The Value of Additives in Refractory Castables – Part 2: Castables with Silica Fume

D. Schmidtmeier, A. Buhr, D. Zacherl, Z. Tian, S. Klaus, J. Dutton

Part 1 of this paper covered low cement refractory castables without silica fume. These included tabular alumina and spinel based materials for the highest temperature applications. However, silica fume is widely used as a fine filler in low cement castables for intermediate and high temperature applications. The use of fine matrix fillers requires the addition of additives for homogeneous dispersion of the fine particles during wet mixing (refactories WORLDFORUM 6 (2014) [3] 75). Part 2 of this paper compares the performance of traditional and modern additive concepts in silica fume castables with regard to additive dosage, storage stability of the dry mix, flow properties, working and setting time and also the strength development during curing.

1 Introduction
Silica fume containing low cement castables are used in a wide range of refractory applications. These castables contain additives for deflocculation of the fine and super-fine components and for adjustment of working time of the castable during installation. The additives have a significant influence on the performance of the castable with regard to flow behaviour, e.g. flow decay, and the cement hydration and strength development during curing. Installation failures due to late or non-hardening of the castable lining or insufficient green strength development, can create a high level of “frustration” for all parties involved. The most popular additive concepts for silica fume containing castables are phosphate based systems due to their low cost. They often require a citric acid addition in order to achieve the desired working time of the castable. This can have a detrimental effect on the cement hydration and strength development. Organic additive based systems such as dispersing aluminas M-ADS/W provide a more reliable and user friendly alternative, but they are more costly. The paper discusses extended test series performed with different phosphate additive systems and the dispersing alumina system M-ADS/W. The flow behaviour, cement hydration, and strength development were investigated. For a reliable castable performance, a robust behaviour during installation is desired. This also applies to the storage stability of dry mixed castables. The results of short term aging tests of castables with different additive systems are discussed in the paper.

2 Dispersing aluminas
Dispersing aluminas are dispersing agents, designed as pre-mixes, which allow easy dosage and homogenisation. The main functions of the dispersing aluminas are described by Kockegey-Lorenz, et al. [1]. The amount of silica fume in low cement castables is typically three to five, sometimes up to eight percent. For silica fume containing systems M-ADS and M-ADW are used (Tab. 1). In addition to their dispersion function, the setting behaviour can be steered in a very controlled way by combining the retarding M-ADS and the accelerating M-ADW. The recommended total amount is about 1 % for low cement and 0,7 % for ultra-low cement castables. By keeping the total amount unchanged, the rheological performance of dispersing aluminas remains stable no matter which ratio of S/W is

<table>
<thead>
<tr>
<th>Product Effect</th>
<th>M-ADS 1 Retarding</th>
<th>M-ADS 3 Strong retarding</th>
<th>M-ADW 1 Accelerating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Composition [%]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>91</td>
<td>95</td>
<td>96</td>
</tr>
<tr>
<td>Na₂O</td>
<td>1,40</td>
<td>1,40</td>
<td>0,10</td>
</tr>
<tr>
<td>B₂O₃</td>
<td>1,30</td>
<td>2,50</td>
<td>0,55</td>
</tr>
<tr>
<td>CaO</td>
<td>0,02</td>
<td>0,02</td>
<td>0,02</td>
</tr>
</tbody>
</table>

Tab. 1 Typical product data – dispersing aluminas for silica fume containing castables

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3 Test castables

Two low cement vibration castables with 5 % (VIB 5M) and 3 % (VIB 3M) of a 94 % grade silica fume were selected for the test series. In addition to dispersing aluminas, sodium-tripolyphosphate (STPP) and sodium-hexametaphosphate (SHMP) were also chosen, as they are still widely used as additives in silica fume containing castables. For the adjustment of working and setting time, retarders such as citric acid or sodium citrate are often used in combination with phosphates. Therefore combinations of phosphates STPP or SHMP with citric acid were also included. Test mix compositions and test results for selected additive dosages are given in Tab. 2.

In addition, some tests were done with castables containing only 3 % instead of 5 % silica fume. The amount of tabular −45MY Li was then increased by 2 %. The castables with 3 % silica fume showed a 10–15 % less flow at the same water addition.

