

## **ArcelorMittal Dofasco #2 Blast Furnace Stove Repairs**

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### **ARCELORMITTAL DOFASCO # 2 BLAST FURNACE STOVE REFRACTORY FINDINGS AND INNOVATIVE DESIGN AND REPAIR SOLUTIONS**

#### **Abstract**

This paper will discuss ArcelorMittal Dofasco's #2 Blast Furnace #5 Hot Blast Stove refractory findings and repairs completed in 2008. The significance of improving the refractory configuration, the installation methods, and the short turn-around time for the repair will be discussed. For this emergency repair there was no time to re-engineer the complete stove and get sufficient brick shapes.

An alternative repair using monolithic materials was successfully implemented to overcome these issues including the casting of a complete monolithic dome.

The first year of operational results, refractory thermal data and performance will be reviewed. Several innovative construction methods and new technology which have been implemented will be reviewed as well.

#### **Background and History**

No. 5 Stove is one of three stoves supporting the operation at #2 Blast Furnace. These small 20 foot diameter Silica design stoves were built in 1985 and operated for three years. During the 1988 reline #4 stove was found with a collapsed skin wall in the lower combustion chamber requiring a 27 foot high castable repair. The alleged expansion issues were resolved in the skin wall repairs of #5 and #6 stove by saw cuts in the skin wall of #5 Stove which extended from the lower combustion chamber to a height of 5 meters. Areas of #6 stove skin wall were replaced as required. The stoves were in service a total of 12 years, cycled in and out of service 5 times over a 23 year period before the 2005 reline. During the 2005 reline and subsequent inspection of the stoves, #4 stove was found with a breach in the lower combustion chamber wall. #5 and #6 stove showed no concerns at that time.

The design incorporated Silica brick in the dome and upper ring wall brick on the checker side. The Stoves were designed with two layers of silica brick in the combustion chamber walls, in both the inner wall and outer wall. This stove design also used low quality checkers up to the medium high temperature zone. The minimum quality checker in most stoves today is a 40% alumina. The stoves discussed in this paper

used a 32% alumina and a 35% alumina checker in the lower to medium temperature zone.

