate such as pumice or perlite aggregate [2, 3].

Recycling concrete provides a sustainable concrete that the re-use of the demolitions of concrete constructions reduces the amount of material that must be landfilled. The concrete, bricks, ceramics become aggregate and any embedded metals can be removed and recycled as well [4, 3]. In addition, that reduces the economic impact of the concrete used and reduces the need for virgin aggregates. This, in turn, reduces the environmental impact of the aggregate extraction process. By removing both the waste disposal and new material production needs, transportation requirements for the project significantly reduced [5-7]. Lightweight concrete enhanced from non-structural to structural concrete. Also, it used as high strength light concrete [8-15].

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2. Research Significance

This investigation aims to study the possibility of using lightweight concrete cast using recycled aggregate as coarse aggregates. In this research, the fresh and hardened properties of recycled aggregate lightweight “LWC” concrete are studied. The main variables in this investigation are; recycled aggregate used *(crushed light brick, crushed glass, and crushed red brick compared to dolomite as coarse aggregates)*, lightweight additive *(ADDIPOR-55 as 0, 10, 20, and 30% of coarse aggregate volume)*.

The importance of this research is based on the need to know green alternatives to the conventional lightweight natural aggregates to obtain structural lightweight concrete. This research provides data for researchers concerning the behavior of lightweight concrete cast using recycled aggregates as green concrete.

3. Materials and Test Specimens

All tests in this research are carried out in the quality control and testing of the building materials research laboratory in Civil Eng. Dep. at Faculty of Engineering, Menoufia University. The materials used, the preparation of test specimens and testing procedures are discussed in the following sections.

3.1. Materials

The cement used is ordinary Portland cement CEM I) 42.5 N) from the Suez cement factory. It satisfies the Egyptian Standard Specification (E.S.S. 4756-1/2009) [14]. The fine aggregate used is natural siliceous sand that satisfies the Egyptian Code (E.S.S. 1109/2008) [15] and ASTM C-33 [16]. It is clean and nearly free from impurities with a specific gravity 2.6 t/m^3 with a fineness modulus of 2.61. Its main properties are shown in Table (1).

The coarse aggregate used in this research are recycled aggregates compared to natural aggregates. The natural aggregate used is crushed dolomite with a maximum nominal size of 20 mm. The shape of the dolomite particles is angular and irregular with a very low percentage of flat particles. Also, recycled aggregate (crushed light brick, crushed glass, and crushed red brick) were used. They satisfy the (E.S.S 1109/2008) [15] as shown in Tables (2) and Fig.1.

Table 1. Physical properties of the sand used. *(As obtained by test results)*

Property	Value
Specific gravity	2.6
Volumetric weight *(t/m^3)*	1.73
Voids ratio *(%)*	33.81
Absorption *(%)*	0.78

Table 2. Physical properties of the dolomite, crushed light brick crushed concrete and crushed red bricks used. *(As obtained by test results)*

Property	Dolomite	Crushed Light brick	Crushed glass	Crushed red Bricks
Specific gravity	2.55	0.93	2.38	2.13
Absorption *(%)*	0.76	35	0	10
Crushing factor	20	85.6	27.6	49

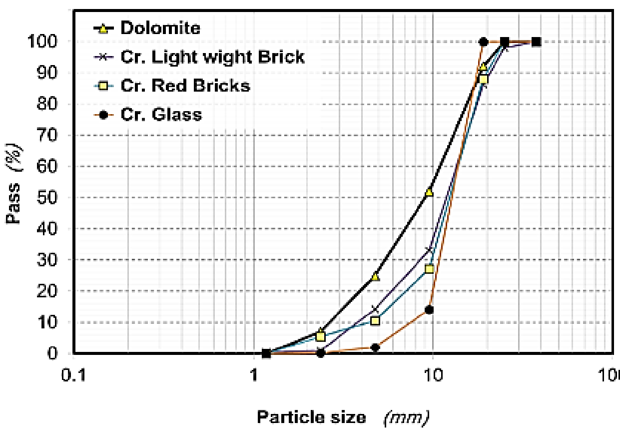

Figure (1). Sieve analysis of coarse aggregates used

Drinkable clean water, fresh and free from impurities was used for mixing and curing processes of the tested samples according to the (E.C.P. 203/2007).

A lightweight aggregate (commercially named ADDIPOR-55) was used to obtain lightweight concrete. ADDIPOR-55 is expanded and extruded foam grains with special size and grading used for producing the light concrete, which has sufficient thermal and acoustic insulation properties, and its density is 22 kg/m^3.

Deformed high tensile steel bars of grade 360/520 with a nominal diameter of 12 mm and length of 160 mm were used as embedded reinforcement for bond tests with a proof stress of 360 MPa. Its mechanical characteristics satisfy the Egyptian Standard Specification (E.S.S. 262/ 1999).

3.2. Concrete and Test Samples

The start point of choosing the proportions of lightweight concrete mixes was conducted firstly based on previous researches [17].

The present experimental program conducted using different valid recycled aggregates compared to natural aggregates as coarse aggregates for lightweight concrete as shown in Fig. (2). ADDIPOR-55 as a lightweight additive was used as a ratio of recycled aggregate *(as 10, 20, 30% of aggregate volume)* to study the feasibility of mixing it with recycled aggregates to light the weight of concrete to have lightweight concrete.

Concrete mixes were cast using crushed light brick, crushed red bricks and crushed glass compared to dolomite. All coarse aggregates used with a maximum nominal size of 20 mm. The samples codes are shown in Table (3).

