STRENGTH DEVELOPMENT OF PORTLAND COMPOSITE CEMENT AND ITS COMPARISON WITH PORTLAND CEMENT

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ABSTRACT
Granulated Blast Furnace Slag (GBS) is a major by-product of steel manufacturing. Many research has been conducted on slag while used in cement. Here we will discuss the real life data of strength development for a period of three years of Portland Composite Cement using slag and limestone, and compare the same with development of strength with Portland Cement (OPC). This Paper presents the results of a test on the effect of Portland Composite Cement mixed with Slag and limestone as per CEM II ratios of BDS-EN 197-1:2003 (Equivalent of En 197) and compared the same with CEM I (OPC) of the same standard for the similar duration. This is of great value in the construction of mass concrete using CEM II as it would save a big amount of money, and on the other hand will provide similar strength like OPC. As slag and fly ash etc. were used for land filling (it will rise the sea level) only, steps were taken to manage these materials by mixing with cement all over the world for more than 75 years. Though the requirement of Cement having Slag has a tendency of lower early strength, but it becomes similar in later stages. The paper would try to establish that at 365 days both CEM I and CEM II show similar compressive strength results, but later on CEM II will show more strength than CEM I. The further development of strength even after 365 days would also be monitored.

Keywords: Granulated Blast Furnace Slag (GBS); Portland Composite Cement; Portland Cement or OPC; compressive strength

INTRODUCTION

Granulated Blast Furnace Slag (GBS) originates in an iron blast furnace. Carefully controlled amounts of iron ore, along with limestone or dolomite, are fed into a blast furnace and heated to 1,480°C. When molten, the iron is kept for steel production and the slag is send to a granulator. Here, the slag is rapidly quenched with large quantities of water and converts to a light coloured glassy sand-like material. The process minimizes crystallization and forms “granulated slag,” which is composed principally of calcium aluminosilicate glass. (Formation of this glass provides slag cement with its cementitious properties.) At this point, the slag is the consistency of fine sand. It is then dewatered and dried. Finally, the slag is interground with Portland cement clinker and limestone to make Portland Composite Cement. EN 197 or BDS EN 197 has allowed producing 27 types of cement which is mentioned in Table of the standard. In the table the CEM II B-M (S-L) allows to mix 21~ 35% slags and limestone with Portland cement clinker and Gypsum.

Composite cement of various types is the major cement produced in Bangladesh. Only around 20% of total produced cement in the country is OPC. Composite cement has been produced here since 2003 after being introduction of the standard BDS-EN 197: 2003. And all major formulation and expertise were provided from abroad. Very few RND works were done among any cement producers to learn any comparison between the newly introduced composite cement and OPC. To overcome this problem, Royal Cement conducted a comparison test between OPC and Composite cement having 15% Slag with no Limestone first in 2003, and later placed that data in various in-house seminars. That test was conducted with a span of one year, and since no Limestone was used the results may be claimed inconclusive. For that reason, in 2011 another similar test was conducted with a span of 3 years period. This has helped to achieve genuine experience of strength development of PCC, and share the same to others.

METHODOLOGY

For the test ASTM test methods were followed; like for determination of setting time, ASTM C191, for Fineness ASTM C204 and finally for compressive strength ASTM C109 were followed. For compressive strength test ASTM Graded Sand conforming C778, 2 inch Cast iron cube moulds were used, Lime saturated water was used for curing which conforms to ASTM C511. The range of curing room temperature was 22.5°C~23.6°C. Humidity of curing room was more than 70%.

Both samples *i.e.* CEM I and CEM II B-M (S-L) should have similar physical properties like fineness and setting time, which are very important for such test. Same curing room, as well as same compressive strength testing machines (Pre Calibrated) were used which will eliminate errors due to machine, curing room condition etc.

20 sets (3 moulds in each set) of 2 inch moulds were prepared for each type of cement and they were broken using a calibrated compressive strength testing machine of 300 KN capacity. Samples were cured according to ASTM C109 and tested on 1 Day, 2 Days, 3 Days, 4 Days, 5 Days, 6 Days, 7 Days, 14 Days, 21 Days, 28 Days, 35 Days, 42 Days, 49 Days, 56 Days, 180 Days, 365 Days, 1.5 Years, 2 Years, 2.5 Years and finally for 3 Years.