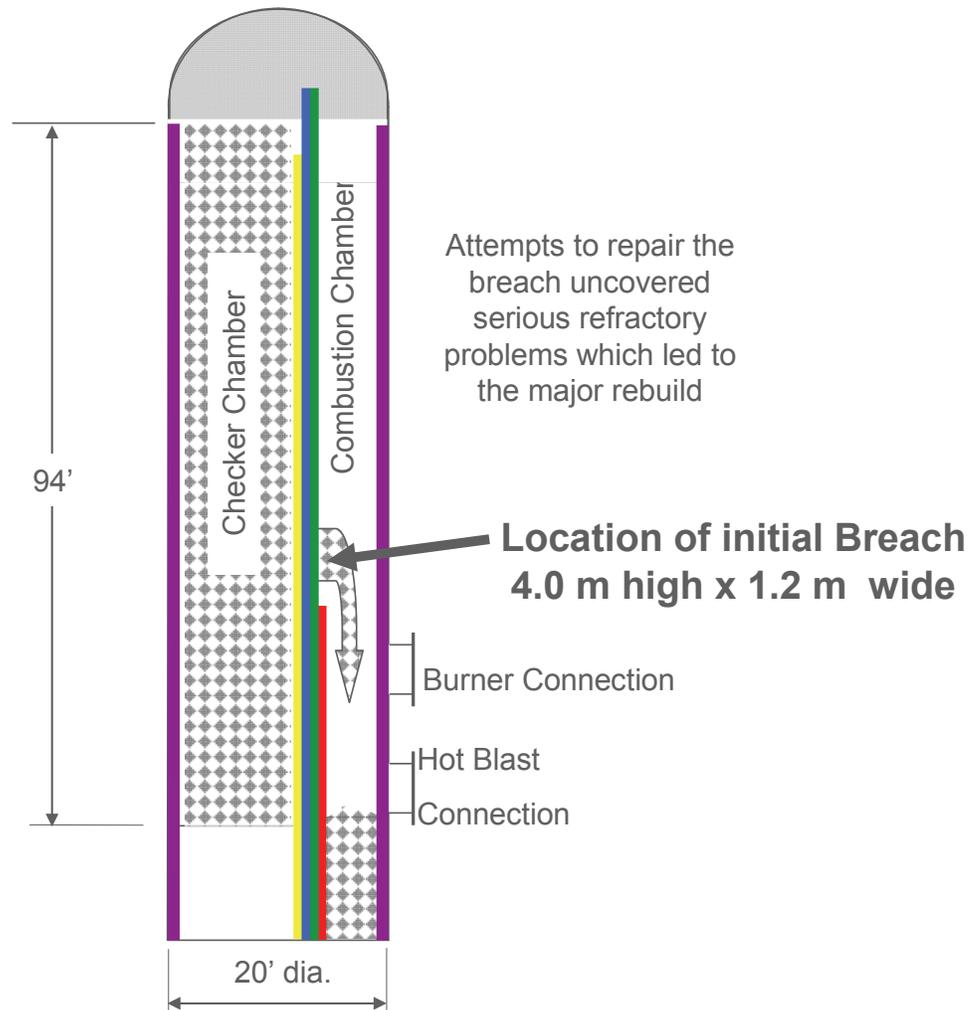


Figure 1 Stove Vertical cross-section with the damaged area

### The found damage and failure

On May 30<sup>th</sup>, 2008 operators at #2 Blast Furnace experienced problems with #5 stove: high pressure drop across the stove, the inability to maintain hot blast to the furnace and a large quantity of checker brick in the well of the hot blast valve. An emergency internal high temperature inspection of the dome was conducted the following day and the dome was found to be in the same condition as inspected June 5<sup>th</sup> 2005 prior to the start up of #2 Blast Furnace. Initial investigation into dome temperatures, stack temperatures and grid temperatures did not indicate any long term deterioration or any anomalies which is not in alignment with the finding of low quality checkers in the hot blast well. A decision was made to cool down the stove for further investigation.

On June 15, 2008 a camera was lowered into the combustion chamber well to locate the breach. A large collapse of the skin wall was noticed, approx. 2 meters in width at a height of 5 meters. A hole in the dog bone wall 1.2 meters by approx 4 meters high permitted the displacement of a large number of checker bricks. Open joints and vertical cracks in the skin wall were evident. Attempts to repair the breach uncovered other serious refractory problems which led to the major rebuild.



Figure 2: The hole in the partition wall

### **Root Cause Failure Analysis**

Overall assessment of situation can be attributed to certain features in the stove design. In hindsight the use of silica brick low in the combustion chamber was unsuitable for the mode of operation in which the stove was used. The lack of a fully gas tight partition wall allows for leakage of combustion gases thru walls resulting in the long term degradation of the partition wall. Evidence of insufficient thermal expansion allowances were seen throughout the stove.

The stoves operated a total of 12 years over the 23 year period following their relines. On five occasions in the life of the stoves at #2BF the stoves were cooled to ambient temperatures. These shutdowns were related to relines or extended downs for market demand. On these occasions, the silica passed through the critical

expansion/contraction temperature on cool down and then on heat up. Longitudinal cracking in the second layer, dog bone wall, provided evidence of the effects of this practice. Vertical cracking in the dog bone wall was first diagnosed as a design issue but contributing to the lack of expansion allowance is the belief that excessive vibration caused the existing expansion joints to pack with crushed brick inhibiting expansion of the brick. This lack of expansion caused severe forces to build up in the corners of the combustion chamber resulting in crushed brick.

