

# APPLICATION OF CALCIUM ALUMINATE CEMENT TO DENSE LOW WATER DEMAND REFRACTORY CASTABLES

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## ABSTRACT

Dense low water demand castables, which use calcium aluminate cement (CAC) as a part of their bonding system, are increasingly used in steel ladles, for hot-face linings in direct contact with the molten metal, because of their technical and economical advantages. The properties and behavior of CAC play a major role at all stages of the life of the refractory.

These modern dense refractory castables can be built around a variety of matrix compositions depending upon the final usage characteristics that are desired. These matrix compositions use a variety of fine reactive fillers such as alumina, fume silica and magnesia together with CAC and additives. Each of these components presents a different series of formulation challenges for the refractory producer, not least of which is the optimization of placing properties while achieving target installed properties.

This review paper presents a study of the behavior of the cement in these castable types, from the placing and hardening properties, through initial strength development, first heating and to the eventual hot properties. Interactions between the calcium aluminate cement, fine fillers such as alumina and fume silica and additives are investigated using a variety of techniques. In particular, the underlying chemical reactions that occur in solution which determine placing properties are discussed. Conclusions are made as to the intrinsic advantages of each matrix system and how the underlying reactions can be controlled in order to achieve target properties throughout the castable usage chain

## INTRODUCTION

Modern reduced cement refractory castables have to meet exacting requirements in terms of both placing characteristics as well as in-service performance targets [1] 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 and hardening rates as well as maintaining 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). The entire system can be considered [2,3] to be an interdependent system. The final characteristics are, as a result, the sum of all the various interactions.

This paper will present a review of the role of the cement in three different systems, alumina/fume silica, alumina/alumina, alumina/magnesia through its interaction with the other components of the matrix. The impact of the different choices made at the formulation stage on placing, hardening kinetics as well as thermo-mechanical performances will also be examined through a range of analytical techniques.

## DEFLOCCULATED CASTABLES - BASIC FORMULATION PARAMETERS

The ability to use castables in metal contact applications was made possible with the development of low cement or deflocculated castables. These castables rely on the use of fine reactive fillers (silica, alumina, chromia, etc.) to more effectively pack particles in the cast mass [1]. At the same time a reduced calcium aluminate cement (CAC) content can be considered due to higher inter-granular contact. Dispersing

additives are then needed to fluidize the fine particles and to allow castable placing at low water additions. The benefits of incorporating these fillers, reducing cement content and using additives are:

- Lower CaO in the castable which limits its low melting  $CAS_2$  and  $C_2AS$  phases thus improving high temperature mechanical properties and corrosion resistance.
- Reduced water demand which reduces porosity and increases density. Corrosion resistance and abrasion resistance are improved through a denser matrix structure.
- Improved particle packing improves thermo-mechanical properties as well as enhancing corrosion resistance.

This logic of deflocculated castables can be extended to castables with very low cement content of less than 2%. The key formulation parameter is to ensure satisfactory placing characteristics at low water demand to maintain the dense low porosity cast structure, otherwise the benefits of these deflocculated castables would be lost. The active binder can be considered to be composed of three interdependent components: the calcium aluminate cement, the additives and the fine reactive fillers [4]. The choice of each of these components becomes critical in controlling castable rheology. Inevitably a trade off must also be made between ideal characteristics and costs. The most commonly used fine fillers are fume silica and fine alumina in conjunction with a high purity calcium aluminate cement, typically a 70% alumina content. The fine alumina and silica will react at high temperature to form mullite (providing CaO% is kept low) which enhances high temperature thermo-mechanical behavior. The additives used will depend upon the specific choice of fillers. Previous studies have shown the impact and the role of additives and fillers in a variety of castable systems [5]. The impact of fume

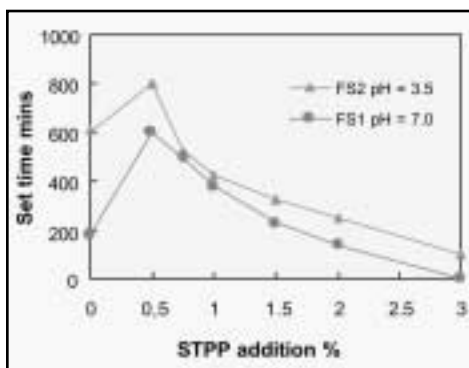
**Table 1. The effect of fume silica type upon castable placing properties**

