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Experimental Study on Replacing Crushed Stone Aggregates by Recycled Aggregate Concrete Cluster

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Abstract

Broken concrete and re-sized output are called recycled aggregate concrete cluster (RACC). Thus, yielded RACC reuse in concrete for sustainability is a welcome thought, which needs research support. Thus, the main aim of this research was to study the effect of replacement of CSA by possible extent inclusion of RACC. Investigations were carried out on C-30 grade concrete mix design as per ACI standard at replacement levels of 10%, 20%, 30%, 40% and 50% CSA by RACC. In present study, relevant ASTM and BS standards were used. At the most, lesser by 13% ~ 15%, values of mechanical and physical properties of RACC in comparison to CSA fulfilled their candidature and offered momentum for further research on RACC embedded concrete. Without doubt, wet concrete workability and hardened concrete performance got affected to some extent. Results of various tests indicated a distinct behavior to comment that around 20% CSA replacement by RACC was optimal and can be compensated with suitable concrete mix design re-engineering. GAMS analysis on multiple test results recognized that optimal replacement of CSA by RACC seems feasible at 20.6% without drastic compromise and anxieties on concrete performance, workability, compressive & flexural strength, and sulfate & chloride attack, water absorption in contrast with control concrete, yet further study is required to confirm the beneficial effects of RACC for more possible applications and suggested to come up with new version EBCS-EN for 20.06% RACC inclusion mix design.

Keyword: Concrete, Crushed stone aggregate, Performance, Recycled aggregate concrete cluster.

1. INTRODUCTION

Concrete is the most significant construction material used in public works and is used for majority of structures all around the world**[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 dumped as waste in landfills, after its service life. The basic ingredients of the concrete are cement, fine as-well-as coarse aggregates and water. Aggregate is a broad category of coarse material used in construction, including sand, gravel, and crushed stone (CSA) and recycled aggregate concrete cluster (RACC).The use of recycled aggregate concrete waste as coarse aggregates replacement in concrete can be useful for environmental protection, economic cost of quarrying operations, processing and transporting. The studies on application of RACC as coarse aggregates replacement are underway in many universities in European, American and Asian nations**[2].**The RACC emanates from constructed civil structures demolition after due necessary processes like manual hammering and screening[**3**].Construction industry, in Ethiopian context, presently hails benefits mostly from recycling carpenter nails, formwork wood and broken bits of burnt bricks. Owing to abundance of natural rock material, the established quarry processes and the business motives, until now in Ethiopia.But in Ethiopia, the demandaggregatestood at 573,558m^3 per annum in 2018. The projected demand aggregates up to 2025 is linearly increasing by almost 10% per annum as per Ministry of Finance and Economic Development report [**4**]. This report also reveals that great disparity exists in production and demand of aggregates, pertaining geography of demand and supply, and owing to uncontrollable influences like varied environment and GDP progress. Often market prices shoot-up for aggregates because of shortage. Simultaneously, minimal knowledge on reduce, recycle and reuse is less recognized and the local construction parties that participate in the construction industry have lack of confidence on how the concrete waste can be recycled into new concrete making. The major problem that should be raised concerns the questions of: (I) what way the recycled aggregate concrete cluster aggregate engineering properties differ from crushed stone aggregate used in concrete? (II) What is the effect of recycled aggregate concrete cluster incorporation on fresh and hardened properties of concrete? (III) What is the possible optimum percentage replacement of recycled aggregate concrete cluster in concrete? Thus, answer to this question, there is an evident obligation of needsto investigate the engineering properties of RACC& the effect of replacing CSA with RACC on concrete properties, such as: workability, strengths, water absorption, sulfate attack and chloride –ingress, laboratory experiments were performed by replacing CSA with 0%, 10%, 20%, 30%, 40% & 50% RACC in concrete mixes through three phases and the results are obtained.

2. LITERATURE REVIEW

Reducing and recycling waste materials generated from construction and demolition by product have become the most important critical issues in 21st century. Improvements of new techniques for handling recycling waste material are one of the major areas of interest'sscholars in recent days.

The effects of RACC replacement of normal aggregates at different proportions for concrete have been reported since AD 1900 by Romans to build wall, roads and channels **[5].** The early studies have only focused on strength properties of concrete. For sure, the use of inclusion of RACC as partial replacement of CSA does modify many concrete properties, i.e. Fresh properties of concrete and hardened properties of concrete **[6],[7].**Though, various researches of many nations like Europe, America, Asia and some African nations' reports show that the effects of use of RACC as a partial replacement of normal aggregates in normal strength of concrete have their pros and cons, a firm scientific outcome was yet to be established. The preceding registered fact is currently of great concerns in India, British, America, Germany, France, Demarks and Japan regards to landfilling and otherwise handling techniques of demolition concrete activities. On the other hand, with ever increasing urbanization and subsequent housing demands, there exists always a shortage of aggregates. According to researchers have reported pertaining to India that aggregate shortage to the extent of 55,000 million m^3 in housing sector, where as the road sector requires an additional 750 million m^3 of aggregates**[8].** Most of the waste materials produced during demolished construction activities as-well-as industries are of major environmental pollution concern **[9].**Vast researches were carried out in Republic of China on RAC to explore their application for various secondary civil structures**.** Thus, the option of reuse of RACC in concrete as coarse aggregates has twin benefits as economical and to abate environmental impact by construction waste[**10**].