Expansion allowance was an early issue with these stoves dating back to the 1988 repair. No.4 stove required extension repairs to its skin wall which were all attributed to expansion problems. As a solution to the neighboring #5 stove a decision was made to create the necessary expansion allowance by vertical saw cuts in the combustion chamber skin wall up to a height of 5 meters. The vertical saw cuts created columns of brick, without any interlocking system in between these columns.

Both skin wall and dog bone walls were weakened due to crack formation. Skin wall cracks developed due to thermal shock and cool down, dog bone wall cracks were formed due to lack of expansion allowance and because too fast a heat up. In the skin wall, saw cuts further decreased wall stability.

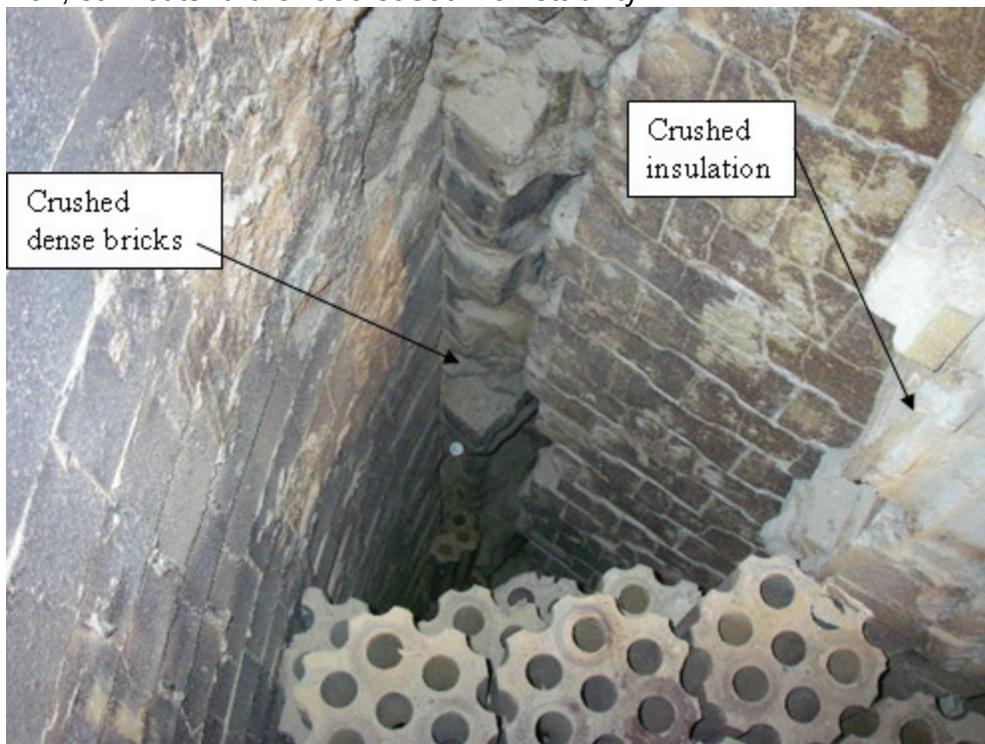


Figure 3: The crushed corners

Extended shutdowns of 24 hours plus in duration allowed the temperatures in the area of the combustion chamber to drop below the critical expansion point for silica brick. At these temperatures the silica undergoes a rapid expansion which is believed to have caused the refractory in the partition wall to deteriorate. The high gas volumes to meet the hot blast demand contributed to the vibrations. There were signs of water damage

in the stove which was attributed back to the demister being removed from the reline scope.

### The Repair

The Stove was demolished in sections; the initial hole in the combustion chamber was thought to be locally repaired at first. Further exposure of the damaged area revealed that the damage was much more substantial than was initially visible from within combustion chamber. After the checkers had been removed up to the bottom of the visible hole in the wall it was clear that the majority of the walls were in bad shape. The expansion system for the silica walls in the combustion chamber entailed a special expansion system under the Dome by means of a so called "Xmas tree" construction. This expansion system had failed over the years and had blocked the silica wall expansion under the Dome. When the hot face wall was removed in the combustion chamber this expansion system in the Dome support wall became visible, it became clear at this point that it was impossible to support the Dome safely and it was decided to remove the Dome. The Stove was demolished with the exception of the grids and about 2/3 height of the ring wall on the checker side. The decision was also made at that time to remove all silica brick from the design.

