Effect of Cement Proportion on Strength of Recycled Aggregate Concrete

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Abstract—**This is an attempt to study the effect of normal and higher cement proportion on the properties of concrete made with Recycled concrete aggregate without adding any water reducing admixture. Workability and concrete strength was the principal target of investigation. Recycled aggregates were prepared from the concrete laboratory wastes of concrete cylinders/cubes dumped after routine strength tests in the Lab courtyard for disposal. Simultaneously, concrete specimen with fresh natural aggregates were tested to compare the properties of Recycled Aggregate Concrete (RAC) with Natural Aggregate Concrete (NAC). Waste concrete cylinders were usually tested at their 28th day's strength but their waste life span in the courtyard ranged from 2 months to 2 years. Several sets of RAC were made by varying the percentage of RCA from zero to 100 percent. After mixing the RCA in different proportions (0, 25, 50, 75 and 100%) with required amount of fine aggregate (sand) the combined gradation of each batch was determined. Three different water cement (w/c) ratio of 0.41, 0.46 and 0.5 were used for each group of mix proportion. Relatively low slump was observed for concrete mixes with normal cement content of 370 kg/m^3 for w/c less than 0.5. But workability (slump) increased reasonably with higher cement amount for all the mixes. Strength gain pattern with ages was found to be similar to normal aggregate concrete in all cases with different RCA replacement. Concrete strength with RCA was found to be lower compared to NAC for normal cement content. But with 30% increase in cement concrete strengths increased and were found comparable for all RCA replacement with that of NAC for a particular age.**

Index Terms—**recycled course aggregate, gradation, workability, natural course aggregate, recycled aggregate concrete, strength of concrete**

I. Introduction

Demolition of old and deteriorated buildings and their replacement with new ones is very regular incident that is experienced by every part of the world. The situation is unavoidable to accommodate changes of purpose, structural deterioration, rearrangement of a city, expansion of traffic system and natural disasters (cyclone, tsunami, earthquake, fire and flood). For example in USA, the construction waste produced from building demolition alone is estimated to be 123 million tons per year. Management of this huge quantity of waste material has been through disposals in landfills. Such large disposal violates the green technology and is becoming a special problem of environmental pollution. Developed countries had and are formulating laws in order to restrict this waste in the form of prohibition or putting taxes for creating specialized waste disposal areas.

Bangladesh is a developing nation where city urbanization started in mid 1990s. Low-rise building owners started to construct high rise apartments replacing their old houses for financial benefits and personal comfort. Unfortunately although a significant number of buildings have been reconstructed in the two metropolitan cities of Dhaka and Chittagong, yet no specific demolition waste management or disposal rules have been enacted by the government or a consensus reached by the building contractors/ property developers. There exists no social awareness as yet regarding this and demolition wastes are disposed off very erratically. A major portion is used in land fill but significant amount are set out in other waste disposal areas which will soon become a source of pollution hazard.

Different use of demolition waste materials is in practice in developed countries like reuse as base course in highway construction and also as recycled aggregate in concrete construction. This study is an attempt to study the possibility of using a specific type of recycled concrete aggregates in concrete production. Specifically, the study is limited to see the effect of different amount of cement content and water cement ratio on the strength and workability of recycled aggregate concrete.

II. Background

As almost no or little work has been undertaken in Bangladesh to use the recycled concrete aggregates, an attempt is made to study the Recycled Aggregate (RA) concrete properties to justify its reuse in construction. Concrete Lab of the Civil engineering department of Bangladesh University of Engineering and Technology provides the most reliable and continuous service to the

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nation performing different quality assurance tests of building materials. Every day on an average eighty sets (240 samples) of concrete cylinders are tested. Post test crushed cylinders are dumped in open courtyard in front of the Laboratory as shown in Fig. 1. We have picked up these crushed cylinders as the source of recycled aggregates for this work. These crumbled cylinders were squashed to pieces using a stone/brick crusher and the recycled aggregates produced (see Fig. 2). It is to be noted that in normal concrete works both natural stone aggregates and brick bats (crushed clay brick chips) are used in Bangladesh. Here crushed cylinders made with natural stone chips have been selected to produce the RA.

