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# The Indian Journal of Research Anvikshiki

Bi-monthly International Journal of all Research

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This special issue on Engineering and Technology 2012 of Anvikshiki brings together the latest developments in technology and gives a base for the future work to be done in respective areas.

I wish the journal to be a great success.

*Bhawna Verma*  
*Assistant Professor*  
*Department of Chemical Engineering & Technology*  
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*Message*

I express my sincere gratitude to the editorial board of prestigious journal ANVIKSHIKI for believing in my technical competencies and choosing me as a reviewer of special issue on Engineering and Technology 2012. I understand that with great role comes great responsibilities. I will try to fulfill this highly valued responsibility with best of my technical knowledge and human values. This journal has been a guiding beacon for scientific community for numerous years & has gained the prestige due to it's original & rich articles. The contribution of ANVIKSHIKI in field of scientific research is immense.

I wish for the phenomenal success of special issue on Engineering and Technology,2012 of ANVIKSHINKI.

*Prabhat*

P K S Dikshit  
Professor  
Department of Civil Engineering  
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### *Editorial Note*

As my nomination as an Subject Expert and Editor for this Special Issue on Engineering & Technology 2012, I have worked a lot to make it successful. I do whatever task is at hand to the best of my ability. I take pride in my work and give hundred percent every time. For those submissions that were not suitable for publication, we tried to let authors know very quickly of our decision, giving them a chance to submit their manuscript to another journal if they so desire. I am fully aware that the prestige and quality of an ANVIKSHIKI Journal depends upon the altruistic participation of reviewers and the fairness and promptness with which the review process is conducted. In this regard, I wish to express my sincere gratitude to all board members for their nice cooperation and sustained effort. However, because of the increased number of submissions and the diversity of research fields involved, we have a difficult task ahead of us requiring a more rapid tempo of review. At the same time, from now on the authors themselves should assume their own inescapable responsibilities. The editor will return immediately any manuscript that is incomprehensible to reviewers on account of substandard grammar and syntax.

Finally, it is a pleasure to thank my Editor in chief for their nice cooperation and valuable suggestion. Now, we all look forward to embarking in a journey that can take ANVIKSHIKI on to the next plateau of excellence.

I hope you will enjoy reading this issue and we welcome your feedback .

With best regards,



Jyoti Prakash

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## AN OVERVIEW ON HIGH ALUMINACEMENTASTABLE BONDING SYSTEM

VIJAY KUMAR\*, ABHINAV SRIVASTAVA\*\* AND V. K. SINGH\*\*\*

### *Declaration*

The Declaration of the authors for publication of Research Paper in The Indian Journal of Research Anvikshiki ISSN 0973-9777 Bi-monthly International Journal of all Research: We, *Vijay Kumar, Abhinav Srivastava and V. K. Singh* the authors of the research paper entitled AN OVERVIEW ON HIGH ALUMINACEMENTASTABLE BONDING SYSTEM declare that, We take the responsibility of the content and material of our paper as We ourself have written it and also have read the manuscript of our paper carefully. Also, We hereby give our consent to publish our paper in Anvikshiki journal, This research paper is our original work and no part of it or it's similar version is published or has been sent for publication anywhere else. We authorise the Editorial Board of the Journal to modify and edit the manuscript. We also give our consent to the Editor of Anvikshiki Journal to own the copyright of our research paper.

### *Abstract*

*The term high alumina cements stands for a family of refractory cements for high performance application; the calcium aluminate cements (CAC) or high alumina cement (HAC). The hydraulic strength development is due to a water bonding reaction of the calcium aluminate minerals to water-resistant hydrate phases (not water dissolvable). It is cold bonding system. Alumina contents of high performance HAC equal or exceed 70%, and remaining CaO content. The difference in mineral constitution between HAC and Portland cement can be seen in the CaO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> Phase diagram. Portland cement occurs in the relatively high CaO region, with C<sub>2</sub>S and C<sub>3</sub>S as its main constituents. Calcium alumina cement on the other hand, occurs in a region with high Al<sub>2</sub>O<sub>3</sub> (and low CaO and SiO<sub>2</sub>), a factor that accounts for their higher melting point and used as refractory cement, where CA, CA<sub>2</sub>, CA<sub>6</sub>, C<sub>12</sub>A<sub>7</sub> are the main constituents in high alumina cement.*

