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Original Research Article

Comparative Study of the Physical Properties of Some Brands of Portland Cement Available in the Libyan Market

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ABSTRACT

The quality of cement is one of the important factors which materially contribute to the strength and durability of structural concrete. Different brands of Portland cement are used in Libya by local contractors for various construction work. However, no comparative study has been ~~made~~ undertaken hitherto to investigate the mechanical and physical properties of the various brands of cement. This study investigates the fineness, soundness, setting time and compressive strength of Libyan cement manufactured by the national Libda, Al-Koms, Al-mergeb and Al- borg plants and also some imported cements sold in the Libyan market. All brands of cement tested have normal and acceptable consistencies. The soundness values for all the brands tested fall below the maximum allowable value of 10 mm. Fineness values for all the brands tested fall within the standard specification limit (2500 cm^2 /g <). Based on the results of compressive strengths alone, all the cements could be acceptable for normal construction work.

Keywords: Portland Cement, Libya, Physical Properties, fineness, soundness.

Introduction

Cement is an adhesive and chemical binder capable of uniting fragments or masses of solid matter to a compact whole [1]. Cement functions by forming a plastic paste when mixed with water, which develops rigidity, sets and steadily increases in compressive strength (hardness) as it reacts with the added water (hydration). Cement is the main integrating factor/framework to which all other materials used in building construction adhere and materially affects the effective structural integrity [2]. Portland cement is composed of four basic chemical compounds: these include tricalcium silicate (C_3S), dicalcium silicate (C_2S),tricalcium aluminate(C_3A) and tetracalcium luminoferrite (C_4AF). For all of these components the silicate moiety plays a crucial role in the attainment of the structural strength of the cement. C_3S easily reacts first with water, with an exothermic heat of hydration and is responsible for early strength development, whereas C_2S reacts more slowly, produces less heat of hydration and is responsible for the later strength development [3]. There are several brands of Portland cement (PC) available commercially but their chemical compositions are essentially the same. Nevertheless, variations in the physical properties of the cement occur due to small changes in the proportional amounts of the chemical constituents [4]. The evaluation of the physical and chemical properties of cement is important for the correct usage of the suitable grade and type before commencing any construction work and the consequent failure of concrete structures is usually attributed to the incorrect selection of the cement material amongst other factors [5]. The key physical parameters used to classify and compare Portland cements include the bulk density, relative density (specific gravity), fineness, setting time, strength, soundness, heat of hydration and loss on ignition.According to Neville [6,7,8] , these parameters for Portland cement are defined as follows : bulk density is the mass of cement particles/air between them per unit volume of the cement sample ,while the specific gravity constitutes the ratio of weight of a given volume of the material and the weight of an equal volume of water. Fineness, the particle size of the cement , affects the rate of hydration and the resultant strength gain ; while fine cement is desirable for rapid strength development, a very fine cement is susceptible to air setting and early deterioration [7] . The setting time of cement, which may be specified for the initial or final stages, characterizes how the paste develops strength and eventually sets from the instance of adding water to its final set phase. The initial setting time of a cement is the period between when water was first added to the cement and when the paste begins to stiffen considerably , while the final setting time is determined from when water was first added to when the cement has developed enough strength and has become hardened sufficiently to sustain a load. Strength can be compressive, tensile or flexural; compressive strength is commonly used in the comparison of Portland cements and concretes produced from them at the site [8]. It is desirable that the initial set of the cement must not be too rapid and the final set must not be too prolonged to enable an adequate strength development to take place during construction work. Assessment of the setting time and strength development rate of any particular cement demands knowledge of its consistency and the consistency of a cement paste measures its ability to flow , expressed as the percentage by weight of water content of the paste to that of the dry cement. Soundness refers to the ability of a hardened cement paste to retain its volume after setting [2].

The aim of this work was to investigate the mechanical and physical properties of some selected brands of cement available commercially in Libyan and to compare the results with standards to determine their overall conformity and to examine brand variation.

