Recycled Concrete Aggregates: A Review

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Abstract - *This paper discusses the properties of recycled concrete aggregate (RCA), the effects of RCA use on concrete material properties, and the large-scale impact of RCA on structural members etc. The review study from the past research yielded the following conclusions in regards to concrete material properties: (1) replacing natural aggregate NA in concrete with RCA decreases the compressive strength, but yields comparable splitting tensile strength; (2) the modulus of rupture for RCA concrete was slightly less than that of conventional concrete, likely due to the weakened the interfacial transition zone from residual mortar; and (3) the modulus of elasticity is also lower than expected, caused by the more ductile aggregate.*

***Key Words*:** recycled concrete aggregate, compressive strength, splitting tensile strength, modulus of rupture, concrete material properties.

1. INTRODUCTION

After the destruction of old roads and structures, the removed concrete is regularly viewed as useless and discarded as annihilation squander. By gathering the utilized concrete and separating it, reused concrete aggregate (RCA) is made. This paper centres around coarse RCA which is the coarse aggregate from the original concrete that is made after the mortar is isolated from the stone which is reused. The utilization of RCA in new development applications is as yet a generally new method. Buck (1977) refers to the start of RCA use as far as possible of World War II when there was excessive decimation of structures and streets and a high need to both dispose of the waste material and rebuild Europe. After the quick need to reuse concrete, the utilization of RCA decreased. During the 1970s, the United States started to reintroduce the utilization of RCA in non-basic uses, for example, fill material, foundations, and base course material (Buck 1977). Since this time, some exploration has been led seeing how feasible RCA is as an alternative to supplant unused natural aggregate (NA) in structural concrete.

2. AGGREGATE PROPERTIES

This segment talks about the properties of RCA when contrasted with NAs. A comprehension of how the total changes after as of now being utilized in concrete can enhance the capacity to depict why RCA may perform contrastingly when utilized in new concrete than NA. The fundamental total properties that are introduced are the density, porosity, and water retention of the total, the shape and gradation of the aggregate, and the aggregate resistance to abrasion and crushing.

2.1 Density, Porosity, and Water Absorption

Residual adhered mortar on aggregate is the primary factor influencing the properties of density, porosity, and water absorption of RCA. The density of RCA is for the most part lower than NA density, because of the adhered mortar that is less thick than the underlying rock. The variety in density is subject to the specific aggregate being referred to. An examination by Limbachiya et al. (2000) demonstrated that the general density of RCA (in the soaked surface dry state) is around 7– 9 % lower than that of NA. Sagoe-Crentsil et al. (2001) revealed mass densities of 2,394 and 2,890 kg/m3 for RCA and NA, separately, around a 17 % contrast. The adhered mortar can be lightweight contrasted with the aggregate of a similar volume, which causes a decline in density. Porosity and water absorption are connected aggregate qualities, likewise credited to the residual mortar. NA, for the most part, has low water retention because of low porosity, yet the residual mortar on RCA has more noteworthy porosity which enables the total to hold more water in its pores than NA. Shayan and Xu (2003) discovered water absorption estimations of 0.5– 1 % for NA and 4– 4.7 % for RCA in the saturated surface dry condition, up to a 4.2 % distinction. Different investigations indicated contrasts where RCA absorption was 5.6 and 4.9–5.2 % contrasted with NA absorption of 1.0 and 2.5 % (Sagoe-Crentsil et al. 2001; Limbachiya et al. 2000). The aggregate qualities of density, porosity, and water absorption are a primary focus in deciding the best possible concrete blend. These attributes ought to be known to constrain absorption limit of totals to close to 5 % for structural concrete, and in this way, the extent of RCA is regularly restricted in concrete blends (Exteberria et al. 2007), as is discussed later in this paper.

2.2 Shape and Gradation

The shape of the aggregate pieces is compelling on the workability of the concrete. Exteberria et al. (2007) cautioned that the technique for manufacturing RCA and the sort of smasher that is utilized in this procedure is influential in the shape of RCA created. NA commonly has precise shape with smooth sides. Sagoe-Crentsil et al. (2001) at first portrayed the plant-delivered RCA as grainy in surface and later talked about that the RCA has an increasingly adjusted, round shape which appeared to enhance usefulness. The leftover mortar on RCA can smooth out the hard edges of the first total. This enables the new mortar to flow better around the aggregate. The impacts of the total shape on usefulness and quality parameters of concrete are examined further later in this paper. Guidelines for concrete aggregates characterize a range inside which the gradation of the aggregate must lie so as to be acceptable aggregate for structural concrete. Both Sagoe-Crentsil et al. (2001) and Shayan and Xu (2003) found that the gradation curves of RCA were inside this predefined range. This demonstrates RCA ought to have adequate gradation by applicable standards without changes being made.

