

EVALUATION OF COMMONLY USED AGGREGATES FOR SUSTAINABLE INFRASTRUCTURE DEVELOPMENT IN BANGLADESH

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ABSTRACT: A good number of infrastructure projects are implemented in Bangladesh during the last decade and many more are still in pipeline. In the financial year 2017-18 approximately 12.7 million tons of aggregate are used by the construction industries. Local sources could supply only 11% of those aggregate and rest 89% are collected from foreign sources. Due to the wide variation of aggregate sources performance of concrete become unpredictable. Therefore, in the present study influence of commonly used coarse aggregate characteristics for building sustainable infrastructure are investigated by evaluating the performance of concrete with various aggregate types. To evaluate performance, six mostly used coarse aggregate sources are selected for this study. A series of laboratory test are conducted to evaluate the ACV, TFV, LAA, EI, FI, specific gravity, water absorption and unit weight for all six aggregates. Additionally, chemical composition and petrographic properties are also explored. Keeping the gradation of aggregate constant, two types of concrete mix (w/c ratio 0.3 and 0.4) were prepared to cast concrete cylinders and beams by using six sources of coarse aggregate. Concrete properties including compressive, tensile and flexural strength are determined. The study finds that physical properties of aggregate generally influence the properties of concrete. However, the influence is significant in case of concrete requiring compressive strength higher than 50 MPa. The outcomes of the study will help the engineers to select appropriate sources of aggregate depending on concrete strength requirements.

Keywords: Coarse aggregate, Concrete, Compressive strength, Aggregate crushing value and Flakiness Index

1. INTRODUCTION

Bangladesh is a developing country where GDP growth rate has hit 7.86 % in the fiscal year 2017-18. It is often said that construction sector is one of the crucial drivers for accelerating economic growth in Bangladesh. Construction sector plays a great role in employment generation, expansion of markets for materials and other commercial activities. Aggregate is one of the mostly used construction materials in all most every construction work. Aggregates have a significant effect on the strength characteristics of concrete in case of high strength concrete. For normal concrete strength may be governed by the interfacial transition zone as it is the strength limiting factor for the case of normal concrete [1], [2]. Characteristics of cement matrix, the interfacial transition zone between the cement matrix and the coarse aggregate usually decide the strength of normal concrete. The usage of water reducing agents in the high strength concrete increases the strength of cement matrix as well as the mechanical properties of interfacial transition zone. Consequently, the properties of coarse

aggregate have become dominant in making high strength concrete. In such high strength concrete, the cracks may get initiated either in matrix or aggregate and propagate across all the three phases making the fracture surface relatively less tortuous [3]. Chemical admixtures and some supplementary cementing materials can be used to improve the workability of concrete without negatively affecting hardened concrete [4]. Aggregate shape, texture, and grading have a significant effect on the performance of fresh concrete [4]. Extensive research works on aggregate properties are reported by many researchers including the effect of different types of coarse aggregates such as grey Granite, Anorthosite, Charnockite, Limestone, and Gneiss on the performance of concrete by Vishalakshi et al. [5], effect of maximum aggregate size on the concrete strength by Grabiec et al. [6], the influence of coarse aggregate mineralogy in mechanical properties of high strength concrete by Orami et al. [7], the influence of aggregate type on the elastic modulus of high strength concrete Beushausen et al. [8].

However, detail research work related to the development of high strength concrete using

available aggregates in Bangladesh is yet to be completed. In Bangladesh, maximum 6,600 psi concrete is made but it is not sufficient for making high-rise structures [9]. One of the challenges for making high strength concrete in Bangladesh is non-availability of good quality stone aggregates [10]. Bangladesh has limited sources of naturally occurring rock [11]. Due to shortage of aggregate researchers in Bangladesh are trying to establish recycled aggregate as an alternative. Study reports that by utilizing 100% recycled coarse aggregate and 100% recycled fine aggregate, it is possible to make concrete of strength over 27.5 MPa. Additionally, it is reported that induction furnace slag can be utilized as coarse aggregate for normal strength concrete [12].

