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RESEARCH ARTICLE

The Effect of Microsilica on Expanding Cement for Micro-annulus Problem in Gas Migration

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Abstract

Gas migration through cement slurry and micro-annuli remains a major well integrity. Improper cementation can lead to micro-annulus formation, enabling gas leakage and increasing blowout risk as downhole pressure decreases. Microsilica has been widely used as an anti-gas migration additive due to its ability to reduce permeability and improve cement stability; however, its effect on expanding cement systems has not been fully evaluated. This study investigates the influence of microsilica on the physical and mechanical properties of expanding cement slurry and its interaction with conventional expanding additives. Three slurry formulations—base slurry with microsilica, base slurry with expanding additive, and a combined microsilica–expanding additive system—were prepared and tested following API RP 10B procedures, including density, rheology, fluid loss, free water, thickening time, compressive strength, and expansion ring testing. Results show that microsilica provides beneficial effects by reducing fluid loss, eliminating free water, increasing compressive strength, and enhancing post-set expansion performance when combined with expanding additives. However, microsilica also increases slurry viscosity and shortens thickening time, potentially affecting pumpability and placement. Expansion ring tests indicate that the combined microsilica–expanding additive slurry exhibits the highest expansion (0.446% at 96 hours), whereas cement with microsilica alone shows initial shrinkage before gradual expansion. Overall, microsilica acts as a complementary additive that improves the performance of expanding cement but requires careful optimization to avoid negative impacts on rheology and setting behavior. The findings highlight the importance of additive balancing in designing cement systems for gas-migration-resistant well completions.

Keywords: Gas Mitigation, Laboratory Testing, Micro-annulus, Microsilica

1. Introduction

Gas Migration through cement slurry and micro-annulus has been a worldwide problem since the early 1960s, especially in the completion of gas-bearing zones. Approximately 80% of wells in the Gulf of Mexico have gas transmitted to the surface through cemented casings (Velayati et al., 2015). In the North Sea and Gulf of Mexico, methane flow rates in 35 wells, and 69% of them had a leakage and the main form of leakage is micro-annulus. These issues are estimated to represent about 25-30% of the primary cement job failures during well completion. Small gas volume downhole will move upwards and increase in volume as the pressure decreases, which will decrease the hydrostatic pressure downhole and potentially lead to more gas coming into the well. This cycle leads to ever-increasing gas inflow, and it will end up with a blowout (Tao et al., 2021). During and after the cementing process, several issues start to take place in cement slurry including fluid loss, dehydration, free water separation, and gelation of cement slurry (Haijin et al., 2010). The improper cement slurry creates crakes and voids in cement. So, it is important to design the right composition of cement slurry.

Microsilica, commonly named silica fume, has been used by industry for more than 15 years. Initially, it was used as a partial cement replacement in concrete and has also been used in oil well cement, it will improve concrete properties both in the fresh and hardened state (Grinrod et al., 1988). Microsilica is a particle that can block a fluid's narrow passage (Shadizadeh et al., 2010). Microsilica can decrease the permeability of cement slurry, aiding in zone isolation, and it is identified as an effective material for reducing gas migration by significantly reducing leakage time (Kwatia et al., 2019). Therefore, this additive is usually named as an anti-gas migration additive in the oil and gas industry.

Good cementing operations need to be carried out to achieve successful cementing and minimize the occurrence of the micro annulus problem as desired (Pattinasarany & Irawan, 2012). Therefore, sensitivity analysis is needed to formulate cement composition to minimize the gas migration phenomenon. In the previous paper, microsilica is one of the common chemicals used to prevent gas migration through leakage.

The purpose of this research is to evaluate the role of microsilica in expanding cement systems and determine how it influences the physical, mechanical, and expansion characteristics of oil-well cement. Specifically, the study aims to compare the performance of three slurry formulations—base slurry with microsilica, base slurry with an expanding additive, and a combined microsilica–expanding additive system—to assess whether microsilica can enhance expansion behavior, improve cement stability, and support long-term zonal isolation. By examining key parameters such as rheology, fluid loss, free water, thickening time, compressive strength, and expansion response, this research seeks to clarify how microsilica interacts with conventional expanding agents and determine its overall suitability as a complementary additive to mitigate gas migration and micro-annulus formation in well cementing operations.

2. Literature Review

2.1 Gas Migration

Gas migration is a worldwide problem, especially in the completion of gas-bearing zones. This phenomenon also referred as gas leakage, annular gas flow, gas channeling, and gas invasion (Velayati et al., 2015). The main provoker which causes the gas phase to intrude into the annulus space is attributed to the channeling mechanism within the cement which caused as a result of improper cement operation. Therefore, the conditions that support the gas phenomenon occur are the annulus hydrostatic pressure has a less or an equivalent value compared to the pore pressure, annulus space allows the entrance of gas, and a path is available through the annulus in which gas migration occurs (Bayanak et al., 2021).