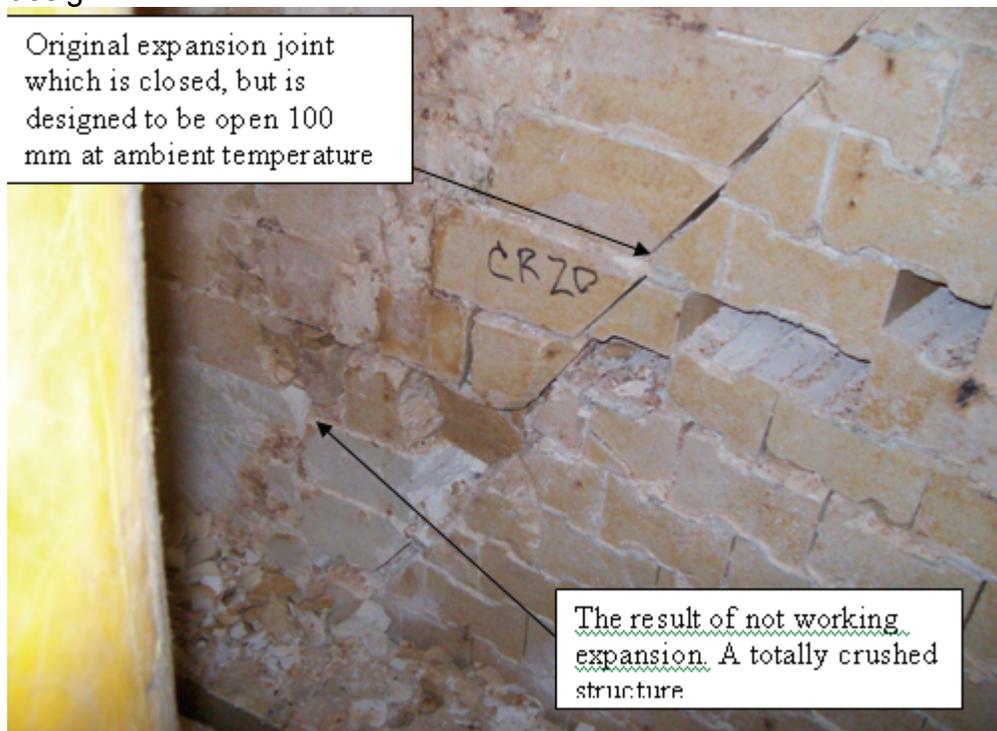


Figure 4: The compromised Xmas tree expansion joint design under the Dome

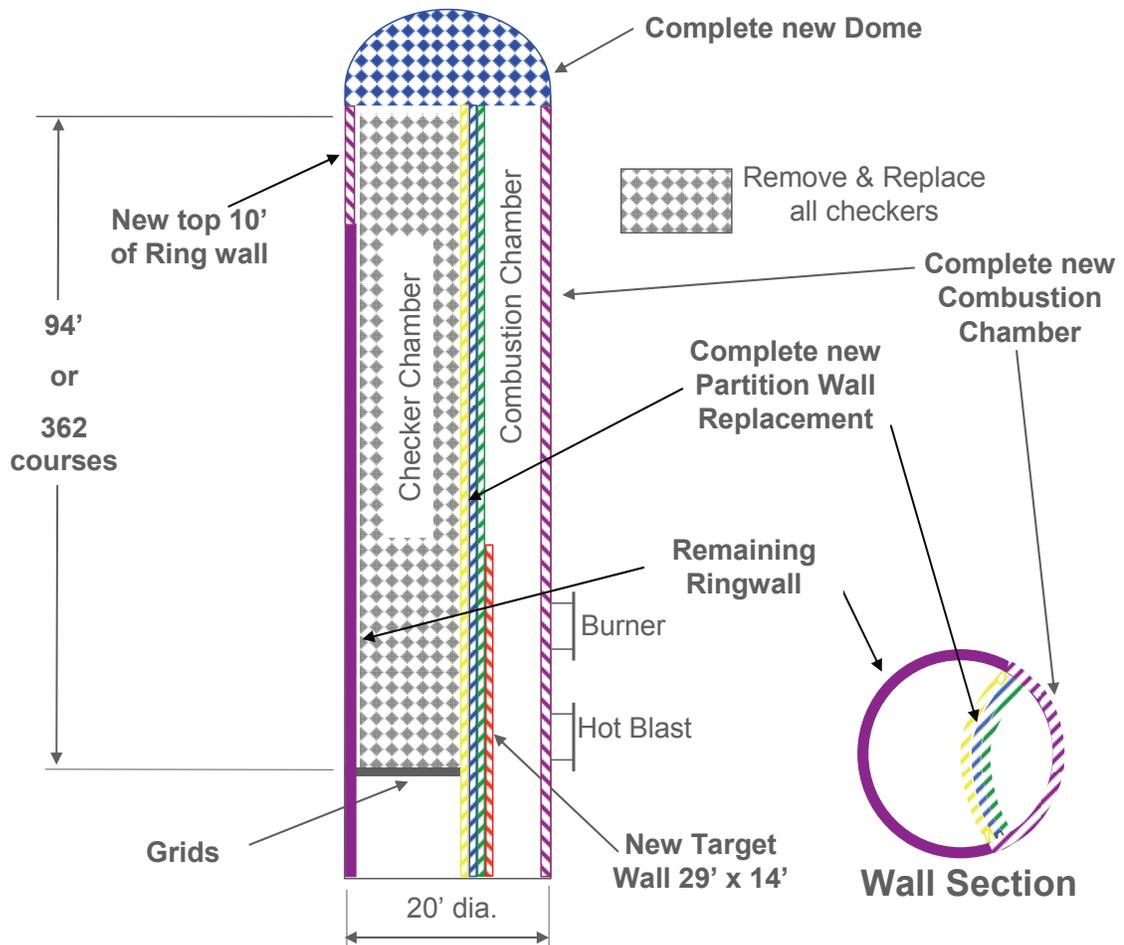


Figure 5 The repaired areas

### Materials and Construction Techniques used. “Fit for purpose”

Mounting challenges with respect to schedule, cost, availability of refractories and more importantly design, provided the opportunity for innovative solutions. Traditionally Hot Blast Stoves are built using bricks only. This involves a large amount of special brick shapes. These shapes have long lead times; also these bricks require designed moulds that are necessary for the pressing of these shapes but add to the delivery time. Another reason bricks are traditionally used is the height of the Stoves, the height puts a long-term pressure load at high temperatures on the bricks. This load under temperature makes the refractory material deform under pressure, temperature and time. For this reason mainly creep resistant alumina bricks are used for the high temperature zones in a Hot Blast Stove. In particular, bricks made from andalusite are higher in thermal shock resistance.

To overcome these issues the special shape bricks were replaced with cast in place sections. The material used in each location was selected to deal with the process condition and working loads of each of these sections. The monolithic solution contained

mainly andalusite materials in the high load areas of the stove. Higher up in the Stove more mullite type materials have been used. In these locations the weight loads as well as the thermal fluctuations are much less than in the lower combustion chamber.

The special shapes for the corners as well as the expansion joints were mainly cast in situ. All the openings like the Burner Inlets and Hot Blast Outlets were all cast in situ in separate sections allowing differential expansion for each wall. The complete inner combustion chamber was cast in situ from the bottom to the top of the walls. The materials were mixed at ground level and pumped up into the Stove.

