



## Study of Bonding Strength at Salt-cement Interface During Cementation of Salt Layers

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### ABSTRACT

Cement has been used for decades in industry to serve various important functions inside oil and gas wells. Due to the complications and variations in the geological and technical conditions of a well, various cement compositions are designed and utilized in different world regions. Many hydrocarbon reservoirs are covered by thick salt formations, which are considered problematic and costly to be drilled and cemented. Cement slurry, as a water based solution, interacts with salt rock, as a result of which cement properties are changed that consequently may jeopardize well integrity across salt formations and successful exploitation of beneath hydrocarbon reservoirs. In this study, based on experimental and industrial experiences, a cement composition is developed that meet the requirements of cementation in salt layers. Experimental investigations are conducted on the bonding strength at the salt-cement interface, as the bonding strength is considered as one of the factors that significantly affect overall cement efficiency in providing well integrity. Results confirm the effectiveness of the developed composition for cementation of salt layers.

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### NOMENCLATURE

$C_3S$	Tricalcium silicate	$PVP$	Polyvinylpyrrolidone
$C_3A$	Tricalcium aluminate	$CaO$	Calcium oxide
$W/C$	Water to cement mass ratio		

## 1. INTRODUCTION

In many locations worldwide, salt layers overlie hydrocarbon reservoirs and serve as high-quality cap rocks in the petroleum system. Thus, effective exploitation of such hydrocarbon reservoirs requires successful passing through these salt layers. However, based on industrial practices, drilling and cementing wells through these layers are usually challenging and costly [1].

Salts are water soluble, with low porosity and permeability; behave plastically in high pressure and high temperature conditions, which may lead to their flow into the wellbore and subsequent problems in the adjacent cement and casing strings.

Challenges of cementing salt layers may be divided into two main categories:

- Creep load of salt on cement
- Interaction of cement slurry with salt layer

Creep is defined as the gradual material deformation under constant stresses over time and in the case of salt layers, may lead to its movement toward the subsequent cement and casing string. To avoid potential risks of cement failure and casing collapse under this load, a uniform cement composition with adequate strength properties should be utilized in the annular space between the casing and formation [2, 3].

Creep load and its effect on wellbore integrity have been subjects of several researches. Wang et al. [4] used a geomechanical model of casing, cement sheath and salt rock to describe the long-term rheological behavior of salt rock and cement sheath under in situ stresses.

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In the work of Jandhyala et al. [5], finite element analysis and structural mechanics are used to study the effect of salt creep load on the stresses inside the cement sheath at various stages of well service life, including drilling, cementing, shut-in, completion, and production. They concluded that addition of elastomers into cement composition could help in withstanding applied loads.

Beside creep load, interaction of cement and salt formation is another important consideration. Most of the formation salts are soluble in slurry as cements are generally water-based systems. This dissolution reaction has two main disadvantageous effects. First of all, salt dissolution in the slurry leads to hole enlargement, which jeopardize the annular space uniformity and overall wellbore integrity. Secondly, slurry and set cement properties are changed after salt dissolution, which may lead to a low-quality cementing operation.

Several authors investigated effects of salt on slurry and set cement properties. The salt may be added as an additive for preparation of cement or it may enter to the cement system from the formation.

Islam et al. [6] studied the effect of sea water with enhanced salt concentrations on the samples from two grades of concrete exposed to simulated sea environment over a year and showed that concrete exposed to sea water of different salt concentrations suffered a loss of compressive strength.

Teodoriu and Asamba [7] studied the effect of NaCl, as an additive, on API class G cement. They showed variations of some main cement properties, including slurry thickening time, set cement compressive strength, dynamic E-modulus and permeability with change in salt concentration. Based on experimental tests, authors concluded that NaCl, as an available and cost-effective additive, produce some attractive effects on well cement performance.

In the work of Lago et al. [8], effect of NaCl salt in the hydration process of class G Portland cement was studied on the first 24 hours of cement hydration. Authors came to the conclusions that presence of NaCl up to 10%, accelerates the hydration process and increases the hydration of C<sub>3</sub>S (tricalcium silicate) and C<sub>3</sub>A (tricalcium aluminate), while the 20% salt concentration leads to delayed hydration.

