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Quality Assessment of Coarse Aggregates Subjected to Multiple Times Recycling

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Abstract

Aggregates obtained by recycling demolished concrete are a good source to replace the natural aggregates partially. Applicability of such recycled aggregates are presented in many literatures. However, most of the studies are conducted on first generation recycled aggregates. The possibility of recycling more than once is yet to be studied. The present study aims to identify the changes occurring in the aggregates after each stage of recycling. First generation recycled aggregates are prepared from demolished concrete blocks collected from real demolition site. Concrete specimens are prepared with them and after attaining sufficient strength, the specimens are broken to produce second generation recycled aggregate. In the similar way, third generation aggregates are produced. Change in aggregate characteristics such as specific gravity, unit weight, water absorption, crushing strength and abrasion resistance after each cycle of recycling are investigated and presented. Suitability of aggregates subjected to multiple times recycling is also presented based on standard requirement.

Keywords: *RCA; concrete recycling; ACV; aggregates.*

1 Introduction

Rapid and massive infrastructural development in the past few decades consumed a large amount of construction materials. Concrete is one of the most used construction materials which is favored by the builders because of its economy, longer life, and low maintenance. Concrete industry is the largest consumer of natural resources which consumes 12.6 billion tons of raw materials every year (Mehta, 2001). A more recent report of 2009 presents that, about 25 billion tons of concrete are being produced each year (CSI Recycling Concrete Full Report, 2009). The extensive production of concrete leads to a shortage of the supply of its ingredients. The coarse aggregates to be used in concreting work are mainly produced by breaking down bolder stones and bricks. Coarse aggregates contribute about 65% of total concrete volume and the global usage of aggregates is more than 13 billion tons per year which is expected to increase up to 48.3 billion tons (Arora and Singh, 2016; Mohammed et al., 2014). The extensive production of concrete is continuously depleting the natural reserve of stone aggregates. On the other hand, many older concrete structures are being demolished to construct new ones which generates a huge amount of demolition waste. Tons of demolition wastes being generated globally mostly ends in the landfills and thus large landfill areas are being occupied (Roknuzzaman and Serker, 2023). The discarded concrete from demolition wastes has the potential to be recycled in the form of reusable aggregates. The aggregate generated from waste concrete is said to be recycled aggregate. The recycled coarse aggregates (RCA) can be used to replace the natural aggregates in making new concrete. In fact, 80% of concrete replacement with recycled materials can really help to transfer traditional concrete into a sustainable material (Manzi et al., 2012). Several studies pointed that within certain limit of replacement good quality concrete can be made using RCA (Kazemi et al., 2019; Deng et al., 2018; Mohammed et al., 2013). The recycled coarse aggregates can also be used in highway pavement construction and other projects provided that their strength and other properties are within acceptable limits (Li and Yin, 2016). Moreover, when some recycled concrete gets older, they may need to be demolished again. This will recreate further concrete waste, which may have the possibility of similar reuse and the recycling process may be continued for several cycles. But at the same time aggregate properties may deteriorate with each cycle of reuse. Deterioration of RCA properties in three generations of recycled aggregates was observed and an alarming quality loss was encountered (Sultana et al, 2021). The continuous property deterioration may make the recycled aggregate unsuitable for a particular usage. Therefore, although the recycled aggregate generated by repeated recycling is a competitive and inventive green product, its quality parameters should be checked and compared to standard requirements to make its suggestive application. Moreover, there are several factors such as amount of old mortar, presence of cracks, age and configuration of parent concrete, etc. which are responsible for wide variability in the properties of recycled aggregate (Hossain et al., 2017; Saho et al., 2016; Abbas et al, 2007). For this reason, recycled aggregates demand extensive studies and research for better understanding of their behavior. This research is proposed to find out the possibility of using coarse aggregates extracted from demolished concrete and the major consideration is to notice the deterioration of its quality with repeated number of recycling.

