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Investigating the Effect of Sulfate Attack on Compressive Strength of Recycled Aggregate Concrete

[1]Mohamed Arafa, [1]*Bassam A. Tayeh, Mamoun Alqedra[1], Samir Shihada[1], Hesham Hanoona[1]

[1] Civil Engineering Department, Islamic University of Gaza, Gaza, Palestine

*Corresponding E-mail: btayeh@iugaza.edu.ps

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Abstract

This research aimed at studying the effect of sulfate attack on the compressive concrete strength with various percentages of recycled aggregate replacements (0%, 30%, 60% and 100%). Water cement ratio (0.42) are used, MgSO4 solution was used with two concentration (6% and 9 %) to represent the effect of sulfate attack on the concrete compressive strength. The experimental tests focused on physical properties of recycled aggregate; density, unit weight, sieve analysis, Los Angles test and specific gravity. Tests have also been performed on 108 concrete cubes samples at 7 days, 14 days and 28 days for compressive strength. The results of compressive strength at 28 days using (0%, 30%, 60% and 100%) recycled aggregate are (330, 280, 266 and 244) Kg/cm2 respectively, with reduction in compressive strength was (15.2%, 19.4% and 26%) for replacement ratio (30%, 60% and 100%) respectively. MgSO4 solution has an effect on compressive strength after 90 days of immersion in 6% and 9% concentrated of MgSO4 solution. The results of this study show that the reduction in compressive strength using recycled aggregate is more sensitive against the sulfate attack compared with natural aggregate.

Keywords: *Recycled aggregate, recycled aggregate concrete, sulfate attack, compressive strength,* $MgSO_4$ *solution, replacement ratio*

1.0 Introduction

As a result of the fast economy development, rapid growth in urbanization has led to huge scale new construction, these construction works require large amounts of consumption and production of natural aggregate, which result in the condensation of natural aggregate resources shortage and the difficulty of sustainable development [1] [2]. About 70% of the construction wastes are composed of concrete wastes, so it is important to establish a recycling technology that reuse the concrete wastes as the material for production the concrete [3]. It is very important to investigate other sources of raw materials in order to reduce energy consumption and available natural resources, crushing concrete to produce coarse aggregate for the production of new concrete is a common way to achieve more environment-friendly concrete, which will reduces the consumption of natural resources as well as the consumption of landfill space [4] [5].

Since aggregate makes up most of the concrete by volume, it makes sense to investigate the use of concrete waste as aggregate in new concrete, the reuse and recycling these type of waste will lead to save and reduction in valuable landfill space and savings in natural resources [6].

Generally the compressive strength of concrete with using recycled coarse aggregate lower than when use natural coarse aggregate. The strength of the concrete with used recycled coarse aggregate can be 10–25% lower than that of conventional concrete made with natural coarse aggregate [6]. The compressive strength (28 days) of concrete with recycled coarse aggregate was 27- 30% less than the strength of the concrete made with natural coarse aggregates [7]. The compresive strenght of the concrete with recycled coarse aggregate at 28 day was slightly lower than the target strength [4]. To improve the strength of concrete with recycled coarse aggregate to equal or exceed to the strength of concrete with natural coarse aggregate [8] suggested to add fly ash or silica fume to the concrete mixture as a fine aggregate replacement.

After successive wars on the Gaza Strip resulted in a large amount of concrete waste, the disposal of these wastes in Gaza Strip is one of the challenging problems; due to the shortage of open lands and the limited size of municipal dumping sites to accommodate large quantities of debris and unprocessed concrete wastes. The random and uncontrolled disposal of construction and demolition wastes creates several undesirable impacts. This demolition waste was estimated according to UNRWA (2009) reports as 600000 tons, and this quantity is added to the previous available construction and demolition [9]. But the demolition waste in the summer of 2014 was estimated according to UNDP reports as 75000 tons until now [10].

This research is aimed at investigation the possibility of using recycled aggregate in concrete mixes, and choose the optimum recycled ratio after the determination of physical and mechanical performance of recycled aggregate used in concrete mixtures. In addition to identify the effects of use sulfate attack solution ($MgSO_4$) with different concentrations on the compressive strength.

