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Use of selected silica deposits of Bangladesh as standard sand in testing compressive strength of hydraulic cement mortars: A proposal for strength correlation

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Abstract

An investigation is conducted to study the possibility of using selected silica deposits of Bangladesh as standard sand in testing compressive strength of hydraulic cements. To this end, silica sands collected from geo-referenced Dupi Tila formation of Bangladesh located near to ground surface were mechanically and chemically processed to remove physical and chemical impurities. Collected deposits show uniformity in grain size and mineralogical composition. X-ray diffraction analysis was conducted to determine chemical composition. Shape and surface morphology of the grains were observed in Scanning Electron Microscope. Cement cubes prepared using the sand samples were compared with those prepared with Ottawa sand in ASTM standard for compressive strength assessment. Finally strength correlations for the samples obtained after mechanical and chemical processing were established, which show close and dependable resemblance with Ottawa sand.

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Keywords: Silica sand, geological deposit, chemical composition, roundness, geo-referencing, XRD, SEM

1. Introduction

Compressive strength of hydraulic cement is an important parameter in the quality control of concrete. Standard sand is used as a filler material in testing hydraulic cement. Shape and size of sand grains depend on the composition of parent rock formation and fracture process. The composition of sand is highly variable, depending on the local rock sources and conditions, but the most common constituent of sand is silica (silicon dioxide, SiO_2), usually available in the form of quartz. The first prerequisite for being standard sand is that, it's geological origin needs to be known via geo-referencing. It is often considered important to select standard sands from local origins and derive correlations with standard sand. In the selection of sand from local origins we shall consider also to identify a source that can offer sands of same property over time. Thus sands collected from older geological deposits bear superiority over the recent ones.

Many countries have already set their standard sands from their local origins. United Kingdom, India, Japan, China, Ethiopia; these countries have done extensive research in setting standard sands from their local origin. In United Kingdom, British Standard (BS 4550-6, 1978) recommends the use of Leighton-Buzzard sand as standard sand for testing and other purposes. Leighton Buzzard is a town in Bedfordshire, England near the Chiltern Hills and lying between Luton and Milton Keynes. In India, Bureau of Indian Standards (IS 650, 1955) recommends the use of locally available standard sand for testing cement. Till 1955, Leighton-Buzzard sand was used for testing cements in India. India has performed extensive research works to find a suitable location for standard sand and finally, locally available sand collected from Ennore, Tamil Nadu is selected as the source of standard sand. The gradation of this sand is same as Leighton-Buzzard sand. Japan uses Toyoura sand as standard sand. Toyoura sand is being used according to Japan Industrial Standards (JIS R 5201, 1997). From April 1997, the cement strength testing standard has been changed to the ISO standard (ISO 679: 2009) and so called standard sand has become ISO standard sand. Toyoura standard sand now known as Toyoura Silica Sand is being produced to the same exacting standards as before. No detailed investigation on the formation of these standard sands is known to the authors.

In recent years a study has been performed in Ethiopia (Berhanu, 2005) to set standard sand from Ethiopian origin for the purpose of construction and testing. For this purpose two sand samples were collected from North Showa (Jema River) and Dire Dawa town. The former is natural sand deposit and the latter one was collected from riverbed crossing the town. Grain size analysis and impurity test results revealed that both local sand samples cannot be used as standard sand as they were collected directly from their natural places. In order to be used as standard sand they had to undergo several processes consisting washing, oven drying, sieving and remixing according to specification. The compressive and flexural strength of mortar cubes made with Ethiopian sand samples gave lower strength compared to that of standard sand. Standard sand used here was CEN (Committee for European Norms) Standard sand. No chemical composition related work was found in this study. There was no study regarding the sphericity of the sand particles of the two samples also. Extent of work and details of laboratory facilities were not cited in the paper. Correlations of sands were performed for twelve samples only. The strength data were compared only for 7 days value. 3 days and 21 days strength comparisons were omitted.

According to American Society for Testing and Materials (ASTM C778) procedure, Ottawa Sand (origin: Ottawa, Illinois, USA) is used for testing of hydraulic cement mortar. In most of the Concrete Laboratories of Bangladesh, ASTM standard is used for testing purpose. Though sand is found abundantly in many places in Bangladesh, most of these are not suitable for the replacement of Ottawa sand because of dissimilarities from engineering specification. No notable work is known so far in Bangladesh regarding the setting of a standard sand. For selecting sand for testing purpose, geological formation and morphological studies have to be performed.

With these backgrounds, this work was directed to identify sand with high silica content from a known and well located formation. Furthermore, easy access for mining, perpetuality of the deposits, gradation, size and shape, chemical composition and color of sand grains are the other important criteria to be considered in selecting an alternative to standard sand. In an attempt to replace Ottawa sand with locally available sand in hydraulic cement mortar test a thorough survey of the available literatures were carried out. Formation of soil deposits in Bangladesh, geology of sites, availability of sand at sites, methods of investigation of sand deposits, methods of proportioning of sand grain, properties of constituting materials of mortar were covered in this review. The sand deposits collected from source were thoroughly washed by water and acid for possible removal of unwanted matters. For determination of chemical composition, X-Ray Diffraction (XRD) analysis was conducted. Scanning Electron Microscope (SEM) observation was performed to assess the shape of locally available sand. To assess the effect of abrasion, Los Angeles Abrasion test was performed. Using local sand, number of batches of mortar was cast, while Bureau of Research and Testing Consultation, Bangladesh University of Engineering and Technology (BRTC, BUET) had tested the same cement samples using Ottawa sand. In testing cement mortar, ASTM specifications were thoroughly followed. The strength of cement mortar using indigenous sand was compared with that of Ottawa sand and the correlations of strength were developed. The whole work has been performed in two different laboratories independently. Both laboratories show similar trends.

2. Locations and geological origin

Bangladesh lies between 20°34' and 26°38'N and 88°01' and 92°41'E and as a consequence falls in the north eastern part of South Asia. The Indian states of West Bengal, Meghalaya, Assam and Tripura border Bangladesh in the west, north and east. Myanmar forms the southern part of eastern frontier. The Bay of Bengal limits the land area in the south. There are hilly ranges in the Eastern and Northern part of Bangladesh. Some of the hill ranges of Chittagong and hill tracts districts continue northward across the Indian state of Tripura and form the hill ranges of north-eastern Sylhet region. This hill ranges attain a much lower elevation and slope more gently than their continuations in Chittagong and hill tracts districts. Most of these ranges have more or less the same geological history as that of the ranges of Chittagong Hill tracts (Khan, 1991). In the Piedmont (An area of land formed or lying at the foot of a mountain or mountain range) of Sylhet region glass sands are available and these sands contain higher silica content. These sands are the residue of weathering action of Dupi Tila sandstone formation (Fig.1).

Dupi Tila sediments occupy the most extensive areas in Bangladesh, much more than the area covered by any other sediment aging from the Paleocene to Recent. The Dupi Tila sandstone spreads all over Bangladesh excepting the southern two third of The Delta, south of the Ganges. It crops out in most of the areas of the hilly regions of Sylhet, Chittagong and hill tracts districts or rests beneath a thin mantle of alluvium. To understand the geological pattern of Sylhet region several borehole data were collected and analyzed. The borehole data were collected from different sites spread over the Moulvibazar district. After analyzing the soil reports Nine (9) different sites which have sand layers very close to surface were selected. The depth of sand layers varied from 2~9m from top of the surface. The sand layer is very much close to the surface in College Road, Sreemangal, Moulvibazar site. The soil layer is within two meters depth from the surface. The coordinates of borehole sites were found from the detailed Upazilla maps published by Local Government and Engineering Division (LGED, 2005) of Government of Bangladesh and given in Table 1. Locations of the boreholes are shown over a Digital Elevation Model (DEM) of Bangladesh in Figure 2. Two of the nine borehole results are shown in Figure 3. We skipped other data for brevity.

After plotting the coordinates on the map, an interesting trend is seen (Fig. 4); all the boreholes were performed in the flat lands which are situated in between the hills. The hills are the uplifted portion of Dupi Tila formation.

The soil of the hills gets washed away by rainfall every year. By this process the silty and clayey portion of soil get washed away leaving a layer of sand. This deposition of sands takes place for years. The unique geology of these places is that the places are situated in the piedmont of Dupi Tila formation. The sands are available in good extent. At location 1 the sand is reddish in colour. And at location 2 it is whitish in colour. Both the sands sites are being recharged by annual rainfall events. So the source is perpetual. As long as the hills around the sites are present the sites will be recharged every year.

