

CB11 - Challenges in Operation of Rodding Induction Furnaces in Ma'aden

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Abstract

The Ma'aden Rodding Shop induction furnaces have had a consistent performance over the years despite increased production due to amperage increase. However, several challenges and interruptions were encountered during the initial years of production with frequent stoppages of rodding production on furnaces due to:

- Improper operational control on the materials,
- Metal temperature control,
- Relining practices and relevant tools optimization for relining and measurements,
- Absence of digitalization to capture the real time data without any alarm system,
- Sinter programs based on the available raw material and design gaps to control the sinter curve at initial cycles,
- Absence of furnace planning system to cover all related activities of the furnaces, including scheduled preventive maintenance (PM),
- Failure to keep correct liquid level inside the furnace without affecting production.

These problems were addressed one by one. The outcome of these changes was seen immediately. Increased furnace life was achieved, and there has been almost no production loss due to service life of the furnaces during the last 7 to 8 years. This paper will cover our experience over the years with rodding shop changes and industry benchmark control of the rodding process.

Keywords: Rodding shop, Induction furnace, Digitalization, Induction furnace lining life.

1. Introduction

Ma'aden Aluminium (MA) is a joint venture between the Saudi Arabian Mining Company (Ma'aden) and Alcoa. Almost ten years after its establishment, Ma'aden Aluminium is now a fully integrated aluminium processing complex worth 10.8 billion USD.

The Alumina product from the Ma'aden refinery unit is processed in our fully operational 720 smelting pots, which are operated at 410 kA after amperage creep-up. The smelter was designed for 720 pots with an original pot amperage of (370-390) kA with an annual production capacity of (740 000 – 780 000) t/year.

The primary Aluminium is produced using the Hall-Heroult process with the consumption of Carbon blocks called anodes. These anodes are part of Rodded anodes as electrical carrying conductor in the electrolysis process. Rodded anodes are the final product of Rodding shop along with Crushed bath and Crushed butts. The Rodding shop primarily consists of major material handling units to recycle the spent butts from Reduction after the electrolysis process and mostly struggle with reliability issues due to the nature of process.

Apart from material handling and recycling, the prime function of Rodding is sealing anode blocks with the processed stems by pouring the liquid Cast iron at around 1485 °C. For melting

this Cast iron, 3-tonne Coreless Induction furnaces are generally used. Ma'aden Rodding has three units of Induction Furnaces to cater the daily requirement of around 55 tonnes of molten metal supply for sealing around 580 Rodded assembly as a final product for Reduction.

As a basic principle of Induction, an alternating electric current from an Induction power unit flow into a water-cooled copper coil (Figure 1). Electric current flowing in one direction in the induction coil creates an electromagnetic field that induces an electric current flow in opposite direction in the metal charge inside the furnace, producing heat that rapidly causes the metal to melt [1]. The copper coil is kept from melting by cooling water flowing through it. These furnaces operate at a nominal frequency of 250 Hz with output of 1500 kW.

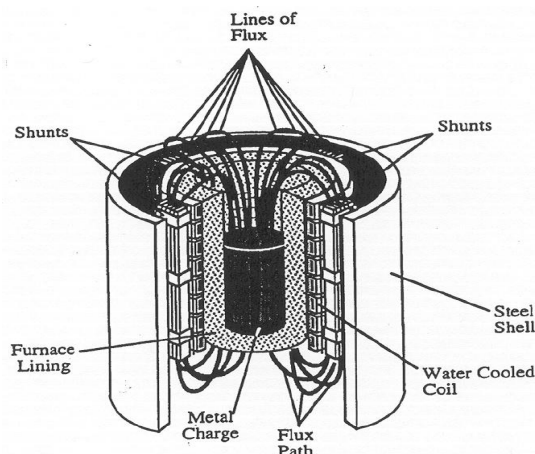


Figure 1. Typical induction furnace cross-section.