All insulation brick walls were built the traditional way, the checkers were removed and sorted and marked per quality. The shortage was from the damaged section and was replenished with new checkers. This allowed lowering the lower quality checkers to the bottom section of the Stove thus upgrading the quality of checkers specific to its elevations. The world wide search for this specific checker brick was not successful. Only one alternative shape was found to be acceptable and with a higher replacement ratio 15,000 of these checkers were air freighted from Poland to meet the schedule.

The nature of this repair required engineering services on site working closely with the project team. With the majority of the refractory removed, detail drawings were required for every step of the way so that fabricators, suppliers and contractors could apply the new design requirements and apply the methodology required for a monolithic installation.

The original design included an insulating wall on the checker side of the partition wall. Due to differential expansion and the forces of differential checker and wall movement this layer was mainly crushed and fractured. In the new design this wall was eliminated and replaced with an insulation wall in between the partition and combustion chamber wall. Incorporated in the design was the need to provide a gas tight barrier between the combustion chamber and the checker chamber. See Figure 6 showing the installation of stainless steel sheets within the wall design. The final design also included an increase in the combustion chamber cross sectional area to assist in reducing stove vibration.



Figure 6: Gas Tight Barrier in Combustion Chamber wall.

The main partition wall on the checkers side was built using standard stove key bricks; the middle expansion joint was formed using pre-cast shapes. This wall was the main form used together with the checkers as the form for the castable inner combustion chamber walls. An integral part of the construct ability was the use of a preformed acrylic expansion joint.

Rigid enough to support a castable pour, this design also provided the necessary tongue and groove interlock. The material's thermal properties and ignition characteristics made it a very good expansion joint selection. An estimated 700 sq. feet of this acrylic sheet was burned out during heat up of #5 Stove with no visible emissions.



Figure 7: The Castable Combustion Chamber

To further improve on the schedule the Dome was constructed independently from the walls. The Dome Hot Face was cast in place in sections using an “igloo type” form. The Dome was designed with a large Tongue and Groove construction to lock in the different sections but the key was designing for the required independent expansion of the different sections. Extensive laboratory work to develop a suitable refractory material was required to suit this particular application and support this project.

