REFRACTORY DESIGN EFFECT ON SUBMERGED ARC FURNACE LIFE AND PRODUCTION PERFORMANCE – THE ZIMBABWE ALLOYS EXPERIENCE

J. Chirasha and N.R. Shoko

Zimbabwe Alloys International P.O. Box 530, Gweru-Zimbabwe
E-mail: jchirasha@zal.co.zw and nshoko@zal.co.zw

ABSTRACT

Refractory design remains the most fundamental factor in furnace construction. Refractory design details and proven technology consideration is of paramount importance to come up with an optimum furnace life and to maintain productivity in the life span of the furnace lining.

The failure to produce a technically or operationally durable refractory design lining could give rise to premature deterioration of the refractory lining and furnace shell.

The premature failure of the furnace lining will lead to extensive heat losses, furnace bath shift, change in taphole orientation and alteration of the Pitch Circle Diameter. A combination of these were experienced at Zimbabwe Alloys' new high carbon ferrochrome furnace.

The Zimbabwe Alloys experience has shown an excellent furnace performance in the first two years of operation although signs of an anomaly showed within the first six months of the new furnace. Production slowed down due to induced problems from refractory failure causing furnace distortions impacting on the availability of the furnace and smelting capacity.

This paper presents the lessons learnt, measures taken to deal with the premature failure and constraints within which the situation was managed.

1. INTRODUCTION

Zimbabwe Alloys has been producing ferrochrome for the past 53 years and has produced 5 different ferrochrome and other alloys amounting to more than three million tonnes.

The furnace under discussion was originally commissioned as a High Carbon Ferrochrome production unit in 1974.

High Carbon Ferrochrome production was discontinued in 1983 due to market constraints. The furnace was then converted to producing Ferrosilicon Chrome.

Ferrosilicon chrome production continued until the year 2000. The market changes saw the 31MVA Furnace converted from Ferrosilicon Chrome to High Carbon Ferrochrome in 2000 as the latter product had better margins of return.

The furnace was operated without problems for the first six months of operation. Movements at the back of the furnace between the shell and the base plate initiated the distortions that later posed challenges related to furnace availability, production, efficiency and safety.

This paper describes the effect of refractory design on furnace operation, efficiency and details lining design shortcomings as observed by the furnace lining behaviour during the furnace production life span.

2. LINING DESIGN

The HCFeCr refractory lining design is fairly straight forward because theoretical modeling for these linings are readily available.

Technical suitability of the lining has been proven in most operations but there is need to pay attention to detail as the building of the furnace is taking place. The detail lining design omissions can give rise to serious operational and efficiency problems impacting on economic production.

Zimbabwe Alloys designed and lined its HCFeCr Furnace as shown in Figure 1.0. It was later found out that expansion for the entire lining of the furnace was not provided for. Bricks were lined directly against the shell. More over the brick to brick expansion was not adequate allowed for from the base of the furnace to the furnace side walls.

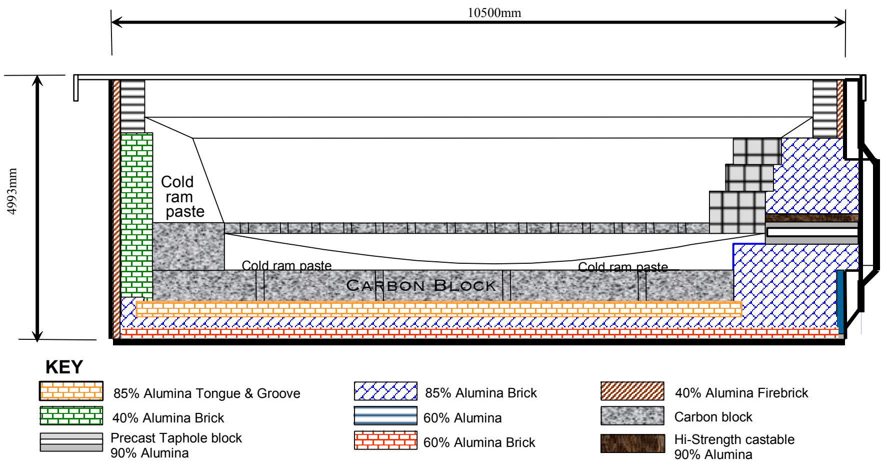


Figure 1: Refractory Lining Section

The base of the furnace was levelled off using a castable material 1300 in order to facilitate the 60% Alumina brick laying which started at the bottom.

