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(54) Title: LIGHTWEIGHT THERMALLY STABLE CEMENT COMPOSITIONS AND METHOD OF USE (57) Abstract <p>A lightweight thermally stable cement composition and slurry, suitable for lining a borehole having setting temperatures at or below 40 °C and anticipated extended anticipated use temperature in excess of 200 °C. The cement composition has a lime to silica ratio less than or equal to 1, and the silica has an average particle size less than or equal to about 15 microns. The composition preferably includes silica flour and silica fume and may include 30 % to 100 % by weight of cement blast furnace slag (BFS).</p>		

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LIGHT WEIGHT THERMALLY STABLE CEMENT COMPOSITIONS AND METHOD OF USE

Field of Invention

This invention relates to cement compositions for lining a borehole. More particularly, the invention relates to light weight thermally stable cement compositions and their method of use.

Background of the Invention

5 A cement blend has been developed in response to potential uses, in particular, in Northern Alberta, Canada. The object is to design a cement system for weak formations with low fracture gradients to be applied at low bottom-hole temperatures with the anticipation that these wells will be steam flooded at a future date to extract out heavy oil from the ground. It is also specified that the distance between the point of application of
10 steam and this subject cement blend system will be such that this cement around the production liner may experience a net temperature of very close to 230 deg C (446 deg F). One object of the invention is for this new blend, when mixed at a density of 1400 kg/m³ (11.69 Pounds Per Gallon, PPG), to be thermally stable at this temperature. In other words, at a specified light weight density this blend must develop sufficient compressive
15 strength (CS), as required by the local regulatory board, yet must also be durable enough to sustain a high steam temperature for the rest of the life of the well.

With the objects in mind as outlined above, and with the theories in mind that underlie thermal stability, a system has been designed where, first, the net lime/silica ratio would be limited to a maximum of 1.0. The ratio is held to not exceed this value in order
20 to assist in maintaining thermal stability. A CaO (lime)/SiO₂ (silica) ratio exceeding 1.0 may lead, according to cement chemistry, to a product called alpha dicalcium silicate hydrate. Such may comprise an undesired product because alpha-C₂SH (C₂SH is the cement chemists abbreviation for a hydrated dicalcium silicate) is believed to be thermally unstable and may lead to a break down of the cement matrix.

25 Most of the literature references are extensive in their treatment of normal density/high density cement designs (> 1800 kg/m³ or 15.0 PPG) in connection with applications for high temperature environments, including steam, fire flooding or geothermal wells. Seldom, however, does the literature deal with light weight cement designs, particularly as light as dealt with in this invention. The only references found, in
30 fact, with respect to light weight designs, were the following:

- (1) Gallus, J. P.; Pyle, D. E.; and Watters, L. T.: "Performance of Oil-Well Cementing Compositions in Geothermal Wells," paper SPE 7591, 1978; and

(2) Gallus, J. P.; Pyle, D. E.; and Moran, L. K.: "Physical and Chemical Properties of Cement Exposed to Geothermal Dry Steam," paper SPE 7876, 1979.

5 The lowest density dealt in these articles is 1470 kg/m³ (12.3 PPG) for a system containing 35% silica flour, 8% perlite and 4% bentonite.

Relating to the above references, two points should be emphasized vis-a-vis the present design:

A. Bentonite may accelerate deterioration of the hydration product (responsible for thermal stability) in the presence of any CO₂. See reference (3) Milestone, N. B.; Sugama, T.; Kukacka, L. E.; and Carciello, N.: "Carbonation of Geothermal Grouts-Pt 3: CO₂ Attack on Grouts Containing Bentonite," Cement & Concrete Res. (1987) 17, 295-306.

15 B. Perlite, an expanded crushed volcanic glass, has open and closed pores. Under hydrostatic pressure, the open pores fill with water and the closed pores get crushed. As a result, the perlite gets heavier and the resultant density is higher than reported by the reference (2) above. Reference (2), however, mentions that up to 100% silica (by weight of cement) may be necessary in lower density systems to ensure slurry stability.

Another point of interest to be mentioned in regard to the cement blends of the present invention is the potentially beneficial use of blast furnace slag (BFS), a by-product of manufacture of iron from iron ores, for oil well cementing.