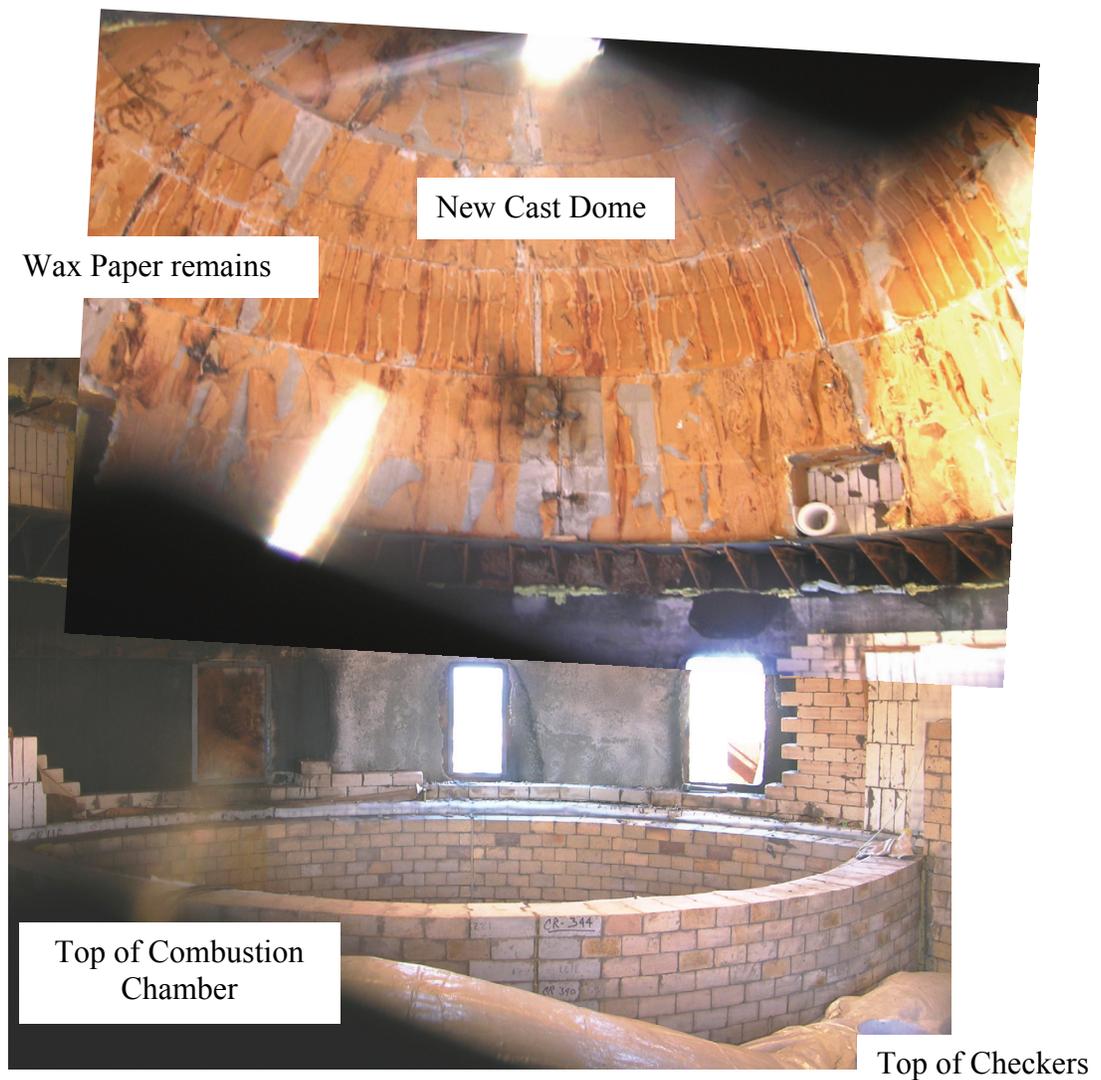


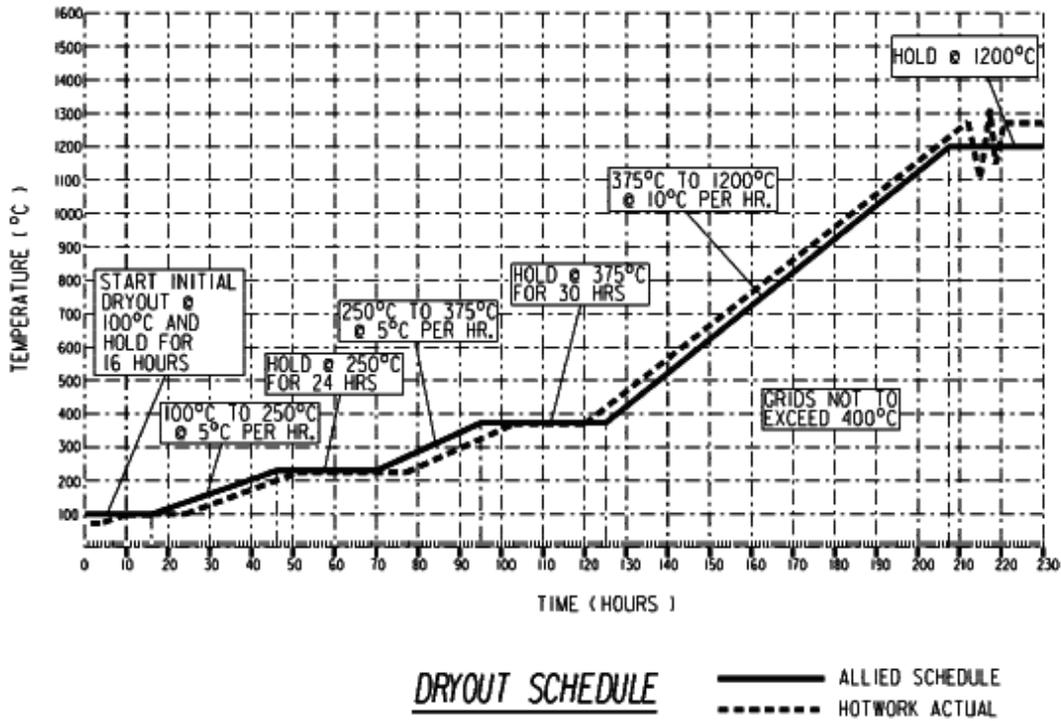
Figure 8: The cast dome supported and the Walls coming up.

