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Effects of Nitrate and Sulfate Attacks on Physical and Mechanical Properties of Concrete by Replacing Virgin Aggregates with Recycled Aggregate Concrete Cluster

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Abstract: Concrete recycling yields a considerable amount of steel and aggregates. Lack of information on recycling and reuse of recycled aggregate concrete cluster combined with construction and demolition waste in Ethiopia. The main aim of the research is to investigate the effects of ammonium nitrate and magnesium sulfate on the mechanical and physical properties of concrete made from stone crushed aggregate by the possible extent of the inclusion of recycled aggregate concrete clusters. The mechanical and physical properties investigated are compressive strength, water absorption, and unit weight. Investigations are carried out on C-30 grade concrete mix design having a water-to-cement ratio of 0.435 and slump of 25~100mm at replacement levels of 10%, 20%, 30%, 40%, and 50% crushed stone aggregate by recycled aggregate concrete cluster. Test specimens were prepared by placing the concrete-based material into 0.15*0.15*0.15m molds. The concrete specimens were immersed in ammonium nitrate and magnesium sulfate solutions with 5% (50g/L) concentrations. After 28 days of curing of specimens in distilled water, some of the specimens were immersed in ammonium nitrate and some of them were immersed in magnesium sulfate solutions until 56 days before testing. Test results showed that the compressive strength decreased when the concrete specimens were treated with ammonium nitrate solutions and as the replacement levels of RACC increased and reduction in compressive strength increased clearly. It is also found that the water absorption of concrete specimens increases while the unit weight of specimens decreases when the specimens are exposed to ammonium nitrate solutions. For specimens immersed in magnesium sulfate solutions, a decrease in compressive strength is found through the conducted experiments as well as the loss in strength increases as the replacement levels increase. The results also showed that water absorption and unit weight of specimens were largely clear, still, for magnesium sulfate, there was an increase in water absorption and a decrease in unit weight as replacement levels increase. It concluded that it was established that recycled aggregate concrete clusters can replace crushed stone aggregate by twenty percent. Thus, Further study is suggested to find the most economical way to compensate for the lost fifteen to twenty percent compressive strengths.

Keywords: Crushed Stone Aggregate, Recycled Aggregate Concrete, Performance of Concrete, Regression

1. Introduction

Worldwide civil structures' demolition of waste material is of great nuisance and especially huge concrete, for which application of waste to wealth views are biased. Durability, compressive strength, impermeability, abrasion resistance, and resistance to environmental attacks are important properties of concrete [1]. No doubt Concrete is the world's most broadly used construction material, but at the same time, it is not an environmentally friendly material because it utilizes large quantities of natural resources and it is also a source of environmental adverse impact because of its CO_2 emission while aggregate is manufactured. It is generally deposited as waste in landfills, after its service life. In such environments, concrete is subjected to processes of degradation involving ion addition and exchange reactions, leading to the breakdown of the matrix microstructure and weakening of the material. Ultimately, the external aggressive species progress and reach the reinforcement, leading to the destruction of the structures. Sometimes this can be extremely rapid and serious such as in acidic environments, while in other cases degradation of the concrete matrix occurs over long periods [2]. Factors that affect the susceptibility of concrete to damage include the chemical composition of its ingredients and physical factors such as porosity, density, and permeability at the time of its exposure to corrosive agents [3]. The chemical composition of the hydrated phases (calcium silicate hydrate (C-S-H), calcium hydroxide ($Ca(OH)_2$), calcium sufflaminate hydrate (ettringite), and mono sulfo aluminate for hydrated Portland cement) and their proportions inside the matrix – which depend mainly on the composition of the binder– mostly determine the chemical stability of the matrix [4]. However, the scale of the problem means that the consequences are severe. Lots of money are spent every year on the restoration of the concrete on structures and manufactured elements deteriorated by different types of degradation [5].

Recent construction material selection processes' progress and stringent consideration on sustainability enforce to think on recycling of demolished aggregate concrete to replace crushed rock aggregate to the possible extent. However, due thought and further research on quality issues of concrete formed by replacement of crushed aggregate with recycled aggregate concrete need investigation. Furthermore, this research has investigated some significance that is required by the use of recycled aggregate concrete clusters as an alternative to crushed stone aggregates [6]. To investigate the engineering properties of recycled aggregate concrete clusters & the effect of replacing crushed stone aggregate with recycled aggregate concrete clusters on concrete properties, such as water absorption and sulfate attacks. The consideration of the mechanisms of how to reuse and recycle aggregate concrete cluster matrices in these aggressive environments is an essential step toward the development of concrete that performs well in these environments and toward the increase of the service life and safety of the structures as well facilities.