20 In the above references, the Gallus et al family of articles teaches Class G cement plus 35% silica flour yielding good compressive strength and low permeability for two (2) years at 460°F in geothermal dry steam. The "Performance of Oil Well Cementing Compositions in Geothermal Wells" article discloses experiments with Class G cement and 40% to 100% silica of varying "20 mesh to 170 mesh" particle sizes. The article teaches leveling of compressive strength and permeability curves after about 6 months and that Class G cement apparently can be made effective by adding sufficient silica, 40% to 80%, to facilitate formation of desirable truscottite.

Other references in the area comprise:

30 (4) "Well Cementing" edited by Erik Nelson and published by Elsevier Science Publishers B. V. and distributed by Elsevier Science Publishing Company Inc., New York, N.Y Chapter 9 titled "Thermal Cements"

(5) Eilers, L. H.; Nelson, E. B.; and Moran, L. K.; "High Temperature Cement Compositions-Pectolite, Scawtite, Truscottite, or Xonotlite: Which Do You Want?" Jour. Of Petr. Tech. (July 1983) 1373-1377.

35 (6) Dillenbeck, R. L. III; Mueller, D. T.; and Orr, B. R.; "The Effect of Microsilica

On The Thermal Stability Of Lightweight Cement Systems", CIM/SPE 116, (1990). The 1980 SPE article by Eric B. Nelson, "High Temperature Cement Compositions" teaches or suggests a lime to silica ratio less than or equal to 1.0 and a Portland cement plus a fine silica of at least 35%. Chapter 9 of the "Thermal Cement Book" edited by Erik B. Nelson tends to teach away from the present invention. The chapter teaches no real solution to the problem of adequate thermal recovery cements. The articles discuss a silica stabilized cement plus "microspheres" and a silica stabilized "foamed" cement (Portland plus 35% silica flour). Each procedure had problems. The article gave no solution for the particular application. The article points out the necessity for a low density slurry. The effect of micro-silica (silica fume) on thermal stability of "light weight cement systems" is disclosed by experiments with silica fumes substituted for silica flour and a cement plus 35% silica mixture. Compressive strength goes progressively down as fume is substituted for flour. No permeability data is given. Test were at 177°C (350°F). The article concludes a substitution of fume for flour "shows promise". The article points out the substitution of fume for flour does give low density.

Summary of the Invention

Novelties of the blends of the present inventions include:

- * They are designed for placement at low bottom-hole temperatures and yet develop compressive strength at a reasonable amount of time, minimizing the rig time, yet when the well is subjected to steam flood, this cement composition is capable of withstanding the severe temperature conditions
- * Inclusive of BFS to contribute to the reaction kinetics towards strength development and thermal stability in the blends
- * High Silica concentration of the magnitude used here to meet the theoretical expectations

The invention comprises a thermally stable low density cement composition having a compressive strength of greater than or equal to 3-45 MPa (500 psi) and permeability of less than or equal to 4 mp after at least 100 days of subjection to temperatures at or at above 200°C; and wherein the composition has a slurry density of less than 1400 Kg/m³ (12 ppg) and a lime/silica ratio of less than or equal to one. The composition comprises cement and between 50% to 100% silica (by weight of cement), comprising silica flour and silica fume. Preferably, the composition includes 30% to 100% BFS (by weight of cement). Preferably, the composite exhibits a compressive strength of greater than or equal to 3-45 MPa (500 psi) after setting for at least 48 hours at a temperature less than 40°C (104°F).

The invention of a light weight thermally stable cement composition suitable for cementing well bores includes an embodiment of cement of Class C or the like; 33% to 50% BFS (by weight of cement), 33% to 80% silica flour (by weight of cement), 13% to 50% silica fume (by weight of cement), a lime to silica ratio of less than 1.0; and water
 5 sufficient to produce a slurry having a density of 1400 Kg/m³ (<12.0 ppg).

