

Article

Recipe of Lightweight Slurry with High Early Strength of the Resultant Cement Sheath

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Abstract: Admixtures of mineral or waste filling materials are used to reduce slurry density. However, the sheath made of lightweight cement slurry has low mechanical performance at the initial bonding time. The required strength is achieved later. This is the main problem when evaluating the cement bond logging. The waiting time for geophysical measurements after injecting and bonding of cement is nowadays increasingly shortened. This is forced by economic factors. Too early geophysical measurements may result in obtaining a false indication of the cement bond logging. The lack of cement or partial bonding, despite the presence of slurry in the annular space is then found. The slurry developed by the author achieves high compressive strength after a short bonding time. Reducing the amount of water in the slurry resulted in a lowered filtration value. This is important in preventing gas migration after the cementing. The designed slurry also reaches the value of 3.5 MPa in a short time. This allows for an earlier commencement of a well drilling. The use of said slurry improves the effectiveness of the well sealing and makes it possible to obtain a reliable knowledge of the bond logging.

Keywords: well cementing; cement slurry; cement sheath; microspheres; compressive strength

1. Introduction

To isolate permeable levels saturated with reservoir fluids, cementing of casing string columns is applied. The purpose of that procedure is to keep the string columns in the well and protect them against corrosion caused by reservoir fluids and gases [1–4]. The annular space is filled with cement slurry which displaces the drilling mud by being injected. Cement slurries are divided into the ones with a ‘normal density’, around 1750–1850 kg/m³, lightweight slurries (below 1750 kg/m³) and heavy slurries (above 1900 kg/m³). The slurry density is chosen based on the geological and technical conditions resulting from the geological structure and well depth [5–10].

This publication refers to lightweight slurries. Such recipes are used when sealing casing string columns in absorbent or weakly compacted rock profiles. They are occasionally used for sealing wells drilled in productive levels with low reservoir pressure, or for reconstruction works. The occurrence of low reservoir pressure is manifested by the disappearance of mud while drilling or the infiltration of cement slurry into the absorbent geological structure. This leads to a decrease in the hydrostatic pressure of the drilling mud in the well and a violation of the pressure balance condition [11–18]. A reduction or complete drop of the hydrostatic pressure of the drilling mud results in a collapse of a well wall and in further complications. If a low reservoir pressure zone and the drilling mud leak occur while drilling such condition can be controlled. To this end, the drilling mud density is reduced and blockers (ground nut shells, sawdust, powdered rubber, cellophane film, or sealing paste) are injected [19–27]. However, during the cementing procedure, it is not possible to intervene if the cement slurry disappears while being injected. This is related to both the designed time of bonding and thickening of the cement slurry, as well as to the properly selected time of the entire cementing

procedure [28–33]. Therefore, a very important step in sealing the casing string columns embedded in loose layers is the use of a reduced density recipe. Such slurry is obtained by adding light mineral fillers into it. By reducing the density of cement slurry, the hydrostatic pressure during cementing is lowered. By so doing, the escape of cement into the low-pressure zones can be prevented. However, the sheath made of the lightweight cement slurry has a low early compressive strength and obtains the required property at a later bonding time [34–42].

The waiting time for geophysical measurements after cement injection and bonding is nowadays reduced, and so is the time required to carry out further works after cementing. This is driven by economic aspects and striving to accelerate the completion of subsequent stages of well drilling. However, too early measurements of the cement bond logging lead to unreliable cement bond logging (CBL—an indication of the condition of the cement bond image). If this is the case, the cement sheath bonding (despite the presence of cement in the annular space) is found to be incomplete or poor (Figure 1). The measurement of the cement bond logging condition is made when the strength of the cement sheath achieves 14 MPa. However, the cement sheath made of the lightweight slurry has significantly lower compressive strength in the initial hydration period. Compressive strength of the cement sheath made from the slurries used previously, after 24 h of hydration, reaches values ranging from about 5 MPa to about 8 MPa (compressive strength values for slurries with a density of about 1500 kg/m³, deposited at a temperature of about 30 °C) [43–48]. The problem of interpretation of geophysical measurements is raised when CBL confirms the absence of cement despite its being injected up to the top. Furthermore, the microstructure of the cement sheath with low early compressive strength is damaged during the post-cementation works. This results in reduced stabilization of the upper part of the casing string columns [49–55]. This contributes to the occurrence of gas migration in the annular space.

