Study on Magnesia Ramming Bottom Lining in Ferroalloy Refining Furnace and Its Application

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ABSTRACT

Magnesia bricks had been used in lining ferroalloy refining furnace (LC FeCr and MC FeMn) at Jilin Ferroalloys Corp. (JFC). The lining lives of these MC FeCr and LC FeCr furnace were around 40～50 days and 20 days respestively for the reason of batch operation and hot shocks.The improvement of lining materials for refining furnace has been one of the important project at JFC. The study on magnesia ramming bottom started in 1997. JFC and magnesia producers cooperated in the project and succeeded in the trials and the related basic study. The lining life is doubled. The refractory saving and production economy are appreciable. The corrosion mechanism of Mg bricks in refining furnace is studied in the paper. The performance, the process of ramming bottom and the lining maintenance are introduced. The lining corrosion of a shut down MC FeCr furnace was observed.The samples taken in the section of the furnace were analyzed by chemistry,mineralogy and X-ray diffraction analyses.The study reveals the direct reason of the prolong lining life.

1 INTRODUCTION

For many years，the magnesia bricks had been used in ferroalloy refining furnaces as lining materials.But the magnesia brick's softening temperature under load was lower and its thermal shock resistance was not very well.CMS(CaO、MgO、SiO_2)was the binder of main matrixes in it and began to form liquid phase at about 1498℃.Because the melting bath temperature in MC FeCr furnace etc.exceeded 1800℃，the magnesia bricks were heavily eroded and the life of furnace lining was shortaged with cold charged material and intermittent operation. Although technicians had taken many measures to maintain furnace lining to prolong its life，the effect is not good.In 1997，JFC conducted the tests of monolithic lining ramming with bulk magnesia ramming materials in a MC FeCr furnace co-operating with refractory producer concerned. The result was ideal.After all-round application and dissemination，the average lining life of 7 refining furnace were doubled，refractories consumption was reduced clearly.In China ，using magnesia bricks as ferroalloy refining furnace lining had been history.

2 RAMMING MATERIAL'S PROPERTIES

The ramming material used in the test is bulk magnesia material with high Fe and CaO content.It is mainly composed of minerals M(MgO)、C_2F($2CaO \cdot Fe_2O_3$)、C_2S($2CaO \cdot SiO_2$)、C_4AF($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$)etc..The primary crystalline phase periclase(M)and the secondary crystalline phase dicalcium ferrite(C_2F) are main ceramic cement phases. The grain boundary diffusion between primary crystalline phase and binding phase and partial solid solution reactions can forms tabilizing microscopic structure at high temperature. From the beginning of campaign , the materials start to sinter at 1350℃ and completed sintering mainly at 1550℃.The original mineralogical composition in working surface in furnace bottom was changed from original $M+C_2F$ to (Mg、Fe)O solid solution and high melting point silicate .The ramming material has obvious advantage than ordinary magnesia brick in the microscopic structure at high temperature. Thus it is successfully used in steel plant's furnace bottoms.To win success in the first test in MC FeCr furnace , according with the characteristics of MC FeCr smelting(high furnace temperature, high slag basicity and high melting point), the refractory producer properly adjusts the material's physical and chemical indexes to furthur improve its properties to meet JFC's demand on the basis of analysing ramming material used in furnace bottoms in steel plant(see table 1).

Table 1 Physical and Chemical Indexes of Magnesia Ramming Material

Indexes		Before Adjustment	After Adjustment
MgO CaO Fe_2O_3 SiO_2 Al_2O_3		≧83 7－9 7－8 ≦1.5 ≦0.7	85.05 6.75 5.30 1.14 0.72
Size(mm)		5－0	5－0
Service Temperature(℃)		1750	1850
Bulk Density(g/cm^3)		>2.2	2.44
Sintering 3 Hours at 1600℃	Density After Sintering(g/cm^3)	>2.8	2.84
	Pressure-resistance Strength(MPa)	>30	48.8
	Advanced Sintering Linear variation(%)	－2.7	－2.5
Main Minerals (X-ray Diffraction Analysis)		$M\cdot C_2F$	$M\cdot C_2F$

2.1 Increasing Refractory Property

Before adjustment, the products were mainly used in steel plant's furnace bottoms and ultra-high power electric furnace bottoms.After improvement, the content of CaO was controlled between 6%～7%, Fe_2O_3 was decreased to about 5%, MgO was increased over 85% and the refractory property was increased to some extent.The service temperature can come up to 1850℃ approaching the actual smelting temperature in MC FeCr furnace.

