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Analysis of the Chemical Compositions of Locally Branded Manufactured Cement of Pakistan

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ABSTRACT

Cement is a key component of concrete; its qualities impact the properties of concrete created using a particular type of cement. In Pakistan, cement brands are used for an enormous amount. As a result, the cement qualities must fulfill the standards defined by the rules. This research compares the chemical properties of Paidaar, Lucky, DG, Fauji, and Bestway cement brands. This research compares the chemical properties of Paidaar, Lucky, DG, Fauji, and Bestway cement brands. The chemical analysis of cement was used to compute the compound composition of C3S, C2S, C3A, and C4AF. It was discovered that the Al_2O_3 and SO_3 levels in Paidaar and Fauji cement exceeded the specified limits. The presence of more SO_3 causes sulphates in cement to expand. Furthermore, a study of four key components (C3S, C2S, C3A, and C4AF) revealed that Paidaar, Lucky, and Fauji cement have less C3S and more C2S, as a result, when compared to other cement brands, it has the lowest strength. When different brands' chemical compositions were compared, the Paidaar, Lucky, DG, Fauji, and Bestway cements fulfilled the standards' recommended ranges. To ensure the quality specified by the standards, Paidaar, Lucky, and Fauji cement require significant quality control during the manufacturing process.

Keywords: Chemical compounds, Ordinary Portland Cement, Oxides, chemical properties.

INTRODUCTION

Concrete is widely used in the construction industry whole in the world. It is used for structural and non-structural purposes. Goldstein believes that 1 tonne of concrete is produced per person annually (Asef et al., 2022). To strengthen the building structure successfully, cement utilized during assembly must have certain features such as strength and setting time. The cement performance will be good if the above-mentioned qualities remain within the prescribed limitations. A range of tests are done to assure the quality of cement in accord with the requirements of the relevant standards (Asef et al., 2022). The amount of cement in the concrete mixture has a direct effect on the production cost, which in turn is reliant on its quality. Economical concrete products can be obtained by using good quality cement. Therefore, specific tests are carried out in laboratories by manufacturing companies in accordance with the applicable standards. Burham cement matched well in both its chemical and mechanical properties and can thus be exposed to loading structures. Dangote cement must be researched further. The developed evaluation technique comparing of ASTM and BSI standards with the technical qualities of local cement brands can be utilized to control product quality during cement manufacturing (Yahaya and Muibat D, 2009). Different brands of Ordinary Portland Cement (OPC) produced and available in Khyber Pakhtoon Khwa, Pakistan, were investigated for various chemical characteristics and compared to British standard standards in this study. The empirically determined composition of the majority of these elements was within the range of the standard values. The physical properties of cement vary due to a change in the amount of chemical composition of the cement (Amin and Ali, 2010). Rafi and Nasir (2014) said

that the composition of all seven cement brands were consistent, and they all met ASTM and PS standards. Cement brand B's cement compound composition contained more silicates (C3S and C2S) than the other cement brands. These oxides mostly affect the concrete's strength qualities. Therefore, this study was conducted to compare the quality of domestic Portland cement in Pakistan. The chemical compositions such as 1 - CaO, 2 - SiO_2, 3 - Al_2O_3, 4 - Fe_2O_3, 5 - MgO, 6 - SO_3, and 7 - LOI of mentioned brands for the comparative analysis. There are 5 Pakistani cement brands namely Paidaar, Lucky, DG, Fauji, and Bestway which are widely used in construction works in Punjab, Pakistan.

Portland cement is made by grinding clinker with gypsum (CaSO4), and clinker is a combination of calcium silicates and ferrites with minor impurities. The primary raw elements used in cement manufacture are lime, silica, alumina, and iron. Some of the oxides included in the raw material react with each other in the kiln, forming distinct potential compounds that are responsible for the various physical qualities of Portland cement (Ali et al., 2008). The chemical composition of cement helps to distinguish different types of cement from each other. The influence of cement on the properties of cement concrete is presented in Table 1. Pomeroy (Evangelista, 2010) presents the standard chemical requirements for each type. The C3S, C2S, C3A, and C4AF are the major mineralogical compounds of cement products. The C3S and C2S compounds play an important role in the strength development of cement. The C3A and C4AF are in small amounts and do not significantly affect cement behavior (Zongjin, 2011). The actual components of cement clinker often have chemically complex amorphous and crystalline structures. Several chemists have been denoted as "elite" (C3A), "belite" (C2S), and various forms of aluminates. The C3A content affects the hydration of cement. A higher amount of C3A 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 C3A leads to rapid setting, false set, loss of slump, and incompatibility of cement admixtures (Gastaldi, 2012). The C3S, C2S, C3A, and C4AF contents can be calculated using Bogue's calculation (Gonalves, 2010).