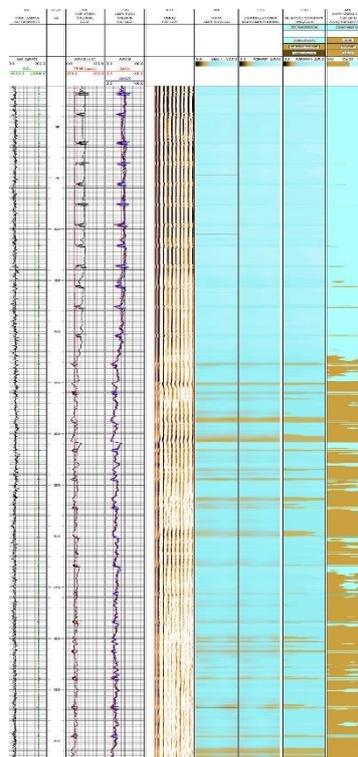


Figure 1. Cement bond logging test at an interval of 0–350 m. Cement slurry with a density of 1550 kg/m³.

Figure 1 shows the cement bond logging of the casing string columns installed in the interval from 0–350 m, where the lightweight slurry with a density of 1550 kg/m³ has been used. The cement sheath

made of that slurry had a compressive strength of 4.2 MPa after 24 h and 7.6 MPa after 48 h. Analyzing the results from the records of a cement bond logging tool, poor cement bonding in the 30–160 m interval can be found. In the 160–350 m interval, however, the bonding was weak and only locally incomplete. The unbound cement locations are marked blue. Such a picture of cement bond logging gives an indication of the lack of cement in the annular space. However, the post-cementing report states that the space is cemented. However, Figure 2 shows the cement bond logging for the interval from 900 m to 1300 m, in which the slurry with a density of 1820 kg/m³ has been used. That cement sheath had a compressive strength of 9.7 MPa after 24 h and 15.6 MPa after 48 h. Figure 2 shows good and very good cement bonding (beige), according to the interpretation of geophysical measurements.

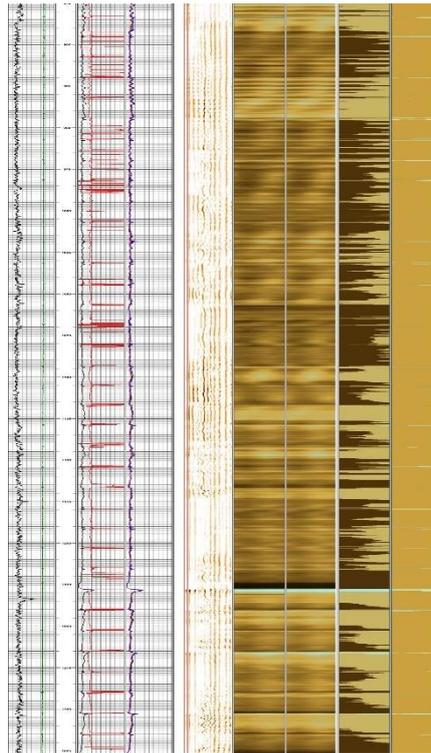


Figure 2. Cement bond logging test at an interval of 900–1300 m. Cement slurry with a density of 1810 kg/m³.

The author found that the cement bond logging depends on the strength of the cement sheath. The problem of interpretation of the cement bond logging occurs mainly when using lightweight slurries. Therefore, a new type of lightweight slurry was designed with increased mechanical strength at the initial bonding time. After application of such lightweight slurry, the measurement results are reliable and reflect the real cement bond logging.