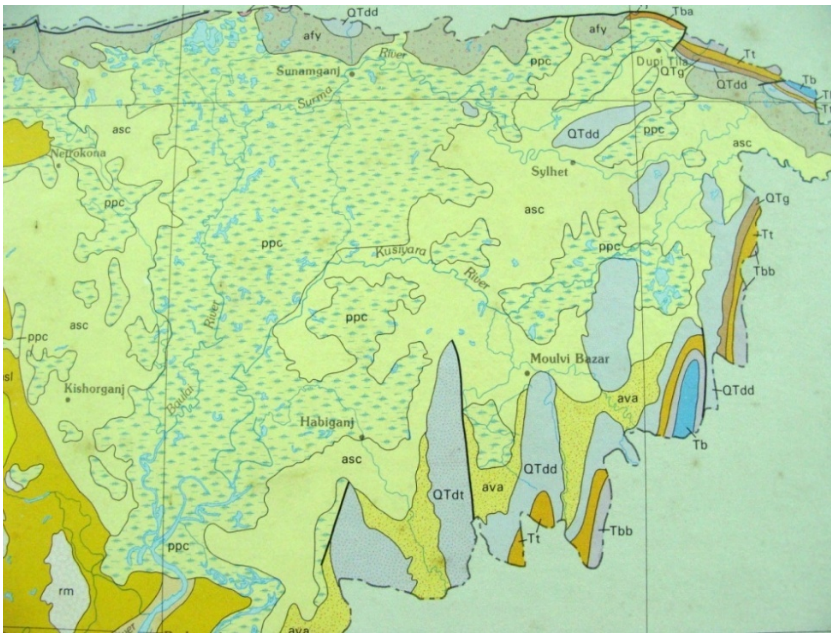


Fig. 1. Geological formation of Sylhet region of Bangladesh (Alam et al, 1990).

Table 1
Location and coordinates of boreholes

Location Name	Identification	Latitude	Longitude
College Road, Sreemangal, Moulvibazar	Sreemangal I	24°18'47.4"N	91°44'16.1"E
Sindurkhan Bazar, Sreemangal, Moulvibazar	Sreemangal II	24°13'53.3"N	91°41'31.7"E
Vimshi, Sreemangal, Moulvibazar	Sreemangal III	24°22'17.1"N	91°38'34"E
Sreemangal sadar, Moulvibazar	Sreemangal IV	24°18'28"N	91°44'18.3"E
Tilokpur, Kamalganj, Moulvibazar	Kamalganj I	24°19'43.8"N	91°51'5"E
Kashimnagar, Barlekha, Moulvibazar	Barlekha I	24°39'15.4"N	92°10'9.7"E
Fultalabazar, Juri, Moulvibazar	Juri I	24°27'22"N	92°8'47"E
Sreepurbazar, Kulaura, Moulvibazar	Kulaura I	24°33'14.6"N	91°58'55.1"E
Moulvibazar sadar	Moulvibazar I	24°29'23.5"N	91°45'16"E

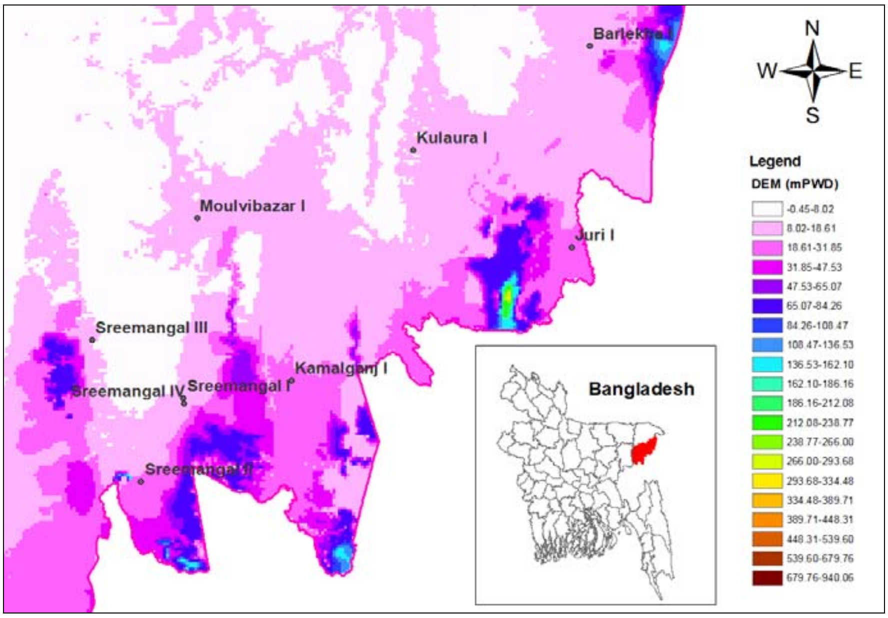
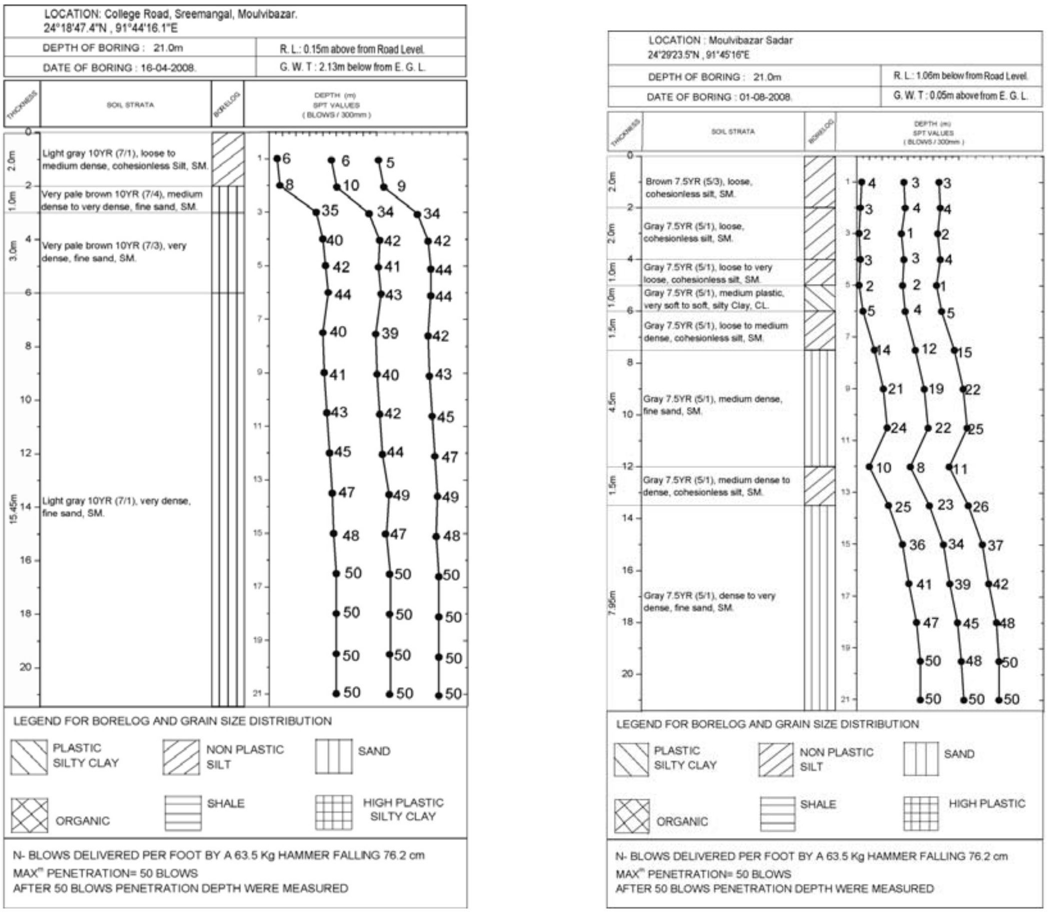


Fig. 2. Location of boreholes in the North-East part of Bangladesh



a) College Road, Sreemangal, Moulvibazar b) Moulvibazar Sadar

Fig. 3. Borehole data in two different sites of Moulvibazar District

Fig. 4. Location of boreholes in the Map (Google Earth, June 10, 2012)

3. Collection and processing

3.1 Processing of sands

Sand is composed of fine materials. It is very prone to debris. The two samples collected from respective locations were transported to Concrete laboratory of BUET. The samples were processed mechanically and chemically with normal water and acid water. After that, they were dried in an oven-dry condition to make moisture free. Finally after grading and proportioning according to Ottawa sand specification, the samples were ready for testing purpose. Some of the samples after drying were separated for X-Ray Diffraction (XRD) and Scanning Electron Microscope (SEM) test. The whole procedure is shown in a flowchart in Figure 5.

3.2 Notations

Sands from Moulvibazar and Sreemangal were selected for the research purpose. Before using for testing the sand samples had to undergo some mechanical and chemical processes. To identify sand in different phases the notation of sand is given in Table 2. Geographical coordinates of the two samples are given in Table 3.