The focus of this paper is mainly on the Hot side (Induction furnace and Casting area) challenges and stabilization over the years of operations by implementing several modifications, industry best practices, digitalization, and data analysis methods.

2. Methodology

Hot side stability starts with stabilization of Induction furnace operating practices and stable life cycle to avoid safety risks associated with molten metal handling while ensuring longer lining life of the furnace for uninterrupted production.

The Ma'aden Rodding shop started-up in mid-2012 with the Hot side equipment at first with the fresh new stems for sealing. Initially, several challenges were faced on the hot side especially with the molten metal availability due to various Furnace issues. As per design, two furnaces should be in operation at a given time and one should be kept on standby for maintenance & refractory activities. However, often only one furnace was available, due to various reasons:

1. Frequent trips during sinter cycle
2. Metal pouring practices for casting
3. No control on the molten metal temperature
4. Sinter curve optimization
5. Quality of charge metal

2.1 Frequent Trips During Sinter Cycle

Sintering is the first step immediately after completion of relining activity and has a major impact on refractory life. It is very important to comply with the complete sinter cycle until completion of the cycle. During initial operations, observed sinter cycle got tripped almost every cycle either

at the beginning or at the end. At the beginning, this was due to malfunction either at the Thermocouple joints or at the cabinet plug (Figure 2). There were no options for physical verification of the actual sinter temperature inside the furnace. At the end of the cycle, sinter aborted due to design limitations of steel former where liquid metal forms at the bottom of furnace and starts melting which leads to sinter cycle abort and need to operate the cycle in manual mode (Figure 3).

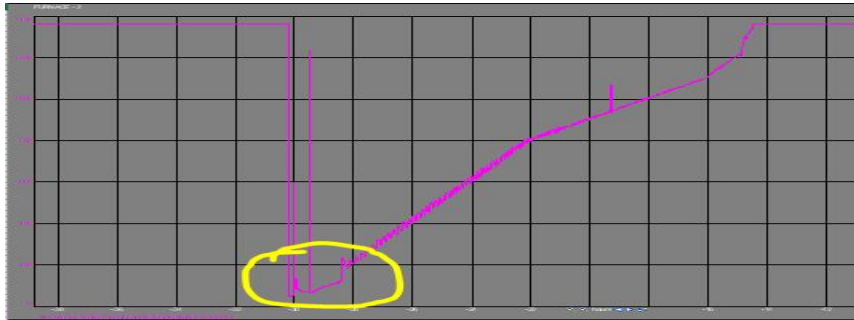


Figure 2. Sinter abort at the beginning due to high temperature.

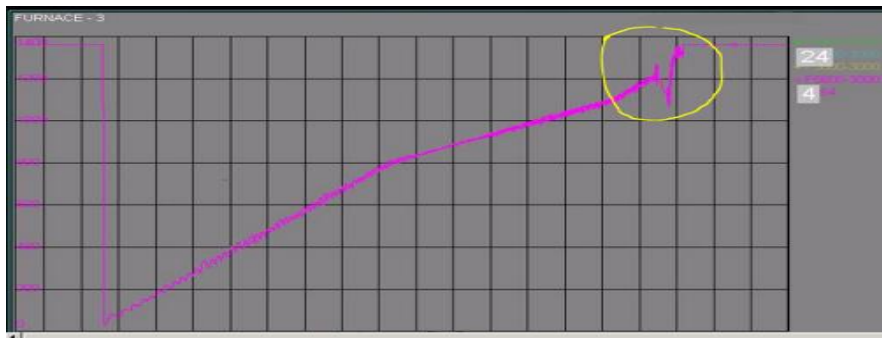


Figure 3. Sinter abort at around 1200 °C.



Figure 4. Molten metal leak due to premature lining failure during sintering.

We had occasions where due to cycle abort, the temperature increased abruptly and damaged the lining (Figure 4).

