Comparative study of ordinary portland cement from different production (Al Fatiah and Al Huarry cement factories), NE Libya

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**ABSTRACT**

This study will discuss the evaluation of clinkers and cement powdered chemistry during manufacturing process from Al Fatiah and Al Huarry Cement Factories then matching with British standard. The bulk geochemical analysis has been carried out using X-ray fluorescence (XRF) and inductively coupled plasma-mass spectrometry (ICP-MS) techniques. The chemical analyses data showed that the limestone at the Al Fatiah Cement Quarry is classified as a high pure limestone and the limestone at the Al Huarry Cement Quarry is a low pure limestone. The studied terra rossa samples showed a suitable composition and could be a good source for SiO$_2$ and Al$_2$O$_3$. The results of homogeneous samples of clinkers and cement powdered were compared to the British Standard.

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1. Introduction

Al Jabal Al Akhdar is a highland area which encompasses the northern most part of Cyrenaica north east Libya, it is consists of Upper Cretaceous to Tertiary marine deposits. The Jurassic and Lower Cretaceous marine deposits are known from the exploratory oil wells. The Al Jabal Al Akhdar is more than 200 Km long and 75 Km wide. Al Faidiyah and Benghazi formations represent a portion of Al Jabal Al Akhdar region. The ages of these two formations are Oligo-Miocene to Middle Miocene respectively were deposited in shallow marine environments (Berggren, 1974; and Klen, 1974).

Fig. (1) shows that the first section is located at Al Fatiah cement quarry between latitude 32° 35’ 46” N and longitude 22° 43’ 21” E of about 25 km east of Dernah City. The terra rossa in this section is located at latitude 32° 36’ 50” N and longitude 22° 42’ 08” E of about 40 Km east of Dernah City and about 20 Km south of Al Fatiah limestone cement quarry. The second section is located at Al Huarry cement quarry of about 18 Km south west of Benghazi City. This section is represented by limestone and terra rossa soil between latitude 75° 31’ 59” N and longitude 73° 32’ 00” E.

The Al Faidiyah Formation is the only detected rocks in the Al Fatiah Cement Quarry. It is composed of skeletal limestone. The Benghazi Formation is the only detected rocks in the other quarries. It is composed of fossiliferous limestone in the Al Huarry Cement Quarry. Cement is typically made from limestone and clay, these raw materials are extracted from the quarry crushed to a very fine powder and then blended in the correct proportions. The blended of raw material is called the raw feed or the raw kiln and is heated in a rotary kiln where it reached temperature of about at 1400°C to 1500°C. The rotary kiln is a tube up 200 meters long 6 meters in diameter which long flame one at the end, the raw materials enter the kiln at the cool end gradually passes down to the hot end then falls out of the kiln and cools down. The raw materials formed in the kiln are described as clinker and is typically composed rounded nodules between 1mm and 25 mm across after cooling, the clinker may be sorted temporarily in the clinker store or may be pass directly to the cement mill. The cement mill grinds the clinker to a fine powder. A small amount of gypsum in a form of calcium sulfates normally ground up with the clinker (Fig. 2). The gypsum controls the setting properties of the cement when water is added (Winter, 2013).

Scope and limitation of the study

1) To describe clinkers and cement powdered chemistry of Al Fatiah and Al Huarry cement quarries during manufacturing process.
2) Make comparison for quality of clinkers and cement powdered of Al Huarry and Al Fatiah cement quarries with British standard of Ordinary Portland Cement Industry.

2. Methodology

About twelve samples of limestones and six samples of terra rossa were collected from the studied quarries. The collected samples were washed thoroughly in distilled water to remove the contamination. Bulk geochemical analyses for major oxides and trace elements were performed using the inductively coupled plasma-mass spectrometry (ICP-MS) technique, which is widely used, at present, for determination of elements in various materials with high precision.
It reacts slowly with water, thus contributing little to the strength during the first 28 days.

$$2\text{CaO} + \text{SiO}_2 = (\text{C}_3\text{S}) \text{ Ca}_2\text{SiO}_3 \text{ Belite}$$

Aluminate (C₃A) this phase has a content in clinker is approximately 7–15 % (Brandt, 2009). It liberates a large amount of heat during the first days of hardening. It also contributes slightly for early strength development. C₃A hydrates very rapidly and will influence early bonding characteristics.

$$3\text{CaO} + \text{Al}_2\text{O}_3 = \text{Ca}_3\text{Al}_2\text{O}_6 \quad (\text{C}_₃\text{A}) \text{ Aluminate}$$

Ferrite (C₃AF) the average composition and constitutes is about 6 to 18 % of a typical clinker (Brandt, 2009). It reduces the clinkering temperature and acts as a flux in burning the clinker. It hydrates rather rapidly but contributes very little to strength development. The iron content is mainly responsible for the dark coloring of cement (Kohlhaas, 1983).

$$4\text{CaO} + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 = (\text{C}_4\text{Al}_2\text{Fe}_2\text{O}_9 \text{ C}_3\text{AF}) \text{ Aluminate Ferrite}$$

### 3. Results and discussion

#### 3.1. Raw materials

Tables (1 and 2) shows that the limestone from Al Fatiah Cement Quarry is classified as high pure limestone (CaO = 55%, using classification of Harris, 1983) and the limestone from Huarry Cement Quarry is classified as low pure limestone (CaO = 49.5%, using classification of Harris, 1983), with some impurities of SiO₂ and Al₂O₃. The studied terra rossa samples show high content of SiO₂, Al₂O₃, Fe₂O₃ and K₂O with low contents of CaO and MgO. These terra rossa samples show a suitable composition and could be a good source for SiO₂ and Al₂O₃ (see Tables 1 and 2).