2.3 Crushing and L.A. Abrasion

Crushing and Los Angeles (L.A.) abrasion tests are proportions of the toughness of aggregate material on its own. There is a general pattern that RCA has higher qualities for crushing and L.A. abrasion than NA, which means when the aggregate is contained and squashed or impacted by steel balls in the L.A. NA has less fine particle break off than RCA. Crushing tests brought about estimations of 23.1 % for RCA versus 15.7 % for basalt (an NA) and 24 % for RCA versus 13 % for basalt in two separate investigations (Sagoe-Crentsil et al. 2001; Shayan and Xu 2003). L.A. abrasion test values for RCA versus NA were found in two investigations as 32 versus 11 % and 26.4– 42.7 versus 22.9 % (Shayan and Xu 2003; Tavakoli and Soroushian 1996). This is a sensible outcome for these tests, in that the RCA has a residual mortar that can sever effortlessly at the interfacial progress zone (ITZ), which is the normally weak territory of concrete. It is logical that, when exposed to loading, the residual mortar on RCA would sever, while NA does not have a comparable covering to lose. The conduct of RCA in crushing and abrasion tests exhibits the shortcoming of the adhered mortar. Since this layer is most likely to sever of the aggregate itself, it is anticipated that the adhered mortar layer may likewise make a feeble connection with concrete.

3. RCA Concrete Material Properties

Since the reused aggregate has unexpected properties in comparison to NA, it behaves on contrastingly in concrete blends and makes the finished concrete perform, in contrast to regular concrete. This segment portrays the variety between the properties of RCA concrete contrasted with traditional NA concrete.

3.1 Compressive Strength

The compressive strength of RCA concrete can be affected by the properties and measure of recycled aggregate. Several elements can impact the compressive strength in RCA concrete, including the water/cement (w/c) proportion, the level of coarse aggregate supplanted with RCA, and the measure of adhered mortar on the RCA. Most research prescribed that, without changes to the blend including acclimations to the w/c proportion, up to 25 or 30 % of coarse aggregate can be supplanted with RCA before the ceiling strength is imperilled. In an examination by Limbachiya et al. (2000), concrete specimens with up to 30 % RCA had meet compressive qualities for w/c proportions greater than 0.25. The data for 30 % RCA pursues that of 0 % RCA for pretty much every w/c proportion tried, while the 100 % RCA information lie at compressive strength values underneath that of 0 or 30 % RCA by around 5 N/mm2. At the most reduced w/c proportions, the compressive strength for blends with RCA turn out to be progressively not at all like regular concrete. Exteberria et al. (2007) found similar behaviour with tests utilizing 25 % RCA that executed just as customary concrete with a similar w/c proportion. This examination tried concrete made with 0, 25, 50, and 100 % RCA concrete blends and inferred that up to 25 % could be supplanted without huge change in compressive strength or an alternate w/c proportion; be that as it may, to get a similar strength with 50– 100 % RCA, w/c proportion should have been 4– 10 % lower, and without this adjustment, the compressive strength for 100 % RCA blends was decreased by 20– 25 % (Exteberria et al. 2007). Recent tests by Kang et al. (2012) likewise demonstrated that the compressive strength was diminished by around 25 % for a similar blend however with 50 % RCA, and decreased by up to 18 % for 15– 30 % RCA blends. Yang et al. (2008) ascribed a decrease in compressive strength for RCA concrete to the expanded water ingestion of the total and found that at moderately low water absorption (generally low RCA division) concrete had identical compressive strength while higher RCA parts and retention compressive strengths were 60– 80 % of that of regular control concrete, however the compressive strength enhanced with age. Since the aggregate can store more water, this water can be discharged into the new mortar after some time to keep on feeding the cement for a more drawn out time, which enhances strength. The level of strength decrease in RCA concrete varies with each source aggregate. Froudinstou-Yannas (1977) likewise discovered that some blends supplanting 100 % of coarse aggregate with RCA had around 76 % of the compressive strength of customary concrete, while blends utilizing distinctive w/c proportions had as low as 4 % decrease in compressive strength. Moreover, a report by Tavakoli and Soroushian (1996) examined the compressive strength of concrete made with two distinct sources for RCA. It was discovered that while RCA, as a rule, diminishes concrete compressive strength because of higher water ingestion of the aggregate and the weak residual mortar layer. It is conceivable to deliver concrete that is stronger than a conventional concrete if the source concrete is stronger than that at which the RCA concrete is proposed to perform. It would be suggested that when utilizing RCA for structural concrete applications, quality tests be performed to guarantee what quality of concrete the RCA is fit for delivering and check what RCA fraction is satisfactory or if there are changes in the w/c proportion required so as to create concrete of the ideal strength.