	LCC 1	LCC 2	LCC 3
Fume silica type			
SiO <sub>2</sub> %	97.5	85.5	91.2
Carbon %	<0.5	4.1	2.0
B.E.T. m <sup>2</sup> /g	20	17	21
pH	6.9	9.4	8.7
Castable flow %			
T=0 mins	158	80	112
T=30 mins	144	0	115
T= 60 mins	140	0	105
Working time mins	95	30	135
Water addition at 5% with 0.03% additives			

silica and alumina type is extremely important. Table 1 shows the result of changing fume silica type in a typical high purity alumina low cement castable which has a 5% addition of a 70% Alumina cement together with 10% of a fine reactive alumina and 5% fume silica.

The effect upon castable workability, as measured by flow under vibration, is extremely marked. The castable working time is clearly dependent upon the quality of fume silica used. It has been shown that the observed behavior is due to differing interactions between the additives, the fume silica and the cement. The effect of additive dosage (Figure 1), in this case sodium tri-poly phosphate, upon setting time with two different fume silica types can be seen. The differences seen are believed to be due to the fact that the hydration of the calcium aluminate cement is modified in the presence of fume silica. Therefore the choice of fume silica must be made carefully to ensure target placing characteristics are met as well as ensuring that minimum variation occurs in the castable due to variation in the quality of the fume silica.

The choice of fine alumina is also important in determining castable placing properties as well as the degree of mullitisation at high temperature. The mullitisation will govern the hot strength development.

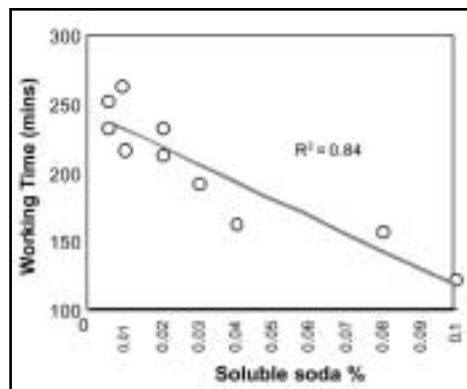


**Figure 1. The effect of fume silica type on setting time**

Using the same base castable system as that used in Table 1, different fine reactive alumina powders were assessed for their effect upon castable placing properties. Two key parameters were found to play a major role in determining castable fluidity, the B.E.T. surface area and the soluble soda (Na<sub>2</sub>O) level in the alumina [2]. In both cases higher B.E.T and soda levels led to reduced flow and shorter working times as well as an acceleration of the CAC hydration. Figure 2 shows the relationship between the soluble soda level in various reactive aluminas and the castable working time. It should be noted that the other properties of fine aluminas such as particle size and crystal size could also have a significant impact upon castable properties.

### THE OPTIMIZATION OF PROPERTIES VIA ADDITIVE SYSTEMS

The control of placing characteristics through formulation modification is also possible by optimizing the dispersing additives. It is possible to add several additives simultaneously, each with a different function, to modify castable rheology. For example, the use of a multiple additive system allows an optimization of the initial castable flow as well as the flow decay. The example in table 2 shows the effect of a multiple additive system upon castable properties. In this example the use of four additives (LCC 5) allows the water demand to be reduced by 20% whilst maintaining placing properties and mechanical properties. Two dispersing additives are used to disperse the fine fillers i.e. the phosphate is used for the fume silica whilst the polyacrylate is used to disperse the reactive alumina. Two types of retarders/stabilizers are added to ensure a working time of 60 minutes even at the lower water demand of 4%.



**Figure 2. The effect of soluble soda on castable working time**

These examples show that the “binder” system in deflocculated castables is comprised of an interdependent combination of CAC, reactive fillers and additives and that the optimization of a castable can only be done by considering all three components simultaneously. A change in one of the components implies a change to the overall system. Therefore one of the most important formulation parameters is the assurance of reliable and repeatable behavior through appropriate selection of stable raw materials. It appears that, provided fume silica, reactive alumina and additives are well chosen, alumina/fume silica systems are castables which are very easy to place and exhibit high mechanical performances at high temperature. They allow, as well, a rapid strength development. This can only be achieved through the use of a highly consistent regular CAC with controlled hydraulic reactivity