Table 3. Samples codes of concrete mix

Code	Sample
D0	dolomite
D1	Dolomite + ADDIPOR-55 *(as 10% of coarse aggregate volume)*
D2	Dolomite + ADDIPOR-55 *(as 20% of coarse aggregate volume)*
D3	Dolomite + ADDIPOR-55 *(as 30% of coarse aggregate volume)*
CLB0	Crushed light brick
CLB1	Crushed light brick + ADDIPOR-55 *(as 10% of coarse aggregate volume)*
CLB2	Crushed light brick + ADDIPOR-55 *(as 20% of coarse aggregate volume)*
CLB3	Crushed light brick + ADDIPOR-55 *(as 30% of coarse aggregate volume)*
CG0	Crushed glass
CG1	Crushed glass + ADDIPOR-55 *(as 10% of coarse aggregate volume)*
CG2	Crushed glass + ADDIPOR-55 *(as 20% of coarse aggregate volume)*
CG3	Crushed glass + ADDIPOR-55 *(as 30% of coarse aggregate volume)*
CRB0	Crushed red brick
CRB1	Crushed red brick + ADDIPOR-55 *(as 10% of coarse aggregate volume)*
CRB2	Crushed red brick + ADDIPOR-55 *(as 20% of coarse aggregate volume)*
CRB3	Crushed red brick + ADDIPOR-55 *(as 30% of coarse aggregate volume)*

Table 4. Mixture proportions of concrete mixes used per cubic meter

Mix code	Components							Tested samples				Curing method
	C *(kg)*	W *(kg)*	F.A *(kg)*	C.A		ADDIPOR-55		Compressive strength	Tensile strength	Flexure Strength	Bond strength	
				Type	Weight *(kg)*	% of C.A volume	Weight *(kg)*					
D0	350 *(3.45 KN)*	175 *(1.72 KN)*	613 *(6.03 KN)*	Dolomite	1226	0	0	9 cubes 10*10*10 cm for each mix	9 cylinders 10*20 cm for each mix	6 prisms 10*10*50 cm for each mix	4 cubes 15*15*15 cm for each mix	Conventional curing by water
D1						10	53.8					
D2						20	107.6					
D3						30	161.4					
CLB0				Crushed light brick	215	0	0					
CLB1						10	8.0					
CLB2						20	16.0					
CLB3						30	24.0					
CG0				Crushed glass	1057	0	0					
CG1						10	56.7					
CG2						20	113.4					
CG3						30	170.1					
CRB0				Crushed red brick	680	0	0					
CRB1						10	34.5					
CRB2						20	69					
CRB3						30	103.5					

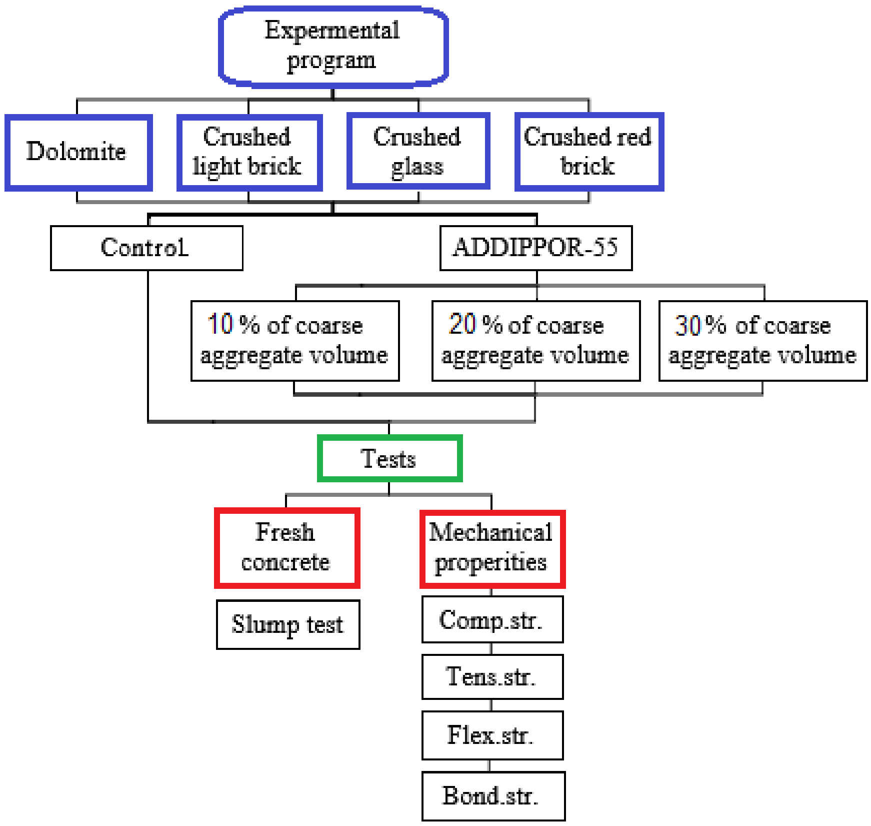

Figure (2). The flow chart of the experimental program

The ordinary Portland cement, graded sand and coarse aggregates with an addition of ADDIPOR-55 *(as 0, 10, 20 and 30% of coarse aggregate volume)* were used. Conventional curing by water was used. The main mechanical properties of concrete mixes are shown in Table (4).

3.3. Performed Tests

The fresh concrete properties obtained in terms of slump values. The standard cone of dimensions 100mm upper diameter, 200mm bottom diameter, and 300mm height was used according to the Egyptian Code of Practice (E.C.P. 203/2007). The main mechanical properties of tested samples obtained in terms of compressive, splitting/ indirect tensile, flexural and bond strengths. Cubes of dimensions 100x100x100 mm were used to obtain compressive strength values. Cylinders of dimensions 100mm diameter and 200 mm height were used to obtain indirect tensile strength values. Prisms of dimensions 100x100x500 mm were used to obtain flexural strength values. Cubes with dimensions of 150x150x150 mm with embedded rebars (12 mm diameter and 160mm length) were used to determine the bond strength between steel bars and concrete. The concrete-steel bond strength is formulated according to E.C.P. 203/2007 as Fbu= fs .φ /(4.Ld) where, Ld (mm) is the bond length of steel; φ (mm) is the diameter of the steel, and fs (N/mm^2) is the tensile stress in steel. If in the previous equation fs= F / (π.φ2 /4), where F (N) is the applied force on the rebar, it then comes out as, Fbu= F / (Ld .π. φ).