3. MATERIALS AND METHODS

The scope, and sequences of the present research packagewas divided into (3) phases as below.

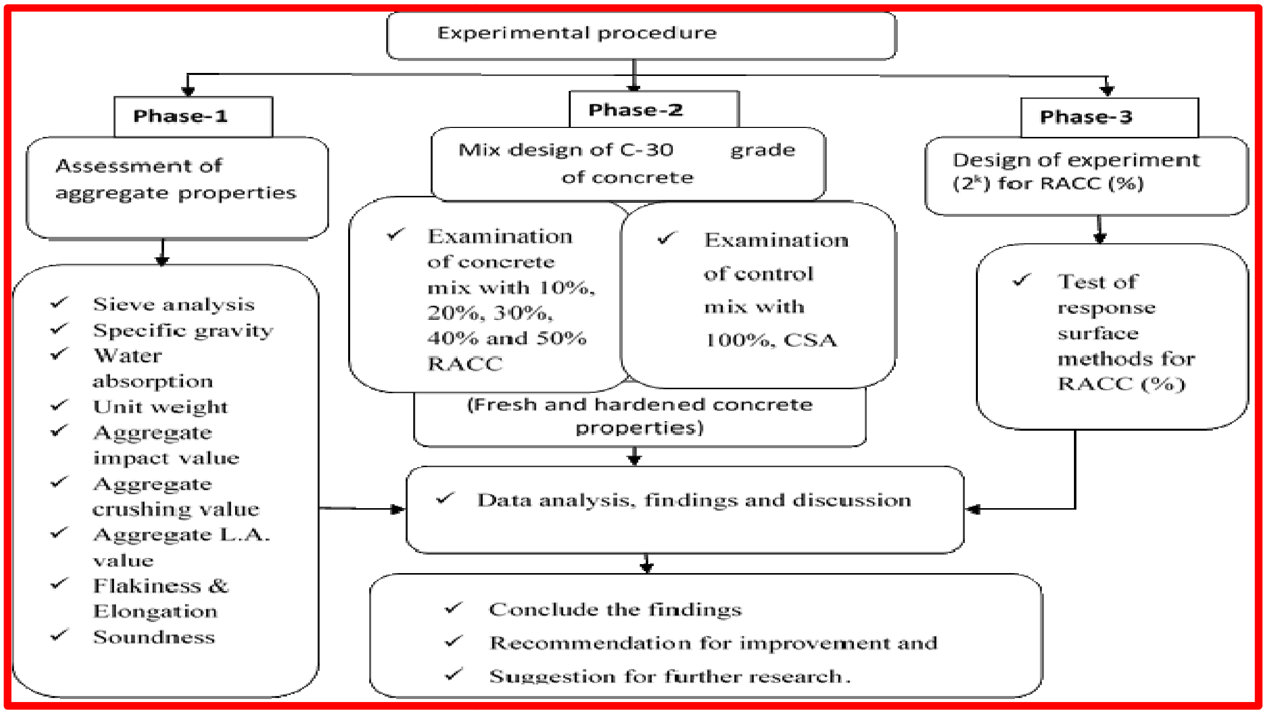


Figure 3.1: The flow chart of the experimental design

3.1 Material types and Source

Cement: the commercially available Portland Cement (PPC), with a relative density of 3.15 was purchased from local suppliers and used as binder material.

Aggregates: Three types of aggregates; like: fine, crushed stone and recycled concrete aggregate were used. Primary, the fine aggregate with the same source and quality (FM) were used for all types of concrete throughout this study. In Arba Minch, konso is the main source of sand for civil construction. Secondly, theCSA were purchased from specific quarry sites periphery of Arba Minch was used as coarse aggregates with 37.5mm of nominal sizes. Thirdly, theRACC was produced by demolishing concrete waste meant to assess the engineering properties of aggregate for different designs of concrete. The produced concrete aggregate cluster were subjected to size distribution and representative grade per fresh normal crushed stone aggregate (4.75~37.5mm) is formulated.

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

3.2 Mix Design of Concrete

Mix design was conducted as per as ACI211.1-91 was followed for design C-30 concrete grade as well as target slump was 25~100mm and necessary precautions to possible extent where be incorporated against variations from standard with respect to concrete ingredients **[11].**Since Ethiopian building code of standard EBCS-EN has not justified local trial mixes design procedure**[12].**

3.3 Casting and Curing Specimens

Prepared mix design concrete is poured in well lubricated mold. The compaction of concrete is achieved through compaction table vibrator. Six mixes with three 0.15*0.15*0.15m of cubes at 7^{th}, 14^{th}, 28^{th} and 56^{th} days and six mixes with two 0.5*0.1*0.1m of rectangular beams at 28^{th} days for each 0%, 10%, 20%, 30%, 40% & 50% replacement of RACC in concrete mixes. The mold along with casted concrete was covered with wet hessian cloth to retain the design mix water. Demolding of the concrete specimen was done after 24 hours and specimens were kept immersed under fresh water for curing. Curing water was changed every week.