Experimental

Material and Methods

Sample Collection: The samples were obtained from purchases in the local markets in the cities of Al-koms, Zlatin, Misurata and Benghazi as shown in table 1.

Sample Pre-treatment: All the samples collected were ground and sieved through a 2mm mesh sieve. The product obtained after sieving was homogenized and kept in clean, labeled polythene bags [9].

Table (1) Samples under study

Sample	code
Zliten Cement Factory	**CZ**
Al-merqeb Cement Factory	**CM**
Lebda Cement Factory	**CL**
Souk Al-Khamis Cement Factory	**CK**
Al- borg Cement Factory	**CB**
Egyptian Cement Source	**CE**
Turkish Cement Source	**CT**

Physical Tests

The following tests were carried out on each of the selected brands of cement namely: fineness test, consistency test, soundness test, setting time test and strength test

- **Fineness Test:**

In this study the Blaine test was used; which measures the volume of air passing at a prescribed average pressure, with the rate of flow diminishing steadily. The time (t) for the flow to take place is measured for a given apparatus and a standard porosity of 0.500, the specific surface is given by the following Equation

$$S=K_2\sqrt{t}$$

where K_2 is a constant. Libyan Standards 97/340 specifies the minimum specific surface area per unit weight as 2250 cm^2/gm for ordinary Portland cement [10].

- **Consistency Test:**

Setting time, soundness and specific surface are used to determine the consistency of cement. Neat cement paste of a standard consistency has to be used for the determination of the initial and final setting times, as well as for the Le Chatelier soundness test. The consistency is measured using a Vicat apparatus, utilizing a 10mm diameter plunger fitted into the needle holder. The water content of the standard paste is expressed as a percentage by weight of the dry cement. According to Libyan Standards 97/340, the range of determined values should lie between 26% and 33% [10].

- **Setting Time:**

The setting times of cement are measured using the Vicat apparatus with different penetrating attachments. For the determination of the initial set, a round needle with a diameter of 1.13 ± 0.05mm is used. This needle, acting under a prescribed weight, is used to penetrate a paste of standard consistency placed in a special mould.

When the paste stiffens sufficiently for the needle to penetrate only to a point 5 ± 1mm from the bottom, initial set is said to have taken place. Initial set is expressed as the time elapsed since the mixing water was added to the cement. A minimum time of initial set of 45 minutes is prescribed by Libyan Standards 97/340. Final set is determined by a similar needle fitted with a metal attachment hollowed out so as to leave a circular cutting edge 5mm in diameter and set 0.5 mm behind the tip of the needle. The final setting time is considered from the moment when mixing water is added to the cement, and is required by the relevant Libyan Standards 97/340 to be not more than 10 hours [10].

- **Soundness Test (Expansion Determination on Cement):**

Unsoundness of cement is not apparent until after a period of months or years; thus, it is essential to test the soundness of cement in an accelerated manner. The Le Chatelier apparatus is used to determine the soundness of cement. A cement paste of standard consistency was prepared. The Le Chatelier moulds were placed on a glass plate and then filled with the cement paste, keeping the slit of the moulds gently closed by tying the moulds with a piece of thread before covering the top of the mould with a glass plate. The whole arrangement was totally immersed in water at a temperature of 20°C for about 24 hours. The moulds were removed after 24 hours with their contents intact and the initial gap or slit of the moulds measured as D_1. The moulds were re-immersed in a water bath and heated for 30 minutes to boiling point and the water kept boiling for about an hour. The moulds were then removed from the boiling water and allowed to cool. After cooling, the distance between the indicators was again measured, D_2. The value of the difference between D_1 and D_2 represents the expansion of cement. According to Libyan Standards 97/340, the soundness of ordinary Portland cement should be less than 10mm [10,11]

- **Compressive Strength Test**:

In this test, the mortar proportions were 3:1 sand to cement (555gm sand + 185gm cement). Water addition was used at a water/cement ratio of 0.4 for all mixes by weight (74gm water), and after mixing the mortar 70.7 mm cubes were made using a vibrating table with a frequency of 200 Hz applied for two minutes. The cubes were demoulded after 24 hours and further cured in water, until tested in wet-surface conditions [12]. Libyan Standards 97/340 requirements of minimum strengths after 3 days (average values for three cubes) are between 23 MPa and 21 MPa, and after 28 days, 41 MPa and 39 MPa, respectively [10].

