HIGH PERFORMANCE CALCIUM ALUMINATE CEMENTS FOR CORROSION RESISTANT CASTABLES

by Christopher Parr, Rainer Roesky, Wang Yongting, Benoît Valdelièvre

Presented at the CSM International Refractory Conference, Beijing, China, April 2001
(Also published in CN Refractories, special issue, Vol. 5 2001 as Calcium Aluminate Cements for Unshaped Refractories)
Abstract

The successful development of high performance castables with a high degree of corrosion resistance relies upon the optimisation of both their placing characteristics and their installed properties.

This is normally achieved through combinations of suitable aggregate systems together with a deflocculated binder phase. This latter component is comprised of high purity Calcium Aluminate Cements in conjunction with reactive fine fillers and additives.

The optimisation of this binder phase to achieve the required properties is complicated, as there exists a series of reactions within the binder phase, which modify the hydration of the Calcium Aluminate Cement. These reactions all have to be controlled in order to obtain the target placing properties, the strength development characteristics and the final in service performance.

As the number of different castable placing technologies have developed over recent years, the constraints upon the refractory formulator have multiplied, as these reactions have become more and more complicated.

This paper presents an engineered Calcium Aluminate Cement that facilitates the optimisation and control of these castable systems. Target placing properties can be easily achieved and the cement has been designed to give a high level of performance including corrosion resistance when used in high performance castables.

Different castable systems are investigated and the results of variations to the formulation parameters presented. Systems investigated include Alumina-Spinel, Alumina-Magnesia, and Ultra Low Cement types. The placing and thermo-mechanical properties as well as the corrosion resistance results are discussed for each system. These clearly show the advantages of the various systems that incorporate this Calcium Aluminate Cement.

Introduction

Modern reduced cement refractory castables have to meet exacting requirements in terms of both placing characteristics as well as in-service performance targets. This has become increasingly important as the scope of possible placing technologies has expanded from vibration placing to self flow and shotcreting technologies. At the same time similar or better in service performance remains a pre-requisite. In order to cope with these additional constraints castable systems have become more complex as additional components needed to be added to ensure correct rheology, flow decay profiles, hardening rates and the maintenance of the final usage characteristics.

As a result, today’s dense castable systems are complex compositions comprised of the following generic elements; aggregates, fine reactive fillers such as alumina and fumed silica, additives and Calcium Aluminate Cement (CAC). This is illustrated in figure 1. The entire system can be considered to be an interdependent system. The final characteristics are a result of the sum of all the various interactions.

Fig. 1 The interdependent constituents of the binder.
For example, the modification of setting time depends not only upon the CAC but also interactions between the CAC and the additives as well as between the fine filler and additives. This is particularly prevalent in the case of systems which do not contain fumed silica. Fumed silica plays a beneficial role in these lower cement castable systems, through a series of interactions which aid the control of working time. When the system is based on only pure alumina and small amounts of cement, the flow decay is seen to be more rapid with the consequence of a shorter working time. This has been demonstrated in previous papers to be due to surface interactions between the additives, the filler and the CAC. The implications for these systems, without fumed silica, are that complex additive systems have to be utilised, which allow the flow decay and working time to be controlled. This makes flow and working time control inherently more difficult.

A further example of the increased constraints that exist in modern refractory castables is seen in the case of systems which contain magnesia. Magnesia is added as a means of forming Alumina-Magnesia spinel in situ to enhance corrosion resistance. However magnesia shows significant reactivity during the placing phase of castables. Previous studies have shown how the addition of fine magnesia disturbs the placing properties of dense deflocculated castables. This can be largely corrected through the use of additional or different additives.

These two examples have shown how the system constraints have become more stringent with the current generation of refractory castables. Optimisation can only be effectively achieved through a simultaneous consideration of all variables. Consequently reduced cement castables have become more complex. There is also a secondary issue related to the reliability of such castables. Small changes in any of the individual components or the accuracy of combination can lead to modification of the castable properties. Additionally, the passage from classical castables containing 20% or more CAC to low cement castables (LCC) and ultra-low cement castables (ULCC) containing 5% and less CAC has rendered modern castables more sensitive. Tolerance to placing property variation (water demand, mixing time, etc.) becomes much lower as the cement content decreases.