**Keywords:** High Alumina cement, Phase analysis, Cementing behaviour, Physical Properties of High Alumina cement.

### *1. Introduction*

The working life of high alumina cement in steelmaking and other ceramic industries is greatly dependent on the material's ability to withstand high temperatures without undergoing significant deformation and corrosion. Therefore, one of the approaches used throughout the latest decades to improve the performance of high alumina cement has been the reduction of the liquid content formed at elevated temperatures on high-alumina refractory castables. Low-melting point eutectic phases are often formed

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in these castables because of the reaction between alumina,  $\text{SiO}_2$ , and  $\text{CaO}$ . Outstanding gains in refractoriness have been obtained through reduction of the amount of  $\text{CaO}$ ,  $\text{SiO}_2$  and increase the  $\text{Al}_2\text{O}_3$  content in high-alumina cement<sup>1</sup>.

## 2. Salient Features Of High Aluminate Cement

Calcium aluminate cements are cements consisting predominantly of hydraulic calcium aluminates. Alternative names are “aluminous cement”, “high-alumina cement” and “cimentfondu”. The main active constituent of calcium aluminate cements is mono-calcium aluminate ( $\text{CaAl}_2\text{O}_4$ )<sup>2</sup>. It usually contains other calcium aluminates as well as a number of less reactive phases deriving from impurities in the raw materials. Rather a wide range of compositions is encountered, depending on the application and the purity of aluminium source used<sup>3</sup>.

Fremy in 1865 prepared various melt of lime and alumina and found them to possess good hydraulic properties and this was confirmed by Michaelis some years later. Schott in 1906 had published a memoir showing the high strength which were given by fused calcium aluminates. Spackman’s aluminate compounds were prepared by adding bauxite to high-alumina slags. A number of natural cements containing additions of Spackman’s calcium aluminates were marketed in the United States about the 1910 under the name of Alca natural cements, but their manufacture was later abandoned. A further study of high-high alumina cements was carried out by P.H. Bates at the U.S.A. Bureau of standards, the first results of which were published in 1921<sup>4</sup>.

Bates prepared high-alumina cements by clinkering in a small (20-foot) rotary kiln and tested their properties in concrete. The high alumina cement ‘CA’ is the main mineralogical ingredient along with  $\text{CA}$ ,  $\text{C}_2\text{A}$ ,  $\text{C}_{12}\text{A}_7$ ,  $\text{C}_4\text{A}_3\text{SO}_4$ ,  $\text{CA}_6$ ,  $\text{Al}_2\text{O}_3$  etc. In high purity high alumina cement have the lower amount of impurities less fluxing agents and as a refractory properties better. So it is better to use high purity, high alumina cement as a binder. Depending up on the amount of impurities present in the HAC it is divided in three groups<sup>5</sup>.

- a. Low purity
- b. Intermediate purity
- c. High purity

T A B L E 1 *Composition & service temperature for such cements*

Types of cement	Composition (% indicated oxide)					Temperature
	$\text{Al}_2\text{O}_3$	$\text{CaO}$	$\text{SiO}_2$	$\text{Fe}_2\text{O}_3$	$\text{TiO}_2$	
Low purity	36-47	35-42	3.5-9	7-16	0.50	1425°C
Intermediate purity	48-62	26-39	3.5-9	1-1.3	0.05	1650°C
High purity	70-80	18-26	0.0-0.5	0.1-0.2	—	<1870°C

In high purity high alumina cement lower amount of impurities i.e. less fluxing agents and as refractory properties better. So it is better to use high purity, high alumina cement as a binder. Depending upon the rate of hydration of different phases, high alumina cement is divided into 3 groups<sup>3</sup>.