Results and discussion

Evaluation of the characteristics of the available brands of Portland cements is necessary in order to ascertain the comatyive product quality of the brands. The experimental results obtained are shown in Table (٢)

Fineness

The fineness or Blaine values in the cement samples studied CZ, CM, CL, CK, CB, CE and CT are (3046.10±71.35, 2998.10±103.88, 3119.75±184.26, 3663.70±234.06, 3104.10±14.48, 3810.50±7.37 and 3440.00±8.16, respectively. All the samples were found to lie within the standard specification limits, as shown in Table (2) and Figure (1). The range obtained in this study conforms to the results obtained by Altwair *et al*., [10] . The particle size of Portland cement affects the rate of hydration which is responsible for the strength gain : the smaller the particle size, the greater the surface area to volume ratio which means there is a greater possibility for the water–cement reaction to take place [13]

Table 2. Analysis on variance (Anova) on physical and mechanical properties of Portland cement

Samples	Fineness (cm^2 /g)	Soundness (mm)	Setting Time (min)		Compressive Strength ($N\backslash mm^2$)	
	Blaine		Final	Initial	28 Days	3 Days
CZ	3046.10 ± 71.35^{a}	1.34 ± 0.53^{a}	353.25 ± 43.96^{a}	192.70 ± 12.73^{a}	45.34 ± 3.93^{a}	23.94 ± 2.17^{a}
CM	$2998.10\pm103.88^{a\,b}$	1.26 ± 0.25^{ab}	253.00 ± 9.22^{b}	136.20 ± 6.80^{b}	42.23 ± 1.77^{b}	24.92 ± 2.65^{ab}
CL	3119.75 ± 184.26^{ac}	0.55 ± 0.25^{c}	267.75 ± 9.24^{c}	165.25 ± 6.02^{c}	51.14 ± 3.49^{c}	25.68 ± 1.58^{bc}
CK	3663.70 ± 234.06^{d}	1.42 ± 0.67^{abd}	205.50 ± 16.69^{d}	151.75 ± 10.87^{d}	42.21 ± 1.35^{bd}	25.94 ± 2.03^{bcd}
CB	3104.10 ± 14.48^{ace}	1.28 ± 0.30^{abde}	242.00 ± 8.34^{be}	201.75 ± 7.63^{e}	57.52 ± 1.73^{e}	23.28 ± 1.68^{ae}
CE	3810.50 ± 7.37^{df}	2.18 ± 0.45^{f}	185.75 ± 5.06^{df}	$85.29\pm0.\ 47^{f}$	29.72 ± 1.07^{f}	23.26 ± 0.49^{abef}
CT	3440.00 ± 8.16^{g}	1.03 ± 0.63^{abdeg}	215.63 ± 6.87^{dfg}	190.19 ± 0.23^{ag}	$42.28\pm1.05bd^{g}$	23.44 ± 1.73^{abefg}
L.S 340-97	**2500<**	**10>**	**600>**	**45<**	**39<**	**21<**
B.S 12-71		**-**	**-**	**-**	**47-67**	**15-20**
ASTM 150-07	**2800<**	-	**600>**	**60<**	-	-

- **Figures in the same column having the same superscript are not significantly different (P> 0.05).**
- **Figures in the same column having different superscripts are significantly different**