There are 3 types of gas migration that have been classified (Bayanak et al., 2021), those are immediate, short-term, and long-term gas migration.

- Immediate gas migration could happen by hydrostatic underbalanced conditions, and the gas may move through fluid displacement from the wellbore.
- Short-term gas migration occurs due to several conditions such as fluid loss, gel strength development, chemical shrinkage of cement, annular bridging, and annular packers. The gas may move through slurry permeability and filter cake permeability.
- Long-term gas migration occurs by 2 conditions such as chemical shrinkage of cement and strength development of cement. There are several migration paths of this type such as cement sheath mechanical failure, free-fluid channel, mud channel, also micro annulus.

2.2 Micro-Annulus

The micro-annulus is a term used to describe the occurrence when the cement is put in place and the casing is pressurized. After the cement sets and the pressure is released, the casing moves away from the cement sheath, creating a small gap or micro annulus between the casing and the cement. This issue can also arise if there is an excess of pipe dope or varnish on the pipe. This can also happen in opposite washed-out parts of the borehole (Lyons, 2010). Gas migration phenomenon can occur through a micro-annulus, which refers to infinitesimal gaps that may form between the casing and liner, as well as around the cement sheath. These gaps may also develop between the cement sheath and the formation after it has been set (Bayanak et al., 2021). The micro-annulus that formed will allow the gas to flow through and around the cement sheath. The first conditions are underbalanced conditions, and the second one is a potential leakage pathway along the cement column. Four forms of wellbore leakage pathways can be developed. These forms are channels within the cement sheath, pathways at the casing, or cement interface or we can call it micro annulus (Al Ramadan et al., 2021). Gas migration can lead to serious environmental hazards such as explosions, fires, noxious odors, and potential emission of carcinogenic chemicals (Sabins, 1990).

2.3 Microsilica

Microsilica or silica fume is an excellent admixture for concrete as it leads to better engineering properties. It reduces thermal cracking, improves durability, and increases strength. Microsilica has been used for construction applications such as high-strength normal and lightweight concrete, concrete with very low permeability, reduction of cost by saving cement, and reduction of chemical attack (by sulfate and acidic waters) (Bubshait et al., 1996). In oil well cement microsilica will also improve both the fresh and hardened properties. Typical improvements in fresh properties are reduced free water and fluid loss, also improved stability. In hardened cement, microsilica will give better strength and bonding, reduced permeability, improved durability, and less strength retrogression (Grinrod et al., 1988). Silica fume particle size is very small (less than 0.5 μm) and therefore can enter the filter cake and lodge between the cement particles, block the narrow passage of fluid, and finally decrease the permeability of the cement cake (Shadizadeh et al., 2010).

2.4 Expanding Additive

The expanding additive is an additive that can facilitate the development of the cement matrix by promoting the formation of foreign crystals within it. The timing of this development is crucial for enhancing shear bond strength. Thus, the reaction can be controlled by choosing the appropriate material, adjusting the combustion temperature, and controlling the fineness of the material used. Cement experiences volume shrinkage after it dries beyond its setting time, leading to fractures during tensile strength development. Expanding cement is designed to counter this issue by expanding during this critical period, effectively addressing the problem of volume shrinkage.

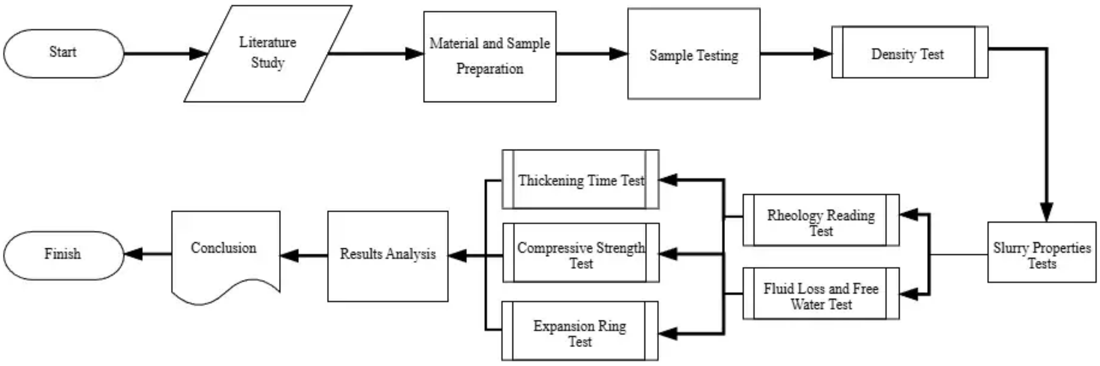

Fig 1. Research workflow

Cement systems that expand after set can reduce micro-annulus and improve primary cementation results (Saroyo et al., 2010).