A possible solution to these concerns is to use a CAC with a low CaO content which has been specifically developed for use in these dense castable systems. Thus, alleviating the need for extremely low CAC additions and highly complex additive systems. The key advantages for using this cement are reduced formulation complexity together with optimised performance. However, sufficient formulation flexibility is still maintained to allow each user to further develop and customise their system as desired.

This paper investigates different castable systems using this type of CAC and shows how excellent placing properties, hardening characteristics and final performance can be achieved through simple and essentially robust model formulations.

### 3 Experimental approach

#### 3.1 Raw materials and formulations

Five base systems were used and these are shown in Table 1 along with the raw materials used in each system. The particle size distributions were calculated using the Dinger and Funk model with a q value of between 0.25 to 0.3 depending upon each specific system. The systems were designed for vibration placing. For all base systems no additives or additive containing materials were used. As seen in Table 1 this gives rise to essentially simple systems which can be reliably produced. Each of the systems used different combinations of reactive fillers from CAC alone (HPA), to reactive alumina and magnesia (LCC-A and Alumina-Magnesia).

The CAC additions have been adjusted to give a range of CaO contents in the final product. The highest CAC addition of 15% would correspond to a MCC castable system, whilst the alumina spinel and alumina-alumina system conform to LCC castable systems with an equivalent lime content of around 2%. The systems containing fume silica have reduced CAC additions thus positioning them at the lower limit of LCC and ULCC systems with around 0.9 –1.1% lime. The interest of using an 80% Alumina CAC is in the ability to maximise the cement content whilst still maintaining a low lime content in the final product. The higher cement contents, lead to
inherently more robust systems which are less sensitive to variations in external placing conditions such as mixing energy, ambient temperature and water additions.

Table 1. Model Systems

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>HPA  (15)</th>
<th>Al-Sp  (10)</th>
<th>LCC  (5)</th>
<th>LCC-A  (10)</th>
<th>AlMgO  (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina</td>
<td>85</td>
<td>61</td>
<td>80</td>
<td>86</td>
<td>80</td>
</tr>
<tr>
<td>Al-Spinel</td>
<td>-</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Binder Phase</th>
<th>Al-Spinel</th>
<th>Al/P152SB</th>
<th>Fume Silica</th>
<th>Magnesia</th>
<th>80% CAC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

The 80% alumina CAC used is a new development, designed for use in reduced cement systems; the basic properties are shown in Table II. The setting times were measured using an Afnor mortar with the water cement ratio adjusted to 0.32 compared to the normally used 0.36. This was to allow easy measurement of flow values given the inherent fluidity of the cement. The long working time can be clearly seen yet the final set follows quickly after the initial set. This has been specifically engineered to aid rapid demoulding once the castable has stiffened.

Table 2. Properties of the 80% Alumina cement

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al2O3</td>
<td>%</td>
<td>80.1</td>
</tr>
<tr>
<td>CaO</td>
<td>%</td>
<td>17.6</td>
</tr>
<tr>
<td>SiO2</td>
<td>%</td>
<td>0.3</td>
</tr>
<tr>
<td>Surface area</td>
<td>m²/g</td>
<td>6-7</td>
</tr>
<tr>
<td>D50 particle size</td>
<td>micron</td>
<td>4-5</td>
</tr>
<tr>
<td>Initial set</td>
<td>minute</td>
<td>180</td>
</tr>
<tr>
<td>Final set</td>
<td>minute</td>
<td>190</td>
</tr>
<tr>
<td>Initial flow t=0</td>
<td>%</td>
<td>85</td>
</tr>
<tr>
<td>Flow t=60</td>
<td>%</td>
<td>71</td>
</tr>
</tbody>
</table>

3.2 Testing

Flow value: the flow value has been determined using a cone with 100 mm base diameter, 50 mm high and 70 mm top diameter. The cone is placed on a vibrating or shock table (ASTM 230C), filled with the castable, then taken away and after 25 shocks or 20 seconds of vibration the diameter of the resulting "cake" is measured and considered as the flow value in mm. Flow value is calculated as a percentage as follows:

\[ FV [\%] = \frac{\text{cake diameter} - \text{initial diameter}}{\text{initial diameter}} \times 100 \]

Working time: the time after which the initial cone would not flow at all under vibration is called working time.