A compressive strength testing machine of 2000 kN capacity was used to obtain compressive strength, indirect tensile strength, and bond strength. A flexure testing machine of 100 kN capacity was used to obtain flexural strength values.

4. Test Results and Discussions

The results of fresh and hardened lightweight concrete properties discussed in this section. The fresh properties are drive in term of slump values while the hardened properties are drive in terms of compressive, splitting tensile, flexure and bond strengths. The concrete cast using dolomite was considered as the referee structural concrete compared to LWC.

4.1. Effect of Using Lightweight Additive (ADDIPOR-55)

The results of slump tests due to the effect of using ADDIPOR-55 are shown in Table (5) and Fig. (3).

Figure (3) shows the relationship between the slump values and ADDIPOR-55 dosage *(as a ratio of coarse aggregate volume)*. The results show that the slump values decreased as the ADDIPOR-55 dosage increased. That is a result of the high water absorption of ADDIPOR-55. In addition, it shows that the flowability of the concrete cast using dolomite is higher than that cast using other aggregate types used. That may be attributed to the lower voids of dolomite surface as well as surface roughness compared to other recycled aggregates used.

Table 5. Effect of ADDIPOR-55 on slump values for different mixes

Mixes		Slump values *(mm)*
Aggregate type	**Code**	
Dolomite	D0	22
	D1	18
	D2	15
	D3	10
Light brick	CLB0	19
	CLB1	17
	CLB2	16
	CLB3	13
Glass	CG0	17
	CG1	16
	CG2	15
	CG3	14
Red brick	CRB0	18
	CRB1	16
	CRB2	10
	CRB3	7

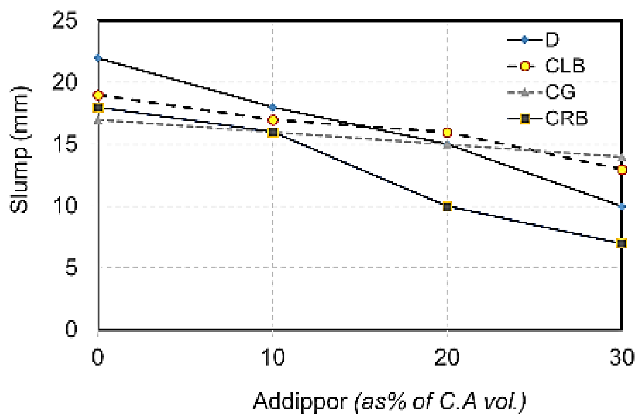

Figure 3. Slump values for different aggregates used

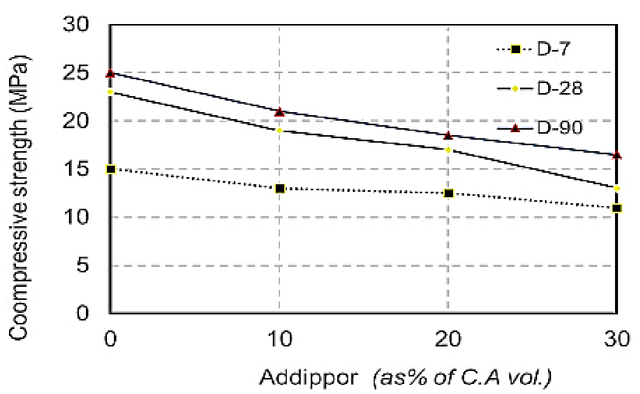

Figure 4. Compressive strength values when using dolomite at different ages due to ADDIPOR-55 dosages

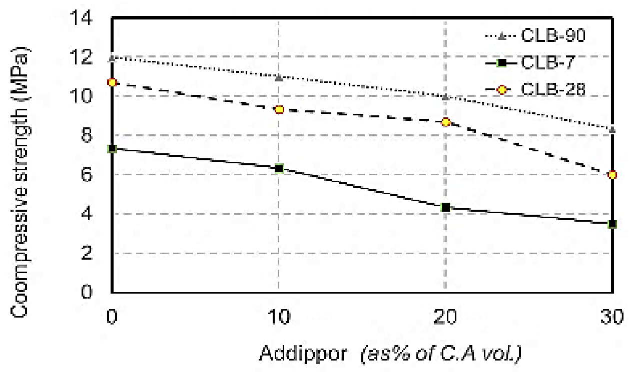

Figure 5. Compressive strength values when using crushed light brick at different ages due to ADDIPOR-55 dosages

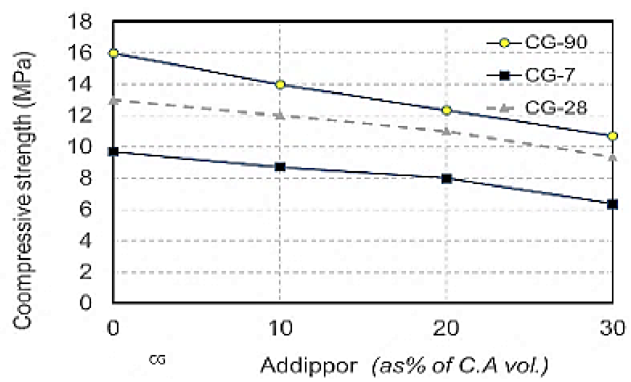

Figure 6. Compressive strength values when using crushed glass at different ages due to ADDIPOR-55 dosages

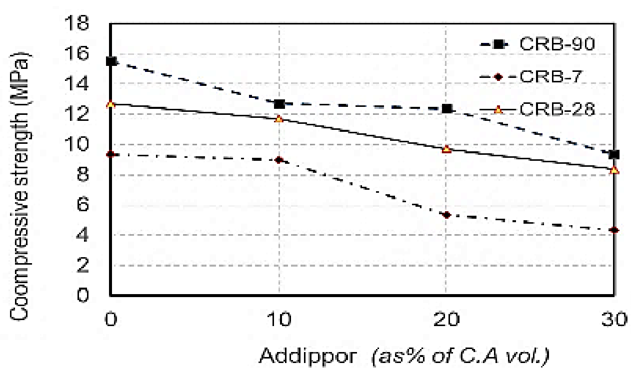

Figure 7. Compressive strength values when using crushed red brick at different ages due to ADDIPOR-55 dosages