2.5 Expanding Cement

Expanding cement utilized in oil well applications is engineered to enhance the structural integrity of the cement sheath and improve zonal isolation. Upon setting, this cement exhibits slight expansion, effectively filling any voids between the cement, casing, and formation, thereby mitigating the risk of gas or fluid migration. The expansion characteristics of this cement significantly augment its sealing efficiency, particularly under challenging conditions such as thermal fluctuations and high-pressure environments. This technology offers multiple advantages, including superior adhesion to the casing and formation, increased resistance to fluid penetration, and improved mechanical properties of the cement sheath. Consequently, these enhancements contribute to more reliable well integrity, minimizing the likelihood of costly remedial operations by ensuring the cement maintains robust bonding and prevents the formation of micro-annuli or other leakage pathways (Jones & Carpenter, 1991).

2.6 Expansion Ring Test

Expansion ring tests use expansion molds to simulate the expansion properties of cement compositions expansion properties in a well's annulus. As the cement slurry dries to a solid during the setting-up period, the cement composition must expand sufficiently to form a good bond with the well casing and the borehole's wall. Otherwise, if the cement shrinks during the hardening process is usually called micro-annulus. Microannulus may form between the borehole wall and the cement column, and between the cement column and the well casing. (Cement Test Equipment Inc., 2017).

3. Methodology

3.1 Research Flow and Method

In this research, the method (**Figure 1**) used is the experimental approach in the laboratory, which consists of the slurry properties test, fluid loss and free water test, thickening time test, compressive strength test, and will end up with expansion ring test. The primary focus in this research is on testing microsilica, will it be a solution for expandable cement. The research begins with a literature study, followed by the collection of the design composition of slurry data, material preparation, sample testing, analysis of the result, and finishing the experiment with conclusions of this research.

3.2 Experimental Material

In this research, some materials are needed to provide the composition of the cement slurry. This test will focus on the use of microsilica which will be compared with the use of an expanding additive in the cement slurry to get the effect of microsilica in the expanding cement. To conduct this research, there are some required materials to support the slurry, The materials are listed in **Table 1** below(Al-Yami et al., 2017).

Class “G” Cement is used as the primary material due to its high early strength and suitability for oil well cementing. Its properties make it ideal for achieving the desired performance criteria in the wellbore environment. Fluid Loss Additive (FLA) is used to control the loss of fluid to the formation, ensuring the cement slurry maintains its essential properties during placement and helping maintain the slurries integrity and effectiveness. Defoamer is used to control the foam that develops while mixing the slurries. Its crucial in the mixing process cause if foaming can develop while mixing as many cement additives can contribute to foaming and it will impact the density of cement slurry and undesirable properties such as slurry gelation. A retarder is used to extend the setting time of a cement system, preventing pre-mature setting in high temperatures, and allowing adequate time for placement. Microsilica (MS), or kindly known as a gas block additive, is the main focus of this research. This additive has a significant role in preventing gas migration through channeling on cement and contributes to the overall stability and performance of the cement slurries. This study will determine the effect of microsilica on expanding performance cement slurry. Expanding Additive (EA) prevents gas migration through micro-annulus by minimizing the cement shrinkage phenomenon after hardening. This additive is used to increase the expanded performance of cement slurry. The materials required above such as “G” cement, FLA, defoamer, and retarder are designated as the base slurry. The materials required above such as “G” cement, FLA, defoamer, and retarder are designated as the base slurry. Therefore, the slurry composition used in this study is shown in **Table 2** below.

The slurries made will go through the mixing stage following API standards. In this study, the selection of mixer speed was 4,000 rpm in 90 minutes and continued with

Table 1. Research materials

Research Materials	Function
Class “G” Cement	Primary cement material
Fluid Loss Additive	Control fluid loss in cement slurry
Defoamer	Reducing foam during mixing
Retarder	Prevent cement from setting to rapidly
Microsilica	Prevent gas migration in cement slurry
Expanding Additive	Prevent shrinkage of cement slurry

Table 2. Expanding-cement slurry composition

Slurry	Fresh Water Sg = 1.00 (ml)	Defoamer Sg = 0.88 (ml)	Fluid Loss Sg = 1.094 (ml)	Retarder Sg = 1.065 (ml)	Microsilica Sg = 1.390 (ml)	Expanding Additive Sg = 3.360 (gr)	“G” Cement Sg = 3.15 (gr)
1 (Base + MS)	303.2	1.2	40.0	2.0	40.0	-	800.0
2 (Base + EA)	335.0	1.2	40.0	2.0	-	32.0	800.0
3 (Base + MS + EA)	318.7	1.2	40.0	2.0	40.0	32.0	800.0

12,000 rpm in the last 15 minutes of the mixing process to avoid clumping in the slurry.

