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Evaluation of the performance of local cement for oil well cementing operations in Algeria

*Mehena Oualit *, Amar Irekti, Brahim Hami*

Research unit: Materials, Processes and Environment (UR-MPE), Frantz Fanon city, 35000 Boumerdès, Algeria

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ABSTRACT

The cementing of oil wells is done using special cement called ''class G cement'', whose properties should meet the requirements of the American Petroleum Institute (API). Algeria, which ranks high among the oil and gas producing countries, has recently begun production of petroleum cement. The aim of this work is to characterize and evaluate the performance of a locally manufactured cement sample intended for oil and gas well cementing operations in Algeria. In this paper, significant properties (thickening time, compressive strength and free water) as well as the rheological behavior of the cement slurry under specific conditions have been experimentally examined. Apart from the initial consistency, which could be resolved by incorporating additives, the results indicated that the locally produced cement meets the requirements of the API standards and can therefore be used for cementing oil and gas wells.

1 Introduction

The cementing operation is an important part of the oil drilling industry. Its success is a decisive factor in the continuation of the next phase. The cementing in a petroleum wells consists to placing a cement suspension (slurry) suitable for a given shoreline in an annular space between the dropped column and the formations. Petroleum cement is a special cement used for the cementing of oil and gas wells. Its main objective is to separate the various production zones and protect the casing from aggressive elements that can cause corrosion.

To do this, several properties are required. The main ones are adherence to the casing walls, being impermeable and possessing sufficient mechanical strength; besides, they must also retain their properties for productive sound. Some requirements of the cementitious material and test procedures are described in the American Petroleum Institute specifications [1].

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* *Corresponding author. Tel.: +213777152300.*
E-mail address: oualitmehena@yahoo.fr

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Portland cement is a fine powder obtained by blending a mixture of 80% limestone and 20% clay that have been baked up to 1450 °C. It is composed mainly of four main minerals which are: alite (C_3S); belite (C_2S); tri-calcium aluminate (C_3A) and tetra-calcium alumino-ferrite (C_4AF) to which 3-5% gypsum ($CaSO_4.2H_2O$) is added [2, 3].

In addition to its role as building materials in the field of civil engineering, cement is considered to be the most current material used for cementation in the petroleum industry [4]. Indeed, 99% of the cementing operations of oil wells throughout the world are carried out by this material [5, 6]. In oil well cementing, cement is used primarily as an impermeable seal material. It is used as a seal to secure and structurally support casing string inside the well and prevent fluid movement between the formations [7]. The success of a well depends on this primary cementing operation. In addition to isolating oil, gas, and water-producing zones, cement also aids to protect the casing from corrosion [8].

The physical, chemical and mechanical characteristics of a Portland cement must meet API requirements to be considered a petroleum cement and can therefore be used in cementing operations for oil wells.

At present, Algeria imports almost 200,000 tons of class "G" cement each year; the average price of one ton of this cement is about 21,000 Dinars. This gives us an annual bill of 420 million Dinars, or the tune of 6 million Dollars, which is excessively expensive. To this end, the Algerian cement industry group (GICA) is engaged in the production of a cement that can be used in the drilling of hydrocarbon wells.

The aim of this study is to characterize and evaluate the performance of sample of cement produced in Algeria (local cement), according to the American Petroleum Institute (API) specifications, and to judge the possibility of classifying it as a class G cement.

2 Materials and methods

2.1 Cement

The cement used in this investigation is produced recently by the Ain El Kebira cement plant, (Setif, Algeria) with ‘’ASLAND’’ as its trade name.

2.1.1 Physical and chemical characteristics of the cement

X-ray fluorescence analysis made it possible to determine its chemical composition, and the result obtained is given in table 1. Its mineralogical composition calculated according to the BOGUE method, and the result obtained is given in table 2. It is noted that ASLAND cement has a C_3A content equal to 2.30%, which makes it possible to classify it as a sulphate-resistant cement (CRS).

Table 1 - Elemental chemical composition expressed as a percentage by mass (%) of ASLAND cement.

Oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	Fe_2O_3	Fire loss
(%)	0,12	1,39	3,75	18,16	0,15	4,03	0,36	65,01	0,17	5,41	0.96

Table 2 - Mineralogical composition expressed as content (%) of the ASLAND cement.

