Pusher Furnace Bottom Side Tearing

at ArcelorMittal Indiana Harbor 84” Hot Strip Mill

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Introduction

Hot Strip Mill Pusher Furnace design dictates that the slabs are pushed across a series of water cooled skids and onto a solid hearth after which they are extracted from the furnace. The action of sliding across both surfaces causes defects on the bottom side of the slab which are commonly referred to as furnace tears. These tears can vary in size and severity. The furnace tears then get rolled over in the Hot Strip Mill, trapping scale beneath the surface. Worst case scenario: the tears result in an embedded lamination which pops out of the surface of the finished coil. These tears are objectionable to the customer and especially detrimental to line pipe customers since they can reduce the pipe wall thickness to below the minimum tolerance. Detection of the tears with surface inspection systems after the Finishing Mill can prove difficult since most bottom side hot mill inspection systems are positioned just ahead of the coilers and the surface has had time to scale over. This paper will discuss the use of a bottom side roughing mill camera to detect these tears prior to finish rolling. It will also describe alarming criteria based on the camera images and the reactions to these alarms to resolve the issues in real time. Also, a glimpse of the diagnostic journey to discover the root causes of furnace tears will be provided.

Background

The layout of the 84” HSM is illustrated below with the camera positioned between R2 and R3 roughing mills. The R2 Camera is a greyscale line scan camera fitted with a near-infrared bandpass filter. This filter blocks all visible light, and utilizes the infrared from the steel bar as its illumination source. Differences in temperature on the bottom slab surface determine how much light the camera detects. Images are captured and are classified by both an automatic classifier as well as visual validation by a qualified user. Tears are classified as to severity and location along the slab length. Prior to the use of the R2 Camera “send back slabs” were utilized to determine furnace condition. The bottom surfaces of unrolled slabs
were examined after extraction to determine furnace tear position and severity. Send back slab examination provides only a small data set of defects as opposed the R2 Camera - which captures image data from each and every slab produced on the Hot Strip Mill.

When reviewing R2 Camera images, two versions are displayed. The normalized version is processed only to bring the average greyscale to a consistent amount (in the event the image is too bright or too dark). This image is utilized by the automatic classifier to detect and identify defects. The embossed version of the image takes the normalized image and applies a filter to highlight the contrast differences. This helps better identify anomalies on the slab to the human eye. The embossed images are reviewed by the qualified user to validate the auto classification.

Example R2 Camera images showing both the normalized image and embossed image are shown below:
The position of the tear along the slab length is recorded and stored in a database. This information is then used to determine the exact location within the furnace where the tears are occurring. Combining laser position data from within the furnace with the R2 image of the slab allows a map of the hearth to be built illustrating where all of the tear positions originate within each individual furnace.

Example of Furnace Hearth Quality Map showing furnace tear positions:

Defined patterns emerge upon examining the hearth maps derived from the R2 Camera images. In the example above the tearing was most prevalent on both the heads and tails of the slabs. Furnace tear patterns change with the life of the hearth. Hearths just after rebuild have more tears clustered in the center of the furnace. Hearths with over a year of wear have the tears clustered around the heads and the tails of the slabs. Reviewing past data confirmed this distinct pattern and its relationship to age of
the hearth. It appears that hearth wear is a major factor in determining at exactly what location along the slab length the tears would occur.

Periodic laser scans of the hearth yield topographic contour map images of the complete surface of the hearth as shown below. The highest elevations on the hearth are shown in red; the lowest elevations in blue. These contour maps reveal that major wear is occurring as a result of the ends of the slabs dragging the hearth in the quarter positions. This then results in a slab shape which, when pushed onto the extractor piers, loads the piers at the slab ends - where the tears occur.

Because laser scans are 3D measurements consisting of millions of data points, cracks, open joints, and buildup imaged with a laser scan can be dimensioned and catalogued. Below is an example of a “puddle” of buildup documented via the laser scan. This information helps determine root causes of buildup formation over the furnace life cycle. Wear patterns over time for all surfaces of the furnace are also documented via the laser scans.
The Furnace Hearth Maps and laser scans are used as an indicator on where to look for the source of the tearing. Scale buildup was found on those piers that corresponded to the location of the tears on the Furnace Hearth Maps. There was a direct connection between the tear on the R2 Camera image, its location on the Hearth Map, and scale nodule buildup in the pier area as seen in the pictures below.