Table 1. Effects of cement on cement concrete properties (Evangelista, 2010)

Cement properties	Cement effects
Drying shrinkage	SO_3 content, the cement composition
Strength	Cement composition (C3S, C2S, and C3A) fineness
Alkali silica reactivity	Alkali content
Placeability	Cement amount, fineness, setting characteristics
Permeability	Cement composition, fineness
Resistance to sulfates	C3A content
Corrosion of embedded steel	Cement composition

In the internal structure are so-called microstructure of cement hydrates takes place after the cement concrete hardens and lasts for months and years. The internal structure of cement hydrates specifies the mechanical comportment and strength of the cement concrete. Calcium oxide (CaO) and silica oxide (SiO_2) play a vital role in the formation of silicate compounds (C3S and C2S). When water is added to the cement, hydration takes place and silicates produce calcium-silicate-hydrate (C-S-H) gel, which cooperates in strength development. The aluminates are rather less strong than the silicates. several methods are defined to calculate the above-mentioned silicates in the cement clinker (Cheung, 2011). of these, the Bogue equation (Eq. 1) is recommended by ASTM C150.

The below equation is valid = $A/F \geq 0.64$.

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

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

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

$$C_4AF = \{(3.0432)F\} \quad (1d)$$

where: A – amount of aluminum oxide (%);
F – ferric oxide (%);
C – calcium oxide (%);
S – silica oxide (%).

In this study, we have taken cement brands, locally manufactured in Punjab, as an independent variable. As a dependent variable, we have taken the comparison results and impacts on cement concrete of construction works. Therefore, this research is related to construction industries that may take benefit in decision-making and planning accordingly to ensure better construction works. There are 5 Pakistani cement brands namely Paidaar, Lucky, DG, Fauji, and Bestway

which are widely used in construction works in Punjab, Pakistan. The goal of this particular research work is to determine the best among all these five cement manufacturing brands.

MATERIALS AND METHODS

For chemical analysis of SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, and LOI, American Standard ASTM C-114 were used. The above-quoted chemical analyses were carried out focusing especially on the cement samples collected from Paidaar, Lucky, DG, Fauji, and Bestway cement brands from the local market in Punjab, Pakistan.

- A total of 15 samples were prepared.
- In which 03 samples for each cement category were used having the weight of 50 grams cement of for each category. Out of this taken 50 grams.
- 05 grams of each cement sample were used for the XRF analysis.
- Burker Machine D2 PHASER was used for XRF analysis.

X-Ray diffraction (XRD) is a non-destructive testing method used to analyze the structure of crystalline materials. The given information detailed below is about the chemical composition of a sample and it does indicate the present phases in the sample.

RESULTS AND DISCUSSIONS

Table 2 shows the chemical composition data reported in weight percent. Furthermore, the chemical compositions of selected cement brands and ASTM C150 allowable limits for Portland cement are also shown in Table 2. The oxide contents are compared with the ASTM C150 standard and it is determined that the oxide percentages of all used cement brands are equal and meet the ASTM C150 acceptable limit.

ASTM specifies the percentage of CaO in OPC within the range of 60% to 67%. All five brands of cement contain CaO within the specified limit which can be observed in Table 2. The amount of CaO has 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 C3S will not form in a satisfactory amount which leads 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 (Gnedenko, 2018), however, slightly lower content is recommended for the ultimate strength which can be achieved progressively over a long period of time. Gnedenko (2018) have found that for the strength increment, it is required to increase the lime-content or improve the fineness of grains, or both.

