REFRACTORY CASTABLES FOR THE LADLE FURNACE DELTA SECTION AT CORUS IJMUIDEN

Flemming Andersen, Corus Research, Development & Technology, The Netherlands

Sander van der Wal, Corus Staal bv., The Netherlands

ABSTRACT

In the ladle furnace delta section at BOS plant No 2 at Corus Ijmuiden a refractory castable is used. The two most important wear mechanisms for the delta section are thermal shock and melting of the refractory material. Therefore the thermal shock resistance and the refractoriness under load will be the most important parameters for selecting an alternative to the currently used material. From the results we have seen that products based on alumina are highly refractory and very resistant to thermal shock above 1200 °C. However at lower temperatures in the range 800°C to 1200°C the thermal shock resistance is relatively low. The thermal shock resistance in this range is significantly higher for products based on bauxite and mullite. However the refractoriness of these products is not as high as for the alumina products. In practice, the worst thermal shock occurs when a new steel ladle is entering the ladle furnace for a treatment and when the electrodes are turned on. At these moments it is expected that the temperature of the hot face of the refractory material is less than 1200°C. Therefore the thermal shock resistance at these relatively low temperatures are more important than at higher temperatures, but in order to reach the high thermal shock resistance at the lower temperatures a compromise must be made on refractoriness. Two specific products are a large improvement regarding refractoriness and thermal shock in the range under 1200°C compared to the currently used product. One of these two is recommended for plant trial. This product is the least brittle at temperatures around 6-800 °C. The delta section is water cooled and a large part of the refractory castable is expected to be at a temperature around 6-800°C. The results from the first plant trial are also presented.

INTRODUCTION

The delta section of the IJmuiden ladle furnace consists of three steel rings for watercooling. Inside the rings a refractory concrete is cast with three holes for the electrodes. It is essential that the delta section lasts at least four weeks (>350 heats) in order to meet the planned maintenance stops.

The currently used castable does not meet this demand and the two main wear mechanisms are melting/disintegration of the refractory due to extreme temperatures and cracking due to thermal shock. In figure 1 and 2 a used delta section is shown.

An alternative material is needed and a selection has been made from commercially available refractory castables. These have been tested in the lab and their results are compared in order to recommend a castable for full scale trials.

POST MORTEM ANALYSIS OF USED REFRACTORY MATERIAL

A piece of the used refractory from the delta section was prepared for microscopic analyses. The piece represents the hot side of the refractory castable and it is essential to trace back the temperature in use.

Fig. 1: Anchor attack and crack behaviour.

Fig. 2: Melting behaviour of castable from below right next to electrode hole.

The sectional plane of the used refractory is shown in figure 3

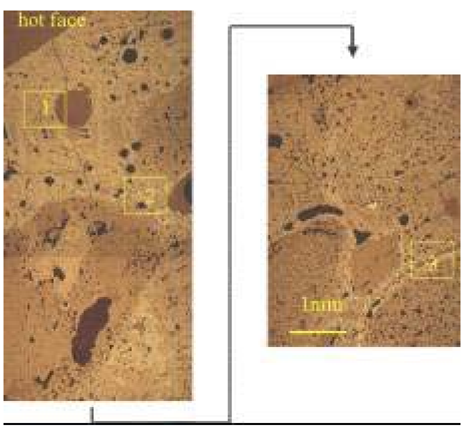

Fig. 3: Cross section of the attacked refractory.

The areas inside the rectangles on figure 3 have been closer identified with reflected light microscopy and SEM EDS.

The layer closest to the hot face (area 1 and 2) indicates that complete melting has occurred.

Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O
0.2	7.4	26.7	2.6	0	0.1

CaO	TiO_2	MnO	Fe_2O_3
24.6	0.2	0.6	36.8

Table I. SEM EDS analysis of Area 1 (Area 2 is almost similar and not included here).

According to of the $CaO-Al_2O_3-Fe_2O_3$ phase diagram the end of the solidification of this upper layer must have been completed at 1335°C. This indicates that the operation temperature must have been higher than 1335 °C. This is done on basis of the measured average chemical composition of the sample. (see table I) In the consideration the alkali elements are not considered but they can cause the actual melting point to be much lower.

