The Development of Non-Destructive Inspection Method for AZS Fused Cast Refractory and the Results of Performance of the Inspected Blocks used in Glass Melting Furnaces (37th AFGM, Bali)

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The quality of fused cast refractory correlates closely with the life of a glass melting furnace. The fused cast refractory is manufactured by electric melting and casting processes. It is well-known that the distinctive features of the fused cast refractory are low porosity and high corrosion resistance. In the casting process, molten material is poured into a mould, and the shrinkage of material occurred during annealing and solidification of the melt. Hence shrinkage cavity (so called as “void”) occurs inside the block, and its location is controlled by casting techniques.

Generally, the void free or semi void free blocks, which are manufactured by removing the upper portion (so called as “riser”) of the cast blocks, are used for the glass contact areas of a furnace such as the side wall, throat and dam wall portions. It is no exaggeration to say that it is very important to check the internal void conditions of the block accurately after removal of the riser because unusual voids might sometimes remain at the unexpected location inside the block due to the unbalance of solidification speed.

The unusual voids would cause localized heavy corrosion in the furnace, and it may shorten the furnace life. We, AGC Ceramics Co., Ltd., developed our non-destructive inspection method by using electromagnetic radar in 1991, and since then the internal-quality check as one of our quality assurances has been carried out before shipment for all important large void free or semi void free blocks of the side wall, throat and dam wall. Our internal-quality check has been carried out for over twenty years.

There are many furnaces, which were installed with AZS blocks inspected by the non-destructive inspection method, and these furnaces have finished their campaign lives without any abnormal corrosion and trouble. It is verified that our well developed non-destructive inspection method is quite effective in achieving the constant and stable furnace life. We are so proud of ourselves that our product is the most reliable in the world. It is reported in this paper that this technique is useful for the reduction of unusual localized heavy corrosion which causes the leakage trouble of molten glass, and helps us to improve the casting techniques.

1. Introduction

AZS fused cast refractory is manufactured by electric melting and casting processes. In the casting process, molten material is poured into the mould, and the shrinkage of material occurs during annealing and solidification of the melt. Throughout the solidification process, shrinkage void appears inside the block, and its location is controlled by casting techniques as shown in fig.1. When the voids occur at the unexpected location inside the block, which is due to unbalanced solidification process, such voids cannot be seen from the outside unless the block is transparent.

In the field of metal casting, the phenomena of void have also been reported as shown in fig.2[1], and the non-destructive inspection method has already been widely used[2].

In the field of glass melting, internal defects of AZS void free or semi void free fused cast refractory is a potential weak point of the melting furnace when it is used in the glass contact areas as the cavity might cause localized heavy corrosion on the block and lead to glass leak.

How to minimize the internal defects of AZS fused cast refractory has been our main concern. Based on this motivation, we started our development of the non-destructive inspection method in 1980’s. The development completed successfully in 1991[3], and we, AGC Ceramics Co., Ltd., have started applying this inspection method for all important large AZS void free or semi void free blocks used for glass contact areas such as the side wall, throat and dam wall portions since 1992.

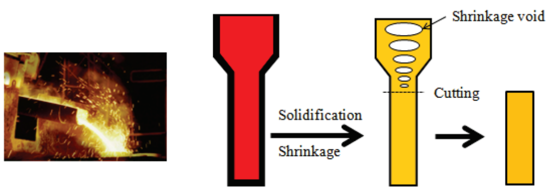


Fig.1 Manufacturing process of AZS refractory block

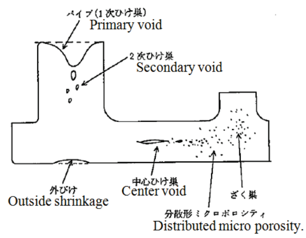


Fig.2 Internal defect in the field of casting metal. [1]

2. Basic study of non-destructive inspection.

2.1 X-ray inspection method

Figure.3 shows the photos of x-ray measurement for MgO-C bonded refractory and AZS fused cast refractory. The white parts in x-ray photo are internal images such as lamination and shrinkage void. Figure.4 shows the relationship between x-ray voltage and thickness which can be passed. Horizontal axis shows the thickness through which x-ray can pass, and vertical axis shows the required x-ray voltage. The relationship is almost linear, and about 800 kV is required in the case of 300mm thickness of AZS. Because of the high voltage, there are problems about safety and cost, and this method could not be adopted as the internal inspection method of AZS block.