#### 3.2. Chemical reaction of mixture in the kiln

At 900 to 1450°C the chemical reactions take place and formed four mineral phases: alite(C₃S), belite (C₂S), aluminate(C₃A) and aluminate ferrite (Ca₄Al₂Fe₂O₁₀ C₃AF) (Fig. 3). Alite (C₃S) is the most important constituent, 38-60% in normal Portland cement dinkers. It is responsible for the setting characteristics and development of the early strength of cement from 1 to 28 days.

$$\text{CaO} + 2\text{CaO} \text{SiO}_2 = (\text{C}_3\text{S}) \text{ Alite}$$

Belite (C₂S) this phase has a content of 15-38 % (Brandt, 2009) of the clinker. It is hardened slowly and is contributed largely to the beyond one week (Tennis and Kosmatka, 2011). It

### Table 1: Chemical analysis data (major oxides in wt. %) of the Al Fatiah quarry samples

<table>
<thead>
<tr>
<th>Formation</th>
<th>Soil</th>
<th>Al Faidiyah Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample No.</td>
<td>1 10 12 14 1 3 4 6 7 9</td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>40.31 44.41 50.66</td>
<td>17.05 16.35 1.49</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.63 0.55 0.82</td>
<td>0.21 0.17 0.02</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>20.20 17.91 14.00</td>
<td>2.44 2.13 0.54</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>15.51 10.53 6.09</td>
<td>1.38 1.29 0.43</td>
</tr>
<tr>
<td>MnO</td>
<td>0.25 0.19 0.11</td>
<td>0.02 0.02 0.03</td>
</tr>
<tr>
<td>MgO</td>
<td>2.00 0.77 0.93</td>
<td>0.06 0.88 1.12</td>
</tr>
<tr>
<td>CaO</td>
<td>5.73 4.86 12.12</td>
<td>43.00 47.72 54.87</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.08 0.09 0.05</td>
<td>0.06 0.04 0.03</td>
</tr>
<tr>
<td>K₂O</td>
<td>5.18 2.81 3.33</td>
<td>0.60 0.47 0.14</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.08 0.06 0.02</td>
<td>0.01 0.02 0.01</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.32 0.21 0.11</td>
<td>0.05 0.04 0.15</td>
</tr>
<tr>
<td>CI</td>
<td>0.07 0.06 0.03</td>
<td>0.04 0.04 0.02</td>
</tr>
</tbody>
</table>

The estimation of alite (C₃S), belite (C₂S), aluminate (C₃A) and aluminate ferrite mineral phases (Ca₄Al₂Fe₂O₁₀ C₃AF) in clinker and cement samples (see Tables 3 and 4). These values coincide with the mineral percentage content in Ordinary Portland Cement specification described by Kohlhaas et al. (1983). The X-ray fluoresces (XRF) analyses of the clinkers have been calculated. This calculation shows that both of the studied quarries contain alite and belite as major a mineral phases, aluminate and aluminate ferrite as a minor mineral phases, while free lime and periclase representative as trace phases in Al Fatiah and Al Huarry quarries, respectively.

The results of homogeneous samples of dinkers and cement powdered were done by comparing with the British Standard Specification. The composition of dinkers is slightly different from cement composition due to addition of gypsum latter (see Table 4).
in expansion cracks commonly known as magnesia expansion (Khan et al. 2008).

### Table 4: Chemical and mineral compositions of the cement powdered samples (major oxides in wt.%)

<table>
<thead>
<tr>
<th>Location</th>
<th>Al Fatiah Quarry</th>
<th>Al Huarry Quarry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample No. 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>21.05</td>
<td>21.66</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>5.45</td>
<td>5.48</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.19</td>
<td>3.79</td>
</tr>
<tr>
<td>CaO</td>
<td>62.50</td>
<td>62.10</td>
</tr>
<tr>
<td>MgO</td>
<td>1.41</td>
<td>1.61</td>
</tr>
<tr>
<td>SO₃</td>
<td>2.80</td>
<td>2.32</td>
</tr>
<tr>
<td>C₃A</td>
<td>1.64</td>
<td>1.60</td>
</tr>
<tr>
<td>Total</td>
<td>97.90</td>
<td>96.95</td>
</tr>
</tbody>
</table>

Amount of Al₂O₃ formed in Al Fatiah and Al Huarry quarries were within specified limit (see Tables 3 and 4). If the lime content is fixed, and the silica becomes too high, which may be accompanied by a decrease in alumina and ferric oxide, the temperature of burning will be raised 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; 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 up so rapidly that it cannot properly be worked in the forms before stiffening occurs. A high loss on ignition indicates pre-hydration and carbonation, which may be caused by improper and prolonged storage or adulteration of Ordinary Portland Cement during transport or transfer (Khan et al. 2008).

