Importance of Consistent Cement Quality for a Sustainable Construction

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***Abstract*—The European Standard (EN) and Sri Lanka Standard (SLS) specifications for Portland cement have largely similar provisions on physical and chemical parameters of cement. However, consistency of cement within standards specifications is significantly high and it affect to standard deviation of concrete. In order to obtain good concrete quality, concrete users need to target a low standard deviation of concrete strength. In order to reduce the standard deviation of concrete strength, the material properties variations need to be lowered. This paper discusses variation in cement properties from 5 different cement suppliers.**

Cement from given suppliers varies between batches/ shipments. It is well understood that there are significant differences in mortar strength, chemical composition, fineness, setting times of same cement type (Type 1) from different suppliers. Experiments were conducted with 48 cement samples of 5 different cement brands collected over 10 months time from January 2011 to October 2011. It was found that all cement brands comply with EN and SLS standards. However, coefficients of variation (COVs) of most parameters, especially strength, are significantly high. This paper answers two key questions; are all nominally similar cements the same? Does cement from same supplier always behave consistently? Finally it recommends cement users and specifies a systematic way to select a consistent cement supplier for an economical and sustainable construction.

***Index Terms*—Cement strength, concrete strength, consistency of cement, standards deviation of concrete, COV of cement.**

I. Introduction

The Cement Industry and Trade estimate the cement market is amounting to 4.2 million MT per annum in Sri Lanka in 2011. According to Trade Sources, Four major cement suppliers are Holcim, Tokyo-Cement, Ultra-Tech and Lafarge who processes more than 85% of the cement bag packing operations and distribution network in the country. Rest of the market requirements are being mainly met by the importers of cement bags [1], [2].

This research focuses on the variation of cement quality of most popular 5 brands of above key suppliers. Samples were secured every month from January 2011 to October 2011. These samples are tested for mortar strength at 1day, 2day, 7 day and 28 day, chemical composition, fineness, consistency (initial & final setting time), water demand and soundness.

II. Experimental Program

A. Collection, Preparation and Testing of Samples

Cement Samples are collected from the market randomly, every month from 4 different suppliers (5 key brands) from January 2011 to October 2011. Samples are names as C1, C2, C3, C4 and C5 to make unbiased study on their properties and variations. As few brands are available from each supplier, the key brand(s) of each supplier is tested. All cements are type 1, ordinary Portland cement (OPC).

B. Compressive Strength of Mortar

Prepared 40mm X 40mm X 160mm prismatic test specimens according to EN 196 -1 standard [3]. These specimens are cast from batch of plastic mortar containing one part by mass of cement and three parts by mass of standard sand with a water/cement ratio of 0.5.

The mortar is prepared by mechanical mixing and is compacted in a mould using a standard jolting apparatus. The specimens in the moulds are stored in a moist atmosphere for 24 hours and then the demoulded specimens are stored under water until strength tests were carried out.

48 cement samples collected over the period were used for the testing. Each cement sample was used to cast for 1 day, 2 day, 7 day and 28 day compressive strength testing. Use the three-point loading method; apply the load vertical, by means of the loading roller till it breaks into two. Each prim half was tested by loading its side faces for compressive strength. Altogether 576 specimens were cast and 1152 (2 X 576) were tested for the compressive strengths.

C. Normal Consistency and Setting Time of Cement Paste

Normal consistency and setting time of cement paste were determined using the Vicat Apparatus according to EN 196-3:2005 standard [4] for collected 48 cement samples.

D. Cement Fineness

Cement fineness were measured in two different methods; Method 1: using sieve analysis according to EN 196-6 standard [5], the residue of 45μm (sieve # 325) were measured. Method 2: The Blaine air permeability apparatus was used to determine the fineness of Portland cement in terms of the specific surface expressed as total surface area in square centimeters per gram of cement according to EN 196-6 standard [5]

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E. Soundness

Soundness Test (Expansion) was done according to EN 196-3 standard [4] using Le Chatelier mould.