Currently, this country depends largely on the various international sources and on few local sources for coarse aggregates. The geological and geo-morphological processes forming the rocks may vary in different locations leading to remarkable variations on the properties of aggregates from different sources. Therefore, it is essential to analyze the characteristics of local as well as known foreign aggregates to be used in various national important infrastructure projects.

In the present study, the influence of aggregate, collected from various sources, characteristics on concrete strength has been studied. A series of physical and mineralogical tests of aggregates have been performed. Concrete cylinders are then prepared and tested for strength evaluation. Finally, a correlation between the concrete strength and aggregate properties has been studied.

2. MATERIALS

2.1 Coarse Aggregate

The coarse aggregate were obtained from six different sources, three from sources within Bangladesh, such as Moddhapara (Mo), Bholaganj (Bh) and Jaflong (Ja) and three from sources outside Bangladesh, namely Pakur – India (PI), Seremban – Malaysia (SM) and Khuong – Vietnam (KV). Samples were crushed as shown in Fig. 1 before delivered by the local supplier.

2.1.1 Physical Test

Gradation of coarse aggregate varies from source to source and has significant effect on concrete strength [5]. However, in order to study the influence of aggregate on concrete properties it is essential to keep the gradation of coarse aggregate same for all samples. Therefore, for the present study gradation of aggregate is kept constant for all six aggregate samples as shown in Fig. 2.



Fig. 1 Crushed samples of various coarse aggregates.

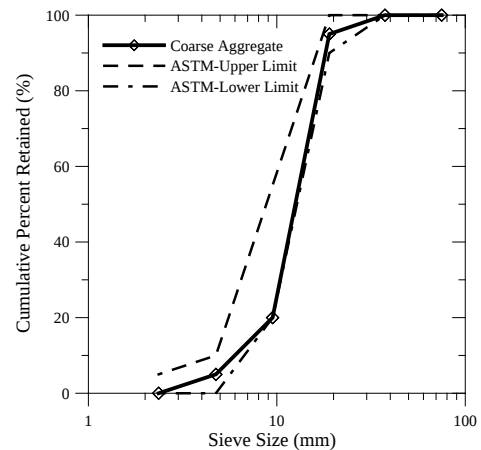


Fig. 2 Constant gradation of coarse aggregate used in this study along with ASTM limits (ASTM C 33).

It is reported that physical properties of aggregate, like strength, shape, size and texture has significant effect on both fresh and hardened properties of concrete [4]. Furthermore, mineralogical composition of aggregate also influences the compressive strength of concrete. Therefore, in the present study a series of physical test, such as aggregate crushing value (ACV), Los Angeles abrasion (LAA), ten percent fine value (TFV), flakiness index (FI), elongation index (EI), fractured face (FF), specific gravity (SG), absorption capacity (AC) and unit weight, has been performed. Properties of various aggregates are summarized in Table 1.

The aggregate crushing value (ACV) and ten percent fine value (TFV) indicate resistance of aggregate against crushing under a gradually applied compressive load. According the ACV result, Pakur-India (PI) has the highest resistance then SM, KV, Mo, Bh, and finally Ja. Based on TFV data, sequence of resistance is PI>SM>KV>Bh>Mo>Ja. Los Angeles abrasion

(LAA) test measures toughness and abrasion characteristics of aggregate. Similarly, PI has highest toughness and lowest abrasion, and sequence for the other aggregates is SM>KV>Mo>Bh>Ja.

Elongation index (EI) and flakiness index (FI) represent shape and size of the aggregate. Fractured face signify rough surface of the aggregate and the test results show that 100% of all six aggregate samples have three or more fractured faces. Specific gravity and water absorption capacity of all six aggregates is similar except for PI and KV with slightly higher value. Unit weight of aggregate samples is almost similar apart from Bholaganj aggregate.