2. Literature Review

Construction & Demolition waste (C&D), if not minimalized economically and scientifically, can result in resource depletion and environmental concern. Scarcity combined with enormous worldwide requirements has necessitated society to practically adopt recycling and reuse of construction demolished production. Positive net benefit, economic and environmental abatement, is found in recycling concrete aggregate clusters. Aggregates investigation with recycled concrete aggregate for compressive strength of concrete at partial replacement level thirty at ages of 7 days, 14 days, and 28 days of curing were determined. The results and conclusion showed that the compressive strengths of concrete increased with the replacement level of recycled aggregate is possible up to fortuity percent [7]. The reuse of construction & demolition of concrete recyclable cluster aggregate waste as an alternative to normal crushed coarse aggregate plays a vital role is economical and also saves natural resources. Research conducted on the compressive strength of recycled aggregate concrete specimens after a curing period of the 7th and 28th days showed that the effectiveness of construction & demolition concrete waste recycling as partial replacement of natural aggregate for a range from thirty percent was possible without compromising the design strength [8]. Research for possible replacement of natural aggregate with demolished concrete aggregate revealed that thirty percent replacement is possible without any significant ill effects. The cost consequence was mentioned as a positive benefit, instead of clear numbers [9]. Normal aggregates need to meet stringent parameters such as crushing value, LAA value, impact value, surface characteristics [10]. To prove their candidature for concrete. The laboratory investigation results indicate that the durability of concrete manufactured from the recycled aggregate concrete cluster is similar to normal concrete [11]. The research on the influence of recycled aggregate on the statistical parameters of the compressive strength, including the mean value, the standard deviation, and the coefficient of variation revealed that the standard deviation and coefficient of variation of the compressive strength of concrete with different recycled aggregate concrete are slightly higher than that of normal concrete [12]. The recycled concrete aggregate is obtained from the construction & demolition of concrete waste structures, which have different hardened properties from natural aggregate in various respects. Experimental investigations were done on the hardened properties of concrete, by partially replacing the natural aggregates with recycled aggregate in the concrete mix. Research has concluded that it is not possible to incorporate the recycled aggregate greater than thirty regards compressive strength and flexural & split strengths for structural elements [13]. ammonium and magnesium nitrate are the penetration of ions, which comes from nitrate-containing ammonium and magnesium through pores into permeable concrete. Attack of ammonium and magnesium on concrete properties can be happened either from inside of the concrete or through the ingress of the nitrate from the outside to the inside of the concrete structures. From the summary of the literature review, there is not too much literature available on the effect of the recycled aggregate concrete cluster as a partial replacement of crushed stone aggregate on ammonium and magnesium nitrate of concrete.

3. Materials and Experimental Program

The laboratory investigations consisted of testing hardened concrete properties. The tests for hardened concrete include compression tests, water absorption, and unit weight tests. These tests are performed at different periods of exposure to aggressive solutions.

3.1. Materials and Source of Materials

A. Cement: As per ASTM C-150, the commercially available Portland Cement (PPC), with a relative density of 3.15 was purchased from local suppliers in Arba Mich Town and used as binder material.

Figure 1. *Gradation cement samples.*

B. Aggregates: As per ASTM C-33, the fine aggregate with the same source and quality (FM) was used for all types of concrete throughout this study. In Arba Minch, konso is the main source of sand for civil construction.

Figure 2. *Gradation of fine aggregates.*

The Crushed stone aggregates were purchased from specific quarry sites periphery of Arba Minch and were used as coarse aggregates with 37.5mm of nominal sizes. The produced concrete aggregate cluster was subjected to size distribution and a representative grade per fresh normal crushed stone aggregate (4.75~37.5mm) is formulated. The recycled aggregate concrete cluster used for this research was collected from deposit site waste of Arba Minch University, around the Main Campus of the institute of technology of area and broken to resize as per standard of aggregate s [14]. The following tests were conducted for crushed stone coarse aggregates and recycled aggregate concrete clusters.

Figure 3. *Gradation of virgin aggregates and recycled aggregate concrete cluster.*

C. Water: ASTM C- 1602 -Portable tap water fit for drinking was used in mixing and curing the concrete of the Civil Engineering laboratory of Arba Minch Institute of Technology.