Sudden thermal shocks during sinter cycle or normal operation created severe cracks of the refractories and allowed molten metal penetration near the coil (Figures 5 to 7). It can be detected by changing Furnace parameters (water temperature), by the ground leak detector, or during the routine inspection on the furnaces.



Figure 5. Coil damaged due to molten metal leak during sintering.

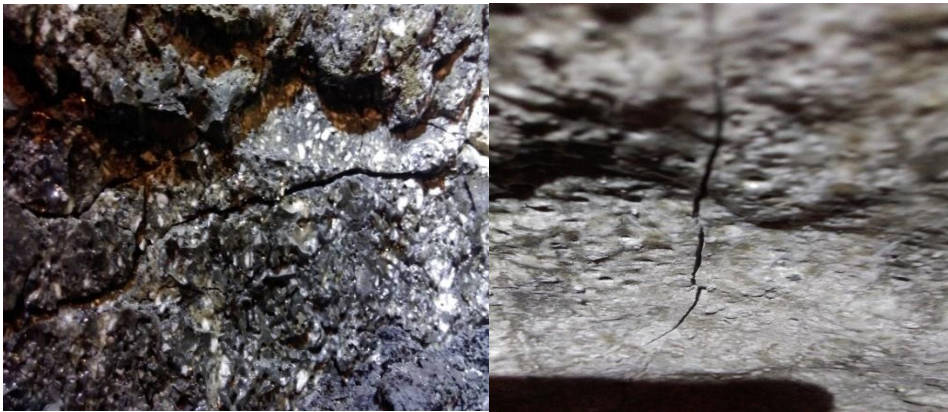


Figure 6. Cracks on the refractory lining.



Figure 7. Coil damaged due to molten metal leak during sintering.

Resolution:

Temperature verification was considered as one of the important steps during the whole cycle. The Melt-manager program was designed in to maintain the power input based on the measured temperature attached with the former cylinder. Any malfunction or connection issue leads to abort the cycle to protect the furnace. However, at the same time damages already started within few minutes before trip.

To overcome the situation as Melt-manager program not allowing us to modify the sinter curve with manual input of time based on pre-defined curve, some alternatives were considered for a trial:

1. An alternate temperature monitoring system through manual handheld device kept little at some distance from the furnace to verify the difference between auto and manual sinter temperatures.
2. A thermocouple protection tube was installed inside the former to protect the cable during the cycle and to avoid temperature malfunction.
3. The pre-defined sinter curve with an operator's checklist was issued to ensure monitoring the difference of both the temperatures and take necessary action if deviations from the program temperature are observed.
4. Pre-defined sinter curve with hourly break-up cycles to continue the cycle in case of sudden trip due to high temperature at middle level of cycle.

2.2 Metal Pouring Practices for Casting

Rodding Operational practices have a significant impact on the overall Hot side stability. The one major contributor considered here was the Furnace pouring practices to maintain the level of liquid metal during the melt cycle.

Apart from the upper lining crack, bottom erosion (Elephant Foot) was a common pattern observed during initial production (Figure 8). This erosion was due to continuous stirring of liquid metal on the lower portion of the refractory since two furnaces were in operation and liquid metal poured to ladles from each furnace for casting. Leftover metal kept at around (40-50) % level and fresh cast iron charged into it for next pouring which allows the liquid metal stirring at the same level during life cycle and eroded the refractory at faster rate compared to the top layers.