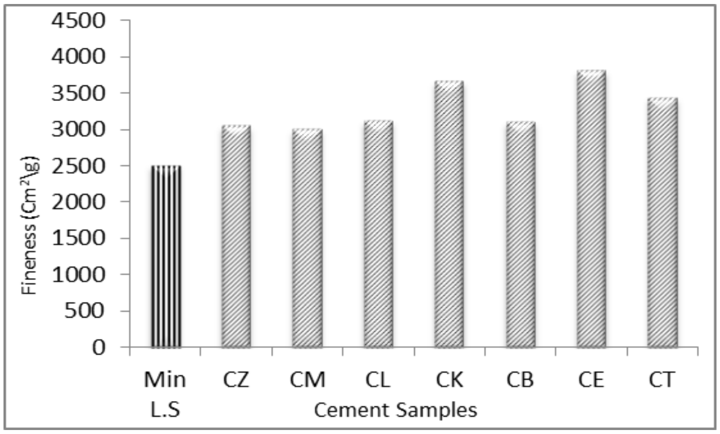

Figure1: Blaine (fineness) of studied cements

Soundness

Table 2 also shows the soundness for all cement samples studied. The maximum expansion was observed in CE at 2.18 ± 0.45 mm and the minimum in CL is 0.55±0.25 mm, while the upper limit Le Chatelet Expansion according to standard specifications is 10 mm. It was concluded that all cement samples have an expansion factor within the permissible limits as shown in Figure (2) Cement expansion, regardless of other factors , is closely related to the magnesia content, especially with longer ageing [14, 15]. If the magnesia content exceeds 2%, it appears in clinker as free MgO (periclase). Periclase interacts with water to form $Mg(OH)_2$ and this is the slowest reaction of components in hardening reaction. $Mg(OH)_2$ occupies a larger volume than the free periclase (MgO) it replaces in the cement, and this naturally compromises the binding of the cement. In reinforced concrete, this can lead to expansion cracks being created, known as magnesia expansion [16-18].

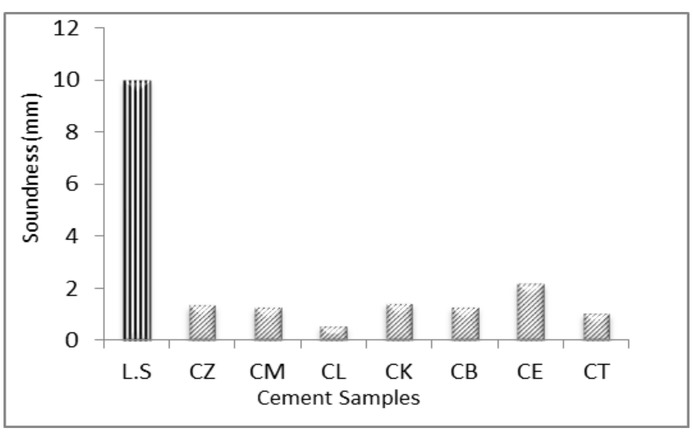

Figure 2: Soundness (Le Chatelier) of studied cements.

Sitting time

The setting time of all the studied cement samples and their comparison with Libyan and American Standards specification is shown in Table 2. The initial setting time for the CE cement brand was the least (85.29 min) when compared to the others, while the CB cement brand was the highest (201.75 min), suggesting that the CB cement would most likely have an inherent delay in the initial setting of about 116.46 minutes when compared with that of CE cement. The setting time of the, apart from any other parameters, is also be closely related with the lime content in clinker and cement. If the lime content is kept fixed, and the silica content is too high, which may be accompanied by a decrease in alumina and ferric oxide, the temperature of burning in the preparation of the cement will be raised significantly and the special influence of the high lime will be lost. If the lime content is too low, which means an increase in the alumina and ferric oxide content ; the cement may become quick-setting and contain a larger amount of alumina compounds, which appear to be of little value for their cementing qualities. Rapid setting is undesirable, and is not permitted by the standard specifications, because the cement sets so rapidly that it cannot properly be worked before stiffening occurs [14]. Another factor contributing to low and high setting times of the cement is the amount of sulphuric acid anhydride (SO_3). High content of SO_3 increases the setting time of the cement [14]. All the samples were found to lie within the standard specification limits as shown in Figure (3) and the range obtained in this study conforms with the results obtained by Omoniyi and Okunola [19].