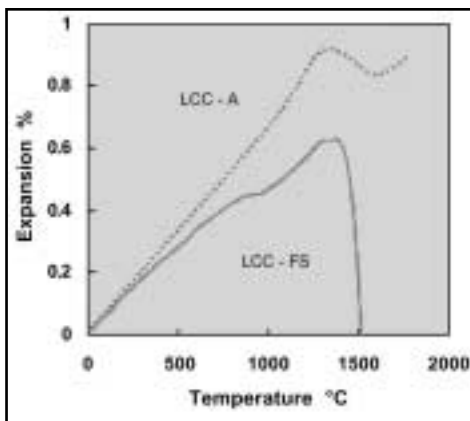
### IMPROVED DEFLOCCULATED CASTABLE SYSTEMS

The previous section considered the formulation fundamentals of typical deflocculated castable systems. These standard low cement castables are somewhat handicapped in terms of high temperature performance. This is due to the formation of CAS<sub>2</sub> and C<sub>2</sub>AS (where C=CaO, A=Al<sub>2</sub>O<sub>3</sub>, S=SiO<sub>2</sub>) phases which are liquid at relatively low temperatures. Thus once these phases form in any quantity the hot mechanical properties deteriorate rapidly.

Improvements to these low cement castables can only be made through a change in the basic mineral system. In the case of deflocculated castables two options exist. Both options involve moving the mineral system from a ternary C-A-S system to

**Table 2. The effect of additive type upon a LCC**

	LCC 4	LCC 5
	Single additive	Multiple additive
Alumina aggregate	80	80
Reactive Alumina 1	10	10
Fume Silica	5	5
70% CAC	5	5
Additives		
Sod. Tri-polyphosphate	0.12	0.03
Sod. Polyacrylate		0.03
Sod. Bicarbonate		0.015
Citric acid		0.015
Water addition %	5	4
Vibration flow %		
T=0	123	109
T=30	80	80
Working time mins	90	60
Cold crushing strength MPa		
110°C	154	165
100°C	166	165
1100°C	210	245



**Figure 3. Refractoriness under load for two castable systems.**

binary systems based upon A-S or A-C. The objective is to reduce the formation of liquids at low temperature within the castable matrix. The first option relies on reducing the CaO level (i.e. the cement content) down to trace levels of <1%. When CaO levels are reduced to ultra low levels then mullite is readily formed at high temperature through the reaction of silica and fine alumina. This controls the high temperature mechanical properties. These ULCC castables exhibit greater mechanical strengths at temperature. The second option is to reduce the (S) silica level and formulate deflocculated castables in the system of alumina-lime. This binary system relies on the formation of  $CA_6$  as the high temperature bonding phase. This is formed through solid phase sintering of the fine alumina and calcium aluminate cement during castable use. The superior mechanical properties can be seen in Figure 3. Here the refractoriness under load of two castable systems is demonstrated. The first is a standard LCC (LCC-FS) based upon high purity alumina with fume silica whilst the second is a low cement castable (LCC-A) with only fine alumina and without fume silica in the matrix.

Removing fume silica from the deflocculated castable poses several problems in terms of maintaining castable placing characteristics. Generally more rapid flow decay profiles and shorter working times are seen with alumina only LC castables. This has been shown to be due to differing interactions within the different castable bond systems [6]. In effect, when fine silica is present as fume silica there is a natural retarding effect which prolongs castable working time. When the silica is removed and replaced with alumina this effect is lost and must be compensated by a change of

	LCC-FS	ULCC	LCC - A
CaO%	1.45	0.58	1.7
Alumina Aggregate	80	80	83
Fume silica	5	5	0
Reactive alumina 1	10	10	0
Reactive alumina 2	0	3	11
70% CAC	5	2	6
Additives	0.054	0.054	0.078
Water addition for a vibration flow of 100% : %	3.8	3.7	5.2
Working time : mins	65	90	20
CCS after 24 hours : MPa	60	38	25
Hot Modulus of Rupture at 1200°C : MPa	24.6	17.7	13.4
Hot Modulus of Rupture at 1500°C : MPa	2.2	6.8	12.6

additive system. This once again reinforces the notion of an interdependent system based upon CAC, reactive fillers and additives. These effects can clearly be seen in the following example.