3.3 Laboratory Testing

In technical, the tests are all performed following API RP 10-B standard (American Petroleum Institute, 1997). The experiments used two temperature conditions for the testing. Tests that run with circulating motion will use samples with temperature conditions of 60 OC (BHCT). Meanwhile, tests that run without rotating or static movements will use samples with temperature conditions of 90 OC (BHST).

*Density Test***.** Density measurements of each sample were carried out using a pressurized mud balance. This measurement is carried out shortly after the mixing process. The density measurement process is carried out by measuring the weight of the volume of the cup containing cement slurry until it gets the most appropriate weight on the arm balance as evidenced by the tool being balanced / stable.

Rheology. In rheology measurement, each sample will go through a conditioning process using an atmospheric consistometer to reach BHCT (Bottom Hole Circulating Temperature) condition. Then the data is read at speeds of 3, 6, 100, 200, and 300 rpm using a viscometer. After obtaining the readings at each rotor speed used, the Plastic Viscosity (PV) and Yield Point (YP) values of each sample can be calculated using the Bingham Plastic model. This test is carried out to measure the viscosity of each sample.

Fluid Loss and Free Water. In the fluid loss and free water measurement, each sample will go through a conditioning process using an atmospheric consistometer to reach the BHCT (Bottom Hole Circulating Temperature) temperature. In the fluid loss test, the sample will be tested within 30 minutes using a High-Pressure High-Temperature (HPHT) Filter Press which will be pressurized by 1000 psi of nitrogen gas injected into the fluid loss test apparatus. The volume of filtrate released from the sample will be recorded and used to obtain the actual value of fluid loss using **Equation 1** (American Petroleum Institute, 1997).

$$\text{Calculated ISO Fluid Loss} = 2\,Q_t\,\frac{5.477}{\sqrt{t}} \tag{1}$$

where Q_t is the volume of filtrate obtained from the test in millimeters and t is the duration of the test in minutes.

Meanwhile, the free water test only requires a measuring cup with a capacity of 250 ml and requires a longer time of about 120 minutes. If there is free water formed from the sample after the test time is complete, the free water content value without pressure can be calculated with **Equation 2** (American Petroleum Institute, 1997).

$$\varphi = \frac{V_F}{V_S} \text{ x } 100\% \tag{2}$$

where φ is the volume friction, in units of %, V_F the volume of free water formed, in units of millimeters, and V_S is the volume of slurry, in units of milliliters.

Compressive Strength. In the compressive strength measurement, each sample will go through a conditioning process using an atmospheric consistometer to reach the BHCT condition. Then the sample will be tested for 24 hours using an Ultrasonic Cement Analyser (UCA) with a non-destructive test for the samples.

Thickening Time Test. In the thickening time test, each sample to be tested needs to reach the BHCT condition by conditioning the samples using an atmospheric consistometer first before testing the sample to find the time for the tested sample to reach the consistency value at 40, 50, 70, and 100 Bc using the HPHT Consistometer tool.

Expansion Ring Test. In this expansion ring test, each sample to be tested will be spontaneously poured into the expansion ring tool until the volume of the tool is fully loaded. Before the expanding mold containing each sample is put into the water bath to reach BHST temperature

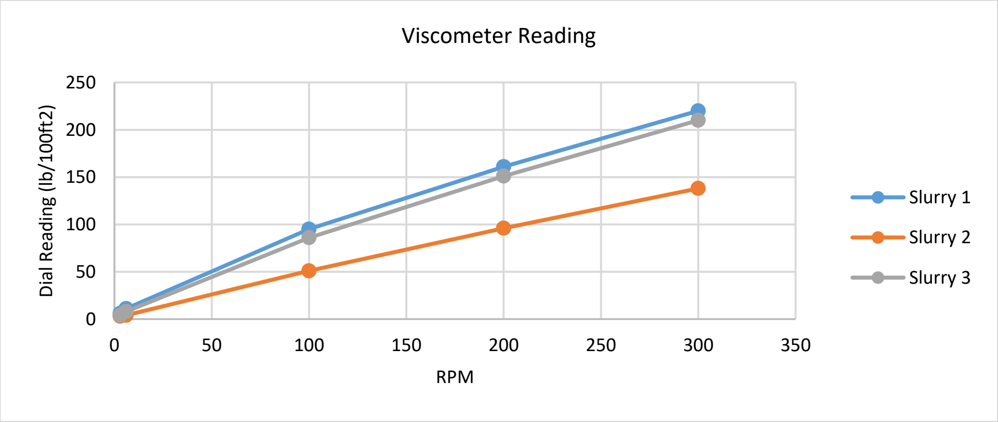

Fig 2. Viscometer reading comparison graph

Table 3. Viscometer reading result

RPM	Slurry 1 (Base+MS)	Slurry 2 (Base+EA)	Slurry 3 (Base+MS+EA)
θ_{300}	220	138	210
θ_{200}	161	96	151
θ_{100}	95	51	86
θ_{6}	11	4	8
θ_{3}	6	3	4

