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Original Research

Comparative Analysis of the Chemical Compositions of Afghani Ghori and Various Pakistani Cement Brands Used in Afghanistan

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Abstract:

Cement is widely used in construction works. In Afghanistan, despite Ghori Portland cement several other Pakistani imported cement brands are used in a vast extent. Therefore, it is required that the cement properties shall meet the standard properties established by the codes. In this study, the Ghori-1 and imported cement brands are compared in terms of chemical constituents and compounds. The chemical composition of Ghori cement was analyzed by conducting XRF/XRD tests and the chemical composition of imported cements were collected from the published research articles. The C_3S, C_2S, C_3A, and C_4AF compound composition was calculated through the chemical analysis of cement using Bogue's equation. It was found that in Ghori cement, the Al_2O_3 and SO_3 contents exceed the specified limits. The higher amount of SO_3 leads to expansion of sulfates in cement. Moreover, based on the comparison of four main compounds (C_3S, C_2S, C_3A, and C_4AF), it was found that the Ghori-1 cement exhibit lower amount of C_3S and higher amount of C_2S which produces the least strength compared to the other cement brands. Some deviations were found in chemical composition of Ghori cement and do not meet the standard values established by the codes which are due to low quality control during the cement production process. Based on the comparison of different brands considering the chemical compositions, the Cherat and Bestway cements met the recommended values given by the standards. The Ghori cement need further quality control during the production process to ensure the codes specified quality.

Keywords: Ordinary Portland Cement, chemical constituents, Chemical compounds, Bogue's formulation

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1. Introduction

The concrete is widely used in construction industry around the globe. It is employed in both structural and non-structural applications. According to the estimation of Goldstein, annually, 1 ton of concrete is produced per each person on the earth [1]. Cement is one of the major components of the concrete which plays an important role in the concrete matrix; it acts as a binding material when mixed with water. The properties of concrete vastly depend on the quality of the cement. The use of poor quality cement in structural works will lead to endanger the lives and properties. Therefore, the quality control is must and it has become a critical factor [2].

The quantity of the cement in concrete mix has a direct effect on the production cost, which in turn reliant on its quality. The economical concrete products can be obtained by using good quality of cement. Therefore, specific tests are carried out in laboratories by the manufacturing companies in accordance with the relevant standards [3-4].

In Afghanistan, it is estimated that more than 300 million tons of cement is used annually, most of which is imported from neighboring countries [5]. There are four cement factories in Afghanistan, namely Pul-e-khumri, Jabal-e Saraj, Herat, and Samangan cement plants. According to a report published by [6], the local cement production is alarmingly low and suppresses by the imports from Pakistan and Iran. The existing plants have been damaged by decades of war and requires restoration and machinery renewal to remain competitive in the market. There are 5 Pakistani cement brands namely Lucky, Cherat, Bestway, Mustehkam and Askari which are imported into Afghanistan and are widely used in construction works.

The physical properties of cement vary due to a change in the amount of chemical composition of the cement [7-8]. Therefore, this study was conducted to compare the quality of the domestic Portland Ghori cement of Afghanistan and aforementioned imported Pakistani cement brands. The chemical compositions such as CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO, SO_3 and LOI of mentioned brands were chosen for the comparative analysis.

Basic Chemistry of Portland

The Portland cement is developed by grinding clinker with Gypsum ($CaSO_4$) and the clinker itself is a mixture of calcium silicates and ferrites with some minor impurities. Lime, silica, alumina and iron are the basic raw materials used in the cement production. Some of the oxides available in the raw material react with each other in the kiln and form different potential compounds, which are responsible for different physical properties of Portland cement [7].

The composition of Portland cement helps to distinguish one type of cement from another. The influence of cement on the properties of cement concrete is presented in Table 1. Pomeroy [9] presents the standard chemical requirements for each type. The C_3S, C_2S, C_3A, and C_4AF are the major mineralogical compounds of cement product [10]. The C_3S and C_2S compounds play an important role in the strength development of the cement. The C_3A and C_4AF are in small amounts and

do not significantly affect cement behavior [3],[10]. The actual components of cement clinker often have chemically complex amorphous and crystalline structures. Several chemists have denoted as "elite" (C_3A), "belite" (C_2S) and various forms of aluminates. The C_3A content effect on the hydration of cement. A higher amount of C_3A leads to early hydration of cement which is mainly controlled by the amount and type of sulfates grounded with the cement. Poor control of rapid hydration of C_3A leads to rapid setting, false set, loss of slump and incompatibility of cement admixtures [12-13]. The C_3S, C_2S, C_3A, and C_4AF contents can be calculated using the Bogue's calculation [14].

