

Research Article

Restoration of Reservoir Caprock: Long-Term Wellbore Sealing and Abandonment through Zeolite Enhanced Cement

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Abstract

Oil and gas wellbores that are drilled into the earth's crust need to be plugged and abandoned, to restore the geological seals once they are no longer producing. The main aim of Plugging and abandonment (P&A) is to ensure that there is no leakage of hydrocarbons into the environment. Since offshore P&A is challenging due to subsurface temperature and pressure conditions, testing zeolite as an additive for improvement of cement properties is an intriguing research topic. This initial research aims to establish the chemical properties of zeolite when added to cement to hypothesize the mechanism of cement property enhancement. This work consists of the initial results in which the microstructural characterization of a naturally obtained zeolite ferrierite (FER) was done to compare it with the existing observations from the literature. Ferrierite was observed to have a needle like orthorhombic crystal structures and spherical crystal aggregates. The chemical composition was confirmed through EDS studies as it is made up of aluminum silicate crystals and proof was shown that the zeolites maintained chemical stability in the cement matrix even after



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hydration. Morphological characterization also showed features that indicated possible self-healing in commercial zeolite cement formulations used for geothermal wells, which was studied as a reference. The phase stability was indicated by XRD studies with ferrierite peaks observed at 2θ values of 25.195 and 25.5204 and it was differentiated in comparison to plain Class-H cement which did not have those peaks. A preliminary strength testing had also shown an improvement in 5% FER added Class-H cement in comparison to 15% and 30% FER added Class-H cement formulations which is promising for further studies.

Keywords

Plugging and abandonment; cement; zeolite; supplementary cementitious materials; Class-H cement; ferrierite

1. Introduction

Plugging and abandonment of deep sub-surface wellbores had faced many challenges over the years. If a cement plug encounters a failure due to harsh temperatures or pressure conditions, or even a low-quality cement plug job, the surrounding ecosystems are damaged due to leakage of hydrocarbons. This is especially a matter of concern for fragile ecosystems like the Gulf of Mexico (GoM). This research seeks to enhance safety by preventing wellbore leakage, protecting environment from oil/gas contaminations, and catalyzing scientific advances benefitting the GoM region and eventually other offshore regions. In addition, advancements in wellbore construction and restoration of subsurface barriers are also required in geothermal energy production as well as in CO₂ geological storage.

The objective of this research is to achieve a near cap-rock like barrier material from engineered materials such as enhanced Portland cement. A survey of the existing literature gives us an initial idea of the advances in this research. This gives us an insight into the drawbacks of Portland cement and how addition of various supplementary cementitious materials (SCMs) helps overcome those. A good barrier material must possess the following features in comparison to the available cement designs (Table 1).

Table 1 Major properties required to achieve a desired Barrier material for P&A.

Property	Low porosity and permeability	Higher strength and more resilience	Better compatibility with sub-surface geology	Chemical stability and resistance to subsurface chemicals	High pressure and High temperature (HPHT) durability.
Advantage	Prevents leakage of hydrocarbons and leaching of invasive and corrosive chemicals	Prevents fractures and sustains the well integrity over a longer run and ensures that the wells do not leak.	Sub-surface compatibility would improve the sealability of P&A materials preventing unwanted leakage through de-bonding pathways.	Makes the cement plug stable at adverse chemical conditions seen in sub-surface as a result improves the longevity of the plug.	Keeps the plug and wellbores stable at HTHP conditions observed downhole.

These properties can be achieved by choosing the right material and optimized slurry design. Brady et al. mentions the importance of choosing the right cement slurry among the various technologies that are used in wellbores like those in Gulf of Mexico [1]. Noting the importance of the right plugging material, this research is directed towards finding a solution for the right formulation to be used to create a robust barrier. Portland cement is the most common base hydraulic barrier material which has been used for wellbore construction and plugging applications [2-4]. Many challenges have been seen especially in plugging of deep-water wells [5]. Rassenfoss et al. also hints on the usage of additive materials in cement to enhance the properties as a scope for future research. A detailed review about various plugging materials and methods was done by Achang et al. which emphasized on various shortcomings of current P&A methods and the potential ways to overcome those [6]. Class-H cement has been one of the preferred materials for offshore plugging purposes like in the Gulf of Mexico (GoM). Various SCMs used in earlier research like Pozzolans, Fly ash, Blast furnace slag, Silica fume and the like had been explored as a part of this literature search. Zeolites were one of the natural minerals which had piqued our interest since they had properties on par with all the earlier used SCMs and even better in some cases. The morphology of zeolites being similar to the aggregates in the cement hydration makes it more compatible with the cement. The increase in strength and chemical stability had been observed in the literature. One very important property that had been observed in zeolite added cement was self-healing which would come in handy when we have failure or micro fractures in cement. Before moving on to Class-H studies, it is important to get an idea of how zeolites interact with Portland cement in general, and how zeolites perform in comparison to other well-known cement additives.