T A B L E 2 *The rate of hydration different phases in HAC*

Hydration rate	Low purity	Intermediate purity	High purity
Fast	CA	CA	CA
	$\text{CA}_2$	$\text{CA}_2$	$\text{CA}_2$
	$\text{C}_{12}\text{A}_7$	$\text{C}_{12}\text{A}_7$	$\text{C}_{12}\text{A}_7$
	C	C	C
Slow	$\text{C}_2\text{S}$	$\text{C}_2\text{S}$	-

	$C_4AF$	$C_4AF$	-
Non hydrating	CT	-	-
	A	A	-

Calcium aluminate cements (HACs) are the most important type of non-Portland or special cements. Even so, the volume used each year is only about one thousandth of that of Portland cement. As they are considerably more expensive (four to five times), it is therefore not economic to use them as a simple substitute for Portland cement. Instead their use is justified in cases where they bring special properties to a concrete or mortar, either as the main binder phase or as one component of a mixed binder phase<sup>5</sup>.

### 3. Manufacture Of High Alumina Cement

The raw materials used for the manufacture of high-alumina cement are lime stone and bauxite. Although alumina is very widely distributed in nature, bauxite is the only suitable material available commercially on a scale adequate for cement production. Bauxite also forms the raw material for the manufacture of aluminium metal of alum and aluminium sulphate, and of certain types of refractories. The material used in Great Britain comes from France and Greece. During the last war, when bauxite was short, use was made of aluminium dross and the red mud from the Beyer process for production of alumina<sup>5</sup>.

High alumina cement was originally manufactured in a water-cooled vertical furnace, open-hearth furnace arranged with vertical stack, Electrical furnace also used for the manufacture of high alumina cement for the small amount, and high-alumina cement is also produced by fusion in a rotary kiln of a type similar to that used in Portland cement manufacture.

For low iron content (<4 per cent  $Fe_2O_3$ ) in high alumina cement, it has not been found possible to clinker the raw materials containing a low iron content that are used commercially. And fast very fast cooling markedly reduces the rates of strength development though not the ultimate strength. Experiments by Berl and Lobein showed that the strength tended to increase the more slowly the mix was cooled and the more completely crystalline the product<sup>6</sup>.

A especially pure type of high alumina cement, white in color, is made in England, France and U.S.A. for use as a bonding agent for castable refractories for use at high temperatures. Alumina instead of bauxite is used as the raw material and the cement which contains 70-80 percent  $Al_2O_3$  is practically free from silica and iron oxide. The pure cement contains CA,  $CA_2$ , and  $Al_2O_3$  and has a much higher melting temperature than ordinary high alumina cement. It is made by a sintering or clinkering process. Sulpho-aluminate cement made by grinding together high alumina cement and gypsum or anhydrite was patented by the Lafarge Company and worked for a time in French Indo – China. It apparently proved difficult to control its properties, and its manufacture was discontinued. Cement based on a mixture of high alumina cement, gypsum and hydrated tetra calcium aluminate is used in the U.S.S.R. as a shrinkage compensating cement studies on mixtures of high alumina cement and gypsum, dehydrated at 600 – 700°C. Suggested that a cement of this type has a resistance to chemical attack similar to high alumina cement, but lower heat of hydration and that it does not suffer from loss in strength when cured at temperatures up to 50°C. This type of cement is, in fact, very similar to the supersulphated slag cements, for, in both, a major product of hydration is calcium sulpho-aluminate. This compound is stable up to about 50°C but at higher temperature it loses water and at 75°C there is a considerable loss in strength with super sulphated cement. It also does not appear possible to get the very high strengths at one day, which is characteristic of high alumina cement at ordinary temperatures, from its mixes with calcium sulphate. The high alumina cement made commercially has been classified by Robson into four types<sup>7,5</sup>.



