International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 08 | Aug 2019 www.irjet.net p-ISSN: 2395-0072

Experimental Review for Suitability Study of Natural Coarse Aggregates (stone chips) and Recycled Coarse Aggregates in Structural Concrete

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Abstract - *Recycled aggregates derived from the construction and demolition waste have potential efficacy in civil construction sector as a substitute to natural aggregate. It not only preserves the natural resources but also lessens the space required for landfill disposal. Thus Recycled Course Aggregates proves itself as environment friendly construction materials. The Principle aim of the study was to determine the suitability of using Recycled Concrete Aggregate (RCA) in different purpose at various structures. The experimental study was accomplished in this work to determine the suitability of using Recycled Concrete Aggregate (RCA) in structural concrete based on a better understanding of its strength, stiffness and durability. This study presents the suitability of recycled concrete aggregate (RCA) over natural aggregates on the key fresh and hardened properties of concrete. Recycled concrete aggregate (RCA) was used to make high-workability concrete replacing with 0 %, 50% and 100% natural coarse aggregate (NCA) by weight. The slump and slump flow of fresh concretes were determined to ensure their workability. In addition, Sieve analysis, Graduation, Density, Impact Value, Crushing Value, the compressive and splitting tensile strengths of hardened concretes were determined. The test results revealed that RCA significantly decreased the workability of concrete and No major differences in the mechanical behavior and durability performance were found when compared with NAC for the same strength class of concrete. It was observed that RCA also imparted change in the compressive strength and splitting tensile strengths of concrete. The concrete with 100% RCA produce 36% lesser compressive strength and 11.5% lower splitting tensile strengths than the natural concrete at the age of 28 days. However, considering the economical State recycled concrete is 24% cost effective than normal concrete when RCA is free of cost. Therefore, recycled concrete has been proved advantageous in low service load structures such as pavement and road, low risk buildings, in landscaping and in retaining walls since overall project cost can be reduce by using recycled aggregate.*

***Key Words*: Natural Coarse aggregate (NCA), Recycle Coarse aggregate (RCA), Structural concrete, Compressive strength, Tensile strength, Hardened Concrete.**

1. INTRODUCTION

The potential for demolition wastes to be recycled in the production of new concrete products has been comprehensively studied in academic settings and successfully demonstrated in the field via test cases. In emerging metropolitan areas that host numerous economic benefits, the use of Recycled Aggregates in all capacities alleviates the encumbrance of demolition waste handling on municipalities that manage landfills. Current research indicates promising economic, waste management, and engineering potential of use of Recycled Aggregates in concrete applications in Bangladesh. The RCA found from the aforementioned sources has mostly been used to yield ordinary or normal-workability concrete. In contrast, a few studies have been performed to produce concrete using the RCA found from tested field-cast concrete and other sources. In this research, the RCA found from the tested field-cast concrete specimens was used to generate concrete substituting 0, 50 and 100% NCA by weight. Aggregate grading, aggregate impact value, slump and slump flow of freshly mixed concretes were determined to ensure high workability and serviceability. In addition, the compressive strength and splitting tensile strength were determined to observe the effects of RCA and its suitability in particular conditions.

2. RESEARCH SIGNIFICANCE

Construction and pulling down wastes produced from demolished buildings and infrastructures form one of the largest waste streams in many developed countries like Bangladesh. The excess and tested concretes also yield a significant amount of construction waste, particularly in developing countries. The recycling of construction and demolition wastes as RCA tenacities disposal problem lessens landfill space, conserves natural resources, declines transport expenses, diminishes environmental pollution, and protects ecological balance. The current study booms the use of RCA obtained from the tested field-cast concrete specimens to generate new concrete. The experimental investigation has accentuated the effects of coarse RCA on a range of fresh (slump, slump flow), mechanical (compressive and splitting tensile), and durability (permeable voids) properties, and thus assessed its suitability for use in high-workability concrete. The research findings are expected to embolden the sustainable development by using RCA in structural and non-structural concretes.