Description of Preferred Embodiments

One successful blend that tended to meet the criteria is as follows:

Blend 1:

ASTM Type III (API Class C) Cement + 33% BFS (by wt of cement) + 33% Fine
 10 Silica flour (by wt of cement) + 20% Silica fume (by wt of cement). This blend was mixed with water at a resultant slurry density of 1400 kg/m³ and gave a yield of 1.283 m³/tonne of the blend. The base blend was tested at the following temperatures to determine the amount of time (hours) needed to develop 3.45 MPa (500 psi) compressive strength (local regulatory board requirement):

	40 deg C	30 deg C	25 deg C
	24 Hours	48 Hours	306 Hours
15	The result of the study at a temperature of 230 deg C:		

	3-day	7-day	28-day
	CS in MPa/Perm (md)	CS in MPa/Perm (md)	CS in MPa/Perm (md)
	4.2 (609psi)/2.45	3.5 (508psi)/2.89	2.9 (421psi)/2.80

Though the trend of the compressive strength value at 230 deg C seems to indicate a possible strength retrogression for this blend, all literature studies reflect a similar pattern for as long as up to the first 90 days after this sudden and extra ordinarily
 20 harsh environmental exposure to high temperature. For these systems, once they get accustomed to this situation, the general trend is a rise of the CS and decreasing permeability.

One thing to notice in this BLEND 1 is that the permeability has been stabilized. Another encouraging result is that this 28-day sample has also been analyzed by X-ray
 25 diffraction (XRD) and Scanning Electron Microscopy (SEM). The result indicates the formation of a mineral known as Xonotlite in more than 80% (by wt of the hydrated cement) which is reported in the literature as a thermally stable (up to 315 deg C) cement hydration product, to be desired in a steam flooded/fire flooded/geothermal well.

When BLEND 1 was modified by adjusting the ratio between silica flour and silica fume towards better thermal stability, by increasing silica flour (from 33% to 40%) and decreasing silica fume (20% to 13%), leaving the total SiO₂ content the same, the following results were observed:

3-day	7-day	24-day*
CS in MPa/Perm (md)	CS in MPa/Perm (md)	CS in MPa/Perm (md)
2.75 (399psi) 4.24	2.54 (368psi) 4.10	4.00 (580psi) 3.88

- 5 * This test was stopped four days earlier due to a leak observed in the pressure pump in the curing chamber

Though the permeability observed in this modified BLEND 1 is higher than that of the original, the trend still seems to be coming down to the equilibrium state after this "shocking" period. The compressive strength of this modified blend definitely looks much superior than the original.

BLEND 2

ASTM Type III (API Class C) Cement + 100% BFS (by wt of cement) + 50% Fine Silica Flour (by wt of cement) + 50% Silica Fume (by wt of cement). This blend was mixed with water at a resultant slurry density of 1400 kg/m³ for a yield of 1.602 m³/tonne of the blend. The following properties of this blend (BLEND 2) have been obtained.

By adjusting other admixtures in this blend, the following data on the compressive strength have been, thus far, generated:

(a) 40 deg C (4.0 MPa or 580 psi in 24 hours); (b) 230 deg C (6.50 MPa or 943 psi in 72 hours)

20 When BLEND 2 was modified, similarly to BLEND 1 reported earlier, by merely changing the proportion of silica flour and fume (increasing silica flour from 50% to 80% by wt of cement and decreasing the silica fume from 50% to 20% by wt of cement), the following results were observed:

(a) 40 deg C (4.8 MPa or 551 psi in 48 hours); (b) 25 deg C (3.5 MPa or 508 psi

in 179 hours). At an elevated temperature of 230 deg C, the following results were obtained:

3-day	7-day	24-day*
CS in MPa/Perm (md)	CS in MPa/Perm (md)	CS in MPa/Perm (md)
6.51 (944psi)/0.68	5.93 (860psi)/0.46	7.60 (1102psi)/0.50

* The test was stopped four days earlier due to a leak observed in the pressure pump in the curing chamber

It is obvious from this test result that the permeability has almost reached an equilibrium at 230 deg C in 24 days and the compressive strength is far superior than the other blends reported here. X-ray diffraction and scanning electron micrograph, however, shows almost 81% Tobermorite crystals (C5S6H5 approximate) and the remaining 19% was quartz.