Blast furnace slag had been used to give thermal stability to concrete and was found to be effective at temperature ranges of ~200-300°C [7]. The mechanism of Blast furnace slag in cement was further studied by Luke et al. [8]. Silica fume had also been used in cement which had shown a reduction in the porosity and permeability and had also shown some advantages in the rheological properties of cement [9]. Pozzolana, like lime and metakaolin, had been used for ages and had

shown better hydration strength properties in cement as they actively took part in the hydration reaction and had also contributed to late strength development due to the same [10]. Olivine was another natural mineral which was used by various researchers. A latest account was seen in the work of Achang et al. [11] where it was observed that the Olivine microparticles act as microfillers and enhance the strength and chemical stability of the resultant cement cores. Fly ash has also been a very popular additive which had shown to increase the strength of cement by taking part in cement hydration, and also showing filler effect similar to silica fume occupying the pore spaces and reducing the porosity and permeability of resultant cement [12-14].

Feng et al. [15], Poon et al. [16], Ahmadi et al. [17], and Chen et al. [18], had shown an increase in the strength of the cement composition on addition of zeolites. Lilkov et al. [19], had done an extensive study on how addition of various zeolites affects the hydration of cement by studying the hydration products of cement. Poon et al had also shown that the porosity of cement samples was affected by the addition of zeolites. Perraki et al. [20], has studied the early hydration characteristics of cement on addition of zeolites. The effect of zeolite addition had also been compared with silica fume and metakaolin additions by Valipour et al. [21]. Markiv et al. [22] and Linek et al. [23] had tested the freeze thaw resistance, as well as the drying shrinkage properties of zeolite added cement. Pacewska et al. [24] had studied the effect of waste zeolites from Fluidized Bed Catalytic cracking on hydration properties of cement. Najimi et al. [25] had studied the effect of adding zeolites on resistance towards sulfate attack, workability, as well as freeze thaw resistance. Nagrockiene et al. [26] had shown the effect of zeolite additions on strength, freeze thaw resistance, and lowered water absorption. Zeolites are shown to improve the strength properties by being added as a cement replacement [27-29] as well as improve the performance of cements at high temperatures and pressures. They were also shown to improve the chemical stability of cement [22, 25, 26, 30]. The hydration properties have also been improved owing to the improved surface area provided as a substrate for hydration to take place, which is due to the periodic porosity seen in zeolites, which helps in transfer of ions during the hydration reaction creating a very good hydration matrix [16, 18, 20, 30]. Shahrabadi et al. had shown the improvement of strength and better performance of cement in sea environments upon addition of zeolites [31-33] which suggests the suitability for our application. The performance of cemented sands had been found to be improved on addition of zeolites which indicates that we could achieve compatibility with formation and hence a better seal [34]. A promising property of zeolite enhanced cement, which had been explored in earlier studies, was the self-healing property of concrete [35, 36]. Autogenous self-healing properties of zeolite additions in cement were studied by Su et al. [36]. In this paper, it was noted that higher percentage additions of zeolite showed a decrease in the strength after healing, which could be attributed to the "blocking effect". The addition of a particular zeolite in cement had also been found to show this property according to the work of Pyatina et al. [37] at Brookhaven National labs. The formulation used in these studies was the one that was adopted to obtain the low-density commercial zeolite cement used in geothermal applications. We would be using this zeolite cement in our studies to observe the interaction of zeolite with cement. The zeolite in consideration in this paper is ferrierite. The properties of this zeolite were studied extensively by Rice et al. [38] giving a very clear picture of the morphological structure which formed the basis of our initial study of this mineral. Work had also been done on optimizing the composite formulation with zeolites for better performance [39-41], and based on all this literature, we have a good basis for our work. To understand the macroscopic property enhancement, it is essential to understand the mechanisms

of cement hydration which take place at a nanoscale on the substrate level as observed by Scrivener et al. They had done an in-depth study into the mechanisms of hydration and the rate controlling steps [42-44]. Studies were also done showing the stability of zeolites in the cement matrix [45]. This provides us the basis for the mechanism that could be observed from cement and this research aims at filling the knowledge gap of how addition of ferrierite zeolite would alter these mechanisms and eventually the macroscopic properties of cement.

The use of zeolites had been relatively new in cement compared to other SCMs. They have morphologies like CSH particles from cement hydration and hence can be compatible with cement. From all the available literature, addition of zeolites had shown improvement in the performance of cement. In this research, we aim to understand the mechanism in which the zeolite acts during hydration which results in these properties. To do that, we characterize the zeolite in the first step. The zeolite chosen for this study is Ferrierite which had been used earlier in a commercially available geothermal well cement. The morphological studies would be done using tools like SEM (scanning electron microscope) and TEM (Transmission Electron Microscopy). Chemical and elemental analysis would be done using the EDS (Energy dispersive X-ray spectroscopy). The phase studies and the mineral identification studies would be done using XRD (X-Ray Diffraction). UCS (Unconfined compressive strength) tests would be performed on cement cores to do the strength analysis.