3.4 Method of Data Analysis

Theconcreteproperties areinvestigatingand optimized by using response surface methodology (Ibtisam et al., 2017).The percent optimization of RACC wasgiven as below.

$$Y = 2^k ----Eq.1$$

- ✓ Whereas-Y is the performance of concrete or responses,
- ✓ 2-levels and K- $N_{\underline{O}}$ influences (RACC)
- ✓ From equation above the following polynomial regression was predicted.

$$Response\ = a0 + a1\,(\%RAC) + a2(\%RAC)^2 ----Eq.2$$

- ✓ Where: $a_{0,}$ a_1 and a_2 are regression coefficients
- ✓ % RAC is independent variable.

4. RESULTS AND DISCUSSIONS

The experimental results are discussed as follows:

4.1 Discussion on physical properties

Figure 3.2: Representative samples of RACC and CSA

The all-inclusivenumerical and percentage results of physical properties of recycled aggregate concrete cluster and crushed stone aggregateare summarized in Table 4.1.

Table 4.1: Results of physical properties for aggregates as per BS and ASTM 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 (%)			12.85	4.92
6.	Elongation index (%)		BS812	21.21	15.13
7.	Soundness test (%)		BS812	9.04	12.02

A. Particle Size Distribution

Particle size distribution of sample is of utmost importance in a view that voids percentage as well-as interconnection govern the engineering properties of particle aggregate matrix. The percentage of RACC and CSA tested sample observation results are graphical presented as below.

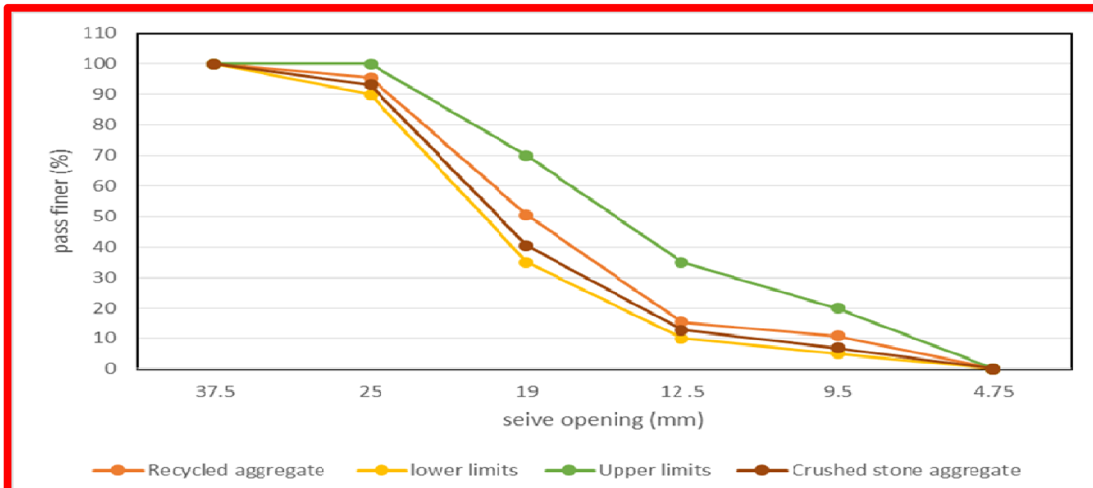


Figure 4.1: Gradation chart for coarse aggregates

Sieve analysis is carried out in accordance with ASTM C-33**[13]**and the present sieve analysis resulted in fineness modulus of 6.32 and 6.44for RACC and CSA respectively.

Sieve analysis results, graphically depicted abovein Figure 4.1, seems that the crushed stone aggregate has more uniformity than recycled aggregate concrete cluster, since crushed stone aggregate are output of controlled sieve in crusher and recycled aggregate concrete cluster are arbitrarily obtained.

B. Specific Gravity and Water Absorption

Specific Gravity: - From Table 4.1, the specific gravity of crushed stone aggregate is 2.67, while recycled aggregate concrete have 2.52 specific gravity, which is 5% less than crushed stone aggregate. These results are acceptable for CSA and RACChave specific gravity of 2.7 and 2.54 respectively, which produce a good quality concrete (Ubagaram J, et al., 2013). ASTM C-127 specifies the required specific gravity for concrete aggregates as2.60~2.70. Thus, the specific gravityof RACC and CSA are acceptable per ASTM C-127**[14].**

The RACC have lesser specific gravity, owing to the fact of attached light weight mortar probably to the tune of 15~30%**[15].**Thus, from specific gravity values, it is suspicious that RACC gives as-good results as CSA while concrete is produced.

Water absorption: -The water absorption of CSA and RACCis 0.4% and 2.29% by weight respectively, which was summarized in Table 4.1. It is clear from the specific gravity results that RACChave greater inherited voids within old attached mortar media. Depending on pore sizes of air/voids and the continuity of voids, water gets absorbed in pore capillaries. This is demonstrated in results which indicate that the RACC water absorption is roughly twotimes higher than CSA. The acceptable limits for aggregates water absorption is 0.2~4% as per ASTMC127.Thus,RACC and CSA of this research study have water absorption extent which is acceptable.