All moulds were prepared and cured following ASTM C109 standard and they were prepared and cured simultaneously to eliminate all possible variables in an industrial test lab. For this reason, it is believed that the results are more conclusive and genuinely comparable to each other; and while put on the plot the graph was also amazingly accurate.

Observations

Some slow development of strength were observed in CEM I (OPC) for the ages of 5~7 days, which was unexplainable. It was anticipated that this is due to the allowed possible standard deviation of the ASTM Test method.

Table 1: Mixing ratio of raw materials in the experimental cements

	Clinker	Slag	Limestone	Gypsum
CEM I	97.5%	--	--	2.5%
CEM II B-M (S-L)	65%	25.5%	7%	2.5%

Table 2: Chemical Composition of Raw Materials

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	IR	LOI	Free lime
Clinker	66.10	19.28	7.82	3.26	1.03	1.68	2.40	0.31	0.89
Slag	40.26	31.60	17.20	0.82	4.81	1.16	3.2	0.78	--
Limestone	51.81	--	--	--	--	--	--	--	--
Gypsum	--	--	--	--	--	35.37	--	--	--

N.B.: Slag was totally dried out of moisture

Table 3: Physical Properties of cements

	Fineness	Residue on R90	Initial Setting Time	Final Setting Time
CEM I	367 m^2/kg	0.2%	140 mins	180 mins
CEM II B-M (S-L)	365 m^2/kg	2.8%	145 mins	190 mins

Equations

The machine reading during breaking were in KN. Value in PSI were found using the following conversion formula;

$$KN = \frac{1000 \times 2.204 lb}{9.81 \times 4 sq.in^2}$$

RESULTS AND DISCUSSIONS

For comparison the data is placed in two separate tables; Early Strength and Later Strength. The values of strength are in lb/in^2 or psi for easy understanding. The data were not rounded up for getting a more accurate curve in the table.

Table 4: Compressive Strength Results of the samples (Early Strength)

	1 Day	2 Days	3 Days	4 Days	5 Days	6 Days	7 Days	14 Days	21 Days	28 Days
CEM I (*psi*)	1180	2340	2677	3120	3315	3483	3876	4606	5112	5560
CEM II B-M (S-L) (*psi*)	768	1540	2078	2378	2640	2950	3080	3470	3820	4200

Table 5: Compressive Strength Results of the samples (Later Strength)

	35 Days	42 Days	49 Days	56 Days	180 Days	365 Days	1.5 Years	2 Years	2.5 Years	3 Years
CEM I (*psi*)	5861	5992	6011	6161	6254	6250	6300	6460	6460	6560
CEM II B-M (S-L) (*psi*)	4600	5000	5310	5740	6070	6340	6600	6840	7060	7110

After placing these values in a plot a figure is found which indicates that though Portland Composite Cement develops at a much slower late at early stage, but it shows higher strength on later stages.

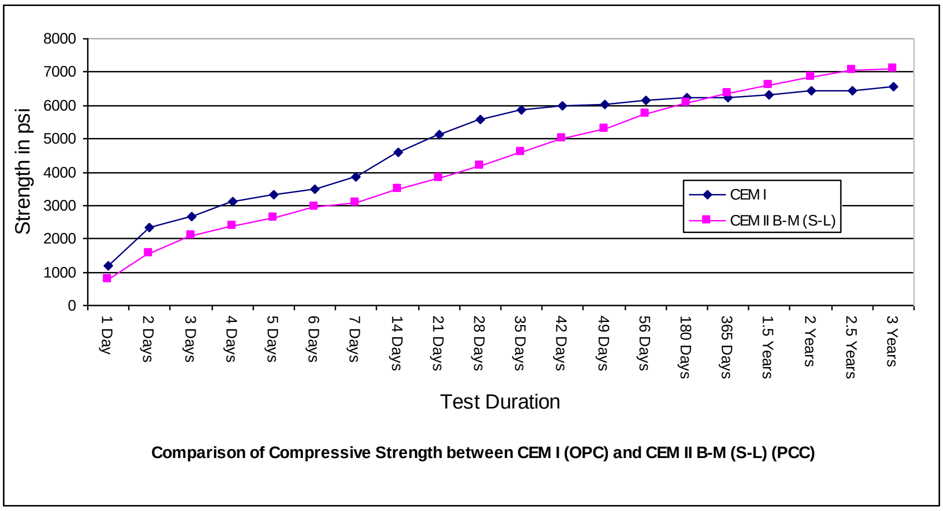

Fig 1: Comparison of Compressive Strength between CEM I (OPC) and CEM II B-M (S-L) (PCC)

