Recyled Concrete Aggregate (RCA) in Structural Concrete of Developing Nation: A Cace Study of Ethiopian Construction Industry

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Abstract: Today, the booming construction in Ethiopia is leading to an increased demolition of concrete structures whereby these demolished structures are disposed at landfills. The current practice is creating a huge amount of waste which is environmentally unfriendly and is becoming the main source of pollution in communities. This paper discusses the potential use of demolished concrete from site tested specimens as a recycled aggregate material for new structural concrete. The mechanical, physical and chemical properties of RCA are studied to understand the suitability in the production of recycled concrete. Tests including gradation, unit weight, soundness, density, and abrasion will be conducted to assess RCA properties. Since the percentage of RCA govern the strength of concrete, a C25 concrete is mixed by the ratio of 25%, 50% & 100% RCA with and without water reducing admixture and a control mixture composed of natural aggregate. The output of this study will highly impact the growing construction industry and communities in Ethiopia thereby reducing waste, saving cost, conserving natural aggregates, building capacity and setting quality standards.

Key words: Recycled Concrete Aggregate (RCA), Demolition, Structural Concrete, Comprehensive Strength

I. INTRODUCTION

The construction of buildings, bridges, and roadway infrastructures continues to increase in the twenty-first century, especially in areas with growing populations. Old structures require maintenance and replacement to meet the level of service and demand of the growing population. Today, the construction industry outpaces the economy growth constituting 11% of worlds GDP which is predicted to increase to 13.2% by 2020. As modern construction continues, two pressing issues become apparent to societies: an increasing production of construction waste and an increasing demand for construction materials.

On one hand, in a typical concrete production setting, out of 1000m^3 concrete cast, an average of 2-4$m^3$of concrete is used for conducting cube tests [1]. This concrete after being tested for its compressive strength is thrown as a land fill. Based on a Central Pollution Control Board (CPCB) report from Delhi, India, 48million tons solid waste is produced where 14.5 million ton waste is produced from the construction waste sector. Out of this waste, only 3% is used in the construction of embankments.

On the other hand, the need for new aggregate is increasing due to the increasing construction industry material demand. As of 2005, six billion cubic meters of concrete are made each year where countries like China currently consume about 40% of world cement production (Wikipedia, 2007). In United States, the Federal Highway Administration estimates that two billion tons of new aggregate are produced each year (FHWA, 2004). This demand is anticipated to increase to two and a half billion tons each year by 2020. With such a high demand for new aggregates, there is a huge concern of limited sources of natural aggregate and availability of new sources.

To address the increasing demand for new aggregates and minimizing the production of waste from demolished concrete structures, many countries have begun to recognize the use of a more sustainable solution through recycling of demolished concrete as aggregates in new concrete, or referred as recycled concrete aggregates (RCA). The solution helps to address the question of how

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to sustain modern construction demands for aggregates as well as help to reduce the amount of waste that enters already over-burdened landfills.

Moreover, recycle concrete aggregates can be used as a raw material for rip-rap, soil stabilization, pipe bedding, landscape materials, and even as an aggregate for base course material. Thus, this study will focus on the possible application of recycled concrete aggregates for use in structural concrete production.

II. OBJECTIVES AND SCOPE OF STUDY

The objective of this study is to i) determine properties of recycled concrete aggregate and asses influence of fresh and harden concrete using RCA, ii) identify the economic feasibility of recycled concrete and determine the feasible percentage use for construction, iii) reduce the impact of waste materials on environment and find out ways of saving cost.

The scope of this study includes performing literature review; developing mix designs for both conventional and RAC; evaluating the fresh and hardened properties of several RAC and conventional concrete mixes; designing and constructing small and full-scale specimens; testing the specimens to failure; recording and analyzing data from tests; comparing test results to current guidelines and previous research findings; developing conclusions and recommendations of this study. While the study will look in the above aforementioned activities, financial, human resource and time constraint are the major limitations of this study.

III. ADVANTAGES AND DISADVANTAGES OF RCA

According to Tushar R Sonawane[2], RCA have the following advantage and disadvantages.

Advantage of RCA

- Used for construction of precast & cast in situ gutters.
- Cost saving: No detrimental effects on concrete & it is expected that the increase in the cost of Cement could be offset by the lower cost of Recycled Concrete Aggregate (RCA).
- Save environment: No excavation of natural resources & less transportation. Also less land is required.
- Save time: There is no waiting for material availability.
- Less emission of carbon due to less crushing.
- Up to 20% replacement of natural aggregate without a need for additional testing for all concrete up to a characteristic strength of 65 MPa, as per Dutch standard VBT 1995 is permitted.