conditions, the sample will be measured through the distance across the pins of the expanding mold and measured using a digital micrometer. In this test, the test was carried out for 3 days or 72 hours and checked periodically every 24 hours to record the development or shrinkage that occurred in the tested sample.

4. Results and Discussion

4.1 Density Test

Density testing from the use of pressurize mud balance tools obtained results in each sample, namely Slurry 1, Slurry 2, and Slurry 3 in accordance with the target requirement of 15.8 ppg. The results of the test can be seen and represented in **Figure 4.1**.

4.2 Rheology Test

Table 3 and **Figure 2** above are the results of reading rheology from testing using a viscometer on the three samples in circulating temperature conditions or BHCT. These results explained that the results of the thickening time of each sample can be seen at rotor speeds 300, 200, 100, 6, and 3 RPM. In sample 1, the results obtained from the rotor speed (RPM) at 300, 200, 100, 6, and 3 RPM are 220, 161, 95, 11, and 6. Then, in sample 2, the results obtained from the rotor speed (RPM) at 300, 200, 100, 6, and 3 RPM are 138, 96, 51, 4, and 3. Then in sample 3, the results obtained from the rotor speed (RPM) at 300, 200, 100, 6, and 3 RPM are 210, 151, 86, 8, and 4.

Based on the plastic viscosity results generated from each sample in **Table 4** and **Figure 3** below, it can be seen that the use of microsilica in samples 1 and 3 has a significantly higher viscosity compared to sample 2 which does not use a mixture of microsilica in it. So, it can be concluded that when the microsilica content is used in the slurry, the viscosity or viscosity of the slurry is increased with evidence of an increase in the reading viscometer value of 37.27% at 300 RPM and an increase in the viscosity value of approximately 30% from the first and second slurry. From the results of the plastic viscosity of each cement slurry with the rise in the composition of microsilica used in the slurry, it gives a higher viscosity value and will affect the level of pumpability of the cement slurry, it can be concluded that the use of microsilica in cement slurry can have a negative effect, where referring to API the tolerance value of viscosity given by API is below 200 cP (Nur et al., 2005). Therefore, the use of microsilica as an additive in cement slurry needs to be adjusted to the needs of the field later.

4.3 Fluid Loss and Free Water Test

Table 5 below is the result of fluid loss and free water released from slurry samples for 30 minutes with a pressure of 1000 psi under circulating temperature conditions or BHCT. The results above show that the fluid loss from Slurry 1, Slurry 2, and Slurry 3 respectively is 22 ml, 26 ml, and 24 ml and the free water formed in each sample is 0 ml. From the results, it can be concluded that the use of microsilica in the slurry will have a positive impact on the results of fluid loss and free water from cement slurry by reducing the volume of filtrate released from the slurry and avoiding the formation of free water in the slurry.

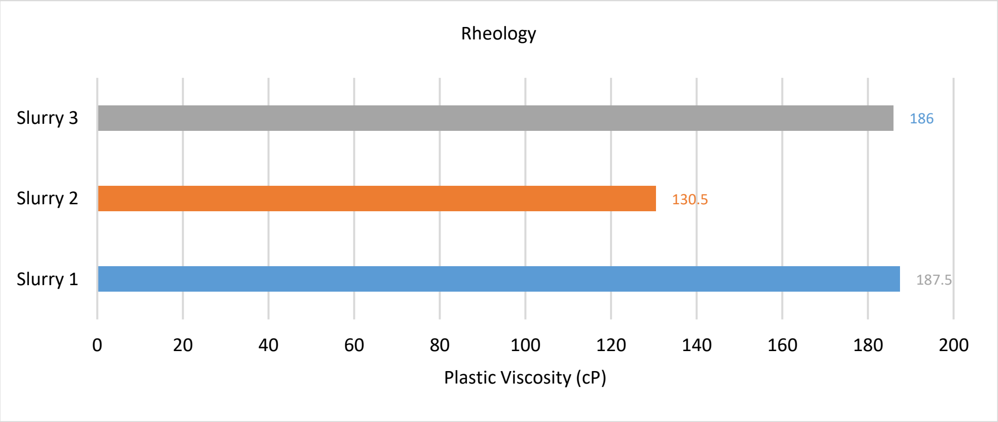

Fig 3. Viscometer reading comparison graph

Table 4. Bingham plastic calculation result

Result	Slurry 1 (Base+MS)	Slurry 2 (Base+EA)	Slurry 3 (Base+MS+EA)
Plastic Viscosity (cP)	187.5	130.5	186
Yield Point (lb/100ft^2)	32.5	7.5	24