After grading the samples, high resolution digital pictures were taken. The physical appearance of different grains size is shown in Figure 6 for Sand I W (red) and Sand II W (white). Where a, b and c are the grain sizes of sand that retained on US standard sieve #30 (600 µm), #50 (300 µm) and #100 (150 µm) respectively. A picture of scale in centimeter (cm) is also shown along the top line of the, which is also taken in the same manner.

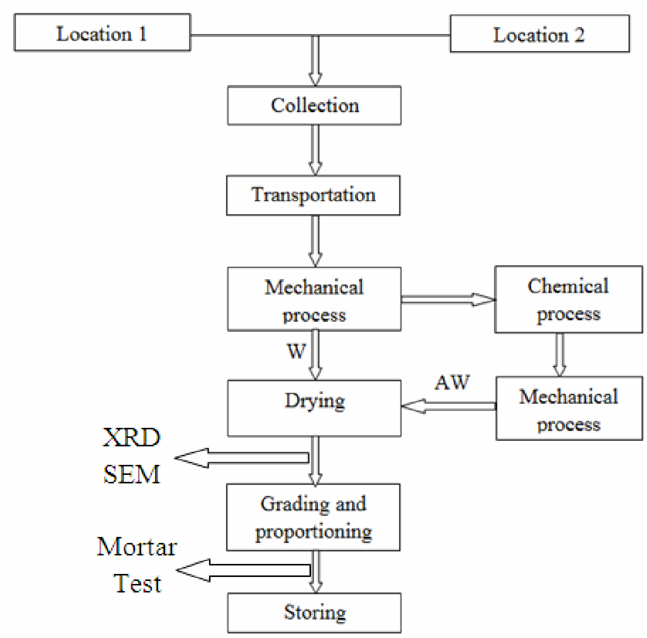


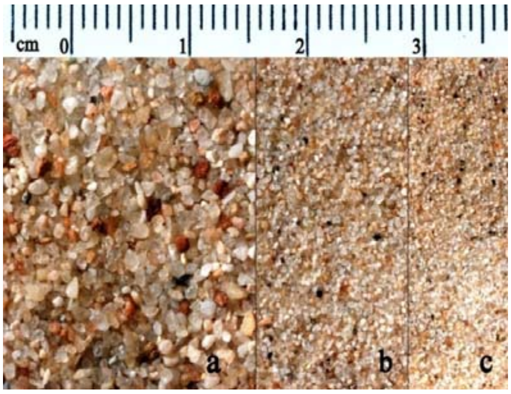
Fig. 5. Flow chart showing different processes

Table 2
Notation of Sands: Virgins, Chemically and Mechanically Processed

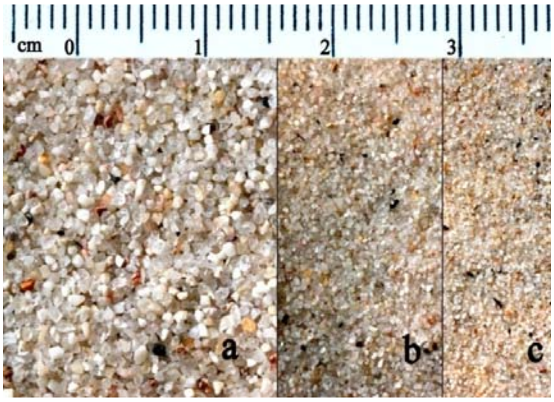
Identification	Description
Sand I	Sand collected from location 1, it is mostly light reddish in colour containing small amount of clay particle, may present Iron (Fe).
Sand II	Sand collected from location 2, mostly whitish or silver colour, containing small amount of clay particle
Sand I W	Sand I obtained after water wash, no clay particle
Sand II W	Sand II obtained after water wash, no clay particle
Sand I AW	Sand I after acid treatment
Sand II AW	Sand II after acid treatment
Sand L	Sand Obtained after mechanical abrasion of 10 kg sample with 12 spherical steel balls and 300 revolution in the abrasion machine
Sand M	Sand Obtained after mechanical abrasion of 10 kg sample with 12 spherical steel balls and 500 revolution in the abrasion machine
Sand N	Sand Obtained after mechanical abrasion of 10 kg sample with 6 spherical steel balls and 500 revolution in the abrasion machine
OSS	Ottawa Standard Sand

Table 3
Location of selected silica deposits

Location Name	Identification	Latitude	Longitude
Stationghat, Sreemangal, Moulvibazar	Sand I	24°18'9"N	91°44'29"E
Mokam Bazar, Moulvibazar	Sand II	24°26'5"N	91°45'51"E



Sand I W



Sand II W

Fig. 6. Physical appearance of Sands at different grain sizes (a) Material retained on Sieve #30, (b) Material retained on Sieve #50, (c) Material retained on Sieve #100

4. Extent of work

Concrete Laboratory of Department of Civil Engineering of Bangladesh University of Engineering and Technology (BUET) was designated as Lab 1 and Concrete Laboratory of Military Institute of Science and Technology (MIST) was designated as Lab 2. Amount of Sand samples and number of cement bags used are given in Tables 4 and 5 respectively.

Table 4
Amount of Sand samples used

Sand ID	Lab 1				Lab 2	
	Experimented (Kg)	Unused (Kg)	Without sieving (Kg)	Unwashed (Kg)	Experimented (Kg)	Unused (Kg)
Sand I W	71.5	-	60	60	13.5	-
Sand I AW	61.5	20	-	-	13.5	7
Sand II W	71.5	-	60	60	13.5	-
Sand II AW	61.5	20	-	-	13.5	7

Table 5
Number of Cement bags used

Sand ID	Lab 1(BUET)		Lab 2(MIST)	
	No. of cement bags	No. of Cubes	No. of cement bags	No. of Cubes
Sand I W	37	333	7	63
Sand I AW	32	288	7	63
Sand II W	37	333	7	63
Sand II AW	32	288	7	63
Total	69	1242	7	252

Therefore total cements tested with W and AW series are 44 and 39 bags respectively. So we have reasonable data available for statistical analysis.

5. Physical properties

5.1 Grain size distribution

In the following two figures gradation of sand samples before and after washing is shown. From Figure 7 and 8 it is clear that previously gradation of sand from Sreemangal and

Moulvibazar differed from Ottawa sand. But after water treatment the gradation of Sand I and Sand II is very close to Ottawa sand gradation.

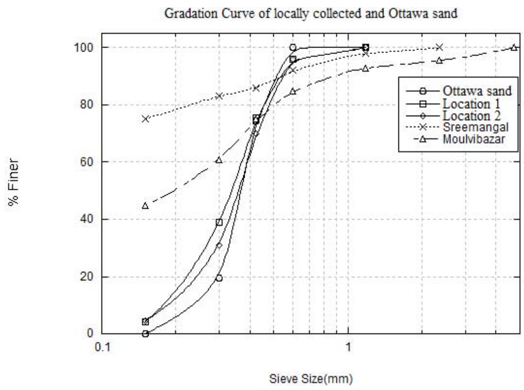


Fig. 7. Gradation curves of sand samples before processing

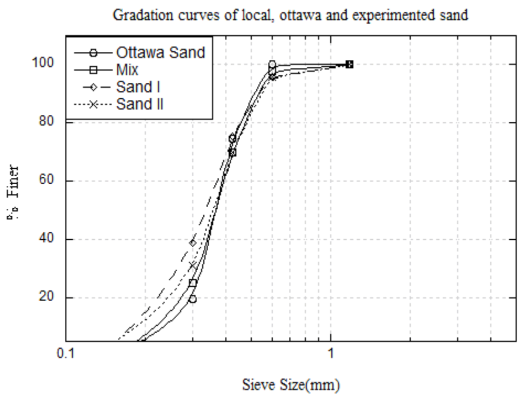


Fig. 8. Gradation curves of samples after processing

Mix sand indicates the sand by which cement mortar test was performed. So it is the proportioning ratio for all sand (Sand I W, Sand I AW, Sand II W and Sand II AW). Samples were prepared by proportioning grains according to average typical gradation values of Ottawa sand. Sand I and Sand II are the original sand collected from field. Sand I have more fine particles than that of Sand II. But both the Sand I and Sand II have more fine particles and larger size particle is less than that of Ottawa sand. The relative proportion of smaller sized particle for mix is greater than that of Ottawa sand and larger size particle is less than that of Ottawa sand.

5.2 Absorption capacity and specific gravity

Specific gravity and absorption capacity were determined using standard test procedures. The values obtained from tests are given in Table 6.

