NEW COARSE TABULAR AGGREGATES FOR IMPROVED CASTABLES

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INTRODUCTION

The use of coarse aggregates with particle size above 10 mm is well known in the refractory industry. Raw materials used in monolithic refractories include brown and white fused alumina lumps, recycled materials, ZAC (zirconia-alumina-silica), bauxite and silicon carbide.

The primary drivers for coarse aggregates in monolithic refractory products include increased wear resistance and higher thermal shock resistance. The wear resistance benefits are a result of less matrix fines needed, which in turn offers a cost reduction of castable formulations.

For applications demanding high purity raw materials white fused alumina lumps has been the only option available. There has been a demand from applications working successfully with tabular alumina, e.g. in steel ladle bottom, for coarser grains of sintered aggregates with the high consistency that is identified with tabular alumina.

The use of coarse grains in monolithic technology has a direct impact on production, installation and also testing of refractory materials. Japan has already developed technology for steel ladle linings many years ago but it is seldom used in the Western world. Coarse tabular products including a new extra large coarse size along their performance in test castables will be presented. In addition, mixing test results performed on laboratory and industrial scale will be offered.

InfilCast® is an established technology where a slip is added to tabular converter discharge balls that are in a mould. An alternative to this castable technology using the new coarsest size tabular product further improves this technology and the first test results will be presented.

PRODUCT PROPERTIES

There exist 14 global Almatis tabular products with the coarsest having grain sizes up to 6 mm. In addition to these products, regional products including coarser sizes up to 15 mm have been introduced successfully in recent years. After successful applications of the coarser products the demand from the market has been for even coarser tabular aggregates. A new generation product 10-25 mm has been developed which has the same material properties as globally standardized tabular alumina T60/T64 from Almatis in terms of bulk specific gravity, chemistry, water absorption and apparent porosity. The typical particle size distribution of coarse tabular products can be found in table 1 and the appearance of the grains is shown in figure 1.

Table 1. Data of coarse tabular alumina T60/T64.

T60/T64	10-25 MM	6-15 MM	5-10 MM	5-8 MM
+ 25 mm	0			
+ 16 mm	44			
+ 12.5 mm	34	5	1	
+ 10 mm	20	30	10	
- 10 mm	2			
+ 8.0 mm				2
+ 6.3 mm		63	69	35
-6.3 mm		2		
+ 5 mm			16	52
- 5 mm				11
+ 4.0 mm			3	
- 4.0 mm			1	

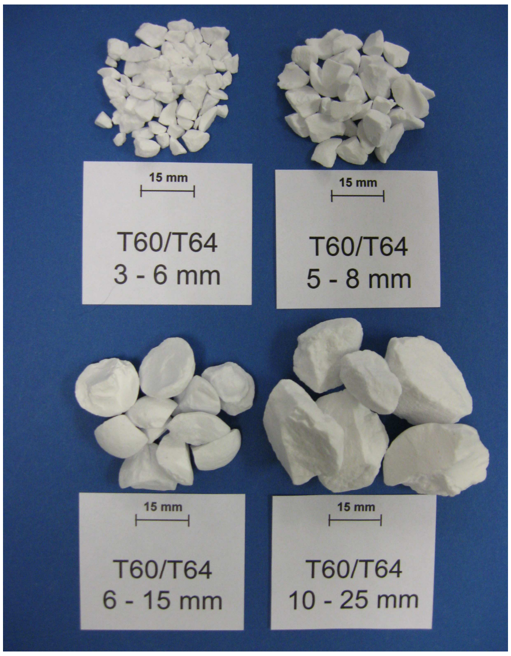


Fig. 1. Coarse sizes of tabular alumina T60/T64.

The advantages of tabular alumina as refractory aggregate were recently discussed in detail by Büchel et al. [1]. It is a very homogeneous product due to the sinter process at high temperatures and it exhibits characteristic features when compared to white fused alumina. The main impurity Na_2O from the Bayer process is homogeneously distributed in the product. The closed internal porosity with very small pore sizes increases the thermal spalling resistance and reduces the bulk density. This results in a lower material demand in application. The open porosity is very low and no large pores can occur. This is a major difference especially when compared to white fused alumina lumps which often show a high amount of macro pores (figure 2). Such large pores can easily be infiltrated by slag and reduce the wear resistance of refractories.