2. Materials and Methods

The chemical properties of a zeolite - Ferrierite would be studied in the process of this research. Zeolites are aluminosilicate minerals which have a distinct porous crystalline structure. The zeolite rock used for the studies was obtained from Lovelock, Nevada, provided by the Trabits group. The zeolite deposits are found in Antelope mining district near Lovelock in Pershing county Nevada. The mineralization is hosted in the bedded tuff in the rock formation. The zeolite cement, which was used later in our studies, was obtained from the Trabits group as well and was produced at the Maryneal plant of Buzzi Unicem company. In the first part of this study, morphological studies are done by observing the cut and polished samples of these zeolite rocks. They were cut into small pieces to have at least two parallel sides. One side was polished with up to 3 μm uniformity by using high precision polishing with an Allied Multiprep™ polisher. The samples thus prepared were observed under the scanning electron microscope (SEM) after drying and carbon coating them. Powdered ferrierite passed through a 425 μm sieve was also observed under the SEM and elemental composition was observed using the EDS. TEM was also performed at high magnifications to observe the finer morphological properties of the zeolite.

A sensitivity analysis was done earlier to understand the chemical properties of this zeolite, by exposing the powdered ferrierite to various chemical conditions like the ones observed in sub-surface [46]. A JEOL JEM-2100 Scanning Transmission Electron Microscope was used for TEM studies of the powdered Ferrierite. The samples were prepared for SEM and TEM by drying them for 24 hours before performing the analysis. Solid rock samples and cement cores were polished to smoothness of up to a uniformity of $\sim 0.6 \mu\text{m}$ and carbon coated before examining them under the SEM and performing the EDS analysis. A ThermoFisher Scios™2 Dualbeam™ SEM with ThermoFisher EDAX system and FIB capabilities was used in these studies. EDS was done on the same samples to obtain an elemental analysis by mapping the distribution of various elements in the sample giving an estimate of the distribution of phases.

XRD of the samples, was done using Bruker D8 advance X-ray diffractometer to confirm the phase present in our material and compare it with the standard ferrierite XRD data from the International Centre for Diffraction Data. This is a widely used technique for finding the mineral composition [47-49] of a material and it was used to detect zeolite and other cement mineral phases. For XRD analysis, the samples including the rock and the hydrated cement cores were made into fine powders with a uniformity of up to $\sim 425 \mu\text{m}$ and then made into pellets in the sample holder used for the XRD analysis. The XRD data was processed using Profex software (Version 4.1.0) which does the peak matching and refinement of the data using mineral and crystal data from its own BGMN database. JCPDS data was also referred to get the exact peak values of ferrierite mineral for our initial phase studies of the pure mineral.

To get an understanding of how this cement composition is going to work, we used an existing zeolite cement formulation. This is a commercially available Class-L composite well cement in which ferrierite is interground with cement clinker which has been used extensively in geothermal well construction. Intergrinding produces a bimodal particle size distribution between the harder clinker and the softer zeolite resulting in increased strength properties. Many zeolite-added cement formulations like this were claimed to be showing self-healing properties [36, 37, 50]. This formulation would help us understand the properties of the resultant cores to adapt the design for Class-H cements to be used for plugging and abandonment.

The initial study of zeolite cement included designing and making of 16 PPG slurries. This cement is usually suited for 10-13.4 PPG low density slurries and has up to 40% Ferrierite replacement in it. However, a new 16 PPG slurry design was developed with the help of industrial experts. Initially, the 16PPG designs of the zeolite were developed in our lab based on API standards for Class-H cement slurries. NextTier oilfield solutions provided the 16 PPG slurry formulation of the zeolite cement which consisted of a heavyweight agent (NWT-310) a friction reducer (KCFR-11) and a retarder (NRT-213). The slurries were made, and cores were prepared by putting them in molds, demolding after 24 hours of hydration, and curing them for 28 days in an environmental chamber at 90°C and 95% relative humidity, simulating the borewell conditions at the sub-surface. Some cement cores were cut and polished to up to $\sim 0.6 \mu\text{m}$ uniformity for initial SEM studies.

Once the properties of this zeolite (ferrierite) are thoroughly studied, it would be mixed in Class-H cement in varying proportions and tested for physical and petrophysical properties. The goal as mentioned earlier is to optimize this cement design for wellbore plugging application. Slurries with 5%, 15% and 30% additions of Ferrierite in Class-H cements are made and are currently undergoing testing. Preliminary strength analysis on ~ 28 -30 days of curing shows that 5% additions of Ferrierite have a noticeable effect on the unconfined compressive strength (UCS) of the resultant cement cores.

For the UCS tests, the samples were cut with 2:1 aspect ratio per ASTM standards, and ground parallel to within 1 thousandth/inch. Pre-test dimensions of the cement cores and their mass was measured for piston control settings. Samples were loaded at constant strain rate, $1\text{e}^{-5}/\text{sec}$. The load was applied in the following manner:

- 1) load piston actuated in stress control until 50 psi reached.
- 2) The piston was then switched to strain (position) control.
- 3) Sample is loaded at constant rate until failure, and then unloaded.

The peak stress condition was calculated from load cell force measurement and sample diameter, reported in the results section. A servo-hydraulic computer-controlled load frame from James Cox and Sons was used to perform the UCS tests.

3. Results

3.1 Elemental and Morphological Characterization

Ferrierite is basically an Aluminosilicate mineral with varying cation concentrations of Na⁺, Mg⁺, and K⁺ giving its distinct porous crystalline structure which is characteristic of zeolites. The initial part of this study is to observe the basic morphological features of the mineral characterizing it based on the features and attributes mentioned in the literature.