A heavier duty 85% Alumina brick followed the 60% Alumina and this also was used predominantly around the taphole area. A Tongue and Grove 85% Alumina brick was put on top of ordinary 85% Alumina brick.

The detailed lining design is shown in Figure 1.

Production started in July 2000 after the furnace was converted and lined for HCFeCr production.

3. CAMPAIGN STATISTICS

3.1. Production Attainment And Efficiencies

Production improved from the time the Furnace was commissioned in August 2000. The 35000 tonnes mark was attained in the first full year of operation and the upward trend continued in 2002 with 45 000 tonnes of production.

In 2003 production started deteriorating and bottomed at 32000 tonnes in 2005, a 30% reduction from 2002 production although the furnace running time was constant.

Figure 2 below shows the production trend from the year of commissioning to December 2005.

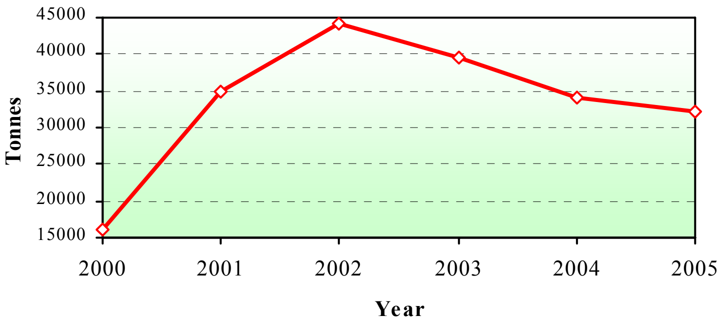


Figure 2: HCFeCr Production

The specific power consumption (KWh/t) which is a direct measure of furnace efficiency utilization of power improved from 4500 kwh/t to the lowest figure of 3400 kwh/t between 2002 and 2003. A value of power utilization of this magnitude could qualify to be one of the best in the convertional HCFeCr process.

Figure 3 below shows the change in specific power consumption in the period of five years of furnace operation.

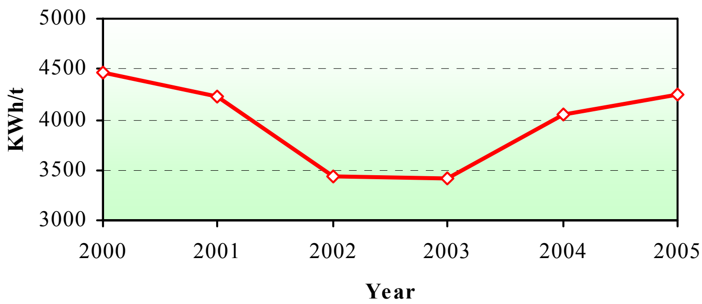


Figure 3: HCFeCr Specific Power Consumption

Chromium Unit Recovery which is the business of ferrochrome production also followed a favourable trend in tandem with both production and power utilization. A recovery of 89% was achieved in 2002 as the best performance of this furnace during its stable period.

Figure 4 below shows the recoveries recorded in the period under review. A visible deterioration of recoveries from 2003 to 2005 showing poor furnace performance.

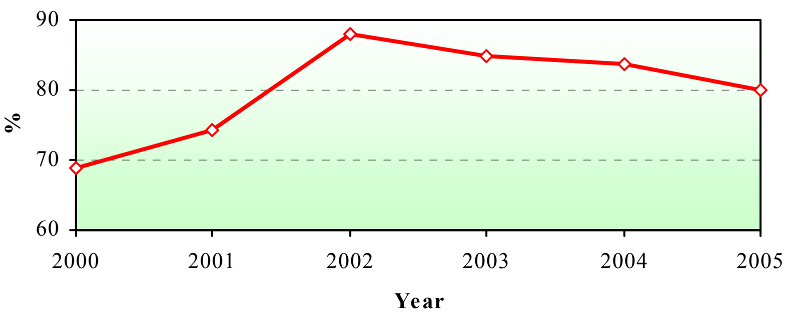


Figure 4: Chromium Recovery

3.2. Production Milestones

A few major land marks were achieved when the Furnace was at peak performance.