F. Chemical Composition of Cement

Chemical compositions were analysed using X-ray fluorescence (XRF) analyser according to EN 196-2 standard [6]. Percentages of Silicon dioxide (SiO_2), Aluminum oxide (Al_2O_3), Ferric oxide (Fe_2O_3), Calcium oxide (CaO), Magnesium oxide (MgO), Sulfur trioxide (SO_3), sodium oxide (Na_2O), Potassium oxide (K_2O), chloride content (Cl) and Loss on ignition (LOI) are measured individually. Using above chemical compositions, compound compositions are calculated using Bogue Composition Formulas [7], [8].

Tricalcium Silicate

$$(C_3S) = 4.07C - 7.60S - 6.72A - 1.43F - 2.85\hat{S} \quad (1)$$

$$\text{Dicalcium Silicate } (C_2S) = 2.87S - 0.75\,C_3S \quad (2)$$

$$\text{Tricalcium Aluminate } (C_3A) = 2.65A - 1.69F \quad (3)$$

$$\text{Tetracalcium Aluminoferrite } (C_4AF) = 3.04F \quad (4)$$

(Only valid when A/F >= 0.64), C = Percentage of Calcium oxide (CaO), S = Percentage of Silicon dioxide (SiO_2), A = Aluminum oxide (Al_2O_3), F = percentage of Ferric oxide (Fe_2O_3), $\hat{S}$ = Sulfur trioxide (SO_3)

III. Results And Discussion

A. Compressive Strength of Standards Mortar Samples

Compressive strength of mortar samples tested on 1day, 2 day, 7day and 28day are compared in below tables and figures

TABLE I: One Day (1D) Strength of Mortar Samples

1D Strength (MPa)	ALL	C1	C2	C3	C4	C5
Min	11.7	14.1	16.0	11.7	17.4	11.7
Max	22.5	21.1	21.9	17.8	22.5	17.6
Mean	18.0	17.9	20.4	15.5	19.5	15.4
STDEV	2.77	2.1	1.7	1.9	1.9	1.9
COV	15%	12%	8%	12%	10%	13%

TABLE II: Two Day (2D) Strength of Mortar Samples

2D Strength (MPa)	ALL	C1	C2	C3	C4	C5
Min	17.9	21.5	26.8	17.9	26.6	20.0
Max	33.4	29.0	33.4	26.8	31.4	29.9
Average	26.8	26.2	29.8	23.4	28.3	25.0
STDEV	3.29	2.2	2.0	2.8	2.1	2.9
COV	12%	9%	7%	12%	7%	12%

TABLE III: Seven Day (7D) Strength of Mortar Samples

7D Strength (MPa)	ALL	C1	C2	C3	C4	C5
Min	32.0	33.8	42.3	32.0	35.0	33.2
Max	49.0	42.5	49.0	41.6	42.9	48.3
Average	41.2	38.2	45.0	39.6	39.4	41.4
STDEV	3.79	3.2	2.1	2.9	2.5	4.0
COV	9%	8%	5%	7%	6%	10%