Before undertaking this pilot research work, the stock pile of these crushed cylinders grew so large that the university authority in consultation with us used it (RA to clear the courtyard) to put an overlay of 200mm thickness in an internal rigid pavement road 6 m wide and 160 m long. Trial mixes were prepared to ensure at least 20 MPa strength for the overlaid RA concrete.

Figure 1. Crushed cylinder wastes in the Lab. courtyard

III. Program Objective

The experimental program was developed based on the following objectives:

a) To compare the physical properties of RCA and their influence on the properties of recycled aggregate concrete (RAC).
b) To compare the properties of RAC with those of natural aggregate concrete (NAC).
c) To study the effect of variation in cement content on the general properties of RAC.
d) To study the effect of increased volume replacement of natural aggregates by RCA
e) To investigate the influence of water cement ratio (w/c) on RAC compared to NAC.

IV. Properties of Constituent Material

Obviously the constituent materials of Recycled Aggregate Concrete (RAC) are cement, sand (Fine Aggregate, FA), Recycled Aggregates (RA), water and often water reducing admixtures. For the purpose of this study no admixture was used although a parallel work was carried out to assess the effect of local admixture on the properties of RAC. The basic properties of the component materials are described below.

Figure 2. Recycled course aggregates

Sand (Fine Aggregate, FA): One particular type of sand locally known as Sylhet sand was used for all the works. The sieve analysis was carried out in accordance with ASTM C136 [1]. Unit weight of aggregates, specific gravity and absorptions were determined following ASTM C29, C127 and C128 [1] respectively. Test results including Fineness Modulus (FM) are tabulated together with coarse aggregate properties in Table I.

Natural Coarse Aggregate (NCA): Natural Coarse aggregate are scarce in Bangladesh. Commonly available NCA in the market are made from boulders. These are collected from river beds in Sylhet district and are then crushed and graded through appropriate sieves (ASTM C136) and blended to get the right size coarse aggregates. Blended NCA were procured directly from the market and a gradation curve for NCA was done. The gradation fell short of ACI prescribed values of coefficient of uniformity but almost met the criterion of coefficient of curvature. The basic properties of aggregates like specific gravity, water absorption and Fineness Modulus (FM) for the aggregates are given in Table I.

TABLE I. Physical Properties of Aggregates

Materials	Absorption (%)	Bulk Specific Gravity	Apparent Specific Gravity	Fineness Modulus (FM)
NCA	0.5	2.67	2.69	8.41
RCA	5.1	2.46	2.66	6.99
Sand (FA)	1.5	2.59	2.65	2.63

Recycled Coarse Aggregate (RCA): RCA are prepared from the waste stock of crushed cylinders tested in the concrete Lab of BUET for concrete strength assessment of concrete cast at different sites all over Bangladesh. The tested crumbled pieces were crushed to smaller sizes to form the recycled aggregates that can be used in concrete mixes. After crushing cylinder wastes in a crusher machine the pieces reduced close to original size of aggregates with mortar adhering around it and some disintegrated to even smaller sizes. Both natural and recycled coarse aggregate were washed over No. 8 (2.36) sieve to remove excess fines from the aggregates. Later the aggregates were air dried and finally sieved (ASTM C136) to determine the grading. Typical gradation curve for RCA is given in Fig. 3. Fineness Modulus, specific gravity and water absorption were determined and reported in Table I. Absorption capacity of the RCA is found to be 5.1% which is relatively high compared to 0.5% of natural course aggregate. FM of RCA is 6.99 as against 8.41 of NCA.