2.2 Increasing Sinter Strength

X-ray diffraction analysis of the magnesia ramming sample shows that the minerals C_2F and M do exist(see figure 1).Thermal insulation

sintering 3 hours at 1600℃, the sample's pressure-insistance strength is 48.8MPa,coming up to that of ordinary magnesia brick .This shows the minerals C_2F composed of Fe_2O_3 and CaO etc.play a high temperature bond role during synthesising to enable the material has good sintering strength, and the diffraction spectrum line of C_2F is strengthened with the decreasing of material size, i.e. C_2F content is increased gradually.The spectral lines 1 to 5 are characteristic ones of M and C_2F with 5 sizes(5～3mm, 3～1mm, 1～0.5mm, 0.5～0.088mm, 〈0.088mm) after screening of the samples.

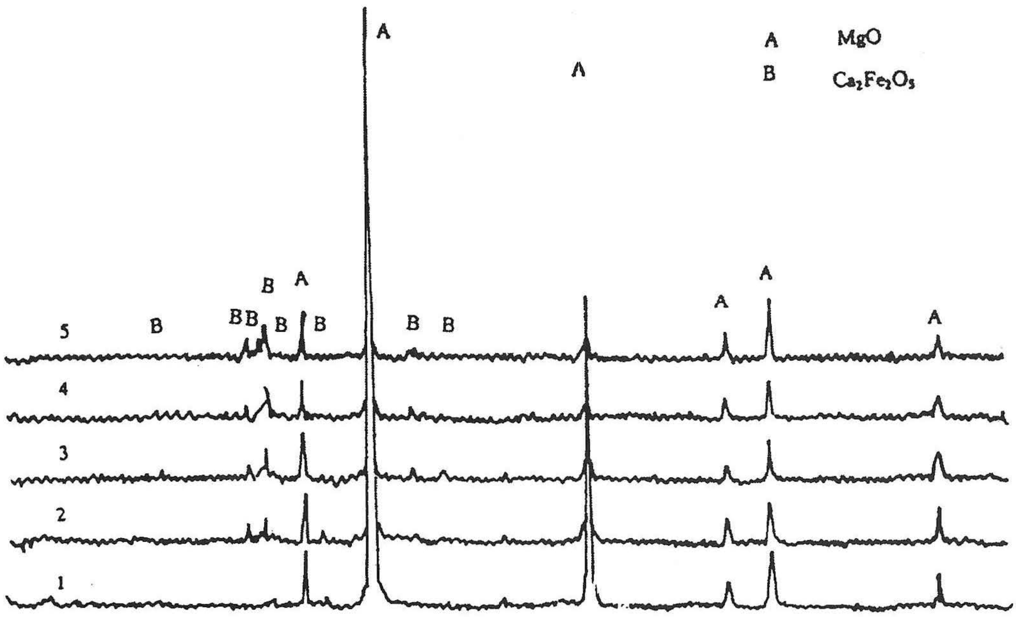

Figure 1 X-ray Analysis Spectral Line of Magnesia Ramming Material Mineralogical Composition

3 FURNACE BOTTOM RAMMING AND FURNACE PREHEATING

According to the structure characteristics of MC FeCr furnace No.605 at JFC, the process is adopted of monolithic ramming in bottom with bulk ramming materials combined with side laying in permanent layer and taphole runner with magnesia bricks.Figure 2 shows bottom laying and ramming situation.