C. Unit weight (bulk density)

Compacted unit weight:-From result Table 4.1 clearly shows that, hebulks compacted unit weight of RACC and CSA are1550 kg/m^{3}and 1450kg/m^{3}while the bulk non-compacted unit weight of are 1430 kg/m^3 and 1400 kg/m^3 respectively. The increment of unit weight from non- compacted to compact in case of CSA is more than 8% RACC. This result implies that the CSAconstituent rearrangement during compaction happens effectively. The ASTM C-29 suggests 1200-1750Kg/m^3 as acceptable bulk unit weight for aggregates to be part of concrete**[16**]. In general, it is true that the bulk unit weight depends on how densely the aggregate is packed in a matrix and its specific gravity. The bulk unit weight of aggregate matrix also depends on their particle size distribution and shapes. Thus, the RACC has less unit weight as compared to CSA implying the presence of high voids in earlier hardened mortar present in the periphery of RACC.

D. Flakiness and elongation

The flakiness and elongation of aggregates was carried out as per ASTM 33**[17].**A flaky particle is one whose least dimension (thickness) of the aggregates. The BS812 suggested that the maximum allowable flakiness and elongation index for concrete aggregates 30%. From result Table 4.1,the flakiness and elongation indices for CSA andRACC respectively are 12.85% & 21.2% and 4.9% &15.1%. The results indicate that the CSA are angular and RACC are mostly spherical.It is true that higher flaky and elongated aggregates matrix will be having higher percentages of voids. The RACC matrix must have lower voids owing to their lesser flakiness and elongation indices, but because of relatively more porous mortar media adhering to RACC this effect might have been compensated.

E. Soundness of concrete aggregate

Table 4.1 clearly shows that, the sodium sulfate soundness losses results were 9% and 12% for CSA and RACCrespectively. Since RACC dis-integrated constituent remains within mortar matrix, these weathering cycles may not have significantly affected the concrete matrix. However, water can penetrate RACC greater than CSA particles, some degradation of the mortar matrix might have stripping. Therefore, the present study met the requirements specified by ASTMC88 as the maximum values of sulfate soundness loss are 16% of aggregate**[18].**Hence, RACC is durable and possible to use in concrete matrix preparation.

4.2 Discussion on mechanical properties

Table 4.2: Results of Mechanical properties for aggregates as per ASTM and BS standards

Types of testing	Methods	Test results of aggregates	
		Crushed stone(CSA)	(RACC)
Aggregate impact value (%)	BS812	14.01	27.04
Aggregate crushing value (%)	B812	17.04	29.00
Abrasion value (%)	ASTMC131**[19].**	15.24	27.75

A. Aggregate impact value

Table 4.2 indicates that the crushed stone aggregate and recycled aggregate concrete cluster have impact value of 14.01 and 27.04 respectively.

B. Aggregate crushing value

From Table 4.2 it was observed that the crushed stone aggregate and recycled aggregate concrete cluster have impact value of 17.04% and 29.00 %respectively.

The results point out that the crushed stone aggregate is by far stronger than recycled aggregate concrete cluster against crushing test. The impact and crushing value for recycled aggregates concrete cluster falls within the lower and upper limit requirements from normal aggregates BS812satisfy. RACCimpact and crushingvalue being under 50% implies their suitability to concrete work as-well-as structural concrete.

C. Abrasion resistance

The Los Angeles (L.A.) abrasion values per ASTMC 131 and C535 for CSA and RACCrespectively are 15.2 % and 27.75%, which are well below the specified structural concrete aggregate abrasion value of 30% and wearing surface concrete aggregate abrasion value of 50%. Thus, it is possible to utilize these aggregates for structural concrete.

D. Fresh and hardened concrete Properties

❖ **Workability**

The workability of all mixes was examined by using slump test, compaction factors test and Vee-bee consistency meter test as per ASTM**[20].**Toexamines the effect of replacement of CSA with RACC on workability.The overall testedend results summarized in Table 4.6.

Table 4.5: Mix ratio of concrete mixes for one meter cubic

Trail mix	Mix ratio of concrete (kg/m^3)				
	Cement	Fine aggregate	Crushed tone Aggregate	Recycled aggregate concrete cluster	Water
0%(control)	1	1.54	2.70	0	0.471
10%	1	1.54	2.44	0.26	0.474
20%	1	1.54	2.17	0.53	0.477
30%	1	1.54	1.90	0.80	0.480
40%	1	1.54	1.62	1.08	0.483
50%	1	1.54	1.35	1.35	0.485

Table 4.6: Test results for fresh properties of concrete

Trail mix designation	slump(mm)	Comp factor (%)	Vee-Bee(s)
Mix1 (0%)	75	0.9	11.6
Mix2 (10%)	70	0.88	11.3
Mix3 (20%)	66	0.87	11.01
Mix4 (30%)	56	0.84	9.71
Mix5 (40%)	50	0.83	8.32
Mix6 (50%)	45	0.81	8.00

Figure 4.2: performing of slump, compaction factor and Vee-bee time for workability

Observation of workability of all mixes was graphically presented in figure below.