Table 5. Fluid loss and free water test results

Result	Slurry 1 (Base+MS)	Slurry 2 (Base+EA)	Slurry 3 (Base+MS+EA)
Fluid loss*	22	26	24
Free water (ml)	0	0	0

* Reported as the amount of fluid loss (ml) after 30 minutes under 1000 psi of pressure difference

4.4 Thickening Time Test

The result of the thickening time test using the HPHT Consistometer is shown in **Table 6** above. In the results above, it is explained that the results of the thickening time of each sample can be seen when the slurry reaches 40 Bc, 50 Bc, 70 Bc, and 100 Bc. In Slurry 1, the results obtained when the slurry reaches 40 Bc, 50 Bc, 70 Bc, and 100 Bc are 4 hours 28 minutes, 4 hours 30 minutes, 4 hours 43 minutes, and 4 hours 48 minutes respectively. In Slurry 2, the results obtained when the slurry reaches 40 Bc, 50 Bc, 70 Bc, and 100 Bc respectively are for 6 hours 50 minutes, 6 hours 55 minutes, 7 hours 1 minute, and 7 hours 5 minutes. In Slurry 3, the results obtained when the slurry reaches 40 Bc, 50 Bc, 70 Bc, and 100 Bc respectively are for 4 hours 10 minutes, 4 hours 17 minutes, 4 hours 23 minutes, and 4 hours 28 minutes. There is an anomaly in the Thickening Time Comparison Chart which is from Slurry 3 at around 33 Bc and 244 minutes, the data was down to 0 Bc. This phenomenon might be happening by the potentiometer of the used Consistometer did not read the sample at that time.

With the results obtained and the graph formed in **Figure 4** below, it can be seen that the use of microsilica as an additive in cement slurry has a significant effect on reducing the time it takes for the slurry to enter the setting phase. With this, it can be concluded that the use of microsilica has a negative impact on cement slurry because the shorter thickening time in oil well cement will affect the pumping time of the slurry and lead to inadequate placement and premature setting, resulting in poor zonal isolation, increased risk of gas migration, and certain well integrity problems. (DeBrujin, 2024).

4.5 Compressive Strength Test

The results of the compressive strength test using UCA are shown in **Figure 5**, which show the process of slurries to achieve the final strength. In the results obtained, it can be seen that the pressures owned by Slurry 1, Slurry 2, and Slurry 3 are 3264 psi, 2839 psi, and 3290 psi respectively. With the results obtained, it can be concluded that the use of microsilica as an additive in cement slurry can have a

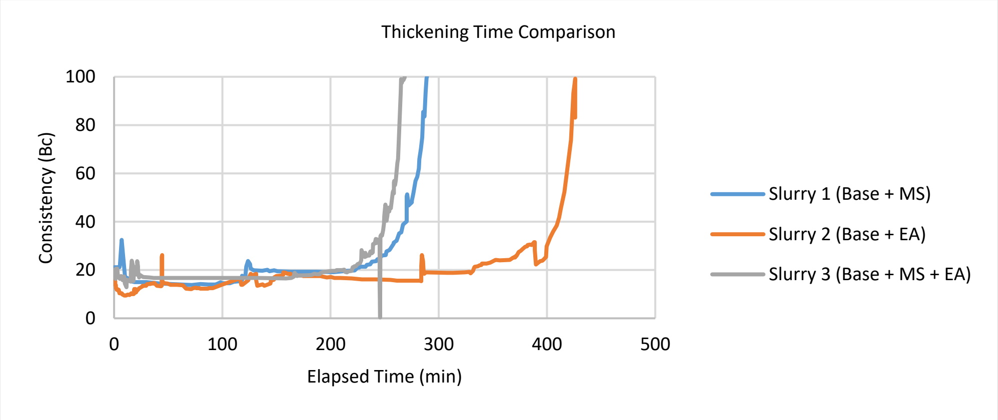

Fig 4. Thickening time comparison graph

Table 6. Thickening time test results*

Consistency (Bc)	Slurry 1 (Base+MS)	Slurry 2 (Base+EA)	Slurry 3 (Base+MS+EA)
40	04:28	06:50	04:10
50	04:30	06:55	04:17
70	04:43	07:01	04:23
100	04:48	07:05	04:28