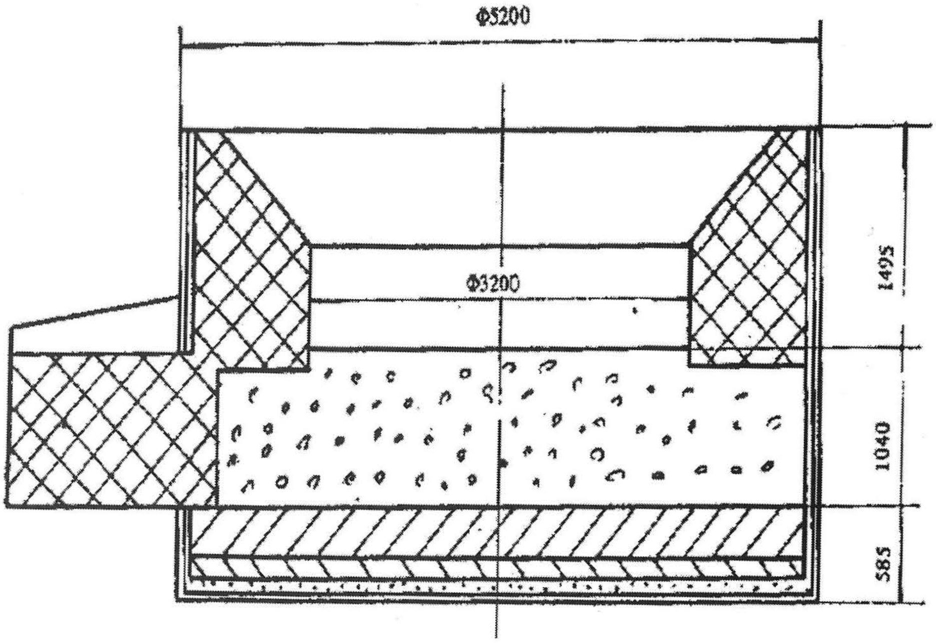

Figure 2 Bottom Ramming Process Diagram(see the draw figure2.jpg)

3.1 Furnace Bottom Ramming

3.1.1 Laying Permanent Layer and Taphole Runner

①Laying 10mm asbestos boards first， then Laying flat clay grains 100mm deep as elastic layer， then laying flat 2 layers clay bricks (130mm deep)，on the layers ，laying side-face 3 layers common magnesia bricks (345mm deep) as permanent layer.

②The taphole runner is still laying with magnesia bricks， deep into the furnace 345mm.

3.1.2 Ramming with bulk ramming material

①The bulk ramming materials are rammed after laying permanent layer.7t bulk materials are laid flat in furnace bottom each time(150mm deep)， and are evenly rammed solidly with flat vibrator to 120mm deep(the volume density is 2.7～2.8g/cm^3).The upper material ramming is continued after raking in the furnace.

②When the furnace bottom is rammed to 920mm deep (totaled 8 layers)， the first layer furnace wall is laid.Then 2t bulk materials are laid flat and is rammed solidly with the flat vibrator .Thus the bulk material is total 1040mm deep after ramming.

③The furnace wall is laying normally after bulk material ramming ， and a slope is rammed with the bulk material in the joint between the in place with furnace bottom and wall.

3.2 Power feeding for Furnace Preheating

Laying a layer lime and SiCr alloy after cleaning odds and ends in the furnace ， strike a arc, put the power on and then the mixture of lime and SiCr alloy are gradually added.The voltage 156V and the current 50～180A are adopted in furnace preheating,and the power consumption is controlled according to the schedule of furnace dry-out.

4.LINING…MAINTENANCE

4.1 Accurately Controlling Taphole Shift Schedule

Taphole shift is the most important for MC FeCr furnace production, delaying shifting schedule will cause the bottom sloping ,then the hot metal will concentrate towards the lower side to accelerate bottom erosion and decrease lining life.Therefore the tapehole should be shifted quickly to level the bottom in case of that the difference is higher by daily observing.