2. Materials and Methods

2.1. Materials

CEM I 42.5R Portland cement was used to make the slurries. The cement contained 2.66% SO₃ and 0.065% Cl⁻. Slurry conditioning agents were added. IF755 cement plasticizer was delivered by CemexPolska. It is a liquefying agent based on a polycarboxylic ether with a density of 1.07 g/cm³ ± 0.02 g/cm³ and a pH of 6.0 ± 1.0. The content of Cl⁻ is below 0.1%, while that of Na₂O does not exceed 1.5%. In order to eliminate aeration, a defoamer was used, which is a mixture of unsaturated fatty acid esters and refined hydrocarbons. The product was supplied by Polski Serwis Płynów Wiertniczych Sp. z o.o., Poland. The slurry contained also an antifiltrating agent and

setting accelerator. The products were supplied by Polski Serwis Płynów Wiertniczych Sp. z o.o., Poland. To eliminate gas microflows, latex was used, which is a water dispersion of styrene butadiene copolymer and latex stabilizer, which is a mixture water dispersion unsaturated ethoxylated alcohols. The latex was supplied by Polski Serwis Płynów Wiertniczych Sp. z o.o., Poland. The inter-grain space was sealed with a 10% addition of micro-cement supplied by Halliburton Micro Matrix. This product contains grains of less than or equal to 10 m and a surface area of approximately 1400 m²/kg. Furthermore, bentonite was used to increase the viscosity of the mixing water, so that the microspheres used to reduce the slurry density did not fractionate. Bentonite was supplied by Certech, Poland.

Loose silica dust (amorphous silica) was used to improve the mechanical performance of the cement sheath made of the slurry. Specific surface area: 18,000 m²/kg [BET], average grain size: approximately 0.15 µm. The silica dust was supplied by HutaŁaziska, Poland. Sodium hydroxide supplied by PCC Polska was added to the slurry recipe. An admixture of IKC 45, increasing concrete strength, supplied by CemexPolska, was also used. That product was formulated based on calcium nitrate. It is a colorless liquid with a pH of 5.5 ± 1.0 and a density of 1.43 g/cm³ ± 0.03 g/cm³. The content of Cl⁻ is below 0.1%, while that of Na₂O does not exceed 1%. The percentage of additives is summarized in (Table 1).

Table 1. Selected compositions of cement slurries cured at a temperature of 40 °C and under the pressure of 10 MPa.

Composition	Action	1	2	3
Water–cement ratio	-	0.85	0.60	0.55
Plasticizer	Cement slurry liquefies	0.2	0.7	0.3
Latex	Lowers filtration, prevents gas migration through hardened cement slurry	5.0	5.0	5.0
Stabilizer	Provides good, even and durable latex dispersion	0.5	0.5	0.5
Bentonite	Is used to increase the viscosity of mixing water	1.5	1.5	1.5
Defoaming agent	Prevents foam formation	0.5	0.5	0.5
Antifiltrating agent	Reduces cement slurry filtration	0.3	0.3	0.3
Setting accelerator	Accelerates the cement hydration process in cement slurry	1.0	1.0	1.0
Microcement	Seals the matrix of hardened cement slurry	10.0	10.0	10.0
Cenospheres	Reduces cement slurry density	0.0	15.0	15.0
Nanosilica	Supplements the pore microstructure of hardened cement slurry	2.0	0.0	0.0
Microsilica	Seals the matrix of hardened cement slurry and has pozzolanic properties	13.0	15.0	0.0
Strengthening agent	Increases mechanical strength	0.0	0.0	1.5
Sodium hydroxide	Accelerates cement hydration and increases the value of mechanical parameters	0.0	0.0	1.5
Cement CEM I 42.5R	It sets the cement slurry	100.0	100.0	100.0

All components in % by mass of cement. Bentonite in % by weight of water.

2.2. Slurry Preparation

Three recipes were prepared to develop the lightweight slurry with high early strength of the cement sheath being formed. The first slurry is the test sample. Samples no. 2 and 3 are lightweight slurries with the addition of microspheres. Compositions no. 2 and 3 were modified to obtain higher mechanical strength values. When preparing the slurry, a certain amount of water is proportioned using a measuring cylinder. The water is poured into the mixer. The mixing speed is then set to 1600 rpm. Bentonite is added to the mixing water and mixed for 30 min. Then, the conditioning agents are added to the slurry and mixed again for 10 min. After that time, loose additives (microcement, microspheres, microsilica, cement) are poured into the mixture with water and mixed for another 20 min. Mixing at low speeds corresponds to preparation of the slurry in well conditions.

The slurry recipe designated with no. 1 in Table 1 was prepared first. The water–cement ratio of the slurry was 0.85, and the amounts of agents are listed in Table 1. Modifications were made to the following recipes which contributed to the increased mechanical strength of the resulting cement sheath.