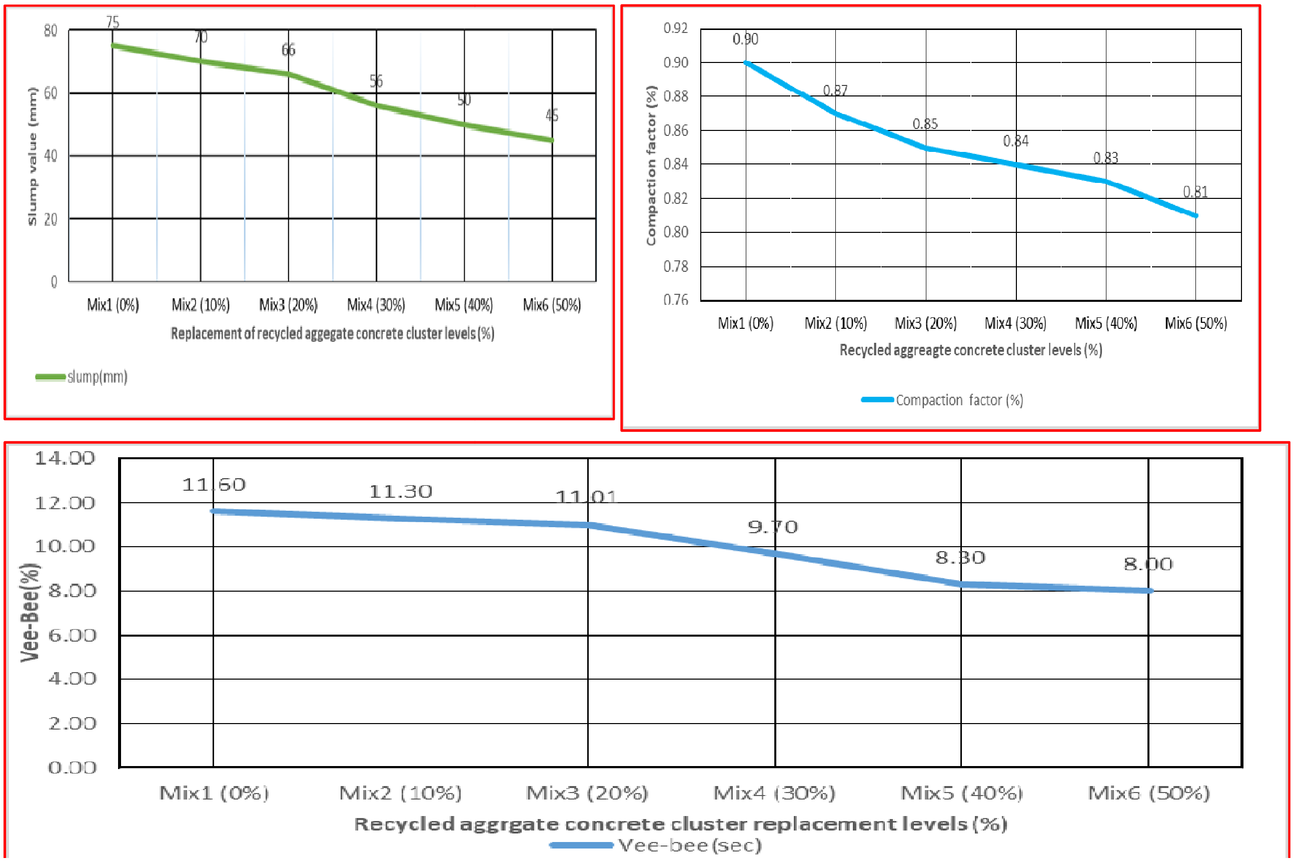


Figure 4.2: Effect of replacements CSA with RACC on workability of concrete

Once, the RACC affinity spheres overlap, the effect of percentage increment of RACC on workability reduces. Similarly, in cases of the Vee-Bee and compaction factor test results was decreased from 12 sec ~8.3 sec. and 88% ~82%, respectively. Researchers have stated that similar trends decreasing of workability due to increasing replacement levels of RACC as a partial substitution of natural [**21**]. Despite spherical shapes of RACC, which obviously would have led to diminish the inter-particle friction; decreased workability may be attributed to harsh surface characteristics of RACC and their percentage increment. The decrease in concrete slump, implying drop in workability, but RACC concrete can be attributed to plastic nature and cohesive property. On the other hand, Workability versus RACC inclusion indicated fairly two distinct slopes implying 20% RACC may not demand considerable additional water for a specific workability.

E. HardenedConcrete Properties

❖ **Compressive Strength Test**

The overall tested results aregiven in Table 4.7 and typical cubes to failures in compressive strength respectively.

Table 4.7: Test results for compressive strength of concrete

Test age (day)	Compressive Strength (MPa)					
	Mix1 (0%)	Mix2 (10%)	Mix3 (20%)	Mix4 (30%)	Mix5 (40%)	Mix6 (50%)
7	28.30	27.80	26.40	24.29	22.07	20.44
14	35.54	34.56	33.34	31.33	29.41	27.83
28	38.61	37.85	36.72	34.02	32.11	30.56
56	46.31	45.52	44.44	40.84	36.80	34.07

Figure 4.3: Compressive strength of concrete

ready for testing and failure surface after testing

Graphical presentation of compressive strengths test results for C-30 grades of all concrete mixes preparation at 7th, 14th, 28th and 56th ages are presented in figure 4.4.