3. AGGREGATE PROPERTIES

In this section the properties of RCA as compared to NCAs are discussed. An identification of how the aggregate changes after already being used in concrete can get better the ability to describe why RCA may perform differently when used in new concrete than NCA. The density, porosity, and water absorption of the aggregate, the shape and gradation of the aggregate, and the aggregate resistance to crushing and abrasion are the key aggregate physical and mechanical properties that are obtained.

Figure-1: Normal aggregate

Figure-2: Recycle aggregate

3.1 PHYSICAL PROPERTIES

The residual adhered mortar on aggregate is the key influencing factor affecting the properties of density, porosity, and water absorption of RCA. The density of RCA is usually lesser than NCA density, due to the adhered residual mortar which has lesser density than that of the underlying rock. The variation in density depends on the specific gravity of aggregates. The adhered mortar can be lightweight in comparison to aggregate of the same volume, which renders the dropping off in density. Porosity and water absorption are associated aggregate characteristics, also regarded as belonging to residual mortar. NCA normally possess low water absorption because of low porosity, but the adhered mortar on RCA possess larger porosity that lets the aggregate to hold more water in its pores than NCA . These values for present study are tabulated in the Table- 1

3.2 AGGERATE SHAPE AND GRAIN SIZE DISTRIBUTION:

On the workability of the concrete, the aggregate shape and gradation have direct effect. The residual adhered mortar on RCA can level the hard edges of the original fresh aggregate. This makes the new mortar to flow better around the aggregate. Aggregate gradation of RCA and NCA in this study is shown below.

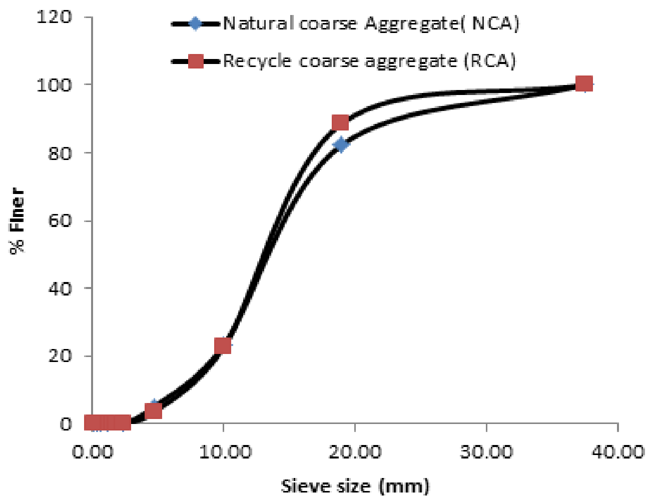

Figure-3: Gradation of NCA and RCA

3.3 CRUSHING AND AGGREGATE IMPACT VALUE:

Crushing and aggregate impact value tests are measures of the durability of aggregate material on its own. There is a common tendency that RCA has higher values for crushing and impact than NCA, meaning when the aggregate is contained and crushed or impacted in the test RCA has more fine particles break off of than NA. Crushing tests produced the values of 23.1 % for RCA vs. 15.7 % for basalt (a NA) and 24 % for RCA vs. 13 % for basalt in two different studies (Sagoe-Crentsil et al. 2001; Shayan and Xu 2003). Los Angeles abrasion test result values for RCA versus NA were obtained in two studies as 32 vs. 11 % and 26.4–42.7 vs. 22.9 % (Shayan and Xu 2003; Tavakoli and Soroushian 1996). This is a sensible result for these tests, in that the RCA has residual adhered mortar that can split off easily at the interfacial transition zone (ITZ), which is the normally feeble part of concrete. It is reasonable that, when subjected to loading, the remaining adhered mortar on RCA would split off, whereas NCA does not have a similar coating to break. The performance of RCA in crushing and impact tests reveals the weakness of the adhered mortar. As this layer is presumably to break off of the aggregate itself, it is reasonably anticipated that the adhered residual mortar layer may also build a frail coalesce within concrete. Table 1 summarizes properties for NCA, RCAs and FA used.