After the nodules are removed from the pier the R2 Camera images no longer show furnace tears in that area. The nodules then reform in the same area and the tears return after several days of operation. When the piers are examined on the subsequent downturns the nodules which had previously been removed reappear in the same locations. The graph below shows the cycle between nodule formation and removal of nodules on each outage, as represented by furnace tears seen on the R2 Camera images. With clean piers at the start of the rolling campaign tears are low and gradually increase as the nodules rebuild.
The nodules are composed of iron oxides - mostly magnetite and hematite. The nodules adhere to the refractory and can only be removed with great mechanical force. Removal of the nodule often results in damage to the refractory as the bond between the nodule and refractory is greater than the mechanical strength of just the refractory itself. The image below is a nodule that broke off at the refractory beneath the point where the nodule formed.

The mode of nodule formation is a combination of oxide (scale), temperature, oxygen, and compressive force (slab weight). Excessive oxygen in the furnace exit area from the constant door opening, combined with the temperature and load of the slab, cause nodules to form on the piers.

**Furnace Tear Tracking**

As mentioned previously, all of the furnace tear data is stored in a database classified by the severity and the location of the tear within a coil. This data is used for three main purposes:

- Remediating the problem areas
- Alarming the Operators of repetitive marks
- Alerting customers to known defect locations
Remediating Problem Areas

The data has shown the pier area (the area surrounding the extractor slots) is where 90% of the nodules form and where the majority of furnace tears originate. These are the areas where nodule buildup must consistently be removed using a proprietary method which can be performed when the furnaces are still firing.

Refractory material trials for the pier area are currently underway in search of a durable self-cleaning product. Experimental results from trials of higher vs. lower alumina materials indicate that the lower alumina products have been moderately more successful in resisting nodule formation. Pier “rail” trials using ceramic vs. alloy material are currently being done— in addition to testing different pier rail configurations. Additionally, a parting agent coating to prevent nodules from adhering to the piers has been used. Typical grouts have been used to fill in cracks in addition to a self-leveling material to fill in micro-cracks. To date we have not found a suitable product that significantly retards nodule growth.

Operator Alarms and Reaction Plan

In late 2014, the R2 Camera images and a classifier developed by the ArcelorMittal Global Research Department was employed to alert the Operators when repetitive tears within a specific location in an individual furnace are occurring. The classifier identifies the severe tears and an alarm screen tells the Operators when they have exceeded a specified threshold. The screen indicates which furnace is in an alarm condition and at what location the tears are being made. The Operators then have a reaction plan to implement in order to resolve the issue. The reaction plan steps include positioning the slabs to try and move off the problem area as well as shutting down the furnace and removing the nodule buildup. In the example below there is a tear on the tail end of the slabs on piers 7 and 8. By charging the furnace to the west (toward the head end) this tear could be eliminated on all but full length slabs.
Throughout 2014 the 84” Hot Strip Mill furnace tear performance has improved significantly through use of the R2 Camera. Furnace tears and their locations within the furnace are identified and alarms are sent to the Operators to resolve repetitive tears in real time. The attached graphs illustrate total furnace tears have been reduced by 40% and severe furnace tears have been reduced by 65% over the course of the last 12 months.
Customer Feed Forward

The location of furnace tears is recorded within the R2 Camera database and the position of these tears in the final product is calculated. Critical customers are supplied with the position of the tear for inspection purposes. The customer then determines whether the defect needs to be rejected or can be reprocessed and made acceptable. This feed forward process has a number of benefits: it limits the liability to something less than a full coil, it reduces the number of missed detections, and it protects the final end user of the material from liability in the finished product. In some cases, customers have installed tracking screens which tell them the exact position of these tears as the material processes through their facility.
Conclusion

The ArcelorMittal Indiana Harbor 84” Hot Strip Mill has a camera which is used to detect furnace tear defects by capturing an image of the bottom surface of every slab. The camera images are reviewed for severity and location of the tears and this information is stored in a database. The database is then used to determine problem areas within each of the furnaces. Scale nodule buildup is the main reason for furnace tears at Indiana Harbor’s 84” Hot Strip Mill. Nodule buildup is removed on a regular basis but returns - often in the same areas. 3D laser scan models of the furnace are used to help identify wear patterns and weak points in hearth construction.

Trials are being conducted to determine if there are refractories that are more resistant to scale nodule buildup. These trials also focus on possible coatings that can be applied to the refractory to act as a parting agent making nodules easier to remove. Alarm screens have been developed to alert the Operators when a repetitive tear exists. The Operators have reaction plans to resolve issues with repetitive furnace tears. Implementation of the reaction plans has resulted in significant reductions in furnace tears throughout the last 12 months. Data from the image database is also used to supply customers with approximate locations of these defects in finished coils. Customers use the location information to assure they send the best possible product to the end user.

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References