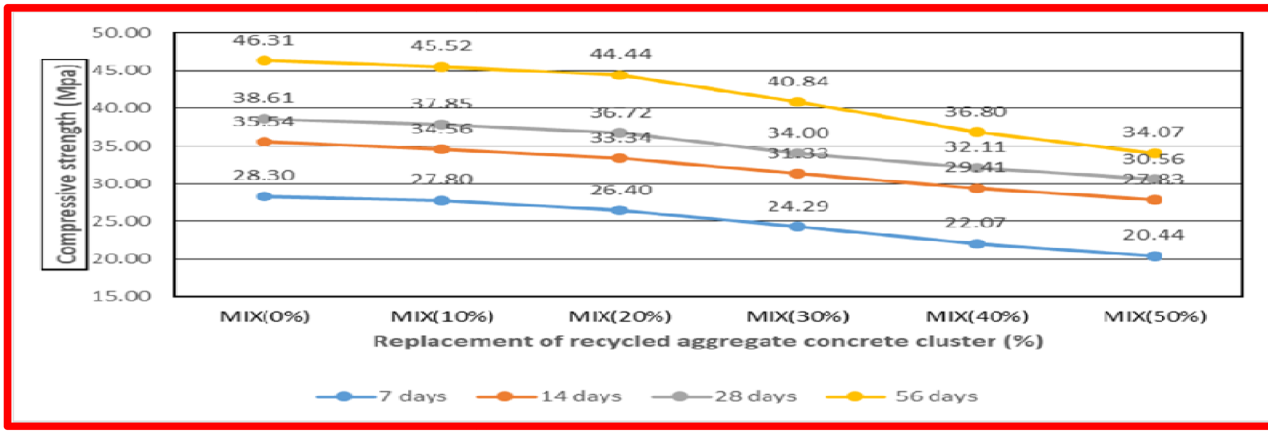


Figure 4.4: Effect of replacement of CSA with RACC on concrete compressive strength.

The percent decrease in compressive strength of concrete for 10%, 20%, 30%, 40%, and 50% of concrete mixes as compared to control concrete was 2%, 5%, 13%,14.25%, &16.42%, respectively. Similar trends were alsoobserved, researchers have stated that similar trends of decreasing of compressive strength due to increasing replacement levels of RACC as a partial substitution of natural aggregate **[22].**When partial replacement of natural aggregate with RACC was prepared. Though, without doubt in wet stage RACC attract more cement paste by virtue of their more hygroscopic character on harsh surface, the hardened concrete strength always decreased as RACC percentage increased. Simultaneously, it is also true that, RACC have lowered specific gravity when compared with CSA because of adhered mortar media around them. Secondly, surface area of combined aggregate media increases as recycled aggregate concrete cluster replacementpercentage increases, since recycled aggregate concrete cluster are finer than CSA. As cement content is constant for all mixes, at higher replacement levels of RACC, cement paste becomes not enough to coat all aggregate particles properly. Thus, the porosity of concrete media increases with increasing inclusion of RACC, consequently decreasing the compressive strength of concrete.It can bealso observed that from test results, even if the concrete mix type of 10%~50% obtained less normal compressive strength, they attained the desired strength at the age of 28 days with the compressive strength of 30.51~37.85 MPa, respectively.

❖ **Flexural Strength Test**

Table 4.8: Test results for flexural Strength of concrete

Test age (day)	Flexural Strength (MPa)					
	Mix1 (0%)	Mix 2 (10%)	Mix3 (20%)	Mix4 (30%)	Mix5 (40%)	Mix6 (50%)
28	**4.83**	**4.585**	**4.48**	**4.27**	**4.07**	**3.44**

Figure 4.5: Flexural strength of concrete

The graphical presentation of flexural strength at 28th days is given in below graph.

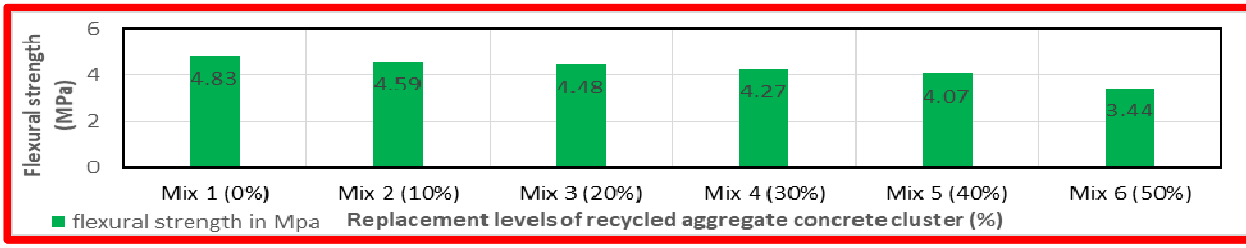


Figure 4.6: Effect of replacement of CSA with RACC on concrete flexural strength

The results presentation in Table 4.8 and Figure 4.4 above, experiment results show that at 28th days, the flexural strength of normal mix was 4.834MPa, while the flexural strength RACC, at 28th days as compared to normal concrete mixes was 5%, 8%, 13%, 19% & 40% respectively.It should be noted that the present decline of flexural strength of concrete was higher than as compared to percent decrement in compressive strength at higher replacement levels.Similar types of decreases of flexural strength due to inclusion of RACC as partial replacement of CSA are also reported by **[6].**Overall, it may be concluded that twenty percent crushed stone aggregate replacement by RACC may be commented as optimal with meager concrete quality compensation, since the further recycled aggregate concrete cluster percentage increment have drastic adverse effect on thus obtained concrete media characteristics.

❖ **Chloride -Ingress**

The chloride –ingress of different concrete mixes, was evaluated at age of 56th days to examine the effective of partial replacement of CSA with RACC are given below.

