

AN EXPERIMENTAL INVESTIGATION ON IMPROVING THE MEDIUM AND LATE-AGE COMPRESSIVE STRENGTHS OF CLASS G OIL WELL CEMENT

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ABSTRACT

In this study, the effects of particle size distribution improvement and dense packing techniques on the 28- and 90-day compressive strengths of class G oil well cement have been investigated. It was observed that limited improvements in the particle size distribution of cement (regarding industrial possibilities) cannot result in a significant increase in 28- and 90-day compressive strengths. Also, in the application of the dense packing technique, silica fume and limestone powders with the grain size less than 45 micrometers cannot be utilized as substitutes for cement, because the addition of these materials simultaneously leads to the shortening of the setting times. The utilization of quartz powder as a filler exhibits partial pozzolanic properties at optimum substitution percentages, i.e. around 6 to 10% by weight; however, it can result in an almost 7% increase in the 28-day compressive strength of the hardened paste of the cement without any considerable effects on its setting times.

Keywords: Class G, Oil Well Cement, Particle Size Distribution, Dense Packing, Compressive Strength

INTRODUCTION

Cement-based materials are used in the oil and gas industry for cementing oil wells. Oil well cement is derivatives of ordinary Portland cement with special properties that are necessary due to the special conditions of oil wells, i.e. temperature, pressure, and the presence of attacking chemicals. The main role of the cement sheath is to permanently isolate all subsurface formations penetrated by a well. This permanent isolation is expected not only

during the oil production but also after the plugging of wells. In any case, the engineering properties of the cement-based materials placed within the wells are of utmost importance [1-4].

The control of setting time of oil well cement during the cementing operation and at the bottom-hole conditions of wells is a very important parameter [5]. In addition, the hardened cement paste must exhibit satisfactory compressive strength and chemical durability to withstand the pressure due to the reservoir formation and the deterioration due to

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the presence of attacking chemicals [4-7]. Class G Oil well cement is intended for use as basic cement from surface to a depth of 2440 m (8,000 ft) as manufactured, or can be used with accelerators and retarders to cover a wide range of well depths and temperatures [7].

Two different techniques to enhance the general engineering properties of the Portland cements include particle size distribution (PSD) improvement and dense packing using suitable supplementary cementing materials. The rate at which a cement particle hydrates when exposed to water greatly depends on its size. A small particle reacts much more quickly than a large particle and a very large particle, larger than about 50 μm , probably will never become fully hydrated, even if exposed to enough water. The PSD is therefore critical in controlling the rate at which Portland cements gain strength. To achieve a good strength development, there must be a certain amount of small particles; but, if there are too many small particles, the cement will set too quickly. The technique of dense packing, by the addition of superfine powders together with or without superplasticizer, also improves the behaviors of paste and concrete considerably. Because of the small particle size of these materials, they function as filler to improve the pore size distribution and reduce the porosity. Because of the space occupation that otherwise would have been occupied by water, more free water is released to upgrade the consistency or workability [8]. In this work, attempts were made to improve the 28- and 90-day compressive strengths of class G oil well cement. Medium and late-age compressive strengths are important, because they depend on the total amount of calcium silicate content (both alite and belite) of the cement which is a quality characteristic determining the properties of the cement including its durability performance under especial conditions. The present work is therefore concentrated on the general

engineering properties (setting time and medium to late-age compressive strengths) of the studied oil well cement but not on its specific technical properties for oil well cementing. This allows the use of common laboratory techniques. The work has two individual parts. The first part deals with the effects of PSD improvement on the properties of the cement and the second part copes with the effects of dense packing technique on the properties of cement using different supplementary cementing materials including silica fume (a highly pozzolanic material), limestone (an almost inert material), and quartz powder (a partial pozzolanic material).

EXPERIMENTAL

Commercial class G oil well cement, silica fume as a by-product of ferro-silica plant, limestone, and quartz were prepared as raw materials. Limestone and quartz were ground in a laboratory ball mill and then the fractions lower than 45 micrometers were separated for being used as a fine substitute for cement. The chemical composition and specific surface area of the materials used are given in Table 1.

Figure 1 represents the PSD curve of class G oil well cement. For improving the PSD and investigating its effects on compressive strength, the coarse fraction larger than 65 micrometers, i.e. 6.7 wt% of the cement, was separated and after being ground to particles smaller than 45 micrometers was thoroughly mixed with the cement. The cement was then used to measure its 7, 28, and 90-day compressive strength and to see the effect of such an improvement in PSD on strength behavior at medium and late ages.