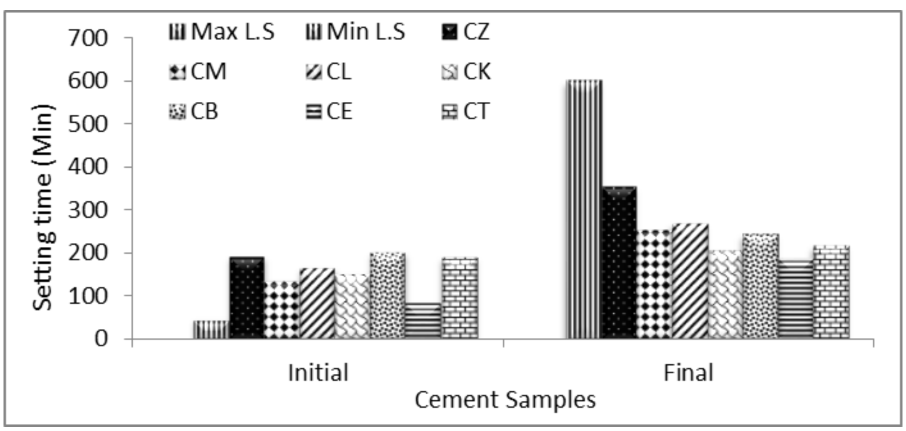

Figure 3: setting time of studied cements

Compressive Strengths

The compressive strengths for all samples of the cements studied were determined at 3 days and 28 days after mixing and the results are shown in Table (2) .The results were close in compressive strength values for all cement samples at an early age. The compressive strengths at 3 days for the cement samples studied range in value from 23.26±0.492 N/mm^2 to 25.94±2.03 N/mm^2, which is within the specification limits as shown in Figure (4), but after 28 days the development of strength increased in the cement samples studied , namely ,CZ, CM, CL, CK, CB, CE and CT where the values ranged from 29.72±1.07N/mm^2 to 57.52±1.73 N/mm^2, all of which lie within the specification limits, with the exception of the CE cement as shown in Figure (4),The range obtained in this study conforms to the results obtained by Omoniyi.et.al [19]. High lime content is associated with early strength whereas a slightly lower content of lime favors the ultimate strength, which develops gradually over a longer period of time. In order to increase the strength it is necessary to raise the lime content, or grind the cement material finer, or both. However, higher cement production temperatures are required to burn the high lime mixtures [18].