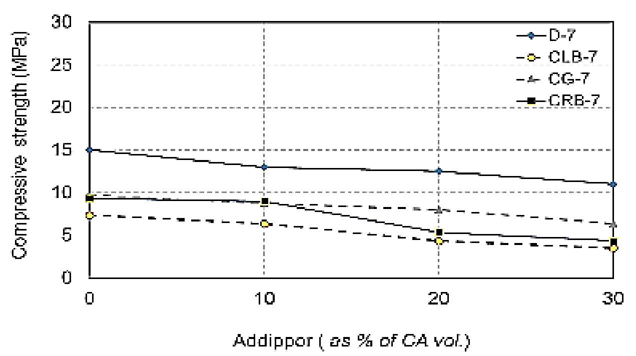

Figure 8. Compressive strength values at 7 days for different recycled aggregate types used with different ADDIPOR-55 dosages

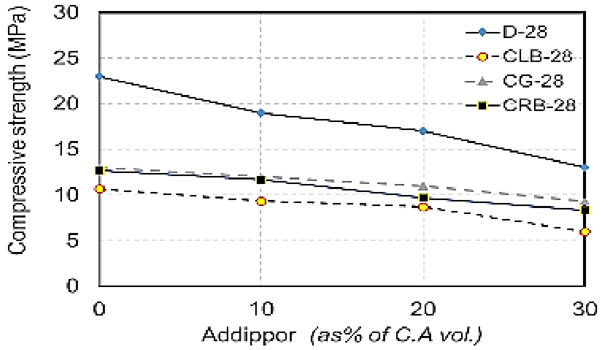

Figure 9. Compressive strength values at 28 days for different recycled aggregate types used with different ADDIPOR-55 dosages

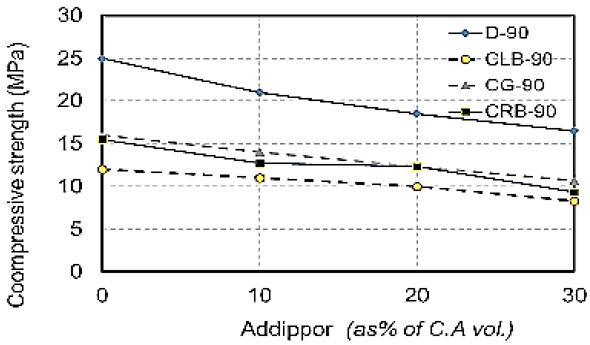

Figure 10. Compressive strength values at 90 days for different recycled aggregate types used with different ADDIPOR-55 dosages

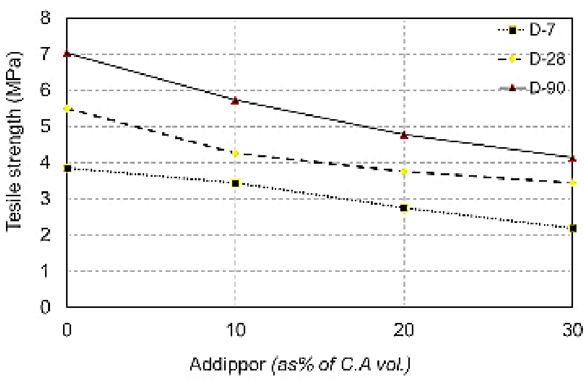

Figure 11. Splitting tensile strength values when using dolomite at different ages due to ADDIPOR-55 dosages

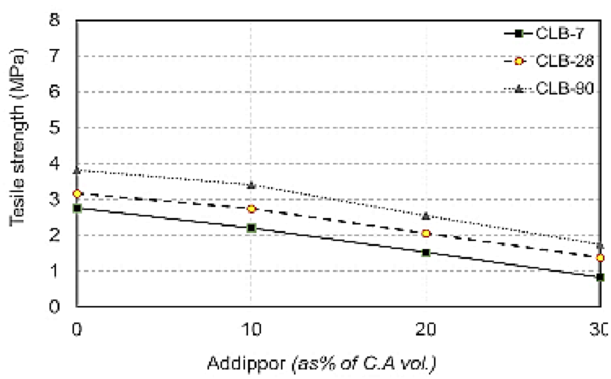

Figure 12. Splitting tensile strength values when using crushed light brick at different ages due to ADDIPOR-55 dosages

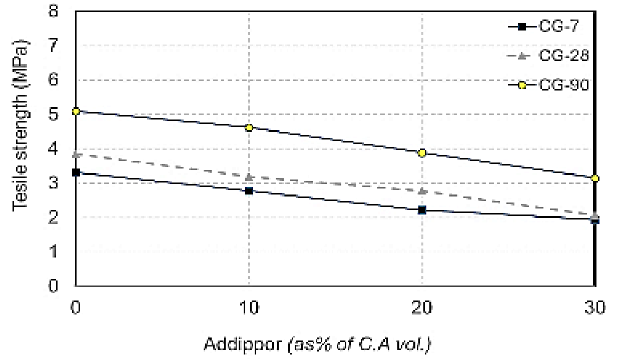

Figure 13. Splitting tensile strength values when using crushed glass at different ages due to ADDIPOR-55 dosages

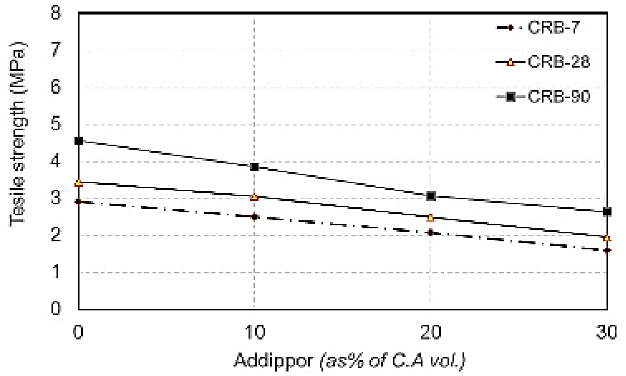

Figure 14. Splitting tensile strength when using crushed red brick at different ages due to ADDIPOR-55 dosages