2. Experimental Program

The concrete samples were prepared using 4 different mixes, each mix distinguish from the other in percentage content of recycled coarse aggregate. Each set of these sets were conducted several tests. These tests were (Concrete cube unit weight, Concrete cube density, Slump test (workability measurement), Compressive strength test at 7, 14, 28, 58, 88, 118 days).

2.1 Materials

The materials that used in this study ordinary Portland cement, natural coarse aggregate, recycled coarse aggregate, sand.

2.1.1 Cement

Portland cement type I was used throughout the investigation. The cement was obtained from local concrete manufacture and kept in dry location.

2.1.2 Water

Tap water, potable without any salts or chemicals was used in the study. The water source was the soil and material laboratory in Islamic University Gaza.

2.1.3 Natural Coarse Aggregates

Two main categories of aggregate were used, coarse and fine aggregates. The classification of aggregate into fine and course is referred to ASTM C33 [11]. Three sizes of crushed limestone coarse aggregate were used with maximum nominal size (25mm) and minimum size of (4.75mm) as illustrate in Table 1. These aggregate were Foliya, Adasiya, and Simsymia as locally known in Gaza Strip. To prepare the samples several aggregate properties should be known.

Table 1: Used aggregates types

Commercial Name Used in Gaza	Size Fraction (mm)
Foliya (Type 1 (25mm)	25-19
Adasiya (Type 2 (19mm)	19 -9.5
Simsymia (Type 3 (9.5mm)	9.5-4.75

2.1.3.1 Specific Gravity

The aggregate specific gravity is a dimensionless value used to determine the volume of aggregate in concrete mixes. Table 2 illustrates the specific gravity value for all natural coarse aggregate which used in the preparation of concrete mixes. The determination of specific gravity of coarse and fine aggregate was done according to ASTM C 127 and ASTM C128 respectively, [12, 13]. The specific gravity was calculated at two different conditions which are dry and saturated surface dry conditions.

2.1.3.2 Moisture content

The aggregate moisture content is the percentage of water present in a sample of aggregate either inside pores or in the surface. Moisture content of coarse and fine aggregate was done according to ASTM C 566 [14]. The moisture content was 0 .23% for all types, the equipment used in this test are dry oven and weighting balance.

2.1.3.3 Unit weight

The unit weight or bulk density of aggregate is the weight of aggregate per unit volume. The bulk density value is necessary to select concrete mixtures proportions. ASTM C 29 procedure was used to determine aggregate bulk density [15].

2.1.3.4 Aggregate absorption

Absorption of aggregate is the weight of water present in aggregate pores expressed as percentage of aggregate dry weight. ASTM C127 was used to determine coarse aggregate absorption and ASTM C128 for fine aggregate [12, 13]. Table 2 illustrates the absorption percentages of all aggregates.

Table 2: Natural Coarse Aggregate physical properties

Aggregate type	SSD wt. (g)	Dry wt. (g)	Wt. $_{\text{in water}}$ (g)	Gsb $_{(dry)}$	Gsb $_{(SSD)}$	Absorption %
Type 1 (25mm)	2008	1973	1194	2.424	2.467	1.789
Type 2 (19mm)	2015	1964	1208	2.411	2.496	2.6
Type 3 (9.5mm)	1901	1872	1155	2.509	2.548	1.6

2.1.3.5 Grading and sieve analysis

The sieve analysis of aggregate includes the determination of coarse and fine aggregate by using a series of sieves. ASTM C136 procedure was used to determine the sieve analysis of course and fine aggregate [16].

Table 3 shows the sieve grading of the three types of coarse aggregates and shows the maximum and minimum passing limits according to [11]. It is also noticed in Table 4 that the sieve grading for every type of coarse aggregate doesn’t fit the requirements of [11]. So it can be mixed to fit the requirements of sieve grading. Many trials of changing the weight of every type in the all mix was made to reach the optimum sieve grading of coarse aggregate.