Flow decay: flow values measured as a function of time and displayed as a curve show with which speed an initial flow decays, or can be maintained.

Exothermic profiles: the exothermic profiles are determined at 20°C and 5°C with samples placed in insulated chambers. A thermocouple, imbedded in a cast sample, is linked to a data capture system and the temperature recorded as a function of the time. The time taken to reach the maximum temperature is recorded.
Cold Modulus of Rupture: MOR values were measured on 4x4x16 cm prisms dried or fired to 110°C, 800°C, 1100°C, 1200°C and 1500°C respectively.

Hot Modulus of Rupture: the Hot Modulus of Rupture and Refractoriness under load values were determined by the Société Française de Céramique using the ISO 2477 and ISO 1893 procedures. Sample size was 150x25x25 mm with 125 mm spacing between the loading points. Tests were conducted in an atmosphere of air. Samples were dried at 110°C before testing without any pre-firing to develop specific microstructures.

Corrosion tests: Corrosion resistance was carried out on proprietary systems by China Steel. The procedure was as per detailed in Y. H. Ko et al with a slag basicity of C/S = 4. The tests were carried out at 1650°C with 30 minutes exposure followed by 10 minutes air shocking. This was continued for 6 cycles. Equal quantities of metal and BOS slag were used (800g) for each cycle.

4 Results

4.1 Placing properties

The placing properties were evaluated using a vibration table and measuring the vibration flow at various intervals from the end of mixing. The initial target flow value was 100 ± 25 %, which is equivalent to a good ball-in-hand consistency. Water contents were adjusted to give the initial target flow values. The flow measurements were performed at 5% water addition with the exception of the HPA system which needed 5.5% and the Alumina Magnesia system where 4.6% water was used.

The flow profile results are shown in Figure 2. As illustrated all systems demonstrated satisfactory flows at very low water additions with the working times ranging from 80 to 140 minutes depending upon the specific system. The beneficial presence of fume silica can be seen with the LCC model formulation which has the flattest flow profile which only starts to decay after 90 minutes. By contrast the alumina magnesia system is the most reactive as the flow starts to decay from t=0. However the flow remains sufficiently high to allow proper placing for over 60 minutes.

Fig 2. Flow properties of the 5 castables

The effect of the magnesia upon the flow properties can be clearly seen. The systems using reactive alumina as the fine filler showed intermediate behaviour between these two extremes. In all cases excellent placing properties, at low water demands, were assured with a working time of at least 60 minutes without the need for any additional additives. This is the case even when reactive fillers such as magnesia are used.

4.2. Hardening properties

One of the challenges of developing modern reduced cement castables is to ensure high flow and long working times without perturbing the hardening properties of the castable. This was evaluated by measuring the exothermic profile as well as the green strengths after 24 hours.
The time to maximum heat generation as measured through the exothermic profile is particularly useful for CAC containing systems and has been successfully adapted for use in refractory systems\textsuperscript{15}. These two parameters have been shown to be useful indicators in predicting the ease of demoulding of concretes\textsuperscript{18}. The time to maximum temperature along with the cold crushing strength (CCS) after 24 hours are shown in Figure 3.

**Fig. 3 Hardening properties of the investigated systems**

The time to maximum temperature is an indication of the onset of mechanical strength development whilst the green strength after 24 hours gives an idea of the maximum strength development potential. In a practical context, 24 hours is taken as an arbitrary point by which time most of the green strength development should have occurred.

In a general context, Figure 3 shows that the onset of mechanical strength development is not affected by the placing properties, as illustrated in Figure 2, as it occurs between 6 and 10 hours. Furthermore the CCS as measured after 24 hours is sufficiently well developed to ensure satisfactory demoulding some time between 10 and 24 hours. The HPA system with 15\% cement showed the highest strength development after 24 hours but also the longest time to maximum temperature generation. This suggests that although the start of mechanical strength development occurs slightly later than the other systems, the potential for strength development is higher. This is as expected for a system with a higher cement content.

The lower lime containing systems had lower green strengths but their hardening profile occurred earlier which suggests that the critical strength for demoulding might be reached earlier.