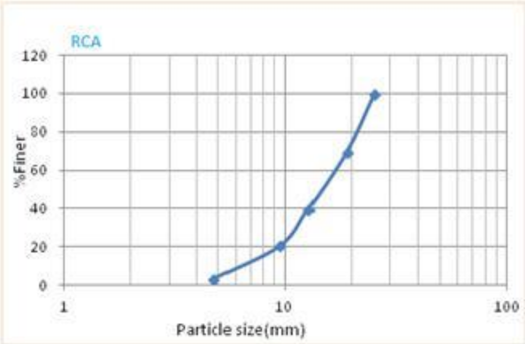

Figure 3. Gradation curve of recycled coarse aggregate

Cement: Ordinary Portland cement (Type I) was used for all the concrete mixes prepared. Brand name HOLCIM (Red) cement was used and its 28 day compressive strength was determined to be 42.4 MPa which is greater than the minimum of 28 MPa required by ASTM C150 [1]. Normal consistency, initial and final setting time requirement of the respective ASTM standards were also satisfied by this brand of cement.

Water: Ordinary potable water from our water supply network pumped in from university Deep tube well was used for all cases.

V. Experimental Investigation

As a first step all the aggregates (NCA, RCA and sand) were collected and their physical properties like FM, water absorption, specific gravities and gradation were determined as already explained. Next Mix design following ACI method was carried out for some specific target concrete strength considering natural coarse aggregates to be used. Different target strength was set considering three different water cement ratio of 0.41, 0.46 and 0.5. The effect of replacing virgin natural aggregates in different proportion (25, 50, 75 and 100%) by RCA was then studied for each of these water cement ratio. Finally, to study the effect of increased cement content on the properties of these recycled aggregate concrete the amount of cement was increased by almost 30% from 370 kg to 476 kg per cubic meter of concrete for all of the previous cases.

A. Mix Design

The original mix design with NCA was done following ACI Mix design procedure ACI 211 [2] for a target concrete strength with a selected water cement ratio/slump. However, for mix design with partial replacement of NCA by RCA three design approaches are available [3]. These are Direct Weight Replacement (DWR) method, Equivalent Mortar Replacement (EMR) method and Direct Volume Replacement (DVR) method. Considering the simplicity, the DVR method has been adopted which is available in [2] and used by some previous workers as well [4]-[5]. During replacement calculation the difference in the SSD specific gravity of the two coarse aggregates has been taken into account to determine the actual weight of replacing aggregate.

B. Concrete Mixing and Casting

The concrete was mixed in a rotating type drum mixture with (wet material) capacity of 0.0425 m^3 (1.5 cft) following ASTM C192 [1]. Upon mixing, the fresh concrete was discharged quickly on to a non-absorbent flat surface and slump test was done using standard slump cone and base plate and the cylinders (100mm dia by 200mm high) were quickly cast. The cylinders were stripped off the molds a day later and immediately immersed in water (curing tank) for curing.

C. Tests

Compressive strength and water absorption of hardened concrete were measured. After appropriate days (like 7 day, 14 day and 28 day) of curing compressive strength of test cylinders were determined. Each cylinder was capped using unbounded steel caps with rubber bearing pads to achieve fairly even load distribution. A load-rate controlled hydraulic concrete block testing machine was used to apply load at a prescribed rate. The compressive strength f_c' was determined as the peak stress corresponding to the maximum load recorded during the test prior to crushing. Slump test was recorded during casting time. Finally, absorption test of cast concrete cubes were measured after 28 days of water curing. On removal from curing tank the cube was wiped off excess water with a towel and wiping was repeated a couple of times within five minutes. Saturated cube weight was recorded and then it was put into an oven and drying continued for 24 hours at 105^{o}C. Next day the oven dry weight was measured and water absorption of relevant concrete was determined. Details are in Ref. [6].