### ULCC AND LCC ALUMINA SYSTEMS

Evidence is shown in Table 3 of the difference in behavior between four castable types, a 'standard' LCC (LCC-FS) model system, an ULCC system a LCC system based only upon alumina as the reactive fine filler and a 70% calcium aluminate cement. As Table 3 shows the system without fume silica has somewhat higher water demand, (for an equivalent flow) shorter working time and lower green strengths. The benefits of this system can be more clearly seen when high temperature strength development is considered. The standard LCC system shows a sharp drop in strength due to liquid phase formation. The ULCC system shows increasing strength development at higher temperatures due to more sintering and presumably more mullitisation. The LCC alumina system shows the highest mechanical strength at 1500°C due to the formation of  $CA_6$ . Therefore the often held belief that any CaO level is detrimental in castable systems is not true for all mineral systems. In fact, within the A-C system the formation of  $CA_6$  can be exploited to yield castables with higher hot strength. However it must be noted that these systems, particularly those developed with 70% alumina calcium aluminate

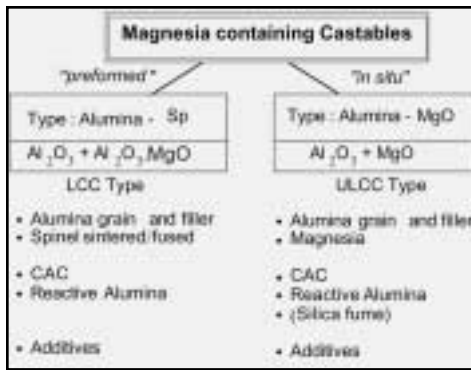
cement, pose the greatest challenges in terms of rheological control. This is developed further in the following section.

### MAGNESIA CONTAINING CASTABLES

Magnesia containing castables can be conceived either by adding a pre-formed alumina-magnesia spinel aggregate or by the reaction of MgO with  $Al_2O_3$  to form in situ spinels within the castable matrix. These two systems present unique challenges in terms of formulation control particularly with reference to placing properties and thermo mechanical behavior. The fundamental differences between the two systems are shown in Figure 4. It is seen that the two types of magnesia containing castables follow two different formulation logics. The alumina spinel castables are similar in conception to the LCC-A type castables discussed in the previous section whilst the spinel forming castables tend to follow an ULCC formulation logic. A deflocculated 'bond' system is however at the heart of both castable types.

### ALUMINA – SPINEL CASTABLES

The base model compositions for Alumina-Spinel castables are found in Table 4. The function of the Alumina-Magnesia spinel aggregates, in limiting slag ingress due to trapping of Fe and Mn in the spinel lattice, has been well documented [7]. The quantity and type of spinel chosen in this example is typical of those val-



**Figure 4. Formulation logics of magnesia containing castables.**

ues found in the literature [8]. These compositions are silica free to ensure that no liquid phase products are formed at high temperature.

The 'bond' system follows the same principle as that explained in the previous section with LCC-A castables i.e. they are deflocculated castables using only fine reactive alumina together with CAC as the reactive binder phase. The type of fine spinel was chosen to be inactive as far as castable placing was concerned but thermally reactive at high temperature. In fact the presence of spinel was not found to have any marked effect upon castable rheology. Due to the nature of the ladle applications with these materials, a high initial flow with a stable flow decay and working time minimum of at least 45 to 60 minutes was considered to be absolutely necessary.

An optimization of the 'binder phase' (CAC, additives and reactive alumina) system was required to achieve these values. Table 5 shows three basic additive systems which meet the basic placing property criteria. Previous work had shown the need to add retarders to the system to compensate for the natural tendency of these Alumina-Spinel castables to lose workability rapidly [9]. The three systems use fundamentally different dispersants with correspondingly different active mechanisms.

Add 1 is a pure electrostatic dispersing system with boric acid as a retarder, add 2 uses a polyacrylate dispersant with two retarders whilst add 3 uses a polymer system with an electrosteric type of dispersing mechanism. In the latter case the dispersing and retarding effect of the polyglycol is so strong that a small addition of an (Lithium Carbonate) accelerator is necessary.