Mineral	C_3S	C_2S	C_3A	C_4AF
(%)	66,28	18 ,51	2,30	15,88

In order to confirm the calculated composition, X-ray diffraction analysis was carried out. The result (Fig. 1) shows very sharp intense peaks whose width is very small. The minerals contained in this cement are well crystallized and the crystals are thus well formed. The cement contains Hatrurite (C_3S), Brownmillerite (C_2S) and tetracalcium alumino-ferrite, (C_4AF) and some C_3A peaks. The presence of gypsum and bassanite ($CaSO_4.0.5\ H_20$) is also noted. Good crystallization observed in particular for C_3S, namely hatrurite (alite) originates from the fact that the latter started to form at about 1300 °C up to 1450 °C, hence good heating and rapid cooling favored the good crystallization obtained.

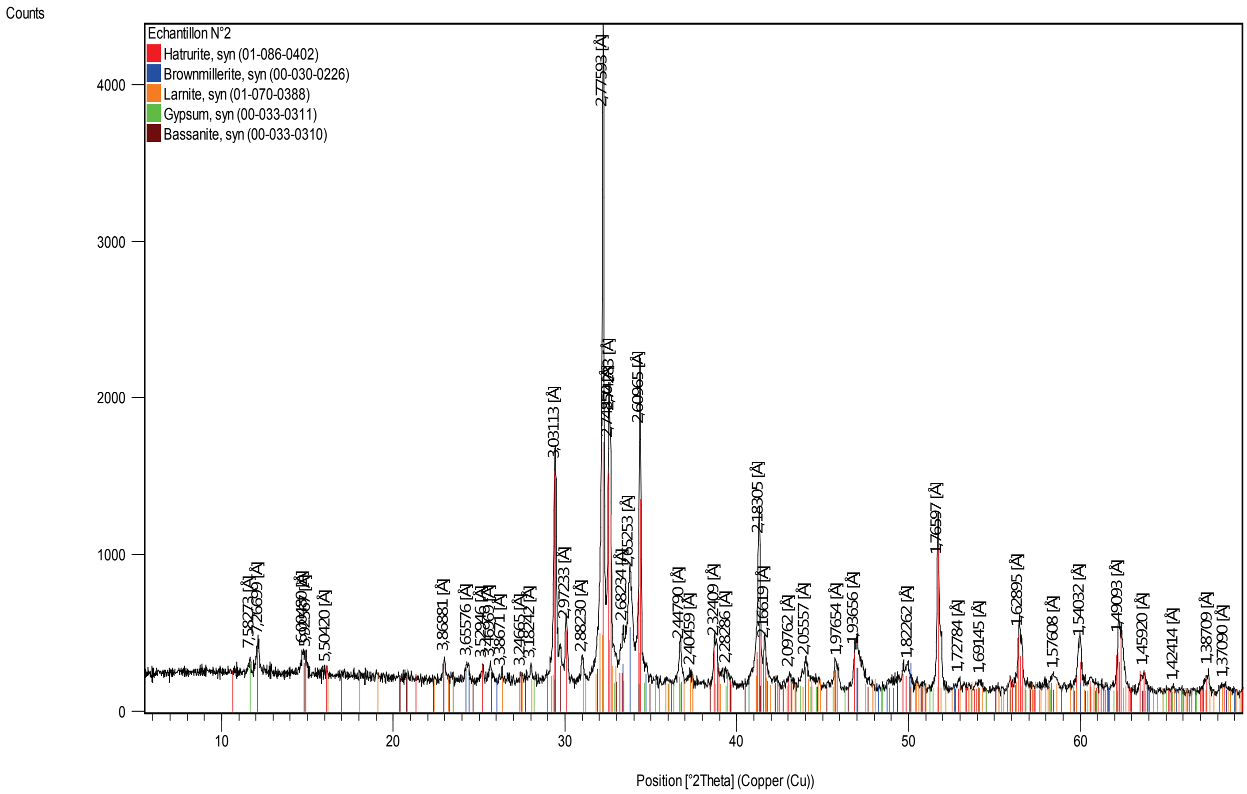

Fig. 1 - X-ray diffraction of ASLAND cement sample.