Disadvantage of RCA

- Less quality (e.g. compressive strength reduces by 10-30%).
- Duration of procurement of materials may affect life cycle of project.
- Land, special equipment machineries are required (more cost).
- Very high water absorption (up to 6%).
- High shrinkage and creep

IV. METHODOLOGY

The study area of this paper is on the laboratory demolished concrete cubes. Samples are collected from Bahir Dar Institute of technology and Amhara Rural Road Authority laboratory units and crushed with a jaw crusher. Depending on specific objectives this research study has six tasks.

Task 1 Perform Review of Literature

The goal of the literature review is to become familiarized with properties of RCA, testing methods and results from previous studies. This knowledge is used for a better understanding of the behavior of the specimens, to avoid mistakes, as well as to provide support for comparisons.

Task 2 Sample Preparation

Natural aggregate from Zenzelima, Site tested concrete (RCA) broken on 7 and 28 day, crashed sand from Bikolo Abay, HRWR (High Range Water Reducer; megaflop sp1), Mossobo OPC (CEM I 42.5) cement and tape water are prepared .

Task 3 Material Testing

In this task different type of testes like gradation, unit weight, specific gravity, water absorption, dust content, silt content of aggregates(both natural and recycled), and sand are conducted to check for compliance with the current standards.

Task 4 Mix design

By the inputs from task 3 according to ACI 211.1-91 economical mix design is made for a 0%, 25%, 50% 100% RCA with and without admixture.

The maximum size of course aggregate and fine were determined to be 28 & 4.75mm respectively. The slump of concrete is considered to be from 25-75mm. The w/c was primarily determined to be 0.48 for all mixes without admixture and 0.35 for all mixes with admixture but since the slump 100% RCA for both cases is zero the w/c is latter changed to be 0.52 for mixes without admixture and 0.48 for mixes with admixture.

Task 5 Casting and Testing of Concrete

Concrete will be casted properly with 150mm*150mm dimension and tests will be made both on fresh and hardened concrete. Slump of each trial is measured for a fresh concrete and comprehensive strength according to

American Society for Testing Materials (ASTM C39C39M) [10] and dry density of hard concrete is made for a 3,7,14 and 28 day harden concrete are measured and recorded for further analysis.

Task 6 Data Analysis
In this task test results from task 5 will be carefully analyzed. Test results of 25%, 50% & 100% RCA mixes are compared with each other and with a control or 0% RCA mix. The average test results of compressive strength of 3, 7, 14& 28 day concrete, slump of each mixes and percentage of RCA are taken for comparison and analysis.

Task 7 Findings, Conclusions and Recommendations
This task synthesized the results of the previous tasks into findings, conclusions, and recommendations on the concrete behavior and response of RCA.

V.REVIEW OF LITERATURE

Out of the total construction demolition waste, 40% consists of concrete, 30% ceramic's, 5% plastics, 10% wood, 5%metal, & 10% other mixtures.

Properties of RCA concrete
When replacement of RCA is increased in concrete mixes, the slump of concrete mixes is decreased. It was expected because recycled aggregate is high in water absorption [7] revealed that mortar over RCA is lead to low slump of RAC. The density of recycled aggregate used is lower than the density of normal aggregate. Porosity of recycled aggregate is also much higher than those of natural aggregates [5]. Generally, the grading curves for recycled aggregate are continuous and they have similar fines modulus for equivalent fraction [5].

Recycled aggregate concrete (RAC) is concrete made from recycled aggregate. It was found that the workability of fresh RAC decreases with an increase an increase in recycled aggregate due to water absorption of mortar adhered to recycled aggregate [4]. The test results showed that the flexural, compressive and split tensile strength of the recycled aggregate concrete is found to be lower than the natural aggregate [6]. Normally as RCA replacement increased, compressive strength will decrease [7]. It was found that RAC with 100% replacement of recycled aggregate have a decrease of 13% in flexural strength compared to normal concrete [3].

Selected International Experience on RCA

A) Scotland – About 63% material has been recycled in 2000, remaining 37% material being disposed in landfill and exempt sites. The Government is working out on specifications of recycling and code of practice. Attempts are being made for establishing links with the planning system, computerizing transfer note system to facilitate data analysis and facilitating dialogue between agencies for adoption of secondary aggregates by consultants and contractors. By August 2012 Zero Waste Scotland has launched a directory of 'high quality recycled aggregate producers' in order to inspire buyer confidence and promote best practice. Converting construction and demolition leftovers (such as waste concrete, brick and asphalt) into recycled aggregates is now a 'standard practice' in Scotland. This practice, however, while diverting waste from landfill, does not always result in aggregate products that have consumer confidence.