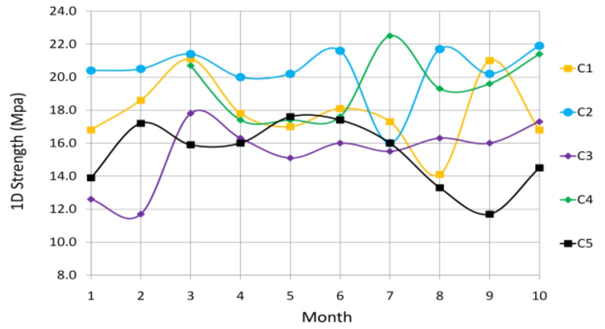

Fig. 1. One day (1D) strength of mortar samples

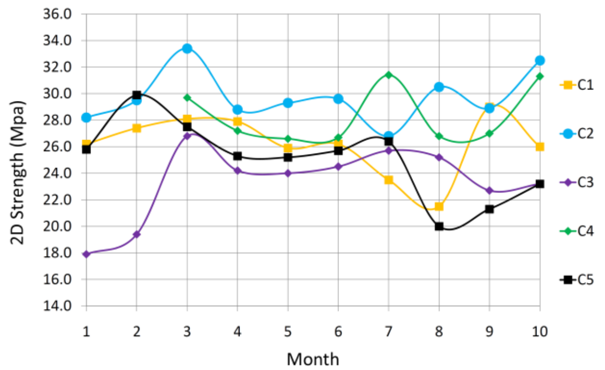

Fig. 2. Two day (2D) strength of mortar samples

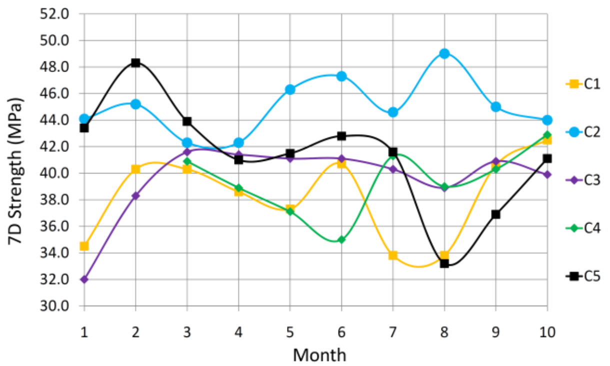

Fig. 3. Seven day (7D) strength of mortar samples

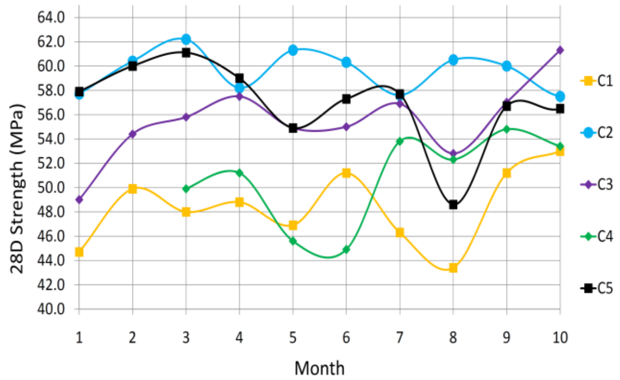

Fig. 4. Twenty eight day (28D) strength of mortar samples

According to EN 197-1[9], early compressive strength of mortar at 2days should be more than 10MPa, standards compressive strength at 28 days should be between 42.5 MPa and 62.5PMa. No limits are given for 1day and 7 days. However, in practice in Sri Lanka, one day strength is tested to understand very early strength for cement product manufacturing such as pre-cast. 7 day strengths are checked to understand the behavior of strength development [10],[11].

According to Sri Lanka standards (SLS), mostly derived from EN standards, only two strength classes (32.5N and

42.5N) are allowed for structural concrete. All cements selected above are 42.5N class. All test samples comply with SLS requirements, mortar strengths are between 42.4MPa and 62.5MPa. However, coefficient of variation in cement (COV) varies significantly from 3% to 6% even within individual suppliers in 28 day mortar strength. As seen in table 4 and figure 4, there is 18.8MPa (maximum of 62.2MPa – minimum of 43.4MPa) strength difference in mortar leading to 9% of COV in all samples [9]-[13].

All cements show similar early strength development patterns, 42% to 56% of 28 day strength in just 2day, and 71% to 79% of 28 day strength in 7 day time. Cement users can remove forms in early days using present day's cement. On the other hand, heat of hydration of cement might cause issues due to this rapid early strength development [14], [15].