From the phases observed in Area 3 it can also be concluded that iron oxide penetrates into thermoshock cracks. The iron oxide in the crack reacts with aluminium oxide and starts to form solid solution followed by interaction with the bond and the titanium from the bauxite.

Indications how iron oxide has penetrated into the cracks are not present in the microstructure but could have been as very fine dust. However this attack mechanism is not believed to be of importance in the overall wear of the delta section.

PRODUCT SELECTION AND TEST METHOD

In table II the selected qualities are shown. Several suppliers have been asked for their recommended products and six products are selected for testing. The standard product (B1) is based on bauxite with alumina. One similar product from supplier C has been tested in order to benchmark the standard product. The idea behind the selection is to identify if refractory castables with a significantly higher refractoriness also meet the demands for thermal shock resistance. All qualities in this evaluation contain calcium aluminate cement as the primary bonding system. In some cases a special fibre material is added to enable fast drying.

Table II. Selected qualities for testing.

Supplier	Product	Base grain
A	A1	Spinelbonded alumina
A	A2	Alumina
A	A3	Fused Mullite
B	B1	Bauxite & alumina
C	C1	Alumina
C	C2	Bauxite & alumina

TEST RESULTS

In table III the density and porosity results are shown. These results are influenced by the amount of water added in the preparation of test samples. Mostly the supplier recommendation is followed, but some times more or less water is used based on the observed flowability of the material, see table III. This is an important part of the test program, since good properties are more easily achieved with castables that densify better with low water additions and what the supplier promises on the data sheet is not always obtainable in practice. However all the tested products are easy to cast.

Table III. Caption for Table I.

Product	$\%H_2O$	Bulk Density	True Density	Apparent Porosity	True Porosity
	%	g/cm^3	g/cm^3	Vol %	Vol %
A1	2.3%*	3020	3657	17.25	17.42
A2	1.4%*	3170	3819	16.24	16.99
A3	6.1%	2675	3071	10.18	12.89
B1	7.1%	2733	3583	20.95	23.72
C1	6.3%	3010	3635	14.67	17.19
C2	5.2%	2808	3320	14.07	15.42

Table III. Cont.

Product	Bulk Density	Apparent Porosity	Crushing Strength
	After firing	After firing	
	g/cm^3	g/cm^3	N/mm^2
	1500°C/ 4hr	1500°C/ 4hr	
A1	2964	21.83	29.1
A2	3088	21.29	31.2
A3	2694	15.40	81.4
B1	2599	25.48	28.2
C1	2894	21.93	74.2
C2	2646	20.71	48.7

The true density is an indication of the chemical composition. The results for the alumina castables are therefore similar as is the case also for the bauxite products. In table IV the chemical composition is shown for each product (supplier data.)

Table IV. Chemical composition (supplier data.)

Product	SiO_2	Al_2O_3	Fe_2O_3
A1	0.1%	93%	0.2%
A2	<0.2%	98%	<0.2%
A3	26%	73%	<0.5%
B1	10%	82%	2.0%
C1	0.2%	97.0%	0.1%
C2	19.0%	78.0%	0.8%

The porosity of these products mainly consists of open pores, while 2-3% is closed porosity. Usually it is desired that the total porosity is as low as possible and that the pore sizes are as small as possible. In some cases ultrafine materials are added in order to achieve a better densification and this is the case of for instance A3 and C2. These two qualities achieve a very low porosity and a high crushing strength (Table III.)

In order to evaluate the thermal shock resistance hot modulus of rupture is evaluated. From this test the bending strength, the E-modulus and the deformation at the time of cracking (epsilon) are measured. Furthermore the coefficient of thermal expansion is necessary. In figure 5 to Figure 8 the results from these tests are shown graphically. The results are used to calculate the theoretical maximum temperature difference (Hasselman R) a material can be exposed to in the case of fast thermal shock, i.e. filling of a metallurgical vessel. In Equation 1 the formula for the Hasselman R [1] parameter is shown (s is HMOR, n is Poisson's ratio=0.25, a is coefficient of thermal expansion and E is the elasticity modulus.)

$$R = \frac{\sigma(1-\nu)}{\alpha E}$$

Equation 1 Hasselman R

In figure 4 the calculated values of Hasselman R are shown graphically for the various products.