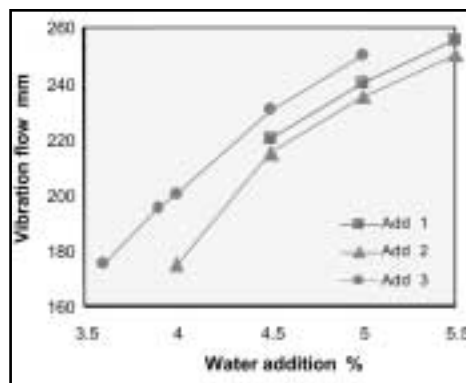
The resulting castable flow for each of these additive types is shown in Figure 5. It

Raw materials	Alumina Spinel	Alumina Magnesia
Sintered Alumina - 7mm	58	82
Alumina-Spinel - 1mm	25	-
Silica Fume	-	2
Reactive Alumina (RA2)	11	8
Magnesia - 0.4mm	-	5
70% CAC	6	3

	Add 1 %	Add 2 %	Add 3 %
Sol. Hexametaphosphate	0.06		
Boric acid	0.01		
Sol. Methacrylate		0.05	
Boric acid		0.022	
Sol. Carbonate		0.001	
Polyglycol			0.3
Lithium carbonate			0.002

was considered that 160mm flow would be the minimum possible consistent with good placing properties. It can be seen that with add 2 and 3 very low water additions are possible (less than 4%) whilst still maintaining sufficient flow properties. Furthermore the working times were in line with the target values. The impact of additives within these formulation logics is evident.

Reactive alumina is also a key formulation component. The alumina plays a role in determining castable rheology due to the interdependent binder system of these deflocculated castables. Furthermore, the reactive alumina will also strongly influence the degree of sintering and strength development at high temperatures. The following example shows the effect of four commercially available reactive aluminas that were selected on the basis of their B.E.T surface area values, particle size distributions and soda contents. A summary of the key properties of these aluminas is shown in Table 6.



**Figure 5. The flow properties of different additive systems.**

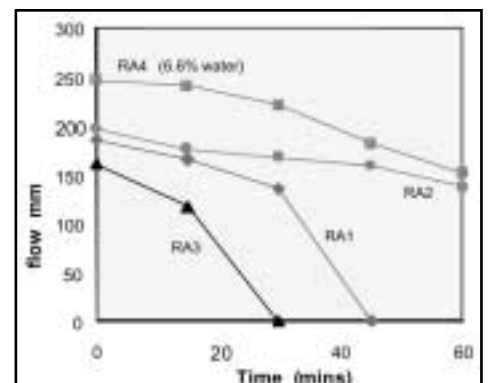
	RA1	RA2	RA3	RA4
<b>Alumina properties</b>				
B.E.T m <sup>2</sup> /g	7.0	3.3	3.0	0.8
Na <sub>2</sub> O %	0.08	0.02	0.26	0.27
<b>Castable properties</b>				
Additive : Add 2				
24 hours	44	44	33	10
110°C	112	116	109	52
Additive : Add 3				
24 hours	25	23	23	24
110°C	98	90	113	92

The impact of alumina type on castable flow profiles is shown in Figure 6. Here, the add 2 system was used and the initial flow was targeted to be 200 mm on an ASTM vibration table. Water demand for each of the castable types was 5% with the exception of RA4 which needed 6.6% water before satisfactory flow performance could be reached.

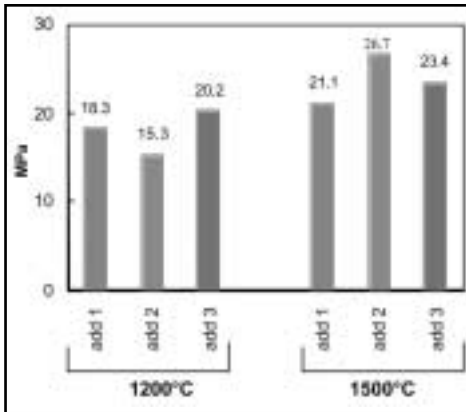
Each type of alumina shows a unique flow profile with each additive system. Changing this to a different additive type(s) would certainly yield differing results.

The optimization of placing properties is done to ensure suitable fluidity at low water demand but at the same time steps must be taken to ensure that strength development, de-molding times and final thermo-mechanical properties are not compromised by an optimization of placing properties. This can be seen in Table 6 where the short term mechanical strengths 24 hours after casting are quoted. It is evidenced in this table that the add 3 system with the optimum flow properties did not yield the best results in terms of mechanical strength development. This would probably have implications for de-molding times.

An analysis of the underlying mechanisms has shown [6] that there exist two types of



**Figure 6. The effect of alumina type upon flow properties.**



**Figure 7. The effect of additive systems upon hot modulus of rupture.**

interactions, which explain a specific working time/flow and the acquisition of mechanical strength. The first interaction is related to the dissolution of the calcium aluminate cement into solution and thus controls working time. The other is the massive precipitation of the cement hydrates which governs the mechanical strength development of the cast structure. Due to the interactive nature of the binder phase the type of additive system and alumina can and does impact upon these reactions, thus controlling flow/working time and mechanical strength development.