Table 1: Effects of cement on cement concrete properties [9]

Cement Properties	*Cement effects*
Placeability	Cement amount, fineness, setting characteristics
Strength	Cement composition (C_3S, C_2S, and C_3A) fineness
Drying shrinkage	SO_3 content, cement composition
Permeability	Cement composition, fineness
Resistance to sulfates	C_3A content
Alkali silica reactivity	Alkali content
Corrosion of embedded steel	Cement composition (esp C_3A content

In internal structure are so called microstructure of cement hydrates takes place after the cement concrete hardens and continues for month and years. The internal structure of cement hydrates specifies the mechanical behavior and durability of the cement concrete. Calcium oxide (CaO) and silica oxide (SiO_2) play a vital role in the formation of silicate compounds (C_3S and C_2S). When the water is added to the cement, the hydration takes place and silicates produce calcium-silicate-hydrate (C-S-H) gel, which cooperate in strength development. The aluminates are rather less strong than the silicates. several methods are defined to calculate the aforementioned silicates in the cement clinker [12-13]. of these, the Bogue equation (Eq.1) is recommended by ASTM C150. The below equation is valid for $A/\mathrm{F} \geq 0.64$.

$$\mathrm{C_3S} = (4.01710)\mathrm{C} - (7.6024)\mathrm{S} - (1.4297)\mathrm{F} - (6.7187)\mathrm{A} - (2.852)\mathrm{S} \quad \text{(Eq. 1a)}$$

$$\mathrm{C_2S} = (8.6024)\mathrm{S} + (1.0785)\mathrm{F} + (5.0683)\mathrm{A} - (3.0710)\mathrm{C} \quad \text{(Eq. 1b)}$$

$$\mathrm{C_3A} = (2.6504)\mathrm{A} - (1.6920)\mathrm{F} \quad \text{(Eq. 1c)}$$

$$\mathrm{C_4AF} = (3.0432)\mathrm{F} \quad \text{(Eq. 1d)}$$

Where,

C is the amount of calcium oxide (%);
S is the amount of silica oxide (%);
A is the amount of aluminum oxide (%);
F is the amount of ferric oxide (%);
S is the amount of sulfur trioxide (%);

2. Materials and Methods:

Ghori-1 Portland cement sample (approximately 5kg) was obtained from Pul-e-khumri cement plant located in Baghlan, Afghanistan. Qualitative and quantitative XRF/XRD analysis was performed on Ghori-1 cement sample following JIS R 5204:2002 standard. Approximately 50gr of cement sample was distributed to Mitsubishi materials co ltd. Usually, 5gr of cement sample is used for the XRF analysis. The X-Ray diffraction (XRD) is a non-destructive testing method used to analyze the structure of crystalline materials. The XRD determines the presence and amount of mineral species in a sample, as well as identifies phases, while the XRF gives detailed information about the chemical composition of a sample but does not indicate what phases are present in the sample. The chemical composition of Pakistan cement brands imported into Afghanistan were collected from the cement factories and published research papers.

3. Results and Discussions:

The XRF test has been conducted on the Ghori cement sample and the main oxides such as CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO, SO_3 and LOI have been determined. These oxides mainly effect on the strength properties of the concrete [2]. The results of chemical composition expressed in weight percent of oxides obtained from the XRF test is presented in Table 2. The intensities of elements, Kα counts per second obtained from the samples' X-ray spectrum is shown in Fig. 1. Furthermore, the chemical compositions of Pakistani cement brands and ASTM C150 allowable limits for Portland cement are also shown in Table 2 [17]. The oxide contents shown in Table 2 are compared with ASTM C150 standard and it is observed that the oxide contents are similar in all cement brands and conform to the allowable limits mentioned by the ASTM C150.

Table 2: Chemical composition of different cement brands by weight percent [17]. Ghori cement's samples has been investigate during this study.