- A daily production of 210.8 tonnes per day was attained in 2002 breaking another one of 202.4 tonnes per day in 2001.
  This was a mega achievement on a furnace rated 31MVA whose maximum theoretical production is 143 tonnes per day.
- A weekly record production of 171.1 tonnes per day was attained with an all time monthly record of 146.7 tonnes per day, better than the designed production capacity.

4. FURNACE PERFORMANCE AND PHYSICAL APPREARANCE CHANGES

Figure 2 to 4 indicated a significant unfavourable shift on production, kwh/t and recovery from 2003 to 2005. This was a major signal flagging on the furnace performance to the effect that something was still not original on the furnace.

4.1. Shell Distortions

After the first 18 months of operation, the furnace base started lifting to about 300-400mm from the horizontal support beams.

The front section of the shell as an effect of the force on the base movement displaced about 600mm outwards together with tap launder. A view of the furnace from the top showing the new shell position as compared to the original position is shown in Figure 5.

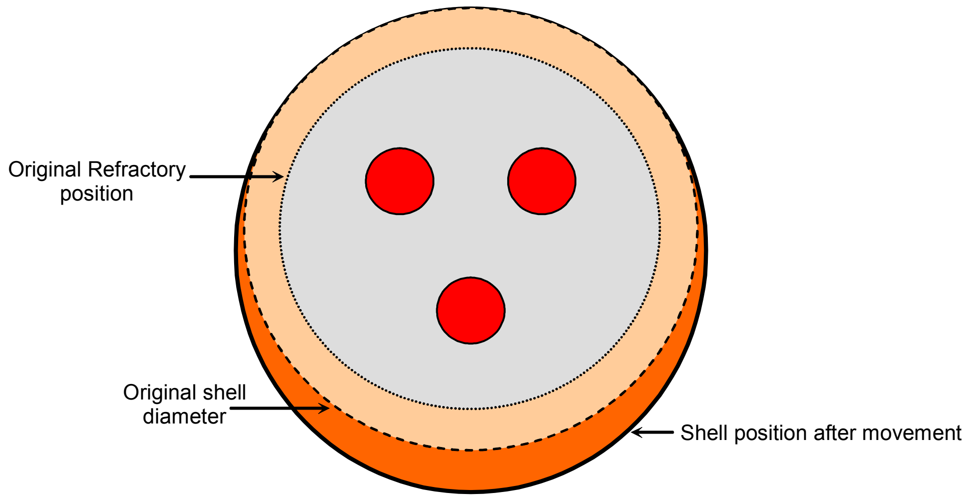


Figure 5: Furnace plan showing relative movement

The taphole lifted 400mm up and 200mm sideways to the right. Weak zones were created and the furnace shell started cracking vertically from the base upwards on either side of the taphole.

4.1.1. Immediate action

It was suggested to cut-off the bolts joining the furnace flange and the base plates to release the tension. After this, the base plate got to its original position but the furnace flange remained up leaving a 400mm gap exposing the refractory. A 400mm wide plate was rolled and welded to close the gap to protect the refractory.

Grouting of the Furnace was carried out each time when flames could be seen on the shell or hot spots. Further movement occurred intermittently increasing the distortion on the furnace.

4.1.2. Furnace distortion effects

Frequent furnace breakouts were experienced and furnace shell cracked. Welding of cracks and grouting continued as a short-term measure.

Production deteriorated at the peak of these problems and difficult tapping conditions prevailed. The movement of the furnace could have affected the PCD and furnace bath causing huge heat losses affecting the water reticulation pipework resulting in water leaks. There had to be major modification on the tapping equipment due to the movement of the taphole and the whole front section in order to circumvent alloy losses.

The availability of the furnace also reduced due to breakouts and frequent water leaks, these affected both power utilization efficiency (Kwh/t) and chromium recovery.

4.1.3. Furnace distortion source

The production performance was poor due to many disruptions to the extent that it became unacceptable. An investigation was carried on the furnace, particularly on refractory design to actual furnace lining.