B. Initial and Final Setting Times

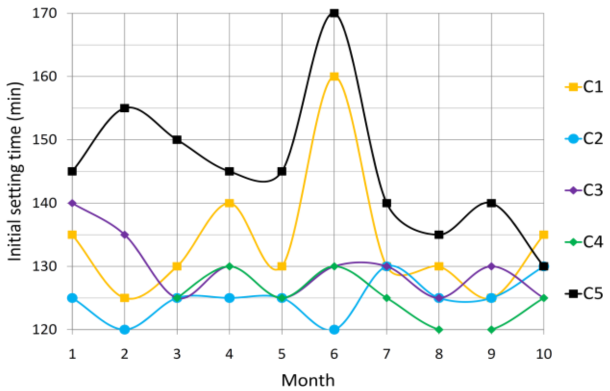

Fig. 5. Initial setting time

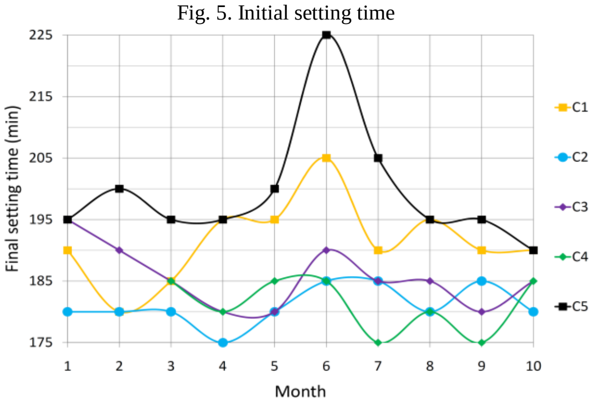

Fig. 6. Final setting time

Initial setting time of most samples lies between 120-130 minutes while final setting time occurs 175-185minutes. However, two cement brands (C1 and C5 shows) significantly high setting times compared to C2, C3 and C4 which has quite stable setting times. According to both SLS 107- part 2 [10] and EN 197-1 [9] standards requirements, initial setting time should be higher than 60 minutes. All cement samples are within limits stated by EN and SLS standards. Final setting times should be less than 600 minutes according to old BS12 [16] requirements. However, No value is specified for Final setting time in EN and SLS standards.

C. Fineness of Cement

As shown in Table V and Fig. 7, Fineness of cement varies from 3110cm2/g to 3995cm2/g, average 3459cm2/g. According to SLS 107- 2 [10] requirements, fineness should be higher than 2250 cm2/g. No limit is defined in EN 197-1 [9]. All cement samples are within limits stated by SLS standards. It seems that now all cement has higher fineness to get high early strength demanded by market situations. Howeven, this causes issues in concrete [17].

TABLE V: FINENESS OF CEMENT

Fineness (cm2/g)	ALL	C1	C2	C3	C4	C5
Min	3110	3250	3300	3235	3490	3110
Max	3995	3860	3675	3505	3995	3495
Average	3459	3621	3467	3330	3741	3202
STDEV	237	193	116	98	190	118
COV	7%	5%	3%	3%	5%	4%
max-min	885	610	375	270	505	385

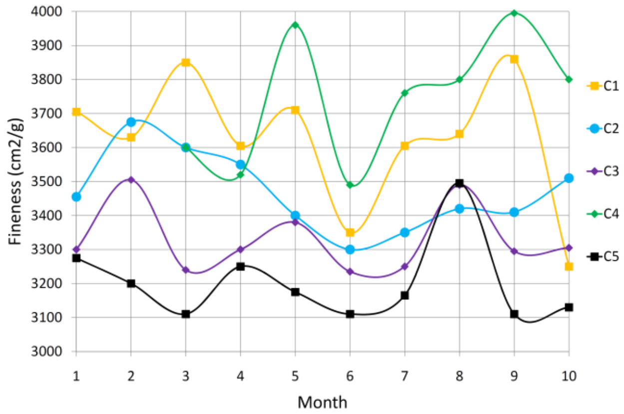

Fig. 7. Fineness of cement

D. Soundness

All cement samples show much less soundness (expansion) 1mm, compared to both SLS107 : 2 [10] and EN 197-1 [9] standards requirements of not more than 10mm. All cement samples are within limits stated by EN and SLS standards.

E. Chemical Composition and Compound Composition of Cement

Chemical compositions determined using X-ray fluorescence (XRF) analyser for cement samples are averaged and presentation in below table.