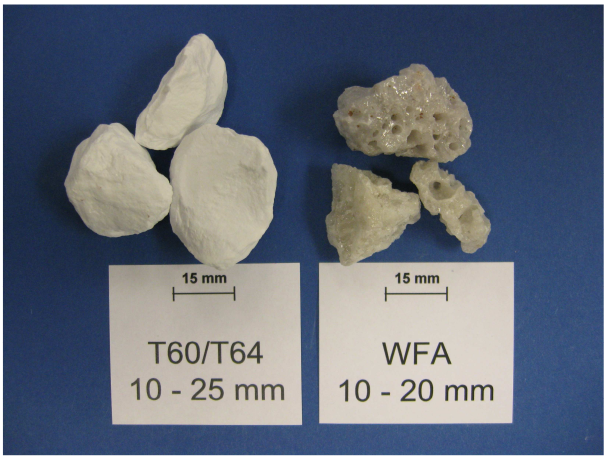


Fig. 2. Tabular alumina and white fused alumina coarse sizes. Homogeneously dense sinter product vs. inhomogeneous fused products exhibiting macro pores.

TEST CASTABLES

Three vibration low cement castables with different top size and one InfilCast® castable were investigated (table 2). Test castable VIB 25 contains the new coarse tabular size 10-25 mm. It has been tested with two different water amounts (3.3 and 3.7 %). The coarse test castables VIB 15 and VIB 25 take advantage of a matrix formulation demonstrating low dilatancy during mixing. This is achieved by E-SY 1000 alumina as the main component of the matrix.

The amount of fine matrix in the test castables decreases when the top size of aggregate increases. VIB 6 contains 25 % of matrix fines below 45 µm. VIB 15 and VIB 25 only contain 20 % matrix fines. The matrix fines are normally the most expensive components of a castable formulation because of the higher cost involved in the fine milling of these products. The use of coarse aggregates is therefore a cost reducing measure in the castable formulation.

Table 2. Composition of test castables.

Castables		VIB 6	VIB 15	VIB 25	INFIL 25
Tabular T60/T64 coarse	%				
10 - 25 mm	%			20	52
6 - 15 mm	%		15	7	
up to 8 mm	%		65	53	
up to 6 mm	%	75			
Tabular T60/T64 fines - 20 MY	%	7			
Infiltration Alumina AFL 13	%				44.6
Reactive Aluminas					
CL 370	%	13			
E-SY 1000	%		15	15	
Cement					
CA-14 M	%	5	5	5	
CA-270	%				3.4
Additives					
ADS / W	%	1	1	1	0.96
Alphabond 300	%				0.24
Water	%	4.3	3.7	3.3 / 3.7	4.2

MIXING OF COARSE AGGREGATES

Lab mixing

Mixing refractories containing coarse aggregates can be extremely challenging. In lab scale testing very few options exist as Hobart-type mixers usually cannot handle the large sizes. Eirich-type mixers have functioned in the laboratory but not all of the time. If a suitable mixer is not available the only other option may be to hand mix the coarse aggregates after the remaining components have been batched.

Industrial mixing trials

Several successful mixing trials have been performed in Europe and North America with refractories containing significant proportions of the new 10-25 mm tabular product. The Zyklos ZK 150HE (figure 3), manufactured by Pemat Mischtechnik GmbH was tested in Freisbach, Germany. In this type of mixer the offset mixing blades rotate synchronously with the mixing pan thus producing high levels of shearing and kinetic energy release. Three 150-kg batches of VIB 25 were mixed with no problems arising. Wet out of the mix occurred very quickly, typically after 40 seconds. The mix was soft, easily workable and exhibited good flows. When the mixer had stopped it could easily be restarted without difficulty. Test panels and bricks were cast from these mixes for lab investigation of physical properties.

Another mixing trial was performed using a Lancaster Hi-Intensive Model K4 mixer. These variable-speed mixers are manufactured by Kercher Industries based in Lebanon, Pennsylvania USA. The mixing principle is very similar except that the mixing tools rotate counter-currently to the mixing pan thus resulting in maximum particle travel distance and a multiple turnover of layers. Two 225-kg batches were tested, one being the VIB 25 batch with very similar results to the German mixing trial achieved. The other batch was a pseudo-plastic mix developed for pumping applications which contains 10 % 10-25 mm tabular. This castable also had a soft texture and was easily workable. Excellent flows were obtained using a vibration table.