2.3. Experimental Procedures

The technological properties of fresh and solidified slurries were tested in accordance with the following standards:

- PN–EN ISO 10426-2. *Petroleum and natural gas industries. Cements and materials for well cementing. Part 2: Testing of well cements.* The tests include the following measurements: slurry density, filtration, and thickening time.
- PN–EN 196-1: 2006 *Methods of testing cement. Determination of Strength.* Compressive strength was tested according to this standard.

Slurries were prepared at ambient temperature. The increase in compressive strength and thickening time was studied in conditions similar to those prevailing in the wells: temperature 45 °C, pressure 10 MPa.

2.3.1. Slurry Density

Density was tested using a Baroid mud balance. The balance consists of an arm with a dish for the slurry on one end, and a calibrated counterweight on the other. The balance arm is provided with a sliding weight and is scaled in the range of 0.8–2.75 g/cm³. The weight is read from the position of the sliding weight when the balance is levelled by appropriate positioning of a level on the balance arm [56].

2.3.2. Slurry Filtration

The filtration test was performed in conditions similar to those present in the wells, namely at high temperature and high pressure. The measurement was carried out using a dynamic filter press. The device allows for testing in well-like conditions at temperatures up to 232 °C and pressures up to 14 MPa [56].

2.3.3. Rheological Properties

The rheological properties were tested based on the determination of shear curves in the velocity range from 1.7 s^{−1} to 1022 s^{−1}. The test was carried out at a temperature of 20 °C ± 2 °C. For testing the rheological properties, an OFITE viscometer model 900 with coaxial cylinders was used. To determine the rheological model of cement slurries, the Rheosolution 3.02 software was used, which is the property of the AGH University of Science and Technology Faculty of Drilling, Oil and Gas [57–61].

2.3.4. Thickening Time

The slurry thickening time was determined using a pressure consistometer. The device enables recording the progress of thickening (maturing) of cement slurry and determining the beginning of the thickening time (30 Bc (Bearden unit) value—conventional value when determining the cement slurry thickening time) and at its end, with a value of 100 Bc [56].

2.3.5. Non-Destructive Compressive Strength Test

The non-destructive testing of the increase in compressive strength of cement slurries was carried out using a model 120–51 Twin Cell UCA (ultrasonic cement analyzer). During the measurement, the ultrasonic wave passes from the transmitter to the receiver. The cement slurry, which is being bound in HTHP conditions, is placed between the transmitter and receiver. A correlation exists between the

ultrasonic wave passage time and the increasing compressive strength. The instruments measure the compressive strength while the cement slurry is being bound in conditions similar to those of a well [62]. The diagram of the device is shown in Figure 3.

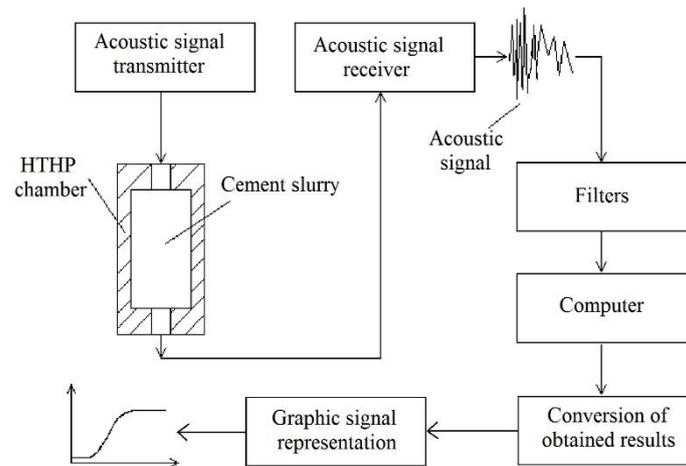


Figure 3. Simplified diagram of the ultrasonic cement analyzer.

