A COMPARATIVE STUDY ON PHYSICAL PROPERTIES OF CEMENT: ASTM AND BDS EN STANDARDS

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ABSTRACT
Reinforced concrete (RC) is widely used in civil infrastructure due to cheap labor and availability of construction materials. Cement is used as a binding material for different ingredients of members of these structures. At present, Bangladesh's cement industry has become the 40th largest market in the world. In Bangladesh, different types of cement are produced and are followed BDS EN 197-1:2003 standard for the standardization. In addition, a standard such as ASTM is widely used as specifications for construction of civil infrastructures. There are some differences of the requirements and specifications as well as testing procedure and evaluation of quality of cement considering BDS EN and ASTM. Since cement is a global product for construction industry, a comparison among the requirements and specifications of cement using different standards might become necessary. A review study has been conducted to figure out the different specifications and requirements for the properties of cement following ASTM and BDS EN. In addition, an experimental program is carried out to determine the different physical properties such as normal consistency, initial and final setting time, and compressive strength of cement. Two types of cement such as Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC) are considered in the experimental program. OPC grade 52.5N and PCC grade 42.5N are used. Specimen preparation and testing have been conducted for each cement sample on the same day. From the experimental results, it has been shown that compressive strength of cement for OPC 52.5N grade following ASTM standard is found to be 71% higher at 28 days than that from the minimum requirement. However, this strength is shown to be 22% higher at 28 days following BDS EN standard.

Keywords: Cement; standards; ASTM; BDS EN; grades; setting time; compressive strength

INTRODUCTION
The development of cement industry in Bangladesh dates back to the early-fifties but its growth in real sense started only about a decade. Till 1990, about 95 percent of the country's demand for cement had been met through import. The country has been experiencing an upsurge in cement consumption for last 6/7 years. The transition of traditional low rise buildings to high rise ones has pushed up the use of cement. Increase in demand for cement has soared up due to mainly the property sector boom and infrastructure development in the country. With the implementation of large-scale infrastructure projects, exhilarated pace of urbanization, construction of apartment buildings and multi-storey shopping complexes in urban areas, and changes in the taste and economic condition to a large number of rural people, aspiring for modern houses, the demand for cement has been gaining momentum by the day. Now, cement industry in Bangladesh has become the 40th largest market in the world. Bangladesh is producing different types of cements following BDS EN (Bangladesh Standard- European Norm) 197-1:2003 standard. In addition, ASTM (American Society for Testing and Materials) standard is still widely used around the world for the specifications and requirements in different development projects. From the earlier studies, it has been shown that the requirements and specifications for each standard vary from one to another. However, for a global construction material, a comparison among the specifications, requirements and test results following different standards might become necessary. Therefore, the main objective of this paper is to identify the requirements and specifications for cements considering BDS EN and ASTM. In addition, an experimental program is conducted to determine the different physical properties such as normal

consistency, initial and final setting time, and compressive strength of cement following both the standards. The obtained test results are compared with the requirements following both the standards.

COMPARISON OF REQUIREMENTS FOLLOWING BDS EN AND ASTM STANDARDS

Two types of cement categories such as Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC) are widely used around the world as binding materials for concrete. PCC is also known as blended cements in many standards. OPC Type-I is the most common type of cement in use which has more than 95% clinkers. It conforms with the Bangladesh Standard BDS EN 197-1:2003 CEM-I 52.5, European Standard EN 197 type CEM-I, and American Standard ASTM C150 PC Type I. OPC is the most common type of cements which is used in general concrete construction when there is no exposure to sulphates in the soil or groundwater. PCC is a variation of OPC which includes a mixture of a pozzolanic material having a portland cement clinker ranges from 65% to 79% and is widely used in Bangladesh. Pozzolan or similar materials such as volcanic ash, clay, slag, silica, fume, fly ash, or shale are used in different types of blended cements. It conforms to BDS EN 197-1: 2003 CEM-II/B-M (S-V-L) 42.5 and ASTM C595 Types of IP/IS/IL/IT. Physical requirements such as compressive strength, initial and final setting time in ASTM standard are provided in C150 and C595 for OPC and PCC cements, respectively. BDS EN197-1:2003 specify the physical requirements for both the cement types. OPC and PCC grades are identified considering 28 days compressive strength of cement. 42.5 MPa strength is normally used for CEM II type and 52.5 MPa is used for CEM I type. In both cases, specification for initial setting time is provided. However, both the initial and final setting time of cement are considered in ASTM standard. Compressive strength of cement at 2 and 28 days are required following BDS EN while 3, 7, and 28 days strength requirements are followed in ASTM. Letters "N" and "R" are used in BDS standard to specify the normal strength and high early strength requirements for a cement grade. Table 1 provides the compressive strength and setting time requirements following BDS EN and ASTM both for OPC and PCC cements. From the table, it is observed that specifications for initial setting time are different for different grades of cements as per BDS EN. However, no requirement for final setting time is provided. On the other hand, both the initial and final setting time are provided in ASTM standard as requirements. Initial setting time is the same both for OPC and PCC as per ASTM.