3.2. Experimental Program

3.2.1. Mix Design of Concrete

Ethiopian building code of standard (EBC2, 1995) has not justified local trial mixes design procedure. Thus, the mix design process as per ACI 211.1-91 was followed for the design of C-30 concrete grade as well as target slump was 25~100mm and necessary precautions to a possible extent were incorporated against variations from standard concerning concrete ingredients [14, 15]. The concrete mixes prepared from the replacement of virgin aggregates with recycled aggregate concrete clusters are given in the table below.

Table 1. *Details of RACC trail concrete mix.*

Trail Mix	M1	M2	M3	M4	M5	M6
Content	0%	10%	20%	30%	40%	50%

Figure 4. *Mixing ingredients of concrete.*

3.2.2. Casting and Curing Specimen and Experimental Procedures

This experiment utilized ammonium nitrate and magnesium sulfate as aggressive solutions. The following parameters were chosen to demonstrate degradation effects on compressive strength., Water absorption and Unit weight., whereas the ammonium nitrate and magnesium sulfate solutions with the following concentrations were used to investigate their effects on the concrete is 5% (50g/L) with 0%, 10%, 20%, 30%, 40%, and 50% replacement levels of recycled aggregate concrete clusters compared as samples were immersed in distilled water as control samples.

Test specimens were prepared by placing the concrete specimen's material into 0.15 × 0.15 × 0.15 m molds. After 24 hours, the specimens were demolded and placed in a water tank at room temperature for 28 days. After 28 days of curing of specimens, some of the specimens were immersed in ammonium nitrate and some of them were immersed in magnesium sulfate solutions until 56 days before testing with total samples of 36 cubes and without using the solution 18 cubes as well as water absorptions 18 cubes were cast. Each series of samples were finally dried in an oven. Such drying is necessary to carry out water absorption and loss of mass measurements. The test program to be deployed to achieve the objectives of this study is shown in Figure 6.

Figure 5. *Solution of ammonium nitrate and magnesium sulfate and concrete specimens.*

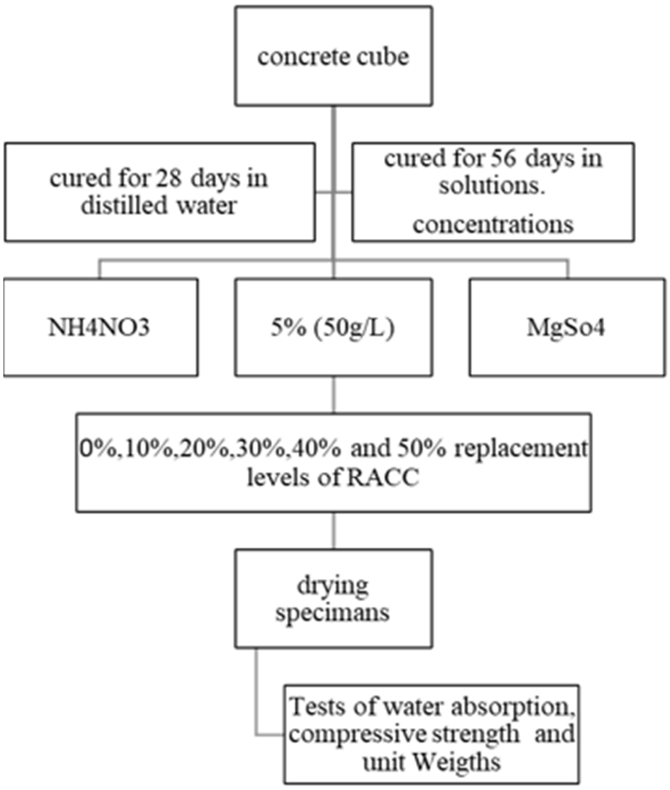

Figure 6. *Experimental program steps chart.*

3.2.3. Method of Data Analysis

Analysis of the performance of concrete (hardened) was done by EXCEL PACKAGE and was used for found the optimum arguments of concrete hardened properties in which virgin aggregates are replaced partially by recycled aggregate concrete clusters.

4. Results and Discussions

4.1. Comparison of Aggregate Properties and Testing Procedures

A. Physical Properties

All-inclusive results of physical properties of recycled aggregate concrete cluster and crushed stone aggregate are presented in Table 2 and Figure 7 respectively.