A granulometric analysis is carried out using a Laser LA 950 granulometer. The ASLAND cement sample analyzed has a particle size which ranges from 1.72 µm to 262.37 µm with a median size of 20.16 µm. The Blaine fineness is 4200 cm^2/g.

2.2 Experimental procedure

In order to determine the performances of the local Portland cement (ASLAND), experimental tests were carried out on the cement slurry. The experimental protocol followed to prepare the different samples (cement slurry and specimen) is dictated by the API Specifications 10A [10].

Table 3 - Experimental conditions and slurry composition.

Test Conditions	**Value**
Bottom Hole Static Temperature (BHST), ºF (ºC)	140 (60)
Bottom Hole Circulating Temperature (BHCT), ºF (ºC)	125 (52)
Bottom Hole Pressure, psi (MPa)	5160 (35.6)
Heat Up Time, min	28
Slurry Composition	**Value**
Cement Weight (g)	694,44
Volume of water (ml)	305,55
Density	1,90
Water/cement ratio (W/C) (%)	0,44

The mixer used is from CHANDLER Engineering, driven by two mixing speeds of 4000 and 12000 rpm. The measurement of the slurry properties, such as rheological parameters are only done after conditioning the latter in an atmospheric consistometer in order to simulate the temperature at the bottom of wells. Some properties such us thickening time, compressive strength, free water and rheological parameters of the cement slurry were calculated according to API specification 10A and API Recommended Practice 10B [9, 10]. The material amounts used and the test conditions are given in table 3.

2.3 Thickening time

The thickening time test informs us about the time interval until the cement slurry remains handled (pumpable) [11]. In other words, it is the time between the initial mixing of the slurry (water + cement) and the setting time [12]. Bearden units of consistency (Bc) is the unit of consistency of cement slurry [11]. The Thickening Time (TT) test is realized using a High-Pressure High-Temperature (HPHT) ''Pan American'' consistometer which can range up to a pressure of 30,000 psi (206.8 MPa) and a temperature of 400 °F (204 °C). The test conditions (temperature and pressure) can be simulated according to the actual conditions in the well. This test is stopped when the slurry has reached a consistency considered as not pumpable in the well. The maximum consistency between 15 to 30 minutes after the initiation of the test and the time required for the slurry to reach a consistency of 100Bc were evaluated [9, 10].

2.4 Free water test

The purpose of the free fluid test is to determine the segregation tendency of the cement slurry. This phenomenon can create problems after the cementing of the wells, leaving a part of the column cemented. The principle of this test is simple: It consists of placing the cement slurry in a graduated cylinder of 500 ml and measuring the quantity of free fluid floating above the cylinder after two (2) hours of rest [15]. The cement slurry undergoes a preconditioning for 30 minutes in an atmospheric thermometer CTE model M200. The preconditioned suspension was remixed for 10 seconds before being poured into a 500 ml graduated flask according to API specification 10A [10]. The mouth of the balloon is sealed and the experimental device is then left to stand for 2 hours. The supernatant fluid on the cement suspension is recovered and measured with a syringe to determine the free water content ($\hat{W}$) as a function of mass and cement density using eq. (1).

$$\hat{W} = (\mathrm{Vw})_{x}\,\mathrm{Sg} + \frac{100}{\mathrm{Ms}} \qquad (1)$$

Where (Vw) is the volume of free fluid measured (supernatant fluid), expressed in milliliters;

''Sg'' is the specific gravity and ''Ms'' is the initial mass of the slurry in grams.

2.5 Compressive strength and SEM analysis

The compressive strength is determined according to Section 7 and Annex D of API Specifications [1]. This occurs at ordinary temperature and pressure on cement test pieces of standardized dimensions (5×5 cm), previously kept at the temperature and pressure of the zone to be cemented. For this study, the tests were carried out on samples cured at 38 °C and 60 °C during 8 hours. The measurements are made using a hydraulic press, type CHANDLER Engineering.

The microstructure of the cured sample was analyzed at the laboratory after crushing with an XL-20 scanning electron microscope.

2.6 Rheology study

According to Shahriar [17], the control of the rheology of cement slurry intended for oil wells facilitates the implementation and the placement of the latter during the cementing operation. Poor cement bonding, zone communication and ineffective stimulation treatment can be generated by incomplete mud removal [14]. The rheology of cementitious suspensions can have a direct influence on the setting time and hardening of the solids, on the properties and rate of released free fluids, as well as on the friction pressures [15]. The tests for determining the rheological parameters are often carried out under atmospheric pressure and a handling temperature not exceeding 190 °F (88 °C) [9]. The rheological behavior of slurry at different temperatures is measured in this test (shear stress as a function of shear rate).