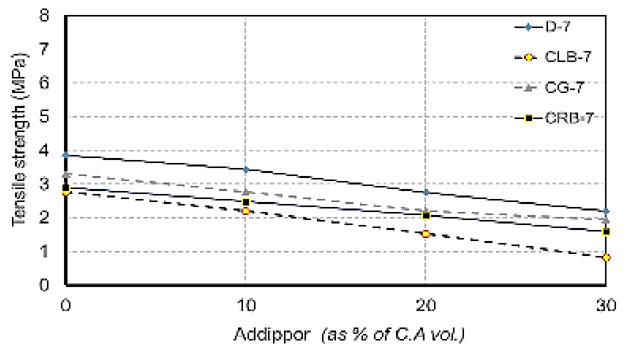

Figure 15. Splitting tensile strength values at 7 days for different recycled aggregate types used with different ADDIPOR-55 dosages

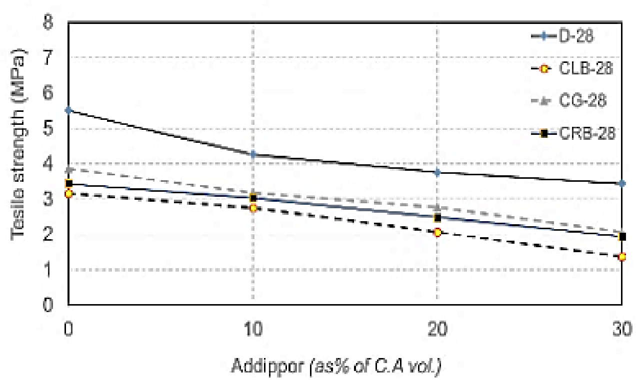

Figure 16. Splitting tensile strength values at 28 for different recycled aggregate types used with different ADDIPOR-55 dosages

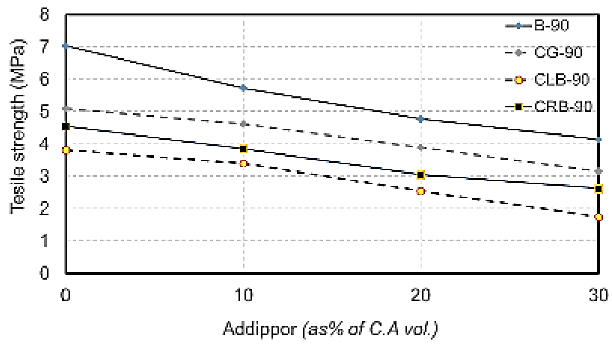

Figure 17. Splitting tensile strength values at 90 days for different recycled aggregate types used with different ADDIPOR-55 dosages

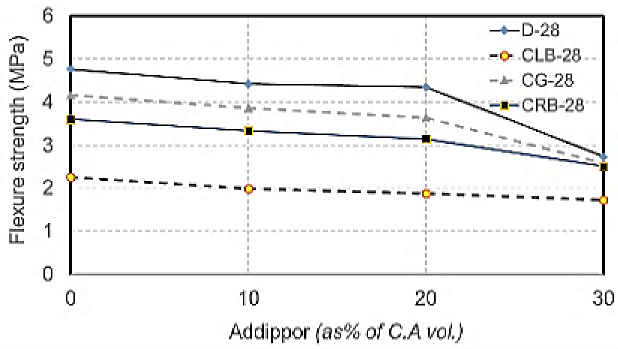

Figure 18. Flexure strength values at 28 days for different recycled aggregate types used with different ADDIPOR-55 dosages

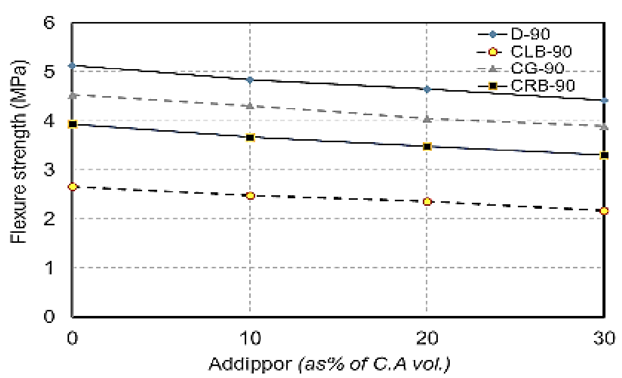

Figure 19. Flexure strength values at 90 days for different recycled aggregate types used with different ADDIPOR-55 dosages

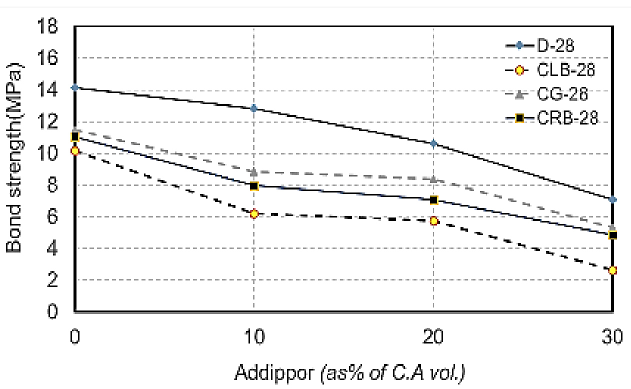

Figure 20. Bond strength values at 28 days for different recycled aggregate types used with different ADDIPOR-55 dosages