2 Methodology

2.1 Materials

2.1.1 Recycled Aggregate

Recycled coarse aggregate (RCA) for this study was sourced from demolished culvert located at Kaharole, Dinajpur. The age of the source concrete was 5 years. Demolished concrete blocks were collected and crushed to the standard aggregate size. Figure 1 shows the collection site and making of RCA from concrete blocks.

Figure 1. Collection of demolished concrete blocks and making of RCA

2.1.2 Concreting Ingredients

Besides RCA, natural stone aggregates (NA) collected from Panchagarh, Bangladesh was used as reference with which the properties of RCA are compared. The maximum size of coarse aggregates (recycled and natural) was kept at 25 mm. Other ingredients for making concrete such as fine aggregate, binder, and water were collected or managed locally. Table 1 shows the properties of the ingredients used in this study.

Table 1. Concreting ingredients and their properties.

Ingredient	Parameter	Details Information
Fine Aggregate (Natural coarse sand)	Fineness Modulus	2.40
	Specific Gravity	2.65
	Water absorption	2.0 %
Binder (Ordinary Portland Cement)	Specification and Standard	CEM-1, 52.5 N ASTM C150, Type – 1
Water		Potable tap water

2.2 Experimental Program

2.2.1 Multiple Times Recycling

As explained in section 2.1.1, RCA was prepared by breaking down the demolished concrete blocks manually. The RCA thus obtained from parent concrete is named 1st generation recycled aggregate (RAG1). Concrete specimens were made using the RAG1 as coarse aggregate and the resulting concrete was named 1st generation recycled concrete (RCG1). The RCG1 specimens were broken after 56 days to produce 2nd generation recycled aggregate (RAG2). In a similar manner RAG3 was produced. Designations of multiple times recycled aggregate are presented in Table 2.

Table 2. Designations of aggregates

Designation	Elaboration	Source
RAG1	1st generation recycled aggregate	Demolished concrete from structure
RAG2	2nd generation recycled aggregate	Demolished concrete specimens made with RAG1
RAG3	3rd generation recycled aggregate	Demolished concrete specimens made with RAG2
NA	Natural aggregate	Virgin stone aggregate

2.2.2 Mix Design

Concrete mix design procedure developed by American Concrete Institute (ACI 211) was followed as this method is best suited for recycled concrete (Bairagi et al., 1990). Standard C-25 concrete with a specified strength of 25 MPa and required average strength of 33 MPa was selected for a standard slump in the range of 75-100 mm. Table 3 shows the proportions of different ingredients for making concrete.

Table 3. Designation of concrete mixes and proportion of ingredients

Designation	Elaboration	Coarse aggregate Type	Slump (mm)	Water cement ratio	Proportion (kg/m^3)			
					Water	Cement	Fine aggregate	Coarse aggregate
RCG1	1st generation recycled concrete	RAG1	75-100	0.50	193	387	707	941
RCG2	2nd generation recycled concrete	RAG2			193	387	694	899

2.2.3 Making of Concrete and Recycled Aggregate

Concrete cylinders 100 mm in diameter and 200 mm in height were made in sufficient quantities. After 56 days of curing, the specimens were first subjected to some compressive and tensile strength test and after that, they were broken into standard aggregate sizes. Figure 2 shows some instances of the process.

Figure 2. Making RCA of different generations

2.2.3 Testing of Aggregates

Some physical and quality parameters for coarse aggregate such as specific gravity, water absorption, unit weight, aggregate crushing value and Los Angeles abrasion value were investigated after each cycle of recycling. The tests were conducted following standard procedures as tabulated in Table 4.

Table 4. Tests of aggregate and their standards

Property under test	Test Standard
Specific gravity	ASTM C127 – 15
Water absorption	ASTM C127 – 15
Unit weight	ASTM C29 / C29M - 17a
Aggregate Crushing Value	BS 812-110:1990
Los Angeles Abrasion Value	ASTM C131/C131M-14

All the tests were conducted on RAG1, RAG2, RAG3 and NA keeping the test conditions identical.