*Reported as elapsed time (in hh:mm time format) to reach a certain consistency

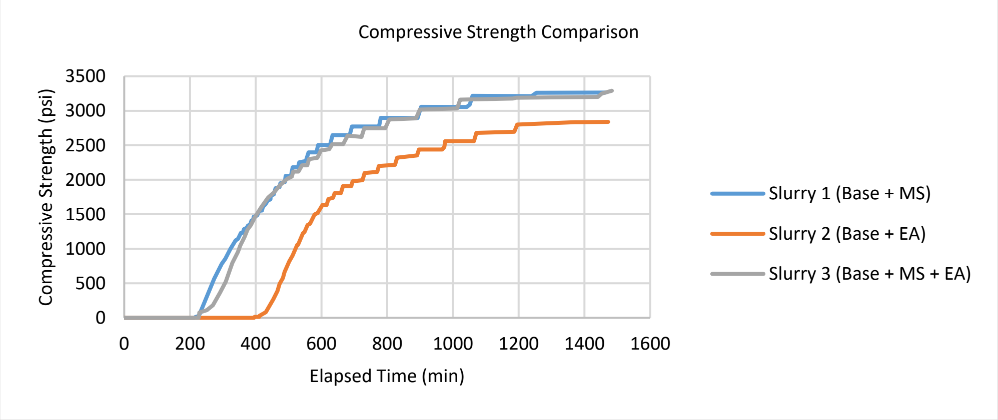

Fig 5. Compressive strength comparison graph

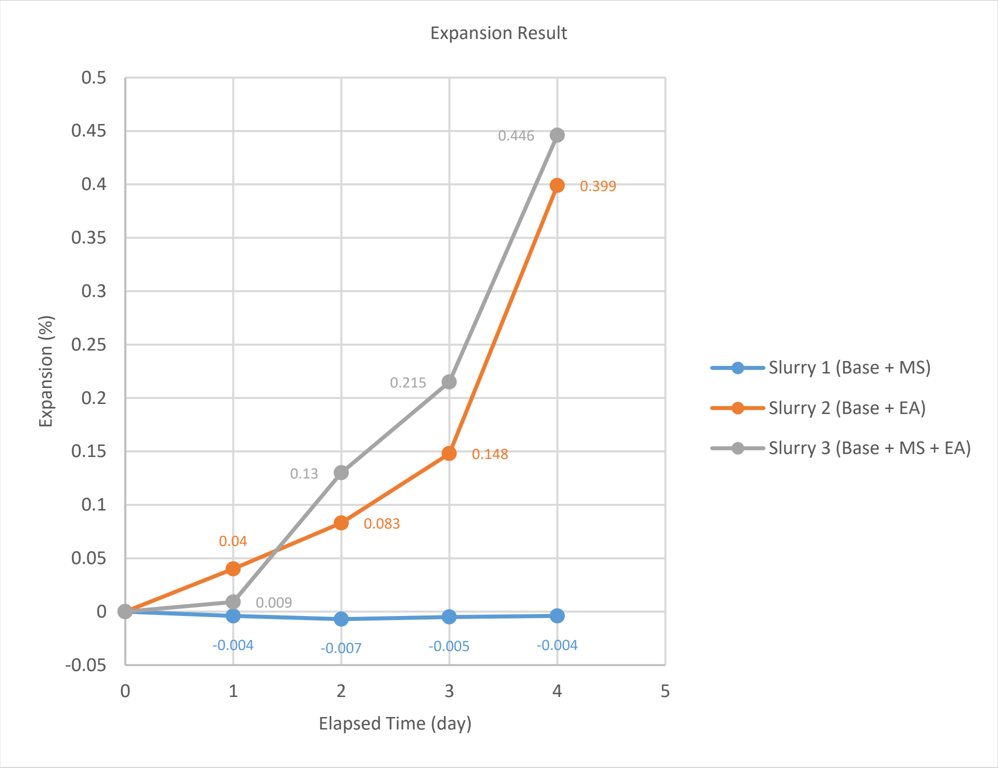

Fig 6. Expansion ring test comparison graph

Table 7. Expansion ring test result

Elapsed Time (hour)	Slurry 1 (Base + MS)		Slurry 2 (Base + EA)		Slurry 3 (Base + MS + EA)	
	Width of expansion mold (mm)	Expansion percentage (%)	Width of expansion mold (mm)	Expansion percentage (%)	Width of expansion mold (mm)	Expansion percentage (%)
Start	14.992	-	15.032	-	14.985	-
24	14.981	-0.004	15.145	0.04	15.010	0.009
48	14.972	-0.007	15.263	0.083	15.347	0.130
72	14.977	-0.005	15.446	0.148	15.585	0.215
96	14.980	-0.004	16.146	0.399	16.231	0.446

positive impact on cement strength, namely the effect on the final strength of cement obtained is greater than Slurry 2 with composition without the use of microsilica.