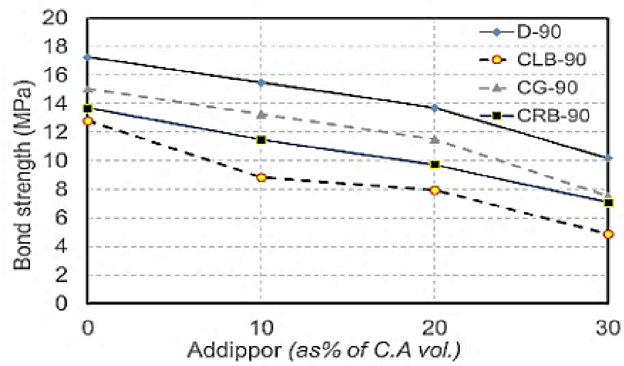

Figure 21. Bond strength values at 90 days for different recycled aggregate types used with different ADDIPOR-55 dosages

The results of the main mechanical properties showed in Table (6) and Figs. (4) to (20). Figures (8) to (10) show the relationship between the ADDIPOR-55 dosage and compressive strength values at 7, 28 and 90 days, respectively. The figures showed that the maximum compressive strength at test ages of 7, 28 and 90 days are obtained at 10% ADDIPOR-55 as a dosage of coarse aggregate "C.A" volume for all different coarse aggregate used for concretes in this study. Also, the ultimate compressive strength of concrete made with dolomite is higher than that of the concrete made with crushed glass by about 35.3%, 43.5%, and 36% at 7, 28 and 90 days ages, respectively. This result is a result of the high hardness and high weight of dolomite comparing to glass. The compressive strength values of the concrete made with dolomite are higher than that for concrete with crushed red bricks by about 37.7%, 44.8%, and 38% at 7, 28 and 90 days, respectively. Generally, using ADDIPOR-55 shows negative influence on strength but satisfactory lightweight concrete with sufficient strength.

This may be because of the high voids ratio of red brick comparing to dolomite, which affects negatively on the strength, in addition to its low weight comparing to dolomite. In addition, the compressive strength of the concrete made with dolomite is higher than concrete with crushed light bricks by about 51%, 53.5%, and 52% at 7, 28 and 90 days, respectively because of the high voids ratio and high water of light brick comparing to dolomite which affects negatively on compressive strength.

Figures (13) to (19) show the relationship between the ADDIPOR-55 and the splitting tensile strength. The maximum splitting tensile strength at 28 and 90 days obtained at the ADDIPOR-55 ratio equal to 10% of coarse aggregate by volume for all coarse aggregate used as a result of the negative influence of ADDIPOR -55 on the strength due to its characteristic of high water absorption and lowering the weight of concrete. Results showed that the maximum splitting tensile strength of concrete mixes cast using dolomite is higher than that cast using crushed glass, crushed red bricks and crushed light bricks by about 14%, 24.8%, and 28%, respectively at 7 days tests because of the high weight and hardness of dolomite comparing to other aggregates. Those values become lower by about 30%, 37.6%, and 42.5% at 28 days tests while becoming lower by about 27.6%, 35.3%, and 45.7% at 90 days tests compared to those cast using dolomite.

Figures (18) and (19) showed the flexural strength values for different dosages of ADDIPOR-55. The maximum flexural strength values at 28 days was obtained at ADDIPOR-55 dosage equal to 10% of coarse aggregate "C.A" volume for all coarse aggregates used as there is an inverse relationship between ADDIPOR -55 dosage and flexure strength value due to its negative effect on the strength due to its low weight and high water absorption . The results show that the maximum flexural strength of concrete cast using dolomite is higher than that recorded for samples cast using crushed glass, crushed light bricks and crushed red brick by about 12.5%, 52.8%, and 24.4%, respectively at 28 days tests. Also, concrete cast using dolomite is higher than that recorded for crushed glass, crushed light bricks and crushed red brick by about 30%, 11.7%, and 23.4% at 90 days tests because there is an inverse relationship between concrete strength and its weight.

Table 6. Results of Mechanical properties of concrete mixes

	Compressive strength *(MPa)*			**Tensile strength *(MPa)***			**Flexure strength *(MPa)***		**Bond strength *(MPa)***	
	7-days	**28-day**	**90-days**	**7-days**	**28-days**	**90-days**	**28-days**	**90-days**	**28-days**	**90-days**
D0	15.0	23.0	25.0	3.854	5.510	7.038	4.76	5.14	14.16	17.25
D1	13.0	19.0	21.0	3.439	4.268	5.732	4.43	4.84	12.83	15.49
D2	12.5	17.0	18.5	2.755	3.375	4.777	4.35	4.65	10.62	13.71
D3	11	13.0	16.5	2.197	3.439	4.140	2.74	4.43	7.07	10.18
CLB0	7.35	10.7	12.0	2.771	3.169	3.822	2.25	2.66	10.18	12.83
CLB1	6.35	9.35	11.0	2.213	2.755	3.408	1.99	2.48	6.20	8.85
CLB2	4.35	8.7	10.0	1.529	2.067	3.548	1.88	2.36	5.75	7.96
CLB3	3.5	6.0	8.35	0.828	1.385	1.752	1.73	2.18	2.65	4.87
CG0	9.7	13.0	16.0	3.312	3.854	5.096	4.16	4.54	11.5	15.03
CG1	8.7	12.0	14.0	2.771	3.185	4.618	3.86	4.31	8.85	13.27
CG2	8.0	11.0	12.35	2.213	2.771	3.885	3.64	4.05	8.40	11.50
CG3	6.35	9.35	10.7	1.943	2.070	3.153	2.59	3.90	5.31	7.52
CRB0	9.35	12.7	15.5	2.898	3.439	4.554	3.60	3.94	11.06	13.71
CRB1	9.0	11.7	12.7	2.484	3.041	3.854	3.34	3.68	7.96	11.50
CRB2	5.35	9.7	12.35	2.070	2.484	3.057	3.15	3.49	7.07	9.73
CRB3	4.35	8.35	9.35	1.592	1.943	2.627	2.51	3.30	4.87	7.08