To evaluate the effects of dense packing on strength behavior, silica fume and powders of limestone and quartz with a grain size smaller than 45 micrometers were used; a number of binary systems were designed and prepared with the addition of 2, 4, 6, ..., and 14% (relative

to the mass of the cement) of them as a substitute for cement.

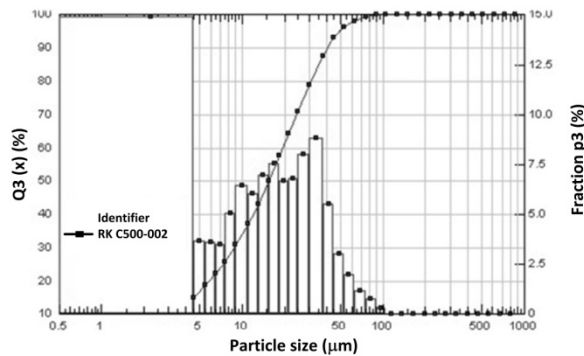


Figure 1: PSD-curve of class G oil well cement

A water-to-dry binder ratio of 0.38 was used to prepare pastes. The pastes were then cast into specimens of the size of $2 \times 2 \times 2$ cm³ and stored in an atmosphere of more than 95% relative humidity at 25 °C for the first 24 hrs. After demolding, the specimens were immersed in water at 25 °C for further curing until the time of testing. The blends were characterized and studied by relative visual workability and measuring their initial and final setting times, 28 and 90-day compressive strengths, and total 80 day shrinkage.

Table 1: Chemical composition (wt%) and specific surface area (Blaine, cm².g⁻¹) of materials

Oxide	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	LOI	Blaine specific surface area
Class G oil well cement	22.43	3.86	4.48	64.26	1.75	2.07	0.59	0.75	1.95	2954
Silica fume	96.12	0.82	-	-	-	-	-	0.40	2.61	18000
Limestone	0.54	0.35	0.14	51.95	1.16	-	-	-	42.16	5210
Quartz	95.82	1.72	-	2.30	-	-	-	-	-	4820

RESULTS AND DISCUSSION

Particle Size Distribution Improvement

Research works have proved that PSD is an important factor in determining not only the rheological properties of the cement, but also its strength behavior. The experimental results show that an increase in the slope of PSD-curve, while keeping a suitable consistency, can considerably increase the compressive strength of cement; in fact, the higher the slope of the curve is, the superior the strength behavior of the cement becomes [9]. The highest slope achievable by industrial cement mills is around 1. However, on laboratory scales, it is possible to increase the slope to values quite higher. Here, the class G oil well cement used has a relatively suitable PSD with a mean particle size and PSD-curve slope of 21.49 micrometers and 1.15 respectively. As it can be seen, the PSD of the cement is relatively good and, by considering current capabilities on industrial scales, just small improvements in the PSD are possible.

Therefore, the improvement done in the PSD of the cement is limited to just decreasing the amount of relatively coarser fraction of the cement, i.e. the fraction larger than 65 micrometers, which not only improves the total fineness of the cement, but also increases the slope of the PSD-curve. The results obtained for 7, 28, and 90-day compressive strengths after such an improvement are presented in Table 2.

Table 2: Effect of particle size distribution improvement on compressive strength

	Compressive Strength (MPa)		
	7-day	28-day	90-day
Before improvement	50.0	56.2	60.0
After improvement	55.7	59.5	60.0

As it can be seen, such an improvement in the PSD of the cement can just result in a limited increase in compressive strengths at relatively early ages. The 7-day compressive strength is increased by less than 12%, whereas 28-day compressive strength is raised by just less than 6%. The 90-day compressive strength remains

unchanged. Therefore, limited improvements in PSD by regarding the industrial possibilities can result in a slight increase in 28-day compressive strength, but it does not significantly increase 90-day compressive strength.

Dense Packing Technique

Considering the relative visual workability of the pastes confirms that any substitution of cement by silica fume leads to a decrease in the workability of the cement paste due to its relatively high specific surface area and hence its high water adsorption; however, the substitution of cement by limestone or quartz powders enhances the paste workability.