Refractory type and quality was verified correct. There was no provision for expansion gap. Bricks were lined or put against the shell on the sides and therefore during expansion they pushed out the shell in all directions but more severely around the taphole area as this was the weakest area of resistance as a result of activity related to the tapping operation. Expansion also between the bricks themselves was not provided which created even a bigger force on the shell.

5. THE DECISION TO RELINE/REBUILD

Poor furnace performance and frequent disruption of production became the main consideration to reline or rebuild the furnace. A decision to reline could not be simply reached because of the expensive nature of such a job and the furnace had only operated less than 5 years compared to the 8-10 years life expectancy.

5.1. Patch The Existing Lining, Replace The Distorted Section Or Reline?

Relining a furnace is a disruptive activity on cash flow and other activities as a result very detailed consideration was given to all possible alternatives.

The alternatives identified were:

- Repair the furnace as and when a lining area failure occurred.
- Effect a partial repair on either side of taphole area.
- A full reline of the furnace.

The option of patching the furnace as and when a lining failure occurred was considered to be a temporary solution and not very conducive to the continued reliability of the furnace as a result of the possibility of untimely disruption of the operation. This was in any event, the modus operandi whilst the planning of a meaningful repair was being pursued. Effecting a partial repair either side of the furnace taphole area was a very feasible option.

A full reline of the furnace was the best idea because it minimized the risk on further operation but the time and cost of the project was prohibitive since the Company was operating a single furnace.

6. FURNACE PARTIAL REPAIR

On further assessment after a partial reline was agreed upon, the available resource could only allow a 43^{O} either side of the taphole instead of the 60^{O} but was a good enough repair.

6.1. Dig Out

The shell area around the taphole was removed to cover 43^{O} on either side of the shell to facilitate the furnace digout and replace the refractory. Digging was done into the feed zone on this part of the section.

Figures 6 to 8 below shows the process of furnace digging:

Figure 6: Furnace digging in progress

Figure 7: Left side Cavity after brick movement due to distortion

Figure 8: Right side Cavity after brick movement due to distortion

6.2. Metallurgical/Structural Observations

The right side of the taphole had suffered severe refractory movement as was seen by distorted brickwork. On the left side, the movement left a big cavity between the shell and some refractory bricks.

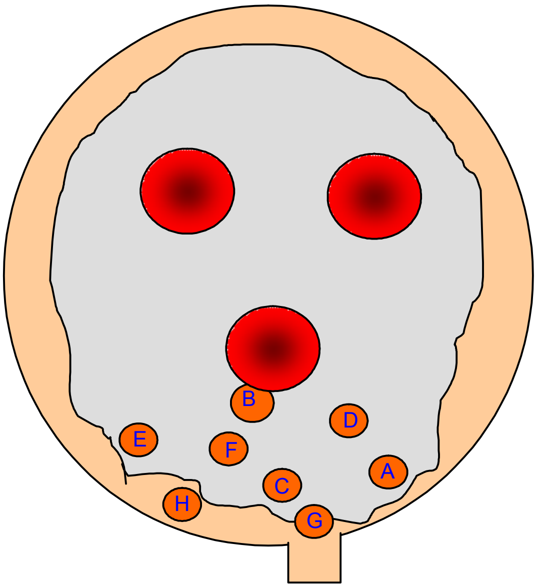
Figure 9 below shows the analysis of samples taken at different and related points during furnace digout. A mixture of fused, semi-fused and unfused raw materials were observed together with metal and slag.

The expansion of bricks and the subsequent distortion left weak zones in the refractory lining, these were observed as the alloy and slag were found between layers of distorted refractory bricks which areas caused breakout.

The hearth remained intact in spite of all the movement experienced by the furnace shell and particularly around the taphole.