Table 2. *Results of physical properties for aggregates as per standard.*

Tests of Physical properties		Methods	Test results of aggregates	
			Crushed stone	Recycled aggregate
1. Fines modulus (FM)		ASTMC-33	6.44	6.23
2. Specific gravity	Bulk specific gravity	ASTMC-127	2.67	2.52
	Saturated surface dry Specific gravity (SSD)		2.68	2.58
	Apparent specific gravity		2.70	2.68
3. Water absorption capacity (%)		ASTMC-127	0.4	2.29
4. Unit weight (kg/m^3)	Compacted unit weight	ASTMC-29	1550	1450
	Loose unit weight		1430	1400
5. Flakiness index (%)		BS812	12.85	4.92
6. Elongation index (%)			21.21	15.13
7. Soundness test (%)		BS812	9.04	12.02

B. Particle Size Distribution

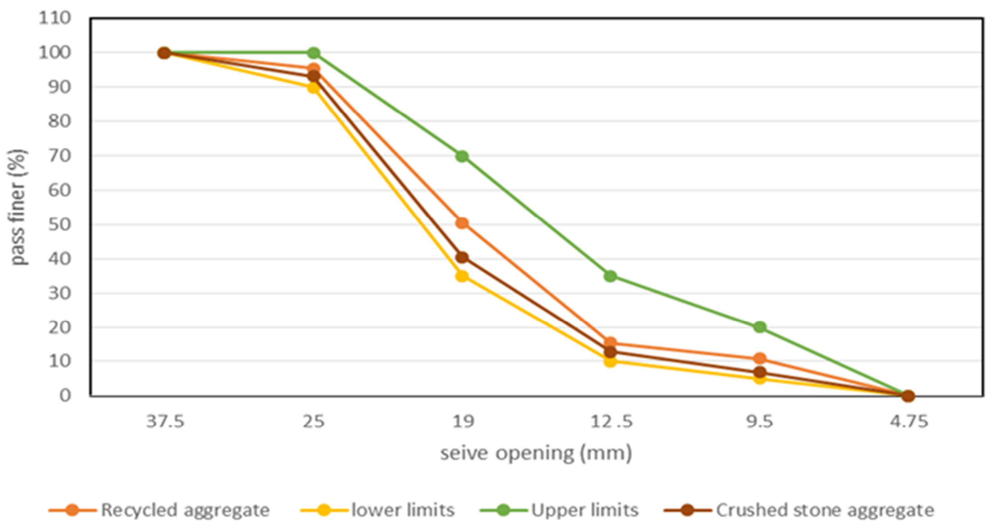

Figure 7. *Gradation of virgin and recycled aggregate concrete cluster.*

From given results of the particle size distribution of the sample is of utmost importance in view that voids percentage as-well-as interconnection govern the engineering properties of particle aggregate matrix. Thus, existing characters are enhanced by having a binder material called cement paste to yield concrete.

C. Mechanical Properties

Table 3. *Results of Mechanical properties for aggregates as per ASTM and BS standards.*

Types of testing	Methods	Test results of aggregates	
		Crushed stone	Recycled
8. Aggregate impact value (%)	BS812	14.01	27.04
9. Aggregate crushing value (%)	B812	17.04	29.00
10. Abrasion value (%)	ASTM C131	15.24	27.75

As results presented in the table above, the values of quality stating physical and mechanical properties values for recycled aggregate concrete cluster were lower mostly by thirteen~ fifteen percent than crushed stone aggregate, but their absolute values were acceptable for structural concrete as per ASTM and BS.

4.2. Hardened Properties of Concrete

A. Ammonium Nitrate (NH_4SO_3)

Test results showed that the compressive strength decreased when the concrete specimens was treated with ammonium nitrate solutions and as the replacement levels of RACC increase and reduction in compressive strength increase clearly. It is also found that the water absorption of concrete specimens increases while the unit weight of specimens decreases when the specimens exposed to ammonium nitrate solutions. The summarized results are given in Table 4, as below showed.

Table 4. *Results of NH_4SO_4 into recycled aggregate concrete at 56th days.*

Trail mix	Average of initial compressive strength) cured in distilled water (MPa)	Average of compressive strength cured in NH_4SO_3 (MPa)	Final loss of strength (%)
Mix 1 (0%)	46.3	43.29	6.95
Mix 2 (10%)	45.5	41.81	8.83
Mix 3 (20%)	44.4	40.15	10.59
Mix 4 (30%)	40.8	36.34	12.27
Mix 5 (40%)	36.8	30.31	21.41
Mix 6 (50%)	34.1	26.31	29.61