Sample	*Compounds Weight (%)*						
	CaO	*SiO2*	*Al2O3*	*Fe2O3*	*MgO*	*SO3*	*LOI*
Ghori	61.67	21.08	6.15	2.28	1.23	3.51	2.45
Lucky	60.89	20.78	5.11	3.17	3	1.74	2.31
Askary	62.2	20.12	5.53	3.47	1.71	2.29	1.45
Bestway	61.7	21	5.04	3.24	2.56	1.51	1.83
Mustehkam	61.24	20.75	5.3	4.26	2.03	1.82	1.53
Cherat	63.53	21.24	5.56	3.24	0.93	2.55	1.24
Standard DEV.	0.85	0.36	0.37	0.58	0.72	0.67	0.45
ASTM C150	60-67	17-25	≤6	≤6	<6	<3	<3

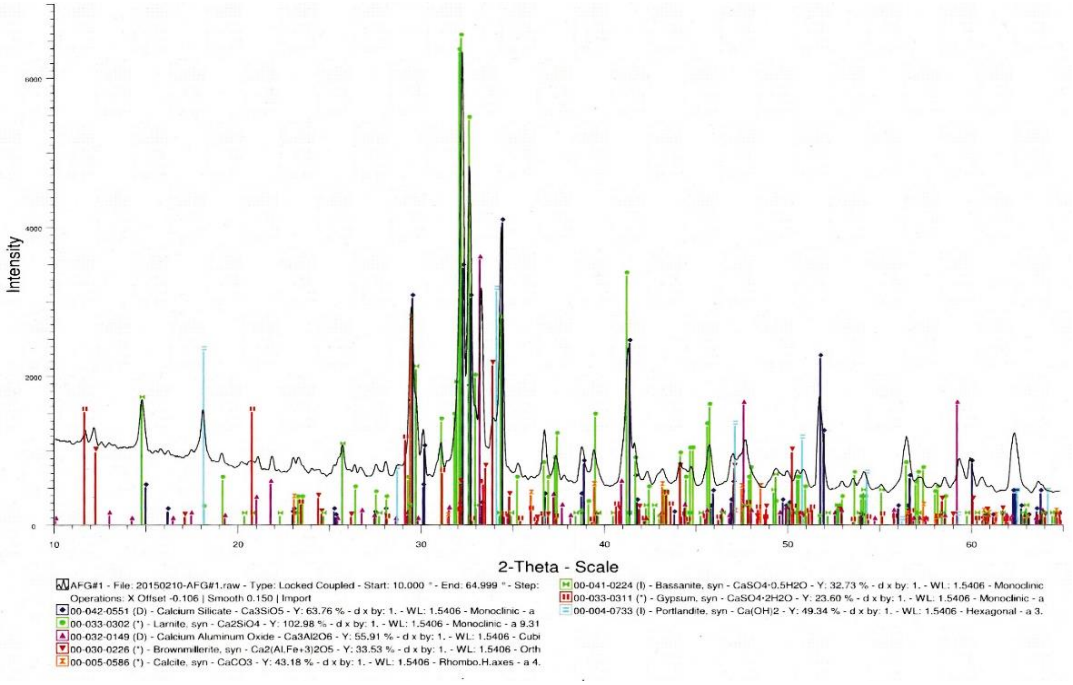


Fig. 1: The XRD analysis of the Ghori-1 cement.