Table 6
Specific gravity and absorption capacity of different sample

Sand ID	Absorption Capacity %	Specific Gravity		
		Bulk	Bulk (SSD)	Apparent
Sand-I	0.58	2.51	2.52	2.54
Sand-II	0.28	2.66	2.66	2.68
Sand-I W	0.52	2.61	2.63	2.65
Sand-II W	0.54	2.61	2.62	2.65
Sand-I AW	0.58	2.59	2.61	2.63
Sand-II AW	0.36	2.63	2.64	2.65
Ottawa	0.16	2.64	2.64	2.65

Specific gravities of the tested sands are close to the typical Ottawa sand value. It’s lesser in case of Sand I only, due to the presence of greater clay content. In case of Sand I specific gravity after water washing increases but after acid treatment it decreases. In case of Sand II specific gravity decreases, then increases for water and acid treatment respectively.

6. Measurements and observations

Although there are many applications of Ottawa sand, the main concentration was given to the compressive strength characteristics of locally available sand and compared the result with the strength of Ottawa sand. To explain the strength characteristics it is necessary to evaluate some other physical and chemical properties of both Ottawa and locally available sand.

6.1 Shape

To identify the shapes of locally available sand, Scanning Electron Microscope (SEM) was used and the test was performed in SEM laboratory, Centre for Advanced Research in Science (CARS), University of Dhaka. Shapes of figures obtained from SEM are given in Figure 9 through Figure 16.

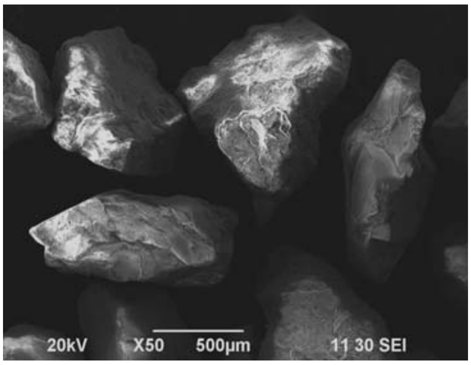


Fig. 9. Shape of Sand I W (#30)

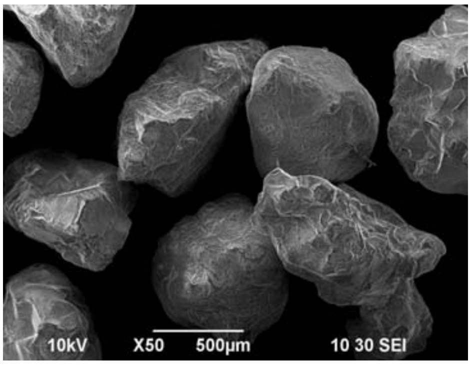


Fig. 10. Shape of Sand I AW (#30)

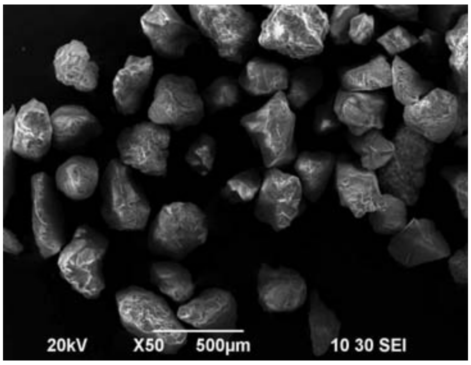


Fig. 11. Shape of Sand I W (#100)

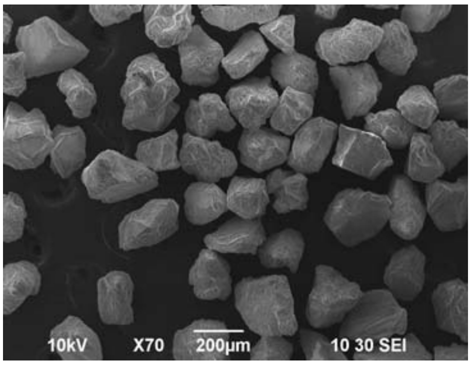


Fig. 12. Shape of Sand I AW (#100)

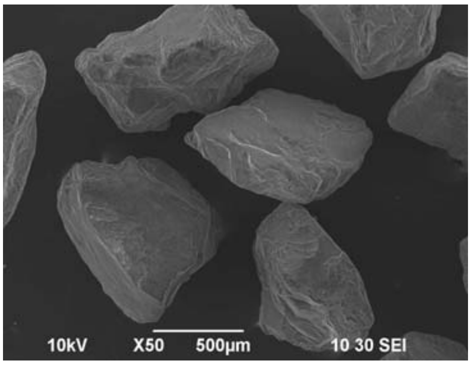


Fig. 13. Shape of Sand II W (#30)

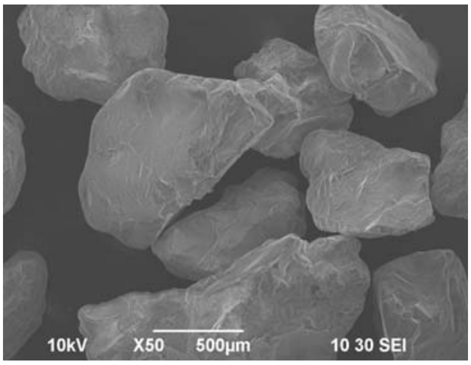


Fig. 14. Shape of Sand II AW (#30)

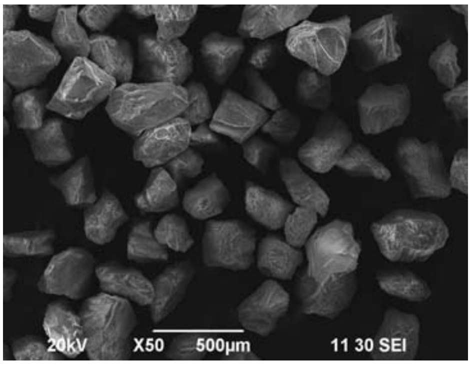


Fig. 15. Shape of Sand II W (#100)

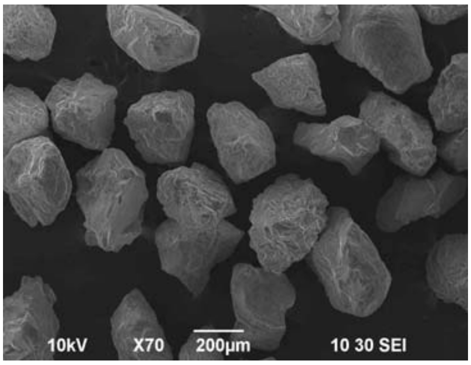


Fig. 16. Shape of Sand II AW (#100)

The SEM analysis images show that selected sands are angular in nature. Shape is an important parameter of sand grains for compressive strength. Strength can be affected by shape, if sufficient angularity is present. In that case lower strength is obtained compared to Ottawa sand. Shape of Ottawa sand is rounded and its shape is more or less uniform. Thus variation in test results does not happen due to the shape of Ottawa sand.

From Figure 9 through Figure 16 it is also seen that, Sand II has greater angularity compared to that of Sand I. It is also seen that most of water washed samples (i.e. W series) are angular for all sizes for both Sand I and Sand II. After acid washing the angularity increased at very small extent. This phenomenon occurred due to the extra mechanical treatment during acid treatment.

6.2 Chemical Constituents Using XRD

Chemical composition especially silica content is very important for the standard sands. Ottawa sand has more than 99% silica content. To identify any other material that may impart in strength gaining or loosing is also important. X-Ray Diffraction (XRD) analysis is very dependable test method to analyze the mineralogical composition of any material. XRD analysis was conducted in Bangladesh Atomic Energy Commission (BAEC). Sands are composition of different sized particles. X-ray analysis can give better result if individual sizes of particle are used. Individual particle size was used in XRD analysis.

In the Figures 17 to 22, graphs were plotted taking count vs. 2θ value. For understanding the effect of acid treatment W and AW sample data were plotted in same graph. The value of 2θ value of AW series is shifted 10° right to compare the effect of acid treatment.

Percent of material content does not depend only on the peak count value but also the FWHM (Full Width at Half Maximum) value. From graph it is seen that for larger grain size peak counts of Q decrease after acid treatment and for smaller grain size it increases for both sands. Peak counts of Fe for Sand I increases after acid washing but it decreases for Sand II.