3. Results and Discussion

3.1. Slurry Density

The research focused on lightweight slurries, since it is in these slurries that the greatest issue is the low mechanical strength of the stone. Such cement slurries are described in the literature [63]. As shown in Table 2, the slurries have a density in a range from 1.54 g/cm³ (slurry no. 2) to 1.58 g/cm³ (slurry no. 1). The base slurry no. 1 has the highest density but contains the greatest amount of mixing water (water/cement = 0.85). As shown in Table 1, the following slurries contain 15% addition of aluminosilicate microspheres and smaller amounts of water. The result of reducing the water content is an increase of the slurry rheological parameters. Therefore, slurries 2 and 3 contain more liquifying agent. This effect makes the density of slurries no. 2 and 3 comparable to the slurry no. 1. In standard slurries, the introduction of aluminosilicate microspheres reduces the mechanical strength of cement stone being formed due to the increasing porosity [2,14]. For example, in [63], slurry no. 12 has a compressive strength of only 2.9 MPa after 48 h. Therefore, slurry no. 2 contains 15% of microcement which provides extra sealing to the cement matrix and the water/cement (w/c) ratio is reduced to 0.6. Slurry no. 3, however, contains no microcement but less water; w/c = 0.55 (Table 1).

Table 2. Properties of cement slurries with additives and admixtures.

Composition no.	w/c	Density (g/cm ³)	Filtration, (cm ³) After 30 min of Measurement	Thickening Time (h:min)		Time in which Strength Was Achieved 3.5 MPa (h:min)	Compressive Strength Tested with the Ultrasonic Cement Analyzer, (MPa)			
				30Bc *	100Bc *		6 h	12 h	24 h	48 h
				1	0.85		1.58	733.0	5:55	7:10
2	0.60	1.54	85.0	6:30	7:20	4:54	4.24	6.93	9.45	11.32
3	0.55	1.57	174.0	5:10	6:00	6:13	3.07	13.04	20.98	25.36

* Bc—The Bearden unit is used when determining the change in consistency of cement slurry during setting.

The thickening time (consistency change) was tested in HTHP consistometer (temperature 40 °C and pressure 10 MPa), dynamic conditions, time to reach temperature and pressure 20 min).

3.2. Slurry Filtration

The filtration tests were performed at 40 °C under dynamic conditions. The slurry filtration tests were carried out for 30 min. As shown in Table 2, the base slurry no. 1 has the greatest filtration of 733 cm³. Such a high filtration value is the result of the highest w/c ratio, which is 0.85 for that slurry. Slurry no. 2 has a filtration rate of 85 cm³. In that slurry, the filtration rate is lower due to the presence of 15% microcement and a lower water–cement ratio (0.6) (Table 1). In slurry no. 3, the filtration is 174 cm³, and it has the lowest water–cement ratio. The lack of microcement in said recipe results in an increase of the filtration value compared to slurry no. 2.

3.3. Rheological Properties

In order to determine the rheological properties of the slurry, a measurement was made as for the greatest shear rate range (up to 1022 s⁻¹). Based on the results obtained, the rheological parameters corresponding to a specific rheological model were calculated. Furthermore, the slurry flow curve was drawn (Figure 4). As shown in Table 3, the slurries tested can be classified as non-Newtonian fluids and are described by the Casson and Herschel–Bulkley models. Base slurry no. 1 has a flow limit of C_{ss} 8.77 Pa. The H_B consistency coefficient of that slurry is 0.086 Pa·sⁿ, and the apparent viscosity amounted to 40.50 mPa·s. As shown in Figure 4, the flow curve for that slurry has the lowest rise profile. Correspondingly low values of the rheological parameters analyzed are caused by the large amount of water in the slurry (Table 1). The addition of microspheres and microcement to slurry no. 2 (Table 1) and a reduction of the w/c ratio leads to an increase in rheological parameters despite the content of 0.7% dispersant. Figure 4 shows the highest flow curve for slurry no. 2. The presence of loose fractions in slurry no. 2 causes an 8-fold increase in the C_{ss} flow limit compared to the base slurry [45]. The H_B consistency coefficient of that slurry was 29.9 Pa·sⁿ, while its apparent viscosity amounts to 190 mPa·s (Table 3). To slurry no. 3, without the microcement, the strengthening agent and NaOH were added. Such a modification leads to decreased values of the rheological parameters compared to slurry no. 2. This is confirmed by the lower flow curve of slurry no. 2 compared to that of the slurry no. 3, as shown in Figure 4. As can be seen in Table 3, the flow limit C_{ss} of slurry no. 3 was 19.80 Pa, and the consistency factor H_B was 2.86 Pa·sⁿ. The apparent viscosity of that slurry was 170 mPa·s. Increased values of rheological parameters are favorable in the lightweight slurry as the microspheres do not fractionate. However, it is necessary to use higher injection pressures during the cementing procedure.