General Discussion

The lime/silica ratio has been maintained at less than 1.0 in all four cement compositions reported above. BLEND 1 and its modified form have CaO/SiO₂ ratio of about 0.88 whereas BLEND 2 and its modification design have this lime/silica ratio of about 0.64. So, theoretically all these four systems should be thermally stable, suitable for pumping into wells of bottom-hole temperature of up to 315 deg C. However, most of the literature data are for normal density cement slurries and not for low density systems. A lower lime/silica ratio (i.e. higher silica concentration) has been suggested for lower density cement composition. The limited amount of data generated so far does support this theory. The percentage of silica, say in BLEND 1 and modified BLEND 1, is about 53%, whereas it is 100% in BLEND 2 and its modified version (both by wt of cement). It can be argued that the actual value of this silica concentration in these blends (all four) may be higher than what it may appear. The argument behind this statement is that slag though not considered as a pozzolanic material, instead is considered as a hydraulic material. But it is well known that the hydraulic property of slag is much lower than that of cement. The silica contribution from BFS is quite significant. So, a certain amount of this contribution should be considered in determining the total percentage of silica.

Normally, an alkaline system is needed to activate slag. Such activator may be available from the hydration product of Portland cement when a blend of cement and slag is used. Sodium metasilicate has been reported as an activator for BFS, and a small amount of sodium metasilicate has been included in "other admixtures" package used in

*One such common activator is a mixture of sodium hydroxide and sodium carbonate

each of the four blends discussed here for controlling the set time or the slurry stability or other properties. Yet, a competition between this sodium silicate and the Ca(OH)_2 generated from the hydration of Portland cement in these blends should occur. If any portion of this Ca(OH)_2 is used up to activate slag, that will also slow down the overall reaction rate towards the formation of the thermally stable minerals. Sodium silicate may play another role in future stage of hydration to facilitate the formation of Pectolite, another very strong and stable crystal.

High silica concentration is needed to form Tobermorite (approx. formula $\text{C}_5\text{S}_6\text{H}_5$ in the Cement chemist's notation) which is a strong binder. There is more than one crystal form of Tobermorite reported in literature. They are termed based on their X-ray spacings. Most common of them are 14 Angstrom Tobermorite ($\text{C}_5\text{S}_6\text{H}_9$, forms at around 60 deg C), 11.3 Angstrom one with approximate composition of $\text{C}_5\text{S}_6\text{H}_5$ (forms between 110-140 deg C). The other Tobermorite (9.3 Angstrom one) of approx. composition $\text{C}_5\text{S}_6\text{H}$ forms between 250-450 deg C. The 11.3 Angstrom Tobermorite with time and proper reaction environment will convert to Xonotlite ($\text{C}_5\text{S}_5\text{H}$ at 3.65 Angstrom spacings and between 150-400 deg C) which reacts with excess quartz to form Truscottite ($\text{C}_6\text{S}_{10}\text{H}_3$ at 19 Angstrom X-ray spacings and between 200-300 deg C). The majority amount of the 28-day hydration at 230 deg C of the BLEND 1 composition has been identified as Xonolite. If coarser than 325 mesh silica flour were used, instead of Xonolite, afwillite ($\text{C}_3\text{S}_2\text{H}_3$), kilchoanite, or calcio-Chondrodite would have been the product. None of these are as strong materials as Xonotlite. The major product in the modified BLEND 2 after 24 days of hydration at 230 deg C has been identified as 11.3 Angstrom Tobermorite instead of Xonotlite or Truscottite. The reason behind not finding Xonotlite or Truscottite in this blend can be explained as follows: BLEND 1 has more cementitious materials per unit mass compared to modified BLEND 2. More cementitious materials in the reactants should favor the formation of calcium silicate of the type suitable for that particular reaction environments. In addition to that, the reaction kinetics in BLEND 1 is definitely going to be much faster than the modified BLEND 2 composition because the former contains relatively more finer particles per unit mass than the later. These two reasons, just cited, should be enough to accelerate the whole hydration kinetics at some constant temperature (say 230 deg C) for BLEND 1 more than that of the modified BLEND 2. Needless to mention that the modified BLEND 2 was hydrated for 96 hours less at 230 deg C than that of the BLEND 1.