The rheological parameters of the fluid sample used in this study were measured with variable rotational speeds using Fan coaxial viscometer model 900 illustrated in Fig. 2.

Fig. 2 - Coaxial viscometer, model 900.

This apparatus makes it possible to measure the shear stress as a function of the speed of rotation. It makes it possible to determine the rheological characteristics of the slurry that are:

- Plastic viscosity (Vp): It represents the coefficient of proportionality between the shear stress and the velocity gradient, it can be calculated by eq. 2 according to [9].

$$\mathrm{Vp(cp)} = 1{,}5(\theta 300 - \theta 100) \tag{2}$$

Where θ300 is 300 rpm dial reading and θ100 is 100 rpm dial reading. They represent the number of revolutions per minute (unit: rpm).

- Yield value (Yv): The slurry does not move unless it is subjected to a shear greater than the shear threshold called 'Yield Value', it can be calculated by eq. 3 according to [9].

$$\mathrm{Yv(lbf/100ft^2)} = \theta 300 - Vp \tag{3}$$

- The gel: determined at 10 seconds and at 10 minutes. Measured in " Pound-force / square foot " Lb/100ft^2.

3 Results and discussion

3.1 Physical and mechanical properties

The results of pumping time test, compressive strength (average of three samples) and free water are summarized in table 4. The API requirements are also mentioned.

Table 4 - Performance test results and API 10A requirements.

Tests	W/C ratio	Density	Free water (Ŵ) (%)	Pumpability time at 35 MPa, 52 °C		Compressive strength, Psi (MPa)	
				Consistency at 30 min	T.T (100B$_c$) (min)	8 hours at 38 °C	8 hours at 60 °C
Results	0,44	1,90	2,5	37 B$_c$	112	1935 (13,34)	2136 (14,72)
API requirements	0,44	1,90	< 5,9	< 30	90 ÷ 120	> 300 (2,06)	>1500 (10,34)

T.T (100Bc): Thickening time at a consistency of 100 Bc

By comparing the results obtained with the API requirements (Table 4), it can be concluded that the value of the maximum consistency recorded after 30 minutes which is equal to 37 Bc exceeds the value required by the API specifications 10A [10] which stipulates that the value must not exceed 30 Bc. The result obtained for this test (consistency) show a consistency value which is outside the margin allowed by the norm. The sample studied has an initial consistency of 37Bc which could adversely affect the pumping time of the slurry during cementing operations. Therefore, additives are now mandatory in order to resolve this problem. The results of the free water tests, thickening time at 100Bc and the compressive strength are satisfactory and meet the API specifications. The high values of compressive strength at early age can be attributed to tricalcium aluminate (C_3A). This mineral is the most reactive compound with water and has a fast setting time. It is because the hydration of the aluminates is very fast that cement manufacturers add gypsum to the clinker to control these reactions. It could also due to the high content of C_3S (66.28%) and the good hydration of cement particles thanks to its Blaine fineness (4200 cm^2/g).

3.2 Rheological Properties

The rheological study makes it possible to deduce the values of the rheological parameters, namely the plastic viscosity, the threshold stress (yield value) and the gel of the slurry.

Table 5 shows the results of rheology tests conducted at BHCT of 125 ^oF (52 ^oC). It can be noted that the value of plastic viscosity (P_V) was below 100 cp (100 mPa.s), a value which is desirable to keep cement slurry pumpable [13]. The results of yield value and gel are also satisfactory and allow the suspension of cement to be pumped.

Table 5 - Rheological properties of local cement at Bottom Hole Circulating Temperature (BHCT) of 125 ^oF (52 ^oC).

Rheological properties	Revolutions (rpm)						
	θ_3	**θ_6**	**θ_{30}**	**θ_{60}**	**θ_{100}**	**θ_{200}**	**θ_{300}**
Reading average	22 .3	27.3	47	67	88	115	131
Plastic viscosity, cp (mPa.s)	64,5 (64,5)						
Yield value, lb./100ft^2 (Pa)	66,5 (31,84)						
Gel lb./100ft^2 (Pa)	at 10sec			at 10min			
	29,2 (13,98)			80,8 (38,68)			

3.3 SEM Analysis

Samples of the cured slurry were examined by scanning electron microscopy showed in Fig. 3 and analyzed with energy dispersive X-ray (EDS) illustrated in Fig. 4.

