Rheological and structural investigations on cement slurries

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ABSTRACT

The cost of drilling wells for geothermal power plants are considerably affected by the slurry used for the cementing job. Present slurry used for geothermal wells has a relatively high water content which results in a low early strength. To shorten the production process for each well the slurry was modified by help of chemical admixtures and a light-weight aggregate.

INTRODUCTION

Geothermal power plants play an important part in the electric power production in Iceland. More geothermal power plants are both under construction and being planned, because of the rapid increase in demand for electricity. The driving force for this development is the growing aluminium industry in Iceland. If the trend continues, Iceland will be one of the major producers of aluminium worldwide by the year 2010.

The wells are a fundamental part of a geothermal power plant. They are drilled vertically into the rock formations of former volcanoes in the earths crust. A geothermal well consists of 3-4 drilling sections, each with a different diameter. After each drilling section, a steel casing is placed into the well and the space between the rock and the casing is filled with cement slurry. When the annular space is filled completely with slurry the cementing work is finished. The time span between pumping the slurry and the hardening affects the drilling cost for each well greatly. The faster the slurry hardens, the more economical the drilling operation becomes because of the reduced waiting time for the drill. Present cement slurry has a relatively high water content which results in a low strength and a slow hydration progress. The objective of this study was to determine (1) if an acceleration of the hardening process is possible with slight modifications on the slurry presently used for the cement works, (2) while at the same time keeping rheological parameters and density constant or close to the slurry presently used. Several slurry types were tested and compared with respect to rheology and strength.

MATERIALS AND METHODS

Tests on materials used

Three locally available cement types were incorporated in the study. At the present slurry expanded perlite is used as light-weight aggregate, Wyoming Bentonite is added to the slurry as a stabilizer and silica sand as a filler. In a first step of the present study the effect of w/c-ratio on rheology in blank mixes was evaluated. Thereafter, the strength development at different w/c-ratios was investigated. When the w/c-ratio is lowered, the specific gravity of the slurry will normally increase. One requirement for

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the new slurry was that the density should not exceed 1,65 kg/m^3. This was achieved by adding a light-weight aggregate to the slurries with a lower w/c-ratio. The light-weight aggregate is produced from glass waste by Liapor, Germany. The chemical admixtures investigated were polycarboxylate based and melamine-naphtalene based products.

Tests on fresh and hardened slurries

Three basic slurries were evaluated at this stage of the testing program. Mix A (reference) characterizes the slurry presently used for the cementing works. Mix A has a w/c-ratio of 0,80.

Mix B characterizes a slurry at a w/c-ratio of 0,65. The polycarboxylate based polymer was added as dispersing admixture. The light-weight aggregate was added to keep the density in the vicinity of ~1,65 kg/dm^3.

Mix C characterizes a slurry at a w/c-ratio 0,50. By increasing the content of light-weight aggregate the density was kept constant at ~1,65 kg/dm^3.

Slurries were mixed in a Hobart mixer. Rheological measurements were carried out in a ConTec Rheomixer and a ConTec Viscometer 6. The ConTec Viscometer 6 (see Figure 1) is a traditional coaxial cylinder system. The ConTec Rheomixer (see Figure 2) is a more innovative portable rheometer which can also be used at a construction site. Rheomixer measures the G-yield (mA) and H-viscosity (mA·s) while Viscometer 6 measures the corresponding yield stress (Pa) and plastic viscosity (Pa·s). The stiffer the mix, the higher is the measured value for G-yield (mA) in Rheomixer or the yield stress (Pa) in Viscometer 6. Rheological data obtained with both machines is based on the Bingham model.

Figure 1. ConTec Viscometer 6

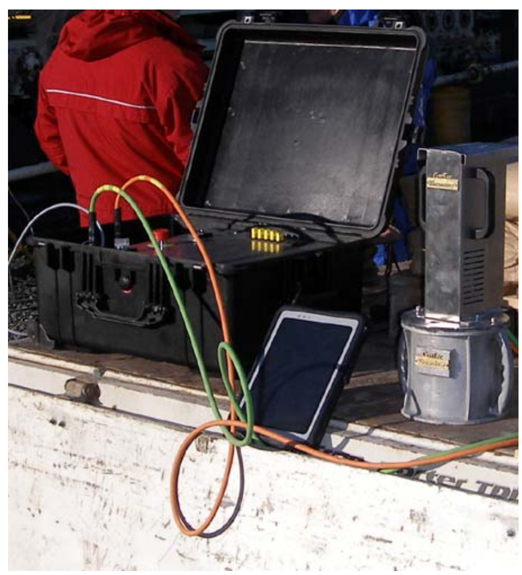

Figure 2. ConTec Rheomixer

RESULTS

Table 1 shows the rheological properties of Portland cement C3 in mix A (no admixtures). The results reported for G-yield and H-viscosity are the mean of the 13 and 15 minute measurement.