Table 3: Sieve grading of natural coarse aggregate types

	ASTM C 33-03		Aggregate Type					
Sample Description	Min	Max	Type 1 (25mm)	Check	Type 2 (19mm)	Check	Type 3 (9.5mm)	Check
SIEVE SIZE	%	%	%		%		%	
mm	Passing	Passing	Passing		Passing		Passing	
37.5	100	100	100	OK	100	OK	100	OK
25	100	100	100	OK	100	OK	100	OK
19	90	100	67.54	NOT OK	97.8	OK	100	OK
12.5			4.23		57.6		100	
9.5	20	55	4.62	NOT OK	14.3	NOT OK	93.4	NOT OK
4.75	0	10	3.06	OK	3.56	OK	26.25	NOT OK
2.63	0	5	2.06	OK	2.32	OK	6.54	NOT OK

Table 4: Coarse aggregate grading -ASTM C33-03

Sample Description	Type 1 (25mm)	Type 2 (19mm)	Type 3 (9.5mm)	ASTM C 33-03		Check with standard ASTM
	49.50%	26.80%	23.70%			
	Coarse Aggregate					
	Mix Of Aggregate			min	max	
SIEVE SIZE	% Passing			%	%	
mm				Passing	Passing	
37.5	100			100	100	OK
25	100			100	100	OK
19	83.3			90	100	NOT OK
12.5	41.2			35	80	
9.5	28.2			20	55	OK
4.75	8.6			0	10	OK
2.63	3.2			0	5	OK

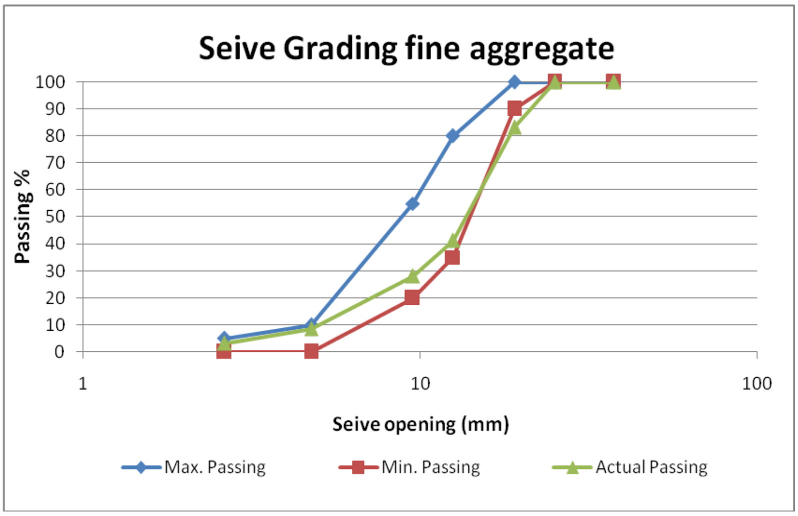

Figure 1: Natural coarse aggregate gradation -All in Coarse Aggregate

The 95th percentile is 22 mm.

2.1.4 Natural Fine Aggregates

Table 5 illustrates the fine aggregate according to sieve grading as defined in [11]. The physical properties of used sand illustrates in table 6.

Table 5: Sieve Grading of Gaza Sand

Sample Description	sand	ASTM C33-03 Fine AGG.		Check with standard ASTM
Opening Mm	% passing	% passing	% passing	
4.75	100	95	100	OK
2.36	100	80	100	OK
1.18	100	50	85	NOT OK
0.6	98.75	25	60	NOT OK
0.425	89.35	10	30	NOT OK
0.3	50.52	5	30	NOT OK
0.15	2.02	2	10	OK
0.075	0.6	0	7	OK
Pan	0	0	0	OK