Table 7. Relative strengths and decreasing ratios for coarse aggregates used

Coarse aggregate	**28 days Compressive strength *(MPa)***	***Decreasing compared to dolomite (%)***	**Weight of concrete *(KN/m³)***	***Decreasing compared to dolomite (%)***	**Relative strength *(%)***
D0	23	*reference*	26.57	*reference*	86.55
D1	19	- 17.4 %	26.08	- 1.8 %	72.85
D2	17	- 26 %	24.11	- 9.2 %	70.50
D3	13	- 43.5%	22.64	- 14.8 %	57.43
CLB0	10.7	- 53.5 %	23.13	- 13 %	46.26
CLB1	9.35	-50.8%	22.44	- 15.6 %	41.67
CLB2	8.7	-48.8%	21.46	-19.3	40.55
CLB3	6	-53.8	19.68	- 25.9 %	30.48
CG0	13	- 43.5%	24.61	- 7.4 %	52.83
CG1	12	-36.8%	23.92	-10%	50.18
CG2	11	-35.3%	23.33	-12.2%	47.16
CG3	9.35	-28%	22.64	- 14.8 %	41.30
CRB0	12.7	- 44.8 %	24.11	- 9.2 %	52.67
CRB1	11.7	-38.4%	23.72	-10.7%	49.33
CRB2	9.7	-42.9%	23.33	-12.2%	41.59
CRB3	8.35	-35.8%	22.64	- 14.8 %	36.89

Figures (20) and (21) shows the effect of using different dosages of ADDIPOR-55 on the bond strength values. The maximum bond strength at 28 days obtained at an ADDIPOR-55 dosage equal to 10% of coarse aggregate volume for all coarse aggregate used. The results show that the maximum bond strength of concrete with dolomite is higher than that of the concrete made from crushed light brick, crushed glass, and crushed red bricks by about 18.8%, 28% and 22%, respectively at 28 days tests and by about 14%, 25%, and 20%, respectively at 90 days tests. That may be because of the negative role of ADDIPOR-55 in weakening the bond between concrete molecules and therefor the bond between the steel and concrete.

Table (7) showed the relative strength of the samples cast using dolomite compared to other recycled aggregates used. The better values recorded for samples cast without ADDIPPO-55. Better values obtained for samples cast using dolomite comparing to the other aggregates used.

4.2. Effect of Using Recycled Aggregates

4.2.1. Fresh Concrete Properties

The results of slump tests due to the effect of using different aggregate types used in this study are shown in Table (5) and Fig. (3).The results showed that the slump values decreases when using recycled aggregates compared to using dolomite.

When using light brick as concrete aggregates slump values decreased compared to using dolomite with a decrease in weight by about 13%. Using crushed glass decreases the value of slump comparing to using dolomite while the weight decreased by about 7.5%. Also, using crushed red brick decreases the slump values comparing to using dolomite with a decrease in weight by about 9.25%.

At 10 % of ADDIPOR-55 as an optimum ratio of coarse aggregate volume, the better slump value (better workability) occurs when using crushed light brick with a decrease in weight by about 14% compared to dolomite. The worst workability was observed when using crushed glass and crushed red brick comparing to dolomite with a decrease of about 8.3% and 9%, respectively compared to dolomite.

4.2.2. Hardened Concrete Properties

4.2.2.1. Compressive Strength

The results of compressive strength tests shown in Table (6) and Figs. (4) to (10). Figs. (4) to (7) showed the splitting tensile strength at different ages for each aggregate type used. Figs. (8) to (10) showed the differences between splitting tensile strength values at each age for different aggregate types used.

The results show that the compressive strength values when using crushed light brick as coarse aggregate decreased by about 53.5% compared to using dolomite with a decrease in weight by about 13% due to the lighter in weight, which makes lower strength than dolomite. Using crushed glass decreased the values of compressive strength by about 43.5% compared to using dolomite while the weight decreased by about 7.5% that is why the voids of glass are too small but its weight is less than dolomite that makes concrete with dolomite is higher in compressive strength. Using crushed red brick decreased compressive strength values by about 44.8% compared to using dolomite with a decrease in weight by about 9.25% as a red brick has more voids ratio than dolomite in addition to its lower weight comparing to dolomite.

When using 10% of ADDIPOR-55 as a lightweight additive, the better compressive strength values obtained with using crushed glass with a decrease in weight and strength by about 8.3% and 36%, respectively compared to dolomite. The worst strength values occur when using crushed light brick with a decrease in weight and strength by about 14% and 50.8%, respectively compared to dolomite. That may referee to the presence of voids and the high crushing factor compared to dolomite.

4.2.2.2. Tensile Strength

The results of splitting tensile strength tests shown in Table (6) and Figs. (11) to (17). Figs. (11) to (14) showed the splitting tensile strength at different ages for each aggregate type used. Figs. (15) to (17) showed the differences between splitting tensile strength values at each age for different aggregate types used.

The results showed that the splitting tensile strength values decreased when using crushed light brick by about 42.5% compared to using dolomite with a decrease in weight by about 13% due to the high voids ratio of light brick, which decreases both weight and strength. Using crushed glass decreased the value of tensile strength by about 30% comparing to using dolomite with a weight loss of about 7.5% as glass has much lower voids ratio than light brick. When using crushed red brick values decreased by about 37.6% compared to using dolomite with a decrease in weight by about 9.25% as a red brick has lower voids ratio than light brick but higher than glass .

When using 10% of ADDIPOR-55, it was found that the better tensile strength values obtained when using crushed glass compared to using dolomite with a decrease in weight by about 25.5%. The lowest values obtained when using crushed light brick with a decrease in weight by about 35.5% compared to using dolomite.

4.2.2.3. Flexure Strength

The results of flexure strength tests are shown in Table (6) and Fig. (12). The test results showed that the flexure strength values decreased by about 52.8% with a decrease in the weight by about 13% when using crushed light brick compared to using dolomite. Using crushed glass decreases the value of flexure strength by about 12.6% and decreases the weight by about 7.5% compared to dolomite. Using crushed red bricks decreases the flexure strength values by about 24.4% with a decrease in the weight by about 9.25%.compared to dolomite.