As discussed previously it is important not to compromise high temperature properties through the optimization of the casting process. Figure 7 shows the effect of additive type upon hot modulus of rupture at 1200°C and 1500°C. In all cases the castables contained the RA2 alumina which had given good flow and working times along with suitable strength development. As can be seen the additive type has a noticeable effect upon hot strength development. Add 1 has little impact upon sintering activity between 1200°C and 1500°C. In contrast add 2 appears to have a marked effect upon strength development at 1500°C. Add 3 shows similar behavior to add 1. It is considered that there are two factors, which could explain these differences. Firstly, the additive systems strongly influence placing characteristics and, consequently, installed porosity of the castable. Secondly, the residual elements from the additives could act as mineralisers for promoting solid state sintering at high temperature. These two factors together would alter the microstructure and therefore the mechanical strengths at temperature.

## ALUMINA – MAGNESIA CASTABLES

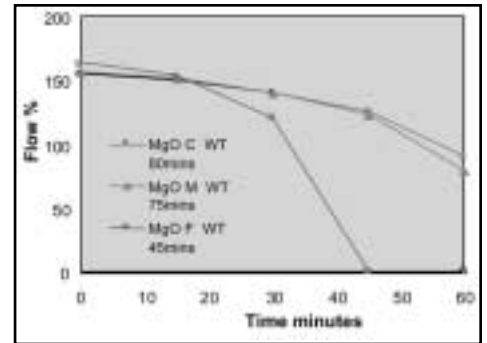
The base model composition for Alumina-Magnesia castables is illustrated in Table 4. The formulation basis is an ULCC system with smaller or trace amounts of fume silica. The spinel phase is formed in situ and since it is produced by reaction in the matrix, has been found to offer a high degree of corrosion resistance in certain ladle applications. This type of formulation approach presents three inter linked challenges, which need to be addressed for reliable application:

- Impact of magnesia upon castable rheology which leads to short working times and rapid flow decay [11].
- Risk of magnesia hydration and subsequent destruction of the castable [12].
- +8% volume expansion when spinel forms in the castable matrix [13].

These three issues are somewhat related. For example fine reactive silica (fume or precipitated) is sometimes incorporated into these castables to fulfill several functions. It is primarily added to control thermal expansion [14], through the idea of auto stress relaxation with liquid phase formation to compensate for the expansive reaction during spinel formation. Secondly, fume silica facilitates rheological control and thirdly it has been suggested as a means to control magnesia hydration.

Due to these three factors the choice of magnesia becomes the key formulation parameter for these types of castables. Two of the important considerations are illustrated below. Figure 8 shows the impact of magnesia fineness upon castable flow and working time. Three synthetic magnesia's, coarse (<0.4mm), fine (<0.1mm) and medium (mix coarse and fine) types were evaluated in a castable based on the base composition in Table 4. The effect of the fine magnesia can be seen as a lower flow, more rapid flow decay and shorter working time. A change in either additives and/or silica type would be needed to correct this type of behavior.

The underlying reasons for these differences in castables behavior are due to chemical interactions which can be illustrated with the technique of calorimetry analysis. The heat flow curves of a ULCC castable show the appearance of an additional peak (pi) when MgO is added to the system. The position of this peak is dependent more

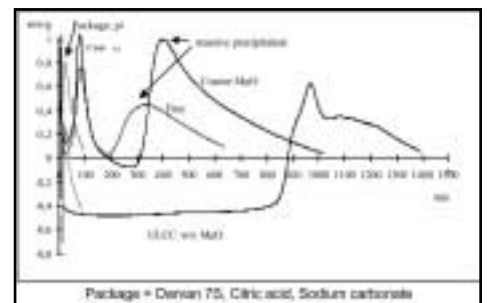


**Figure 8. The effect of magnesia fineness upon castable flow.**

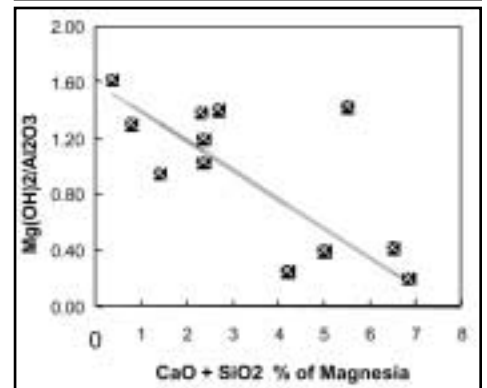
from the admixture system employed in the castable than from the MgO fineness used. Its appearance as seen in Figure 9 shows that an exothermic reaction takes place which can disturb workability [11]. The peak representing massive precipitation, however, seems to be influenced by the MgO fineness leading to an earlier hydration for fine MgO.