4 Experimental

The castable components were dry mixed in a Hobart mixer type A 200 at speed one for 1 min and for another 4 min after the addition of water. The flow properties after 10, 30, and 60 min were measured by the cone test (lower diameter 100 mm, upper diameter 70 mm, height 50 mm). The setting behaviour was determined by the exothermal method (EXO) and partially by measuring the ultrasonic velocity (US). Both methods and terminology were described in detail by Gierisch, et al. [3]. Test bars were prepared and tested according to the European standard DIN-ISO 1927 part 5 and 6. Cold crushing strength (CCS) and cold modulus of rupture (CMoR) were measured after 24 h curing at 20 °C.

For the investigation of the storage stability, 5 kg batches of dry mixed castables were used. Selected mixes were stored in an

Fig. 1 Dispersing alumina combinations and their influence on castable setting. Exothermic reaction of a low cement castable with 5 % silica fume

Tab. 2 Test mix compositions and test results of VIB 5M containing 5 % silica fume

<table>
<thead>
<tr>
<th>Mix</th>
<th>VIB 5M DA</th>
<th>VIB 5M STPP</th>
<th>VIB 5M STPP/CA</th>
<th>VIB 5M SHMP</th>
<th>VIB 5M SHMP/CA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Components [%]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T60/T64</td>
<td>up to 6 mm</td>
<td>62</td>
<td>82</td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td>Alumina</td>
<td>CT9 FG</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Silica fume</td>
<td>94 % SiO₂</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Cement</td>
<td>CA-14 M</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>M-ADS1</td>
<td>–</td>
<td>0,4</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>M-ADW1</td>
<td>–</td>
<td>0,6</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>STPP</td>
<td>–</td>
<td>0,1</td>
<td>0,1</td>
<td>0,05</td>
<td>0,05</td>
</tr>
<tr>
<td>SHMP</td>
<td>–</td>
<td>0,03</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Citric acid</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0,03</td>
<td>–</td>
</tr>
<tr>
<td>H₂O</td>
<td>4,5</td>
<td>5,0</td>
<td>5,0</td>
<td>5,0</td>
<td>5,0</td>
</tr>
<tr>
<td>VIB-Flow</td>
<td>10 min [cm]</td>
<td>23,5</td>
<td>23,0</td>
<td>23,8</td>
<td>23,0</td>
</tr>
<tr>
<td></td>
<td>30 min [cm]</td>
<td>23,0</td>
<td>23,5</td>
<td>23,5</td>
<td>23,3</td>
</tr>
<tr>
<td></td>
<td>60 min [cm]</td>
<td>23,0</td>
<td>23,0</td>
<td>23,0</td>
<td>23,0</td>
</tr>
<tr>
<td>EXO</td>
<td>Start 1</td>
<td>66 min/21,8 °C</td>
<td>4,3 h/20,8 °C</td>
<td>n.d.</td>
<td>6,0 h/20,9 °C</td>
</tr>
<tr>
<td></td>
<td>Start 2</td>
<td>8,1 h/20,6 °C</td>
<td>13,0 h/22,9 °C</td>
<td>n.d.</td>
<td>8,9 h/23,2 °C</td>
</tr>
<tr>
<td>Max</td>
<td></td>
<td>10,1 h/25,5 °C</td>
<td>10,1 h/25,5 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCS</td>
<td>20 °C/24 h [MPa]</td>
<td>24</td>
<td>29</td>
<td>26</td>
<td>34</td>
</tr>
<tr>
<td>CMoR</td>
<td>20 °C/24 h [MPa]</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>
open bucket in a climate cabinet at 20 °C and 65 % relative humidity for 1, 7, and 14 days. The setting behaviour (EXO) was tested for fresh and aged test mixes. The cement hydration with silica fume, phosphate, and citric acid was investigated with a heat flow calorimeter, (designed at the University of Erlangen), at a consistent temperature of 23 °C ± 0,1 °C. The calorimetric test method is described in detail by Kuzel [4].