Initial and Final Setting Times

Figures 2 to 4 represent the effects of filling materials on the initial and final setting times of cement. As it can be seen in Figure 2, both initial and final setting times decrease at relatively lower percentages of silica fume but slightly increase at substitution contents higher than 10%. The decrease of the setting times is due to the relatively high capacity of silica fume in water adsorption. The increase in setting times at relatively higher percentages of substitution could be attributed to the agglomeration behavior of silica fume in the absence of any dispersing agents.

Both limestone and quartz powders decrease setting times almost linearly. The addition of limestone, however, is more effective than quartz in decreasing the setting times. This is probably due to the reactivity of calcium carbonate with the tri calcium aluminate phase of the cement.

The decrease in setting times for the case of limestone and, in particular, quartz powder can also be attributed to the phenomenon of water adsorption. The particles of both limestone and quartz powder are smaller than 45 micrometers

and these two materials are therefore significantly finer than cement. Such higher fineness can provide a relatively considerable capacity of water adsorption for these materials. Nevertheless, this water adsorption is quite lower than that of an ultra-fine material such as silica fume. Quartz powder is thus quite less effective in decreasing the setting times of the cement in comparison to silica fume.

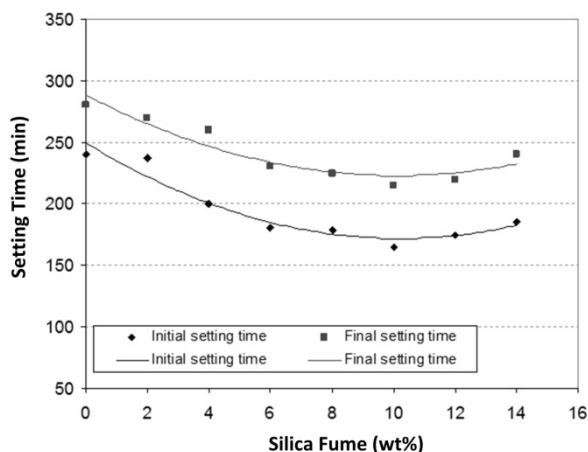


Figure 2: Effect of silica fume on the initial and final setting times of cement

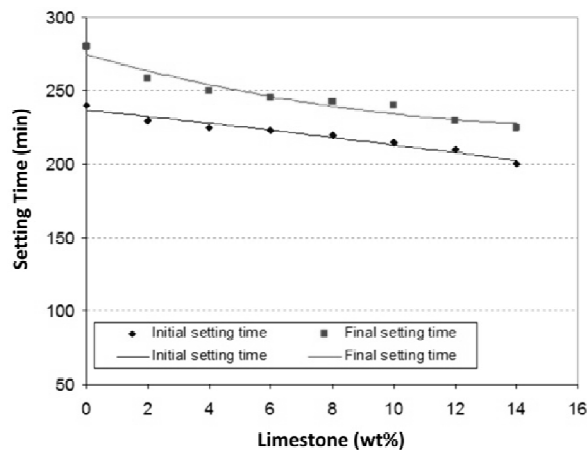


Figure 3: Effect of limestone powder on the initial and final setting times of cement

Compressive Strength

The results of 28 and 90-day compressive strengths are presented in Figures 5 and 6. All the tested filling materials are effective in increasing the compressive strengths. As it can be seen, maximum 28 and 90-day compressive

strengths are achievable at substitution percentages in the range of 6 to 10% by weight for each of the filling materials used. Such an increase in compressive strength is generally due to both filling and pozzolanic effects of the additive materials used. Comparing the effects of the filling materials employed, it is seen that silica fume provides a marked improvement in both 28- and 90-day compressive strengths. In the case of silica fume, however, in addition to the filling effect, the pozzolanic reactivity of the material, i.e. reaction with calcium hydroxide and water and generating additional calcium silicate hydrates, is also a major factor in strength improvement. It is reported that the presence of ultra-fine particles of silica fume can accelerate cement hydration reactions by providing suitable nucleation centers for hydration products [10, 11]. The substitution of cement by filling materials at concentrations higher than 10 wt% decreases both 28- and 90-day compressive strengths. This is due to the fact that, firstly, a limited substitution of the cement by a filling material is to be considered for achieving dense packing and higher contents do not give rise to dense packing. Secondly, relatively higher substitution percentages leads to the effective removal of cement hydraulic phases responsible for strength behavior and the introduction of inert or less reactive additive materials.