A special grading of aggregates called combined grading was done in this investigation. The proportion of fine and course aggregate in a mix is called combined grading. This is strongly advocated by Shilstone [7] who divides the total gradation into three fractions, coarse, intermediate and fine. He also suggested that aggregate gradation be done on volume basis rather than weight. So, combined aggregate gradations for all the RCA replacement were carried out but these graphs are not given here for obvious reason (except one shown in Fig. 4, for 100% RCA with FA). All exists elsewhere [6]. However, Shilstone introduced two factors called “Coarseness Factor (CF)” and “workability factor (W)” derived from the total aggregate gradation. CF is defined as 100.Q/(Q+I) where Q is plus 3/8 inch (9.5mm) size coarse particle and (Q+I) is the total coarse aggregate up to No. 8 (2.36mm) sieve (expressed as percentage).

The other factor Workability (W) is simply the percentage of material passing No. 8 sieve. A little variation of this workability is “Adjusted Workability factor” (W-adj.) and it reflects the influence of the amount of cementitious material on workability [8] (Shilstone & Shilstone Jr. (1987). These factors CF and W derived from combined aggregate gradation can often explain certain behavior of concrete and mix better compared to the usual separate gradation curves. For example, Ashraf [9] observed some dependence of concrete strength on Coarseness Factor (CF). She also pointed out that FM and fine aggregate to total aggregate ratio (fa/ta) plays a key role in design of concrete mix. This is an important point that may be studied seriously for design of RCA concrete in future.

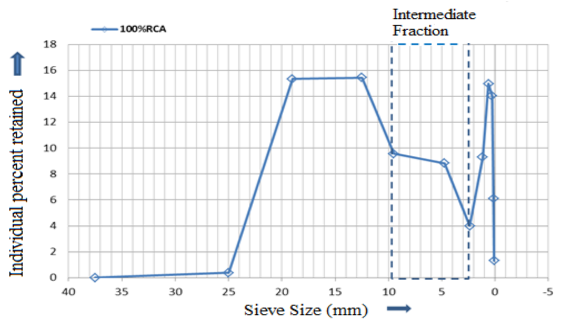

Figure 4. Combined gradation for 100% RCA

VI. Test Results and Discussion

As mentioned earlier that two cement contents were allowed to prepare the mix, one with 370 Kg/m^3 and the other having 476 Kg/m^3. For convenience the first is called normal mix and the latter is termed rich mix. The primary test records were the strength of concrete at 7, 14 and 28 days and the slump values with varying water-cement ratio and amount of NCA replacement by RCA. Variation of slump for different RCA replacement and cement content (normal and rich mix) with variation in water-cement ratio is shown in Fig. 5.

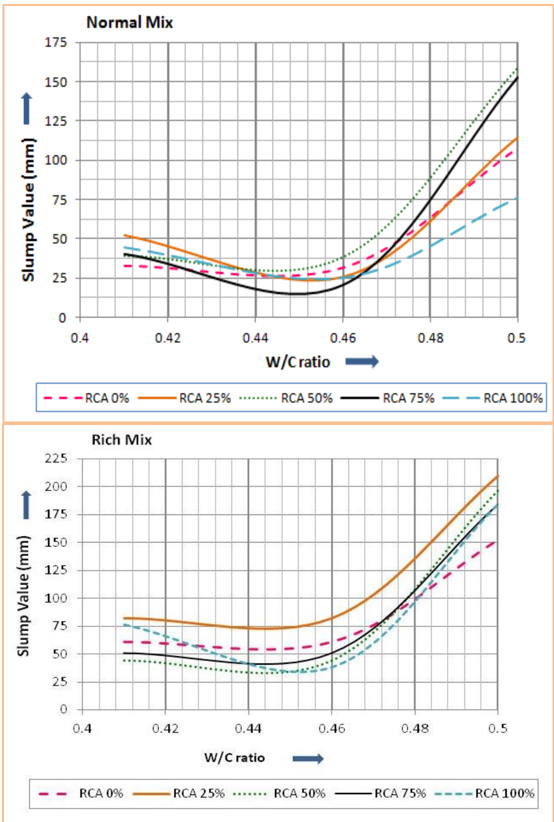

Figure 5. Slump variation of concrete mixes with different RCA replacement and cement content