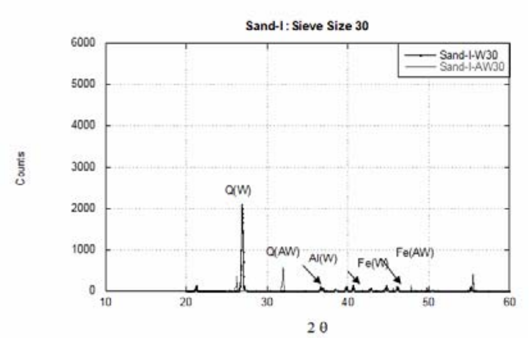


Fig. 17. X-ray diffraction of Sand I on grain size retained on #30

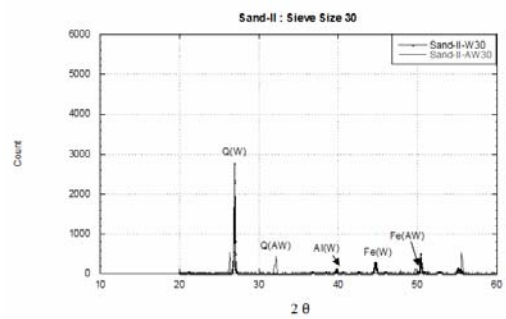


Fig. 18. X-ray diffraction of Sand II on grain size retained on #30

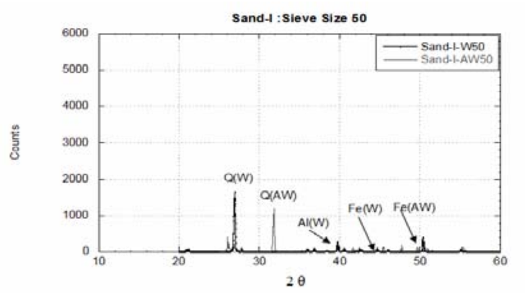


Fig. 19. X-ray diffraction of Sand I on grain size retained on #50

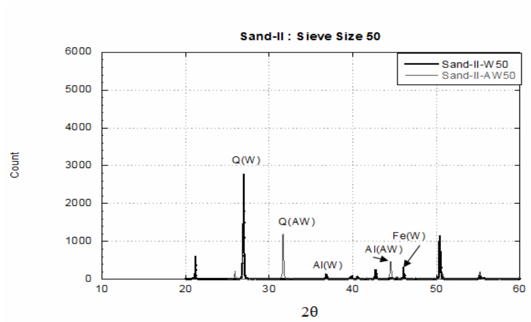


Fig. 20. X-ray diffraction of Sand II on grain size retained on #50

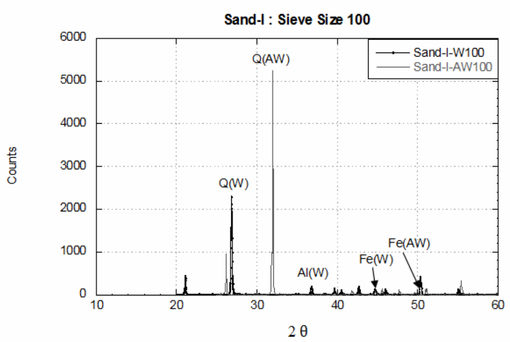


Fig. 21. X-ray diffraction of Sand I on grain size retained on #100

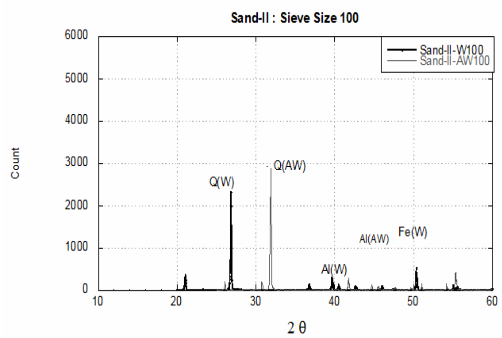


Fig. 22. X-ray diffraction of Sand II on grain size retained on #100

6.3 *Mechanical Abrasion and Roundness*

A part of sand was mechanically abraded in a Los-Angeles Abrasion Machine using different number of spherical steel balls (each one is 46.8 mm in dia and average mass is between 390 to 445 gm) and different revolution. The mechanical abrasion test was performed to reduce the angularity of sand grain. At first, 10 kg of sand was taken to the machine and then the certain number (6 or 10) of balls and the desired number of revolutions (300 or 500) were carried out. Finally, the resulted sand samples were thoroughly washed with water for further analysis.

Roundness is the degree of smoothing due to abrasion of sedimentary particles. It is expressed as the radius of the average radius of curvature of the edges or corners to the radius of curvatures of the maximum inscribed sphere. Roundness has to do with the sharpness of the edges and corners. It is independent of shape. The term 'roundness' has been much misused in the literature and in many cases has used interchangeably with shape. There are many different methods of determining the roundness of sand grain. Each of the methods is shown in Table 7.

Table 7
Various methods usually used to determine the roundness of the sand grain

Proposed by	Formula	Notes	Range
Wentworth (1919)	D_k / L_w	Ratio of the diameter of curvature of the sharpest corner to the long axis of the grain	0 to 1
Wentworth (1922)	$2\ D_k / (L+I)$	Ratio of the curvature of the sharpest corner to mean pebble diameter	0 to 1
Wadell (1932) (a)	$(\sum D_i / N) / D_r$	Average ratio of the diameter of curvature of all corners to the diameter of the largest inscribed circle	0 to 1
Wadell (1932) (b)	$N/ (D_r / \sum D_i)$	Reciprocal of the average ratio of the diameter of the largest inscribed circle to the diameter of the curvature of all corners	0 to 1
Kuenen (1956)	D_k / I	Ratio of the diameter of the sharpest corner to the intermediate axis of the grain	0 to 1
Dobkins and Folk (1970)	D_k / D_i	Ratio of the diameter of the curvature of the sharpest corner to the diameter of the largest inscribed circle	0 to 1

Notations: D_r is the diameter of the curvature of any corners; D_k is the diameter of the curvature of the sharpest corners; D_i is the diameter of the largest inscribed circle; N is the number of corners, including those whose diameters are zero; L_w is the longest diameter measured through the sharpest corner; L is the length of grain, in the projected plane; I is the width of the pebble, in the projected plane

Among the methods of determining roundness of sand grain, the method described by Wadell (Wadell, 1932) is widely used. According to Wadell, roundness may be expressed as the ratio of average radius of curvature of the several corner edges to the radius of curvature of the maximum inscribed sphere.

So, Roundness, $\rho = (\sum r_i/R)/N$ (1)

where r_i = the individual radii of the corners

R = the radius of maximum inscribed circle

N = number of corners

As pointed out 'roundness' has been used carelessly. The terms 'rounded', 'sub-rounded', 'sub-angular', and 'angular' are also loosely used. In order that these terms may have a more precise meaning, they have been redefined in quantitative terms in a manner analogous to the more exact redefinitions of the common size terms. Russell and Taylor set up five roundness grades. These are given in Table 8. Their scale of values were modified by Pettijohn to make the class size according to geometric rule.

Table 8
Roundness grades according to Russell and Taylor, and Pettijohn

Grade Term	Russell and Taylor (1937)		Pettijohn (1949)	
	Class Limits	Arithmetic Mid-Point	Class Limits	Arithmetic Mid-Point
Angular	0 ~ 0.15	0.075	0 ~ 0.15	0.125
Subangular	0.15 ~ 0.30	0.225	0.15 ~ 0.25	0.200
Subrounded	0.30 ~ 0.50	0.400	0.25 ~ 0.40	0.315
Rounded	0.50 ~ 0.70	0.600	0.40 ~ 0.60	0.500
Well rounded	0.70 ~ 1.00	0.850	0.60 ~ 1.00	0.800

6.4 Observations of mechanical abrasion

The radii of each of the circles drawn on the corners of the sand grain on the images of the samples were calculated using Adobe Illustrator. A sample figure on calculation process of roundness is given in figure 23 for Ottawa sand. The values of roundness (ρ) were calculated and given in the table 9. The overall roundness values are incorporated in Table 9.

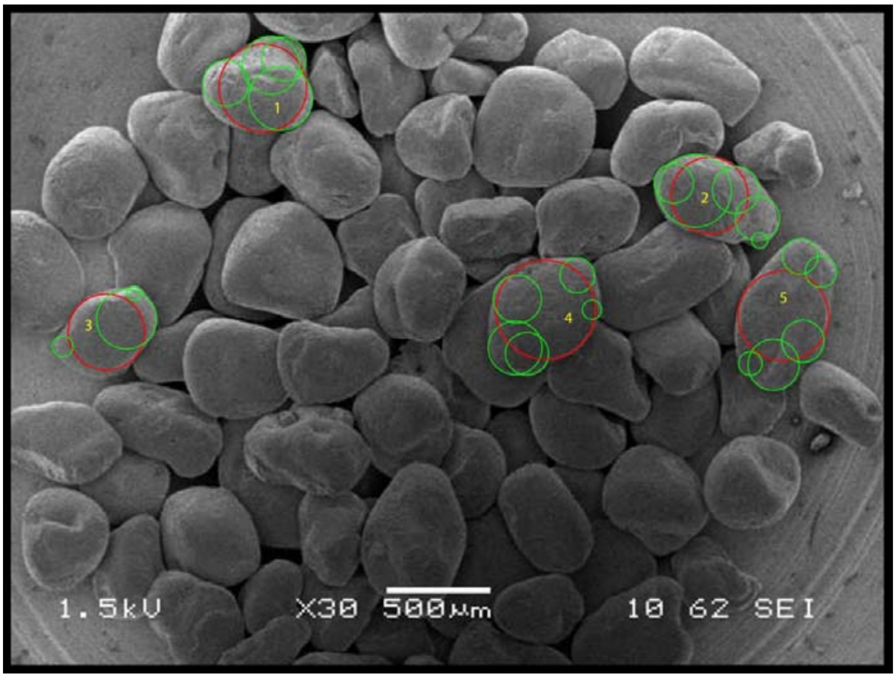


Fig. 23. Determination of roundness of Ottawa standard sand

Table 9
Overall roundness of sand samples and their classes

Sample name	Roundness, ρ	Roundness Grade
Sand W	0.28 ± 0.106	Sub-rounded
Sand AW	0.27 ± 0.188	Sun-rounded
Sand L	0.22 ± 0.057	Sub-angular
Sand M	0.22 ± 0.054	Sub-angular
Sand N	0.23 ± 0.081	Sub-angular
OSS	0.45 ± 0.178	Rounded