The reason for selecting different kinds of silica (silica flour and silica fume) is as follows. The average particle size of silica fume is less than one micron and that of silica flour is about 15 micron. Coarser than silica flour is unsuitable for high temperature

stability. So, a balance between the flour and fume must exist. Silica fume will facilitate low temperature compressive strength development which is a necessity in this application to abide by the local regulatory board as well as to minimize the rig time. Silica fume also helps in bringing some stability of the slurry preventing excess free water separation.

5 However, dry blending of high levels of silica fume in most of the blending procedures is difficult because of the inherent nature of these fumes of sticking to the surface of the vessel instead of having free flow character due to the generation of high statical electric current. Also, there are some scattered beliefs that a high concentration of silica fume does cause micro cracks in set cement. The effect of silica flour (325 mesh) for high

10 temperature stability is well documented. This is the main reason for looking at a compromise between the levels of flour and fume so that a sufficient strength can be developed at relatively lower bottom-hole temperatures during placement, yielding minimum 'waiting-on-cement' time while yet the composition has a sufficiently large amount of silica flour to favor the reaction towards the formation of thermally stable

15 materials at elevated temperature when the well is subjected to steam flooding.

Discussion Re BFS, in particular, and other issues.

The advantages of including BFS are that (a) because of its 1:1 lime:silica ratio, it is more thermally stable than Portland cement; (b) it can accept the lime produced from the hydration of Portland cement and convert it to thermally stable Tobermorite, and other

20 materials; (c) in addition to being a source of silica, BFS is synergistic with additional silica (externally added) to form thermally stable system at elevated temperature; (d) instead of being just a source of silica, it is more reactive than silica or fly ash or any pozzolanic materials. The disadvantages are that potassium and/or sodium ions present in BFS are known to be detrimental in "the fluid loss control" property. It is a source of silica and

25 does enter into the calculation of the lime/silica ratio.

Additives are important in adjusting the Thickening Time, Rheology, Fluid Loss property, etc. needed for each particular operations and are not in the matrix of the base Blend Composition.

The lime/silica ratio of the batch of Class C cement we are using will be 65.3/21.9 = 2.98; to compute the lime/silica ratios of BLENDS 1 and 2 respectively:

30

BLEND 1			BLEND 2		
	Lime	Silica		Lime	Silica
Class C cement (100 gms)	65.3	21.9	Class C Cement (100 gms)	65.3	21.9
BFS (33% BWOC; 33 gms)	11.9	12.5	BFS (100% BWOC; 100 gms)	36.2	37.8

Silica Flour + Fume		Silica Flour + Fume	
(53% BWOC; 53 gms)	<u>53.0</u>	(100% BWOC; 100 gms)	<u>100.0</u>
TOTAL	<u>77.2</u> <u>87.4</u>		<u>101.5</u> <u>159.7</u>

Ratio = $77.2/87.4 = .88$

Ratio = $101.5/159.7 = .64$

The above assumed both silica flour and silica fume are 100% SiO₂.

The composites can be blended without BFS and still they will work. Due to the higher cost of BFS, commercially, it may not become attractive to increase it further, or even to use it, at least in all situations.

5 Compositions with a lime/silica ratio of as low as 0.64 are rare and have not been used in oil well cementing.

Use of more than 48 hours to develop 3.45 MPa is undesirable. A maximum of 72-80 hours may be acceptable in very rare and difficult situations. Other than some local regulatory board requirements, longer time to develop compressive strength means higher
10 rig time which is expensive. Normally, as soon as sufficient compressive strengths is developed from the cement setting (called Waiting on Cement Time, WOC) to support the casing, drill crew can go back to the rig for further drilling.

If one were to monitor the compressive strength development and the permeability of the set cement up to 180 days (6 months) for some selected compositions, one would expect the general trend of the compressive strength to increase and the permeability to decrease, based on the available known chemistry. From the compositional point of view, one can forecast the reaction kinetics from the available chemicals in the system and the reaction conditions. Both the compressive strength and the permeability of the expected mineralogy is known and thus can be predicted.