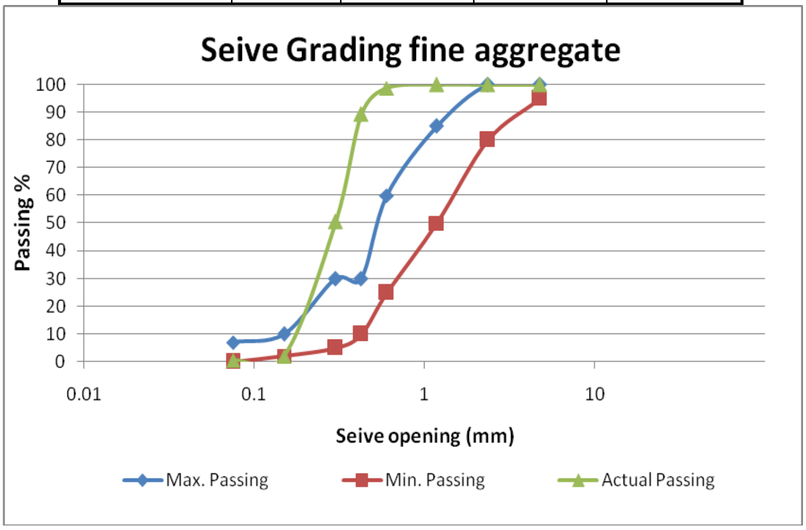

Figure 2: Sieve grading fine aggregate (Gaza sand)

Table 6: Recycled Coarse Aggregate physical properties

Gsb Dry	2.275
Gsb SSD	2.375
Absorption %	4.429 %
Dry unit weight	1370 kg/m3

2.1.5 Recycled aggregates

The recycled aggregate is collected from one of the Gaza Municipality sites- because the following reasons, maximum size is not much greater than 37.5mm size, good grading and the impurities like bricks, asphalt, glass, wood etc. were neglected.

Recycled coarse aggregate were collected and tested. Table 7 illustrate the physical properties of recycled coarse aggregate. Table 8 and Figure 3 showed the sieve analysis of recycled coarse aggregate. The Los Angeles test also done, the percentage of abrasion of the recycle coarse aggregate was 36% which is considered a high ratio compared to natural aggregate (6 %).

Table 7: Recycled Coarse Aggregate physical properties

Gsb Dry	2.275
Gsb SSD	2.375
Absorption %	4.429 %
Dry unit weight	1370 kg/m3

Table 8: Grading of recycled coarse aggregate

Sample Description	Sand	ASTMC33-03		Check with standard ASTM
		min	max	
Opening Mm	% passing	% passing	% passing	
37.5	100	100	100	OK
25	100	100	100	OK
19	99.86	90	100	OK
12.5	51.26			
9.5	20.21	20	55	OK
6.3	2.59	10	30	NOT OK
4.75	0	0	10	OK

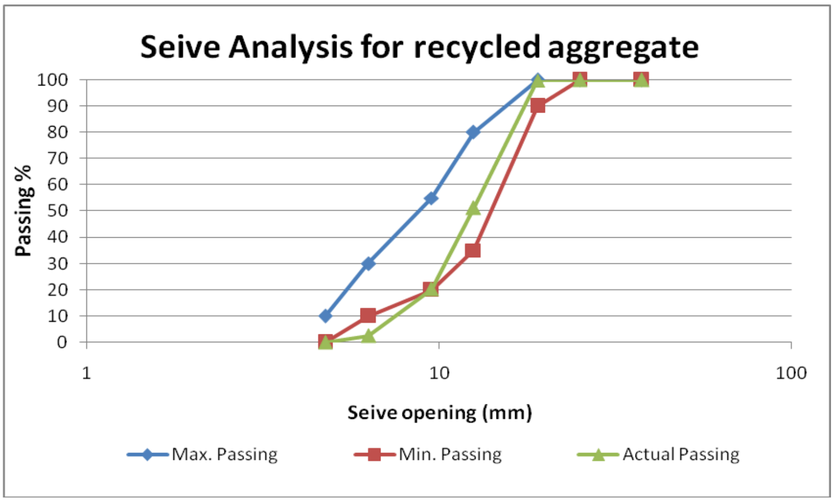

Figure 3: Grading of recycled coarse aggregate

The 95th percentile is 18 mm that mean it's within poorly graded aggregate.

2.7 Job Mix

According to ACI C-211.1 this Mix design was performed, Table 9.

Table 9: Mix design.

Component \ RR%		0% Wt.(kg/m^3)	30% Wt.(kg/m^3)	60% Wt.(kg/m^3)	100% Wt.(kg/m^3)
Type 1 (25mm)	N	634	443.8	253.6	0
	R	0	190.2	380.4	634
Type 2 (19mm)	N	343	240.1	137.2	0
	R	0	102.9	205.8	343
Type 3 (9.5mm)	N	304	212.8	121.6	0
	R	0	91.2	182.4	304
Sand		639	639	639	639
Water		169.5	179	188.5	201.2
Cement		309	309	309	309

3. Results & Discussion

3.1 Density

Table 10 and Figure 4 show the results of the concrete density of at 28 day age with the versus percentage of coarse recycled aggregate. It's shown that the concrete density decreases as percentage of coarse recycled aggregate (replacement ratio) increases, the decrease in density between RR% of 30 and 60 is small compared with decrease between RR% of 0 and 30 that can be referred due to interlocking between aggregate particles.