The value of roundness of Ottawa standard sand is 0.45 and it is classified as rounded sand by Pettijohn gradation of sand. The values of roundness of the local sand samples after mechanical and chemical treatment are 0.28 and 0.27. Both the samples belong to ‘subrounded’ class. The values of roundness of the sand samples obtained after mechanical abrasion with Los Angeles Abrasion Machine are nearly 0.22 and all these samples belong to subrounded class. The values of the roundness of the local sand samples indicate that there is a reduction in roundness after mechanical abrasion. SEM analyses show that the number of secondary corners have been increased after mechanical abrasion. There are a few numbers of secondary corners in OSS. As the number of secondary corners has been increased after mechanical abrasion, the value of roundness has been decreased substantially. OSS is rounded but the local sand sample is subrounded in nature. Thus usage of the OSS in testing hydraulic cement mortar would provide good workability, but lower compressive strength. In contrast, the subrounded local sand sample would have lower workability, but higher compressive strength. If we give more time to produce mortar than that for OSS, the local sand could be considered as feasible for testing hydraulic cement mortars.

6.5 Strength Comparison with Ottawa Sand

Hydraulic cement mortar test was done in two different laboratories independently with various cements. First laboratory is concrete laboratory, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), where almost all the tests were done and data from this lab is denoted by Lab1. In this lab Cement used for casting was taken from Bureau of Research and Testing Council (BRTC), test samples and corresponding BRTC test result was used for the strength data of Ottawa sand. Sand I W and Sand II W were tested together along with Ottawa sand. Similarly Sand I AW and Sand II AW were tested together along with another batch of Ottawa sand. On the other hand few tests were done by Military Institute of Science and Technology (MIST) [Siddiquee et al (2010)] students in the concrete laboratory of MIST and data from this laboratory is denoted by Lab2. In Lab2, cement used for both W and AW series are same.

7 Discussions on Results

A number of tests were done previously such as grain size distribution, specific gravity and absorption capacity, SEM, X-ray diffraction to explain the strength characteristics of locally available sand with respect to strength of Ottawa sand. In this section material characteristics of local sand as well as Ottawa sand is analyzed first. Then the strength result analysis is done with the help of these material characteristics. At the same time effect of water washing and acid washing is discussed.

7.1 *Comparison of physical properties*

Ottawa sand is white variety, natural rounded deposit with pale gray/white/silver color. It may be spherical to semi-spherical. On the other hand Sand II has similar color. However, Sand I is reddish in color due to the presence of iron and the reddish color is also remained after acid washing i.e. in Sand I AW.

Ottawa sand is spherical to semi-spherical on the other hand none of the local sand is not spherical rather than it is semi-spherical. All of these are slightly angular. From Figure 9 through Figure 16 it is seen that most of mechanically treated samples (i.e. W series) are angular for all sizes for both Sand I and Sand II. But after chemical treatment the angularity is reduced at very small extent. From Figure 9 through Figure 16 it is also seen that, Sand II has less angularity compared to that of Sand I but more angularity than that of Ottawa sand.

7.2 Comparison of chemical properties

Chemical composition of graded sample for individual particle size was determined by X-Ray Diffraction analysis for local sands. Typical values were used for Ottawa sand. Graph of X-ray analysis was given in Figure 17 through Figure 22.

The chemical composition of individual particle size that found from X-ray diffraction analysis is given in Table 10 and the overall composition of sample is in Table 11.

Table 10
Chemical composition of individual particle size of local sand

Sieve#	Sand I W			Sand I AW			Sand II W			Sand II AW		
%	30	50	100	30	50	100	30	50	100	30	50	100
Q	87.98	89.06	99.12	80.09	81.10	97.10	94.14	97.38	97.42	86.34	90.62	95.55
Fe	10.24	8.59	-	15.13	11.62	-	4.90	2.00	2.58	10.64		1.83
Al	1.78	2.34	0.88	4.78	-	-	0.96	-	-	3.02	3.76	0.42
$NaNO_3$	-	-	-	-	1.88	-	-	-	-	-	-	-
Fe_3Si	-	-	-	-	5.40	-	-	-	-	-	5.61	-
FeNi	--	-	-	-	-	2.90	-	-	-	-	-	-
KCl	-	-	-	-	-	-	-	0.62	-	-	-	-
Al_2SiO_5	-	-	-	-	-	-	-	-	-	-	-	2.20

Table 11
Overall Chemical composition of locally available sand

% constituent	Sand I W	Sand I AW	Sand II W	Sand II AW
Q	91.4	84.94	96.87	91.17
Fe	6.7	9.28	2.61	2.16
Al	1.89	0.76	0.15	2.81
$NaNO_3$	-	1.11	-	-
Fe_3Si	-	3.19	-	3.31
FeNi	-	0.73	-	-
KCl	-	-	0.37	-
Al_2SiO_5	-	-	-	0.55

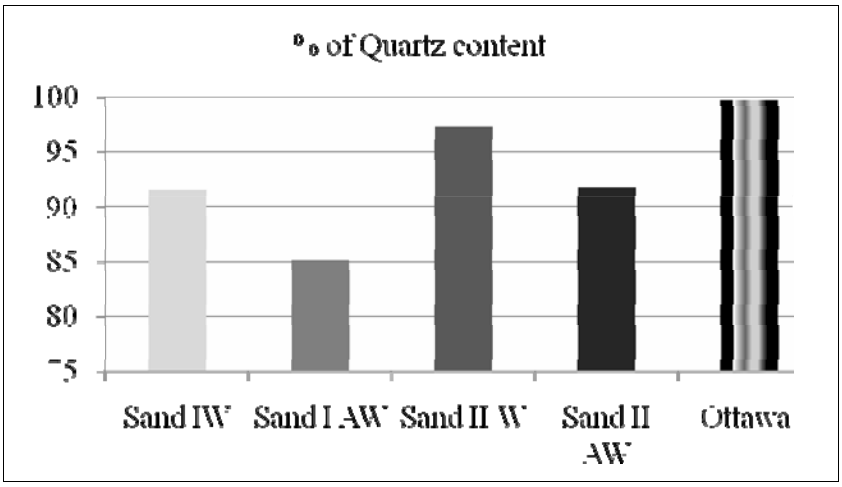


Fig. 24. Variation of quartz content in different sand

For X-ray analysis particular size of samples were used. Then overall composition is determined by providing weightage value obtained from sieve analysis i.e. their % of presence. The sample that retained on sieve #30, #50 and #100 are analyzed. The % presence of #30, #40, #50 and #100 are 2, 28, 45 and 25 respectively. The value of #40 can be divided between #30 and #50 equally. So weightage value of #30, #50 and #100 was 0.16, 0.59 and 0.25 respectively. The variation og Quartz content is shown in Figure 24.

Quartz content in sand is very important since it is chemically inert and strong enough to carry load. From X-ray analysis the values of quartz content was plotted in bar (Figure 24) which shows that, Sand II W is best suited with Ottawa sand based on the consideration of Quartz content. From X-ray analysis the values of Quartz content with grain size is shown in Figure 25, which shows that, percentage of Quartz content increases with the decrease in grain size. This is because in larger particle there is a tendency to adhere foreign particles with its surface. On the other hand in smaller particles there is low tendency to adhere foreign particles. So there are lower impurities in smaller particles and for that quartz content is comparatively higher than that of larger particles.