It was noted that in general the slump values were very low for normal mix with lesser cement content at low water-cement ratio (at or below 0.46) for all types of aggregates including NCA. At w/c of 0.5 reasonably higher slumps of 100 mm or more were measured for all but the 100% RCA concrete. Highest slump was recorded with 50% RCA replacement. On the contrary, for rich mix with higher cement content, increased slump was recorded from w/c of 0.46 and over 200 mm slump was recorded for 25% RCA replacement at w/c = 0.5. Thus workability of fresh mix was highest with 50% RCA replacement for normal mix and 25% replacement for rich mix. It is suggested that concrete with RCA aggregate replacement should have water-cement ratio greater than 0.46, preferably close to 0.48 if used without water reducing admixture. This will ensure workable mix normally.

TABLE II. Absorption of Hardened Concrete (by wt.)

w/c	Type of Mix	For 0% RCA	For 25% RCA	For 50% RCA	For 75% RCA	For 100% RCA
0.46	Rich	4.3	3.2	3.7	3.3	4.0
0.46	Normal	4.5	3.2	3.1	4.9	4.0
0.50	Normal	5.6	2.8	3.4	3.0	2.7

As the permeability instrument was not in order, water absorption of concrete cubes was measured for three cases as an alternative. These are given in Table II. It is noticed that the absorption capacity is less significantly influenced by the amount of cement content and RCA replacement. Surprisingly, absorption in concrete made with natural aggregate is found to be little higher compared to RCA mixed concrete.

TABLE III. Compressive Strength of RAC and NAC

% of RCA		Concrete Strength (MPa) (Normal Mix)			Concrete Strength (MPa) (Rich Mix)		
	w/c →	0.41	0.46	0.5	0.41	0.46	0.5
	Age (days)						
0	7	28.6	28.8	20.0	36.9	20.1	25.3
	14	31.2	32.8	23.0	40.5	21.5	28.0
	28	35.3	35.8	26.3	44.8	28.8	28.9
25	7	29.8	25.6	22.0	37.0	32.3	25.4
	14	32.3	29	27.0	38.2	36.5	29.3
	28	38.1	32.1	30.1	44.4	38.5	30.0
50	7	31.3	26	18.2	39.6	39.1	30.1
	14	35.4	30.5	21.8	43.0	39.4	31.4
	28	37.6	35.1	24.7	46.5	45.3	36.0
75	7	27.9	24.7	16.9	35.8	29.7	29.9
	14	32.6	31.1	21	50.3	36.7	34.0
	28	35.6	32.9	27.6	42.6	41.7	37.9
100	7	19.1	26.1	20.0	35.3	35.6	32.0
	14	22.2	31.7	25.0	50.8	38.8	35.2
	28	26.5	33.1	27.5	44.0	43.2	38.0

Compressive strength of concrete is the most widely used index of practical significance compared to most of the other properties. In general other properties are somewhat related to strength by certain ways and the compressive strength is relatively easy to determine.

Thus, it is very common to use this parameter to assess the quality of the concrete. Most of the research carried out on recycled aggregate concretes is centered on determining the compressive strength and use it to evaluate the suitability and performance of the new concrete. Compressive strength of all the different concrete mixes with varying cement content, water-cement ratio and RCA replacements is summarized in Table III. Each strength value is the average crushing strength of three cylinder samples [7].

ACI 555 committee [10] reviewed several studies, investigating the effects of RCA on conventional concrete and found that performance of concrete with RCA depends on several factors, including the source of recycled concrete and more specifically the quality of the concrete from that source. It is believed that concrete made from recycled aggregates can achieve close to if not same compressive strength as the original concrete from which they are made. Performance of concrete with RCA depends partly on the water cement (w/c) ratio of the original concrete and mostly on the w/c ratio of the newly prepared concrete. Performance of concrete with RCA can also depend on the recycled fine aggregates [11].