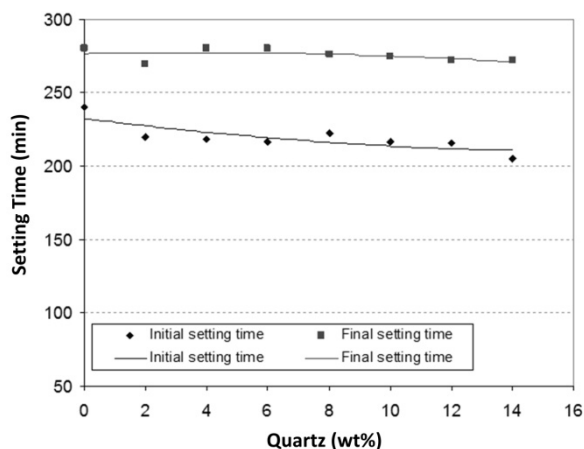


Figure 4: Effect of quartz powder on the initial and final setting times of cement

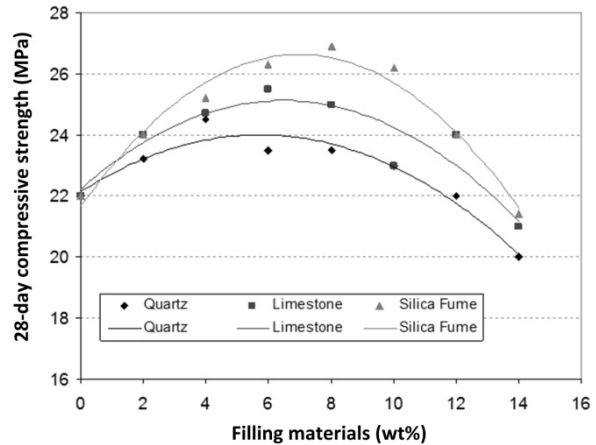


Figure 5: 28-day compressive strength of the cement blends

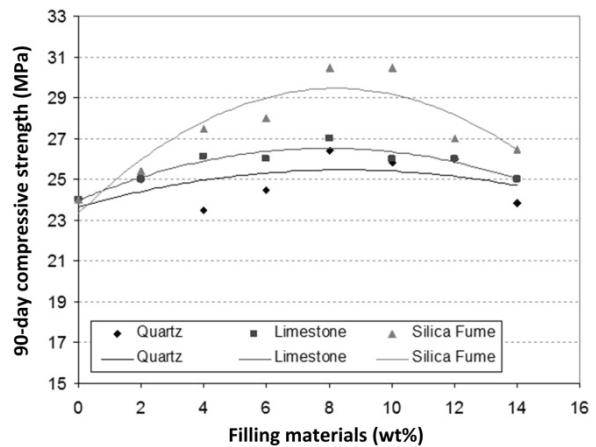


Figure 6: 90-day compressive strength of the cement blends

Shrinkage

Figures 7 to 9 represent the results of total 80-day shrinkage of the blends. In all cases, the total 80-day shrinkage decreases as the amount of filling material is increased.

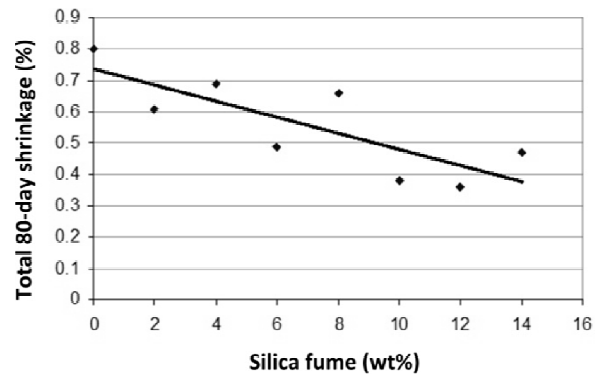


Figure 7: Total 80-day shrinkage of the cement/silica fume blend

As it can be seen, silica fume is more effective in reducing the amount of shrinkage due to its pozzolanic behavior which causes the densification of the microstructure of the hardened cement paste and therefore reducing the amount of shrinkage. In the case of limestone and quartz powders, the decrease in total 80-day shrinkage is quite less.