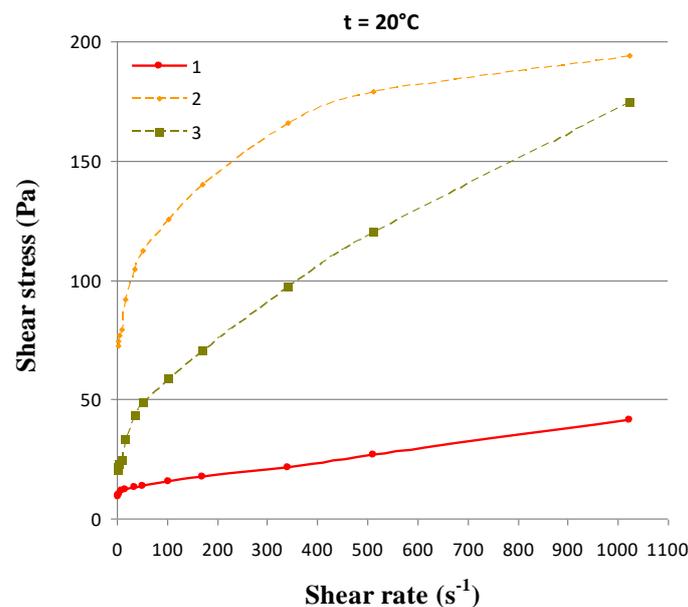


Figure 4. Flow curves of cement slurries at the temperature of 20 °C.

Table 3. Rheological properties of cement slurries with additives and admixtures.

Rheological Properties	Temperature of Measurement (°C)	Composition of Cement Slurry		
		1	2	3
Yield stress value C_{SS} (Pa)	22	8.7696	76.5356	19.7906
Consistency index $_{HB}$ (Pa·s ⁿ)	22	0.0861	29.8990	2.8613
Flow index $_{HB}$ [n](-)	22	0.8464	0.2484	0.5771
Apparent viscosity at 1022 s ⁻¹ (mPa·s)	22	4.4984	189.9930	170.9930

C_{SS} - value described by Casson's rheological model. $_{HB}$ - value described by the Herschel–Bulkley rheological model.

3.4. Thickening Time

The slurry thickening time test is carried out with an HTHP consistometer. The measurements were made at a temperature of 40 °C and a pressure of 10 MPa. The time to reach the indicated test temperature and pressure is 20 min. It is the time required to inject the slurry during cementing. The test was carried out in dynamic conditions and the slurry was in constant motion, which corresponds to its being injected into the well [14,16]. According to the data in Table 2, the base slurry begins to thicken (30 Bc) after 5:55 h and the thickening ends at (100 Bc) 7:10 h. As can be seen in Table 2, the second slurry takes longer to thicken than the base slurry, despite having a 15% microcement content in its composition. The value of 30 Bc was obtained 35 min later than of the test sample no. 1, and the value of 100 Bc was recorded 10 min later than in the slurry no. 1. The longer thickening time was caused by the presence of 0.7% liquefier. Slurry no. 3, in which a calcium nitrate-based agent and NaOH were used, had the shortest thickening time. The thickening time reduction is due to the presence of NaOH and Ca(NO₃)₂.

3.5. Compressive Strength (Ultrasonic Cement Analyzer—UCA)

As opposed to tests with a consistometer, UCA tests are conducted in static conditions. At this stage, the slurry was not mixed, which corresponds to building up mechanical strength after being placed in the well. The slurry was placed in an autoclave chamber and heated to 40 °C for 20 min. At the same time (20 min), the pressure in the autoclave increased to 10 MPa. As the cement slurry set, the damping force of acoustic wave that passes through the binding cement was measured. Based on that, the development of mechanical strength during the slurry hydration was determined. The UCA was also used to establish the time after which the cement sheath reaches the strength of 3.5 MPa. It is the minimum value at which drilling can be continued in the well [45]. In the UCA test, the early strength increases faster than the consistency measured with a pressure consistometer. This is due to the fact that the slurry tested with the UCA was in static condition.