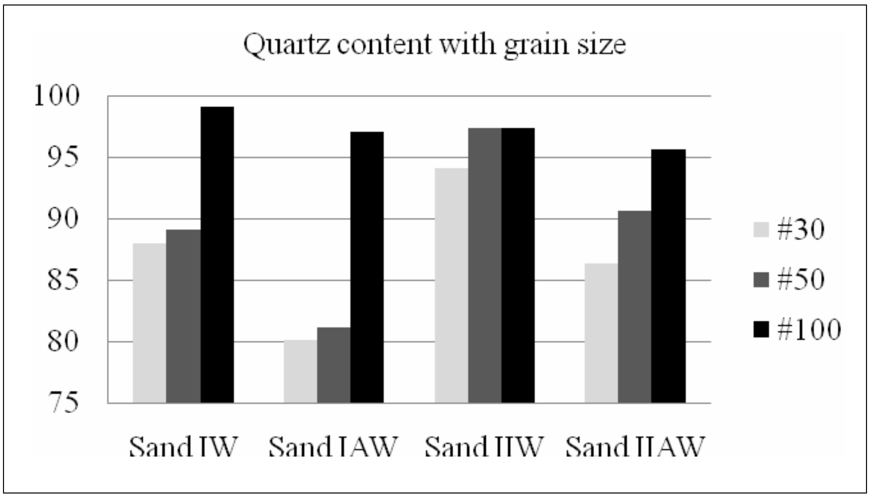


Fig. 25. Variation of quartz content with grain size in different sand

From Figure 25, it is also seen that Quartz content decreases after chemical treatment for both sands. This is because disintegration of particles results from acid action i.e. relatively smaller particles get smaller. Since in smaller particle the quantity of Quartz is relatively higher and after chemical treatment these smaller particles disintegrate and gets washed out. As a result Quartz content decreased. Another reason is that with the presence of acid, Fe reacts with SiO_2 and form Fe_3Si. As a result SiO_2 decreases. On the other hand, Fe is very strong and is not disintegrated upon acid action rather than it reacts with SiO_2. So for decreasing Quartz content the relative proportion of Fe may increase or for reacting with SiO_2, Fe content may decrease. The Fe content of chemical treated sample is the resultant of above two actions. In Sand I, Fe content increases and for Sand II Fe content decreases after acid washing.

7.3 Graph with correlation for strength

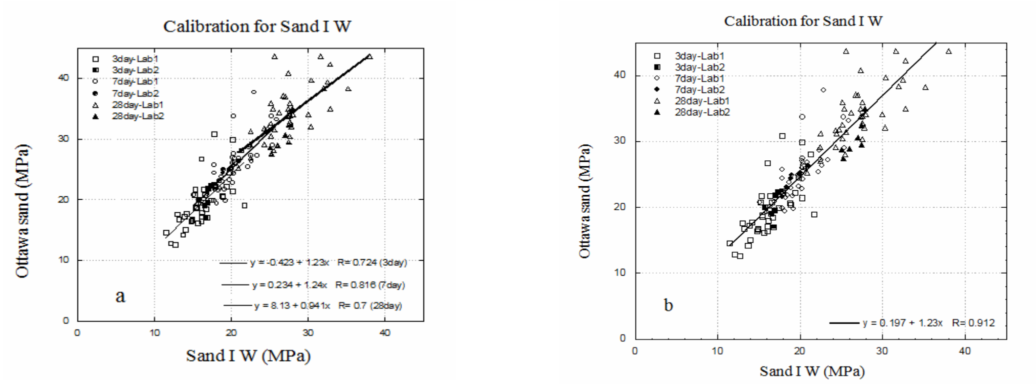
For correlation any order of polynomial may be used but in that case the significance of each coefficient must relate with the property of sand. In this work, contribution of adhered materials and angularity of sand grains were considered as the key properties. Therefore, for correlating second order polynomials were used.

After testing cement by both local and Ottawa sand, the correlation is assumed to be linear taking strength of Ottawa sand is dependent variable and the equation was found in the form of:

$$Y = \alpha X + \beta \tag{2}$$

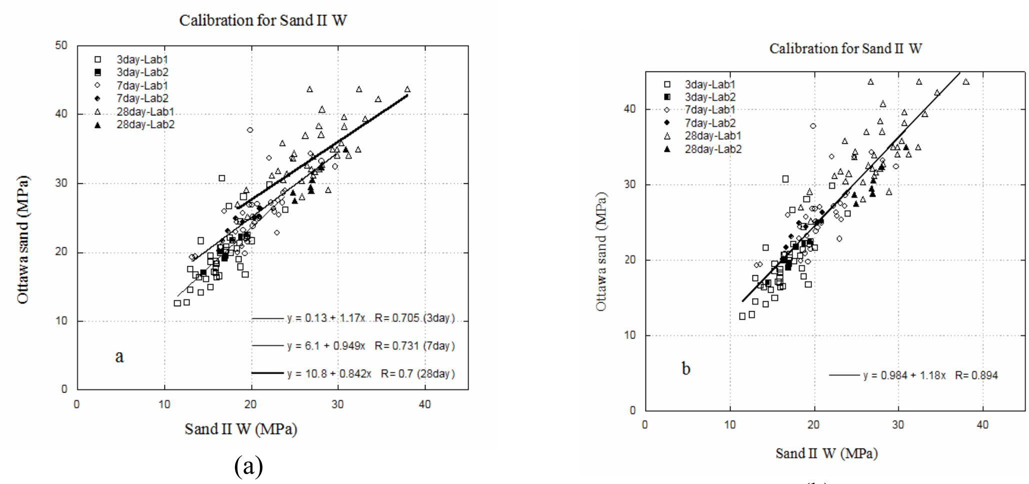
where, α is the slope of straight line and β is the intercept from Y axis. α value should be unity. If α value is greater than 1, it means the rate of strength gaining is lower than that of Ottawa sand due to insufficient hardness of local sand. Smaller value of α than 1 means the rate of strength gaining is higher than that of Ottawa sand due to presence of Ca, Fe, Al which can impart strength i.e. in presence of Fe, pozzolanic effect shows delayed strength. β value should be zero for perfectly spherical sand particle. If particle has sufficient angularity then it can take stress without the presence of cement as it happens in soil. So it is the direct indication of roundness.

The plots of strength with correlations from lab data are given in Figure 26 through Figure 29.



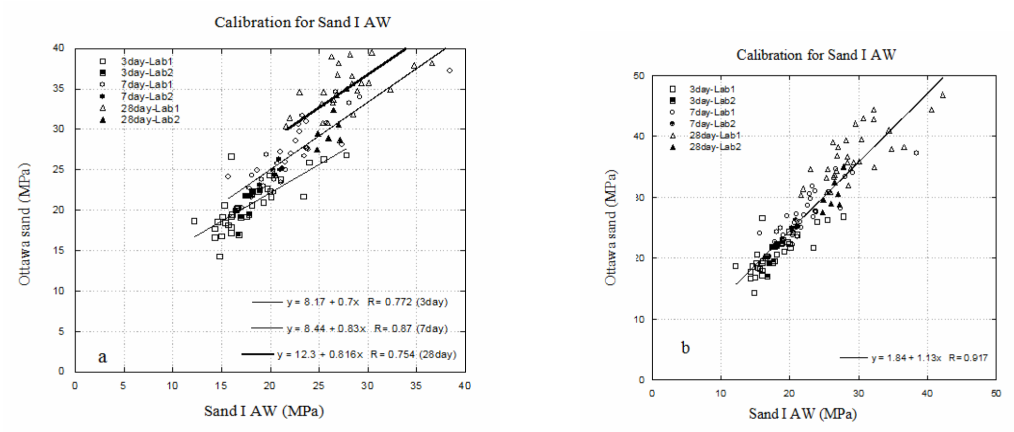
(a) (b)

Fig. 26. Graph of strength with correlation for Sand I W. (a) Day wise correlation (b) General correlation



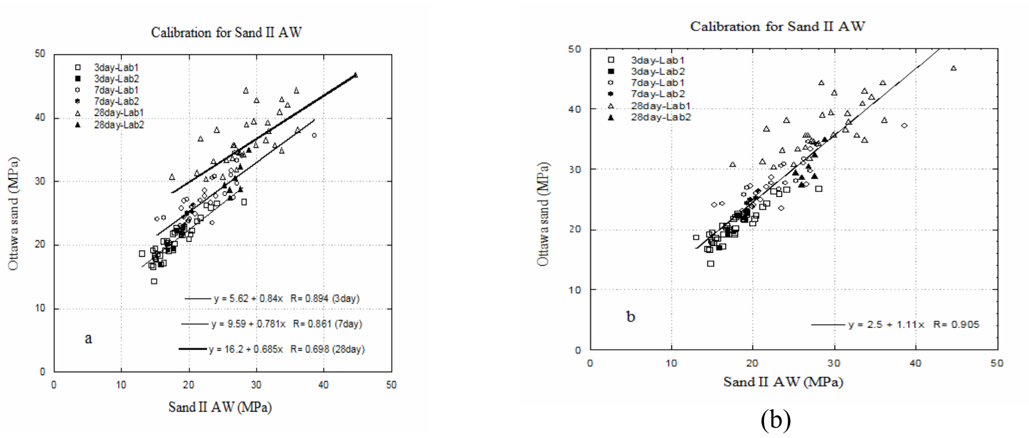
(a) (b)

Fig. 27. Graph of strength with correlation for Sand II W. (a) Day wise correlation (b) General correlation



(a) (b)

Fig. 28. Graph of strength with correlation for Sand I AW. (a) Day wise correlation (b) General correlation.