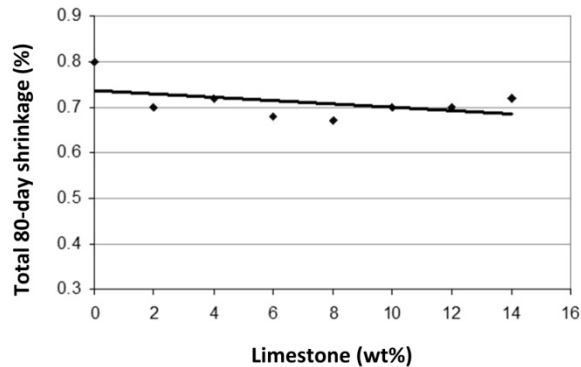


Figure 8: Total 80-day shrinkage of the cement/limestone powder blend

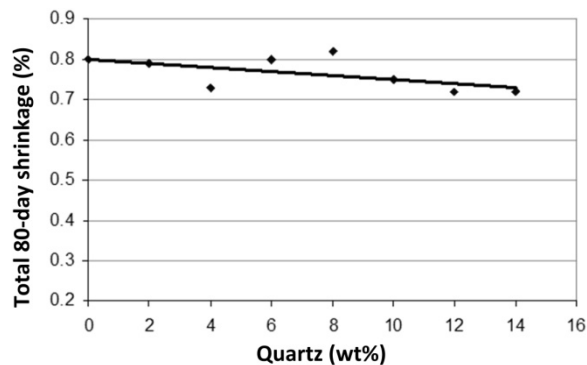


Figure 9: Total 80-day shrinkage of the cement/quartz powder blend

CONCLUSIONS

The present work has focused on the improvement in medium and late-age (28- and 90-day) compressive strengths by different techniques. The results confirm that the application of dense packing technique with quartz powder is useful without imparting significant shortening effects on setting times. The improvements can be attributed to both shrinkage control and the partial pozzolanic properties of the quartz powder. Silica fume and

limestone powder with grain size smaller than 45 microns cannot be utilized as a substitute for cement to improve the compressive strength of class G oil well cement, because their addition simultaneously results in shortening setting times. The utilization of quartz powder at optimum substitution percentages, i.e. around 6 to 10% by weight, however, can increase the 28-day compressive strength of the hardened paste of cement by about 7% without any considerable effects on its setting times.

REFERENCES

- [1] Andersen P. J., Johansen V., "Particle Packing and Concrete Properties, American Ceramic Society". **1995**, 12, 111-146.
- [2] Heikal M., Diadamony H. E., and Morsy M. S., "Limestone-filled Pozzolanic Cement", *Cem. & Concr. Res.* **2000**, 30, 1827-1834.
- [3] Bonavetti V., Donza H., Menendez G., Cabera O., and Irassar E. F., "Limestone Filler Cement in Low W/C Concrete: A Rational Use of Energy", *Cem. & Concr. Res.* **2003**, 33, 865-871.
- [4] Pera J., Husson S., and Guilhot B., "Influence of Finely Ground Limestone on Cement Hydration", *Cem. & Concr. Comp.* **1999**, 21, 99-105.
- [5] Svermova L., Sonebi M., and Bartos P. J. M., "Influence of Mix Proportions on Rheology of Cement Grouts Containing Limestone Powder", *Cem. & Concr. Comp.* **2003**, 25, 737-749.
- [6] Saout G. L., Le'colier E., Rivereau A., and Zanni H., "Chemical Structure of Cement Aged at Normal and Elevated Temperatures and Pressures" *Part I. Class G Oilwell Cement*, *Cem. & Concr. Res.* **2006**, 36, 71-78.
- [7] Hodne H., Saasen A., O'Hagan A. B., and Wick S. O., "Effects of Time and Shear Energy on the Rheological Behavior of oil Well Cement Slurries", *Cem. & Concr. Res.*, 30, 1759-1766.
- [8] Niu Q., Feng N., Yang J., and Zheng X., "Effect of Superfine Slag Powder on Cement

- Properties”, *Cem. & Concr. Res.* **2002**, 32, 615-621.
- [9] Glasnovi A. and Hraste M., “The Grinding Equation in the Investigation of the Coarse Dispersing System of Cement”, *Cem. & Concr. Res.* **1982**, 12, 415-424.
- [10] Agawa K., Uchikawa H., Takemoto K. and Yasui I. V.,” The Mechanism of the Hydration in the System C3S Pozzolans”, *Cem. & Concr. Res.* **1980**, 8, 683-696.
- [11] Davraz M. and Gunduz L., “Engineering Properties of Amorphous Silica as a New natural pozzolan for use in concrete”, *Cem. & Concr. Res.* **2005**, 35, 1251-1261.