4.2 Controlling proper slag basicity

Proper slag basicity is not only the need of reduction reaction, but also the need of prolonging bottom life.When the basicity is lower, furnace wall is eroded heavily;when the basicity is higher,the heat load in the bottom is increased , the bottom is eroded quickly.Thus the slag basicity is adjusted from 1.8～1.9 to 1.7～1.8 to ensure the furnace wall erosion rate matching with the bottom.

The average slag compositions during testing are as follows.

CaO	SiO_2	MgO	Fe_2O_3	Al_2O_3	Cr_2O_3	CaO/SiO_2
48.55	28.23	7.89	0.99	7.75	3.97	1.72

4.3 Repairing the wall timely

As the bottom erosion rate is slow, repairing the wall appears to be very important.Every day,there are special workers inspecting the wall, repairing the weak place with the lime and waste magnesia bricks to avoid metal break-out and increase furnace production rate.

5 RAMMING TEST RESULT

Because of good monolithic sintering performance and spalling resistance of magnesia ramming material, over turning on furnace bottom is not occurred during the test. The furnace condition is stable, the smelting is successfully, and the obvious effects were achieved .The average excess output is 3.487t/d, unit electricity consumption is decreased 76kWh/t than that of plan.Lining life is prolonged 2.6 times than before, refractory consumption is decreased 2.5times, and the bottom erosion rate is decreased from 23mm/d to 8.7mm/d during smelting.The actual erosion rate of the bottom level was not exceeded 1mm/heat.The benefits from reduction of consumption , electricity saving and output increasing are total 700, 000yuan(Renminbi).Technical indexes are shown in table 2.

Table 2 Comparing of Technical Indexes

Production		Unit Power Consumption(kWh/t)	Lining Life /d	Refractory Consumption (kg/t)
Total Producti	Daily Production/t			

on/t	Plan	Test	Play	Test	In 1996	Test	Mg bricks	Ramming material
4579.981	35.0	38.487	1920	1844	45	119	50	18.72

6 FURNACE DISSECTION AND ANALYSING

Dissecting lining is very helpful to understanding furnace refractory erosion situation and study erosion mechanism of magnesia ramming material. So 605# furnace is dissected after running 119 days.

6.1 Selecting Samples

Figure 3 shows sampling positions in the dissected furnace.

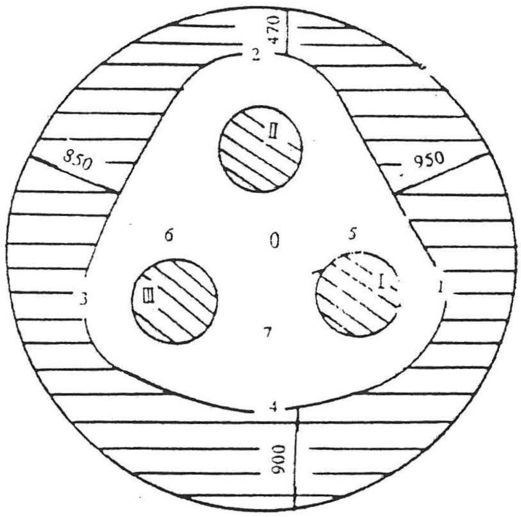

Figure 3 Schematis Diagram of Sampling from 605# Furnace Dissected

In figure 3, 1 to 7 are planned positions for sampling.To convenience sampling, furnace wall between Ⅰ to Ⅲ electrode and 3 layers permanent layer magnesia bricks side-face laid below the wall are cleaned to reveal clay brick layer.Thus the sampling positions 1 and 3 are revealed.The sampling positions 1 and 3 are that of furnace wall beside the Ⅰ and Ⅲ electrode.Each area are divided into 3 sampling positions,upside,medium and underside to convenience longitudinally observing sintering situation.Positions 5, 6 and 7 are sampling points below metal butt and up the magnesia bricks for analysing bottom refractory erosion mechanism.For the samples from 1, 3, 5, 6 and 7 positions are representatives, the positions 2 and 4 are not sampled.