Figure 3A shows a homogeneous structure with low porosity. This confirms the results of the compressive strength found previously. Indeed, the mechanical resistances are inversely proportional to the porosity; that is, the resistances increase with the decrease in the porosity and consequently the durability of the material becomes important [16]. Portlandite $Ca(OH)_2$ can also be observed in figure 3D in platelets. A large crack appears on the right side of the same figure. Well-formed crystals of large sizes can be noticed in figure 3C, which can be attributed to calcium silicate hydrates CSH, a main product of the hydration of Portland cement.

On the other hand, figure 3B shows a certain porosity of the sample. Also small needles can be distinguished which can be attributed to the primary ettringite, a gypsum-based compound which acts as a cement paste regulator. In order to confirm the chemical composition of the different products, EDS microanalysis was carried out on the point 127 of the figure 3B. The result of this analysis is shown in figure 4.

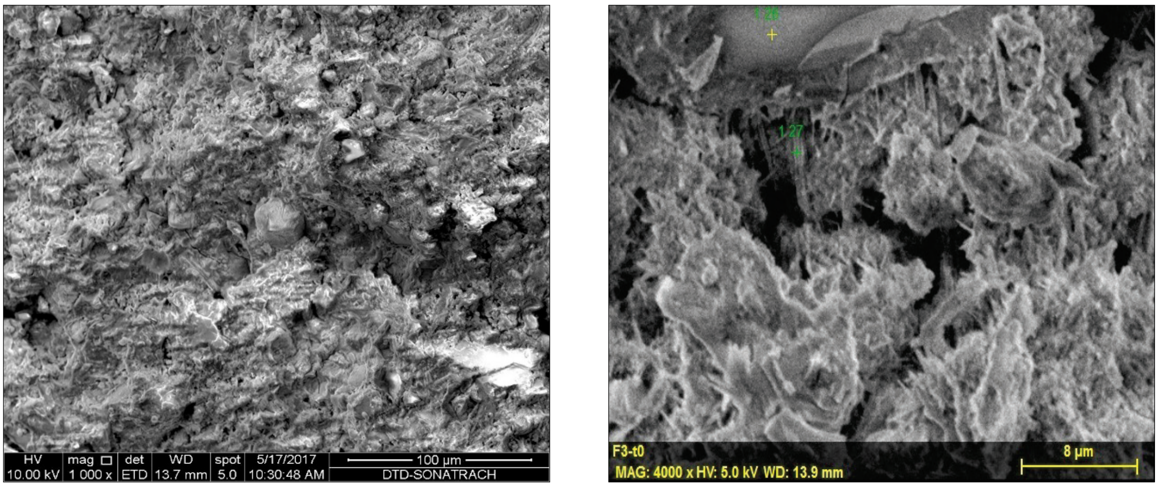

Image 3A : (x1000) Image 3B : (x4000)