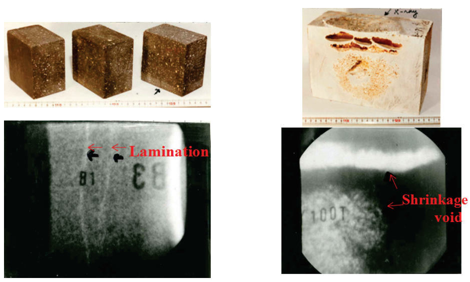


Fig.3 Internal defect inspection of some refractories by x-ray.
Left: MgO-C bonded refractory
Right: AZS fused cast refractory

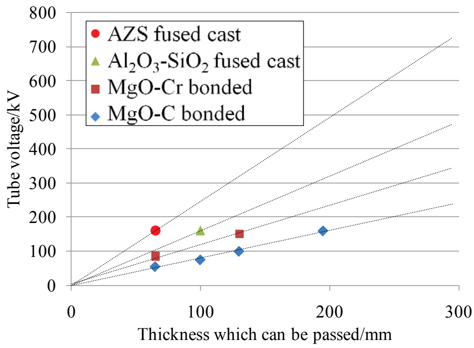


Fig.4 The relation between voltage and thickness which can be passed.

2.2 Electro-magnetic wave inspection method

Table.1 shows the examples of inspection results of AZS side wall refractories by electro-magnetic method, and actual internal structure at the cutting surface. Electro-magnetic radar device transmits microwave from one side of the block, and receive the reflected wave from internal defect. This measurement is carried out continuously with moving the device horizontally. The depth of defects can be calculated from time delay of reflected wave by using equation.1. First row of table.1 shows the reflected wave image which is carried out some image processing according to our judgment algorithm. Black part in this image shows the area which include internal defect, and it can be seen only in sample-A. On the other hands, second row shows the actual internal structure at the cutting surface. Actual internal void can be seen only in sample-A, and no void in sample-B.

Table.1 Examples of detected internal defects and actual photograph of cutting surface.

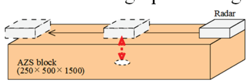
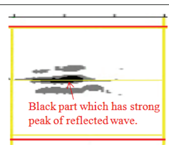
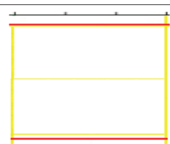
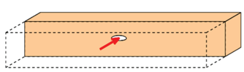
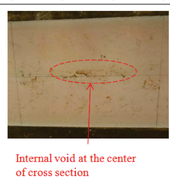
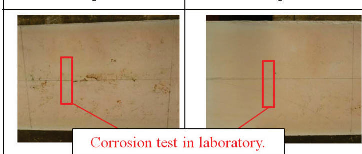
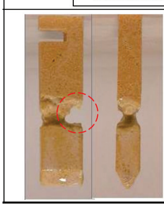
	Sample-A	Sample-B
Reflected wave image which carried out image processing 		
Internal structure at cutting surface 		

Table.2 Results of TC-11 corrosion test of sample-A and B.
(Soda-lime 1500C × 24hr)

Sample-A	Sample-B
	
	

$$D = \frac{ct}{2\sqrt{\varepsilon}} \qquad \text{Eq. 1)}$$

D : Depth of internal defect(m) ε : Relative permittivity of AZS
c : Velocity of light(m/sec) t : Time delay until electromagnetic waves come back (sec)

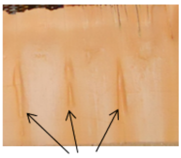
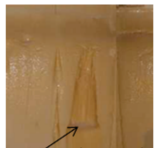
In order to confirm the effect of internal defects to the corrosion resistance, TC-11 corrosion test was carried out with using these samples. The results are shown in table.2. Unusual heavy corrosion can be seen only in sample-A which has internal defect. It is confirmed that internal defects can be a weak point at laboratory. Electro-magnetic method has not only exact measurement capability but advantage of low cost and short time for measurement. So as one of our quality assurances, we, AGC Ceramics Co., Ltd., have carried out this inspection for all important large void free or semi void free blocks of the side wall, throat, dam wall since 1992.