4.1 Determination of additive dosage

Additive and water additions were adjusted to comparable vibration flow at lowest possible water addition. Focus was not only on flow after 10 and 30 min, but also after 60 min, to ensure a working time which is sufficiently long for on-site installations. For the dispersing alumina different ratios of M-ADS 1/M-ADW 1 were tested. For the phosphates two series of tests were performed. Firstly, different phosphate additions were tested at a fixed citric acid addition of 0,03 %, and in a second test the citric acid dosage was varied while keeping the phosphate content constant. Results for VIB 5M are shown in Fig. 2–6. The time of EXO Max is also given in the figures. Arrows are indicating the mixes shown in Tab. 2. When using dispersing aluminas M-ADS 1 and M-ADW 1 stable flow properties are achieved for both test castables at a low water addition of 4,5 %. Only at a high M-ADW 1 content does flow decay occur at 60 min due to an early setting start. By the adjustment of the M-ADS/W ratio the demoulding time (EXO Max) is steered in the range of 8,3–19,8 h for VIB 5M and 4,4–10,4 h for VIB 3M. If longer working and setting times are required, the replacement of M-ADS 1 by the stronger retarding M-ADS 3 enables further extension without risking ultra-long or never setting times. For the strength tests a dispersing alumina ratio of 0,4 % M-ADS 1 and 0,6 % M-ADW 1 was selected.

The test castables containing phosphate additives generally require a higher water demand of 5 % when compared to M-ADS/W (4,5 %). The 0,5 % higher water addition which is required for the phosphate dispersed mix might result in lower strength values after firing at 800 °C/5 h.
when compared to the dispersing alumina system as reported by Schnabel, et al. [2]. VIB 5M dispersed with STPP shows an acceleration of the cement hydration with increasing amounts of STPP (Fig. 3). Without addition of citric acid and 0.1 % STPP in the mix, flow decay already occurs after 30 min and there is no flow at 60 min. By the addition of citric acid flow up to 60 min can be achieved.

However, the cement hydration is very sensitive to the amount of citric acid as can be seen from the EXO Max times in Fig. 4. EXO Max increases from 13 h at 0.03 % to about 50 h at 0.05–0.07 % citric acid. Slight over-dosages of citric acid in practice would result in an increasingly retarded cement reaction and strength development.

VIB 3M with STPP generally shows the same trends, although the lower amount of silica fume results in a later cement hydration. EXO Max with 0.1 % STPP and 0.03 % citric acid increases from 13 – 23 h when decreasing the silica fume content from 5 to 3 %. When using 94 % grade silica fume and 0.1 % STPP, flow at 60 min can be achieved without addition of citric acid. However, when using 97 % grade silica fume in VIB 3M, very strong flow decay at 30 min and no flow at 60 min occurs and this system would not work without addition of citric acid. This example shows how complex the adjustment of additive systems based on phosphates can become because the additive package is also very sensitive to the amount and quality of fine fillers such as silica fume.

Contrary to STPP, SHMP acts as a retarder in VIB 5M (Fig. 5). Good flow properties are achieved at a dosage level of 0.05 % SHMP even without the addition of citric acid (Fig. 6). However, when citric acid is added for the extension of working and setting time, EXO Max becomes significantly longer (30 instead of 9 h with addition of 0.03 % citric acid and even 66 h at 0.07 % citric acid).

VIB 3M with SHMP shows the same strong retarding effect of citric acid addition, and a flow at 60 min can be achieved without citric acid. At 0.03 % citric acid, SHMP addition first retards the cement reaction at 0.05 % (from 24 to 41 h), but then slightly accelerates it at higher amounts. When using the higher purity 97 % grade silica fume, SHMP shows small but acceptable flow decay with citric acid. Yet the EXO Max time rises steeply from 7 to 25 h at 0.03 % citric acid.

Experiments with polyphosphates are not part of this paper, but were also performed in extended test series. They showed a similar trend as SHMP. In general all the phosphate systems in this work showed a high sensitivity for citric acid additions which are often applied in practice to steer the working time of the castables. Late cement hydration and strength development and low robustness against changes in the silica fume grade are disadvantages.

4.2 Influence of silica fume

It is well known that the silica fume quality influences the castable properties, e.g. wet out, flow and setting. Myhre [5] reported on the impact of impurities of 97 % grade microsilica, such as carbon and potassium, on flow and setting. Higher impurity levels deteriorated the flowability and significantly increased the working time of the castables. One can imagine that the exchange of silica fume grades with different impurity levels requires adjustment of the additive system. Even batch to batch variations of the same silica fume grade may result in performance differences. For selected mixes the 94 % grade fume was replaced by a 97 % grade fume. Especially for the test castable with 3 % silica fume, differences in additive dos-
4.3 Castable setting and strength development

After placing a castable into a mould or a former, the process of strength development is of high importance. Within a specific time period, sufficient strength has to be developed for de-moulding and further processing.