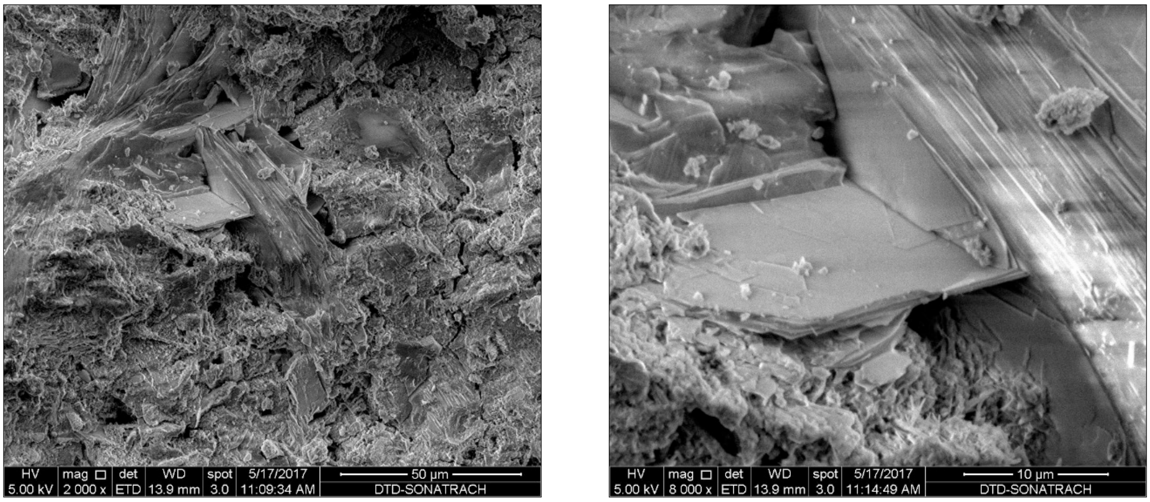

Image 3C : (x8000) Image 3D : (x2000)

Fig. 3 - Scanning electron micrographs (SEM) of the cured slurry.

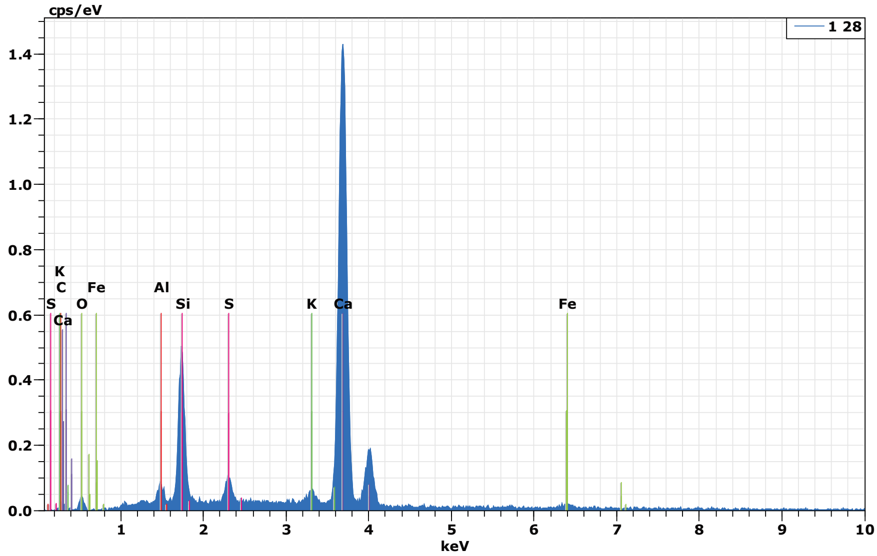

Fig. 4 - EDS spectrum taken at the point 127 of the figure 3B.

The spectrum of point 127 of figure 3B shows the ordinary elements often found in a paste of cement and concrete such as calcium with a high content, iron, Si, Al, O and K, this last element comes from alkali (K_2O).

The presence of sulfur ‘S’ can confirm the assumption made with previously that the needles could be attributed to primary ettringite whose chemical formula is $Ca_6Al_2 (SO_4)_3 (OH)_{12} 26 H_2O$.

4 Conclusions and perspectives

According to the results of this experimental investigation, it could be concluded that the laboratory compliance tests on the local cement sample such as compressive strength and free water meet the requirements of the API 10A standard and demonstrate compatibility with the slurries used for cementing casings and surfaces. In addition, the results of the values of the rheological parameters obtained are also very satisfactory and meet the API requirements. However, ASLAND cement has a slightly accelerated pumping time with an initial consistency that exceeds 30 Bc at 30 minutes, possibly due to its high fineness and rapid hydration.

On another register, the analysis by electron microscopy showed that the cured slurry has homogeneous structure with the presence of usual well-formed crystals of calcium hydrosilicates CSH and needles of primary ettringite. The low porosity contributed to obtaining high compressive strength.

The success of a cementing in a sounding requires many qualities of cement that it does not always bring together when it is used without additives; it is the case of this local cement studied. However, the latter could be used for cementing operations provided that the problem of pumping time is solved with the addition of appropriate additives (set retarder and hardening).

Finally, it is recommended to study the effect of additives (retarders, accelerators, stunning ... etc.) on the physical properties in the fresh state (rheology) and hardened (porosity, permeability, diffusion ... etc.) of this cement.

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