To perform the study, the as received Ferrierite minerals in both polished rock and powder forms, were observed using SEM and TEM. We also perform EDS to get the chemical composition of the same. Once the Morphological features are clearly observed and comparable to the literature, the chemical stability of the material was tested. The fluids used to perform these tests namely the high pH (Ca(OH)₂), Low pH (HCl), Salt conditions (NaCl), and organic fluid (oil) were chosen and the samples were placed at 95°C in order to simulate the various sub-surface chemical, and temperature conditions. This work was published earlier concluding the chemical stability of zeolite in simulated hydration and downhole conditions. Given below in Table 2 are the compositions of the various materials that were used in this study including the mineral and chemical additives that were used in making the cement slurry later. CFR-3 is the friction Reducer, and D-Air 5000 is a commercial defoamer used in our cement formulations, both acquired from Halliburton.

Table 2 Weight% of chemical composition for various materials used in cement slurry designs.

Composition	Zeolite Cement	Class-H cement	CFR 3	Bentonite	D-Air 5000	Ferrierite
Al ₂ O ₃	6.47	1.47	--	12.03	--	8.16
SiO ₂	29.65	16.28	--	78.79	1.52	82.43
SO ₃	9.48	6.97	98.81	--	61.47	--
K ₂ O	1.81	0.53	--	0.6	--	6.05
CaO	46.27	68.08	0.33	2.2	36.62	1.12
TiO ₂	0.52	0.23	--	0.26	--	0.13
MnO	0.26	0.1	--	0.06	--	0.01
Fe ₂ O ₃	5.31	5.93	--	5.72	--	1.81
ZnO	0.06	0.14	--	--	--	--
SrO	0.17	0.28	--	0.04	0.15	0.06

The SEM images are shown below in Figure 1 showing the bulk morphology of this mineral as well as TEM images magnifying the crystal morphology. EDS was performed for the chemically treated ferrierite powdered samples, which showed slight changes in the morphology and elemental composition. A detailed account was given in earlier work [38].