ASTM specifies the amount of SiO_2 in Portland cement within the range of 17% to 25%. It has been experiential that all five brands are well within the range. Further, the ASTM standard has suggested the Al_2O_3 content to a maximum of 6% whereas, the Paidaar and Fauji cement exceeds the limit. On the other hand, the amount of Fe2O3 oxide is well within the acceptable range suggested by ASTM C150. The variations of oxides are shown in Figure 1. 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. Because alumina and ferric oxide both behave as fluxes, they must be kept below certain limitations. A high alumina content produces more C3S and causes a rapid setting of cement, which in turn decreases the workability of cement.

Furthermore, the Paidaar and Fauji cement exceeds the ASTM specification for SO_3. The maximum allowable SO_3 content is limited between

Table 2. Chemical composition of different cement brands by weight percent

Sample	Paidaar	Lucky	DG	Fauji	Bestway	ASTM C150
CaO	62.02	61.76	63	61.81	62.01	60-67
SiO_2	21.08	21.56	20.09	20.76	21.01	17-25
Al_2O_3	6.2	5.53	5.65	6.26	5.32	≤6
Fe_2O_3	2.39	3.16	3.55	3.95	3.19	≤6
MgO	1.23	2.99	1.76	2.56	2.62	≤6
SO_3	3.66	2.45	2.53	3.5	1.55	<3
LOI	2.39	2.31	1.49	1.82	1.88	<3

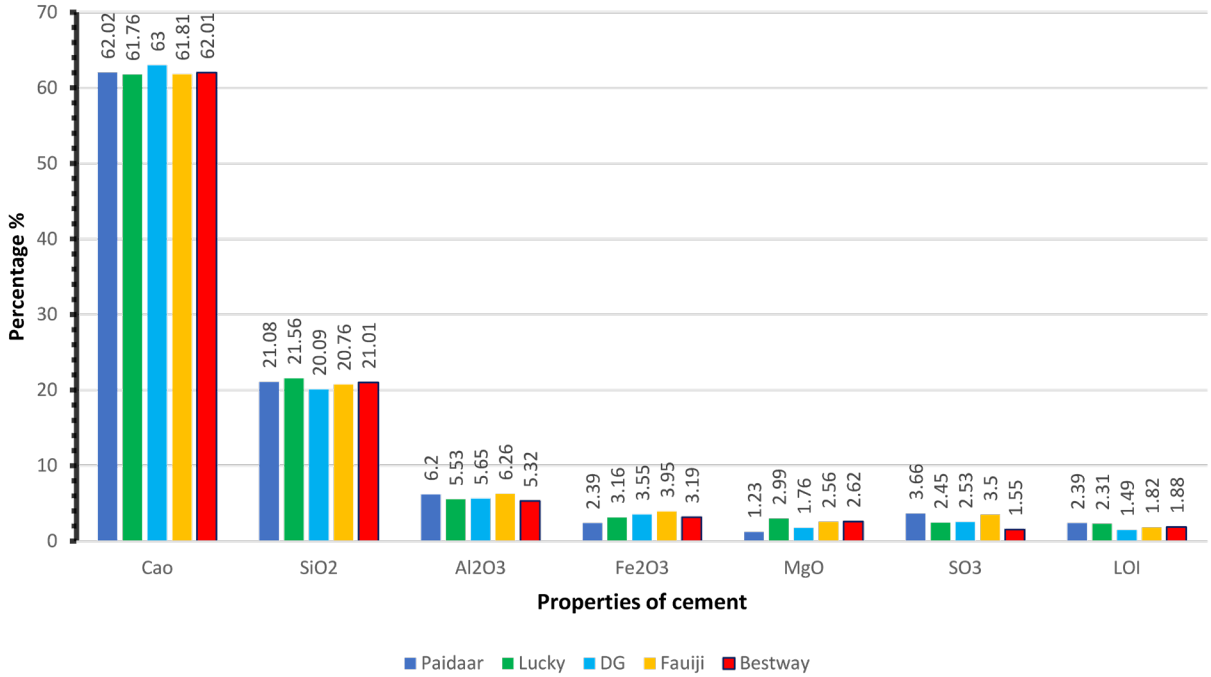

Figure 1. Comparison of oxide contents of different brands by weight percent

1.5 to 2.5%. The allowable SO_3 content prevents sulfate expansion. The higher amount of SO_3 content in Paidaar and Lucky cement can cause the expansion of sulfates, therefore, to avoid the sulfate expansion and as well as control the setting time effectively, the appropriate amount of calcium sulfates in the form of gypsum shall be added to the clinker.

