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Cementing Using Nano Silica for High Temperature and High Pressure Geothermal Wells

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ABSTRACT

Recently, nanoparticles are getting popular and are being used in various fields to produce new materials which are of great use due to their special properties. This paper briefly refers about the effect of nano silica on various properties of cement. The HTHP conditions have poor effect on the cement causing decrease in its strength and increase of permeability so the use of nano silica becomes very essential as they work well under HTHP conditions. Due to high reactivity of nano silica is highly effective in improving the slurry impermeability, mechanical properties and rheological properties of a material. Nano silica also affects the setting time of the cement. In cement matrix because of nano silica the porosity and permeability were reduced up to a great extent and it also helps in increasing the compressive strength. Cements which were designed using these nano silicate structures have minimum permeability among all the other ones, which were made using different methods.

1. INTRODUCTION

In recent years, nanotechnology is being widely used in different materials and systems. In this technology nanostructured materials are used to improve the properties. Nowadays, nanostructured materials are also used in cement based building materials (Mohammadmehdi et al., 2012).

On reducing the dimensions of a material up to an extent of nano level causes great changes in their properties, one of the reasons for such change is the increase in surface area, which affects the surface morphologies and energies. All these factors contribute in changing the properties of the material (Sobolev et al., 2016).

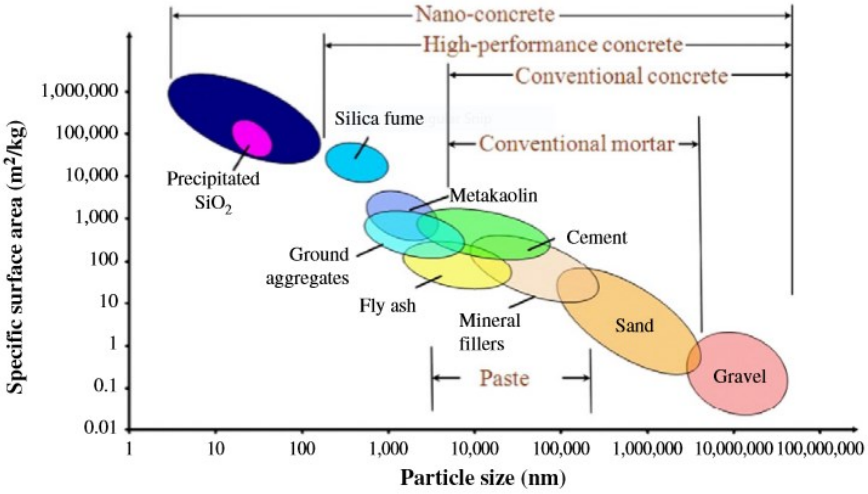

Fig. 1 Size range of the ingredients of concrete (Sobolev et al., 2016, Quercia et al., 2012).

At present many supplementary materials are used to improve the properties of portland cement, it includes the use of waste or recycled materials (like condensed waste glass, silica fume, nano silica and coal fly ash etc.) and it is also receiving considerable attention from the scientific community (Berra et al., 2012). Many researchers tend to use waste glass in cement due to its high disposal cost and stricter environmental regulations (Aly et al., 2011). Due to this the supplementary cementing materials are encouraged all around the world as they not only improve the properties of cement but are also good for the environment.

This paper outlines the effect of nano silica on various properties of the geothermal well cements.

2. IMPORTANCE OF CEMENTING

Cementing is an important operation in construction of geothermal wells. Its basic function is to fill the annular space and protect the casing against corrosion. It also helps in detaching the productive and non- productive zones (Jafariesfad et al., 2017). Moreover the HTHP Conditions can cause a cement failure (Xu et al., 2018). So, the quality of cement used in casing plays an important role

during drilling operations. Poor quality of cement could ruin the work while high quality cement could provide a good casing that would help the borehole last for a long time (Roddy et al., 2009). The strength of the geothermal well cements generally depends on the environmental conditions, time, and additives (Mohammadmehdi et al., 2012).