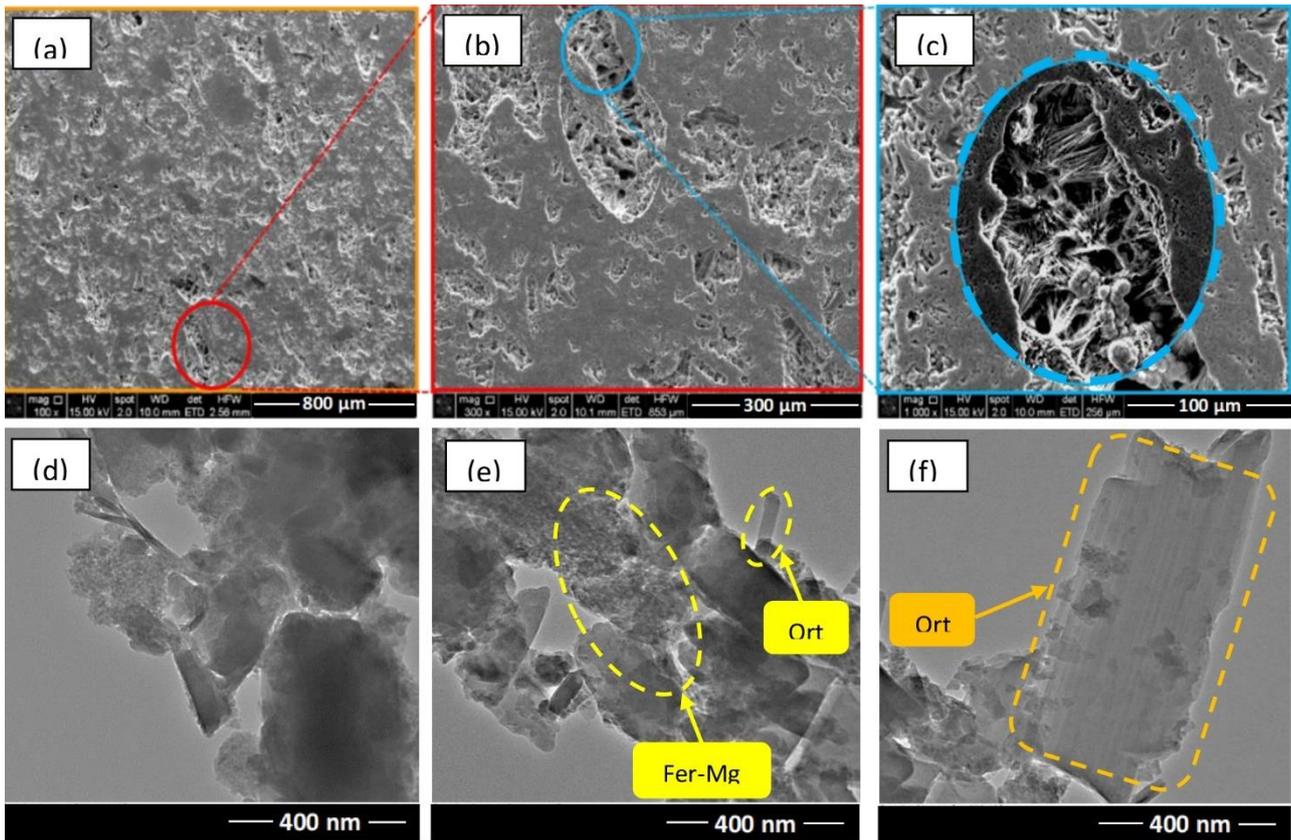


Figure 1 SEM obtained for samples of polished and carbon coated ferrierite at: (a)100x low magnification; (b) 300x Higher magnification; (c) 1000x High magnification image. The SEM shows ferrierite crystal networks. Spherical aggregates characteristic of ferrierite are highlighted in the blue oval with a higher contrast. TEM obtained for samples of powdered ferrierite at: (d)25000x magnification showing the different morphologies; (e) 30000x magnification highlighting the characteristic crystal structures of ferrierite-Mg (Fer-Mg) and orthorhombic crystal structures (Ort); (f) 30000x magnification image focusing on a single orthorhombic structure.

The chemical stability of the zeolite ferrierite under varying chemical conditions was established in earlier work [46] leading to our hypothesis that the Ferrierite would be acting more as a scaffolding structure for hydration to take place rather than directly taking part in the hydration reaction as a chemical additive. The results of SEM images from fractured areas of the zeolite cement cores prepared from the 16 PPG slurries that were developed are shown below. These observations show the unreacted Ferrierite crystals which were observed in the cement matrix as well as morphological features indicating a possible self-healing nature of these cements on addition of ferrierite, also reported by Pyatina et al. [37]. These can be observed in Figure 2 and Figure 3.

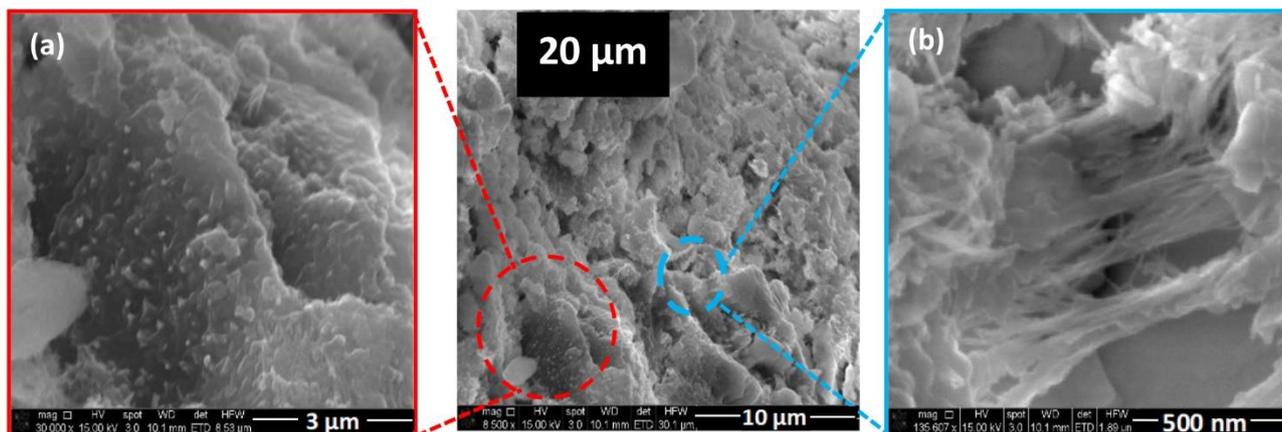


Figure 2 Fractured core samples of zeolite cement showing features like (a) 30,000x magnification under SEM showing newly hydrated crystals and (b) 135,607x magnification under SEM indicating possible self-healing properties as secondary hydrated crystals can be seen.