6.2 Erosion Situation

The joints within 3 layers magnesia bricks side-face laid in furnace bottom are full of hot metal.The thickness of the metal stored in joints , especially between the 1st and the 2nd layers is about 10～30mm .Therefore the ramming material should be rammed

directly on clay bricks instead of magnesia bricks.
The erosion thickness of the wall are not equal. The erosion thickness of wall beside 3 electrodes is about 400～500mm，and that of wall between electrodes is about 850～950mm.This is because that the distance between the former and the electrode is shorter，radiation temperature is higher，the ramming material melting rate in the furnace was higher than that of the latter.During furnace dissection，it was discovered that the cracks in sinter layer at wall's working area were gradually increased with the decreasing of the temperature. This shows that magnesia ramming material lining should be used continually.Once the shutdown period was longer,cold cracking would occurred to decrease lining life.
The ramming material sample from dissected lining has four clear layers:erosion layer，sinter layer，transition layer and original layer.
Erosion layer(or working face) contacting with melt bath,10～20mm deep，is gradually desinteqrated to white pieces or white powders as the temperature lowered.The sinter layer is deep brown and compact. Being in high temperature for long time，it was gradually widen from above to below.The above was 40mm wide，and the below in the furnace wall was come to 150～200mm.The transition layer was under semi-sintered condition，with brown colour.The original layer was light brown.

6.3 erosion analyses

The chemical analysis results of samples from dissected lining were shown in table 3.

Table 3 The Chemical Analysis Results of Samples from 605# Furnace lining dissected

Nos	SiO_2	CaO	Fe_2O_3	MgO	Al_2O_3	Cr_2O_3
I --1	3.49	14.1	7.79	73.49	1.66	0.19
I --2	2.84	13.87	7.66	74.89	1.53	0.13
I --3	1.97	14.32	5.35	73.97	2.93	0.09
I --4	6.55	7.01	5.89	76.77	0.77	3.78
III--6	8.74	15.5	2.72	72.00	1.15	0.28
III--7	4.37	10.49	4.10	80.28	1.22	0.30
III--1	1.97	10.26	7.15	78.27	1.05	0.13
III--2	2.18	13.18	5.05	77.52	1.17	0.15
III--3	2.62	12.24	3.78	81.37	0.99	0.29
Original sample	1.14	6.75	5.53	85.05	0.72	

Note:①The Roman numerals in Nos. represent the ones of the electrode;
②The Arabic numerals 1，2 and 3 in Nos. represent respectively samples from the top ，medium and bottom of furnace wall，5，6 and 7 represent samples from furnace bottom refractory nearby certain electrode.

Table 3 shows，contracting with original samples，CaO content in the samples from dissected lining is clearly increased，and its content in sinter layer comes to 10%～14%;SiO content is clearly increased ，especially for the three samples from furnace bottom,it is increased from original sample 1.14% to dissected lining samples 6%～8%，.The result illustrates that high basicity slag produced in metal smelting and furnace atmosphere have osmosized the ramming material to a certain degree.CaO combining with SiO_2 into silicate phase with higher melting point can protect the bottom from erosion.

The mineralogical composition of representative dissection samples are analysed and studied in X-ray diffractometer and mineralographic microscope.Figures 4 and 5 show X-ray diffraction analysis spectral lines.The three spectral lines marked above,medium and below represent respectively three samples from wall's sinter layer numbered Ⅲ-1，Ⅲ -2，Ⅲ -3，the main minerals are M，C_2F and C_2S.Figure 4 shows that the characteristic spectral line of C_2S is strengthened gradually，i.e.C_2S content increases gradually.Figure 5 has 2 spectral lines，both representing powdered samples numbered Ⅲ-6. Line 1 represents lump sample and line 2 represents fine sample. The main minerals in the above samples are M，C_2S，C_2F and C_3MS and the main crystal phases both are M，the difference between the 2 samples is that C_2S content in fine sample is more than that in lump sample，though the fine sample is desintegrated seriously.