Fig. 3. Mixer with tiltable mixing pan (Zyklos ZK150HE, courtesy Pemat Mischtechnik GmbH, Germany).

A third mixing trial has been performed using an Eirich model RV08 on a castable similar to VIB 15. Fast wet-out was achieved and the mixing process was extremely smooth. Restarting after the mixer had stopped was no problem as only 1 – 2 mixing vessel rotations were required to achieve stable mixing again.

For those with inadequate blending and/or packaging equipment for handling coarse grains, all other components in a refractory can be dry mixed and a separate supply of the coarse aggregate can be provided for addition during wet mixing at the installation or pre-cast shape production site. As coarse aggregates are suitable for larger monolithic installations, supply in big bags is generally preferable and available.

INFILCAST® TECHNOLOGY

InfilCast® is an alternative monolithic placement technology which takes advantage of coarse aggregates [2-4]. Instead of mixing the whole castable composition for the installation, the coarse particles are introduced into a mould and subsequently fully infiltrated with a special slip (figure 4). The main component of the slip is infiltration alumina (AFL products [5]), which embodies all the experience gained through the development of high performance matrix products. The new tabular size 10-25 mm as coarse aggregate provides an interesting alternative to the screened converter discharge tabular alumina balls (CDS) of about 20 mm diameter. The irregular shaped grains can provide an interlocked grain structure which enhances the mechanical strength.

The mixing procedure for the slip in a Hobart A 200 planetary lab mixer differs slightly from the normal castable mixing. In addition to the one minute dry mixing at speed 1 followed by four minute wet mixing at speed 2, another one minute wet mixing at speed 1 is applied. In industrial applications the mixing of the slip has proven to be very flexible and robust, and even simple gravity mixers can be used.

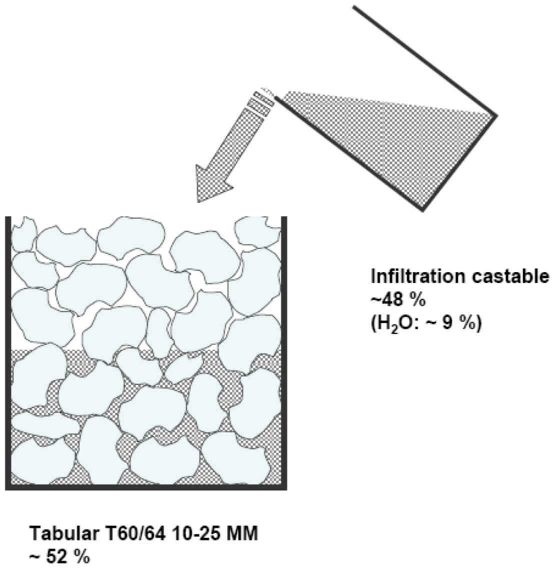


Fig. 4. Principle of InfilCast® technology.

RESULTS AND DISCUSSION

Testing of castable samples was done at German refractory institute DIFK, Bonn. Samples of half normal brick size (230 mm x 64 mm x 54 mm) were cut from the test panels of the mixing trials (300 mm x 300 mm x 100 mm).

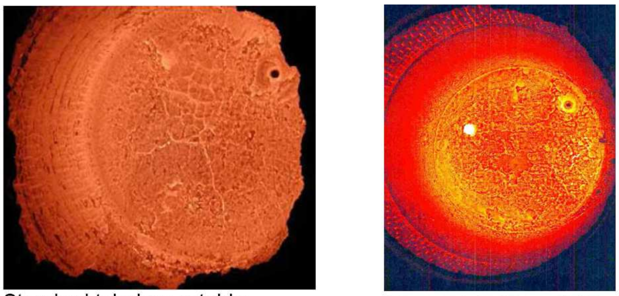
An increase of the aggregate top size in castable results in a reduced mixing water demand (table 2). This benefit, though, may only be realized when the coarse aggregate is mixed with all other components at the onset. If the coarse aggregate is mixed in a second step after the water has been mixed with the other components more water may be needed. When less water is present open porosity will be reduced upon drying and firing of the parts. Less open porosity ultimately leads to higher strengths, less liquid penetration and increased slag resistance. Apparent porosity after pre-firing at 1200 °C decreases from 15.4 % for VIB 6 to 12.2 to 13.2 % for the coarser VIB 15 and VIB 25 (Table 3).