Table 1 Physical properties of coarse aggregate

Properties	PI	KV	SM	Mo	Bh	Ja
ACV (%)	12	17	17	19	20	21
LAA (%)	12	21	16	26	28	32
TFV (kN)	290	220	240	190	210	170
EI (%)	23	23	16	21	19	20
FI (%)	17	15	12	22	19	20
FF [†] (%)	100	100	100	100	100	100
SG (SSD)	2.88	2.80	2.65	2.74	2.64	2.66
AC (%)	1.19	0.57	0.72	0.83	0.94	0.74
Unit wt. (kg/m ³)	1673	1677	1626	1682	1567	1669

[†] 100% of aggregates have 3 or more fractured faces

2.1.2 Chemical Test

Aggregate mineralogical composition has substantial effect on concrete strength as reported by [7]. Hence, in the current study chemical composition of all six aggregates are determined through a wavelength dispersive X-ray fluorescence (WDXRF) and the results are shown in Table 2. From the test results it is evident that only Khuong – Vietnam (KV) is calcium oxide based and all the other aggregates are silica based. Beside these other major components are ferric oxide, aluminum oxide, magnesium oxide and potassium oxide.

2.1.3 Petrographic Analysis

Petrography analysis appraises the quality of course aggregate. In this analysis aggregate particles are initially subjected to geological classification. Analysis is done following ASTM C-295 and the results have been sketched out in Table 3. As shown in the table, parent rock for PI, SM and Mo is igneous type; whereas, parent rock for KV, Bh and Ja is sedimentary. On the other hand, PI is basalt, KV is lime stone and rest are granite type rock.

2.2 Fine Aggregate

Fine sand are river sand obtained from Sylhet district in Bangladesh. These particles almost entirely passing the 4.75 mm (No. 4) sieve and predominantly retained on the 75 μ m (No. 200) sieve. The properties of fine aggregate are shown in Table 4.

Table 2 Chemical composition of coarse aggregate

Properties	PI	KV	SM	Mo	Bh	Ja
SiO ₂ (%)	56.2	4.59	67.2	57.3	83.3	82.0
Fe ₂ O ₃ (%)	11.9	1.71	4.80	9.69	3.19	3.20
Al ₂ O ₃ (%)	10.7	1.02	10.3	9.24	4.65	5.43
CaO (%)	10.4	78.7	5.10	11.6	2.77	2.68
MgO (%)	3.62	12.6	0.99	4.20	0.94	0.82
K ₂ O (%)	3.16	0.36	8.14	3.46	3.22	3.93
TiO ₂ (%)	1.80	0.22	0.62	1.03	0.60	0.61
Na ₂ O (%)	1.54	0.17	1.94	2.26	0.83	0.91
P ₂ O ₅ (%)	0.35	0.05	0.35	0.56	0.18	0.17
SO ₃ (%)	0.22	0.24	0.17	0.09	0.10	0.12
SrO (%)	0.06	0.19	0.02	0.12	0.02	0.02
Cr ₂ O ₃ (%)	-	0.03	0.06	0.07	0.05	-
MnO (%)	-	0.03	0.09	0.15	0.05	0.04
ZrO ₂ (%)	0.02	-	0.03	-	0.14	0.07
ZnO (%)	0.02	0.02	0.06	-	-	-
Rb ₂ O (%)	0.02	-	0.08	0.01	0.02	0.02

Table 3 Rock classification of aggregates

Aggregate Source	Origin	Rock Type
PI	Igneous	Basalt
KV	Sedimentary	Lime Stone
SM	Igneous	Granite
Mo	Igneous	Granodiorite
Bh	Sedimentary	Granite
Ja	Sedimentary	Granite

Table 4 Properties of Sylhet sand

Properties	Ref. Standard	Test Results	Unit
Fineness Modulus (FM)	ASTM C136	2.78	-
Specific gravity	ASTM C128	2.61	-
Absorption capacity	ASTM C128	1.7	%
Unit weight	ASTM C29	1466	kg/m ³

2.3 Cement

For the present study an ordinary Portland cement (OPC) collected from local manufacturer has been used. The OPC cement, also classified as CEM I – 52.5 N, was produced following the Bangladesh Standard BDS EN 197-1: 2003. The physical and chemical tests were conducted in the laboratory and presented in Tables 5 and 6, respectively.