A second example of the impact of magnesia type is shown in Figure 10. Here the hydration resistance of different magnesia types is assessed in an autoclave test (1 hour at 7 bar and 150°C). The degree of hydration is measured by XRD using the alumina peaks as the stable reference.

The difference in hydration resistance is shown with the higher purity magnesia



**Figure 9. Heat flow curves for binder phase of castables containing MgO.**



**Figure 10. Hydration resistance of selected magnesia.**

types (lower impurities) showing generally lower hydration resistance. The choice of magnesia would also be made after due consideration of the impact on spinel formation, microstructure and thermal expansions. Thus the situation becomes one of managing an inevitable compromise with conflicting demands rather than optimizing a single parameter. These examples show that the performances of spinel forming magnesia castables are very sensitive to the raw materials characteristics and their interactions between each other.

## DEFLOCCULATED CASTABLE SYSTEMS BASED UPON 80% ALUMINA CAC

It is evident from the previous section that low cement systems based upon alumina alone are more difficult to control with respect to placing properties. The use of a 70% alumina cement and fine reactive alumina requires relatively sophisticated additive combinations to achieve required placing properties. This is especially true where reactive fillers such as alumina and magnesia are employed. A new and alternative approach is to use an 80% alumina cement specifically adapted for these reduced cement castable systems. The 80% alumina CAC used in the following example is a new development, designed for use in reduced cement systems; the basic properties are shown in Table 7. 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 demolding once the castable has stiffened.

This cement was substituted into two types of castable systems:

Property	Unit	Value
Al <sub>2</sub> O <sub>3</sub>	%	80.1
CaO	%	17.6
SiO <sub>2</sub>	%	0.3
Surface area	m <sup>2</sup> /g	6-7
D50 Particle size	Micron	4-5
Initial set	Mins	180
Final set	Mins	190
Initial flow t=0	%	85
Flow t= 60	%	71

- The base alumina spinel castable system is shown in Table 4. The cement addition was increased to 10% to achieve a constant (compared with the 70% CAC) CaO content of 1.7%. The amount of additional reactive alumina was decreased by a corresponding amount (i.e. 10-6=4 so addition =7%). No additional additives were used.
- The alumina magnesia system was modified to contain 6% of an 80% CAC, 1% fume silica, 5% magnesia (-100 microns) and 8% reactive alumina of the type RA2. As with the Alumina Spinel system no additional additives were used.

The placing characteristics for the two systems are shown in Figure 11. As can be seen, the 80% CAC ensures in both castable systems, an excellent flow at low water additions. In addition the working times are between 60 and 124 minutes, which are sufficient to ensure satisfactory placing. These excellent placing properties are achieved in relatively simple systems. In addition, the hardening kinetics of these systems are not delayed. Measurements using an ultrasonic technique [14] have shown quite the opposite and strength development rates are more rapid than corresponding systems based on a standard 80 alumina cement.

Other physical properties after firing [15] are equivalent to those obtained via the use of 70% alumina cements and essentially more complicated formulation types. For example, the hot modulus of rupture of the Alumina Spinel system with the 80% CAC gave values of 14.7 Mpa at 1200°C and 24.2 Mpa at 1500°C. These values compare favorably with the 70% CAC based systems discussed in the previous sections.

## CONCLUSION

A wide range of castable systems are available today. A significant part of this

progress has been due to development of the 'binder phase' of these high technology refractory castables.

It is possible to adjust castable placing characteristics by modifying the binder phase components which include calcium aluminate cement, reactive fine fillers and additives. Due to the interdependence of these components they must however be optimized simultaneously. Furthermore this can only be done within the context of each specific castable type. This must always be done with consideration to the target final installed properties.