When the walls came up to meet the Dome the underpinning construction was removed in sections and the walls were bricked up to support the Dome. This construction approach required the design and installation of a platform capable of supporting 60 tons of castable while workers below continued to lay brick and install checkers.

### **Dry Out & Heat Up**

The monolithic combustion chamber walls, target walls and dome required a specific heat up schedule. Hot face and cold face thermocouples were embedded in the castable in key locations during construction to ensure a controlled and thorough dry-out. Dome thermocouples are typically used to control the heat up rate and schedule. The high readings in thermocouples located in the lower combustion chamber required that they become the control thermocouple for heat. After temperatures reached 375°C in the schedule and based on other thermocouple readings, the control thermocouple was moved back to the dome for the remainder of the heat up. The significance of this is that the previous heat ups of #5 stove, #4 & #6 as well, likely experienced the same

temperature issues during heat up in this area of the stove where the silica brick begins. This is further evidence that silica brick was used too low in the combustion chamber given the use of the stove.



**Future Risks**

In late October 2008, #5 stove was successfully brought back on line and has been performing to expectations ever since. There has only been one hot spot identified in the regular infrared thermograph program that required grouting to resolve.

Summary - Average	Units	#4 Stove	#5 Stove	#6 Stove
# Cycles	-	82	80	79
TOB	min	70	85	78
TOG	min	145	135	136
Dome Temperature at End of Gas Cycle	°C	1296	1306	1294
Dome Temperature at Start of Blast Cycle	°C	1279	1273	1272
Stack Temperature at End of Blast Cycle	°C	77	87	78
Stack Temperature after 5 mins of Gas Cycle	°C	92	89	96
Stack Temperature at End of Gas Cycle	°C	331	296	338

The failure mechanism seen in #5 Stove has started to occur in #4 and #6 stove. In July of 2009 #4 Stove was removed from service to repair a breach in the combustion chamber wall, exact location experienced on #5 stove. Unfortunately the extent of the damage included the loss of a large amount of checker brick. The temporary hot repair

was performed externally using strategically placed engineered nozzles, core drillers and a gunnite crew who had the services of a high temperature camera to provide visual direction. Visual inspection using the high temperature camera also uncovered #6 stove in the early stages of failure. In December of 2009 similar hot repairs were performed to #6 Stove to stabilize the combustion chamber wall and maintain the availability of the stoves until such time as it makes economic sense to reline.



Figure 9: #6 Stove Combustion Chamber wall and corner failures

High temperature camera visual inspections are ongoing to monitor the status of these stoves.

### Conclusions

- Process data did not show any anomalies or long term deterioration of the stove until it was too late. High temperature visual inspections seem to be the only means to validate the condition of the stoves.
- A cross functional team approach between the ArcelorMittal Dofasco, the refractory supplier and contractors proved to be an excellent team effort.
- The monolithic construction enabled us to build a Stove without the many special brick shapes traditionally used for a Stove. The monolithic partition wall has proven to be much more gas tight compared to the traditional brick wall.
- When a catastrophic stove failure took place innovative techniques and solutions effectively overcame traditional brick delivery issues.
- The repaired stove has met all process expectations since it has been put into operation.
- Technology has allowed us to do repairs to extend stove life which were not possible 10 years ago.

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