Figure 4.7: Solution of sodium chloride and sodium sulfate, and concrete specimens ready to dipping

Table 4.9: Results of chloride ions ingress into recycle aggregate concrete at 56th day

Trail mix	Average of initial compressive strength) cured in H_2O (MPa	Average of compressive strength cured in sodium chloride (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

The chloride ingress effect is evident from the results illustrated in Table 4.12which indicates loss of compressive strength cured in sodium chloride solution as 7%, 8.8%%, 10.6%, 12.3%, 21.4% & 29.6% of original strengthin numerical values respectively for 10%, 20%, 30%, 40% and 50% CSA replaced by RACC. Increase in chloride ingress and subsequent obvious decrement in compressive strength of concrete can all be related to lowered density. The old mortar attached to RACC has higher porosity, which accommodates chloride ingress easily and thereby promotes decrement in compressive strength.

F. Sulfate Resistance

Table 4.10: Results of sodium sulfate into recycled aggregate concrete cluster cubes

Trail mix	Average of initial compressive strength cured in H_2O (MPa)	Average of compressive strength cured in Na_2SO_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

Table above gives the loss examine of sodium sulfate attack on concrete cubes made from both CSA alone and partial RACC was carried out in specifiedcompressive strength of concrete containing 10%, 20%, 30, 40%, and 50%

RACC was decreased by about 4%, 10%, 13%, 16%, 23% and 33% respectively as compared to reference concrete. Thus, the study resultsindicate that there is a direct relationship between %RACC and loss of compressive strength.

G. Water Absorption

The final results are summarized in Table 4.10 below.

Table 4.11: 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 56th 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

Graphical representation of water absorption results of concrete mixes at different replacement levels was given in figure below.

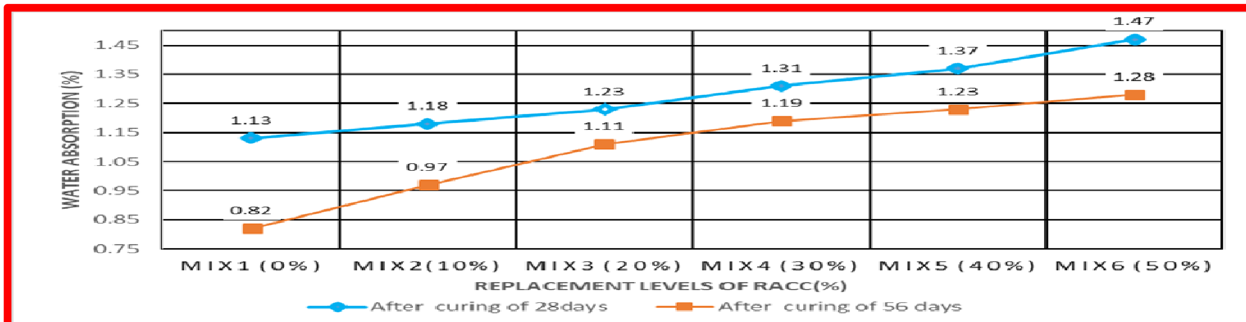


Figure 4.8: Water absorption results of concrete mixes at 28th and 56th days

From result Table 4.14and Figure 4.8, it can be observed that the specimens cured for28th days, water absorption of concrete mix with 10%, 20%, 30%, 40% and 50% RACC was1.17%,1.23%, 1.31%, 1.36% and 1.41% respectively.Whereas, after 56 days of curing, the water absorption of normalconcrete was 0.82%. The water absorption for concrete with 10%, 20%, 30%, 40% and 50% of RACC inclusion in place of CSAwas 0.97%, 1.11%, 1.19%, 1.23% and 1.28% respectively. In over-all, water absorption went on growing as %RAC inclusion increased, weather it is of absorption of water by 28th day or 56thday cured samples.

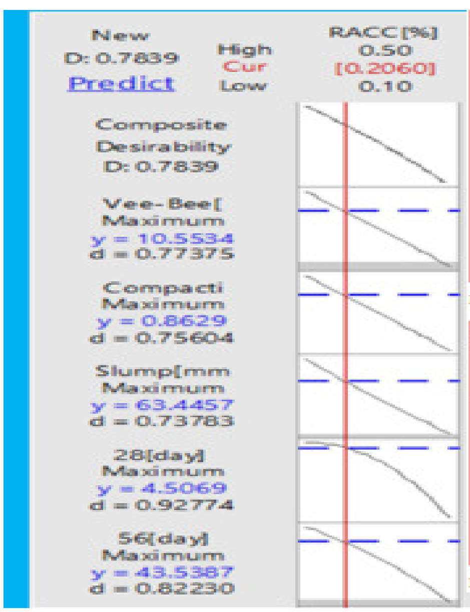
4.3 Phase Three:RACC inclusion optimization

From the software model,the optimum value of RACC calculated and the regression analysis using %RACC as independent and performance of fresh & hardened concrete properties as the dependent variable.

