In-depth Analysis of Thermal Profiles during Industrial Dry-out of Low Cement Castable

Yong M. Lee[1], Kurt Johnson[1], Sanjay Kumar[2]
[1]ArcelorMittal Steel, Global R&D, East Chicago, USA, [2]ArcelorMittal Steel, Burns Harbor, USA

ABSTRACT

Low cement castable is prone to steam spalling due to low permeability during dry-out. Many contribution have been made to understand the dewatering behavior of low cement castable and ways to avoid steam spalling. Practical questions about heating rates and holding time were raised during industrial application. The current work will present in-depth analysis of temperature profiles of low cement castable during large-scale industrial dry-out and compare them with laboratory studies.

1. INTRODUCTION

Low cement castable has been widely used in reheat furnace hearth applications because of its good mechanical properties at elevated temperatures. Improvement of mechanical strength at elevated temperatures has been achieved by replacing large amounts of calcium aluminate cements with fine alumina powders. These fine alumina powders reduce porosity and improve high temperature mechanical properties. Fine alumina powders, however, complicate the dry-out procedure because fine alumina powders reduce permeability significantly. Steam spalling often occurs if moisture is entrapped in pores and expands during dry-out to a point exceeding the refractory critical strength [1-10]. Steam spalling is so powerful that it could affect massive areas of castable.

An investigation was performed for an incident of steam explosion of low cement castable which occurred during a large scale industrial application in an effort to establish countermeasures [11]. A critical temperature range was established to mitigate the risk of steam spalling. Three distinctive dewatering regions were found in large samples. Among three regions, the rate of dewatering was the largest between 500°F (260°C) and 700°F (371°C). A slow heating rate can be implemented in industrial application to eliminate explosive spalling between 400 and 700°F for this material. During industrial application, the following practical questions were raised about heating rates and holding periods.

- Which is more efficient step for dry-out, slow heating rate vs. holding period?
- What happens during holding period?

The current work will present in-depth analysis of temperature profiles of low cement castable during large-scale industrial dry-out and compare them with laboratory studies.

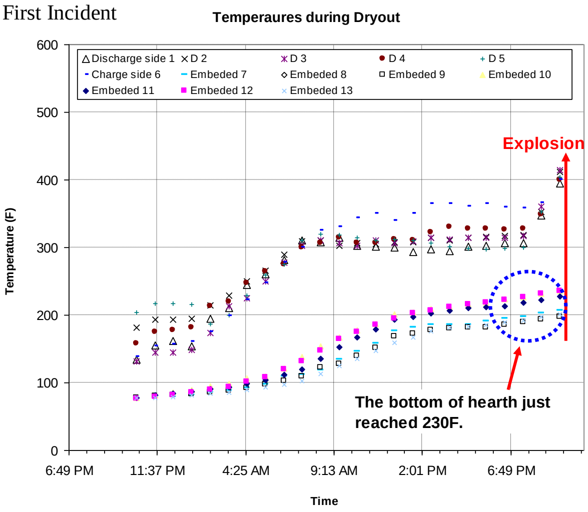
2. TEMPERATURE PROFILES DURING HEARTH DRYOUT

Industrial dry-out temperature profiles are very essential information to understand dewatering process of large scale castable. Since steam spalling occurs in very rare cases, it is difficult to accumulate industrial data. Whether a steam explosion occurs or not, temperatures from different locations are very essential to understand the dewatering process in castables. Several cases of dry-out will be discussed.

Incidents of steam explosion

Temperature profiles were obtained from two incidents of steam explosion and are shown in Fig. 1. The furnace, sub-hearth, and differential temperatures are summarized in Table 1.

First Incident



Second Incident

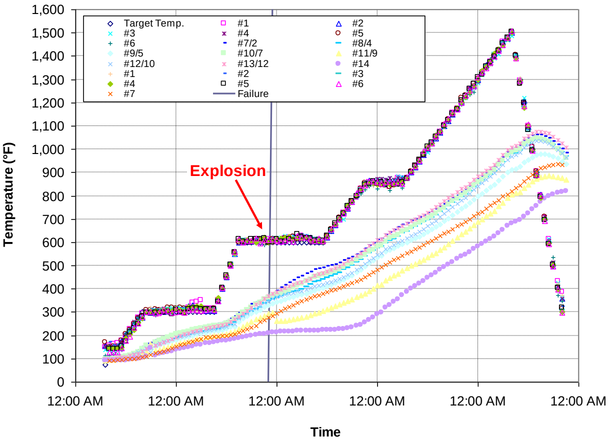


Fig.1: Temperatures of furnace and sub-hearth during dry-out.

Tab. 1: Temperatures of furnace and sub-hearth for explosive spalling incidents.