3. NANO SILICA AS AN ADMIXTURE

Nano silica is one of the most commonly used nano materials in the oil well and geothermal well cements. It is a solid compound of silicon and oxygen, in a way smaller size than the average cement particles. In the last few decades it has been proven to be an ideal admixture as it decreases the porosity, permeability and setting time and also increases the compressive strength of the cement (Ershadi et al., 2011). Nano silica is basically a pozzolanic compound which when hydrothermally treated with calcium hydroxide would form compounds possessing cementitious properties (Belkowitz et al., 2010). And, the cement with nano silica is also great for the environment since it does not produce high quantity of carbon dioxide which normal cement does. Due to this nano silica has been a popular admixture in the cementing of HTHP geothermal wells (Roddy et al., 2009).

4. EFFECT ON THE RHEOLOGICAL PROPERTIES OF CEMENT

The rheological behaviour of the cement paste is generally shown by Bingham equation i.e. $\boldsymbol{\tau}=\boldsymbol{\tau}_0+\boldsymbol{\mu}_0\boldsymbol{\vartheta}$ where, $\boldsymbol{\tau}_0$ (Pa) is yield stress, $\boldsymbol{\mu}_0$ (Pa.s) is the plastic viscosity and $\boldsymbol{\vartheta}$ (s^{-1}) is the shear rate. It can also be represented as **T= g + h.N**, where, **T** is torque, **N** is rotational speed and **g** and **h** are yield stress and plastic viscosity respectively. An experiment was conducted in such a way that at every 15 minutes the speed of the rheometer was brought to zero and was kept constant for 30 seconds and then in the next 30 seconds the speed was again increased to 100 rpm. A graph (Figure 1) was plotted using Bingham's model and from the down curve of that graph, the values of g (yield stress) and h (plastic viscosity) were obtained. The impact of the content of nano silica on the rheological behavior can be seen from the above figure (Figure 2a). It clearly shows the increase in the torque with respect to testing time by the addition of nano silica due to which there is an increase in plastic viscosity and yield stress. Figures 2b and 2c show that even after adding nano silica, the plastic velocity is only slightly increased while the yield stress of the cement paste increases to a large extent (Senff et al., 2009).

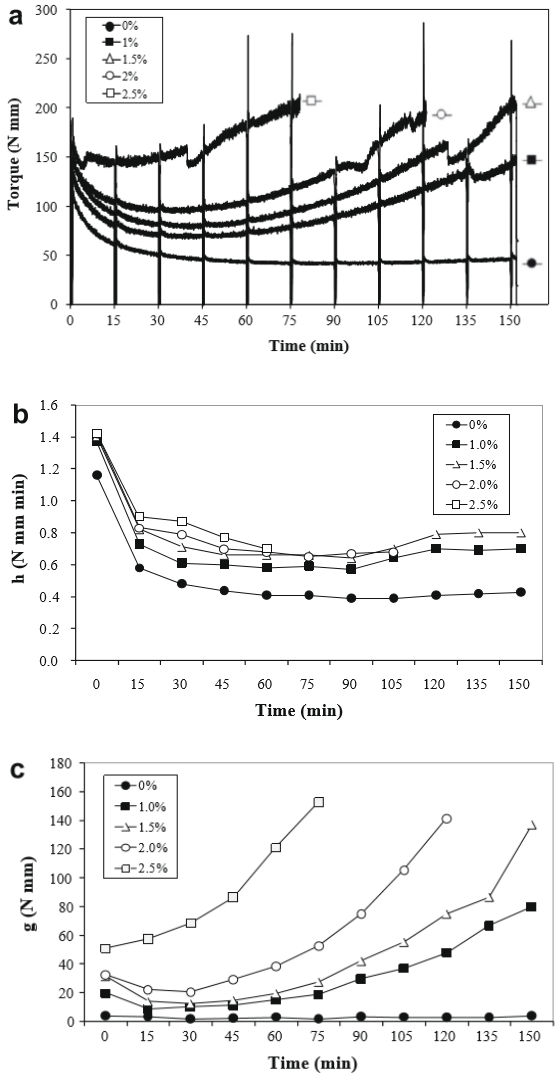

Fig. 2 Effect of nano silica concentration on the rheological properties of cement a) torque; b) viscosity (h); c) yield stress (g). (Senff et al., 2009)

5. EFFECT ON POROSITY AND PERMEABILITY OF CEMENT

Porosity is a parameter which resembles the amount of void space in material or hard substance. Porosity is the percentage ratio of void volume to the bulk volume and it indicates the amount of space available for the storage of fluid which affects the properties of cement sheath like compaction. On the other hand, permeability is a parameter which shows how easily fluid can pass through pores. It resembles the ease of flow of the fluid under a pressure difference and helps in determining the performance of the cement sheath. The cement sheath is supposed to seal the zones and prevent fluid migration under HPHT conditions which happens only when the permeability is lower. Cementing provides stability to the wellbore so it is important that there is no cracking or fracturing in the hardened cement.