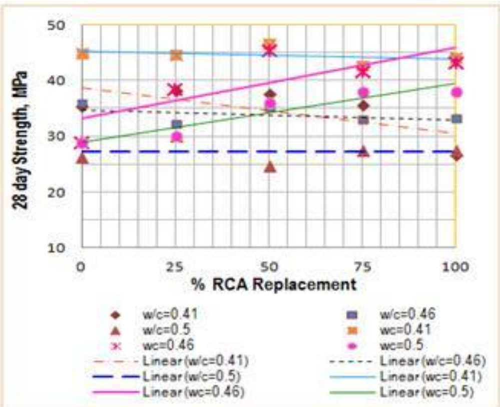

Figure 6. 28 day strength of NAC and RAC for diff. w/c ratios

Compressive strength at 7, 14 and 28 day of five different set of concrete containing five different mix proportions of RCA at three different w/c ratios for both normal mix and rich mix can be compared from Table III. Fig. 6 graphically compares the 28 day strengths of NAC and RAC with different amount of RCA replacement and three water-cement ratios (marked w/c for normal and wc for rich mix in Fig. 6). It may be noted that change in strength for a specific w/c ratio and cement amount is not remarkably different with variation in RCA replacement. Generally, slight decrease in strength is noticed with increase in RCA amount but with rich mix (higher cement proportion) strength of RAC is found to increase with extra amount of RCA replacement for w/c ratio of 0.46 and 0.5. Compressive strength was found to increase or remain within close to that of Natural Aggregate (NA) up to 50% of RCA and with 25% RCA replacement the strength can be considered virtually unchanged.

The other key aspect studied was the strength gain characteristic of RCA concrete. Hasan and Kabir [12] reported that rational polynomial can very effectively model the strength gain pattern of stone aggregate normal concrete (made with ordinary Portland cement).

In this investigation, rational polynomial curve fitting was done with MATLAB to model strength gaining of all the six possible variable sets of data [two mix types (normal & rich) and three w/c ratios]. Two of these graphs are presented here in Fig. 7. Normal mix and rich mix curves are shown here for one water cement ratio case of 0.5 (i.e. w/c=0.5).

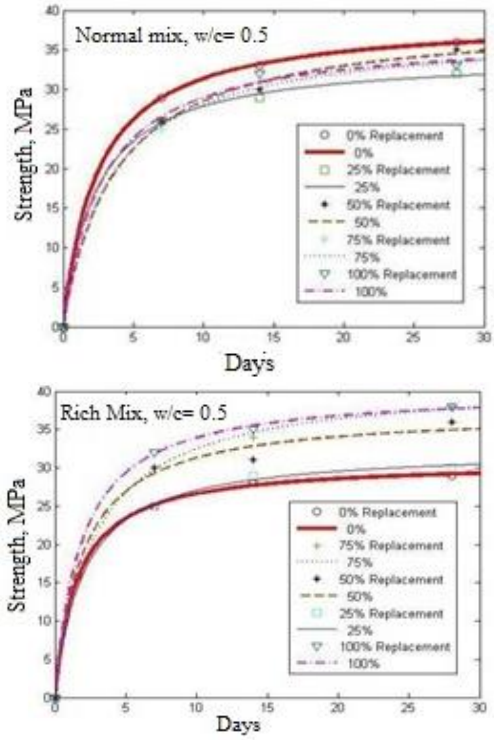

Figure 7. Strength gain characteristics of NAC and RAC for different mix and w/c ratios

Strength gain features for every concrete mixes with NCA and RCA are remarkably similar for all the cases studied. The gain in strength is followed very closely in most cases. Exceptions are 100% RCA normal mix with w/c=0.41 and NCA rich mix at w/c=0.41 (not shown here). In either case the rate of strength gain is significantly lower than the other mixes. For rich mix with w/c=0.5, strength gain rate is also slightly less for NAC and 25% RAC compared to remaining three cases. This is apparent from the plots in Fig. 7.