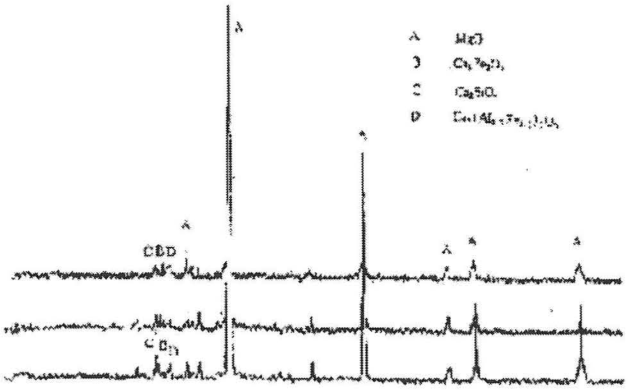

Figure 4 X-ray Analyses Spectral lines of the above，medium and below sinter layer in furnace wall

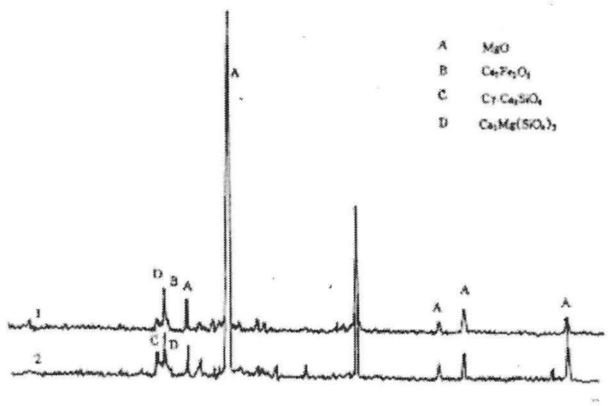

Figure 5 X-ray Analysis Spectral Lines of Erosion Layer Contacting with Melting Bath

Microscope studying result is basically identical with that of X-ray diffraction analysis, i.e. sinter layer is mainly composed of the minerals. M, C_2F and C_2S etc.(see figure 6).In figure 6, periclase crystal grains are bigger, M is surrounded by cement phase C_2F etc..Some crystal boundaries diffuse each other connecting to an organic whole.Therefore the compression strength and compactness of sinter layer is obviously higher than that of transition layer and original layer.

The microscopic structure of integrated lump sample from erosion layer is shown in figure 7.The major compositions in the mineral are M and C_2S, occasionally a little unsolved C_2F is observed.Comparing with figure 6,many silica phases such as C2S etc. are filled within periclase crystal boundaries in erosion layer.The periclase crystal grains are eroded by melt silica phases to turn smaller, and the crystal grain periphery is not as clear as that of sinter layer.