6.3. Refractory Lining

Refractory lining started after wide consultations with refractory consultants and experienced Furnace lining companies. The following recommendations were to be adhered to as the lining of the furnace was being done:



Samples Analyses

	Cr_2O_3	FeO	MgO	CaO	Al_2O_3
A	51.6	29.1	14.2	1.26	9.1
C	35.6	29.0	15.7	1.01	16.8
E	44.8	27.6	12.0	1.12	15.1
G	12.4	6.5	34.7	2.12	20.8
H	15.6	26.0	16.4	2.76	15.0

	Cr	Si	P
B	57.1	4.86	0.043
D	65.7	3.31	0.041
F	48.4	3.97	0.041

Figure 9: Analysis of Material from Dig-out Area

(i) A 75mm gap was left between the new refractory and new shell.
(ii) An expansion gap of 2mm between the bricks was left.
(iii) New taphole block installation to the original position.
(iv) A ceram GT90 carbon based material filled the 75mm expansion gap.

Figure 10 to 12 shows the structure of the furnace as the work progressed to partially rebuild the furnace.

Figure 10: Initial stage of Refractory Installation

Figure 11: Final stage of Refractory Installation

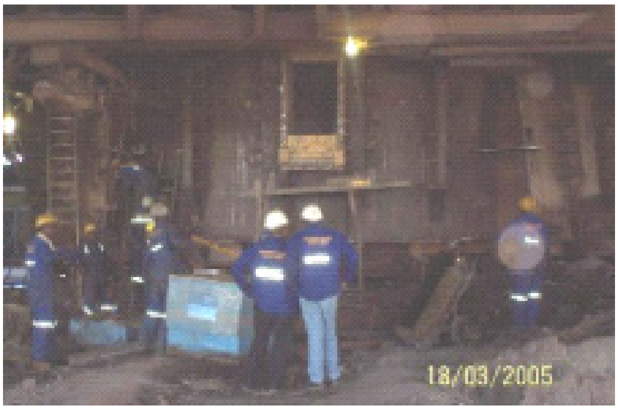


Figure 12: Complete Refractory and Shell Installation

Figure 13 below shows the new shell in position relative to the old one.

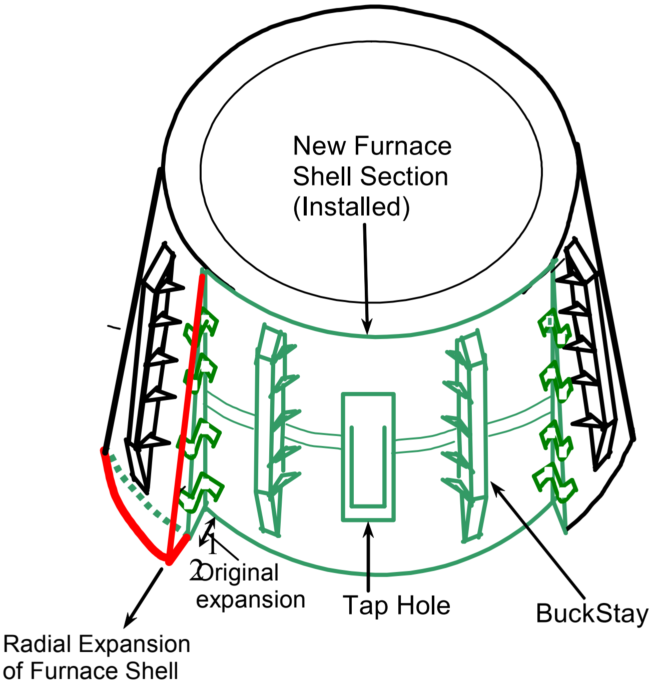


Figure 13: State of Furnace after repairs

The furnace base cooling was also modified in the process and furnace side walls in front of the taphole had cooling mechanism installed. The repair lasted 14 days.

7. PERFORMANCE AFTER THE REPAIRS

There was a significant shift on furnace output, kwh/t and recovery after the furnace repairs.

The Graphs, Figure 14 – 16 shows the comparison of production, chromium recovery and specific power consumption six months prior to the partial repairs and six months post the repairs.

Production improved by 5622 tonnes for a period of six months (36.6%) after furnace repairs. The chromium recovery significantly shifted to close to 90% after the furnace partial rebuild.