3 Results and Discussion

3.1 Change in Specific Gravity and unit weight

The change in specific gravity and unit weight is shown in Figure 3.

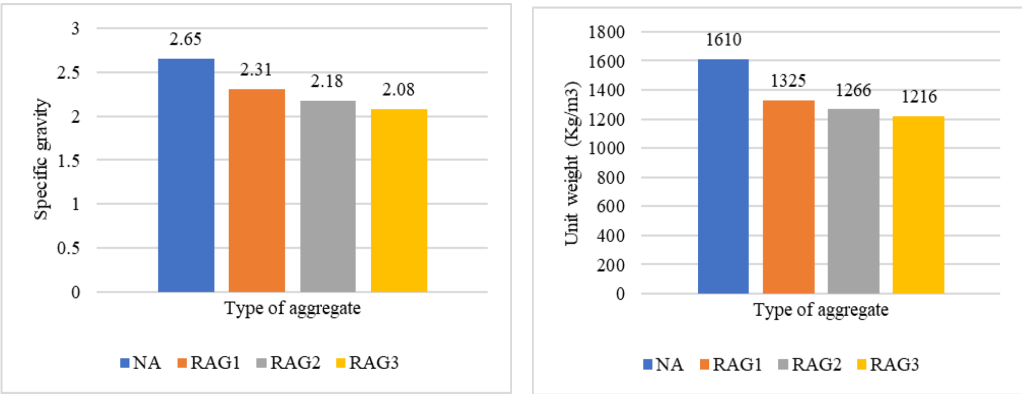

Figure 3. Specific gravity and unit weight of aggregate

Both the specific gravity and unit weight are found to decrease at higher generations of recycled aggregate. The specific gravity of normal weight aggregate lies between 2.5 and 3.0 (Olanipekun et al., 2006). The natural stone aggregates used in this study had a specific gravity of 2.65 which was in that range, but the recycled aggregates of any generation had lower specific gravity which indicates that they are lighter than NA. A possible reason for this may be the addition of porous mortar in the recycled aggregates which have lower specific gravity than the stone particles. For the same reason, unit weight also decreased with successive repetitions of recycling.

3.2 Water absorption in recycled aggregate

Water absorption is an important quality parameter of coarse aggregate. Ideal aggregates should have low water absorption. The natural aggregates used in this study had a water absorption of only 1.4%. As shown in Figure 4, water absorption values of recycled aggregates are considerably higher than that of NA. The 1st generation RCA had more than 4 times high water absorption compared to NA. 2nd and 3rd generation RCA had almost equal water absorption.

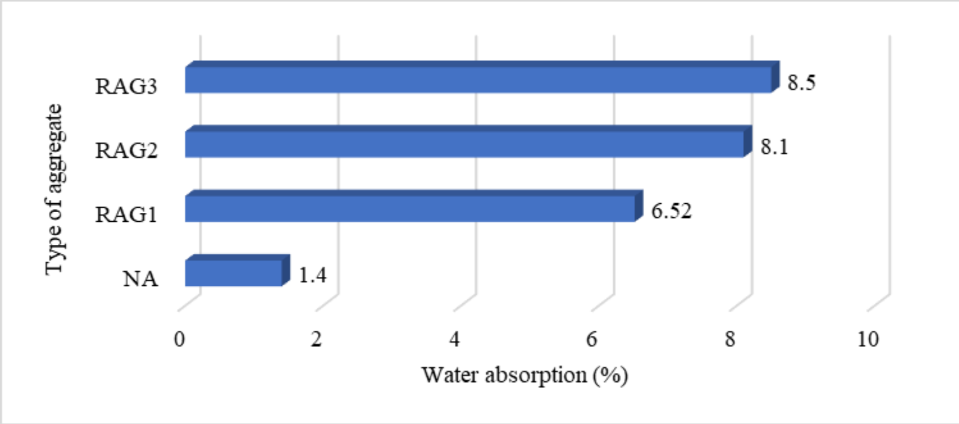

Figure 4. Increase in water absorption for multiple recycling.