*Setting behavior of clinker phases:*

Fast setting phases	:	$C_3A, C_{12}A_7$
Moderate setting	:	CA
Slow setting	:	$CA_2, C_4AF$
Non setting	:	$CA_6, Al_2O_3, C_2AS$

*CA (Mono calcium Aluminate)*

- It is principal hydraulic compound.
- It gives high strength.
- Specific properties slow setting.
- M. P. = 1605°C

*CA<sub>2</sub> (Mono calcium Di-aluminate)*

- Auxiliary Phase.
- M. P. - 1700 - 1790°C.
- Low in strength.
- Slow setting.

*C<sub>12</sub>A<sub>7</sub> (Mayenite)*

- Short IST and FST.
- Hydrates and hardens quickly.
- M. P. - 1415 - 1495°C.
- Gives Low Strength.

*C<sub>2</sub>AS (Gehlenite)*

- Slow setting.
- Little tendency to hydrate.
- Undesirable phase.
- M. P. - 1590°C

*C<sub>4</sub>AF (Tetra CaAlumino ferrite)*

- No contribution to setting.
- No contribution to strength

*4. Effecting Of Impurities During Clinker Firing*

Silica, iron oxide, Titania and alkalis can affect the hydration and firing for example: high SiO<sub>2</sub> amounts in the high alumina cement CaO-Al<sub>2</sub>O<sub>3</sub> raw mix lead to the formation of the non-hydrating Gehlenite (C<sub>2</sub>AS) phase during firing.

Types of high - alumina cement:

T A B L E 3 *Types of high alumina cement*

Type	Color	Al <sub>2</sub> O <sub>3</sub> (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	SiO <sub>2</sub> (%)	CaO(%)	Source of alumina
1	Grey	37-40	11-17	3-8	36-40	Red bauxite
2	Light grey	48-51	1-1.5	5-8	39-42	Red bauxite
3	Cream grey	51-60	1-2.5	3-6	30-40	White bauxite
4	White	72-80	0-0.5	0-0.5	17-27	Alumina

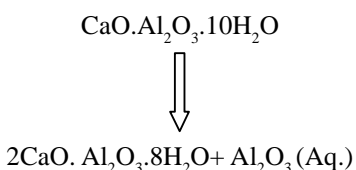
Properties of high - alumina cement:

- Rapid strength development, even at low temperature
- High temperature resistance/refractory performance
- Resistance to a wide range of chemically aggressive conditions

*5. Hydration Of High – Alumina Cement*

Both physical and chemical changes take place when water is added to the cement. The hydration converts to the anhydrous cement powder into various hydrated phases. The hydrated phases does under certain circumstances the most important product of normal hydration is  $\text{CaO}, \text{Al}_2\text{O}_3 \cdot 10\text{H}_2\text{O}$  metastable 'Hexagonal' hydrates ( $\text{CAH}_{10}$ , or  $\text{C}_2\text{AH}_8$ ) and they tend to transform into the 'Cubic' hydrate ( $\text{C}_3\text{AH}_6$ ) only stable alumina Hydrate existing over a wide range of temperature. The pure calcium aluminates show no such behavior when treated with very limited amounts of water, and the solution curves remain similar to those obtained in the presence of large excess of water and their concentration in the solution increases as the water: cement ratio is decreased. Finally concluded that at low temperature the hydrated monocalcium aluminate was formed in high alumina cement pastes and that at about  $20^\circ\text{C}$  the hydrated dicalcium aluminate and alumina gel appeared, while at higher temperatures transformation  $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$  occurred. The relative extent to which the mono and the dicalcium compounds appear is likely to be influenced by the alkali content the cement, since the presence of alkali considerably modifies the equilibrium in the system  $\text{CaO}-\text{Al}_2\text{O}_3-\text{H}_2\text{O}$ <sup>8</sup>.