Generally speaking, coarser grains act as a strong skeleton for a refractory. This reality means that refractories using larger aggregates will typically shrink less than refractories using smaller sizes. And, with fewer changes in a refractory's physical dimensions, the formation of cracks is less likely to occur. First trials in a monolithic steel ladle bottom have proved this advantage of larger aggregates (Figure 5).

The permanent linear change (PLC) of the test castables after firing at 1500 °C confirms this observation (table 3). VIB 6 shows a slight firing shrinkage at 1500 °C (PLC -0.24 %). Conversely, the coarser test castables VIB 15 and VIB 25 show a slight expansion (PLC +0.51% and 0.16 to 0.25 %).

Table 3. Data of test castables

Castables		VIB 6	VIB 15	VIB 25 3.3	VIB 25 3.7	INFIL 25
C MoR						
110°C / 24h	MPa	12	14	13	8	5
1000°C / 5h	MPa		9			
1200°C / 5h	MPa	15		10	8	4
1500°C / 5h	MPa	53	45	37	37	21
CCS						
110°C / 24h	MPa	130	88	175	150	66
1000°C / 5h	MPa		88			
1200°C / 5h	MPa	143		150	133	82
1500°C / 5h	MPa	260	> 130	257	250	195
Density						
110°C / 24h	g/cm^3	3.23	3.34	3.32	3.28	3.30
1000°C / 5h	g/cm^3		3.29			
1200°C / 5h	g/cm^3	3.16		3.22	3.21	3.23
1500°C / 5h	g/cm^3	3.15	3.26	3.22	3.21	3.21
PLC						
1000°C / 5h	%	-0.09	+0.01			
1200°C / 5h	%			+0.25	+0.31	+0.16
1500°C / 5h	%	-0.24	+0.51	+0.16	+0.25	+0.02
App. Por.						
110°C / 24h	%	8.6	5.8	5.0	6.2	10.6
1000°C / 5h	%		10.1			
1200°C / 5h	%	14.1		12.1	12.6	12.9
1500°C / 5h	%	15.4	12.2	12.9	13.2	14.1



Standard tabular castable
Typical crack formation for large monolithics

Coarse tabular castable
No cracks

Fig. 5. Monolithic steel ladle bottom with tabular based castables. Standard 6 mm castable in comparison to 15 mm castable after a comparable number of heats.

Thermal spalling resistance has been shown to significantly improve when larger coarse aggregates are used. Kubota et al [6] show that, with the optimum amount of well-dispersed coarse aggregates, crack propagation is hindered due to deflection or branching after interacting with the large aggregates.

INFIL 25 shows advantages in modulus of rupture (MoR) when compared to the previously reported InfilCast® test castables based on sphere shaped tabular alumina aggregate [4]. The values of INFIL 25 are about twice as high at all pre-firing temperatures. The new tabular size 10-25 mm can overcome the weakness of the InfilCast® technology in applications where flexural stress rather than compressive stress occurs.

CONCLUSION AND OUTLOOK

It is prevalent in these times that refractory consumers are desiring longer service life while at the same time demanding decreasing costs. In this day and age it is generally very difficult to accomplish both at the same time; however, using coarse tabular aggregates this can be realized.

Coarse aggregates are best suited for the more severe duty applications such as steel ladles, whether it be in the ladle bottom, well blocks, impact pads, etc. In addition to steel ladles other applications may include the delta section of electric arc furnace roof and the impact area of tilting runners.

Many properties of refractories are greatly enhanced when coarser aggregates are used, from tensile and crushing strengths, abrasion and erosion resistance, lower open porosity and thermal spalling resistance. Since less matrix fines are necessary in refractories containing coarse aggregates the costs of these mixes are reduced. Coarse aggregates aid in the mixing of refractories and faster wet-out times can be obtained; this is positive in that there is less likelihood of an over addition of water to a batch. Further mixing and pumping trials are planned.

Coarse tabular aggregates are extremely pure chemically and can easily replace other coarse aggregates. The prominent quality associated with standard tabular can be expected with the coarse grades as it is also a homogeneously produced sintered product.

The harmonization of the coarse T60/T64 sizes is ongoing, with the goal making them global tabular products so exactly the same specifications can be expected from all manufacturing locations. The supply of these products is very reliable as they are dedicated for the global refractory market. Most sizes are available from all of Almatis' locations in every region.

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