B) Gaza- As a result for the huge amounts of debris after the last war on Gaza Strip 2009, and due to the shortage of the natural materials in addition to the limited size of municipal landfill sites to accommodate large quantities of debris, the recycling of these materials gains a lot of interest and a potential uses were discussed and studied. According to the governmental information: There are 4 crushers in Gaza strip working with a rate of 3300 ton/day, and the amount of debris need to be crushed is estimated about 1,200,000 tons [8]

C) Netherlands – More than 40 million Construction & Demolition waste is being generated out of which 80% is brick and concrete. A number of initiatives taken about recycling material since 1993, such as prevention of waste, stimulate recycling, promoting building materials which have a longer life, products which can be easily disassembled, separation at source and prohibition of Construction & Demolition waste at landfills.

D) USA – there is 650M ton Construction& Demolition waste per year. It accounts for about 22% of the total waste generated in the USA. Reuse or recycling of Construction & Demolition waste is one component of larger holistic practices called sustainable or green building practice. Green building construction practices may include salvaging dimensional number, using reclaimed aggregates from crushed concrete, grinding drywall scraps, to use as soil amendment at the site. Promoting "deconstruction" in place of "demolition". Deconstruction means planned breaking of a building with reuse being the main motive.

E) Japan – Much of the R&D in Japan is focused on materials which can withstand earthquake and prefabrication. 85 million tons of Construction & Demolition waste has been generated in 2000, out of which 95% of concrete is crushed and reused as road bed and backfilling material, 98% of asphalt + concrete and 35% sludge is recycled.

F) Singapore – Construction & Demolition waste is separately collected and recycled. A private company has built an automated facility with 3, 00,000 ton per annum capacity.

G) Hong Kong – Concrete bricks and paving blocks have been successfully produced impregnation of photo catalyst for controlling Nox in ambient air.

H) India – Use for embankment purpose in bridges, roads etc. up to 3% to 4% of total production.

I) Ethiopia-there is no trend of using RCA.

VI. Results and Discussions

Different tests are conducted for the demolished concrete according to ASTM standard.

Table 1- Test Results of RCA and Natural Aggregate

No	Item	RCA	Natural
1	Bulk Specific Gravity,	2.65	2.8
4	Water Absorption (%)	3.54	1.89
5	Bulk density(kg/m^3)	1510	1653
6	Moisture content (%)	2.34	0.22
7	Gradation	good	poor

Gradation of RCA
It is found that recycled concrete aggregate are reduced to various sizes during the process of crushing and sieving, which gives the best particle size distribution. The gradation of natural aggregate is not good since it needs serious of crushing stages.

Specific Gravity
The specific gravity in saturated surface dry condition of recycled concrete aggregate was found to be 2.65 which is less than natural aggregate but satisfying the standards. If specific gravity is less than 2.4, it may cause segregation; honeycombing & also yield of concrete may get reduced.

Water Absorption
The RCA from demolished concrete consist of crushed stone aggregate with old mortar adhering to it, the water absorption is measured to be 3.54 which is relatively higher than that of the natural aggregates. Thus the water absorption results are satisfactory. This will tend the concrete to high degree of shrinkage.

Bulk Density
The bulk density of recycled aggregate is 1510kg/m^3 which is lower than that of natural aggregate but within the standard thus results is satisfactory; due to less Bulk Density the mix proportion for natural and RCA concrete gets affected.

Properties of fresh and harden RCA concrete

Slump of RCA concrete
100% RCA concrete totally loses its slump as compared to natural aggregate concrete with the same w/c. To get the same slump of 100 % RCA with the conventional concrete additional water which reaches up to 5.5% is required. Hence the w/c gets affected due to very water absorptive nature of RCA. Using High range water reducer for RCA will help to attain the required slump with the same w/c.

Table 2 Slump Test Results of Fresh Concrete

Mix	% of RCA	Slump(mm) with different w/c		
		0.35	0.48	0.52
C[1]	0		25	
RAC-W[2]	25			45
	50		0	34
	100			20
RAC-A[3]	25			50
	50			40.5
	100	0		35

1- Control mixture (0% RCA)
2- Recycled aggregate concrete without admixture
3- Recycled aggregate concrete with admixture

Comprehensive strength of RAC
The average compressive strengths of cubes for both RCA and natural aggregate at the age 3, 7, 14 & 28days and reported in Table 3. As expected, the compressive strength of RAC is slightly decreased with an increase in proportion of RCA. The amount of reduction in strength depends on replacement ratio and w/c ratio. As per test results a demolished concrete (RCA) from laboratory cubes can be used for new concrete up to 50% ratio with natural aggregate by maintaining their desired strength and workability. 100% RCA is not workable and the concrete has void which will decrease the strength unless it is pre soak or saturated surface dry before mixing.