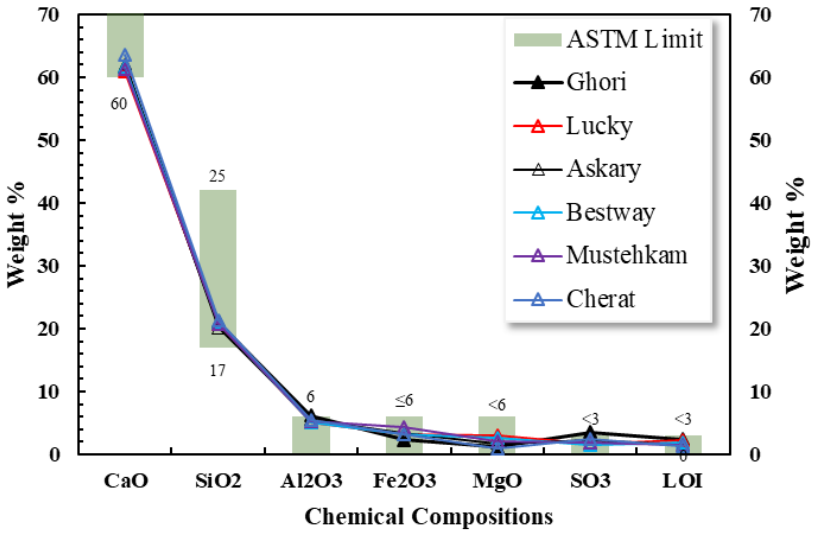


Fig. 2: Oxides content by weight percent vs. ASTM limits

ASTM specifies the percentage of CaO in OPC within the range of 60% to 67%. All six brands of cement contain CaO within the specified limit that can be observed in Table 2. The amount of CaO have a significant effect on the strength development of OPC, therefore, the CaO content is limited; when the lime content is too low the main strength forming mineral C_3S will not form in sufficient amount which lead to low early strength, while the higher lime content causes early strength, when it is too high the free lime increases which on hydration creates unsoundness [18], however, slightly lower content is recommended for the ultimate strength which can be achieved gradually over a long period of time [19]. Furman and Welcher [18] has found that for the strength increment, it is necessary to increase the lime content or improve the fineness of grains, or both.

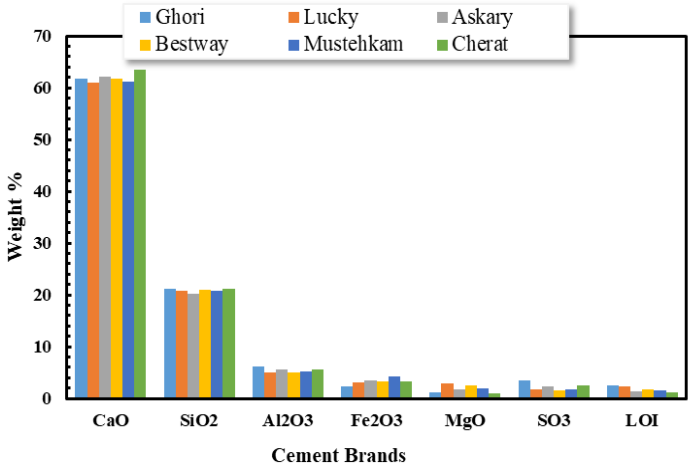


Fig. 3: Comparison of oxides contents of different brands by weight percent [17].

ASTM specifies the amount of SiO_2 in Portland cement within the range of 17% to 25%. It has been observed that all six brands are well within the range. Further, the ASTM standard has suggested the Al_2O_3 content to a maximum of 6% whereas, the Ghori cement exceeds the limit. On the other hand, amount of Fe_2O_3 oxide is well within the acceptable range suggested by ASTM C150. The variations of oxides are shown in Fig 2 and Fig 3, respectively. If the lime content is fixed and the silica content is too high, it may reduce the alumina and ferric oxide content and the burning temperature will be raised. Alumina and ferric oxide both act as a flux so these must be kept within controlled limits. A high alumina content produces more C_3S and cause rapid setting of cement, which in turn decrease the workability of cement.

Furthermore, the Ghori cement exceeds the ASTM specification for SO_3. The maximum allowable SO_3 content is limited between 1.5 to 2.5%. The allowable SO_3 content prevents the sulfate expansion. The higher amount SO_3 content in Ghori cement can cause the expansion of sulfates, therefore, to avoid the sulfate expansion and as well as control the setting time effectively, appropriate amount of calcium sulfates in the form of gypsum shall be added to the clinker [20].

Moreover, the variations of MgO are presented in Table 2 and as well as plotted in Fig 2 and Fig 3, respectively, it is noted that the contents of MgO are well within the acceptable range suggested by ASTM. If the MgO is beyond the specified limit, it means that free MgO (periclase) is available in the clinker. Small amounts of Periclase are not a problem, but large amount of free MgO is undesirable, the Periclase may hydrate and the MgO will convert to MgOH which is an expansive reaction and can cause damage [21]. Table 2 also provides the data for LOI, which is a measure of the cement quality in terms of its carbon content and moisture. It is noted that the results are well within the acceptable limits mentioned by ASTM.