Incident	Furnace	Sub-hearth	ΔT between furnace and sub-hearth
1	400°F (204°C)	200-230°F (93-110°C)	170-200°F (94-111°C)
2	600°F (316°C)	210-380°F (99-193°C)	220-390°F (123-217°C)

The first incident of explosive spalling occurred at 400°F furnace temperature, which is lower than active dewatering region. The heating rate was 50°F/hour. The second incident of explosive spalling occurred at 600°F holding period just after 50°F/hour heating period. Comparing to the first incident, the second incident of explosive spalling was very obvious because it occurred in active dewatering region with high ΔT. It was concluded that high heating rate would contribute to both incidents of explosive spalling. Lower heating rates in the range of 15-25°F/hour have been adopted in the critical dewatering region to eliminate explosive spalling.

Successful dry-out

Examples of two successful dry-out will be discussed. Thermocouple locations are important to provide various thermal responses during dry-out.

Dry-out of Plant A

The concept and details of dry-out in plant A are as follow:

- Lower heating rate such as 15°F/hour was used in the critical region and a higher heating rate was used after the critical temperature region.
- Control thermocouples were located close to the top ceiling of furnace.
- Other thermocouples were installed on the surface of hearth and between hearth and sub-hearth.

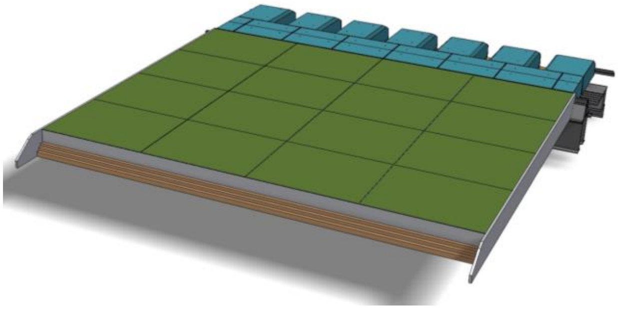


Fig. 2: Schematic drawing of Plant A reheat furnace hearth

The schematic drawing of reheat furnace hearth is shown in Fig. 2. The locations of various thermocouples are shown in Fig. 3.

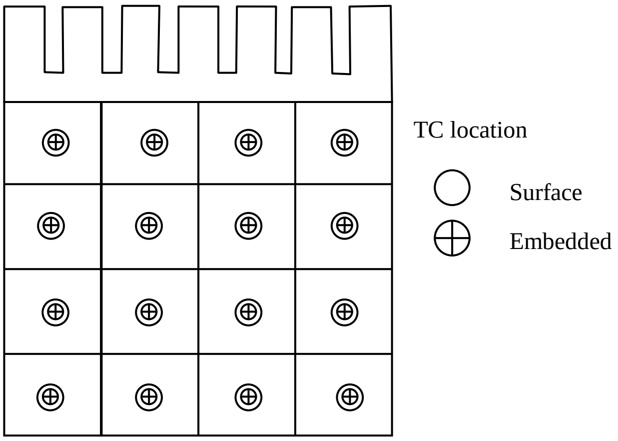


Fig. 3: Thermocouple locations

The temperature profiles of dry-out are shown in Fig. 4. It is observed that the target temperatures are close to soak zone temperatures and slightly higher than the hearth surface temperatures. The thermocouples of soak zone are located on the ceiling of furnace.

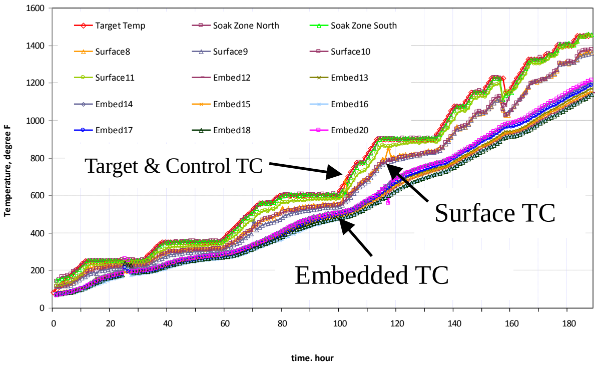


Fig. 4: Temperature profiles during dry-out in Plant A

Dry-out of Plant B

The concept and details of dry-out in plant B are as follow:

- Lower heating rate such as 25°F/hour was used in the critical region and a higher heating rate was used after the critical temperature region.
- Control thermocouples were located close to the hearth surface.
- Other thermocouples were installed on the surface of hearth and between hearth and sub-hearth.

The schematic drawing of Plant B reheat furnace hearth is shown in Fig. 5. The locations of various thermocouples are shown in Fig. 6.