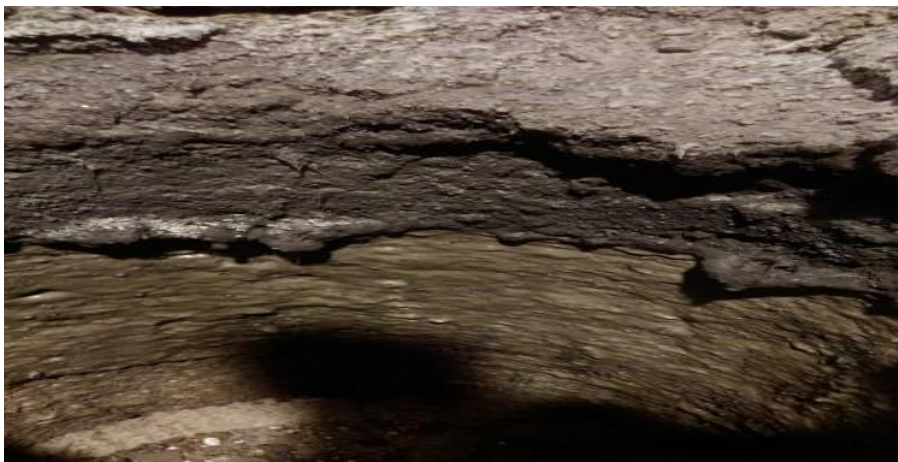


Figure 8. Refractory lining erosion by metal stirring (elephant foot).

Resolution:

A trial was conducted for the Hot area operations control with different pouring practices with the cast car. The objective was to avoid the type of failure on the furnace refractory without affecting the Rod shop production. As per initial discussion with Furnace operators and general consideration, keeping some molten metal inside the furnace was helping the Furnace operators for quick melting the charge metal and easy slag skimming, overall work-motion study considered to reach on win-win situation without affecting the Rodding productivity (Figure 9).

Four different possible scenarios were tested during trial:

- 2 Induction Furnace & 2 Casting Cars (each CC taking metal from each Furnace)
- 2 Induction Furnace & 2 Casting Cars (each CC taking from same Furnace)
- 1 Induction Furnace & 2 Casting Cars
- 1 Induction Furnace & 1 Casting Car

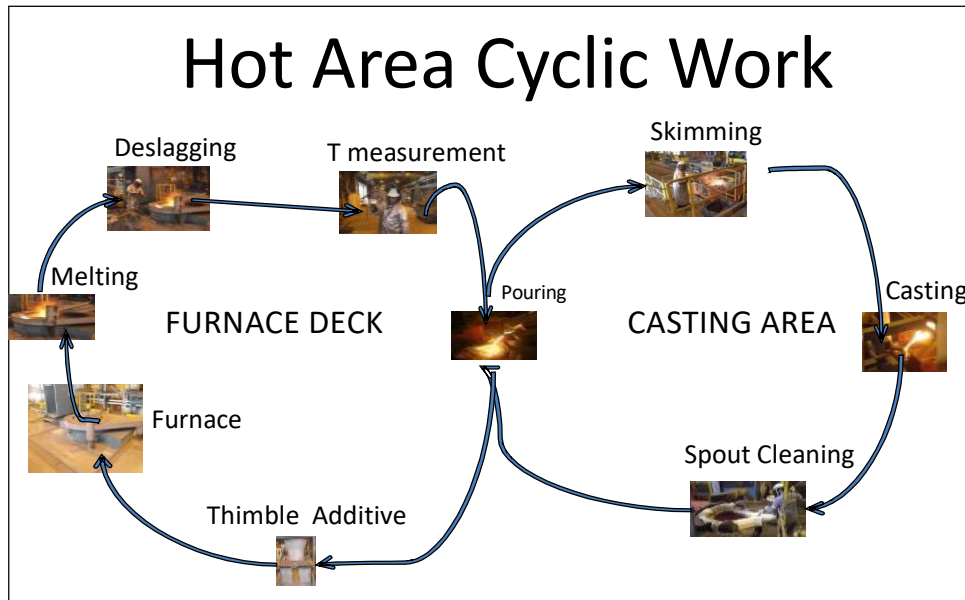


Figure 9. Hot area cyclic work-flow study.