Simao et al. [9] evaluated the effect of different concentrations of halite (NaCl), carnalite (KMgCl<sub>3</sub>·6H<sub>2</sub>O) and taquidrite (CaMgCl<sub>3</sub>·12H<sub>2</sub>O) on the main characteristics of a semi-saturated cement, including free fluid content, thickening time, compressive strength and rheological properties. Based on experimental results, authors suggested that using a semi-saturated slurry for cementing salt layers in Brazil provide a good quality cementing operation.

Among the cement properties that are studied in the abovementioned works, almost no attention is paid to the bonding strength between cement and formation,

which defines quality of the process at the formation-cement interface and is considered as one of the factors that significantly affect overall efficiency of the well cementing operation [10, 11].

As a result of ion exchange between excess slurry water and salt rock, most of the salts dissolves in cement even after it's hardening, which leads to formation of a saltwater gap at formation-cement interface and consequently a low-quality cementing operation.

In this work, a salt saturated slurry composition is developed and used for cementing a salt rock sample in a laboratory model to investigate the quality of cementing operation by analyzing the bonding strength at cement-salt rock interface.

## 2. MATERIAL AND METHODS

To select optimum cement composition, following techniques are considered to have a good bonding strength at salt-cement interface at all stages of their interaction:

- Reduction of excess water in the cement slurry.
- Providing volume expansion in set cement.
- Preparation of cement slurry with an aqueous solution of a similar salt.

Water to cement mass ratio (W/C) is a slurry parameter that can be adjusted in a specific range to control the water content of the cement slurry. To see the effect of water reduction on boning strength at salt-cement interface, cement slurry with W/C of 0.5 and 0.45 were prepared and result were compared.

Polyvinylpyrrolidone (PVP) was added as a plasticizing (fluidizing) agent, which provides the possibility of W/C reduction without any further problem in cement flow-ability and pumping.

To provide volume expansion in set cement, calcium oxide (CaO) was added to the system as an expanding agent. Finally, NaCl was used in the mixing water of cement slurry to minimize salt dissolution from rock sample in the cement.

Cement samples were prepared based on standard procedures, which involved dry premixing of ordinary Portland cement, PVP and CaO an then mixing the dry power with water at a rate of 2000 revolution per minutes for 2 minutes. All chemicals were provided by local producers in the Russian Federation. Prepared samples with different additive are presented in Table 1.

Cylindrical NaCl samples (diameter of 40 mm and, height of 50 mm) were prepared using a special coring machine (Figure 1) from bulky salt samples in laboratory and placed at the middle of a steel cylinder. Cement slurry of developed composition was poured then around the salt rock sample. The whole cement and salt system was left in the laboratory conditions

(temperature 24 °C, atmospheric pressure, exposure to air) for hardening as the time passes (Figure 2).

To determine bonding strength at salt-cement interface at different hardening stages, tangential stress, required to press-out cylindrical salt samples (Figure 2) from cement of different compositions was measured and reported.

Schematic of the device, which has been used for tangential stress measurement is shown in Figure 3.

The press machine applies force to move out the salt sample from the cement ring. This force is recorded to be used in the following tangential stress formula:

$$\sigma_t = \frac{F}{A_t} \tag{1}$$

where  $F$  is the force, applied by press machine to move out salt sample from cement ring,  $A_t$  is the lateral area of

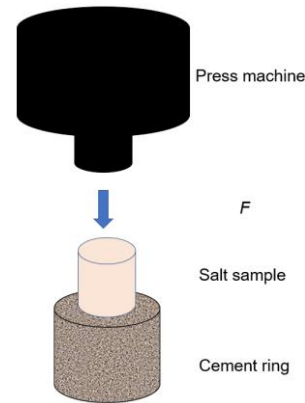


Figure 3. Schematic of the measuring device

cement ring and  $\sigma_t$  is tangential stress. Calculated tangential stress is reported as the contact bonding strength.