(b)

(a)

Fig. 29. Graph of strength with correlation for Sand II AW. (a) Day wise correlation (b) General correlation.

The correlation of strength is assumed to be straight line in the form of Y= αX+β, where α is the slope of straight line and β is the intercept from Y axis. From plots, in most of the cases α value are greater than unity. That means the strength obtained by using experimented sand is less than that of Ottawa sand. Presence of adhered materials results in the decrease of strength and relative proportion of quartz content. Another reason is that the gradation of experimented sand was not same as that of Ottawa sand. The presence of β -value in all equations represents the existence of angularity in all samples which was also observed by SEM test. Table 12 summarizes the correlations derived from the Figures 26-29.

From the analysis of plots, Figure 30 is further drawn where α value shows that the coefficient for 28 days is always smaller than 1. That means the strength value using local sand is greater for 28 days due to the presence of Fe and Al. These two constituents impart delayed strength known as pozzolanic effect. So, chemical treatment was not effective with respect to pozzolanic effect as Fe cannot be removed. More the adhered materials, less is the strength. As a result α - value will increase. α values of different sands also decrease after acid wash for all maturity stages. That means the higher strength than that of mechanically treated sample. α value also decreases after acid wash for both sand for all maturity stages.

Table 12
Coefficients from graph

Sand IW				Sand I AW		
	α	β	R	α	β	R
Total	1.23	0.197	0.912	1.13	1.84	0.917
3 days	1.23	0.423	0.724	0.7	8.17	0.772
7days	1.24	0.234	0.816	0.83	8.44	0.87
28days	0.941	8.13	0.7	0.816	12.3	0.754
Sand IIW				Sand II AW		
Total	1.18	0.984	0.894	1.11	2.5	0.905
3 days	1.17	0.13	0.705	0.84	5.62	0.894
7days	0.949	6.1	0.731	0.781	9.59	0.861
28days	0.842	10.8	0.7	0.685	16.2	0.698

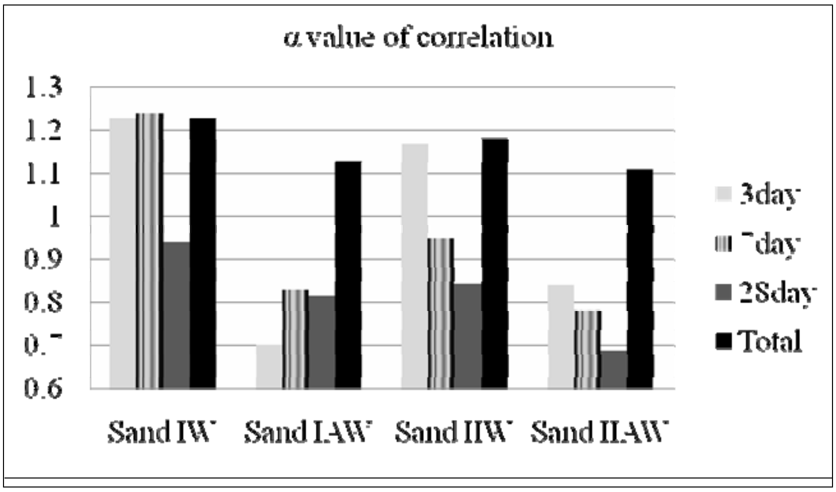


Fig. 30. Day wise correlation coefficient of α

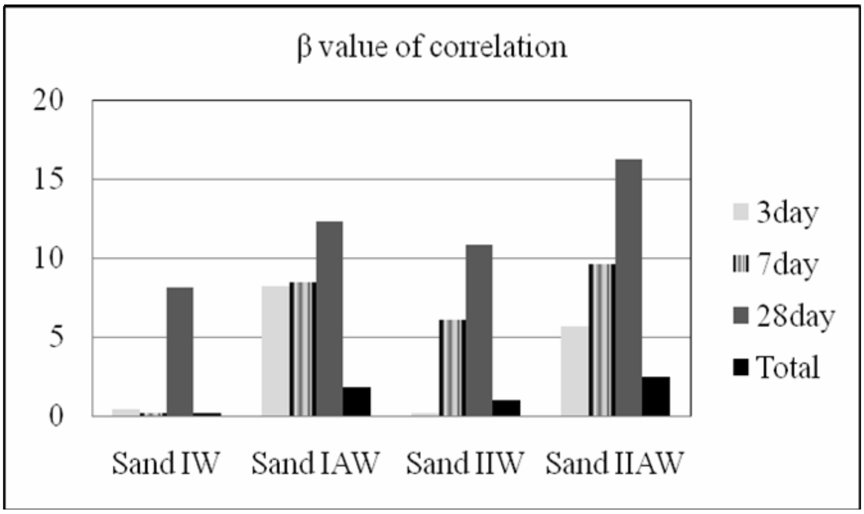


Fig. 31. Day wise correlation coefficient of β

β value is the direct indication of angularity. From Figure 31, it is shown that β value of Sand I W is less than Sand II W i.e. Sand II W is more angular than Sand I W. value increases after acid washing due to more mechanical process while acid washing i.e. angularity increases through mechanical process. So, acid wash is not effective with respect to angularity. The more the angular grain more is the β value.

For all sands regression coefficient is almost 0.9. So, curves for all sand show good correlation. Though, the coefficients for individual maturity stages show lower regression value due to less data. Straight line interpolation is an assumption. Individual particle sizes of samples are used for SEM and X-Ray Diffraction analysis since it gives better understanding.

8. Conclusions and Recommendations

Geological sand deposit has the property of uniformity in composition, preventive to seasonal variation and fixed origin. So, it is more logical to use geological sand deposit as a replacement of Ottawa sand in cement mortar testing. The sand we used was collected from the piedmont of Dupi Tila formation. This piedmont deposit is recharged every year by rainfall. This is a perpetual source of sands. As long as the hills around the sites are present the sites will be recharged every year. From physical appearance it is clear that our both samples contained clayey particles which were needed to be washed. As the gradation did not resemble with Ottawa sand, the samples were re-proportioned. Thus the total processing procedure includes washing, oven-drying, grading and proportioning.

From X-Ray Diffraction analysis, it was seen that unwanted particles such as Fe, Al were present. So as an initiative to remove Fe and Al, the samples were treated with 0.1N HCl acid. However, it had little significance upon the removal of Fe and Al.

Another important factor is the shape of sand that is to be used in testing cement. The shape of Ottawa sand is spherical to semi-spherical whereas experimented sands are more likely angular found from Scanning Electron Microscope (SEM) observation. After chemical treatment angularity was reduced slightly.

The fact is that the sand to be used for mortar testing should contain high silica content. That is the sand grains must remain inert when the bond between the cement paste and the grains broke during testing. Silica content for experimented sand was around almost 90% for both mechanically processed samples. But after chemical treatment, silica content decreased and Fe content increased. So chemical treatment process could not give favorable results. Silica content of Sand II W has a maximum value of 96.87%.

From strength correlation graph it is seen that, there is a uniform trend between experimented sand and Ottawa sand. The coefficient of regression values (R) are around 0.90 for both experimented sand. Regression analysis gives good correlation as enough and symmetrical data were available. In view of statistical consideration it can be said that, all experimented sand can be used as the replacement of Ottawa sand in cement testing. But on the consideration based on silica content and Iron content, Sand II W is more similar with Ottawa sand. However, any of these experimented sands can be used as a replacement of Ottawa sand for the purpose of cement testing. General equations are more convenient to use than day wise correlation.

Sand I W	$Y=1.23X+ 0.197$	$R= 0.912$
Sand II W	$Y=1.18X+ 0.984$	$R= 0.894$
Sand I AW	$Y=1.13X+ 1.84$	$R= 0.917$
Sand II AW	$Y=1.11X+ 2.50$	$R= 0.905$

Cement tested with any of these sands and putting the value of strength as “X” in above corresponding equation the value of “Y” can be calculated which can be termed as the strength of that cement using Ottawa sand.

We are now working to develop a systematic process for mechanical and chemical treatment. To standardize mechanical process, new standard instruments can be developed which can ensure better purification of sand. Another important task was to remove Iron and Aluminum. From their percentage of presence the concentration of suitable reagents can be calculated and they can be removed. Two processes can be used for wide scale processing and manufacturing of the sands for use in testing purpose.

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