Table 3 presents the mineralogical compositions obtained from Bogue's calculation and how they deviated from the ASTM standard. Fig. 4 compares the proportion of the mineralogical components of above mentioned cement brands. The C_3S and C_2S compounds mainly effect on the early and eventual strength of cement paste, respectively. Among six samples, the Ghori and Mustehkam have lower C_3S content compared with ASTM. The Ghori, Askari, and Mustehkam products have a combined C_3S and C_2S content less than 71%, an index for high quality cement recommended by [10], [22]. The higher C_2S content in Ghori, Lucky, Mustehkam, and Cherat cements implying later strength characteristics.

It is seen in Fig 4 and Table 3 that the amount of silicates (C_3S and C_2S) is minimum in Ghori cement (69.55%), and is maximum in Cherat and Bestway brands (72.93%) and (72.45%), respectively. According to the Table 2. there is a difference of about 4.6% in silicates between the Ghori and Cherat cement brands. Upon hydration, Cherat cement will produce more C-H-S gel compared with other brands and will cause higher strength and Ghori cement will produce the least strength compared to the other cement brands.

Table 3: mineralogical composition of chosen cement brands estimated based on Bogue equations

Sample	Mineral Compounds			
	Alite (C_3S)	Belite (C_2S)	Celite (C_3A)	Ferrite (C_4AF)
Ghori	36.20	33.35	12.44	6.93
Lucky	46.06	25.09	8.18	9.64
Askary	51.59	19.05	8.79	10.55
Bestway	48.71	23.73	7.88	9.85
Mustehkam	44.65	26.06	6.85	12.95
Cherat	47.88	25.05	9.26	9.85
Standard DEV.	4.83	4.22	1.75	1.76
ASTM C150	45-65	7.0-32	4.0-12	8.0-12

The characteristics of Portland cement based on chemical compounds are described in Table 4. The effects of C_3S, C_2S, C_3A, and C_4AF on early strength, long

term strength, hydration heat, drying shrinkage, and chemical resistivity of cement are summarized in mentioned table 4. The higher the C_3S, the higher the early strength (3-28days) with an average long time strength development, average hydration heat, average drying shrinkage, and average chemical resistance. The higher the C_2S amount, the lower early strength with higher long-term strength development, low hydration heat, drying shrinkage, and high chemical resistance. The higher the C_3A, the higher one-day strength with low long time strength development following higher hydration heat and drying shrinkage. The lower the C_4AF content the lower the early and longtime strength development following low hydration heat and drying shrinkage.

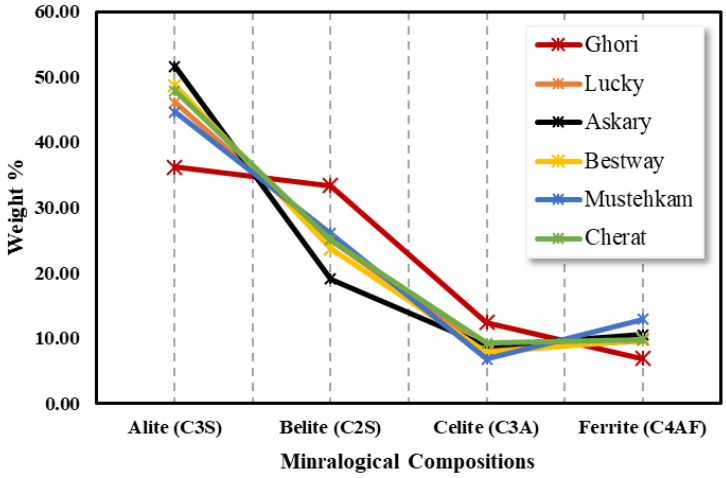


Fig 4: comparison the proportion of the mineralogical components of cement brands.