When adding ADDIPOR-55 (as 10% of coarse aggregate volume), the better flexure strength obtained when using crushed glass compared to using dolomite with a decrease in weight by about 11%. The lowest values obtained when using crushed light brick with a decrease in weight by about 49% compared to using dolomite.

4.2.2.4. Bond Strength

The results of bond strength tests are shown in Table (6) and Fig. (15). The results showed that the bond strength decreases by about 25.6% with a decrease in weight by about 13% when using crushed light brick compared to dolomite and this may be because of the highest lightweight comparing to other coarse aggregates that affect widely on the bond between steel and concrete. Using crushed glass decreases the values of bond strength by about 14% with a weight decrease of about 7.5% compared to using dolomite as glass has heavier than light brick and as a result, it has more bond strength than light brick. Also, using crushed red brick decreases the bond strength values by about 20% compared to dolomite with a weight decrease of about 9.25%.

When ADDIPOR-55 was used (at the optimum value of 5%), the better bond strength obtained with crushed glass compared to dolomite with a decrease in weight by about 14%. The lowest values obtained when using crushed light brick compared to dolomite with a weight decrease by about 43% comparing to dolomite.

4.3. Effects on the Weight of Samples

Using suggested recycled aggregates in this research producing lightweight concrete. The weight of samples cast using light brick, crushed glass and crushed red bricks are lighter than that cast using dolomite by about 13%, 7.4%, 9.2%, respectively with strength loss of about 53.3%, 43.5%, and 44.8%, respectively at 28 days tests.

Increasing the ADDIPOR-55 dosage decreasing the weight of concrete samples up to 25.9% with a strength loss for dolomite, light brick, crushed glass and crushed red bricks up to about 43.5%, 43.9%, 28.1%, and 34.3%, respectively compared to using those aggregates without ADDIPOR-55.

5. Economic Study

From the economic point of view *(without taking in to consideration labour costs)*, using recycled aggregates is more economic than using neutral aggregates especially crushed glass then crushed red bricks from the point of strength but as non-structural uses *(in the range of this study)*. Using light bricks is cost less compared to dolomite used. Concrete using Light brick costs about 513 L.E. for one cubic meter of concrete while dolomite costs about 1300 L.E. /1 m^3 when using the optimum percentage of ADDIPOR-55. The strength of concrete obtained by using dolomite with optimum percentage of ADDIPOR-55 is better than that using light brick at the same percentage of ADDIPOR-55 by about twice but the light brick is lighter in weight than dolomite by about 1.13 times.

6. Conclusions

In this research, a series of experiments have been performed to investigate the behavior and the properties of recycled aggregates lightweight "LWC" concrete. Based on the experimental results presented in this paper, the following conclusions could be drawn as follow:

1. Recycled aggregate concrete "RAC" is less suitable for structural concrete compared to conventional concrete with natural aggregate.
2. Using suggested recycled aggregate decreases the concrete weight. The decrease in weight for concrete cast using crushed light brick, crushed glass, and crushed red brick are 13%, 7.4%, and 9.2%, respectively with strength loss of about 53.5%, 43.5%, and 44.8%, respectively compared to that cast using dolomite only.
3. For lightweight concrete with all suggested aggregates used, the optimum ADDIPOR-55 dosage is 10% of coarse aggregate volume.
4. The Slump value of the lightweight concrete with dolomite is higher than the lightweight concrete with crushed light brick, crushed glass, and crushed red brick by about 13.6%, 22.7%, and 18 %, respectively. When using ADDIPOR-55 the weight of samples decreased by about 14%, 8.3%, and 9.1%, respectively with a decrease in slump values by about 5.6%, 11%, and 11%, respectively.
5. Using ADDIPOR-55 as a lightweight aggregate additive decreases the concrete weight and strength. The decrease in weight at 10% of ADDIPOR-55 for concrete cast using crushed light brick, crushed glass, and crushed red brick are 14%, 8.3%, and 9.1%, respectively with strength loss of about 50.7%, 36.8%, and 38.4%, respectively compared to those cast using dolomite with the same dosage.
6. The tensile strength of the lightweight concrete cast using dolomite is higher than lightweight concretes cast using crushed lightweight brick, crushed glass and crushed red bricks as aggregates by about 42.5, 30 and 37.5%, respectively. Using ADDIPOR-55 decreases the tensile strength by about 35.5%, 25.3%, and 28.7%, respectively with a decrease in weight by about 14%, 8.3%, and 9.1%, respectively compared to those cast using dolomite with the same dosage.
7. The flexure strength of the lightweight concrete cast using dolomite is higher than lightweight concretes cast using crushed lightweight brick, crushed glass and crushed red bricks as aggregates by about 52.8%, 12.6%, and 24.4%, respectively. Using ADDIPOR-55 decreases the flexure strength by about 11.5%, 7.2%, and 7.3%, respectively with a decrease in weight by about 14%, 8.3%, and 9.1%, respectively compared to

those cast using dolomite with the same dosage.

8. The bond strength of the lightweight concrete with dolomite is higher than lightweight concretes with crushed lightweight brick, crushed glass and crushed red bricks as aggregates by about 28%, 18.7%, and 21.9%, respectively. Using ADDIPOR-55 decreases the bond strength by about 51.7, 31 and 38%, respectively with a decrease in weight by about 14%, 8.3%, and 9.1%, respectively compared to those cast using dolomite with the same dosage.

Generally, it can be concluded that recycled aggregates can be used in lightweight concrete because it can gain a lighter weight. In addition, using recycled aggregates decrease environmental impact and save natural resources. Lightweight aggregate can be used with recycled aggregates to produce suitable structural lightweight concrete for small to medium loads. As an application, it can be used for last floor slabs, which can guarantee suitable strength and heat isolation for those slabs.

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