Table 1: Comparative requirements for physical properties of OPC and PCC cements

STANDARDS	BDS EN				ASTM	
Physical Requirements	BDS EN 197-1:2003				C 150	C 595
	42.5N	42.5R	52.5N	52.5R	OPC	PCC
Compressive Strength (MPa)						
-2 days	≥ 10	≥ 20	≥ 20	≥ 30		
-3 days	---	---	---	---	12	13
-7 days	---	---	---	---	19	20
-28 days	42.5 to 62.5	42.5 to 62.5	≥ 52.5	≥ 52.5	28	25
Setting Time (minutes)						
-Initial Setting Time (min.)	≥ 60	≥ 60	≥ 45	≥ 45	45	45
-Final Setting Time (min.)	---	---	---	---	375	420

EXPERIMENTAL PROGRAM

An experimental program is carried out to assess the different physical properties following ASTM and BDS-EN standards. Two types of cement such OPC and PCC are considered. OPC with grade 52.5N and PCC with 42.5N are used in the present study. Normal consistency, setting time and compressive strengths are determined for each case following ASTM and BDS EN standards. Although 2 days and 28 days compressive strengths are required for cement following BDS EN standard, compressive strengths at 3, 7, and 28 days are evaluated to assess the development of strength with age as well as for a comparative study.

PREPARATION OF SPECIMENS AND EXPERIMENTAL RESULTS

(a) Normal consistency and setting time of cement

The amount of water that brings the cement paste to a standard condition of wetness is called normal consistency. Both the ASTM and BDS EN standards use manual Vicat apparatus to determine the normal consistency of cement as a percentage of dry cement. The suitable temperature for this test is (23 ± 2)°C and relative humidity is more than 50% according to ASTM C187. The temperature shall be maintained (20 ± 2)°C and a relative humidity of not less than 50% following BDS EN 197-1. The same diameter and the weight of the plunger are used for measurements. According to ASTM, the cement paste shall be in normal consistency when the plunger rod settles to a point 10±1mm below the original surface in 30 sec after being released. However, the paste is considered in a normal consistency when the distance produce between the plunger and base plate of the mould of 6±2 mm in 30 sec after being released. Table 2 shows the normal consistency values of OPC considering both the ASTM and BDS standards while table 3 shows those values for PCC.

For the determination of initial and final setting time of cement, the same Vicat apparatus is used with a needle diameter of approximately 1 mm. The same temperature and relative humidity as mentioned for the normal consistency test is used. The cement mould using the same amount of water as used for consistency is kept in moist cabinet or moist room for 30 min after moulding without being disturbed as per ASTM C191. The elapsed time between the initial contact of cement and water and the penetration of 25 mm into the paste is the Vicat time of setting or Vicat initial time of setting. The final setting time is obtained when the needle does not sink visibly into the paste. On the other hand, the filled mould and base plate is placed in the container filling with water so that surface of the paste is submerged to a depth at least 5 mm as per BDS EN 196-3. After sometime the paste is lifted from water and kept under the needle. The needle is released freely. Penetration into the paste is calculated after 30 minutes of releasing. The time elapsed between zero time (starting time of mixing of cement and water in a mixer) and the time at which the distance between the needle and the base plate (6 ± 3) mm measured to the nearest minute is the initial setting time of the cement. The mould is then inverted to determine the final setting time. Final set are made on the face of the specimen originally in contact with the base-plate. The elapsed time is measured from zero to that at which the needle first penetrates only 0.5 mm into the specimen as the final setting time. Tables 2 and 3 provide test results both for the initial and final setting time of OPC and PCC, respectively. From the tables, it is shown that both the cements satisfied the ASTM and BDS standard requirements. Initial setting time is higher for PCC than that of OPC and is matched better with BDS EN requirements.