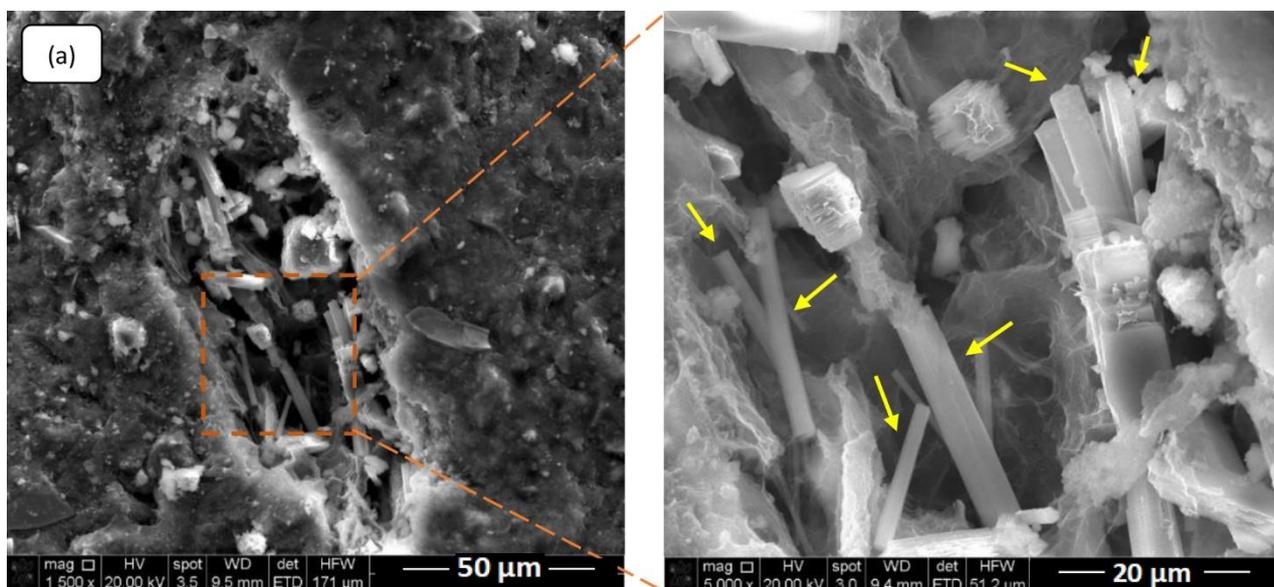


Figure 3 Unreacted Ferrierite observed in pore spaces within the cement matrix of polished zeolite cement core. (a) A pore on the cement surface of a polished zeolite cement core observed at 1500x magnification (b) Ferrierite crystals observed at 5000x magnification.

Various morphological features were observed in cement cores after cutting and polishing. Some clearly showed needle like crystal structures of unreacted zeolite present in the cement matrix, as shown in Figure 3. The phase identity is chemically unaltered, which supports the hypothesis that zeolite remains unreactive in the cement matrix during hydration, at ambient pressures. Energy dispersive spectroscopic analysis on the same samples show silicon and aluminum rich phases, which have their own regions well demarcated from the cement matrix further supporting hypothesis of unreacted zeolite grains in the cement matrix. Further studies of these phase boundaries are under way to explain the reaction mechanism of zeolite during hydration. A

composite EDS map as well as a line profile of one of the zeolite phases observed is shown below in Figure 4.