TABLE 1. Different cement compositions

No.	Composition	W/C
1	<b>Base composition:</b> Portland cement, water	0.5, 0.45
2	Portland cement, water, CaO (5, 7, 10 % wt.)	0.5
3	Portland cement, water, NaCl (2, 5 % wt.)	0.5
4	<b>Final composition:</b> Portland cement, PVP (0.25% wt.), Cao (5% wt.), NaCl (2% wt.)	0.45



Figure 1. Preparation of NaCl samples using coring machine



Figure 2. Cylindrical salt sample inside cement

### 3. RESULTS AND DISCUSSION

Figure 4 shows process of cement interaction with cylindrical salt (NaCl) sample during hardening process. Visual observations showed that at the stage of cement hydration there is an active interaction between excess water of cement slurry with the surface of the salt sample; while due to the hygroscopicity of the salt, its outer surface is actively dissolved and a salt-saturated water layer is created between the salt sample and the cement at the final stage of its hardening, which practically leads to a low bonding strength at the salt-cement interface.

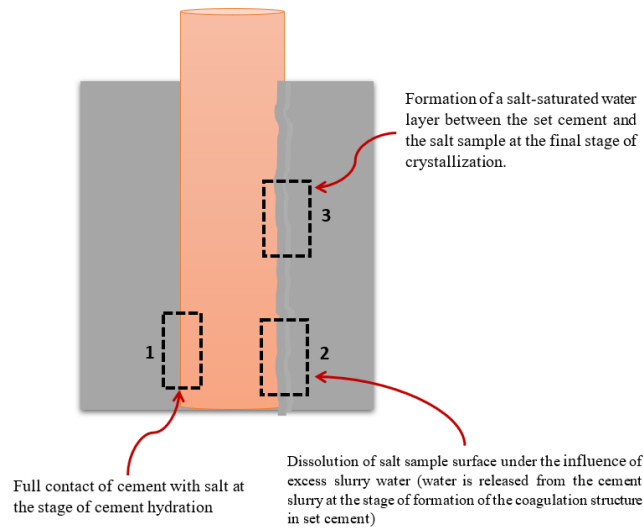
Figure 5 shows the results of bonding strength evaluation at the interface of base cement composition (W/C = 0.5) and salt sample (all experimental data are presented in Appendix 1 in tabular form).

Presented data in Figure 5 indicate that there is almost no contact bonding strength of the cement with the salt sample (less than 0.02 MPa after a week of hardening). At the same time, spontaneous falling out of the salt sample from the cement rock was observed during the preparation for pressing-out on the press machine.

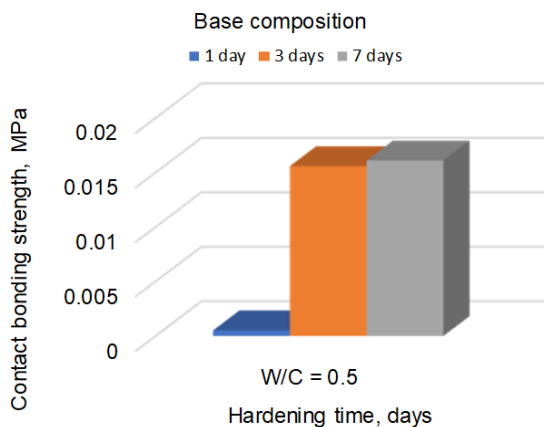
Figure 6 shows the variation of bonding strength at base cement-salt interface with a decrease in W/C.

As it can be seen, the tangential stresses at the salt-cement interface increase by more than 5 times with a decrease in W/C to 0.45. This is due to the fact that minimizing water content in the cement slurry leads to less solubility of the salt rock on the surface of the sample during its initial contact with the cement slurry.

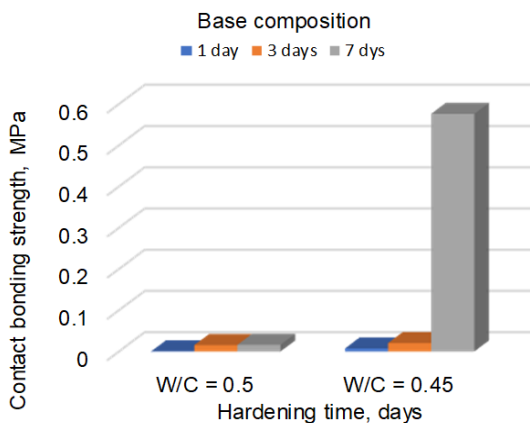
Variation of bonding strength at salt-cement interface with the concentration of CaO in the composition of base cement is presented in Figure 7. It