Table -1: Physical properties of NCA, RCA and FA

Physical property	NCA	RCA	FA
Nominal maximum size (mm)	19	19	4.75
Fineness modulus	6.89	6.85	2.96
Bulk density in compacted condition (kg.m−3)	1270	1545	1615
Saturated surface-dry based specific gravity	2.63	2.55	2.68
Oven-dry based specific gravity	2.54	2.49	-
Open porosity (vol. (%))	5.2	1.45	-
Absorption (wt. (%))	2.15	0.70	1.40
Moisture content (wt. (%))	1.52	0.22	0.45
Angularity number	9	7.5	-
Aggregate impact value (wt. (%))	12	12.5	-

3.4 CONCRETE PROPERTIES:

As the recycled aggregate possesses a little bit dissimilar properties than NCA, it acts differently in concrete mixes and results the finished concrete to execute response unlike conventional concrete. In this study, approximate method was used to produce the concrete mix where 1: 1.5:3 mix ratios were used for cement, fine aggregate and coarse aggregate. Three water – cement ratio (w/c) ratio 0.7, 0.6 and 0.5 were used to check the proper workability of concrete and 0.6 water cement ratio was used for compressive strength test and splitting tensile test for workable concrete. The following section describes the variation between the properties of RCA concrete compared to conventional NCA concrete.

4. FRESH CONCRETE PROPERTIES

4.1 WORKABILITY:

Workability is a complex concept for fresh concrete and associated with various properties like consistency and cohesiveness. This indicates the amount of useful internal work required to fully compact the concrete without bleeding or segregation of aggregates in the finished concrete work. Workability is one of the physical factors of fresh concrete which dictates the strength and durability. Since the slump indicates the mobility of fresh concrete for which the concrete mixture can flow during placement, and the slump test is simple and quantitative, most mix design procedures depend on slump value as a crude indicator of workability. The workability of concrete was evaluated with respect to slump and slump flow which is directly improved with the increase of water – cement ratio. The use of RCA as substitute of NCA reduced the slump value and flow of concrete, as can be seen from Figure-4.