As an additional measurement of the hardening characteristics, use was made of a newly developed ultrasonic technique. This technique\textsuperscript{18} measures the ultrasonic propagation speed through a cast sample from the time the castable is placed into the mould to the time of complete mechanical strength development. The points at which the initial structure (VL) develops and at which significant mechanical strength is obtained can be identified. This corresponds to the start of the massive precipitation of the CAC hydrates. Secondly, the technique allows the Young’s modulus to be calculated as a function of time so that the rate of strength development can be calculated. A comparison for the alumina spinel and alumina magnesia systems are shown in Table 3. Comparisons are made with SECAR\textsuperscript{80}, another 80\% Alumina cement, labelled E and the new 80\% alumina cement. The table shows the point VL and the Young’s Modulus values.
Table 3. Strength development of Alumina Spinel and Alumina Magnesia castables

<table>
<thead>
<tr>
<th>VL (h)</th>
<th>Young’s Modulus at 15 hours (MPa)</th>
<th>Young’s Modulus at 20 hours (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-SP with new 80% CAC</td>
<td>6.5</td>
<td>40</td>
</tr>
<tr>
<td>Al-Sp with SECAR 80</td>
<td>4</td>
<td>29</td>
</tr>
<tr>
<td>Al-MgO with new 80% CAC</td>
<td>5</td>
<td>29</td>
</tr>
<tr>
<td>Al-MgO with cement E</td>
<td>8</td>
<td>22</td>
</tr>
</tbody>
</table>

As can be seen from the table the new cement in the alumina-spinel system (Al-Sp) takes slightly longer to initiate the structure development. Once initiated it proceeds at a much quicker rate than either the SECAR® 80 or the other 80% Alumina cement containing system.

Hence it can be expected that the minimum strength necessary for demoulding would be reached earlier in the case of the new 80% Alumina cement. The easily achieved placing properties can however be modified through the use of classical additives to either retard or accelerate the hardening. This can be particularly useful in the case of extreme low temperature ambient conditions.

Examples of this are shown in the following sections.

4.3. The modification of placing properties – low ambient temperature

Figure 4 shows the effect of working time of the HPA system when two different accelerators are added. These tests were conducted at 5°C. It can be seen that without any addition of additives the working time is around 160 minutes. This is only a slight increase upon the value of ~140 minutes measured at 20°C which shows the inherent temperature stability of this system.

The use of either Lithium Carbonate or Sodium Aluminate results in an almost linear decrease of working time as the dosage increases. Although above 0.05% addition, the effect of lithium carbonate seems reduced. There is also a parallel decrease in the time to reach the exothermic peak whilst the mechanical strengths remain largely unchanged.

Another approach to engineer specific properties is through the use of Aluminium metal. This addition has the benefit of both reducing the hardening time as well as consuming water through the reaction which liberates hydrogen\(^\text{19}\).

This reaction produces Alumina trihydroxide (\(\text{AH}_3\) where \(\text{A} = \text{Alumina} \text{ and } \text{H} = \text{Water}\)).

This normally has a strong accelerating effect reducing the nucleation time of the calcium aluminate cement and is thus an effective accelerator. The effect of Aluminium addition upon the exothermic peak can be seen in Figure 5.
Fig. 5 The effect of Aluminium addition on the working time of system HPA at 5°C

As illustrated the effect of Aluminium is to decrease the time to the exothermic peak with increasing addition. These measurements are conducted in an insulated box which is necessary at 5°C in order that small temperature changes can be recorded.

The exothermic reaction becomes more vigorous with greater heat generation as the amount of Aluminium increases. The time interval over which heat is liberated also decreases again showing a more vigorous reaction. At low addition levels of 0.1% or less the heat profile is only slightly modified but there is a strong effect on the exothermic peak time. Without any additives the exothermic peak occurs around 7 hours at 5°C. This can be compared with a time of 9 to 11 hours at 20°C.

Thus by decreasing the ambient temperature from 20°C to 5°C only a slight increase in exothermic peak time is seen. It can be reasonably expected that the hardening and demoulding times would be therefore similar from 5°C to 20°C. The reduced low temperature sensitivity of this system based upon this new 80% Alumina cement is once again illustrated.