Table 10: Average 28 day density of concrete strength

Replacement Ratio (RR %)	Density (kg/m^3)
0	2405.6
30	2367.7
60	2357.1
100	2330.0

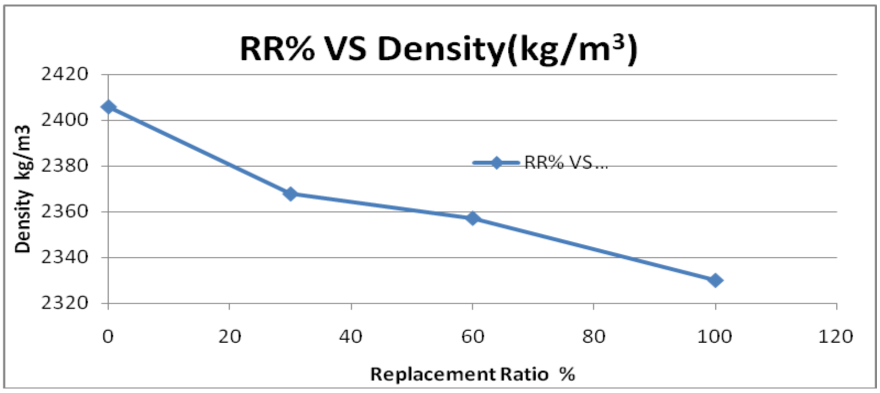

Figure 4: Average 28 day concrete density versus percentage of recycled aggregate

3.2 Workability

The slump value was used as indication of mix workability and all the mixes were designed for 80-100 mm slump value. Table 11 and Figure 5, shows a decreasing of workability when the replacement ratio increases that can be referred to friction due to cementation of aggregate particles.

Table 11: Average slump value of concrete specimens

Replacement Ratio (RR %)	Slump (mm)
0	60
30	35
60	15
100	10

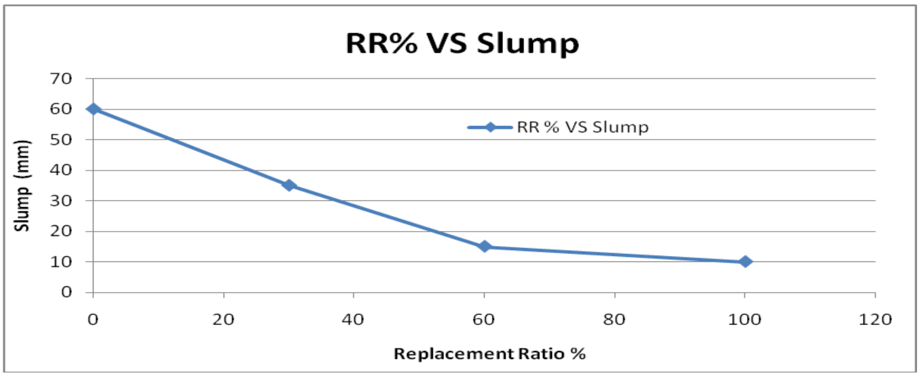

Figure 5: Average slump value of concrete specimens

3.3 Compressive strength

The compressive strength of concrete is affected by both the aggregate properties, and the characteristics of the new cement paste that is developed during the maturing of concrete. The potential strength of concrete is partially a function of aspects related to mix proportioning such as cement content, water/cement ratio and choice of suitable aggregate but also a function of proper curing when chemical bonding develops. The w/c ratio, proper compaction and adequate curing, affect the development of concrete microstructure, and also affect the amount, distribution and size of pores.

The most important parameters of the aggregate that affecting on the compressive strength are shape, texture, maximum size and the strength of coarse aggregate, in addition the effect of replacement ratio is considered in this study.