Table 2 demonstrates that the base slurry, which contains no microspheres, has the lowest compressive strength. After 6 h, a strength of 1.04 MPa was obtained, which increased to 9.18 MPa after 48 h, as shown in Figure 5. The time to reach the strength of 3.5 MPa was 10:04 h.

The following slurry no. 2 contains 15% microspheres which usually reduce mechanical strength. To improve the strength of that slurry, 15% microsilica was used and the amount of water was reduced. 0.7% dispersant was added to increase pumpability of the slurry. Table 2 demonstrates that after 4:54 h, the solidified slurry had a strength of 3.5 MPa. Sample no. 2 had a higher compressive strength than the test sample no. 1. After 6 h, the strength was 6.24 MPa, and then it increased to 11.32 MPa after 48 h, as shown in Figure 6.

However, slurry no. 3 had the highest strength values. It is also a lightweight slurry, but without the addition of microsilica. The presence of 1.5% Ca(NO₃)₂ and 1.5% NaOH caused a considerable increase in strength after 12 h of hydration. As shown in Table 2, after 6:13 h, the slurry had a strength of 3.5 MPa, and 13.04 MPa after 12 h. It is a higher value than that for slurry no. 2 after 48 h. As shown in Figure 7, in the following hours, the strength of slurry no. 3 continued to increase. After 48 h of hydration, it had a strength of 25.36 MPa. The mixture of sodium hydroxide and a calcium

nitrate-based agent caused a very significant increase in the mechanical strength at the initial hydration time. This is due to the shortening of hydration time, which is proven by the shortest thickening time (Table 2). Slurry 3 demonstrates application properties. The recipe no. 3 is simple and has very good mechanical performance. That slurry constitutes a valuable solution for use in industrial conditions and is suitable for sealing loose layers.

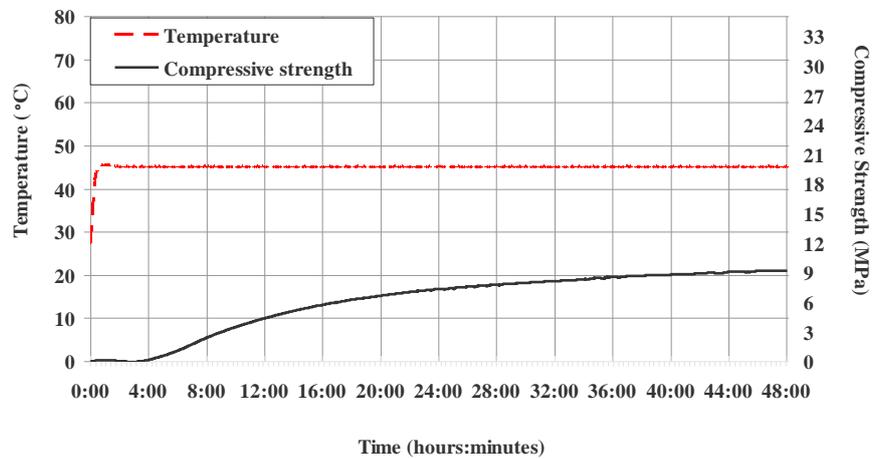


Figure 5. The compressive strength increase curve of sample no. 1.

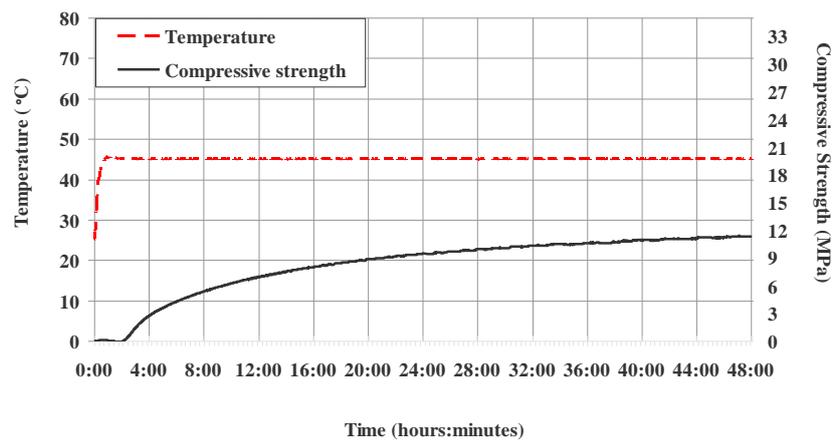


Figure 6. The compressive strength increase curve of sample no. 2.