“The main hydration reaction in high alumina cement”:



This alumina gel on ageing gradually crystallizes as gibbsite ( $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ). The extent to which  $\text{CAH}_{10}$  or  $\text{C}_2\text{AH}_8$  predominate in the hydration products depends on the temperature and also the cement. If  $\text{C}_{12}\text{A}_7$  is present in the cement the  $\text{C}_2\text{AH}_8$  appears more freely, as hexagonal plates. If there is any exposure to carbon dioxide, hexagonal plates of  $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{H}_2\text{CO}_3 \cdot 11\text{H}_2\text{O}$  is also formed. The predominance of  $\text{CAH}_{10}$  increases as the temperature is decreased and at  $15^\circ\text{C}$  or below the content of  $\text{C}_2\text{AH}_8$  as reported by various investigators has usually been small. When pure CA is hydrated, the critical temperature above which  $\text{C}_2\text{AH}_8$  formed is about  $23^\circ\text{C}$ . However the amount of  $\text{C}_2\text{AH}_8$  reported by different investigators form high alumina cement at temperatures between about  $20^\circ\text{C}$  and  $23^\circ\text{C}$  varies considerably. It may perhaps be influenced by the alkali content of the cement as well as by the  $\text{C}_{12}\text{A}_7$  content. The di-calcium aluminate hydrate, with ferric oxide replacing part of the alumina,  $\text{C}_2(\text{AF})\text{H}_8$  is also formed from the ferrite compound in the cement. There is also a tendency for more of the di-calcium aluminate hydrate to appear on ageing, either by conversion of  $\text{CAH}_{10}$  or from further hydration of the ferrite compound in the cement. At  $25^\circ\text{C}$  and above the initial main hydration products are  $\text{C}_2\text{AH}_8$  and hydrated alumina, and as the temperature is raises further, the isometric compound  $\text{C}_3\text{AH}_6$  increasingly becomes the dominant product within days of weeks. At temperatures of  $25^\circ\text{C}$  and upwards the isometric  $\text{C}_3\text{AH}_6$  is formed from the ferrite in amounts increasing with time and temperature. The extent to which  $\text{Al}_2\text{O}_3$  is replaced by  $\text{Fe}_2\text{O}_3$  in the hydration product form high alumina cement is still uncertain. After one day the original anisotropic grains of the cement have largely disappeared and have been replaced by the gel together with the typical spherulitic growths of hexagonal plate groups and needles<sup>9</sup>.

## 6. Effect Of Temperature On Hydrated High-alumina Cement

The high alumina cement cured at high temperatures or subsequently exposed to them in a moist state, has a reduced strength. This is closely connected with the change in the nature of the hydration products. The compounds  $CAH_{10}$  and  $C_2AH_8$  produced at ordinary temperatures are metastable, and on prolonged ageing tend to change into the cubic compound  $C_3AH_6$ . At ordinary temperatures this change is very slow and may never occur in concretes kept dry, but it must be expected to occur, even though very slowly, in wet concretes. At high temperatures it occurs rapidly. Midgley has defined 'half conversion' as the state in which the quantity of  $C_3AH_6$  is equal to that of  $CAH_{10}$  as determined by DTA. For neat cements, the time for half conversion was about a week at  $50^\circ\text{C}$ , 100 days at  $40^\circ\text{C}$  and estimated 20 years or so at  $25^\circ\text{C}$ . A concrete cube stored in water for 27 years at  $18^\circ\text{C}$  was found to be about half converted but samples from a 30 year old concrete pile extracted from the seabed showed little signs of conversion, the predominant compound still being  $CAH_{10}$ . The maximum temperature of the sea in the region concerned was about  $18^\circ\text{C}$ . When high alumina cement is hydrated at relatively high temperatures, i.e.  $35\text{--}45^\circ\text{C}$ , the cubic compound is rapidly formed and can readily be observed under the microscope when hydration takes place in excess water, and detected by X-rays in pastes of the consistence used in practice. Its presence is also indicated by the manner in which the hardened cement loses water on heating. Thus the compound  $C_3AH_6$  loses most of its water between  $225^\circ\text{C}$  and  $275^\circ\text{C}$  of wider temperature range. It is found that the loss occurring between these temperatures increases markedly in cement cured at higher temperatures, or subsequently exposed to such temperatures in a wet condition<sup>10</sup>.