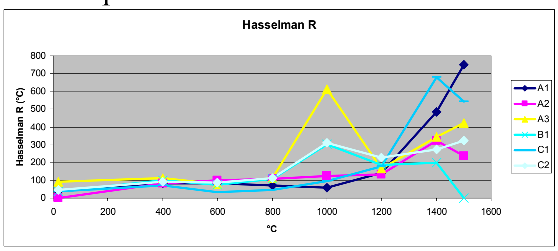

Fig. 4: Hasselman R.

The hot modulus of rupture is influenced by the quality of casting, but it is carefully evaluated, during casting of test samples, how much water is needed for good flowability. The obtained results are therefore also indicative for the overall quality of the castable. The deformation and E-modulus are not significantly influenced by the casting, but more by the chemical composition of the material.

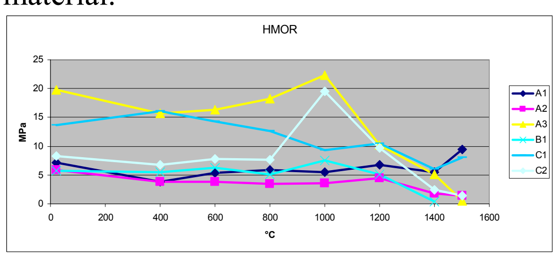

Fig. 5: Hot modulus of rupture.

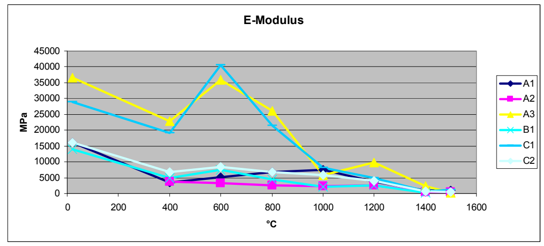

Fig. 6: Elasticity Modulus.

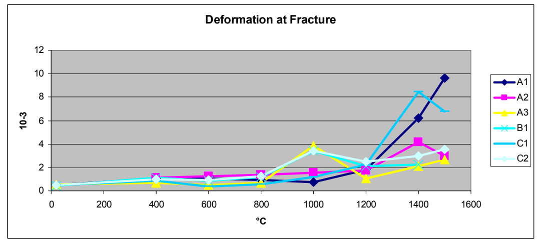

Fig. 7: Elasticity (epsilon.)

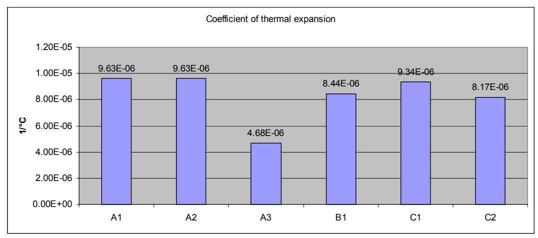

Fig. 8: Coefficient of thermal expansion.

It is known that the currently used castable melts under the conditions between the electrodes in the delta section. In the refractoriness under load test it is evaluated at what temperature level a product will start loosing its dimensional integrity. This is happening before total melting of the product occurs. However the test indicates the maximum service temperature for a specific product. This is shown in figures 9 and 10 (the latter being the creep behaviour after reaching 1600 °C.)

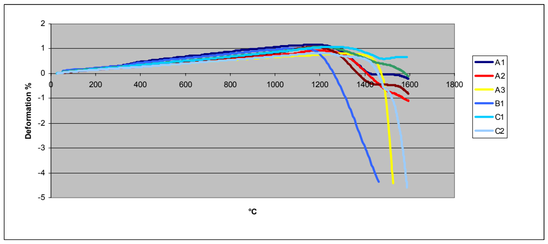

Fig. 9: Refractoriness under Load.