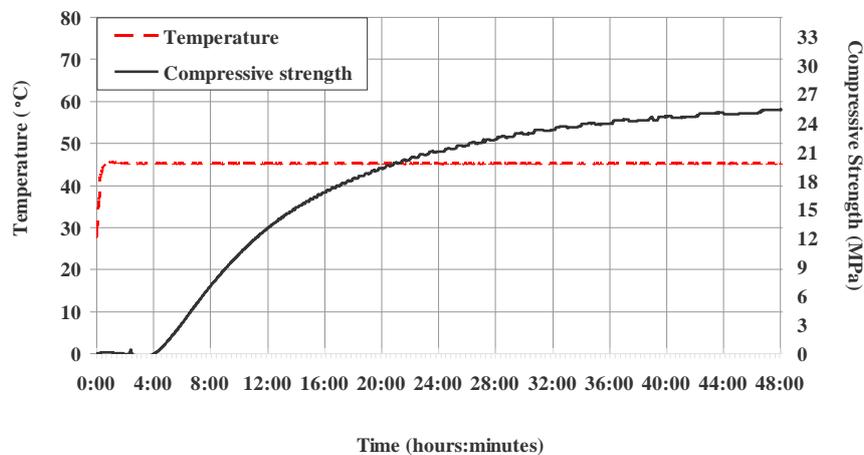


Figure 7. The compressive strength increase curve of sample no. 3.

4. Conclusions

1. A new recipe was designed to address the demand for high-strength and lightweight slurry, striving to improve the cement bond logging. Recipe no. 3 is a lightweight slurry with high early strength of the resultant cement sheath. When designing such slurry, more water is used or light filling additives are added to its composition. Such solutions, however, reduce the mechanical strength. The lightweight slurries used currently do not achieve such high strength. The new lightweight slurry recipes presented herein contain less water. Lightweight slurries, the recipes of which are presented here, have comparable thickening time, which is important during injection into a well.

2. The filtration of the designed lightweight slurries is four to eight times lower than that of the test lightweight slurry sample. This was achieved by reducing the amount of water in the slurry and by adding microspheres. Filling and strengthening agents are added to reduce the decrease of compressive strength. Reduction of filtration is necessary to counteract gas migration after cementing.

3. The new formula of the lightweight slurry designed by the author reduced the hydration time needed to achieve 3.5 MPa by half. This is very beneficial from an energetic and economic point of view, as it makes it possible to continue the drilling works earlier.

4. An addition of microsilica and reduction of the amount of water in the slurry no. 2 leads to the most considerable increase of strength in the first hours of hydration. The increase in strength ranges from 407% (after 6 h) to 123% (after 48 h), compared to the test slurry no. 1, while for slurry no. 3, an addition of 1.5% sodium hydroxide and 1.5% calcium nitrate results in a comparable increase in strength. The improvement in strength in the latter case ranges from 295% (after 6 h) to 276% (after 48 h) compared to test slurry no. 1. The designed lightweight slurries with a high strength of cement sheath can improve the cement bond logging reading. The use of those slurries (no. 2 and 3) reduces the possibility of damage to the structure of the cement sheath during further drilling for the next section of casing strings.

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Nomenclature

CBL	the cement bond logging documents the evaluation of the integrity of cement work performed on an oil well
pH	in chemistry, it is a scale used to specify how acidic or basic a water-based solution is
BET	the specific surface area is a property of solids defined as the total surface area of a material per unit of mass (with units of m^2/kg or m^2/g) or solid or bulk volume (units of m^2/m^3 or m^{-1}). It is determined by adsorption isotherm analysis. The test is carried out using a BET isotherm (isothermal Brunauer–Emmett–Teller), which is a particular form of a linear equation
Bc	the pumpability or consistency of cement slurry, measured in Bearden units of consistency (Bc), a dimensionless quantity with no direct conversion factor to more common units of viscosity
UCA	Ultrasonic Cement Analyzer.
HTHP	High Temperature High Pressure
w/c	water–cement ratio—expresses the amount of water per cement unit
Css	the liquid is described by Casson’s rheological model
HB	the liquid is described by the Herschel–Bulkley rheological model

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