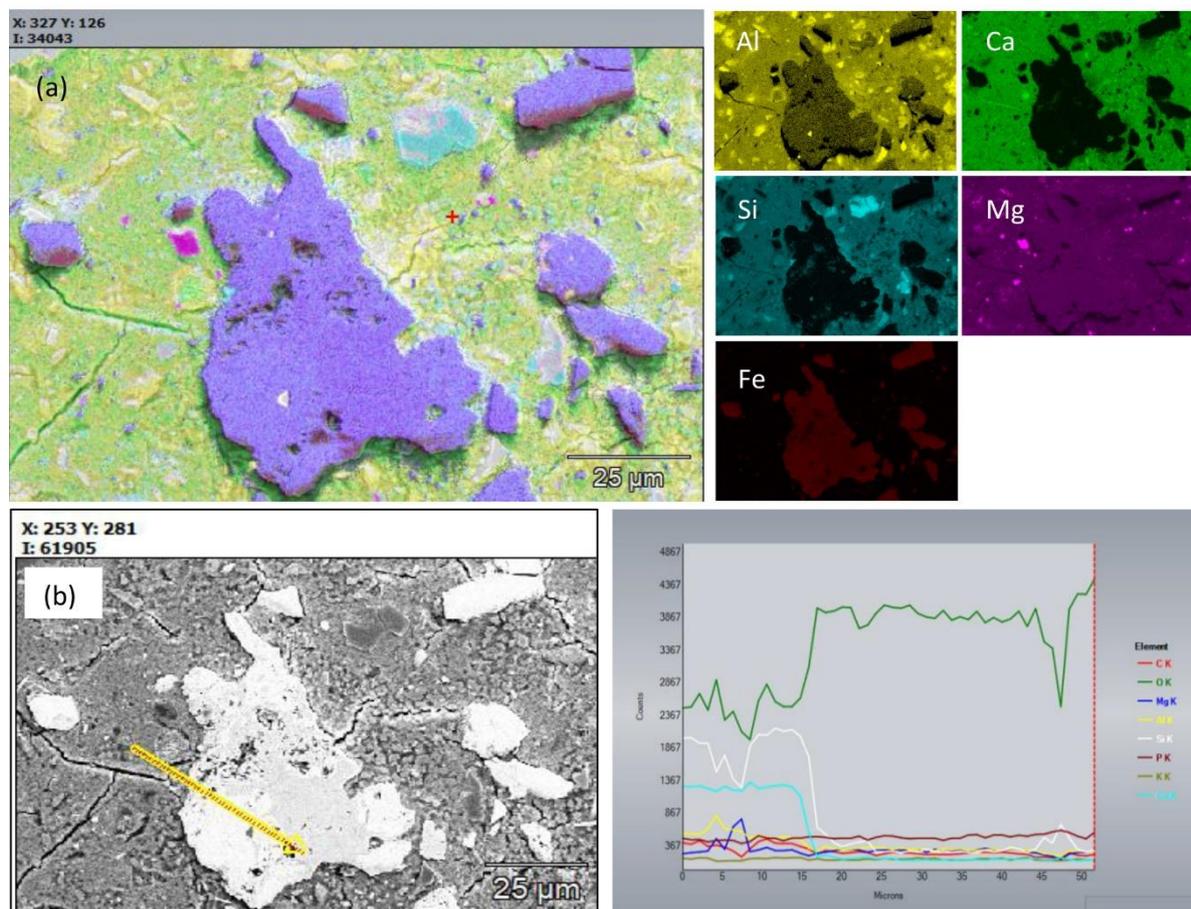


Figure 4 Unreacted Ferrierite observed within the cement matrix of polished core of commercial zeolite cement formulation. (a) A composite EDS map of feature on the cement surface of a polished zeolite cement core observed at 1500x magnification, highlighting the phase which consists of aluminum, silicon as well as traces of iron and magnesium, with a lack of calcium which is present all throughout the cement matrix, showing that the possible phase is of Ferrierite which is the zeolite used in this cement. (b) EDS line profile of the feature showing a sharp drop in the counts for calcium and silicon, which are major chemical components of cement matrix showing that this phase is foreign to cement matrix and is most likely a phase formed as a result of zeolite interaction with cement. Also the increase of oxygen content indicates the presence of oxides of aluminum and silicon which are the building blocks of zeolite.

3.2 Mineral Phase Characterization

To support the hypothesis and the above morphological and chemical observations, it is important to have an insight into the phase characteristics and how the zeolite existed as a stable phase in the resultant cement formulations on adding it to cement. The following results show the phase stability of the zeolite in cement. Figure 5 below compares the XRD results of plain zeolite with zeolite cement formulations and neat Class-H cement formulations to distinguish the phases.

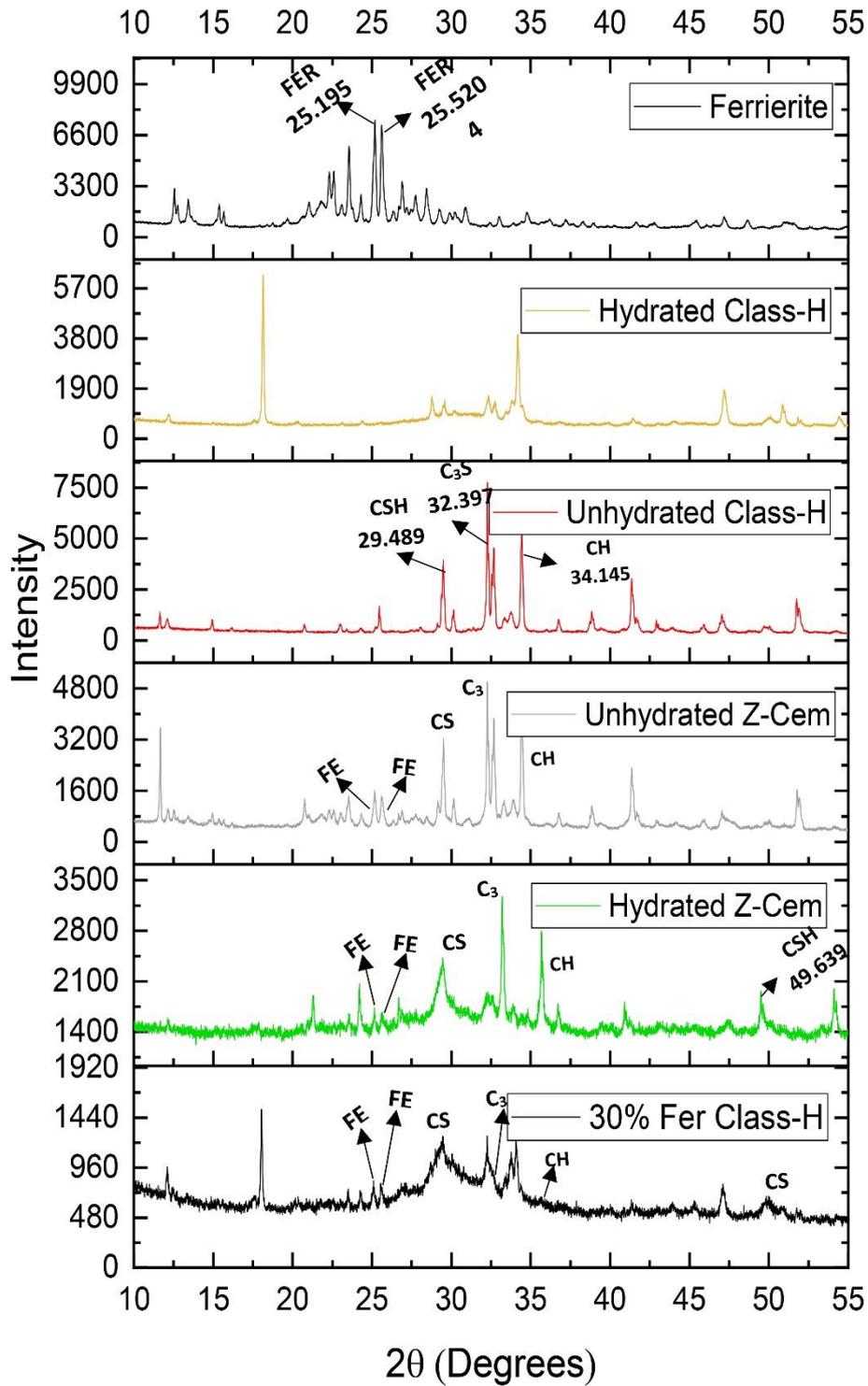


Figure 5 XRD results showing Phase comparison between Ferrierite, Hydrated Class-H, Unhydrated class-H, Unhydrated zeolite cement, Hydrated zeolite cement and, 30% Ferrierite added class-H cement (powdered Hydrated core) suggesting the initial success of Class-H cement design with ferrierite additions. The X-axis shows the 2θ values and Y-axis contains the peak intensities for in this graph, the ferrierite peaks (2θ of 25.195, 25.5204) which are highlighted in the ferrierite XRD plot are also observed in Zeolite cement and 30% Ferrierite added class-H cement. The other cement phases are highlighted to show the phase similarity in the cement matrix.