4.4 The modification of placing properties – high ambient temperature

The placing properties were also assessed when subjected to an environment of 35°C ambient temperature. The system chosen was the Alumina-magnesia system as this had the shortest working time at 20°C of all systems studied. It would therefore present the most rapid flow decay and the shortest working time at 35°C. At 20°C the recorded working time was between 75 and 90 minutes with an exothermic peak at 6.4 hours. Increasing the ambient temperature to 35°C reduced the working time to 25 minutes with the exothermic peak at 2.5 hours. For certain applications, in these extreme ambient temperature conditions, a longer working time would be advantageous. This was achieved through the use of an addition of a sodium polyacrylate, SPA, (low molecular weight, pH 8-10). The results are shown in Figure 6a.

Fig. 6a The effect of a sodium Polyacrylate on the working time of AlSp system at 35°C
The 6a shows the effect of the SPA additive on the working time. The working time gradually increases as the amount of SPA increases making the control of working time relatively easy. Above 0.1% addition, the retarding effect of SPA diminishes, having reached 80-90 minutes which was the recorded working time at 20°C. The impact on the exothermic peaks is shown in Figure 6b. For additions of SPA in the range 0% to 0.15% the exothermic peak increases in a linear relationship ($y = 105x + 1.25, r^2 = 0.9625$). There is therefore a significant delay to the peak when SPA additions increase from 0.1% to 0.15% yet this is not accompanied by any major improvement in working time. Therefore the practical maximum addition would be in this range of 0.1 to 0.15% addition for this specific additive. There was no effect on other measured properties such as mechanical strength.

4.5 Mechanical strength development and hot properties

After firing at differing temperatures, samples were tested for their cold modulus of rupture. This test tends to give more discriminating values after firing than the more commonly used Cold Crushing Strength (CCS). This is particularly true in the range of temperatures from the onset of dehydration (200°C) of the hydraulic binder to the start of ceramic reactions (~1000°C). MOR results are shown in Figure 7 for the four systems, HPA, Al-Sp, LCC-FS and Al-MgO.

A comparison of the HPA system with SECAR 80 is also shown. The lower values that are seen with SECAR 80 are due in part to the fact that 6.7% water had to be used to achieve satisfactory placing properties. This compares with 5.5% used in the HPA system with the new 80% alumina cement, the advantages of the low water demand being clearly translated into gains in mechanical strength development. Each system shows significantly different sintering characteristics depending upon the choice of fine reactive fillers that are used. The systems which contain some fume silica and very low cement contents (as measured by lime content) show increasing MOR values as firing temperature increases. Fume silica has previously
been shown\textsuperscript{20} to contribute to the strength
development of castable systems.

The LCC system with 5\% fume silica shows the
highest strength development, at the mid
temperature range, of all the systems tested. As
the firing temperature increases then the
presence of liquid phases (CA\textsubscript{2} and C\textsubscript{2}AS) will
also contribute to the higher cold modulus of
rupture values.

The Alumina systems show a stable MOR value
through the temperature range to 1200\(^\circ\)C. Above
this temperature an increase in strength is
observed due to the formation of CA\textsubscript{2} and CA\textsubscript{6}
phases.

The Alumina Spinel system is even more marked
with a high increase in strength between 1200\(^\circ\)C
and 1500\(^\circ\)C. The formation and structure of CA\textsubscript{6}
\textsuperscript{21,22} is presumed to be responsible. In all cases
the low strengths associated with the CAC
dehydration temperatures is avoided.

\textbf{4.6. Hot Modulus of Rupture}

The effect of the formation of high temperature
phases CA\textsubscript{2} and CA\textsubscript{6} can be seen in \textit{Figure 7}
where the hot modulus of rupture (HMOR)
values are shown for the two systems HPA and
Alumina Spinel.

The HMOR for the MCC HPA system remains
relatively constant between 1200 and 1500\(^\circ\)C
whereas the Alumina Spinel system can be seen
to increase.

The effect of solid state sintering being clearly
visible in the latter case. The high temperature
stability of these systems was confirmed with the
refractoriness under load measurements where
a total deformation of 0.21 to 0.24 mm was
measured for both the HPA and the Alumina
Spinel system.