3.3.1 Effect of replacement ratio (RR %) on the compressive strength

Table 12 and Figure 6 illustrate the average compressive strength of the concrete at 7days, 14days and 28 days in relation with the recycled aggregate replacement ratio. It's clear that when the replacement of recycled aggregate ratio increases (RR %), the compressive strength decreases.

Table 12: Average compressive strength of concrete specimens at (7d, 14d and 28d)

(RR%)	7 Days		14 Days		28 Days	
	fc' (kg/cm2)	% of loss	fc' (kg/cm2)	% of loss	fc' (kg/cm2)	% of loss
0	324.4	0	279	0	330.3	0
30	259.4	20	254.1	8.9	281.7	14.7
60	257.1	20.7	242.3	13.2	266.6	19.3
100	221.8	31.6	208.3	25.3	240.4	27.2

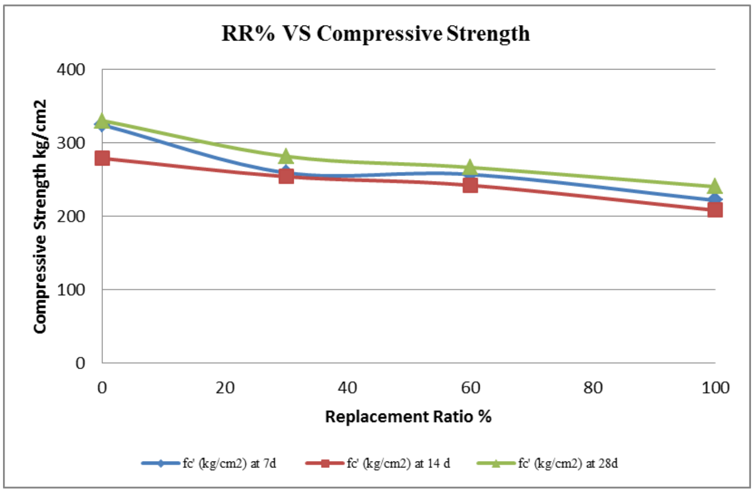

Figure 6: Average compressive strength of concrete specimens at (7d, 14d and 28d)

3.3.2 Effect of $MgSO_4$ solution on the compressive strength

The concrete cubes after curing for 28 days were immersed in solution with different concentrations (6% and 9%) of $MgSO_4$ for 30, 60 and 90 days, the compressive strength was recorded for each replacement ratio.

Table 13 and Figure 7 show the results of compressive strength of concrete specimens after immersed them in 6% $MgSO_4$. The compressive strength decrease when the replacement ratio of recycled coarse aggregate increase.

Table 13: Average compressive strength of concrete specimens at 6% $MgSO_4$

(RR%)	58 Days		88 Days		118 Days	
	fc' (kg/cm2)	% of loss	fc' (kg/cm2)	% of loss	fc' (kg/cm2)	% of loss
0	324.4	0	303.7	0	291.8	0
30	259.4	20	234.1	22.9	224.4	23.1
60	257.1	20.7	225.5	25.7	213.6	26.8
100	221.8	31.6	203.1	33.1	190.3	34.8