VIB 5M–DA and VIB 3M–DA show good workability over a period of more than 1 h and achieve de-moulding strength (EXO Max) relatively shortly after the end of working time. EXO Max occurs about 8–10 h for the selected additive ratio of 0,4 % M–ADS 1 and 0,6 % M–ADW 1.

Good green strength of 24 MPa for VIB 5M–DA is achieved after 24 h (Tab 2). VIB 5M containing only phosphate additives STPP and SHMP show comparable EXO Max and green strength results. However, to avoid flow decay with STPP and to achieve extended working times with phosphates in general, the addition of citric acid is often required. As a consequence the strength development is delayed. Citric acid additions in the range of 0,03–0,07 % only slightly increase the working time, but significantly retard the cement hydration and strength development. E.g. the addition of 0,03 % citric acid retards the EXO Max peak of VIB 5M–SHMP to 30 h and 0,07 % to 66 h. Such long de-moulding times are often not acceptable for both on-site installations and pre-cast shape production where formers are removed at the latest after 24 h and pre-cast shapes are very often de-moulded after a couple of hours.

Fig. 7 shows cold crushing strength at 20 °C after 24 h curing and EXO Max of all additive packages tested in VIB 3M. It is clear that a late EXO Max results in low curing strength after 24 h. Castables with an EXO Max above 24 h have insufficient green strength for de-moulding, handling and transport. Mechanical damage of the cast piece or lining is very likely and may often be discovered at a later stage during drying or firing of the material. M–ADS/W dispersed castables achieve high green strengths due to a reliable early exothermal reaction for all adjusted ratios.

The impact of citric acid on the cement hydration was further investigated with heat flow calorimetry under tightly controlled conditions using a paste based on tabular alumina ~45MY Li and containing 20 % cement, 10 % reactive alumina RG4000, 3 % silica fume, and 0,1 % polyphosphate. Citric acid was added in the range of 0–0,08 %. The heat flow curves show two distinct peaks, a smaller sharp peak (I) within the first hours and a later broader peak (II) which comes from the main cement reaction (Fig. 8).

The first peak is caused by a reaction of phosphate in combination with cement, but it is not related to hydration of the cement and produces only a small amount of heat and therefore strength in technical castables. This stiffening usually occurs rather quickly within the first hour(s) after casting and is often considered as the start of setting and the cement hydration. However, it is obvious that the cement hydration only occurs hours later.
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As shown in Fig. 8, this first reaction can be retarded by citric acid with a roughly linear relationship between citric acid amount and retardation achieved. This makes the use of citric acid as a retarder so popular in the industry. However, the citric acid also has a retarding effect on the main reaction (II) but here the relationship is far from being linear. Small increases of citric acid result in strong retardation of the main reaction and at 0.08 % citric acid the intensity of the reaction also becomes weaker. This is shown by a broader and flat peak in Fig. 8. This confirms the observations made with the test castables at increasing amounts of citric acid, where EXO Max becomes very long and sometimes not easy to detect because of the flat broad peaks. This indicates a hampered sub-optimal cement hydration reaction.

In order to check the strength development of phosphate dispersed castables in comparison to M–ADS/W castables, strength testing of castables with 97 % grade silica fume and selected additive systems (Tab. 2) was performed parallel to ultrasonic and exothermic reaction measurements during curing (Fig. 9–10). For the dispersing alumina castable the increase in ultrasound velocity correlates well with the strength development and a reasonable cold crushing strength of 22 MPa is already achieved after 8 h (Fig. 9). Strength development will continue even after 24 h. The phosphate/citric acid castables show a stepped increase of US velocity where a first increase to 3–4000 m/s cannot be related to a measurable cold crushing strength which only appears after further increase of US velocity which takes place after 20 to 24 h. The CCS level of these castables after 24 h curing is significantly lower when compared to the dispersing alumina castable, and only after 48 h curing are they on the same level.