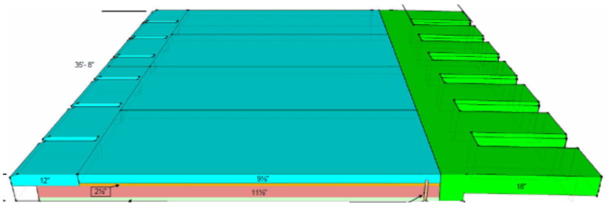


Fig. 5: Schematic drawing of 0.241m hearth and 0.292m sub-hearth (10.89m width x 14.50m length)

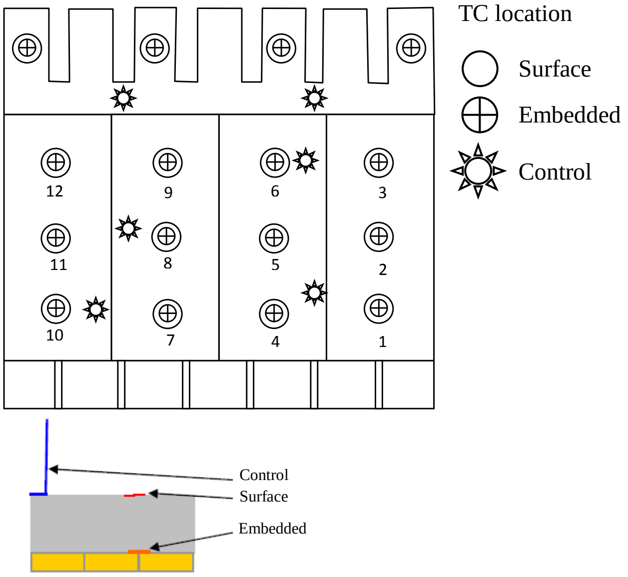


Fig. 6: Thermocouple locations

The temperature profiles of dry-out are shown in Fig. 7. It is observed that the target temperatures are very close to the hearth surface temperatures. These results were anticipated since the control thermocouples are close to surface thermocouples. The temperatures of embedded thermocouples ranged from 30°F to 150°F less than target depending on thermocouple locations. It is thought that this variability results from the burner locations. This suggests that extra effort should be required to install enough thermocouples to monitor temperatures during dry-out.

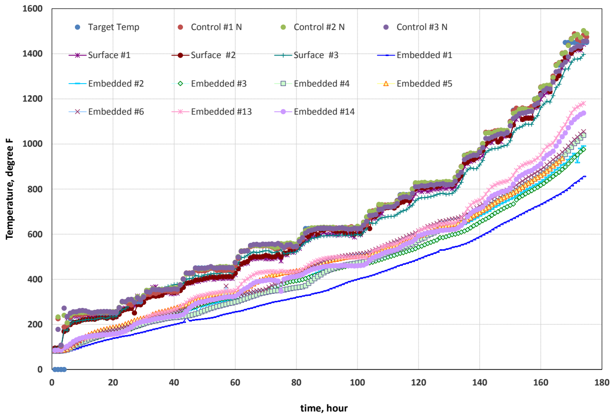


Fig. 7: Temperature profiles during dry-out in Plant B

3. DISCUSSION

The previous studies show that a critical region in dry-out schedules ranges from 400°F (204°C) to 700°F (371°C) in furnace temperatures for these refractory materials. Active dewatering in large scale LC castables occurs between 500°F and 700°F and completes mostly beyond 700°F. As shown in Fig. 4 and 7, the dewatering is considered to be completed when the surface temperatures of hearth castables reach 800°F. Once most of dewatering is completed, the heating rate could be increased to accelerate the dry-out procedure. To better understand the two successful dry-outs, the industrial data are simplified as follows.

- Surface and embedded temperature data are averaged.

- The middle internal temperatures of hearth castable are estimated using the following relation.

Middle internal temperature = Surface temperature – (Surface temperature – Embedded temperature)/2

Dry-out temperature profiles are drawn again up to 800°F and shown in Fig. 8. The findings are:

- Internal temperature of hearth castable increases faster in heating periods than holding periods.

- Holding periods are not effective to increase internal temperature of hearth castable since internal temperature rises very slowly.

- The holding periods at 250°F and 350°F are not considered effective because internal temperatures are not high enough to initiate dewatering.