It the Figure 1 one more observation can be found, whereas the strength of the OPC has a tendency to stabilise after 180 days or six month with only 4.8% development in rest of the time; the CEM II was clearly gaining strength day by day and the rising tendency of plot shows some upwards trend even at 3 years duration (17% increase in strength in the same time).
The benefits of limestone filler (LF) and granulated blast-furnace slag as partial replacement of portland cement are well established. However, both supplementary materials have certain shortfalls. LF addition to portland cement causes an increase of hydration at early ages inducing a high early strength, but it can reduce the later strength due to the dilution effect. On the other hand, BFS contributes to hydration after seven days improving the strength at medium and later ages.
Slag Cement has higher resistance to sulphate and salinity content sand and environment. When Portland cement hydrates, it forms calcium-silicate hydrate gel (C-S-H) (about 50~60%) and calcium hydroxide ($Ca(OH)_2$) or C-H (about 20~25%). C-S-H is the "glue" that provides strength and holds the concrete together. Permeability is related to the proportion of C-S-H to $Ca(OH)_2$ in the cement paste. The higher the proportion of C-S-H to $Ca(OH)_2$, the lower the permeability of the concrete as C-H is a by-product of the hydration process that does not significantly contribute to strength development in normal portland cement mixtures. When slag cement is used as part of the

cementitious material in a concrete mixture, it reacts with $Ca(OH)_2$ to form additional C-S-H, which in turn lowers the permeability of the concrete.
When slag cement is incorporated in a concrete mixture, less heat is generated and thermal stress is reduced: Due to increased strength with slag cement, the total cementitious content can be reduced. Portland cement content is reduced by the percentage of slag cement used. Hydration characteristics of slag cement are such that the early rate of heat generation and peak temperature of the concrete are reduced.
The composite cement price in lower, thus bigger saving during volume usage.
The Quality of the material used are also another important criteria, the similar curve may not be achieved without getting similar type of GBS Slag.
In both of the studies it is found that at the age of 365 days both CEM I and CEM II are showing similar results, of which surprisingly CEM II has a bit higher strength. The result also indicates that the both CEM I and CEM II cement uses in the experiment has the tendency to gain strength even after 1 and 2 years. The tendency of the curve is still upwards even after 3 years.

CONCLUSIONS

This plot indicates that cement containing slag may produce higher strength than OPC after systematic curing which is the main requirement for the development of concrete strength. As the civilisation develops, people are using up most of their environmental resources by manufacturing product like cement. A big volume of virgin raw materials is consumed each year to produce clinker for cement. This causes a vast release of Carbon-di-Oxide into the environment. The production of clinker cannot be stopped, but the volume can be reduced by using by-products like Granulated Blast Furnace Slag. About 300 KG of Slag is produced during production of one Metric Ton of Steel. And this huge amount of slag can help to reduce the stress on the environment by helping cement to gain similar results like OPC. PCC has many more benefit to the environment; such as less heat production, protection against chemical attack etc.
In contrast to the stony grey of concrete made with Portland cement, the near-white colour of GBS cement permits architects to achieve a lighter colour for exposed fair-faced concrete finishes, at no extra cost. To achieve a lighter colour finish, GBS cement also produces a smoother, more defect free surface. Dirt does not adhere to GBS concrete as easily as concrete made with Portland cement, reducing maintenance costs. GBS cement prevents the occurrence of efflorescence, the staining of concrete surfaces by calcium carbonate deposits.
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REFERENCES

Neville, AM and Brooks, JJ. 1999. *Concrete Technology.* London: Addison, Wesley Longman Limited. 29p.
Supplimentary Cementing Materials for Use in Blended Cement (RD112T), by Rachal J. Detwiler, Javed I. Bhatty and Shankar Bhattacgarja, Portlan Cement Organisation (PCA). 14p, 26p.