Table 1. Various metal pouring scenarios (scenario 2 is the option chosen and still being followed)

Criteria	Scenario-1 2 Furnaces with 2 CC (each ladle from each furnace)	Scenario-2 2 Furnaces with 2 CC (Both ladle from same furnace)	Scenario-3 1 Furnace with 2 CC	Scenario-4 1 Furnace with 1 CC
Productivity (Assemblies/ shift)	336	410	308	249
Furnace Life	Faster erosion on bottom due to stirring movement	Increased life due to low erosion on the bottom	Increased life due to low erosion on the bottom	Faster erosion on bottom due to stirring movement
Remarks	Tight in terms of preparation as both furnaces should be ready at the same time to give metal to both CC at the same time, no options for Spout-top repair due to molten metal inside	Flexibility to prepare 1 furnace at a time while get ready the requirements before charging into empty furnace, easy for Furnace spout-top repair	Tight in terms of logistics and metal preparation as Furnace to keep ready before the next pouring	Easy to operate with low demand but can't continue

2.3 No Control on Molten Metal temperature

Uncontrolled liquid metal temperature during melting (higher than 1500 °C), before pouring, or during bridging is not only a safety risk associated with the furnace but also severely contributed to refractory deterioration (Figures 10 to 11) which could lead to multiple stoppages of furnace due to various faults. Figure 10 shows the trend of the furnace temperature(°C), as measured.

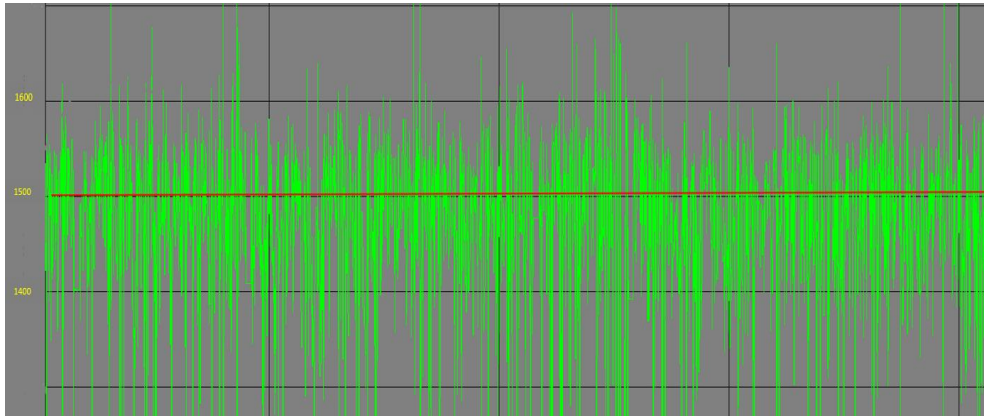


Figure 10. Furnace temperature(°C) measurement trends.

It was difficult to identify and track the temperature readings as measurement was done manually, using tempstik temperature indicators before pouring to Cast cars. The high temperature mostly got unnoticed without tracking and was only observed at the time of Furnace inspection with eroded condition, high furnace parameters, or damaged insulation sheets. This resulted in downtime of the furnace for repair and servicing.



Figure 11. Burnt insulation layers on high temperature.

Resolution:

Minor digitalization initiatives were implemented on each furnace to capture the metal temperature and displayed with an alarm once the maximum temperature was exceeded. An automatic temperature capturing system was installed. Tempstik probes for manual measurements were removed from the furnace floor to ensure that all the temperature data are taken by automatic measurement only. This automatic temperature sampling system was connected to a Programmable Logic Controller (PLC) server and linked to the daily reporting system. A high temperature alarm system was installed on the Furnace to avoid increasing the power input to Furnace by operators.

2.4 Sinter Curve Optimization

The Sintering curve plays a major role in the Furnace life consistency. Throughout the operational period, the sintering curve was continuously optimized to understand its impact and enhanced the furnace refractory life.