3.3 Effect of multiple recycling on strength of aggregate

Aggregate crushing value (ACV) is an indicator of its strength. Suitability of an aggregate in pavement application is judged by its ACV. Higher ACV indicates lower strength of aggregate. As shown in Figure 5, ACV increases after each time of recycling. Since an additional interfacial transition zone is added after each cycle of recycling, the aggregates become weaker and for this reason breaking them into smaller pieces becomes easier resulting in a higher ACV. Also, in a previous study it was found that attached old mortar increases the ACV value (Serker et al., 2022). Since, the RCA of higher generations are expected to contain more old mortar, their ACV should also be high. For concreting work, it is recommended to use aggregates having ACV less than 30% (Zhang et al., 2021; BS 882, 1983). Therefore the 1st and 2nd generation RCA can be used for concrete work and the 3rd generation one is not suitable.

3.3 Effect of multiple recycling on abrasion resistance

Los Angeles Abrasion (LA) value indicates the resistance of the aggregate against degradation. An aggregate with a lower LA value usually possesses higher durability. Figure 6 shows the LA value for RCA of different generations. The RCA of higher generation contains more old mortar attached to the surfaces of stone particles and this mortar readily separates under the abrasive charges of LA machine resulting in a higher LA value. The LA value for structural concrete should be limited to 40% (de-Juan & Gutiérrez, 2009), and therefore, the 3rd generation RCA should not be considered for concreting work.

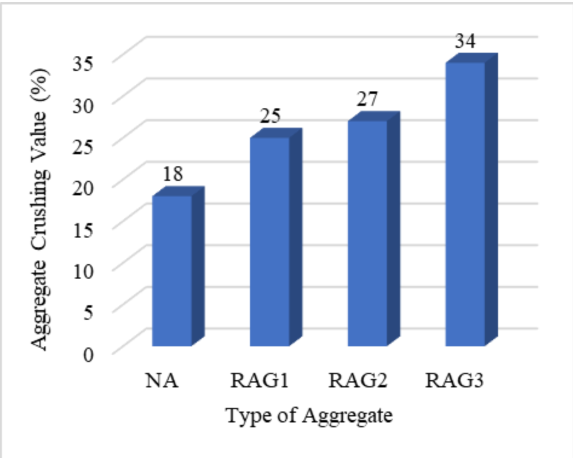

Figure 5. Increase in ACV for multiple times recycling

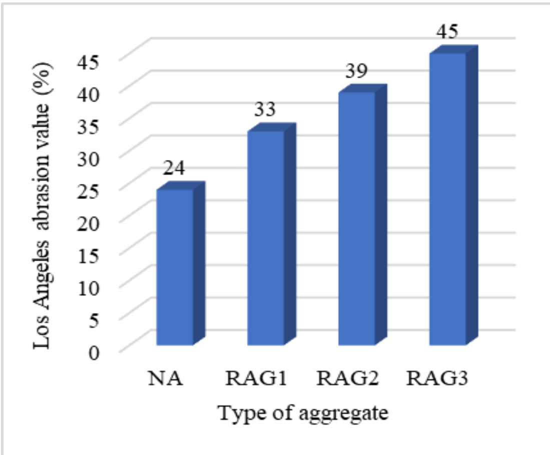

Figure 6. Increase in LA for multiple times recycling

4 Conclusion

The addition of old mortar and ITZs in successive number of recycling makes the aggregates inferior in quality. However, two times recycling was found to be safe, as the 1st and 2nd generation RCA met the requirement of

ACV and LA to be used in making concrete. The 3rd generation RCA possesses ACV and LA higher than the limiting values and hence, it should not be used in concrete work. Nevertheless, concrete specimens should be made with the aggregates and tested to confirm the finding. In the next phase of this study, it is planned to test the concrete for strength and durability so that their suitability can be assessed.

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