Table 5 Physical properties of cement

Properties	Ref. Standard	Test Results	Unit
Specific Gravity	ASTM C188	3.15	-
Strength, 3 days		30.2	MPa
Strength, 7 days	ASTM C109	36.3	MPa
Strength, 28 days		46.6	MPa

Table 6 Chemical composition of cement (ASTM C 114)

Name	Test Results (%)
Silicon di-Oxide (SiO ₂)	19.74
Aluminum Oxide (Al ₂ O ₃)	5.06
Ferric Oxide (Fe ₂ O ₃)	3.21
Calcium Oxide (CaO)	64.67
Magnesium Oxide (MgO)	2.11
Insoluble Residue (IR)	0.7
Sulfur tri-Oxide (SO ₃)	2.43
Tricalcium Aluminate (C ₃ A)	9.7
Loss on Ignition (LOI)	1.63
Total Alkalis (Na ₂ O+0.658K ₂ O)	46.6

2.4 Admixture

In order to maintain the workability at low water-cement ratio a modified polycarboxylate based admixture is used in this study. It is a high range water reducing super plasticizer with negligible sensitivity against aggregate variations. It has a relative density of 1.08 kg/l at 25°C. As per the manufacturer, recommended dosage is 0.5 to 2% by the weight of cement.

3. CONCRETE MIX PROPORTION AND PREPERATION

It is widely reported that influence of aggregate is insignificant for regular concrete with w/c ratios between 0.4 and 0.7. However, concrete with high compressive strength with low w/c ratio may depend on aggregate properties. Therefore, to study the effect of aggregate properties in concrete performance, two w/c ratios (0.3 and 0.4) has been

considered in this study.

Mix design of concrete has been performed according to ACI 211-91. Mix proportions for 1 m³ of concrete for each aggregate type are presented in Table 7. In total, twelve mix proportions have been considered with six different aggregate types and two different w/c ratios. Concretes were designated with coarse aggregate type and w/c ratio. For example, PI-03 represents Pakur-India coarse aggregate and 0.3 w/c ratio.

Table 7 Mix proportion for 1 cum of concrete

Designation	Water (kg)	Cement (kg)	CA (kg)	FA (kg)	Admixture (ltr)
PI-03	205	683	1037	501	6.83
PI-04	205	513	1037	650	3.85
KV-03	205	683	1040	470	6.83
KV-04	205	513	1040	618	3.85
SM-03	205	683	1008	449	6.83
SM-04	205	513	1008	597	3.85
Mo-03	205	683	1043	455	6.83
Mo-04	205	513	1043	603	3.85
Bh-03	205	683	972	480	6.83
Bh-04	205	513	972	629	3.85
Ja-03	205	683	1035	427	6.83
Ja-04	205	513	1035	575	3.85

Concrete cylinders, 100 mm by 200 mm, were prepared in two layers with the help of vibrator for compressive strength and split tensile strength. Beside these, concrete beams, 100 x 100 x 500 mm, were also casted for flexural strength test.

4. RESULTS AND DISCUSSION

At 28 days concrete cylinders were tested for compression and split tensile test in a 3000 kN capacity compression machine; beams were tested for flexural strength in 1000 kN capacity universal testing machine. Just before the test samples were removed from the water tank and surface dried with rags.

4.1 Compressive Strength

Compression test were performed for twelve sets of cylinders for six aggregate types and two w/c ratios. Fig. 3 represents the test results. As shown in the figure, concrete with aggregate from the Seremban – Malaysia (SM) produced the highest compressive strength in case of both w/c ratios of 0.3 and 0.4. On the other hand, concrete

with aggregate from Jaflong (Ja) showed lowest compressive strength. Beside these concrete with KV and Mo showed good compressive strength. Except for concrete with Pakur-India (PI) compressive strength concrete is related to strength properties of aggregate, such as ACV, LAA and TFV. Aggregate from PI has shown highest strength compare to other aggregates. However, because of its high elongation index (EI) and flakiness index (FI) the compressive strengths of concrete with PI fall short of the expected results. Furthermore, lime stone aggregate from KV showed good compressive strength despite having relatively high EI value.