4.6 Expansion Ring Test

Table 7 above is the result of testing the expansion/ shrinkage of cement using an expansion mold on the three samples under static temperature conditions or BHST. In the results above, it is explained that the results of the expansion ring test for each sample can be seen as the expansion percentage generated in each slurry after reaching the test time of 24 hours, 48 hours, 72 hours, and 96 hours.

In Slurry 1, the results obtained from testing for 24 hours, 48 hours, 72 hours, and 96 hours respectively are -0.004%, -0.007%, -0.005%, and -0.004%. In Slurry 2, the results obtained from testing for 24 hours, 48 hours, 72 hours, and 96 hours respectively are 0.040%, 0.083%, 0.148%, and 0.399%. In Slurry 3, the results obtained from testing for 24 hours, 48 hours, 72 hours, and 96 hours respectively are 0.009%, 0.130%, 0.215%, and 0.446%

Based on the results in **Table 7** and clarified by the graph of the expansion ring test results in **Figure 6** below, in Slurry 1 until 48 hours of testing there is a shrinkage that occurs before the cement can expand gradually. When compared to slurries 2 and 3, without any assistance of EA, cement requires a relatively long time to get the expansion effect on cement. This is expected because basically cement has a shrinkage phase after the cement hardens or known as drying shrinkage where after the cement hardens, the water contained in the cement leaves the concrete (hydration process) and results in volume changes. In addition, volume reductions can occur by thermal contraction. (Tran et al., 2021)(BASF Corporation, 2016).

In the comparison of slurries 2 and 3, the addition of microsilica to Slurry 3 is seen to have a considerable effect on cement expansion performance. Therefore, it can be concluded that the addition of MS can have a positive impact on improving the expansion performance of the cement after it hardens. However, it should be noted that under some conditions achieving cement expansion performance still requires the presence of EA in the cement slurry.

Table 8. Effect of microsilica on cement slurry

Physical Properties	**Effect**	**Description**
Rheology	Negative	Increased viscosity will affect the pumpability of the cement slurry.
Fluid Loss and Free Water	Positive	Reduction in the volume of filtrate released from the slurry and avoiding the formation of free water in the slurry.
Thickening Time	Negative	Shorter thickening time will affect the pumping time of the slurry.
Compressive strength	Positive	Improved cement strength
Expanding	Positive	Being an addition to improve cement expanding performance after cement hardened.

4.7 Result Summary

Table 8 above is the results summary from all tests of microsilica effect on cement physical properties. In these results, the use of microsilica in cement slurry had a positive effect on several properties such as fluid loss, free water, compressive strength, and expanding properties. Meanwhile, the existence of microsilica in the cement slurry has a negative effect on rheology and the thickening time properties.

From rheology properties, the use of microsilica on cement slurry has given a negative impact by increasing the viscosity of cement slurry which affects the pumpability of the cement slurry. In fluid loss properties, using microsilica has reduced the volume of filtrate released from the cement slurry. In terms of free water properties, the use of microsilica has support to avoid the form of free water in the cement slurry. In the compressive strength, the use of microsilica has improving cement strength. In the expanding properties, the use of microsilica has improved the cement expanding performance after cement hardened. However, to achieve this effect, the cement still needed the main additive to expand (which is expanding additive) then the microsilica will be an addition to the cement slurry composition.

5. Conclusions

This study demonstrates that microsilica plays a complementary role in enhancing the performance of expanding cement systems. Among the three formulations tested—Slurry 1 (Base + Microsilica), Slurry 2 (Base + Expanding Additive), and Slurry 3 (Base + Microsilica + Expanding Additive)—only the combined system delivered the most effective expansion behavior. Slurry 3 consistently showed the highest and fastest expansion development over time, outperforming Slurry 2, which exhibited only moderate expansion when using the expanding additive alone. In contrast, Slurry 1, which contained only microsilica, did not expand and instead experienced slight early shrinkage before stabilizing. These observations confirm that microsilica alone cannot provide expansion but works synergistically with expanding additives to improve the expansion performance and reduce shrinkage. Additionally, microsilica contributed positively to reducing fluid loss, eliminating free water, and increasing compressive strength, although it also increased viscosity and shortened thickening time. Overall, microsilica is beneficial as a supporting additive in expanding cement systems when properly balanced with an expanding agent, enhancing long-term sealing integrity while requiring careful management of its effects on slurry handling and placement.

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