The choice of calcium aluminate cement and fillers will eventually govern the properties of the castables in place. Although compromises between placement characteristics and final thermo-mechanical properties have to be made, it has been shown that today's available selection of 70% or 80% alumina calcium aluminate cements gives the designer of castables a wide range of possibilities in order to achieve the targeted properties.

## ACKNOWLEDGEMENTS

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## NOTE

A detailed description of model systems used and their associated raw materials are available from the authors

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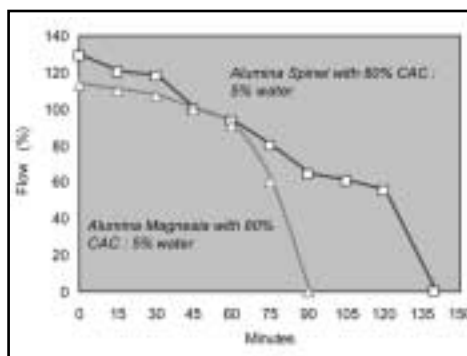


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## **NAM Sees Evidence of Strengthening Recovery**

A March 6 Commerce Department report indicating that new orders for manufactured goods rose 1.6 percent in January, following a more modest 0.7 percent rise in December, is the third recent statistic indicating that a broad-based recovery in manufacturing may be in the works, said National Association of Manufacturers chief economist David Huether.

"The release, which shows that shipments of both durable and nondurables accelerated in January, is notable for its dispersion," Huether said. "Excluding transportation, which I expected to rise as automakers rebuild stocks following historically strong sales in the 4th quarter, both orders and shipments rose at a healthy pace of 1.2 and 1.8 percent respectively.

"Thankfully, the report reflects only a modest downward revision to the preliminary report on January durable goods orders that came out last week," Huether said. "When combined with the February ISM report that manufacturing activity expanded last month, the release offers persuasive evidence that the industrial sector is gaining momentum.

"Inventories continue to be worked off, though at a slower rate of -0.6 percent compared to the two previous monthly declines that averaged -1.1 percent," Huether said. The inventory correction is over in the auto sector and the overhang in the rest of manufacturing is moderating significantly.

"However, due to a weak profit picture, an over-valued dollar and sluggish growth abroad, I expect the recovery to be modest during the first half of 2002, with manufacturing output growing at an annual rate of roughly 2 percent during the first six months of 2002," Huether concluded.

## **Workforce Shortages**

Despite the recession in manufacturing and the economic downturn, America's manufacturers are having a hard time finding qualified, skilled workers, according to The Skills Gap 2001, a nationwide survey conducted by the NAM, the Center for Workforce Success and worldwide professional services firm Andersen.

The study confirms a trend many refractories manufacturers have seen in recent years.

Eighty percent of manufacturers report a moderate to severe shortage of qualified job

candidates. More than two-thirds of the firms surveyed said their most serious workforce shortages are in production areas, a shortage encompassing entry-level workers to machinists to technicians and engineers. Most ominously, some 60 percent of manufacturers say the lack of adequately skilled workers makes it difficult to maintain the production levels necessary to meet demand. A stunning 40 percent report that they can't implement new productivity improvement.

The survey also showed that workforce deficiencies range far beyond keeping up with the latest in technological advancement.

"The major areas of concern have shifted back to the fundamentals, with basic employability skills--meaning timeliness, work ethic and other issues--cited as the number one deficiency for both current hourly workers and applicants for hourly positions," according to NAM President Jerry Jasinoski. "Poor reading and writing skills among hourly workers were a problem for one-third of the companies surveyed, while a quarter indicated shortfalls in basic math, communication and English language skills."

NAM projects a possible shortage of up to 10 million skilled workers by 2020.

## **St. Louis Refractory Symposium**

"Refractories for the Continuous Casting of Steel" was the theme of the Thirty-Eighth Annual Symposium on Refractories held by the St. Louis Section of the American Ceramic Society in conjunction with the Refractory Ceramics Division of ACS.

About eighty attendees from across the refractories community preregistered for the two day seminar held in Chesterfield, Missouri. In addition to more than a dozen technical papers, participants had six presentations on research in progress from students from the University of Missouri-Rolla, the University of Montreal and the University of Alabama.

In a departure from the past, the meeting featured a table top exposition with twenty vendors participating.

A highlight of the event was presentation of the prestigious T. J. Planje Award to Roy J. Bottjer, long time participant in, and asset to, the refractories industry.

Congratulations to Roy on his achievement and to the St. Louis Section and RCD on another job well done.

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