The original sinter curve started with preheating rate of 110 °C/h. The peak temperature was 1600 °C for holding. This was considered too high for the furnace refractory based on lining life results. Thus, lower peak temperatures were tested. The holding time at fusion period and the pre-heat rate were also modified (Figure 12)

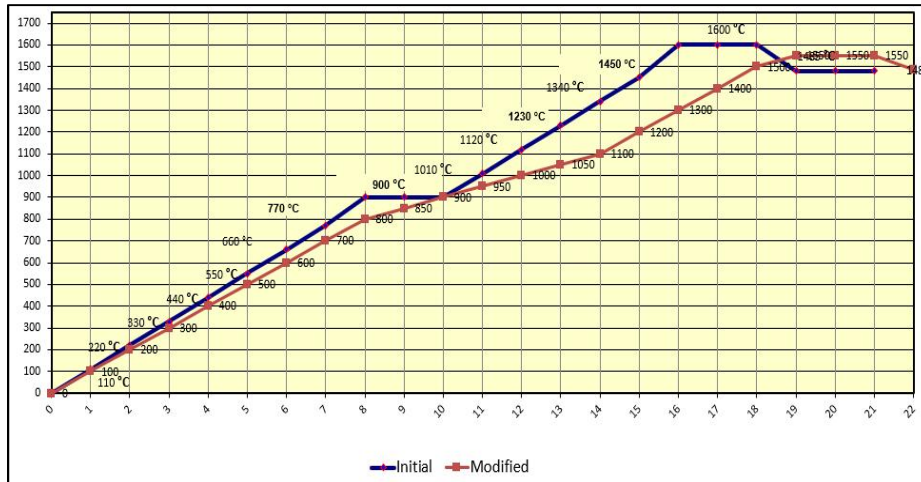


Figure 12. Initial vs modified sinter curve.

Table 2. Furnace life cycle timeline.

Start Timeline	Preheat rate (°C/h)	Holding temp (°C)	Fusion (800-1100 °C) duration (h)	Sintering duration (h)	Tonnage life (t)
Aug-12	110	1600	5	21	265
Oct-14	110	1550	5	21	414
Sep-15	100	1550	6	22	510
Jun-16	100	1530-1550	6	22	590

Resolution:

Several changes are considered on the sinter curve based on the different timeline with the changes on preheat rate, final holding temperature, fusion duration, and total sintering hours. Sinter curves can be selected based on the different ramming mass used for the lining of furnace and binder content present in it. It was important to minimize the fusion temperature to avoid any potential cracks, which was a very common observation with the initial cycles. Below is the improved life based on the modification on the sinter curve (Figure 13).

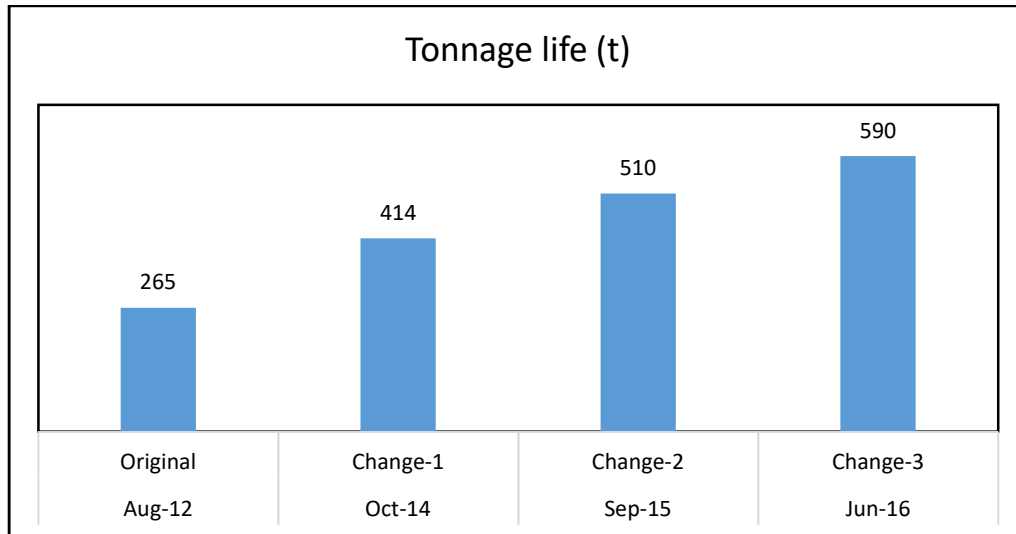


Figure 13. Improved life with sinter curve modifications.