These values compare favourably with those
previously obtained \textsuperscript{23} for 70\% Alumina CAC
systems. In this case it was necessary to use
additive packages comprised of 2 or 3 additives
to achieve low water demands and high hot
strength values. In these examples, only the
relatively simple base formulations were used
without any additional additive systems. These
HMOR values show the usage characteristics
that can be obtained with the new 80\% CAC and
the fact that it is not absolutely necessary to
reduce CaO values to a minimum when such
systems are employed.

Tests were also carried out with alumina spinel
systems based upon Chinese raw materials. The
aggregates and fine fillers were replaced with
fused alumina, sintered alumina spinel and
reactive aluminas from local producers. Water
contents increased to 6-7\% for equivalent
placing properties. Once again satisfactory
properties were achieved without recourse to
complicated additive systems. Compared to
similar SECAR 80 based systems the hot modulus
values increased by over 50\% with maximum
values of 12 Mpa being achieved even at these
higher water demands. These results confirm the
inherent high temperature properties of the new
80\% CAC and the benefits of the formation of
CA\textsubscript{6} as the high temperature bonding phase.XRD
confirmed the increased presence of CA\textsubscript{6} in the
systems with the new 80\% CAC.
4.7. Corrosion Resistance

Corrosion tests were performed on representative systems and included some commercial products as a comparison. Two systems were compared: an alumina spinel castable along with an alumina magnesia castable designed to form the spinel phase in situ. The latter systems included a small addition of fumed silica. The optimisation of the fume silica content is detailed in reference 24. In these tests a small amount of penetration was observed with the Alumina Spinel system but none with the Alumina Magnesia system. The erosion resistance of all the Alumina Magnesia systems was lower than the Alumina Spinel system and the in-house proprietary product using the new 80% Alumina cement showed the lowest erosion resistance amongst those systems tested.

Table 4. Corrosion Resistance

<table>
<thead>
<tr>
<th>Castable type</th>
<th>Ca content (%)</th>
<th>Silica content (%)</th>
<th>Erosion (%)</th>
<th>Penetration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina-Spinel</td>
<td>1.70</td>
<td>-</td>
<td>28.20</td>
<td>8.60</td>
</tr>
<tr>
<td>Alumina-Magnesia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• With 80% CAC</td>
<td>1.36</td>
<td>0.75</td>
<td>22.54</td>
<td>-</td>
</tr>
<tr>
<td>• Commercial product 1</td>
<td>1.36</td>
<td>0.50</td>
<td>25.20</td>
<td>-</td>
</tr>
<tr>
<td>• Commercial product 2</td>
<td>1.28</td>
<td>0.80</td>
<td>26.91</td>
<td>-</td>
</tr>
</tbody>
</table>

A new 80% Alumina cement, called SECAR Plenium® has been developed which overcomes these difficulties. The results presented show that through the use of this new 80% Alumina cement excellent placing properties and application properties can be achieved in a variety of dense lower cement castable systems.

Three key advantages are seen for the refractory formulator:

♦ Excellent placing, hardening, mechanical and corrosion resistance properties are obtained through the use of essentially simple and robust formulation types. The exhibited systems didn’t need additional and complex additive systems to achieve the target placing characteristics at low water demands. This is even true for systems such as Alumina – Magnesia where the use of highly reactive fillers such as magnesia normally perturb the placing characteristics.

♦ The use of the new 80% Alumina cement allows a higher cement dose for an equivalent CaO content in the resulting castable. This gives additional robustness to the castable in terms of a reduced sensitivity to placing parameters such as ambient temperature and water addition.

♦ Sufficient flexibility is built in to the cement to allow the refractory formulator the possibility to target characteristics through the use of simple accelerating or retarding additives.

5 Conclusions

Traditional 80% alumina cements have a high degree of incompatibility in dense reduced cement systems which use reactive fillers. This results in high water additions along with difficulties in controlling the placing properties of such castables. As a result cements such as SECAR 80 have not been preferred for reduced cement castable systems.

6 Acknowledgements

The authors express their thanks and gratitude to all co-workers of Lafarge Aluminates and Lafarge Central Research Laboratory for their support in the experimental work and their invaluable contribution in discussions. In addition, the authors express grateful thanks to Mr. Y. H. Ko for conducting the corrosion tests.
References


19. Y. Naruse, S. Fujimoto, S. Kiwaki, M. Mishima, “Progress of additives in monolithic refractories", New Developments in