Table 4.12: Performance criteria and regression equation for concrete properties

Performance measures (y)	Polynomial regression equations for concrete properties Take on RACC(%) coded as "x"	
Slump(mm)	$14.3x^2- 74.60x +78.20$	
Compaction factors (%)	$x^2-0.18x+0.90$	
Vee-Bee(sec)	$-1.1x^2- 8.65x+ 12.38$	
f_{c7}-days	$-5x^2 - 16x +29.58$	
f_{c14}-days	$-3.57x^2- 15.36x + 36.28$	
f_{c28}-days	$1.4x^2- 20.06x + 40.12$	When the "X" values
f_{c56}-days	$-27.1x^2- 14.5x + 47.68$	Range between:
f_{fr28}-days	$- 7.36x^2+ 1.70x +4.47$	St. $1<5x<2.5$

From 10~50% intervals the polynomial regression equations for concrete properties was developed by substituting each parameters into slump, compaction factor, Vee-Bee, compressive and flexural strength are respectively $14.3x^2$-74.60x +78.20, x^2-0.18x+0.90,-1.1x^2- 8.65x+ 12.38,-5x^2 - 16x +29.58,-3.57x^2- 15.36x + 36.28, 1.4x^2- 20.06x + 40.12, -27.1x^2- 14.5x + 47.68 and - 7.36x^2+ 1.70x +4.478were graphical and numerical possible optimal solution are shown in the following Figures.

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positive variables X;
Variables Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z;
Equation obj1,obj2,obj3,obj4,obj5,obj6,obj7,obj8, cl;
obj1..Z1=E=14.3*X*X-74.60*x +78.20;
obj2..Z2=E=x*x-0.18*x+0.900;
obj3..Z3=E=-1.1*x*x- 8.65*x+12.38;
obj4..Z4=E=-5*x*x-16*x+29.582;
obj5..Z5=E=-3.57*x*x-15.36*x+36.28;
obj6..Z6=E=1.4*x*x-20.06*x +40.12;
obj7..Z7=E=-27.1*x*x-14.5*x +47.68;
obj8..Z8=E=-7.36*x*x+ 1.70*x +4.478;
cl..5*x=g=1;
Model Assefa/all/;
Solve Assefa using NLp MAXIMIZING Z5;
Display x.L,Z1.L,Z2.L,Z3.L,Z4.L,Z5.L,Z6.L,Z7.L,Z8.L;
```

Figure 4.11: Equation ready for solve by using non-linear program from GMAS

```
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n


----      15 VARIABLE X.L                 =        0.200
             VARIABLE Z1.L                =       63.852
             VARIABLE Z2.L                =        0.904
             VARIABLE Z3.L                =       10.606
             VARIABLE Z4.L                =       26.182
             VARIABLE Z5.L                =       33.065
             VARIABLE Z6.L                =       36.164
             VARIABLE Z7.L                =       43.696
             VARIABLE Z8.L                =        4.524
```

Figure 4.12: Optimum solution of recycled aggregate concrete cluster from GMAMS

Figure 4.9: Optimization results from analyses and validation of experiment

From experimental data analysis figure 4.9 above, it can observean optimum value of slump, compaction factor, Vee-Bee,compressive strength and flexural strength of concrete properties by use of 21% RACC was

63.45mm,0.86%,10.55sec, 43.54MPa and4.51MParespectively. The above results imply that 10%RACC in concrete matrix may have resulted in scattered isolated presence of them along with their affinity sphere for water present in cement paste distributed in new fine aggregate mix. 20%RACC will definitely bring their isolation from far discrete to closer. 30%RACC replacement might have brought their influences overlapping as-well-as absorbing of water to too much or deficient extent for overall mix matrix to achieve strength. Thus, more than 20%RACC have drastic effects on fresh and hardened as well as rest all concrete properties.

4.4 CONCLUSION

1. The values of quality expressing engineering property like specific gravity, rodded bulk density, impact value, crushing value, abrasion values for recycled aggregate concrete cluster are lower mostly bythirteen ~ fifteen percent than crushed stone aggregate, but their absolute values are acceptable for structural concrete as per ASTM and BS standards.
2. Despite having made water absorption adjustment in mix design for recycled aggregate concrete cluster, concrete workabilityreduced (slump, compaction factor and Vee-Bee by 7~14%, 3~4% and 3-5% respectively) from control concrete at 20% recycled aggregate concrete cluster. Thus, the inclusion of more than 20%RACC can be attributed to RACC gaining discrete phase to cluster phase in concrete.
3. The compressive and flexural strength of hardened concrete decreased by 5% ~ 8% and 19% ~ 30% at 20% and 30~50% RACC inclusion in comparison with total CSA concrete. Increment up to 10.59%, 12.95% and (1.23% & 1.11%) were observed for chloride, sulfate attacks and water absorption capacity respectively at 20% recycled aggregate concrete cluster.Therefore, compromise in compressive and flexural strength, chloride, sulfate attacks and water absorption capacity change 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.
4. GAMS and MINITAB software analysis exercise on research findings indicate that 20.60% recycled aggregate concrete cluster inclusion option is optimal with meager or minor quality compromise which is comfortable.

ACKNOWLEDGMENTS

First of all, I would like to thank the Almighty of GOD, who gave me the commitment and tolerance to pass various obstacles and come up with the accomplishment of this research, Secondly and foremost, deepest gratitude goes to my advisor Rajish A (Dr.), for his supervision, giving constructive comments, valuable guidance, and advice on several issues, and also for spending his precious time for improving the quality of this research. I wish to express my thanks also to appreciate my laboratory assistance for their willingness to helps that, I raised. Especially,my special thanks go to Construction Technology and Management department staff members for their support in guidance and clarification on the concepts under study.

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