2.5 Quality of Charge Metal

Recycled cast iron from spent butts is cleaned in the cleaning drum after the thimble press machine (Figure 14). Cleaning drum efficiency is directly linked to the impurity's removal from the recycled cast iron and the charge metal quality to the furnaces [2] Frequent lifter failure in the drum resulted in poor (low) retention time of cast iron and blockages on the discharge mesh. Furthermore, dedusting inefficiencies increased the fines content in the recycled metal. Impurities (mainly Sulphur) due to their nature attack the Silica refractory and generate excess amounts of slag at the end of melting (Figure 15).



Figure 14. Output of cleaning drum.

Resolution:

Cleaning drums are considered as one of the main equipment affecting cast iron quality. They were prioritized in terms of maintenance focus to improve cleaning efficiency. Some long term and short-term actions identified to maintain the cleaning efficiency of thimbles:

1. Modifications on the lifter design and material to increase the retention time of thimble inside the drum.
2. RPM monitoring and linked with PLC to confirm design parameter of rotation during operating cycle.

3. Routine cleaning of the mesh to remove the blockages for proper impurities elimination from the drum.
4. Periodic flow measurement to ensure the suction rate inside the drum to separate the fine particles from thimbles.

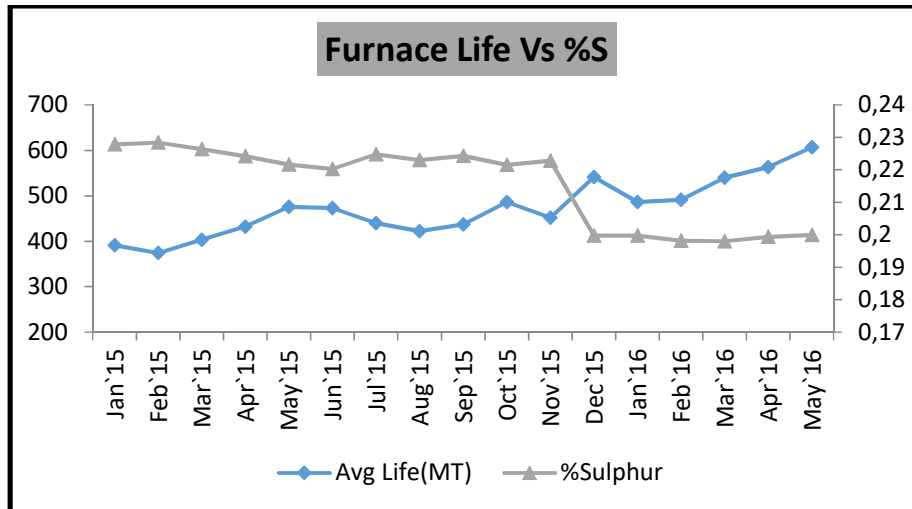


Figure 15. Correlation between the furnace life and the sulphur concentration in the metal (S% trial timeline of 2015 and 2016).