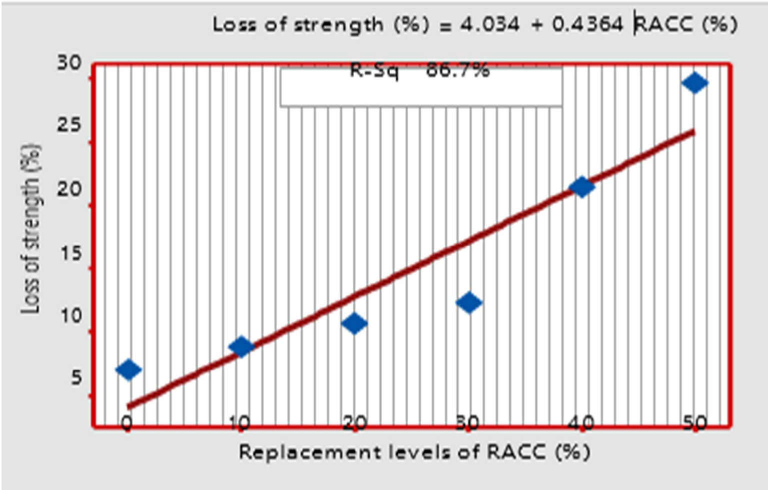

Figure 8. *Regression analysis results of NH_4SO_4 into recycled aggregate concrete at 56th days.*

From regression analysis table and figure above, the relatively loss of compressive strength result were obtained at ages of 56th days after curing in NH_4SO_3 solution. It can be observed that the coefficient of determination, R^2 come to be 0.867, which is closely unity. It means that there is a prefect correlation between regression line and data points.

B. Magnesium Sulfate ($MgSO_4$)

Table 5. *Results of $MgSO_4$ into recycled aggregate concrete at 56th days.*

Trail mix	Average of initial compressive strength cured in H_2O (MPa)	Average of compressive strength cured in $MgSO_4$ (MPa)	Final loss of strength (%)
Mix 1 (0%)	38.61	37.25	3.65
Mix 2 (10%)	37.85	34.38	10.09
Mix 3 (20%)	36.72	32.51	12.95
Mix 4 (30%)	34.02	29.23	16.39
Mix 5 (40%)	32.11	26.05	23.26
Mix 6 (50%)	30.56	22.90	33.44

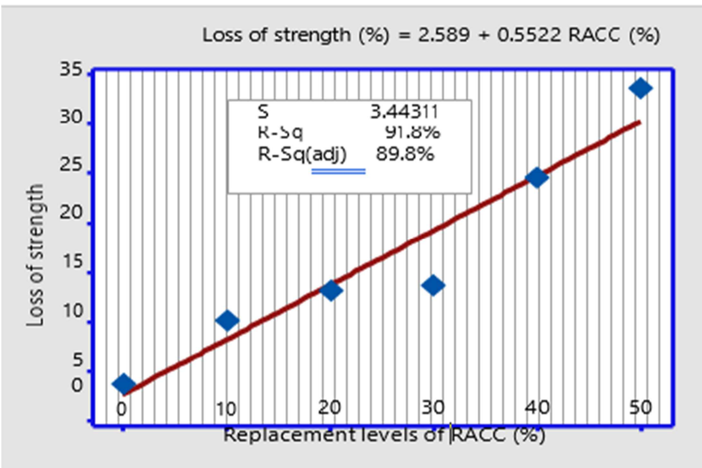

Figure 9. *Regression analysis results of $MgSO_4$ into recycled aggregate concrete at 56th days.*

The study results indicate direct relationship between percentages recycled aggregate concrete cluster and loss of compressive strength. Figure 9 illustrates the correlation between the concrete cubes sample were piled in magnesium sulfate solution and loss of compressive strength cubes for each spaceman at 56th days. It also from regression analysis Figure, the relatively loss of compressive strength result were obtained at ages of 28th days after cured in magnesium sulfate solution. It can be observed that the coefficient of determination, R^2 come to be 0.918, which is closely agreement. It means that there is a prefect correlation between regression line and data points.

C. Water Absorption

The water absorption of concrete of concrete properties was examined at age of 56th days, after curing of 56th days to examine the effective of partial replacement of crushed stone aggregate with recycled aggregate concrete cluster, and the observation results are given in Table 6.