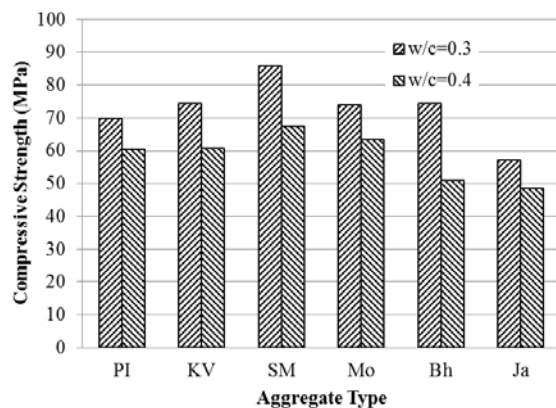


Fig. 3 Compressive strength of concrete with six coarse aggregate types at 28 days age for w/c ratios of 0.30 and 0.40.

4.2 Split Tensile Strength

Similar to compression test, split tensile tests were performed for concrete with six aggregate type and two w/c ratios. Fig. 4 displayed the tensile test results. Like compressive strength, concrete with SM aggregate showed the highest tensile strength; whereas, concrete with Ja aggregate gave the lowest strength. Concrete with KV and Mo also performed well.

4.3 Flexural Strength

Concrete beams were tested for flexural strength. Loads were applied at one-third and two-third points and flexural loading capacity were calculated accordingly. Fig. 5 displayed the flexural strengths concrete with aggregate and w/c ratio variations. As shown in the figure, concrete with aggregate from KV and PI have shown the highest flexural strength despite having high EI and FI values. On the other hand, SM, with lowest EI and FI values, based concrete has not yield higher flexural strength. This implies that aggregate shape has very little effect on flexural

strength of concrete.

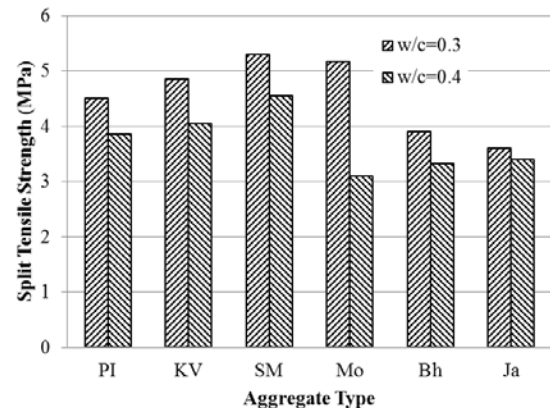


Fig. 4 Splitting tensile strength of concrete with six coarse aggregate types at 28 days age for w/c ratios of 0.30 and 0.40.

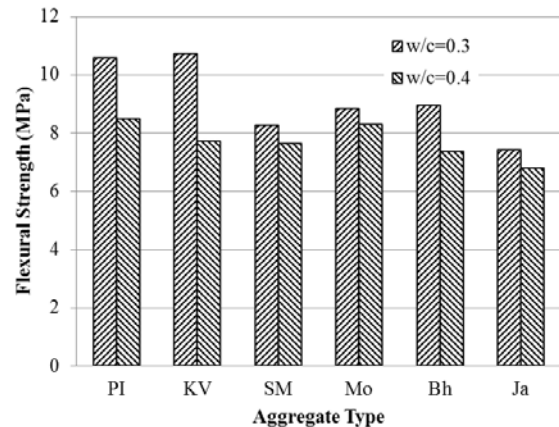


Fig. 5 Flexural strength of concrete with six coarse aggregate types at 28 days age for w/c ratios of 0.30 and 0.40.