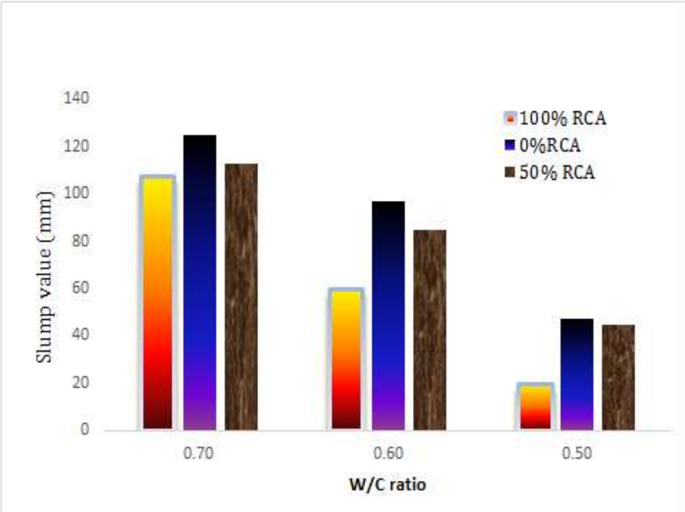

Figure-4: Slump value for different w/c ratio

5. HARDENED CONCRETE PROPERTIES

5.1 COMPRESSIVE STRENGTH:

Compressive strength of RCA concrete can be affected by the properties and proportion of recycled aggregate. A number of parameters such as the water/cement (w/c) ratio, the percentage of coarse aggregate replaced with RCA, and the amount of adhered residual mortar on the RCA may affect the compressive strength of RCA concrete. Most research reported that, without altering any component in the mix involving adjustments to the w/c ratio, up to 25 or 30 % of coarse aggregate can be replaced with RCA before the ceiling strength is compromised. The compressive strength curve of NCA, RCA and 50% RCA concrete is shown in figure 3. RCA had an off-putting impact on the compressive strength of concrete especially at 28 days, as evident from Figure 3. The concretes with 50% RCA and with 100% RCA rendered an analogous compressive strength. The concrete with 100% RCA produced a lesser compressive strength than the concrete with solely NCA, particularly at 28 days. The compressive strength of 100 % RCA at 28 days is around 36 % less than compressive strength of 100% NCA while it is somewhat improved at 31 % less in case of 50% RCA concrete. The weakness of RCA attributed to porous adhered mortar prevailed over its surface roughness at RCA, hence providing attenuation in the compressive strength of concrete. Besides, the angularity of RCA is a contributing factor that provides a poorer compressive strength by affecting the physical packing of concrete at a lower mobility.

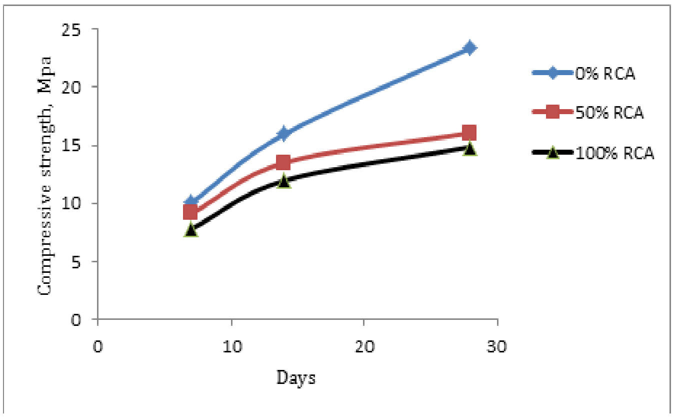

Figure-5: Compressive strength of concrete for different RCA proportion.

5.2 SPLITTING TENSILE STRENGTH:

The splitting tensile strength results are presented in Figure 6. From the figure it was observed that 28 days splitting tensile strength was considerably more than 7 days splitting tensile strength. The NCA performed better than RCA in splitting tensile strength. The 7 days splitting tensile strength of 50% RCA showed 15% lesser values than 100% NCA whereas 100% RCA showed 24% lesser tensile strength. In case of 14 days strength both 50% RCA and 100% RCA showed almost same attenuation of strength. But the maximum decrease in the splitting tensile strength at 28 days was found 39 % in 50 % RCA while this was 35% in 100% RCA in comparison with 28 days 100% NCA splitting tensile strength. The increase in 28 days splitting tensile strength was slightly high in the presence of higher RCA proportion

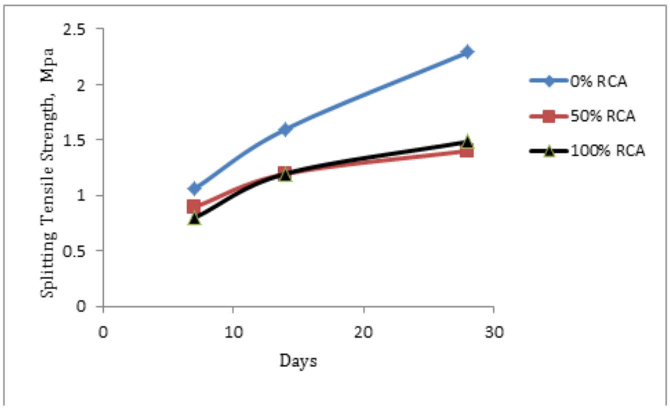

Figure-6: Splitting tensile strength for different RCA proportion.