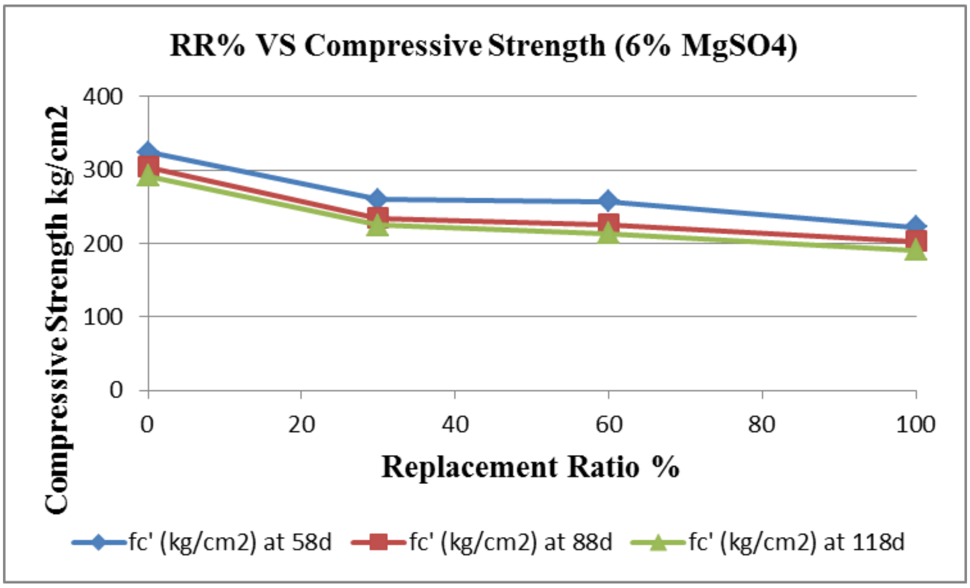

Figure 7: Average compressive strength of concrete specimens at 6% $MgSO_4$

Table 14 and Figure 8 show the results of compressive strength of concrete specimens after immersed them in 9% $MgSO_4$. The compressive strength decrease when the replacement ratio of recycled coarse aggregate increase, also the compressive strength decrease as the $MgSO_4$ concentration increases.

Table 14: Average compressive strength of concrete specimens at 9% $MgSO_4$

(RR%)	58 Days		88 Days		118 Days	
	fc' (kg/cm2)	% of loss	fc' (kg/cm2)	% of loss	fc' (kg/cm2)	% of loss
0	317.5	0	298.3	0	285.9	0
30	256.7	19.1	231.4	22.4	219.5	23.2
60	252.5	20.5	218.5	26.8	204.7	28.4
100	215.2	32.2	195.2	34.6	182.4	36.2

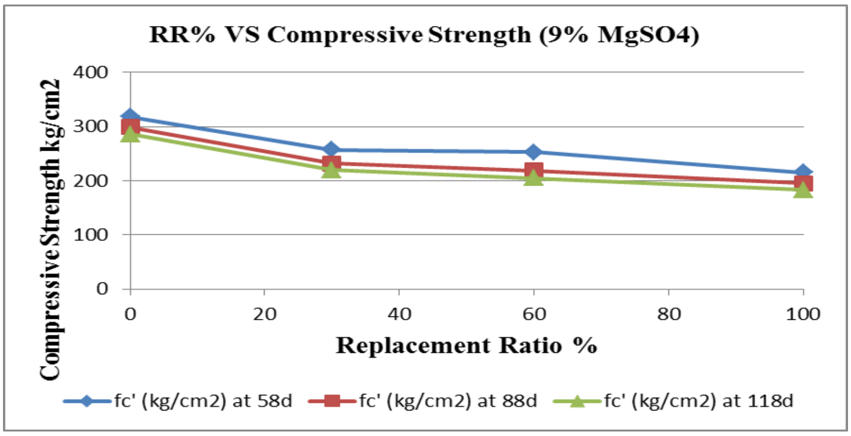

Figure 8: Average compressive strength of concrete specimens at 9% $MgSO_4$

4. Conclusions

Experimental works on the use of recycled aggregates have proven that good quality concrete could be produced with recycled aggregates. The use of aggregates produced from recycled construction and demolition waste should be further promoted. Based on the experimental investigation reported in the work, the following conclusions are drawn:

The dry density of recycled aggregate is about 93 % of the dry density of natural aggregate, the all density of recycled aggregate is about 96 % of natural aggregate concrete, which is not much lower than natural aggregate concrete density.

The workability of recycled aggregate concrete mix is lower than natural Aggregate concrete mix.

The compressive strength of concrete increases as the percent of recycled aggregate decreases, the reduction in compressive strength was (15.2%, 19.4% and 26%) for replacement ratio (30%, 60% and 100%) respectively.

The compressive strength of concrete increases as the concentration of ($MgSO_4$) decreases, the reduction in compressive strength after 90 days of immersion in 6% concentration of $MgSO_4$ solution was (11.6%, 20.4%, 19.9% and 20.8%) for replacement ratio (0%, 30%, 60% and 100%) respectively.

The reduction in compressive strength after 90 days of immersion in 9% concentrated of $MgSO_4$ solution was (13.4%, 22.1%, 23.3% and 24%) using replacement ratio (0%, 30%, 60% and 100%) respectively.

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