Table 1. Rheology of cement C3 at different w/c-ratios

Device	Viscometer 6		Rheomixer	
w/c-ratio	Yield stress (Pa)	Plastic viscosity (Pa·s)	G-yield (mA)	H-viscosity (mA·s)
0,90	-	-	-	-
0,80	25	1	29	12
0,70	70	1	82	23
0,65	130	2	172	43

Table 2 shows the 1 day strength of mixes A, B and C produced with cement C3. Results were obtained on prisms, size 40 x 40 x 160 mm.

Table 2. 1 day strength of slurries at different w/c-ratios

Cement	C3
Filler	Silica sand and Liaver
w/c-ratio	Strength (MPa)
0,80	5,6
0,65	10
0,50	15,9

Table 3 shows the rheological data of three slurries with different type of light-weight aggregate.

Table 3. Rheology of three slurries with two types of light-weigth aggregate

Slurry	Mix A		Mix B (P)		Mix B (L)	
LWA used	Expanded perlite		Expanded perlite		Liaver	
Testing age (min)	G	H	G	H	G	H
6,5	-	-	27	24	16	5
13	17	14	31	31	16	8
15	-	-	32	30	18	9
30	-	-	27	34	20	11
60	28	14	45	32	22	14
120	31	8	54	37	29	16

The G is the measured G-yield (mA). The H is the measured H-viscosity (mA·s). Mix A was measured on site by use of ConTec Rheomixer. Mix A was used for the cementing job of the so-called surface casing of well HN03 of the Hellisheidi geothermal power plant. Mixes B1 (P) and B2 (L) were produced and measured in a laboratory.

DISCUSSION

Effect of w/c-ratio on rheology

Figure 3 shows the effect of w/c-ratio on G-yield (mA) in blank mixes (no admixtures). The thick line indicates cement C3 at different w/c-ratios. Compared to other cements tested in the study cement C3 had the lowest water demand. This is quite natural as cement C3 is an import cement whereas C1 and C2 are icelandic cements. Due to ASR damage in the past, all icelandic cements are blended with approx. 4% silica fume. Due to the high specific surface, silica fume increases the water demand.

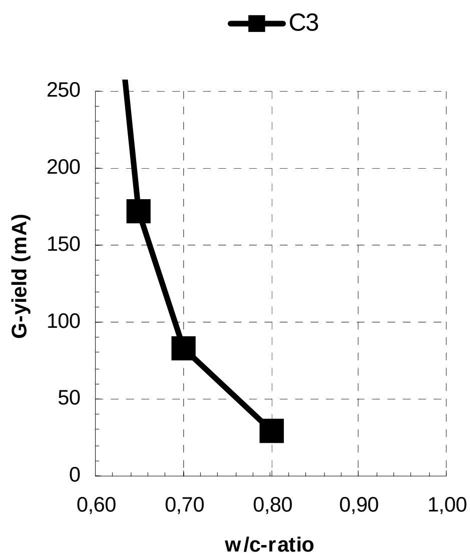

Figure 3. Effect of w/c-ratio on rheology

Effect of w/c-ratio on 1 day strength

By lowering the w/c-ratio from 0,80 to 0,65, the strength increased by a factor of 1,7. By lowering the w/c-ratio from 0,80 to 0,50, the strength increased by a factor of 2,7. The density of mix B and C was kept in the range of 1,65 kg/dm³ by adding the Liaver light weight aggregate.