Moreover, the variations of MgO are presented in Table 2 and as well plotted in Figure 1. 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 a large amount of free MgO is undesirable, the Periclase may hydrate and the MgO will convert to MgO which is an expansive reaction and can cause damage. Table 2 also provides data for LOI, a measure of cement quality based on carbon content and moisture. It should be emphasized that the results are well within the ASTM permissible limits.

Table 3 presents the mineralogical compositions obtained from Bogue's calculation and how they deviated from the ASTM standard. Figure 2 compares the proportion of the mineralogical components of the above-mentioned cement brands. The C3S and C2S compounds mainly affect the early and eventual strength of cement paste, respectively (Winter, 2012). Among five samples, the Paidaar, Lucky, and Fauji have lower C3S content compared with ASTM. The Paidaar, Lucky and Bestway products have a combined C3S and C2S content of less than 71%, an index for high-quality cement recommended. The higher C2S content in according to Table 2. there is a difference of about 4.6% in silicates between the Paidaar and DG cement brands. Upon hydration, Bestway cement will produce more C-H-S gel compared with other brands and will cause higher strength and Fauji cement will produce the smallest strength compared with the other cement brands.

Table 4 presents the lime saturation factor (LSF), Silica ratio (SR), and Alkali ratio (AR) for the cement brands used in this study. Figure 3

Table 3. Mineralogical composition of chosen cement brands estimated based on Bogue equations

Sample	Paidaar	Lucky	DG	Fauji	Bestway	ASTM C150
C3S	37.01	42.1	53.1	44.2	48.76	45-65
C2S	26	32.9	33.1	33.75	24	7.0-32
C3A	13.01	8.88	8.79	6.86	7.66	4.0-12
C4AF	7	9.65	10.23	12.89	10.1	8.0-12

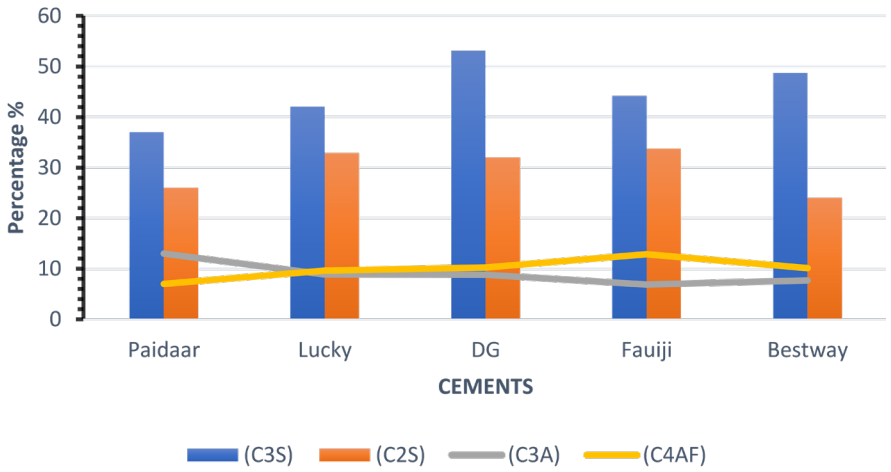

Figure 2. Comparison of the proportion of the mineralogical components of cement brands

presents the data of LSF for all five brands used in the study. The LSF denotes the ratio of the amount of lime in the cement that is mandatory to form C3A, C3S, and C4AF in the clinker. The ratio controls of C3S to C2S in the clinker. The higher LSF indicates higher C3S to C2S. The LSF value typically ranges between 0.92–0.99. The Lucky, DG, and Fauji cement brands indicate a higher ratio of Belite (C2S) but Paidaar, Lucky and, Fauji cement lesser ratio of Alite (C3S), whereas Paidaar and Bestway cement brands' LSF values are within the specified limits. The LSF, SR, and AR are calculated based on the following equations (Winter, 2012):

$$LSF = CaO\ (2.8\ x\ SiO2 + \\ + 1.2 \times Al2O3 + 0.65\ x\ Fe2O3) \quad (2)$$

$$SR = SiO2\ (Al2O3 + Fe2O3) \quad (3)$$

$$AR = Al2O3\ Fe2O3 \quad (4)$$

The other two factors SR and AR shown in Table 3 are also important aspects of a cement's chemical composition. The SR, and AR of all cement brands are satisfactory and conform to the ASTM-recommended specifications. This study fulfilled the study gap and the recommendation for improvement of locally utilized cement that has/