3. The results of performance of the inspected blocks used in glass melting furnaces

Many furnaces, installed with AZS blocks inspected by the non-destructive inspection method, have finished their campaign lives. The investigation on the situation of the side walls has been carried out by counting a number of blocks with unusual corrosion.

Table.3 shows the various types of corrosion patterns of the AZS side wall blocks. First type shows upward drilling from horizontal crack. These are influenced by cracks which depend on heating-up, insulation structure, and other condition. They have no relation with internal defect. So this type is not counted as unusual corrosion. Second type shows corrosion from joint gap. The corrosion along vertical joint gap, and upward drilling from horizontal joint gap of the bottom may be influenced by condition of joint gap or design concept. So this type is also not counted as unusual corrosion. Third type shows unusual corrosion different from the type one and type two. Internal defects may cause this type of corrosion, so the number of blocks which have this type of corrosion pattern is counted.

Table.3 Various types of corrosion patterns of the AZS side wall blocks.

1) Upward drilling from horizontal crack.	2) Corrosion from gap.	3) Unusual corrosion without joint gap and clear crack.
 Horizontal crack	 Along vertical joint gap  Upward from horizontal joint gap	  Unusual corrosion

Talble.4 shows the results of performance of the AZS fused cast blocks without non-destructive inspection manufactured before 1991. Furnace-A has 16.2% of side wall blocks with unusual corrosion. Furnace-B has 28.6%. Fig.5 shows the photo of unusual corrosion in Furnace-B. Unusual corrosions different from the type one and type two can be seen.

On the other hands, table.5 shows the results of performance of the inspected AZS fused cast blocks which have been manufactured after 1992. It can be seen that unusual corrosion drastically decreased. Fig.6 shows the photo of side wall blocks of Furnace-E. It has a homogeneous corrosion pattern without any unusual corrosion. These results show that our well developed non-destructive inspection method is quite effective in achieving the constant and stable furnace life.

Table.4 The results of performance of the AZS fused cast blocks without non-destructive inspection manufactured before 1991

Furnace	glass	The numer of total investigated blocks	The number of blocks with unusual corrosion	The rate of unusual corrosion
Furnace-A	CRT	74	12	16.2%
Furnace-B	Container	21	6	28.6%

Fig.5 The photo of unusual corrosion in Furnace-B.

Table.5 The results of performance of the inspected AZS fused cast blocks which have been manufactured after 1992

Furnace	glass	The numer of total investigated blocks	The number of blocks with unusual corrosion	The rate of unusual corrosion
Furnace-C	Container	25	0	0.0%
Furnace-D	Container	34	0	0.0%
Furnace-E	CRT	28	0	0.0%
Furnace-F	CRT	92	0	0.0%
Furnace-G	Float	60	0	0.0%

Fig.6 The photo of side wall blocks without unusual corrosion in Furnace-E.

4. Conclusions

We, AGC Ceramics Co., Ltd., challenged to develop this unique inspection method in 1980's, and finally succeeded in the development of the non-destructive inspection method of AZS by using electromagnetic radar in 1991. And we have started applying this inspection method for all important large AZS void free or semi void free blocks used for glass contact areas such as the side wall, throat and dam wall portions since 1992.

Our internal-quality check has been carried out for over twenty years. It has been proved that internal inspection can prevent unusual corrosions on the block. It can minimize internal defects of the blocks used in the glass contact areas. Hence we are so proud of ourselves that our product is the most reliable in the world and can contribute to safeguard the furnace life.

5. References

1) Casting and solidification, P49, Fig.2.30, The Japan Institute of Metals and Materials.
2) Metal data handbook rev.3, P295, The Japan Institute of Metals and Materials.
3) Hosoda, Ushimaru, Samejima, Pat.5363106,FR , Pat.2689245,IT, Pat.1287883,JP, Pat.3262606.