Table 2: Normal consistency and setting time for OPC 52.5N cement

Test standard	Consistency (%)	Initial setting time (min)	Final setting time (min)
ASTM	26	167	273
BDS-EN	30	165	240

Table 3: Normal consistency and setting time for PCC 42.5N cement

Test standard	Consistency (%)	Initial setting time (min)	Final setting time (min)
ASTM	26	182	240
BDS-EN	32	195	255

(b) Compressive strength of cement

Cement as a binding material in concrete or mortar is usually subjected to compressive stresses. Mortar is a mixture of cement and sand in a specified ratio on which the strength of the mortar depends. The mechanical strength of hardened cement is most important for structural use. According to ASTM C109, compressive strength of the hydraulic cement mortars is determined by using 2 inch or 50 mm cube specimens as shown in Fig. 1(a). Room temperature should be maintained (23 ± 3)℃ and a relative humidity should be above 50%. A 2.75 parts of sand is mixed with 1 part cement where as water–cement ratio should be 0.485. The sand used for making test specimens shall be natural

silica sand conforming to the requirements for graded standard sand in specification C778. Hand tamping is used in a layer of mortar about 1 inch or 25 mm (approximately one half of the depth of the mold) in all of the cube compartments. In each cube compartment, 32 times in about 10s in 4 rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen is used. When the tamping of the first layer in all of the cube compartments is completed, the compartments are filled with the remaining mortar and then tamping is done as specified for the first layer as shown in Fig. 1(b). The prepared test specimens are shown in Fig. 1(c). Immediately upon completion of molding, the test specimens are kept in moist room or moist closet for 24 hours. Then the specimen is kept in the water mixing with lime water for determining compressive strengths at 3, 7, and 28 days.

(a) Mould for compressive strength test (b) Hand tamping for compaction (c) ASTM mould with mortar

Fig.1: ASTM mould, hand compaction and specimens for compressive strength test of cement

Compressive strength is determined on prismatic test specimens 40 mm x 40 mm x 160 mm in size as shown in Fig. 2(a) following BDS EN standard. These specimens are cast from a batch of plastic mortar containing cement- sand ratio of 1:3 with a water-cement ratio of 0.50. According EN 196-1 CEN standard sand is used in preparation of mortar. CEN reference sand is a natural, siliceous sand consisting preferably of rounded particles and has a silica content of at least 98%. The moisture content is less than 0.2% expressed as a percentage by mass of the dried sample. The mortar is prepared by mechanical mixing and is compacted in a mould using a standard jolting apparatus as shown in Fig. 2(b). The specimens in the mould are stored in a moist atmosphere for 24h and then the demoulded specimens are stored under water until strength testing. The prepared specimens for compressive strength test are shown in Fig. 2(c). For a comparative study, these specimens are prepared and tested on the same day as done for ASTM specimens.

(a) Mould for compressive strength test (b) Jolting apparatus for compaction (c) BDS EN mortar filled moulds

Fig.2: BDS EN standard mould, jolting apparatus for compaction and prepared mortar specimens

From the experimental results, it is shown that all the tested specimens satisfied the minimum strength requirements both for ASTM and BDS EN standards. Figs. 3(a) and 3(b) present the compressive strength results of cement mortars for OPC and PCC, respectively. As mentioned earlier, cement grades OPC 52.5N and PCC 42.5N are used in the experimental program.