Table 6. *Water absorption results of concrete mixes at 28th and 56th days.*

Trail mix	Average of water absorption at 28th days (%)	Average of water absorption at 56^{th} days (%)
Mix 1 (0%)	1.13	0.82
Mix 2 (10%)	1.18	0.97
Mix 3 (20%)	1.23	1.11
Mix 4 (30%)	1.31	1.19
Mix 5 (40%)	1.37	1.23
Mix 6 (50%)	1.47	1.28

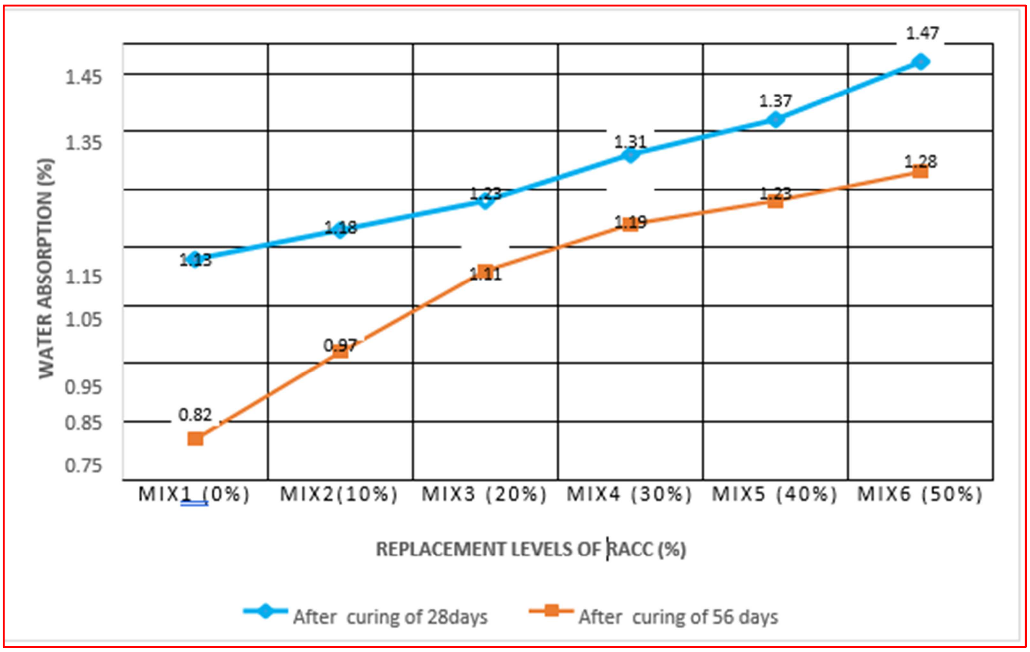

Figure 10. *Water absorption results of concrete mixes on the 28th and 56th days.*

The study results showed that water absorption went on growing as the percentage of recycled aggregate inclusion increased, whether it is of absorption of water by the 28th day or 56th day of cured samples. The reduced increment rate of water absorption for 56th-day cured samples compared to 28th-day cured samples.

The reduced increment rate of water absorption for 56th-day cured samples compared to 28th-day cured samples. The regression analysis has found the correlation between 56th - days density of concrete mixes and water absorption of concrete at the 28th and 56th days of concrete samples were loss of compressive strength changes, which are shown in Figure 10. Its remarks from obtained results of Ammonium nitrate, magnesium sulfate solution, and water absorption indicate a direct relationship between percentages of recycled aggregate concrete cluster and loss of compressive strength. This was implying that the old mortar attached to recycled aggregate concrete cluster has higher porosity, which accommodates easily nitrate and sulfate in the side concrete surface and thereby promotes decrement in compressive strength.

5. Conclusion

Test results showed that the compressive strength decreased when the concrete specimens were treated with ammonium nitrate solutions and as the replacement levels of RACC increased and reduction in compressive strength increased clearly. It is also found that the water absorption of concrete specimens increases while the unit weight of specimens decreases when the specimens are exposed to ammonium nitrate solutions.

For specimens immersed in magnesium sulfate solutions, a decrease in compressive strength is found through the conducted experiments as well as the loss in strength increases as the replacement levels increase. The results also showed that water absorption and unit weight of specimens were largely clear, for magnesium sulfate there was an increase in water absorption and a decrease in unit weight as replacement levels increase. Loss of compressive strength changes its slope once recycled aggregate concrete cluster surrounded by new crushed stone aggregate and cement paste mix changes recycled aggregate concrete cluster densification leading to recycled aggregate concrete cluster surrounded old mortar becomes closer.

It concluded that it was established that recycled aggregate concrete clusters can replace crushed stone aggregate by twenty percent. Thus, further study is suggested to find the most economical way to compensate for the lost fifteen to twenty percent compressive strengths.

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