3.2 Splitting Tensile Strength

Splitting tensile strength is less influenced by RCA content than compressive strength. A few past and ongoing tests (e.g., Kang et al. 2012) demonstrate that the splitting tensile strength of RCA concrete is equivalent to traditional concrete. At times, RCA concrete performed better than NA concrete with regards to tension. As indicated by Exteberria et al. (2007), the enhancement is expected to the enhanced assimilation of the mortar connected to the reused aggregate and the powerful ITZ, which shows a decent bond among aggregate and the mortar lattice. While this lingering mortar makes a debilitated spot for compressive inability to happen, restricted amounts enhance the ductile limit by making a smoother change among mortar and aggregate.

Unlike compressive strength, high-strength concrete blends with low w/c proportions indicate a significantly more noteworthy enhancement in split tensile strength. The samples with lower w/c proportions have more enhanced tensile strength than the higher w/c proportions when aggregate size and dry blending time don't have a particular impact. Most RCA concrete samples at the lower w/c proportion have appeared enhanced tensile strength. By and large, the certainty interim of the deliberate RCA tensile strength is more noteworthy than the deliberate NA elasticity.

3.3 Modulus of Rupture and Elasticity

The modulus of rupture, a proportion of flexural quality, and the modulus of elasticity (otherwise called Young's modulus), a proportion of concrete stiffness, are frequently anticipated from compressive strength, yet these connections don't represent RCA concrete just as NA concrete. This section inspects every modulus and how RCA influences these qualities of concrete.

The modulus of rupture isn't very much represented by the standard association with compressive strength. Tavakoli and Soroushian (1996) depicted that the modulus of rupture trial of RCA concrete gave progressively shifted outcomes. The RCA concrete performed better as far as the modulus of rupture than regular concrete at the higher water-cement proportion, however, it performed more regrettable at the lower water-cement proportion. Since the current model relating compressive strength and flexural strength is insufficient, there ought to be more research on the effect of RCA on concrete flexural strength so that another more accurate relationship can be created. Yang et al. (2008) inspected how water assimilation of RCA and the strength of RCA source concrete impact how well compressive strength predicts modulus of rupture. This paper reasoned that RCA concrete made with RCA from high quality source concrete with low water ingestion perform like ordinary concrete, while low-quality source RCA with high water retention yields a modulus of rupture not exactly anticipated, likely because of the frail residual mortar layer (Yang et al. 2008). Since both compressive and tensile strength by and large decline under similar conditions that reason decreased flexural strength, this conclusion is sensible. While in flexure at the top of the sample encounters compression while the lower partition encounters tension. If either the compressive or tensile limit of the sample is endangered; the flexural quality will likewise be influenced. Tensile strength was additionally more prominent than the anticipated an incentive for concrete with RCA from a high strength source with low water retention. Like the modulus of rupture, the impact of RCA on Young's modulus of concrete requires further research to build up a relationship that can be utilized to more readily foresee the conduct.

4. Conclusion

This paper has talked about the properties of RCA, the impacts of RCA use on concrete material properties, and the extensive scale effect of RCA on structural members. Aggregate properties are most influenced by the residual mortar on RCA. Due to this reason, RCA is less dense, increasingly permeable, and has a higher water retention limit than NA. While RCA and NA have similar gradation, RCA particles are more rounded in shape and more fines severed in L.A. abrasion test. Supplanting NA in concrete with RCA diminishes the compressive strength, yet yields proportionate or predominant split tensile strength. The modulus of rupture for RCA concrete was less that of traditional concrete, likely because of the debilitated interfacial transition zone from the residual mortar. The modulus of elasticity is likewise lower than anticipated, caused by the more ductile aggregate.

REFERENCES

[1] Buck, A. D. (1977), ``Recycled concrete as a source of aggregate'', ACI Journal, vol. 74, pp. 212–219.

[2] Exteberria, M., Va´squez, E., & Marı´, A. R. (2007), ``Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete", Cement and Concrete Research, vol. 37, pp. 735–742.

[3] Froudinstou-Yannas, S. (1977), ``Waste concrete as aggregate for new concrete'', ACI Journal, vol. 74, pp. 373–376.

[4] Limbachiya, M. C., Leelawat, T., & Dhir, R. K. (2000), ``Use of recycled concrete aggregate in high-strength concrete'', Materials and Structures, vol. 33, pp. 574–580.

[5] Sagoe-Crentsil, K. K., Brown, T., & Taylor, A. H. (2001), ``Performance of concrete made with commercially produced coarse recycled concrete aggregate", Cement and Concrete Research, vol. 31, pp. 701–712.

[6] Shayan, A., & Xu, A. (2003), ``Performance and properties of structural concrete made with recycled

concrete aggregate'', ACI Materials Journal, vol. 100(5), pp. 371–380.

[7] Tavakoli, M., & Soroushian, P. (1996), ``Strengths of aggregate concrete made using field-demolished concrete as aggregate", ACI Materials Journal, vol. 93(2), pp.182–190.

[8] Yang, K.-H., Chung, H.-S., & Ashour, A. F. (2008), ``Influence of type and replacement level of recycled aggregates on concrete properties'', ACI Materials Journal, vol. 105(3), pp. 289–296.