TABLE VI: AVERAGED CHEMICAL COMPOSITION OF CEMENT

	CHEMICAL COMPOSITION (%)							
	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Cl
C1	2.57	19.97	4.96	3.64	64.2	1.76	2.33	0.01
C2	3.71	20.38	4.79	3.26	64.4	0.98	2.21	0.02
C3	4.33	19.56	4.75	3.39	63.8	1.68	2.03	0.01
C4	2.88	19.70	4.80	3.36	63.8	2.05	2.59	0.03
C5	2.03	21.33	5.12	4.03	64.3	1.00	1.83	0.01

F. Loss on Ignition (LOI)

According to EN 197-1 [9], LOI should be less than 5%. According to SLS107-2 [10], LOI limit to 4% maximum. However, limits are extended to 5% if calcareous minor constituent included. It shows that cement C1, C2, C4 and C5 are within limits stated by both EN and SLS standards and C3 exceeds SLS limit unless calcareous minor constituent included.

G. Chloride Content (Cl)

According to EN 206-1 [18] limits for chloride content in concrete expressed as percentage of chloride ions by mass of cement. Maximum Chloride content in concrete limit to 0.1% in concrete with pre-stressing steel, to 0.2% in concrete with steel reinforcement and 1.0% for concrete not containing steel. EN 197-1 [9] limits maximum chloride content to 0.1%. SLS107-2 [10], limits chloride content to 0.1%. It can be concluded that all cement samples are comply with maximum chloride limits and safe to use for any type of concrete.

H. Sulfate Content (SO_3)

According to EN 197-1 [9], limits for maximum sulfate (SO_3) content to 3.5%. According to SLS 107-2 [10], limit maximum sulfate (SO_3) content to 3% if C_3A content is more than 5% and maximum sulfate (SO_3) content should not exceed 2.5% if C_3A content is less more than 5%. All cement samples are within limits stated by EN and SLS standards.

I. Magnesium Oxide (MgO)

In EN 197-1 [9], no limit is specified for maximum Magnesium oxide (MgO) content. According to SLS 107–2 [10], limit maximum Magnesium oxide (MgO) content to 5%. All cement samples are within limits stated by SLS standards.

TABLE VII: AVERAGED COMPOUND COMPOSITION OF CEMENT

	C1	C2	C3	C4	C5
C3S (%)	57.2	64.2	66.3	65.8	54.4
C2S (%)	8.0	10.4	7.3	7.2	20.4
C3A (%)	6.2	7.2	7.0	7.0	6.7
C4AF (%)	9.8	9.9	10.4	10.2	12.3

All cement has high Tricalcium Silicate (C_3S) content (low Dicalcium Silicate (C_2S) content) which lead to much faster hydration rate, contributes to higher early strength gain. Thus, cement with a higher proportion of C_3S, as is the case with most of today's cement, will tend to have a higher early strength, and allow for early form removal or post tensioning. On the other hand, cement with higher C_3S will cause issues due to heat of hydration specially in mass pouring [18],[19].

Tricalcium Aluminate (C_3A) liberate a large amount of heat during the first few days of hardening, and together with C3S and C_2S may somewhat increase the early strength of hardening cement. Low percentage of C_3A cement is more resistant to sulfates. All cement show desirable C_3A content of 6-7% [18]-[20].

Tetracalcium Aluminoferrite (C_4AF) contributes very slightly to strength gain and contribute to the color effects that makes cement gray [18]-[20].

IV. CONCLUSIONS

Variations in physical and mechanical properties (compressive strength, fineness, residue, setting times, soundness and water demand) and chemical composition (LOI, Cl, SO_3, MgO, C_3S, C_2S, C_3A, C_4AF) of key cement brands are significantly high. Even though all cement suppliers comply with EN and SLS standards, coefficient of variations of most cement parameters are quite high due to change of supply source time to time. If cement specifies and users study cement variations and adopt their concrete mix designs accordingly, they can reduce amount of cement content in their mix design. On the other hand specifying low variation cement supplier such as C2, hopefully a single source cement supplier, will add value to reduce total cost of concrete thought construction phase. While C3 and C5 show average COV, it would be the second choice for specifies and users. However, selecting C1 and C4 will definitely lead to significant variation in cement strength and will make cement users very uncomfortable due to its variations in most of parameters including strength, hopefully due to various cement sources within very short period of time.