Hence, it is essential that the cement has minimum porosity and permeability. For groundwater protection, casing is an important operation. Isolation to fresh water zones and groundwater is provided by casing strings from inside the well which is an important element of good completion. If it has high porosity and high permeability, then there is the possibility of breaking or fracturing of the channels of the cementing layer as it decreases the bearing ability of the cement.

Ershadi et al., 2011 did experiments in which sample preparations were made in accordance with API. In this experiment, a high-speed propeller type mixture was used for the initial mixing of cement slurries. In the cement, powder additives were added with water at an interval of 20 seconds at 4000 rpm. This experiment determined that if nano silica was added in type G cement, porosity decreased from 1% to 3% and permeability reduced from 0% to 1.5%. However, there was an increase in permeability if the concentration of nano silica was increased from 1.5% to 3%.

All these experiments proved that if the concentration of nano silica is kept between 1% and 1.5%, it is beneficial as it decreases both porosity and permeability. But if the concentration of nano silica exceeds 1.5%, porosity will decrease although there is an increase in permeability which is not helpful in maintaining cement sheath integrity

Table 1. Porosity and Permeability of various cement slurries with different nano silica concentration (Ershadi et al., 2011)

No. of slurry	Porosity and Permeability in different amount of nanosilica		
	%nanosilice	*Porosity (%)*	*permeability(md)*
S1	0	45	0.1
S2	1	30	0.001
S3	1.5	30	0.01
S4	2	29	0.019
S5	3	28.5	0.02

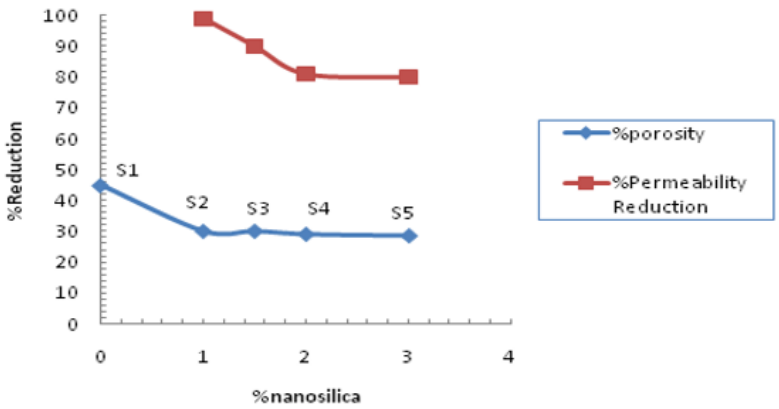

Fig. 3. Reduction in porosity and permeability in percentage (Ershadi et al., 2011)

6. EFFECT ON SETTING TIME AND COMPRESSIVE STRENGTH

The measurement of the change in the velocity of an acoustic signal is a method to determine the compressive strength of the cement as a function of time and this is obtained from Ultrasonic Cement Analyser (UCA) which is in accordance with API units. This method is non-destructive and there is no wastage of slurry samples because this instrument takes just one sample to test the compressive strength of the cement and also gives the history. The compressive strengths which are measured by this method have been proven to be more accurate than the one measured with mechanical methods (Rao et al., 1982). after adding some specific amount of nano silica, decrease is observed in the compressive strength of the cement. Slurry density also increases with an increase in the amount of nano silica up to 5%. It becomes more homogeneous leading to increased compressive strength. Observation of the sample under a microscope shows the microstructure and also the reaction of $Ca(OH)_2$ crystal with nano silica

which in return results in the improvement of microstructure formed between the binding paste and the aggregates present in the slurry. For long term, nano silica is better than $CaCl_2$ in increasing the compressive strength of the cement (Ye et al., 2007).