Effect of different light-weight aggregate on rheology

The effect of light-weight aggregate on rheological properties was measured in ConTec Rheomixer. Figure 4 shows the workability of three mixes under laboratory conditions. The thick line indicates mix A. Mix A contained approx. 4% expanded perlite as light-weight aggregate. This mix was used for the surface casing of well HN03. Due to the high water content of the reference mix, the G-yield is low and no workability loss occurred during a testing period of 2 hours. The plastic viscosity decreased slightly during the testing period. The broken line indicates a mix at w/c-ratio of 0,65, where cement content and amount of silica sand is increased. Therefore, the specific gravity of the slurry increased from 1,65 to 1,76. It can be seen that the G-yield increases in time, resulting in workability loss occurrence. The plastic viscosity increased during the testing period.

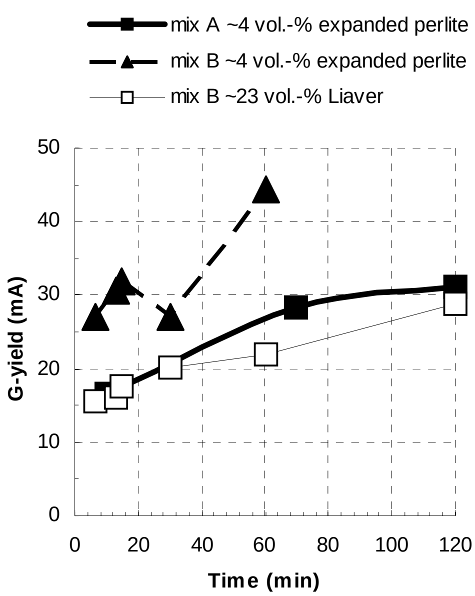

Figure 4. Effect of light-weight aggregate on G-yield

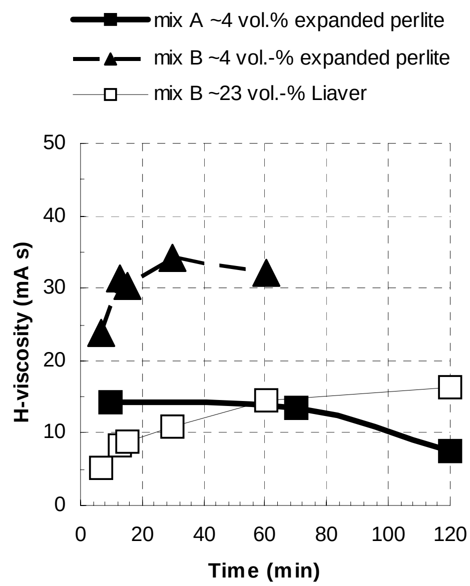

Figure 5. Effect of light-weight aggregate on H-viscosity

The thin line indicates the mix containing ~23 vol.-% Liaver. The w/c-ratio of this mix was 0,65. By adding the light-weight aggregate, the specific gravity was kept at 1,65. No segregation (swimming of light weight aggregate on slurry surface) was observed during measurements. The Liaver was well distributed in the slurry. The rheological parameters G-yield and H-viscosity were close to those of the reference mix.

FINAL REMARKS

Cement slurries have been investigated with respect to their rheological and structural properties. The purpose of this study was to modify the cement slurry presently used in order to accelerate the production process for geothermal wells. An important issue was the density of the modified slurry. The density of the modified slurry should not exceed 1,65 kg/dm³.

The hardening process of the slurry was accelerated by reducing the water content. Two modified slurries were tested. First, mix B with a w/c-ratio of 0,65. Second, mix C with a w/c-ratio of 0,50. By adding a light-weight aggregate, the density of the slurry was kept constant at 1,65 kg/dm³. Admixtures were added to mix B and C to control workability/flowability.

The yield value in the modified slurries could be lowered to that of the reference slurry. The plastic viscosity in the modified slurries is considerably higher than that of the reference slurry. This might result in higher pumping pressure during the cementing process.

Future research will include pumping tests with a slurry based on cement C3, the Liaver light-weight aggregate at a w/c-ratio of 0,65 and 0,50, and the admixture preferably used. The rheology will be controlled by use of a dispersing admixture.

ACKNOWLEDGEMENTS

The work reported here is a cooperation project between University of Iceland and the Icelandic Building Research Institute. We would like to gratefully acknowledge the support of Reykjavik Energy. The authors also thank the colleagues of IBRI Rheocenter for their help and in special Ásbjörn Jóhannesson for helpful editorial comments.

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