Table 4: Characteristics of Portland Cement based on chemical compounds

Main Compounds	*Early Strength*	*Long Term Strength*	*Hydration Heat*	*Drying Shrinkage*	*Chemical Resistivity*
C3S	from 3-28 days Large	Medium	Medium	Medium	Medium
C2S	Low	after 28 days Large	Low	Low	Large
C3A	One day strength large	Low	Large	Large	Low
C4AF	Low	Low	Low	Low	Medium

Table 5 presents the lime saturation factor (LSF), Silica ration (SR), and Alkali ration (AR) for the cement brands used in this study. Fig 5 presents the data of LSF for all six brands used in the is study. The LSF represents the ratio of quantity of lime in the cement that required to form C_3A, C_3S, and C_4AF in the clinker. It

controls the ratio of C_3S to C_2S in the clinker. The higher LSF indicates higher C_3S to C_2S. The LSF value typically range between 0.92 -0.99. The Ghori, Lucky, and Mustehkam cement brands indicate the higher ratio of Belite (C_2S) to Alite (C_3S), whereas Askari, Cherat, and Bestway cement brands LSF values are within the specified limits. The LSF, SR, and AR are calculated based on the following equations [23]:

$$LSF = \frac{CaO}{(2.8 \text{ x } SiO_2 + 1.2 \text{ x } Al_2O_3 + 0.65 \text{ x } Fe_2O_3)} \quad \text{(Eq. 2)}$$

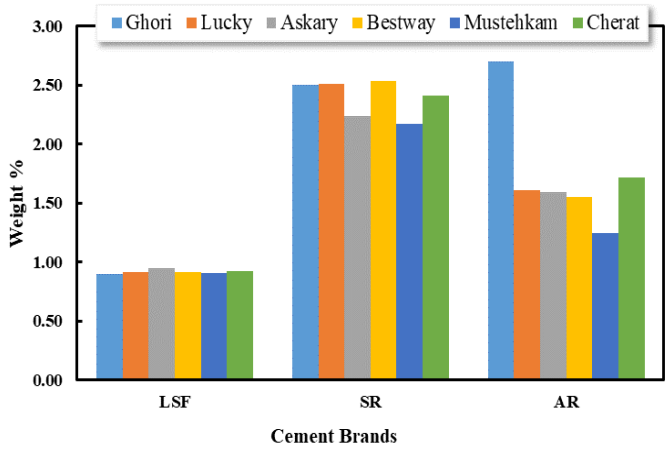
$$SR = \frac{SiO_2}{(Al_2O_3 + Fe_2O_3)} \quad \text{(Eq. 3)}$$

$$AR = \frac{Al_2O_3}{Fe_2O_3} \quad \text{(Eq. 4)}$$

Table 5: Quality control properties of cement products

Sample	*Quality control properties of cement*		
	LSF	*SM*	*AM*
Ghori	0.90	2.50	2.70
Lucky	0.91	2.51	1.61
Askary	0.95	2.24	1.59
Bestway	0.92	2.54	1.56
Mustehkam	0.91	2.17	1.24
Cherat	0.92	2.41	1.72
Standard DEV.	0.02	0.14	0.45
ASTM C150	0.92-0.98	2.0-3.0	1.0-4.0

Fig. 5: LSF, SR, and AR values of different cement brands



The other two factors SR and AR shown in Table 3 are also the important aspects of a cement chemical composition. The SR, and AR of all cement brands is satisfactory and conforms to the ASTM recommended specifications.

4. Conclusion:

This paper presented the comparative analysis to study the properties of locally available cement (Ghori-1) and Pakistani imported cements used in Afghanistan. Chemical properties of all six brands were studied and succeeding the discussion following conclusions are drawn:

- The chemical composition of all six brands were similar and conformed ASTM requirements. Ghori cement exhibited lower silicates (C_3S and C_2S) compared to the other cement brands. Based on the proceeding of discussion, it was found that the Ghori cement with lower C_3S content and higher C_2S content will produce the least early strength compared to the other cement brands. Moreover, higher content of SO_3 was observed in Ghori cement which can cause expansion of sulfates. Therefore, proper control on amount of Gypsum is required.
- Chemical composition influences the quality of cement such as setting time, compressive strength, drying shrinkage, and soundness. If the constituents of cement are limited within specified standard limits, the mixture behaves satisfactory in the klins and produce good quality cement.
- Based on the comparative analysis of different imported and locally available cement brands in Afghanistan; Cherat and Bestway cement brands were found to be suitable and recommended to be used in concrete structures in Afghanistan.
- It was found that due to poor quality control during the cement production in Afghanistan, some deviations were found in chemical composition of OPC compared to ASTM C150.

5. Acknowledgement:

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6. Conflicts of Interest:

All authors declare that they have no conflicts of interest to disclose.

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