CA shows a fall in strength, parallel to that of high alumina cement, on curing at high temperatures, as indicated by the data in below table.

T A B L E 4 *Compressive strength of HAC cured at high temperature*

Age	Compressive strength (lb./in <sup>2</sup> )	
	Stored in water at $18^\circ\text{C}$	Stored in water at $45^\circ\text{C}$
1 day	8715	6425
7 day	10140	3415
28 day	10770	2450

The change from the less basic forms of the hydrated calcium aluminates to the cubic  $C_3AH_6$  is thus closely associated with the marked loss in strength. There is much evidence, however that it is the volume change on conversion, rather than the mineralogical nature or morphology of the hydrates formed, that is responsible for the fall in strength. Unless there are compensating factors these volume changes make the converted cement much more porous than the original. As will be shown later, this development of porosity is partly compensated in mixes of low water: cement ratio by the continuing hydration of anhydrous cement. It has also been found that  $C_3AH_6$  and  $AH_3$  can give as high strength as  $CAH_{10}$  if the porosity is low, and that the increase in porosity on conversion decreases with to water cement ratio<sup>11</sup>.

#### *Applications*

Because of their relatively high cost, calcium aluminate cements are used in a number of restricted areas.

- In construction concretes, rapid strength development is achieved, even at low temperatures.
- In construction concretes, high chemical resistance is possible.
- In refractory concretes, strength is maintained at high temperatures.
- As a component in blended cement formulations, various properties such as ultra-rapid strength
- Development and controlled expansion can be obtained<sup>5</sup>.

### 7. *Salient Features Of Castable Refractory*

The hydraulic monolithic refractories (or) refractory castables are mixture of calcium aluminate cement (refractory cement) and suitably graded refractory aggregates. The cement in refractory castables reacts with water at room temperature and forms a strong solid mass. This is mostly used for quick furnace lining and repairing. A Refractory Castable may be macroscopically characterized as a structure consisting of large aggregates bonded together by a finer bond phase or matrix. Today's dense Castable systems have complex compositions comprised of the generic materials such as aggregates, fine reactive fillers like alumina and microsilica, calcium aluminate cement (HAC) and deflocculants. The entire system can be considered to be an independent system and the final characteristics are as a result of the sum of interactions of all. Depending on the specific type of refractory, the aggregate and matrix may be of similar or vastly different in chemical and physical properties. It is evident that almost infinite combinations exist when different aggregates, bonding matrices and particle size distributions for a particular type of Castable are considered. The relative proportion of the constituents, their chemistry and mineralogy influence the flow and refractory property of the castables. Conventional castables contain a high proportions (15-20%) refractory cement and water (8-15%). The presence of CaO associated with cement is detrimental to the refractory as it is a flux for alumina-silicate materials to form low melting phases<sup>12</sup>.

Monolithic castables are replacing the traditional fired and shaped refractories at a much faster rate due to some inherent advantages mentioned before. The refractory aggregates serve an important role in determining the service temperature of castables. Packing density of castables can be improved by filling the voids between aggregates with micronized powdery materials. The commonly used superfine particles are microsilica, reactive alumina etc. which improve the performance of castables. Finer Cr<sub>2</sub>O<sub>3</sub> was also used for this purpose but the refractory makers became aware of its environmental hazards. Various methods are employed in the placement of monolithic like ramming, casting, gunning, spraying etc. Ramming masses are used mostly in cold applications where proper consolidation of the material is important<sup>13</sup>.