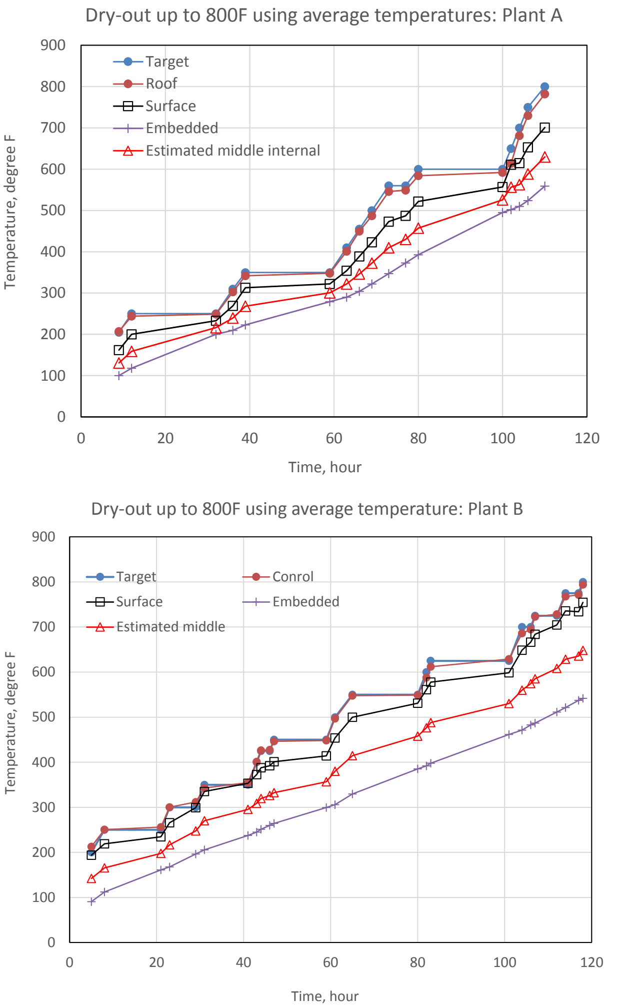


Fig. 8: Simplified plot using average temperatures and estimated temperatures in the middle of hearth castables

Temperatures of 230-250°F (110-121°C) has been widely used to dry out small scale castable samples. In cases of large scale castable, the pressure buildup in castable pores raises the evaporation temperature for water, as shown in Fig. 9.

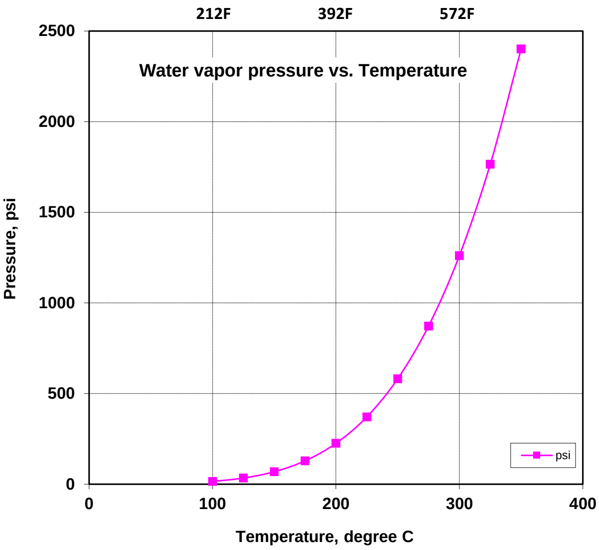


Fig. 9: Water vapor pressure vs. temperature using Antoine equation

Considering active dewatering range of 500 to 700°F, the surface temperatures and estimated internal temperatures of hearth castable are summarized from Fig. 8 and shown in Table 2. It is very interesting to point out that surface and internal temperatures are very similar even though each dry-out case happened in different plants. Both plants used similar type of low cement castable, but the manufacturers were different. It seems that physical and thermal properties of the two castables are very similar.

Tab. 2: Surface and internal temperatures of hearth castable at 500°F and 700°F during dry-out in Plant A and B.

	Plant A		Plant B	
Target Temp	Surface	Internal, Estimated	Surface	Internal, Estimated
500°F (260°C)	423°F (217°C)	373°F (189°C)	454°F (234°C)	380°F (193°C)
700°F (371°C)	615°F (324°C)	563°F (295°C)	649°F (343°C)	560°F (293°C)

4. CONCLUSIONS

An in-depth analysis of temperature profiles of low cement castable was investigated during large-scale industrial dry-out. Industrial dry-out procedures typically contain several holding and heating periods.

The heating period increases the internal temperature of hearth castable faster than holding periods. Holding periods are not effective to increase the internal temperature of hearth castable since internal temperature rises very slowly. The holding periods at 250°F and 350°F are not considered effective because internal temperature does not reach high enough to initiate dewatering. Low temperature holding periods could be shortened or replaced by slower heating period.

Internal temperatures of hearth castable are estimated from surface temperatures and embedded sub-hearth temperatures during dry-out. During active dewatering between 500°F (260°C) and 700°F (371°C), the internal temperatures of hearth castables range from 373°F (189°C) to 563°F (295°C).

The temperatures of embedded thermocouples are varied from 30°F to 150°F depending on thermocouple locations. These temperature differences would result from the burner locations. It is also recommended to install enough thermocouples to monitor temperatures of large castable area during dry-out.

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