Table 3 Comprehensive Strength Test Results

Mix	% of RCA	W/C	Strength of concrete (Mpa)			
			3	7	14	28
C	0	0.48	20.24	25.2	29.29	33.1
RCA-W	25	0.52	22.22	24.92	26.3	29.74
	50	0.52	20.29	23.78	25.68	28.77
	100	0.48	20	19.19	22.01	25.75
		0.52	16.69	22.28	24.1	22.13
RCA-A	25	0.48	17.66	25.48	27.8	31.2
	50	0.48	19.52	23.69	26.32	29.71
	100	0.35	19.92	20.2	25.37	26.18
		0.48	18.18	24.92	25.1	26.33

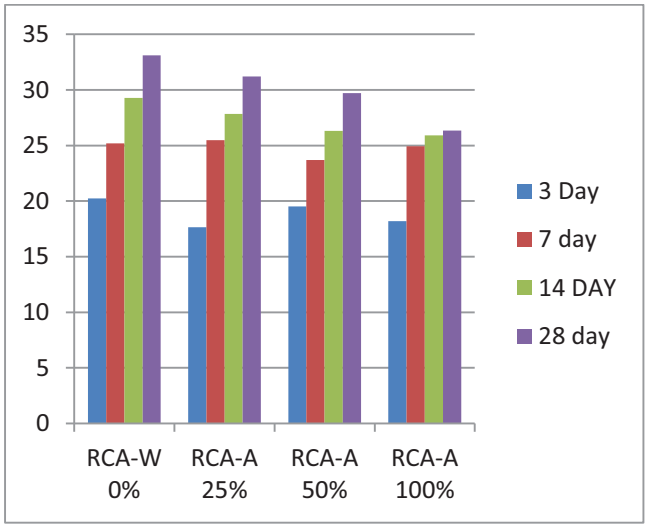

Fig 1. Comprehensive strength Vs % RCA with admixture

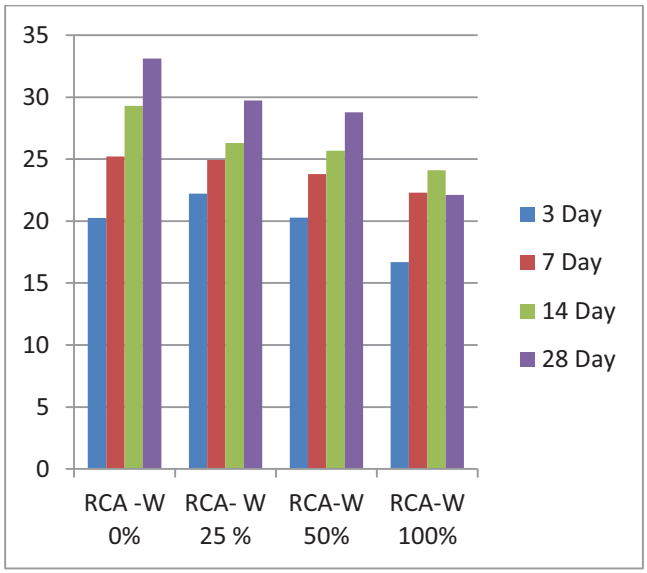

Fig 2 Comprehensive strength Vs % RCA without admixture

VII. CONCLUSIONS

- The workability of RAC decreases with a increase of amount of RCA due to absorptive nature of adhered mortar. The concrete have voids and it has high water absorption capacity. That makes the concrete not to have fair surface finish. Addition of high range water reducer can increases workability of RAC as a result the surface finish of recycled aggregate concrete can be improved significantly.

- RCA from laboratory cubes can be used for structural concrete production up to 50% ratio for site tested concrete specimens. The strength of RAC decreases with an increase in percentage of RCA. The use of high range reducer can increase the strength of recycled aggregate concrete since it reduces the water cement ratio keeping the workability of concrete good.

- Various recycled aggregate tests results such as specific gravity and unit weight are satisfactory as per ASTM standard. This implies recycled concrete aggregates have a potential to be used for new structural concrete production.

- The energy consumption to crash RCA is much more less than virgin aggregate. This makes RCA to be cheap and environmentally friendly by reducing waste disposal and by decreasing Co_2 in the process of crashing.

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