**Figure 4.** Schematics of the interaction between the cement and salt sample at different stages of cement hardening



**Figure 5.** Contact bonding strength of the base cement composition (W/C=0.5) with NaCl

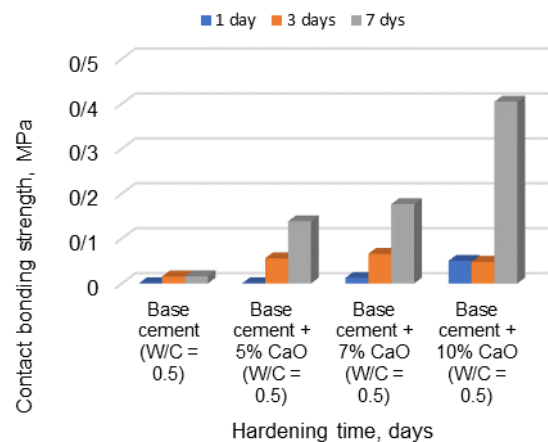


**Figure 6.** Contact bonding strength of the base cement composition (W/C=0.5 and W/C=0.45) with NaCl

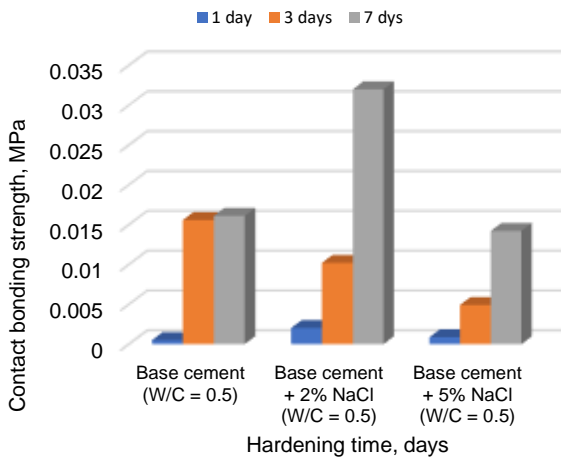
is evident that the volume expansion of the cement composition leads to an increase in the bonding strength of cement rock with salt from 7 to 20 times in compare to the base composition.

Since, as it was noted earlier, the processes of hydration and hardening of cement samples are significantly influenced by presence of sodium chloride in the cement mixing water, studies were conducted to investigate the effect of NaCl in the cement composition on the bonding strength of cement rock with salt rock. Results are presented in Figure 8.

As the data in Figure 8 show, when NaCl concentration of 5% is reached, the bonding strength of cement with salt is significantly reduced; therefore, the NaCl concentration in the cement slurry must be limited. Large concentrations of halite in the cement



**Figure 7.** Influence of CaO in the developed composition on bonding strength at salt-cement interface



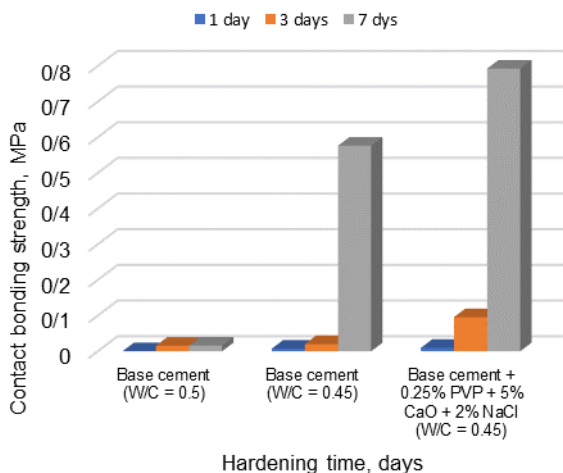
**Figure 8.** Influence of NaCl in the developed composition on bonding strength at salt-cement interface

during its crystallization leads to not only destruction of the internal cement structure, but also to the destruction of contacts with external objects, in particular, with salt rock sample.

Based on the experimental result following final cement composition (W/C = 0.45) was developed and its bonding strength with salt sample was calculated (Figure 9):

- Portland cement;
- PVP plasticizer-0.25% (wt.);
- Expanding additive Cao-5% (wt.);
- Mineral additive NaCl-2% (wt.)

The results of the study showed that the decrease in W/C to 0.45, by addition of the mixture of water 0.25% PVP, 2% NaCl and 5% Cao contribute to an increase of



**Figure 9.** Bonding strength of final developed composition with salt rock sample

contact bonding strength of cement with the salt in 6-7 times compared to the base cement composition.