Table 4. Quality control properties of cement products

Sample	Paidaar	Lucky	DG	Fauji	Bestway	ASTM C 150
LSF	0.92	0.89	0.96	0.9	0.92	0.92-0.98
SR	2.45	1.23	2.2	2.03	2.5	2.0-3.0
AR	2.6	1.75	1.59	1.58	1.7	1.0-4.0

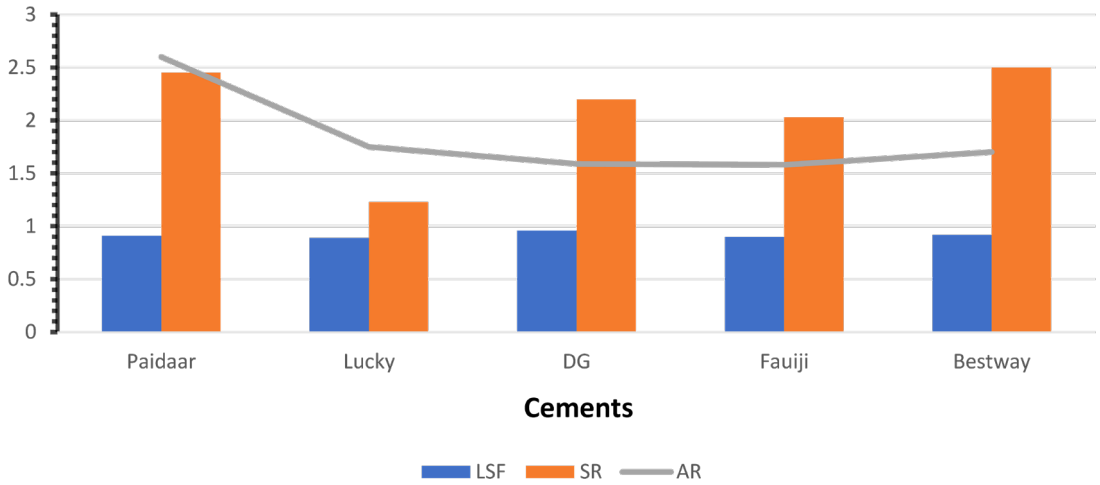

Figure 3. LSF, SM, and AM values of different cement brands

hasn't met the standards. From economic, technological, and ecological points of view, cement has an undisputed role to play in the sphere of the construction industry. The variation in cement characteristics and their effects on concrete properties has been a major area of research in concrete technology. Therefore, thorough research was required to investigate these aspects and the different properties of cement and concrete.

CONCLUSIONS

This paper presented a comparative analysis study of the properties of locally existing cement. The chemical properties of all five brands were studied and succeeding the discussion following conclusions are drawn:

- All five brands of chemical composition were similar and met ASTM standards. Paidaar and Lucky cement had lower silicate levels (C3S and C2S) than the other cement brands. Based on the proceeding of discussion, it was found that the Paidaar and Lucky cement with lower C3S content and higher C2S content will produce the least early strength compared to the other cement brands. Moreover, higher content of SO_3 was observed in Paidaar and Fauji cement which can cause the expansion of sulfates. Therefore, proper control of the amount of gypsum is required.
- Chemical composition influences the quality of cement such as setting time, compressive strength, drying shrinkage, and soundness. If the ingredients of cement are kept under certain standard limitations, the composition behaves well in kilns and generates high-quality cement.
- Based on the comparative analysis of different locally presented cement brands in Pakistan; DG and Bestway cement brands were found to be suitable and recommended to be used in concrete structures in Pakistan.

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