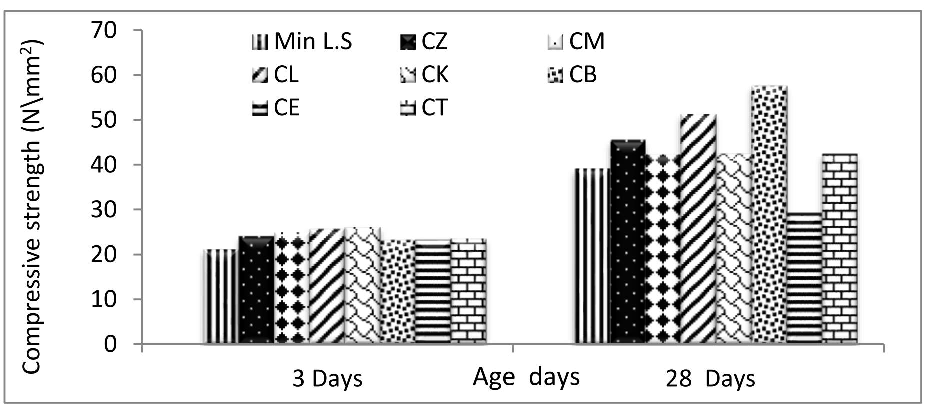

Figure4: Compressive strength of studied cements

Results of cluster analysis of cement properties studied

After applying the cluster analysis method to the studied cement data, several conclusions can be made. The data from the samples of cement studied using the single link clustering method showed the existence of four groups (clusters) of the cements studied here. According to this method, the first group included cements CZ and CB. The second group included cements CM and CL, the third group included cements CK and CT, while the fourth group consisted only of cement CE. It is possible that the quantitative ratios of raw materials are different for the CE cement than for the other types. The chemical properties of cements CZ, CB are very similar to each other and are similar to the cement properties of CM, CL. We notice that the CZ cement plant and the CB plant are located within one geographical area in the Zliten region , whereas the CM and CL plants are located in a different geographical area (Al-Komsthe) which could reflect a slightly different sourcing of their raw materials . With the similar properties exhibited by the cements CT, CK we can predict that the raw materials have a similar geological source and composition and that the surrounding environmental conditions are very similar. The most important thing to emerge is the cement specificity of CE, where it was observed that it did not interact with any other type of cement under study as shown in Figure (5), this may be due to the different geographical nature of the region providing the raw material for this type of cement.

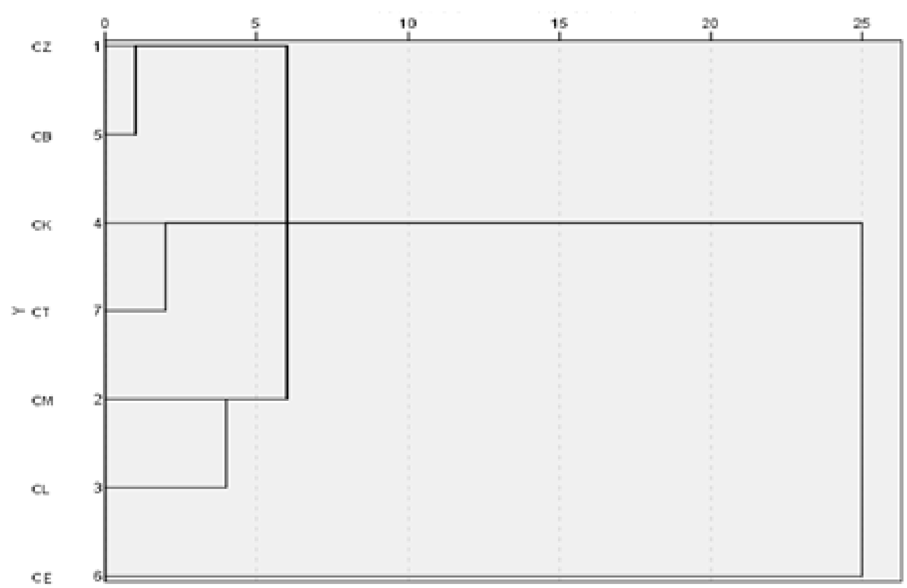

Figure 5: Results of the cluster analysis of the studied cement

Conclusion

In Libya, the demand for cement is increased due to the huge construction projects that are now being undertaken to replace or repair damaged building and infrastructure after a war. To meet the demand for cement, several brands of local and imported cement are being used today with an unfortunate lack of quality control. A comparative study to investigate fineness, soundness, setting times and compressive strength of different cement brands commonly used in Libya was hence undertaken in this work. The result of the analysis indicates that the cement samples under study are generally good for concrete work, especially where no other specific properties are required. Cluster analysis showed the presence of four clusters of cement. It was observed that the sample (CE), an Egyptian sourced cement, did not compare favorably in all aspects with the other types of locally produced cement.

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