Also it is notable that increase in contact bonding strength in all systems with time from 1 to 7 days, has not a linear trend, which is reasonable output as the cement hardening process and it’s strength development is inherently a complex phenomenon.

**4. CONCLUSION**

Analyzing the obtained results, we can draw the following conclusions about the contact bonding strength at the cement slurry-salt rock and cement rock-salt rock interfaces:

- Base cement composition at a standard W/C=0.5 practically does not have contact strength with salt rocks so it cannot provide integrity of the well annular space in the intervals of evaporate salt deposition.
- Maintaining a good-quality contact of cement and salt at all stages of their interaction can be provided by reducing excess water in the cement slurry, increasing the volumetric expansion of the cement composition and preparation of cement slurry with an aqueous solution of a similar salt.
- When the water content in the cement solution is low, the solubility of the salt rock on the surface of the sample is minimized during its initial contact with the cement slurry (this can be the case during slurry movement through the annular space).
- Furthermore, addition of NaCl to the water during cement mixing leads to reduction in setting time of cement slurry, which reduces the interaction time of free water with salt rock. It also contributes to the formation of salt-saturated hydrate neoplasms in the adhesive layer at the subsequent stages of coagulation of the cement and crystallization of the cement rock.
- CaO presence as an expandable agent, provides volumetric expansion of the cement, which in turn leads to increased pressure at salt-cement interface and consequently increased bonding strength.

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#### APPENDIX 1. Experimental data of bonding strength at salt-cement interface

No.	Composition	W/C	Bonding strength at salt-cement interface, MPa		
			After 1 day	After 3days	After 7 days
1	<b>Base composition:</b> Portland cement, water	0.5	0.00051969	0.015590688	0.016110378
2	<b>Base composition:</b> Portland cement, water	0.45	0.00750951	0.02050176	0.57636176
3	Portland cement, water, CaO (5 wt%)	0.5	0.00051969	0.05623042	0.13839334
4	Portland cement, water, CaO (7 wt %)	0.5	0.01247255	0.06620846	0.17674644
5	Portland cement, water, CaO (10 wt %)	0.5	0.05035792	0.0482021	0.4046823
6	Portland cement, water, NaCl (2 wt%)	0.5	0.00202679	0.0102119	0.0319869
7	Portland cement, water, NaCl (5 wt %)	0.5	0.00088347	0.00491107	0.01421351
8	<b>Final composition:</b> Portland cement, PVP (0.25 wt %), Cao (5 wt %), NaCl (2 wt %)	0.45	0.00956	0.09564	0.792546

#### Persian Abstract

#### چکیده

سیمان برای دهه ها به منظور انجام وظایف مختلف و مهم درون چاه های نفت و گاز در صنعت مورد استفاده قرار گرفته است. به دلیل پیچیدگی ها و تفاوت ها در شرایط زمین شناسی و فنی یک چاه، ترکیبات مختلف سیمان، طراحی و در مناطق مختلف جهان مورد استفاده قرار گرفته اند. بسیاری از مخازن هیدروکربنی به وسیله لایه های ضخیم نمکی پوشانده شده اند که حفاری و سیمان کاری آن ها مشکل زا و هزینه بر می باشد. دوغاب سیمان به عنوان یک سیال پایه آبی با سنگ های نمک وارد واکنش می شود که در نتیجه آن ویژگی های سیمان تغییر می کند که این امر نهایتاً می تواند باعث به خطر افتادن یکپارچگی چاه در مقابل لایه های نمکی و استخراج موثر مخازن هیدروکربنی زیرین شود. در این مطالعه، بر اساس تجربیات آزمایشگاهی و صنعتی، یک ترکیب سیمان که شرایط سیمان کاری در لایه های نمکی را داشته باشد، طراحی شده است. آزمایشات بر روی استحکام پیوند بین نمک و سیمان انجام شده است چرا که استحکام پیوند به عنوان یکی از عواملی در نظر گرفته می شود که به طور قابل توجهی بهره وری سیمان در فراهم کردن یکپارچگی چاه را تحت تاثیر قرار می دهد. نتایج، موثر بودن ترکیب طراحی شده در سیمان کاری لایه های نمکی را تایید می کند.