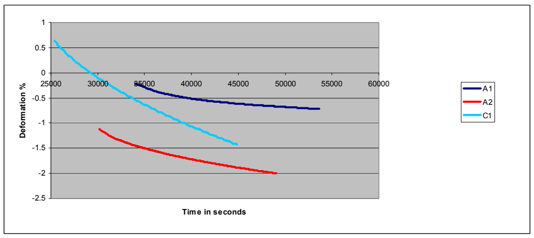

Fig. 10: Creep in compression.

DISCUSSIONS OF TEST RESULTS

Earlier the following conclusions were made:

The operation temperature at the hot face of the delta section is higher than 1335 °C.

The refractoriness of the B1 quality is too low for use in the delta section of the ladle furnace.

Other properties of the B1 are also inferior to what is expected from a refractory castable for use in the delta section.

Wear mechanism as determined by post-mortem analysis:

Melting; the temperature in the application is simply much higher than the melting point of the castable.

Thermal shock 1; cracks are formed in the bulk of the delta section decreasing the already inferior strength of the material.

Thermal shock 2; between each treatment a glassified layer is formed by solidification of molten refractory material. This layer breaks off due to thermal shock and increases the speed of wear significantly.

After a while the star shaped anchor becomes exposed and melts quickly away and leaves the center of delta section without anchor support. Due to thermal shock cracks this piece then easily falls out.

In order to improve the lifetime of the delta section the following alternative solutions can be considered:

- Change of refractory quality to one with higher refractoriness and higher thermal shock resistance
- Longer life due to less melt formation and less crack formation
- Move star shaped anchor closer to cold side or add extra anchor or increase thickness of castable.
- Longer life due to delay of anchor attack

In the following paragraphs the results are discussed per product quality.

A1

This quality is based on cement bonded tabular alumina grains and with a high percentage of spinel binder. The purpose is to increase slag resistance. It is a high-density product (and low porosity), but in the preparation of lab samples more than 2% extra water (in comparison to supplier recommendation) was needed in order to obtain a good flowability. This has a negative influence on the strength properties. The hot modulus of rupture results are almost constant in the whole temperature range up to 1400°C. At 1500 °C the strength increases due to spinel formation. The brittleness (evaluated from E-modulus and epsilon) is rather high at temperatures under 1200°C. At temperatures above 1200°C the material shows more flexibility probably due to formation of viscous phases in the bonding system. At 1400°C and 1500°C the flexibility is extremely high. This also results in a very good thermal shock resistance at temperatures above 1200 °C, even though the coefficient of thermal expansion is the highest of all tested materials.

Regarding refractoriness, this product is the most refractory of all the tested materials.

A2

This quality is the same as the A1 version but without the spinel additions. Again more than recommended water was needed for casting of test samples resulting in a rather low strength. Contrary to the spinel version the bending strength of this product decreases above 1200°C. Regarding thermal shock resistance it also follows the spinel version until 1200°C. Between 1200°C and 1400°C the R parameter increases but above 1400°C it decreases.

This product has a high refractoriness and a low creep.

A3

This product has lower density than it's alumina equivalents described above. This is not due to porosity problems, because this product has the lowest porosity of all tested materials. The low density is mainly due to the chemical composition of this fused mullite based product. The high degree of densification is resulting in very high strength values both from the CCS and HMOR tests. The HMOR is very high (~20 MPa) at temperatures up to 1000°C, where it sharply decreases to a more normal level (~10 MPa) at 1200°C. However above 1400°C the strength of the product becomes almost nihil. This is because of the lower refractoriness of the product when compared to the alumina counterparts. Due to the lower refractoriness it is expected that a viscous phase is formed at rather low temperatures and this is detected in the epsilon values where a maximum is observed at 1000°C. Furthermore the thermal expansion coefficient is less than for all other products and these two factors mean that this product is very thermal shock resistant around 1000°C. At 1200°C the thermal shock resistance is similar to the other products and above 1400°C it is among the best but not as good as A1 and C2. At 600°C this product shows a very high E-modulus. At this temperature the product is very strong and brittle but probably not very thermal shock resistant.