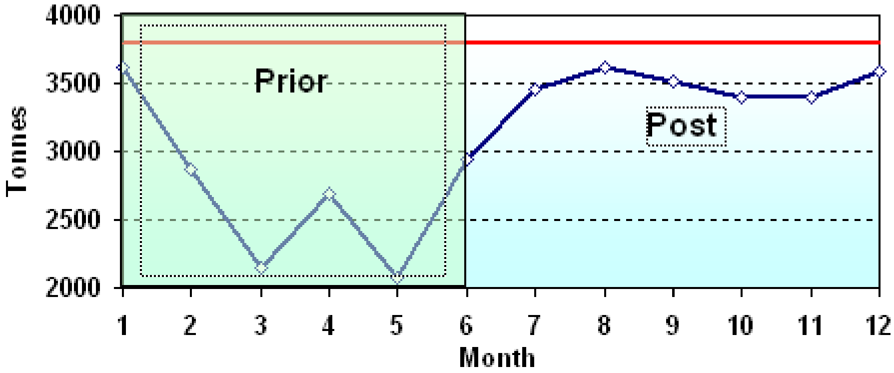


Figure 14: Production

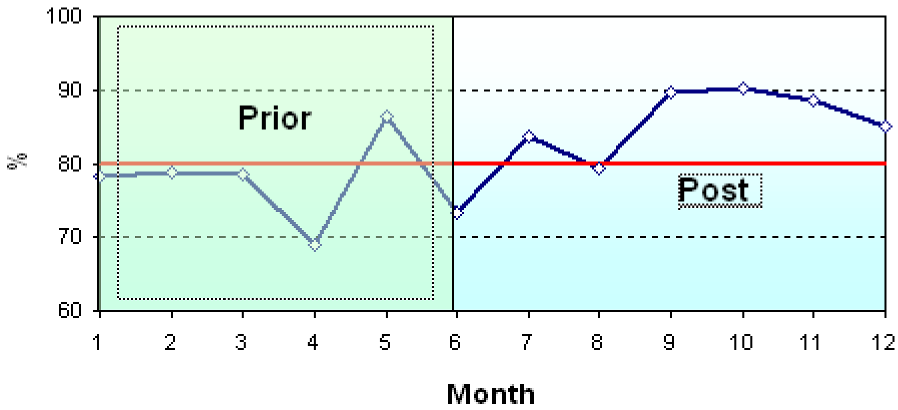


Figure 15: Chromium Recovery

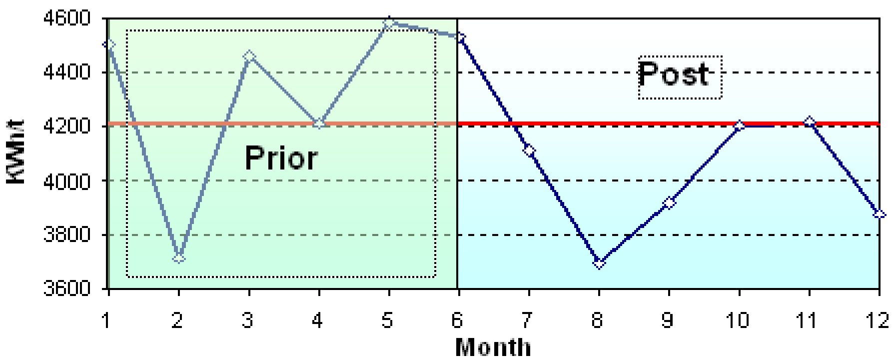


Figure 16: Specific Power Consumption

8. LESSONS LEARNT

The following points summarise the major learning points that emanated from the problems on the 31 MVA Zimbabwe Alloys HCFeCr Furnace.

- Refractory lining fundamentals cannot be overlooked and the details must be thoroughly checked.
- The furnace performance and life can be affected by such small details during the refractory furnace design to the effect of business closure if such a premature failure cannot be correctly addressed.

- The correct expansion between the shell and the bricks themselves must be calculated accurately. Expansion gaps must be installed all the times during furnace lining in relation to the type of the refractory.
- There could have been a merit to quickly arrest the problem as it started, however the pressure on production and cashflow constraints distracted the events. In future it is important to weigh out the benefits today as opposed to rectifying the problem and avoid high production losses which translates into improved revenue.
- Grouting the furnace on areas of hot spots may aggravate shell distortion due to increased expansion after filling up some gaps in the refractory.

9. CONCLUSION

Refractory lining is by far one of the most important features in furnace design to ensure good performance over the life span of the furnace whilst a good return on investment is achieved.