It is owing to the collective effect of augmented hydration products, favorable physical features of RCA and good interfacial bond between aggregate and mortar matrix. Indeed, the present study shows that there was some decrease in the splitting tensile strength with Recycle aggregate portion. This may be due to the reason that the concrete was weaker in the facture plane because of porous microstructure in the presence of RCA. However, the RCA concretes made in this study are not likely to contribute a higher splitting tensile strength than the control (non-RCA) concrete but this may have implication in some specific case.

6. COST OF CONCRETING

Costs involved for unit cubic feet concreting of 100% NCA, 50% RCA and 100% RCA according to PWD cost specification are shown in figure 7. The figure reveals that cost for concrete with 100% RCA is 24 % less than that for 100% NCA whereas it is 12 % less expensive in case of 50% RCA in comparison to 100% NCA. This cost efficacy reduces the overall structural construction cost. Hence, normal aggregate can be replaced by recycle aggregate at optimum proportion for mass concreting.

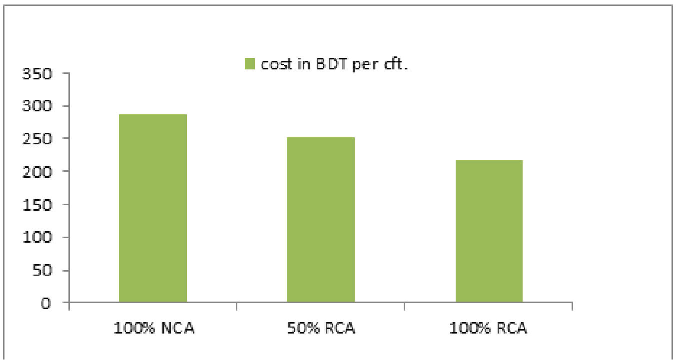

Figure-7: Cost in BDT per cft concrete of 100% NCA , 50% RCA and 100% RCA

6. CONCLUSION

Now-a-days, one of the major challenges in our civil engineering filed is to reduce environmental hazards and protect it from natural and artificial disasters. Regarding this depletion of energy and natural raw materials should be decreased and the utilization of demolition waste should be stimulated simultaneously. The use of recycle returned aggregate from construction and demolition work is showing prospective application in Bangladesh as an alternative of natural aggregates. In this study, the following conclusion can be drawn by analyzing the properties of recycle aggregate & natural aggregate and investigating the concrete characteristics with different RCA proportion by experimental study:

1. RCA reduced the workability of concrete; the decreases in slump and slump flow were higher at a greater RCA content. The harshness of concrete mix was increased due to the angular and rough-textured RCA particles, and thus decreased its slump value and flow of slump.
2. Recycle aggregate and natural aggregate provided almost same aggregate crushing and impact value

which indicates that recycle aggregate can be used as base course in pavement.

3. RCA produced slightly adverse effect on the compressive strength of concrete; the maximum decrease in 28 days compressive strength was 36% for 100% RCA and 31 % for 50% RCA. RCA concrete was weaker than NCA concrete due to porous adhered cement paste prevailed over its surface roughness at RCA.
4. The splitting tensile strength of concrete at the age of 28 days was affected to some extent in the presence of RCA, particularly at the age of 28 days. This is due to the poor physical packing of RCA in concrete. But 100% RCA concrete produced somewhat more splitting tensile strength than 50% RCA concrete. It is a result of the integrated effect of augmented hydration products, favorable physical properties of RCA and good interfacial bond between aggregate and mortar medium.
5. Use of RCA can contribute to relieve the shortage of NCA, cut back on the harvesting cost of NCA, and minimize the construction and demolition wastes in landfill spot. In addition, it will eradicate the transportation cost for gathering NCA to construction site, and for disposing the construction and demolition wastes to landfill site. So the present study shows that cost for concrete with 100% RCA is 24 % less than that for 100% NCA whereas it is 12 % less expensive in case of 50% RCA in comparison to 100% NCA.

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