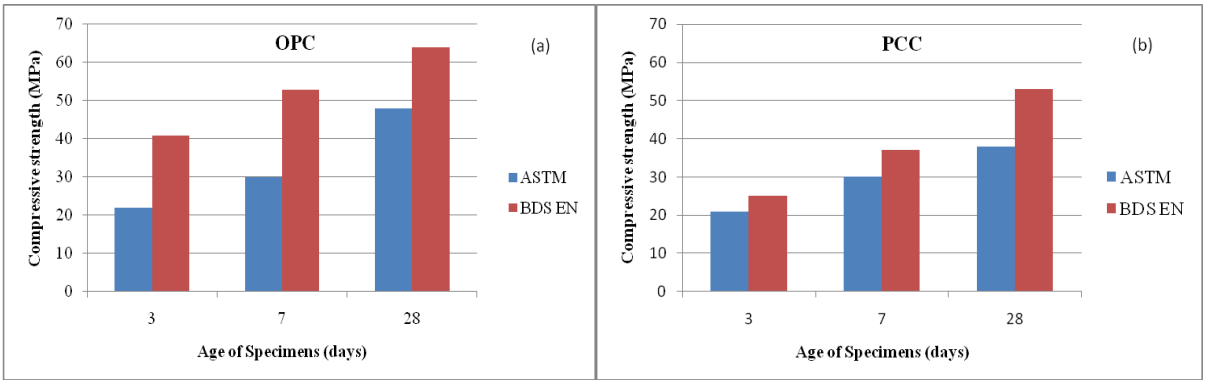

Fig. 3: Test results for compressive strength of cements (a) OPC and (b) PCC

A comparatve study between the requirements and obtained compressive strength is also conducted both for ASTM and BDS EN standards. Figs. 4(a) and 4(b) show the required minimum and obtained strengths for ASTM and BDS EN standards, respectively. The comparison is done both for OPC and PCC strength requirements as shown in the figure. It is observed that obtained test results are well above both for OPC and PCC as per ASTM requirements. The rate of gaining cement compressive strength with age is shown well pattern for both the grades of cement. At 28 days, an increase in compressive strength of 71% for OPC and that of 52% for PCC is reported. On the other hand, an increase of compressive strength at the age of 28 days is obtained only 22% for OPC and 24% for PCC as per BDS EN standard.

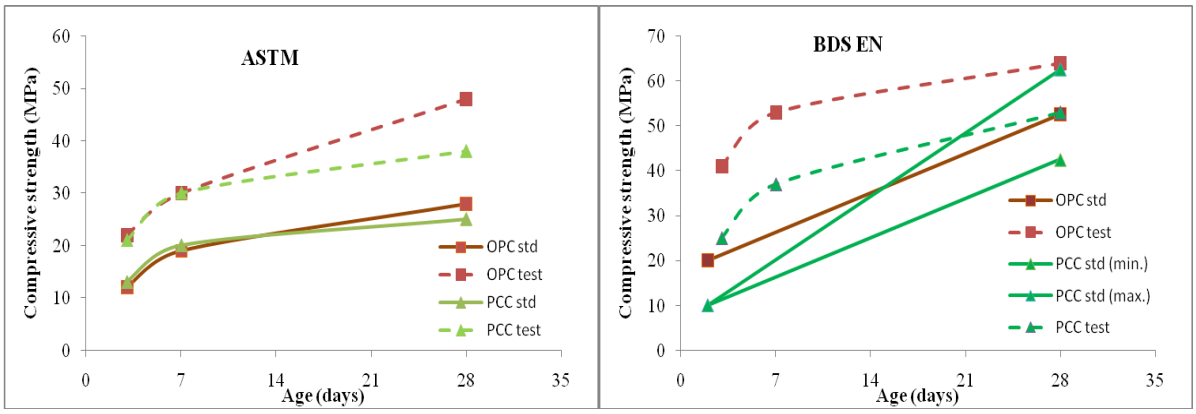

Fig. 4: Comparison of compressive strength requirements and obtained results (a) ASTM and (b) BDS EN

From the study of standard requirements and experimental results, it is observed that the minimum compressive strength requirements for cement are lower values in ASTM than those of BDS EN. Also, initial setting time is the same both for OPC and PCC as per ASTM. Compressive strength enhancement at 28 days is shown higher for OPC than those of PCC following ASTM. However, this enhancement in the strength for tested cement sample is almost the same both for OPC and PCC following BDS EN.

CONCLUSIONS

A review study is conducted on different specifications and requirements for the different properties of cements following ASTM and BDS EN standards. An experimental program is also conducted to determine the different physical properties such as normal consistency, initial and final setting time, and compressive strength of cement. Both OPC and PCC types of cement are considered in the study. OPC grade 52.5N and PCC grade 42.5N are used in the experimental program. Specimen preparation and testing have been done on the same day for each grade of cement samples.
Following conclusions can be drawn from the present study:

- Requirements for initial setting time is provided in BDS EN while both the initial and final setting time are considered in ASTM.

- Specification for initial setting time of tested cement sample is matched better with BDS EN standard.
- Minimum compressive strength values for OPC and PCC are very close following ASTM while those values are well separated as per BDS EN.
- For OPC 52.5N, an enhancement of compressive strength at 28 days is obtained 71% higher than that of the required value as per ASTM while that value is only 22% higher following BDS EN.
- Strength enhancement ratio is higher for OPC than that of PCC as per ASTM while that enhancement is almost the same both for OPC and PCC following BDS EN.

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