#### *Low cement castables*

The low moisture content can be achieved by lowering the percentage of bonding material cement in castables. Thus above concept of low moisture low cement castables is generated. Reduction of the cement about 5-8% without determinately effect on the strength can be achieved by the addition of fine grained refractory materials and a deflocculant for homogenous distribution of the cement and fine grain additive and reduce the mixing water needed. Packing density of the monolithic refractory can be increased. The commonly used superfine materials are silica sol, silica fume, alumina gel, Cr<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>.

Micro fine silica (0.15um dia) is used to get the monolithic refractory having the high mechanical strength, high erosion resistance, good thermal shock resistance and low shrinkage. When low cement castables using super fine silica powder are heated above 1350 – 1400°C. Silica reacts with calcium aluminates of cement bond vitreous anorthite phase which cause the rapid decrease of hot MOR. This drop in hot strength above 1400°C is independent of the type aggregate used.

One of the remedies of this problem is the replacing micro fine silica by micro fine Al<sub>2</sub>O<sub>3</sub> or Cr<sub>2</sub>O<sub>3</sub>. The product Cr<sub>2</sub>O<sub>3</sub> develops a very rigid high temperature above 1400°C bond and it improve the hot strength and other physical properties. The added ultrafine silica powder forms a strong refractory phase mullite at 1300°C. The formation of mullite increases the hot MOR at 1400°C. However this hot strength drops rapidly as the CaO content increase but it solves the setting and hardening problem.

Low cement castables depending on two parameters

- Depends on CaO content
- Mullite content after firing

These two parameters not independent of each other and intensive research work has been carried out to select the bond system from the  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ , CaO phase diagram, to develop the maximum Mullite formation at high temperature and also maintain the proper cold setting and hardening<sup>14,15</sup>.

#### *Ultra-Low Cement Castable (ULCC)*

This can be achieved by lowering the percentage of cement 4% and increasing the percentage of silica fumes max 10% added. This new type of castable is known as ultra-low cement castable (ULCC). Though ULCC has higher hot MOR value than LCC but these materials are very weak in the green strength at low temperatures. So except for the blast furnace cast house application ultra-low cement castable is not use widely<sup>1</sup>.

### 8. Conclusions

Conventional castables have long been associated with ease of application. At the first introduction of low cement and ultra-low cement castables, installation sensitivity was a drawback which discouraged many refractory installers and consumers. The current generation of LCC and ULCC products has significantly improved placement characteristics in comparison to the first generation products. Additionally, refractory installers have learned the techniques and sensitivities required for the use of these products.

Today, precautions are still necessary in the placement of formulations with reduced cement levels. Ease of installation has greatly improved with castables containing lower cement contents. Improvements may be attributed to the increased knowledge of the mechanisms in the interdependence of the cement, fillers and additives. This knowledge has motivated the development of improved cements and fillers which meet the exacting demands and requirements for reduced cement formulations. Despite this knowledge, ULCC and no cement castables still tend to be more sensitive to installation parameters than conventional castables. Each castable type has its own specific characteristics which result in a unique trade off of between robustness and final performance. In the same context each castable type and each bond system have inherent characteristics that mean they do not all work equally well in all applications. A choice needs to be made application by application and it is dangerous to generalize.

The choice of calcium aluminate bonded castables by refractory manufacturers has grown significantly in the past few years. Today, castables are selected both for ultimate performance and ease of installation coupled with reduced risk of installation failure. The single biggest advantage of HAC for castables lies in its flexibility that allows a multitude of castable types and installation technologies to be developed. The basic properties of cold as well as hot cohesion can easily be achieved with calcium aluminate cement bonded systems. This is coupled with a choice of installation robustness versus installed characteristics and performance. No other bond system is able to offer such options.

The selection of calcium aluminate cement must be considered carefully in the quest to optimize performance and installation success. There must be a continuing evolution in the quality of the HAC characteristics to meet the exacting demands of the refractory formulations. For further progress to be made simultaneous development of the castable and the bond system is needed. These developments will surely fuel the growth of castables and their potential replacement for other types of Refractories.

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