All these variations make ineffective use of materials and increase cost of final product. Thus, cement with lower COV will save money in the construction phase and lead to economical and sustainable construction practices.

V. RECOMMENDATIONS FOR CEMENT USERS

Cement uniformity can be considered in cement purchase decisions by cement users such as contractors and concrete suppliers or cement specifies such as consultant engineers and technical officers. Apart from mill test reports from the cement manufacturer, cement users and specifies should request to see 3rd party test reports over the past 10-12 months. Everything else being equal, cement that has a lower coefficient of variation (or low standard deviation) will be more uniform and will generally result in a lower concrete standard deviation. This can result in a lower target average concrete strength with a lower cement content for a given strength level, finally leading to economical mix design. With a complex interdependence of cement and concrete properties, it is important to analyze and evaluate variations in cement properties and its effect on quality of concrete before choosing a supplier for a sustainable concrete construction.

REFERENCES

[1] Federation of Chamber of Commerce & Industry of Sri Lanka. (August 2011). Cement industry trade standard of cement and import inspection scheme. [Online]. Available: http://www.blog.fccisl.lk/2011/08/

[2] *Annual survey of construction industries (western province-Sri Lanka)*, Department of Census and Statistics, 2009, PP 11-16

[3] EN 196-1 2005, *Methods of testing Cement – Part 1: Determination of strength*, European Standard, pp. 1-36. March 2005.

[4] EN 196-3 2005, *Methods of testing Cement – Part 3: Determination of setting times and soundness*, European Standard, pp. 1-18. March 2005.

[5] EN 196-6 2005, *Methods of testing Cement – Part 6: Determination of fineness, European Standard*, pp. 1-24. March 2005.

[6] EN 196-2 2005, *Methods of testing Cement – Part 6: Chemical analysis of cement*, European Standard, pp. 1-24. March 2005.

[7] *Cement manufactures' handbook*, Kurt E Peray, pp. 6-7, 1979.

[8] Neville, A.M., Properties of concrete, Pearson education Limited, pp1-56, 2010

[9] EN 197-1 2000, *Cement – Part 1: Composition, specifications and conformity criteria for common cements*, pp. 1-20. September 2000.

[10] SLS 107-2 2008, *Ordinary Portland Cement – Part 2: Test methods*, pp. 1-24. September 2008.

[11] K. H. Obla, "Variation in Concrete Strength due to Cement," Part III of concrete quality series, *Technical services*, NRMCA, pp. 1-5.

[12] S. Walker and D. L. Bloem, "Variation in Portland cement, proceedings, ASTM International," *West Conoshohoncken*, PA, vol. 58, pp. 1009-1032.
[13] K. Kurtis, "Tests on Portland Cement," Georgia Institute of Technology, pp. 1-27.
[14] Concrete technology today. (July 1997). Portland cement, Concrete and heat of hydration. Portland cement association. [Online]. 18(12). Available: http://www.cement.org/tech/pdfs/pl972.pdf
[15] R. Moser. Mass concrete "material science of concrete". [Online]. Available: http://people.ce.gatech.edu/~kk92/massconcrete.pdf
[16] BS 12-1996, *Specification for Portland cement*, pp. 1-16. May 1996.
[17] S. Ahamed and L. A. Qureshi, "Variation in fineness of fetco cement and effects on other properties of cement and concrete," presented at 29th conference on our world in concrete & structures, Singapore, August 25-26, 2004.
[18] EN 206-1 2000, *Concrete – Part 1: Specification, performance, production and conformity*, pp. 1-72. December 2000.
[19] V. C.Johansen, P. C.Taylor, and P. D. Tennis, *Effect of Cement Characteristics on Concrete Properties*, EB226, 2nd edition Portland Cement Association, USA, pp.1-48, 2006.
[20] D. C. Maclaren and A. W. Mary, *Cement: Its Chemistry and Properties*, Dalhouse University, Halifax, Canada, pp. 1-13.

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