VII. Conclusion

Growing urban housing demand in Bangladesh is popularizing high rise building concept in the two metropolitan cities disposing the old constructions. The government, builders and other stakeholders should find appropriate ways to reuse the building/construction wastes without serious disturbance to the environment. This is an effort to study the possibility of using recycled coarse aggregates in concrete construction works.

From the limited study carried out here, the following conclusions may tentatively be drawn.

1) Grading of recycled aggregates like that of NA has significant influence on the strength and other properties of concrete. Properties of RCA depend more on some interrelated factors like its source, age, original strength, original constituent aggregates etc.

2) Workability increased with higher amount of cement in the mix with different proportion of RCA replacement.

3) 28 day compressive strength of RAC having different amount of replacement is found comparable with that of NAC. Increasing the cement quantity by 30% enhanced the strength of recycled aggregate concrete compared to NAC for higher water-cement ratio.

4) Increased volume replacement of NA by RA decreased the Coarseness Factor (CF) and slightly raised the workability factor of the combined aggregates.

5) Rational polynomial curves can model the strength gain attribute of recycled aggregate concrete exactly as it can do it for NAC. This implies that any two days strength test data (like 3 & 7 or 7 & 14 days) can be used to predict concrete strength at any other day say 28 days.

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REFERENCES

[1] ASTM International, Annual Book of ASTM Standards, V. 4.02, West Conshohocken, PA, 1999.

[2] ACI Committee 211, Standard Practice for Selecting Proportions for Normal, Heavy Weight and Mass Concrete (ACI 211.1), American Concrete Institute, Farmington Hills, MI, 1991.

[3] M. A. Knaack and Y. C. Kurama, "Design of concrete mixtures with recycled aggregates," *ACI Material Journal*, vol. 110, no. 5 pp. 483-493, September-October 2013.

[4] V. Corinaldesi, "Mechanical and elastic behavior of concrete made of recycled concrete coarse aggregates," *Construction & Building Materials*, vol. 24, no. 9, pp. 1616-1620, 2010.

[5] I. B. Topcu and S. Sengal, "Properties of concrete produced with waste aggregates," *Cement and Concrete Research*, vol. 34, no. 8, pp. 1307-1312, 2004.

[6] N. U. Ahmed and M. S. Alam, "Use of recycled aggregates in concreting," B.Sc. engineering thesis, Dept. Civil Eng., Bangladesh Univ. of Engineering & Tech., Bangladesh, Dhaka, 2013.

[7] J. M Shilstone, "Optimizing concrete mixtures," *Concrete International: Design and Construction*, vol. 12, no. 6, pp. 33-38, 1990.

[8] J. M. Shilstone and J. M. Shilstone Jr., *Practical Concrete Mixture Proportioning Technology*, Reference Manual, Shilstone Co., 1987.

[9] W. B. Ashraf, "Concrete mix design procedure using locally available aggregates," M.Sc. Engineering thesis, Dept. Civil Eng., Bangladesh Univ. of Engineering & Tech., Bangladesh, Dhaka, 2012.

[10] ACI Committee 555, "Removal and reuse of hardened concrete," ACI Committee Report, American Concrete Institute, Farmington Hills, MI, 2001, pp. 18-26.

[11] M. Tarek Uddin, A. Z. Khan, and A. H. Mahmood, "Recycling of demolished brick aggregate concrete as coarse and fine aggregates," in *Proc. International Conference on the Regeneration and Conservation of Concrete Structures*, Nagasaki, Japan, June 2015.

[12] M. M. Hasan and A. Kabir, "Prediction of compressive strength of concrete from early age test result," in *Proc. 4th Annual Paper Meet and 1st Civil Engineering Congress*, Dhaka, Bangladesh, December 22-24, 2011, pp. 1-7.

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