The time up to which cement can be molded i.e. it retains its plasticity and can be given any desired shape and during which it will not lose its strength is called the setting time of cement. Some of the factors affecting the setting time are water to cement ratio, temperature, pressure, distribution of particle size in cement, presence of additives, etc. (Zhang et al., 2010). After this time period, the cement starts to harden and loses its plasticity. Cementing on the surface at low temperature conditions can be difficult due to the slow hydration rate and large gap between the initial and the final setting time which in turn affects the time duration for strength development (Pang et al., 2014). On the other hand, initial and final setting times can be reduced by 22% with the addition of nano silica at different time intervals. 7 and 12 nm sizes of particles of silica have been proven to be more effective in increasing cement hydration which also affects the setting time of the cement. The difference between the initial and final setting times decreases with an increasing amount of nano silica in the cement mixture (Chen et al., 2016).

7. FUTURE SCOPE AND CHALLENGES

As discussed in the paper, the benefits of nano silica are observed only up to a certain concentration in the cement mixture due to the agglomeration of particles at higher concentrations depending upon the conditions. The main challenge of nano silica is that certain properties start are affected negatively with an increase in the concentration of nano silica. Hence, it is necessary to establish a qualitative as well as quantitative relationship between the amount of nano silica added in the cement mixture and its subsequent effects on the properties of the cement. Moreover, it is also important to determine the form in which nano silica is added in the cement; as an additive or colloidal or dry powder. Though there has been a number of studies on the mechanical, rheological and fluid properties of the cement and the effect on these properties upon the addition of nano silica, there is no sufficient research on the durability of the cement mortars on properties like carbonation, acid resistance, sulphur resistance and corrosion resistance. It is important that an optimized combination of such properties is studied for the most efficient performance of cement. The studies mentioned in the paper are based upon laboratory conditions where there is less focus on HPHT conditions. Despite the many benefits of nano silica, it is not being used often in oil and gas wells. Hence, it is required that the behaviour of cement is studied at on-field conditions of HPHT wells. More studies are required on the effects of fibres in cement slurry and their use in the development of high performance cement mixture. The combined effect of nano silica and fibrous mixtures is an area to be studied more thoroughly to resolve the problems that are faced by the use of nano silica alone as an admixture in cement. In the past few years, the nano particles of silica have found various uses apart from being used as an admixture in cement. It is being used as an additive for rubber and plastics as it provides high strength to the material in which it is used. In addition to these qualities, it also has some biomedical applications (Bitar et al., 2012). Further studies can be done in this field for an extensive knowledge about the challenges of using nano silica as an admixture in cement.

8. CONCLUSIONS

The Ordinary Portland Cement is the most commonly used cementing material in oil and gas wells. Though this material possesses a wide range of characteristics, this conventional cementing mixture has various shortcomings. Use of additives is necessary to overcome these problems. Nano silica being the most efficient and environment friendly, appears to be one of the most appropriate additives for enhancing the properties of the Ordinary Portland Cement (Nazari et al., 2011). Looking at the various mechanical properties, the addition of nano silica has a positive effect on compressive strength, tensile strength as well as yield strength. Nano silica acts as a nano filler in cement material and increases the density of the cement which can directly affect these parameters. The tensile to compressive strength ratio can be maintained depending on the amount of nano silica used in the cement slurry. The addition of nano silica enhances the compressive strength of the cement but this increase is observed only to a certain level. After a threshold value, a decrease in compressive strength is observed with the increase in the concentrations of nano silica. The yield point of the cement is delayed with an increase in the concentrations of nano silica. However, negligible changes are found in plastic viscosity (Flores-Vivian et al., 2017). Moreover, the cement mixture becomes highly cohesive on the addition of nano silica. The nano sized silica particles distribute non-uniformly in the cement mixture and clog the pores, acting as nano filler and helping in decreasing the porosity as well as the permeability of the Ordinary Portland Cement. At lower concentrations of nano silica, the decrease in the porosity of the cement is observed with an increase in the concentrations of nano silica though these effects are observed only up to a certain amount of nano silica. At higher concentrations, the results for permeability are found to be reversed whereas the porosity keeps on decreasing. The addition of nano silica increases the hydration capacity of the cement slurry which directly affects the setting time. The setting time is reduced to a great extent depending on the time and amount of nano silica added in the cement mixture (Gaurina et al., 2017).

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