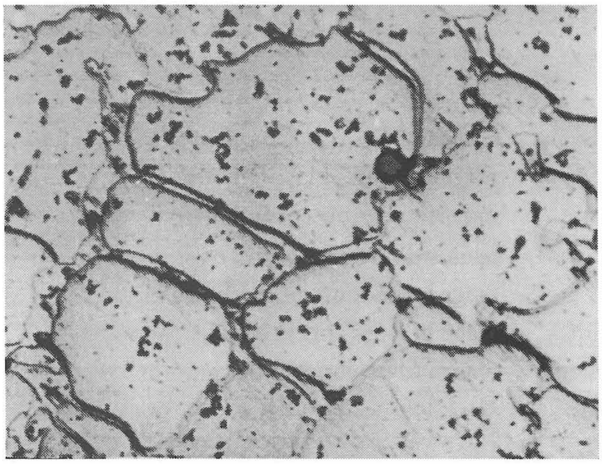

Figure 6 The Microphoto of Sinter Layer

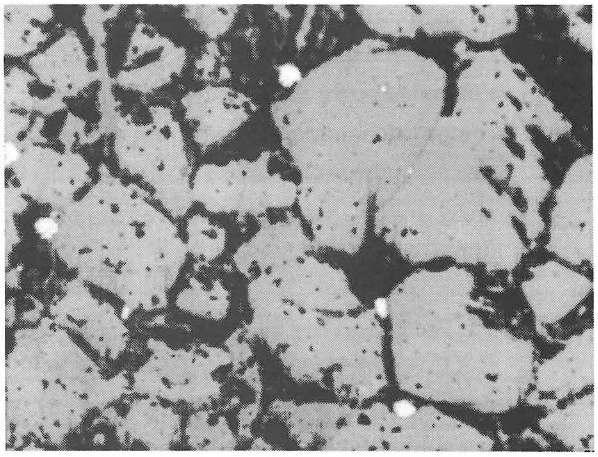

Figure 7 The Microphoto of Erosion Layer

Contacting with melting slag and metal, and because of furnace reducing atmosphere, there are always metal pearls differing in size in erosion layer sample(figure 8).Bigger metal pearls are distributed over crystal boundaries, maybe due to permeating of melting metal.The metal pearls are dispered in periclase crystal grains and very fine.

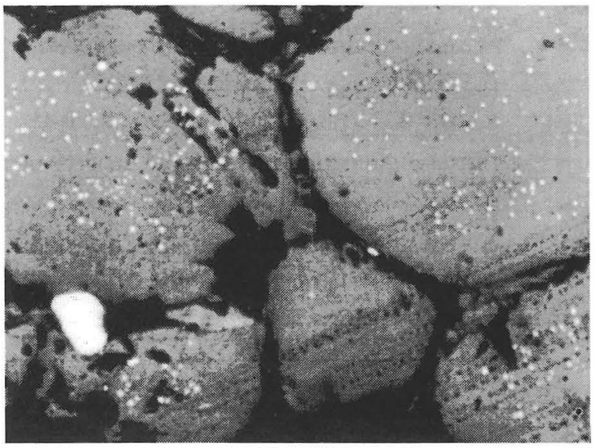

Figure 8 Metal Pearls in Erosion Layer

Through the study and analysis of samples from dissected furnace lining, the knowledge of erosion mechanism of magnesia ramming material are deepened, and the reasons prolonging furnace bottom life are also discovered.The lining erosion is mainly taken place at the boundary of melting slag contacting with the lining.On the one hand, when melting slag containing CaO , SiO_2 and FeO contents with eroded surface,Fe^{+2} is dissolved into MgO to form solid Solution (Mg, Fe)O (RO phase), while CaO and SiO_2 permeates into the lining through the porosity of ramming material to caused the clear increasing of SiO_2 and CaO contacted in erosion layer, transition layer and original layer. Because of high SiO_2 content in melting slag, RO phase is gradually dissolved to result lining eroded slowly. On the other hand, after high temperature decomposition of cement C_2F, Fe^{+2} is dissolved into MgO crystal lattice, Ca^{+2} is combined with Si^{-4} to high melting point mineral C_2S+C_3S to hinder melting slag diffusion and RO phase dissolution to slow down furnace bottom erosion.

Moreover, combination within sinter layer's compactness, transition layer's buffer and original layer's plasticity results better lining monolithic property and thermal shock resistance, and stops to over turn the magnesia bottom in magnesia brick taken place before. This is another important reason of prolonging bottom life.

7 CONCLUSION

7.1The magnesia ramming material used in ferroalloy refining furnaces is mainly composed with high calcium magnesite and iron oxide,and it has proper chemical composition, minerological composition and size composition. It can be well sintered under 1600℃ with high service temperature limit.

7.2 The phase (Mg,Fe)O and minerals C_2S,C_3S with high melting points formed from desolved cement phase C_2F in smelting can slow down furnace bottom erosion.Meanwhile,the rammed bottom has the advantages of good thermal shock resistance and strenghening monolithic property and is no longer over turned in smelting, thus the lining life is prolonged.

7.3The process of lining ferroalloy refining furnaces, melting and lining maintenance resulted in the test provides a good utilization environment for the new ramming material to improve service effect.

7.4 The new refractory material is favorite for its dry ramming, feasible process and obviously decreasing in consumption etc..In China, it has been widely used in 25 ferroalloy refining furnaces with complete success.