In the refractoriness under load test it performs good, but not so well as the alumina based products. From the curves it is observed that this product is more than 250 °C more refractory than B1. Hence it will be a significant improvement regarding both thermal shock and refractoriness.

B1

This product achieve very poor test results and especially regarding refractoriness the performance is far below what is expected from a refractory product for application in the delta section for the ladle furnace. The samples were cast at CRC and the quality of this material is rather good regarding strength properties, however when testing a supplier precast sample strength properties were very poor. This indicates the importance of quality control on supplier precast shapes. The thermal shock resistance at 1000°C is good, however due to the low refractoriness the product can not be used above 1200°C.

C1

This product is equivalent to A2. However the alumina content is lower and the strength is higher. This is probably due to use of more cement. The HMOR slowly decreases with increasing temperature, but it is still a very strong product over the entire temperature range. The strength even increases a little from 1400°C to 1500°C. Just as A3 this product is very brittle around 600°C but at higher temperatures it shows a very good thermal shock resistance. Like the other alumina products the refractoriness of C1 is very high.

C2

This castable is similar in chemical composition to B1. It is also based on bauxite with alumina addition. However due to the large SiO2 content it is expected that microsilica is added in order to reach lower porosities. The water amount needed for casting is also the lowest for all products and the porosity is indeed very low. The HMOR values are high especially around 1000°C where it almost reaches the same value as for A3. Contrary to A3 this product does not have a very brittle zone around 600°C but it is expected that the thermal shock resistance at 600°C only slightly better is. This is due to the larger thermal expansion coefficient of C2. At higher temperatures C2 has a very good thermal shock resistance and at 1200°C it is the best of all products. Regarding refractoriness this product is very similar to A3. Thus application of this product as a replacement of B1 will be a significant improvement.

CONCLUSION

The two most important wear mechanisms for the delta section is thermal shock and melting of the refractory material. Therefore the thermal shock resistance and the refractoriness under load will be the most important parameters for selecting an alternative to the currently used material, B1.

From the results we have seen that the alumina products all are very refractory and very resistant to thermal shock above 1200 °C. However at lower temperatures in the range 800°C to 1200°C the thermal shock resistance is relatively low. Hasselman R, the maximum allowed temperature difference before crack initiation is around 100°C for the alumina products

The thermal shock resistance in this range is significantly higher for the C2, A3 and B1, with A3 showing a very high Hasselman R (~600°C) at 1000°C. However the refractoriness of these products is not as high as for the alumina products. A3 and the C2 are at least 250°C more refractory than B1.

In practice, the worst thermal shock occurs when a new steel ladle is entering the ladle furnace for a treatment and when the electrodes are turned on. At these moments it is expected that the temperature of the hot face of the refractory material is less than 1200°C. Therefore the thermal shock resistance at these relatively low temperatures is more important than at higher temperatures. A high refractoriness is as mentioned also needed but in order to reach the high thermal shock resistance at the lower temperatures a compromise must be made on refractoriness. Both C2 and A3 are a large improvement regarding refractoriness and thermal shock in the range under 1200°C. However even though the calculated thermal shock resistance of A3 is almost twice as good as for C2, C2 is recommended for further trials. This is due to the fact that A3 shows a very brittle nature around 6-800°C. The delta section is water cooled and a large part of the refractory castable is at a temperature around 6-800°C.

Parallel to this project the No.2. BOS plant at Corus IJmuiden has build a mould in order to be able to cast the delta section internally Corus. Regarding material cost a saving of ~50.000 €/year is realised. Furthermore considerable benefits are achieved due to the longer life time. There will be 8 changes of 4 hours less per year and this will give the possibility to increase the number of treatments per year with 16. The new delta section is now standard and no early failures has been recorded yet. Early failures were with the old material often disturbing the production flow at the steel plant.

REFERENCES

[1]To be updated