20 There is no minimum permeability requirement. Depending on the area where that cement is located in the wells, less than one millidarcy is considered acceptable. In some cases it may be 4-5 md and in others it may be 0.1 md or of similar order of permeability is needed.

Compressive strength of 3-45 MPa (500 psi) is not needed everywhere. Some
25 believe that it is required for holding the casing. Others believe that even 0.7 MPa (100 psi) is adequate to hold a casing. But generally, no matter what one believes and practices, up to a minimum of 3-45 MPa (500 psi) for the rest of the well's life is desirable.

The "additive package" is from the chemicals, calcium chloride, lignosulfonates,

sodium metasilicate and polyvinyl alcohol. These chemicals are used for adjusting thickening time, slurry stability (i.e., prevent from settling particles instead of maintaining a homogeneous system), fluid loss control and development of early compressive strength, etc. The base composition of the cement blend remains the same and one can adjust the concentration or the level of lignosulfonates, sodium metasilicate and polyvinyl alcohol for desired properties.

A thermally stable 1400 kg/m³ density cement design can be made without any BFS. In that case, one will have to recalculate the lime/silica ratio to compensate for the loss of lime and silica from BFS, to maintain the same lime/silica ratio as was in the blend with BFS. This will change the kinetics of the hydration reaction. Based on limited study, it is predicted that it will take longer time to develop compressive strength (CS), particularly at low bottom-hole temperature of cement placement.

Depending on the minimum CS required within a certain amount of time either by the local regulatory board or the customer, one will have to adjust the main blend composition with other chemical additives (additive package). These additives are used in a relatively small amount compared to the components of the blend and does not normally enter into lime/silica ratio calculation, nor in the calculation of the slurry density. At present, CaCl₂ and anhydrous sodium metasilicate are used to accelerate the set of the cement slurry and/or to enhance the early compressive strength. There are other chemicals known to assist in these two properties just described.

Portland cement is hydraulic material that is it sets hard and develops CS in water. Silica (flour or fume) is called pozzolanic (pozz) materials, that is it reacts with lime and produces cementitious product. (So, pozz becomes hydraulic when comes in contact with lime.) BFS is called a hydraulic material. If one can measure the degree of hydraulicity, then BFS will definitely be categorized as a material with much less hydraulic property than cement.

The uniqueness of BFS in these blends is that it is thermally more stable than Portland cement because the lime/silica ratio of BFS is more close to the theoretical desired value of 1.0. Also, BFS can react or consume the lime produced from the hydration of Portland cement faster and convert it to a higher degree of thermally stable tobermorite than the pozz can react with in-situ lime. BFS will, thus, assist in the development of earlier compressive strength more than pozz. It is well known that alkali is needed to activate BFS, Lime, Ca(OH)₂, produced during the initial hydration of C₃S of Portland cement can and will activate the BFS which in turn will be more prone to enhance or accelerate the kinetics of BFS hydration. Also, sodium metasilicate used in the blends of this invention can hydrolyze to NaOH (strong base) and silicic acid (weak acid)

Sodium hydroxide can also activate the BFS and a faster hydration can occur. Silicic acid (though very small in amount) is a pozzolanic material and cannot be a detrimental additive.

5 The uniqueness of the blend is not vanished even if one omits BFS from the composition. Uniqueness does not lie on mere placement at low temperature and then
subjecting it to a high temperature. The uniqueness is in placing a low density slurry at
low temperature requiring a certain amount of CS development within a time frame which
is later subjected to high temperature. If any similar incidents are found in the literature,
the slurry is extended (lowered the density) invariably with a material that is crushed under
10 pressure (perlite, spheres, etc.) whereby the downhole resultant density of the slurry,
subjected to the bottom-hole temperature, is much higher than the reported density. This
higher density helps in getting higher CS in the same amount of time compared to a lower
density system.