It becomes obvious, that the stiffening reaction with phosphates is sufficient to increase the US velocity significantly but still no real strength development is taking place. Therefore US measurements of phosphate castables must be evaluated and considered with care and focus should be made on the subsequent increase of US velocity. The EXO measurement provides reliable data for the strength development. Fig. 10 shows how well the EXO peak correlates with the strength development. For dispersing alumina castables the US and EXO curves correlate well and the increase in the curves comes from the main cement reactions from which the strength develops.

It should be highlighted here, that the often applied and popular “cup test” for setting control of refractory castables in the industry must be seen as critical for formulations which show a stiffening reaction which is not related to the cement main hydration reaction. The stiffening of the phosphate castables in this work does develop strength which is high enough that the plastic cup cannot be compressed by hand anymore. However, when testing the strength of the cup (or a proper test bar) in the press, no real strength can be measured. Only for castables where the setting is directly related to the main cement reaction, can the cup test indicate the point of real strength development of the castable setting. This applies for dispersing alumina castables.

4.4 Aging resistance of dry castable mixes

Dispersion and setting control additives are components of modern castables, which can be susceptible to aging and can interact with other castable components such as calcium aluminate cement or other binders. Such interaction between dispersants and binder can have an impact on the flow and setting behaviour of the castables. Depending upon the storage conditions and the
castable composition, the aging during storage can be more or less pronounced. The aging behaviour of properly stored dry mixed castables using different additives was investigated by Gierisch et al. [3]. A silica fume containing low cement castable containing dispersing aluminas was stored under dry conditions in the warehouse. Bagged dry mix did not show any aging trend over the reported period of 9 months. Subsequent measurements confirmed the storage stability over 12 months. Castable flow and setting time remained stable over the entire storage period.

Myhre [6] reported about an aging trial of a sodium-hexametaphosphate dispersed dry mix packed in plastic lined paper bags and stored in an unheated warehouse, and for accelerated aging in a climate room (>50 % RH at 20 °C). The first aging trend was already apparent after 30 days. After 180 days the set time went up to four days for the accelerated storage conditions.

Krebs [7] investigated the influence of citric acid additions on the short term aging behaviour of a refractory castable. The medium cement castable with 0,02 % citric acid which was stored at 20 °C and 65 % relative humidity showed a significant increase in working time. The initially adjusted 45 min increased to 220 min over a period of only 8 days.

Short term aging tests up to 14 days were performed for the test castables with dispersing alumina and test mixes containing STPP or SHMP with and without 0,03 % and 0,05 % citric acid addition. The setting was measured with the EXO method for the fresh dry mix and for dry mixes aged up to 14 days open storage.

The same applies for the 0,1 % STPP containing mix without citric acid. Castable with 0,05 % SHMP started at a longer EXO Max, which increased slightly over storage time. The castables containing STPP or SHMP plus citric acid as retarder already show a long EXO Max at the starting point. After 14 days storage the working time has changed significantly, e.g. from initially 36 h to 64 h for the mix with 0,05 % SHMP and 0,05 % citric acid.

The change in castable behaviour over a short storage period for the phosphate/citric acid systems is very critical and increases the risk of failure during installation. Quality control (QC) testing is not able to monitor the changes happening during storage because the testing is normally performed during or shortly after manufacturing. These problems can be avoided by using a dispersion system which is stable during storage such as dispersing aluminas. These do not interact with the cement binder in the dry mixed castable.

4.5 Additives re-adjustment

The additive ratio is normally adjusted to the respective application and installation conditions prior to castable manufacturing. Nevertheless due to irregular material consumption, longer storage times and changed ambient conditions on-site, which impact the setting behaviour of a castable, re-adjustment of a ready pre-mixed castable can become necessary for acceleration or retardation of the working and setting time. When traditional additive systems are used, where generally small amounts are added, re-adjustments can become very critical. Correct dosing of small amounts of citric acid (e.g. 0,02 %) for retardation and even much smaller amounts of an accelerator (e.g. 0,002 % of lithium carbonate) is extremely difficult to carry out on site. Over-dosing can have drastic effects such as
never-setting of the castable or conversely flash-setting in the mixer. 