3.3. Kiln feed parameters

A set of parameters (modules) is currently used in cement manufacturing to characterize the quality of the raw materials and to ensure the quality of the produced cement (Kebede 2010).

#### 3.3.1. Silica Ratio (SR)

Increasing silica ratio impairs the burnability of the clinker, by reducing liquid phase content and tendency toward formation of coating in the kiln. An increasing silica ratio causes a slow setting and hardening of the cement. With decreasing silica ratio the content of liquid phase increases, this improves the burnability of the clinker and the formation of coating in the kiln (Adieh et al. 2010). Generally in depending on British standard the silica ratio runs between 1.5 to 4.0, low values for silica ratios can be accepted as low down to 1.5, for the all studied dinker and cement powder samples of silica ratio runs between 2.3 to 3.05, these values accepted in which that improves the burnability of the clinker and the formation of coating in the kiln the silica ratio (SR) can be calculated as: SR = SiO₂/Al₂O₃ + Fe₂O₃.

#### 3.3.2. Alumina Ratio (AR)

Alumina Ratio (AR) is characterizing the cement by the proportion of alumina to iron oxide values of alumina ratio are in the range from 1.4 to 3.5. British standard, the AR determines the
composition of liquid phase in the clinker, when it’s lower than 1.4 both oxides are present in their molecular ratios and therefore only tetracalcium aluminoferrite can be formed in the clinker, consequently the clinker cannot contain tricalcium aluminate. This is the case called Ferrari-cement which is characterized by low heat of hydration, slow setting and low shrinking. A high alumina ratio together with a low silica ratio results among other things, in a fast setting of the cement; this requires the addition of a higher gypsum rate to control the setting time requirements for cement. The data of alumina ratio runs between in the acceptable ranges (from 1.4 to 1.9). The alumina ratio (AR) can be calculated as: 

\[ AR = \frac{Al_2O_3}{Fe_2O_3} \]

3.2.3. Hydraulic moduli (HM)

Hydraulic moduli (HM) is represented the optimum lime content which ranges (from 1.7 to 2.3) but the good quality is 2 (Ghosh, 2002). Increasing HM more heat is required for clinker burning the strengths, especially the initial set up and also the heat of hydration rises and simultaneously the resistance to chemical attack decrease (Rao et al., 2011). The hydraulic modulus of good quality cements were approximately 2 as shown in the tables and located in the permitted range (from 1.96 to 2.12) (see Tables 3 and 4). The hydraulic modulus can be calculated as: 

\[ HM = \frac{CaO}{SiO_2 + Al_2O_3 + Fe_2O_3} \]

To attain complete lime saturation in the clinker the total silica must be combined as CaS, all iron oxide must combine with the equivalent amount of alumina to CaAl, and the remaining alumina must combine to CaA. For technical purposes good values of LSF range between 80 to 95, and the all studied samples have a good value of LSF which are ranges between 87 to 94%. As a result of market requirements for cements from different sources to have similar properties and also to optimize clinker production there has been a trend to converge on a ‘standard’ clinker chemistry of lime saturation factor (LSF) is Lime saturation factor is measure the ability of the blend to react leaving no free lime. The lime saturation factor can be calculated as: 

\[ LSF = \frac{CaO}{2.8 SiO_2 + 1.2 Al_2O_3 + 0.65 Fe_2O_3} \]

At most places the achievement of this ideal chemistry will require the use of corrective materials such as sand and iron oxide all modulus estimated for formed clinker run an acceptable ranges and their accuracy of them closed to the British standard.

4. Conclusion

About twelve samples of limestones and six samples of terra rossa were subjected to inductively coupled plasma-mass spectrometry (ICP-MS) technique as well as of nine homogeneous samples for clinkers and cement powdered were subjected to X-ray fluorescence (XRF) technique. The chemical composition shows that Al Fatih Quarry is classified as high pure limestone and Al Huarry Quarry is classified as low pure limestone, consequently the clinker cannot contain tricalcium aluminate. The XRF analysis of clinkers and cement powdered showed that the alite and the belite represented as a major mineral phases aluminite and the aluminate ferrite represented as a minor mineral phases while periclase phase and free-lime occurred as fine very fine grain or trace mineral phases and they are not effected in quality of cement. All the amounts of CaO, SiO_2, Al_2O_3 and Fe_2O_3 and all the modulus estimated for formed dinkers are running an acceptable ranges and their accuracy of them closed to British standard. The comparative study between Al Fatihah and Al Huarry Factories are recommended to encourage quality production.

5. Recommendations

The uses of limestone are widely utilized in many industries such as general constructions and non-constructions: glasses and aggregates, mind dust, paper, paints, rubbers, iron steels, plastics soda ash and oil drilling fluid materials. This project it may need further study using other techniques such as Scanning Electron Microscopy (SEM) and X-ray diffraction (XRD).

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