CLAIMS

1. A lightweight thermally stable cement composition for lining a borehole having setting temperatures at or below about 40°C, comprising:
cement; and
about 50% to 100%, by weight of cement, silica flour and silica fume, having
5 an average particle size less than about 15 microns; and
wherein said composition has a lime to silica ratio of less than or equal to 1.
2. A slurry including the composition of claim 1 and water, the slurry having a density less than or equal to 1400 kg/m³.
3. The composition of claims 1 and 2 wherein said silica includes 33% to 590%, by weight of cement, silica flour and 13% to 50%, by weight of cement, silica fume.
4. The composition of claims 1 and 2 wherein said composition comprises about 30% to 100%, by weight of cement, BFS.
5. The composition of claims 1 and 2 wherein said cement comprises Class C cement.
6. The composition of claims 1 and 2 wherein said composition comprises about 30% to 50%, by weight of cement, BFS.
7. The composition of claims 1 and 2 wherein said silica comprises about 33% to 80%, by weight of cement, silica flour.
8. The composition of claims 1 and 2 wherein said silica comprises about 13% to 50%, by weight of cement, silica fume.
9. A method for lining a borehole with a light weight thermally stable material comprising:
forming a slurry by mixing cement and water with a means for creating a
slurry such that the slurry has a density of less than or equal to 1400 kg/m³ and
5 has lime/silica ratio of less than or equal to 1;
passing said slurry into said borehole; and

setting said slurry to a compressive strength of greater than or equal to 500 psi after no more than 48 hours wherein portions of the borehole have a temperature as low as 40° C.

10. The method of claim 9 wherein said means for creating a slurry includes silica having an average particle size of less than or equal to about 15 microns.
11. The method of claim 9 wherein said means for creating a slurry includes silica flour and silica fume.
12. The method of claim 9 further comprising the step of adding about 30% to 100%, by weight of cement, BFS.
13. The method of claim 9 that includes setting said slurry to a compressive strength of greater than or equal to 500 psi after no more than 300 hours wherein portions of the borehole have a temperature as low as at about 25°C.
14. The method of claim 9 that includes setting said slurry to a compressive strength of greater than or equal to about 500 psi after no more than 24 hours wherein portions of the borehole have a temperature as low as 40°C.
15. The method of claim 9 that includes setting said slurry to a compressive strength of greater than or equal to about 500 psi after no more than 48 hours wherein portions of the borehole have a temperature as low as 30°C.
16. The method of claim 9 that includes subjecting said set slurry to temperatures in excess of 200°C for periods of weeks while maintaining a compressive strength of greater than or equal to about 500 psi.
17. A cement composition produced by the steps comprising:

mixing cement and silica wherein the silica has an average particle size less than or equal to about 15 microns and a weight of between 50% to 100% of said cement and said composition has a lime to silica ratio of less than or equal to 1.
18. A cement slurry formed by the steps of mixing said cement composition of claim

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- 17 with water sufficient to produce a slurry having a density of less than or equal to about 1400 kg/m^3 .
19. A cement slurry formed by the steps of claim 18 wherein said silica includes silica flour and silica fume.

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 97/10255

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C04B28/04 C04B18/14 C04B14/06 E21B33/13

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 C04B E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 501 830 A (MILLER RICHARD ET AL) 26 February 1985 see column 2, line 1 - column 2, line 7 see column 2, line 35 - column 2, line 56 see column 4, line 1 - column 4, line 22 see claims 1,6	1-3, 7-11, 13-19
Y	---	4-6,12
Y	DILLENBECK.R.L. ET AL.: "The Effect of Microsilica on the Thermal Stability of Lightweight Cement systems " CIM/SPE, no. 116, 1990, XP002044825 cited in the application see page 116-2, left-hand column, line 7-14; table 2 ---	1,9,17, 18
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

Intern. Patent Application No

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	WO 90 11977 A (NORSKE STATS OLJESELSKAP) 18 October 1990 see page 3, line 26 - page 3, line 36 see page 5, line 1 - page 5, line 24 see example 2 ---	1,9,17, 18
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A	DE 36 29 769 A (ELKEM AS ;NORSKE STATS OLJESELSKAP (NO)) 5 March 1987 see page 4, line 8 - page 4, line 20 see example 3; tables 3,4 see example 4; table 5 ---	1-19
A	US 3 558 335 A (MESSENGER JOSEPH U) 26 January 1971 see column 2, line 3-7 see column 3, line 26-45; example 1 -----	1-19

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