3.3 Unconfined Compressive Strength

The cement cores that were obtained from the slurry designs with 5%, 15%, and 30% additions of zeolite FER were also tested for unconfined compressive strength (UCS) and were compared to neat Class-H cement. It was noted that 5% addition of Ferrierite had shown a substantial increase in the UCS supporting the data from the literature that zeolite additions showed an increase in the strength properties. The UCS tests were performed as noted in the materials and methods section earlier in this paper. The data was acquired as follows. Table 3 below shows the axial load calculated in Kn, average UCS in psi and calculated aspect ratio of the cores. The aspect ratio of the cores taken for these tests were approximately those of the ASTM standards i.e., 2:1 aspect ratio. The specific strength enhancement of the cement on addition of 5% ferrierite is yet to be studied in detail but the current scope of this paper is limited to showing the chemical properties of the material of interest (zeolite in this case) and how it shows promising property enhancement by remaining as a stable phase in fully hydrated cement matrix.

Table 3 UCS data acquired for Class-H cement cores with different percentages of ferrierite added.

Sample No.	Sample composition	Axial load avg. (Kn)	UCS avg. (psi)	Aspect ratio
1	5% FER	34.71	9,934	1.93
2	15% FER	22.89	6,651	1.95
3	30% FER	22.02	6,319	1.94
4	Neat Class-H	35.28	7,041	1.64

Further, property enhancement on addition of zeolites (ferrierite (FER)) in the applied percentages are going to be studied in future work. This UCS data helps to observe and support the hypothesis which was made based on the studies from the literature and we partially succeed in verifying the same. Addition of zeolites had been shown to be beneficial as seen in most of the literature mentioned earlier.

4. Discussion

The initial SEM and EDS studies had established the chemical and morphological properties of the zeolite identifying it as ferrierite. The EDS on exposure of the zeolite to various sub-surface chemical conditions had changed the surface elemental composition, but the aluminosilicate networks remained intact as can be observed in the XRD analysis. This supports the hypothesis that the ferrierite is non-hydraulic in nature and can act as a supplementary cementitious material that will not interfere with cement hydration directly but would provide morphological template for CSH. The Ferrierite crystals observed in zeolite cement cores support the same. Also, the possibility of self-healing capabilities makes it a potential candidate to be further studied as an addition to wellbore cement for high temperature and high-pressure application, since zeolites exhibit stability under hydrothermal conditions. The phase similarity between commercial zeolite cement and ferrierite added Class-H cement suggest the partial success in adapting the low-density zeolite cement to a new ferrierite added formulation for plugging and abandonment purposes. The

similarity in the phases observed in both the formulations show that they are of the same chemical nature and zeolite remained stable in both the cases. The UCS data obtained comparing the 5%, 15% 30% ferrierite added cements and neat cement show a clear increase in the strength characteristics. This shows that the zeolite that we had chosen for our studies is a correct fit and would in future help us create a robust barrier plugging material.

However, a further research is yet to be done to understand the mechanism behind zeolite enhancement impact on Portland cement hydration products, reported in this paper. The usage of tools like Raman spectroscopy and x-ray microscopy coupled with nano-indentation, would make a considerable addition in an effort to minimize sample alteration via nondestructive investigation. Regarding self-healing properties of fractured cement most realistic testing protocol would be confined flowthrough experiments at reservoir temperature and pressure using relevant formation fluid chemistry. Furthermore, the zeolite enhanced wellbore cement plugs also has potential when used in a multi-composite type of slurry as recently reported by Massion et al [51].

5. Conclusions

As seen in the literature as well as the current work, addition of zeolites as a supplementary cementitious material, could provide enhanced mechanical properties for wellbore plugging and abandonment cement plugs. The chemical stability observed through EDS analysis and XRD characterization respectively help to hypothesize that the Ferrierite would act as a scaffolding structure for cement hydration to take place without any change in the zeolite composition. The current work also shows the preliminary strength test results that indicate the enhancement of strength of the cement cores on addition of a zeolite ferrierite. 5% By weight of cement (BWoC) addition had shown a 41% increase in UCS as noted. Future studies are planned to further investigate strength and the petrophysical property enhancement through cement addition and try to understand the mechanism to support the hypothesis.

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Author Contributions

Sai Vamsi Krishna, had performed all the reported research in this paper under the guidance of Dr. Mileva Radonjic and prepared the manuscript, always in collaboration with advisor. **Dr. Mileva Radonjic**, is the project director and conceptualized, supervised the research reported, and edited and reviewed all the data analysis and writing of the manuscript.

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Competing Interests

The authors have declared that no competing interests exist.

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