4.4 Correlation between Aggregate Properties and Concrete Strength

One of the major objectives of this study is to find a correlation between aggregate properties, such as shape and strength, with concrete strength. Shape of the aggregate is partly depends on the crushing procedure of the rock, and thus, will not be used for direct correlation for concrete strength. However, strength properties of aggregate, such as ACV, LAA and TFV, have significant effect on concrete compressive strength. Fig. 6 – 8 represent concrete compressive strength against ACV, LAA and TFV, respectively except for concrete with aggregate from PI. As mentioned earlier, concrete with PI showed scattered results because of its shape factor of aggregate. The figures also include linear trend lines with r-squared values. In all cases it showed good correlations.

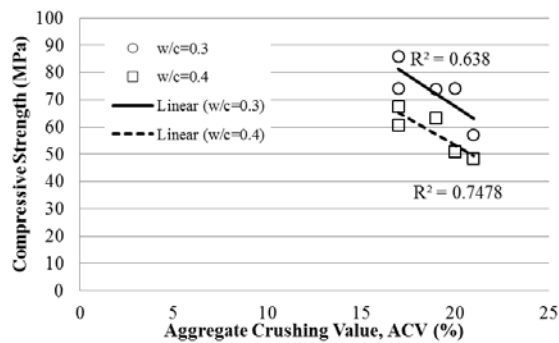


Fig. 6 Compressive strength of concrete at 28 days vs. aggregate crushing value (ACV).

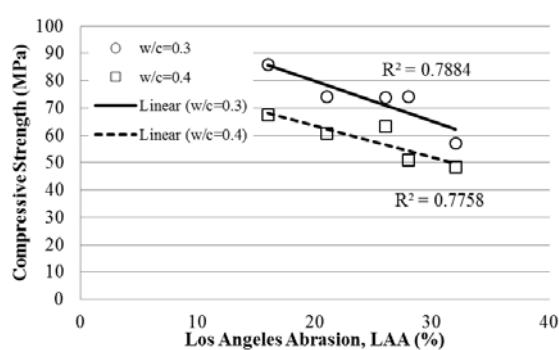


Fig. 7 Compressive strength of concrete at 28 days vs. Los Angeles abrasion (LAA) value.

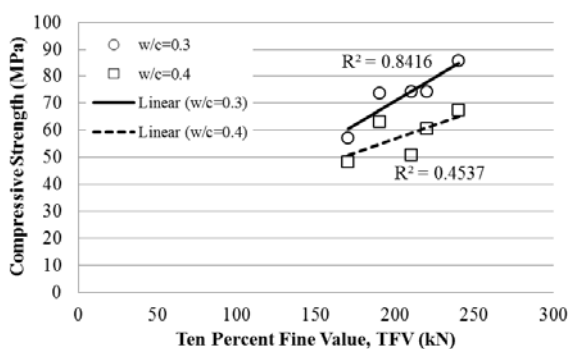


Fig. 8 Compressive strength of concrete at 28 days vs. ten percent fine value (TFV).

As shown in Fig. 6, concrete compressive strength reduces with increasing ACV values. Similar is true for LAA values. As described in Fig. 7, higher the LAA values lower the compressive strength of concrete. For TFV opposite trend observed as presented in Fig. 8. With increasing values of TFV concrete compressive strength increases. It is also observed that in all cases influence of aggregate strength become insignificant for concrete with 50 MPa or less.

5. CONCLUSION

The conclusions that can be drawn from this study are as follows:

- Strength and shape properties of aggregate have significant effect on compressive and tensile strength of high strength concrete. However, for concrete with 50 MPa or less compressive strength this influence becomes trivial.
- Concrete compressive strength increases linearly with decreasing ACV and LAA values and with increasing TFVs. However, this relation is only valid for 50 to 90 MPa strength and for relatively lower elongation and flakiness indexes.
- Shape of aggregates has insignificant influence on flexural strength of concrete.

6. ACKNOWLEDGMENTS

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