2.6 Lack of Furnace Planning

There was no proper Furnace rotation-plan existed to cover all Operational, maintenance and refractory team requirement. Rotation plan to arrange resources based on estimated operation cycle and scheduling of preventive actions well in advance. On many occasions, two furnaces were nonoperational at the same time. Thus, crucial planned activities on the running furnace had to be delayed. Consequences included:

1. Production loss due to furnace availability concern as two furnaces stopped almost near to the similar window for relining, including no scheduling for measurement or repair during normal operations.
2. Unnecessary usage of Furnace with molten metal inside during long shuts
3. Missed opportunities for furnace measurement, repair, and inspection due to improper scheduling.
4. Frequent skips of preventive maintenance activity as it was falling on the day when furnace was in operation.
5. Furnace availability interruptions on high temperatures trips especially during summer as high temperature water coming from cooling towers due to blockages on the fines. This water further blocked the heat exchangers on cooling line and affected the cooling of process. The tank water for the coil cooling is recirculating the same hot water in the line due to less cooling capacity and lead to Furnace trips.

Resolution:

Furnace rotation plan designed with inclusions of expected life cycle, furnace critical parameters, preventive maintenance activity, Furnace repair and measurement window with planned activities, cooling tower & heat exchanger cleaning schedule on the available window before problem arises, long term coil repair schedule etc.

3. Summary and Conclusions

Consistent operational performance was achieved from the hot side with stabilization of Induction furnace availability. The Ma`aden Rodding shop did not suffer any production loss due to Furnace service life since many years of Operation which achieved by gradual improvement over the years by implementation of all modifications (Figure 16). Sustained performance assures the safe practices with low hazards on the high-risk molten metal area.

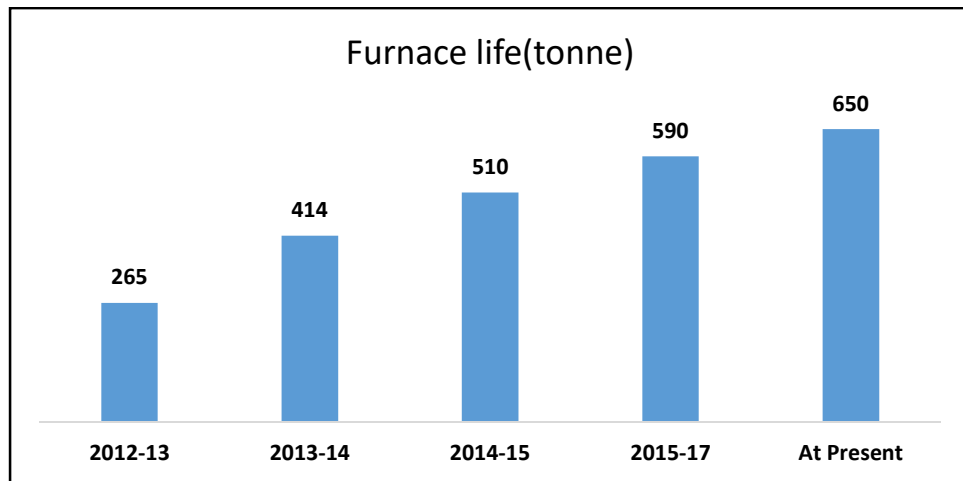


Figure 16. furnace life timeline, considering all different actions taken during the timeline.

Standardized work practices established based on trial results and Quality assurance drive emphasized the uninterrupted performance from Furnaces:

1. Ensured Furnace rotation plan including cast car ladles as part of weekly planning with all stakeholders and compliance on the agreed plan.
2. Daily monitoring of all critical furnace parameters captured and digitalized in system.
3. Periodic measurement and inspection of the furnace lining.
4. Stoppages of Furnace and ladle based on the agreed life cycle and measurement outcomes.
5. Furnace relining checklist for the relining services team and verification by Operation & Technical team
6. Furnace sinter process checklist with all mandatory instructions for the Furnace operators and verification by technical team.
7. Periodic water sampling and chemical dosing for all cooling tower and process water units. Regular blow-down based on the water analysis from the cooling towers.
8. Availability of run-out pits and emergency molds all the time as emergency back-up.
9. Alarm generation while exceeding the parameter specially the furnace temperature as warning and to shut off the power.
10. Compliance on standardized power requirement for all different process steps for better service life.

4. References

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