Dispersing alumina castables provide the opportunity for easily manageable re-adjustment, both for retarded and accelerated setting. Fig. 12 shows the option for later retardation of a low cement castable with 5% silica fume, initially adjusted with 0,1 % M–ADS 1 and 0,9 % M–ADW 1. A further addition of 0,4 % M–ADS 1 extends the working time by about 2 h and the demoulding time by about 2,5 h. If stronger retardation is required M–ADS 3 can be used instead.

For the investigation of later acceleration a castable with long setting was used. This contained 0,9 % M–ADS 3 and 0,1 % M–ADW 1. The addition of the normally accelerating additive M–ADW 1 in the range of 0,4 % did not change the setting pattern of the mix. This may be attributed to a retarding effect by additional dispersing agent, which compensate the acceleration of additionally dosed M–ADW 1. However, accelerated setting can be achieved by the addition of Alphabond 300 [8] up to 0,5 % as shown in Fig. 13.

5 Cost of safety

For refractory installations and pre-cast shape production stable castable processing and product parameters are essential.
Therefore castables are tailored to the individual on-site conditions by the determination of the additive system and the optimum dosage. The correct dosage of these small amounts as well as the homogenisation is mandatory to avoid failures during installation.

The recommended dosage for dispersing aluminas of 1% for low cement castables ensures correct dosage and easy use in castable production as described by Kockegey-Lorenz et al. [1].

Dosage levels used for traditional additives such as phosphates and citric acid are in the range of 0.05–0.2% or even lower. Small deviations in citric acid addition have a strong impact on the placing properties and the setting behaviour of a castable as discussed before. Therefore the risk to impair the performance of the castable due to imprecise dosing and homogenisation is high. Incorrect dosage might well be identified by QC testing. As a consequence castable material has to be re-adjusted or even re-produced. However, bag to bag variations caused by poor homogenisation of such small additive amounts are more difficult to detect as normally only random samples are checked in the QC lab. Problems during installation such as incorrect water addition, inferior densification and late strength development can be expected.

The short term aging caused by the citric acid could lead to more severe failures in castable application. Often the installation takes longer than scheduled due to extended setting of the castable. Sagging can be the result when the former is removed too early. All this may result in conflicts with upcoming R & M activities or lead in the worst case to a bottleneck in production because of non-availability of the aggregate. Due to retarded strength development microcracks, which can hardly be detected after curing, can be introduced to the lining during demoulding. Then, after drying or firing, visible cracks can appear leading to scrap in pre-cast shape manufacturing or reduction in the life of a refractory lining. The same applies for mixes which were re-adjusted on-site with an approximate dosage of retarding or accelerating additives.

Installation failures often cause complaints against the refractory producer and generate costs which are often not recovered completely and which are difficult to quantify, e.g. cost for:

- additional quality control
- complaint handling
- reproduction of material
- production downtime at the end user (worst case)
- bad reputation at the customer and potential loss of business.

In case of failure, the damage for in-house pre-cast shape production is rather low as long as ability to supply is not affected. However in such a scenario internal costs incur and additional resources are needed to investigate and solve the problem. Reliable setting behaviour, which is achieved with dispersing alumina...
M–ADS/W, is essential to ensure a smooth installation and to keep the complaint rate low. Although dispersing aluminas are more costly when compared to the traditional phosphate/citric acid the risk of generating high unanticipated costs is much lower.

6 Conclusion
Traditional additive systems for silica fume containing low cement castables such as different phosphates in combination with citric acid have been compared to the modern polymer based dispersing alumina system M–ADS/W. In addition to the flow behaviour at different dosing levels the cement hydration and strength development has also been investigated with regard to the practical requirements for monolithic linings and pre-cast shape manufacturing. Also, other important practical aspects such as the aging resistance of dry mixed castables during storage and options for the re-adjustment of working and setting time on-site were discussed. Phosphate based additive systems are low cost solutions when compared to dispersing aluminas, but they have several disadvantages with regard to control of working time and strength development, sensitivity to slight overdosages of citric acid, and lower storage stability especially when containing citric acid. Overall, dispersing aluminas provide a much more robust system which strongly contributes to reliable castable performance and avoids installation failures and the frustrating consequences of such failures which may lead to complaints. The higher price of this modern solution is therefore money well spent when the cost/performance ratio is taken into account, especially for more demanding applications where reliable performance is essential.

References