Maximization of Steel Ladle Free Open Rate by Using Shop-Specific Production Parameters

This article will demonstrate how Nucor Steel–Berkeley's shop operating parameters and specific process routes were used to increase ladle free open rate, resulting in less ladle burn opens and improved quality.

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Introduction

Nucor Steel–Berkeley

Nucor Steel–Berkeley is located in the southeastern United States near Charleston, S.C. The facility began casting and rolling material in November 1996 with a typical annual melt of more than 3 million short tons. Nucor Steel–Berkeley produces both sheet and beam products out of one meltshop and operates two independent DC electric arc furnaces (EAF) with an average tap weight of roughly 170 short tons. These EAFs feed a four-station ladle metallurgy furnace (LMF) with two sets of AC electrodes. Berkeley operates a two-tank degasser for grades requiring ultralow carbon and nitrogen specifications. Two continuous casting machines (CSP) feed a 7-stand hot mill for sheet products and a 4-strand caster is used to produce beam products. A fleet of 20 ladles is utilized with ladles used for beam production being of a different brick design than CSP products. Six horizontal ladle walls and two vertical preheaters are used to maintain ladle temperature during operations. Ladles are typically stirred with argon through two bottom porous plugs.

Ladle non-free opens (NFOs) can be detected by various methods: A specific delay time between opening the ladle and visual confirmation that steel is draining from the ladle; if oxygen or other means are used to force steel to drain from the ladle; or some combination of time and abnormal intervention. In any case, an NFO is typically not considered a normal operating event and should be treated as a disruption to normal operations. More importantly, an NFO typically requires some sort of manual intervention which can have quality impacts on the final product. The purpose of this article is to explain some of the variables that may cause NFOs based on findings at Nucor Steel–Berkeley with the hope that the findings could be used to help avoid NFOs and improve overall quality.

Best-in-class free open rates could be considered >99% (<1% NFOs). While this is a practical goal, in a shop like Nucor Steel–Berkeley with roughly 20,000 heats opened at the caster per year, even a 1% NFO rate is 200 heats per year. Zero NFOs should be the goal.

Root-Cause Investigation

Nucor Steel–Berkeley began a formal approach to reduce NFOs after a particularly low free-open-rate year. That is not to say activities were not ongoing to improve NFO rate prior to this project, but a more aggressive approach to reducing NFOs began at this time. A team consisting of caster operations, refractory operations and process engineering was put together with the expectation of decreasing NFOs. The multidisciplinary team was chosen to represent areas where improvements could be implemented quickly. The first steps undertaken by this team were to evaluate NFO heats from the caster perspective by watching videos of NFO heats. The following thoughts were used to guide

root-cause analysis after viewing caster NFO videos:

- If a significant amount of ladle sand falls from the ladle but the ladle does not free open, this could indicate that there is a steel skull over the ladle well block or the ladle sand sintered layer grew too thick as a function of residence time and cannot be collapsed by the static pressure of the steel in the ladle.
- If some sand falls from the ladle but the ladle does not free open, this could indicate that there is an obstruction in the ladle well block that occurred before or during sanding. This could occur due to foreign material entering the well block area during the sanding operation or the sand mound being disrupted by foreign material after the sanding operation. An additional cause could be the ladle sand sintered layer grew too thick as a function of residence time and chunks of sintered sand wedge themselves in the well block refractory stack, or steel/slag penetrated the ladle sand to some degree and solidified within the well block refractory stack.
- If no sand falls from the ladle but the ladle does not free open, this could indicate a significant issue with sanding the ladle, poor sanding sizing distribution, poor well block refractory stack design or an issue(s) with caster operations.

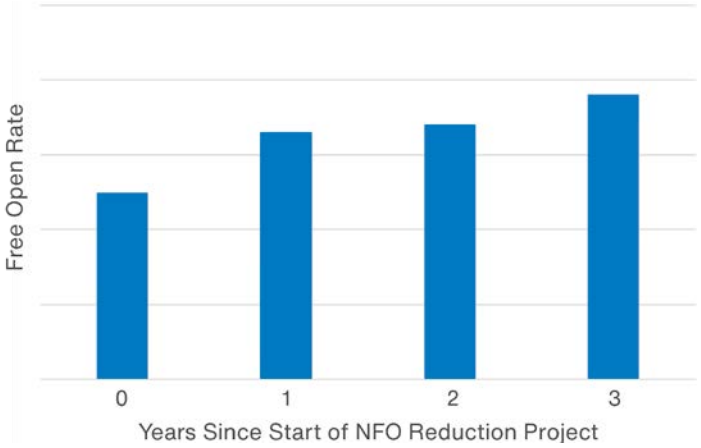
Observation of these NFO mechanisms helped to diagnosis which step in the process could have resulted in the NFO. For example, a case where no sand falls could mean that the ladle was not properly sanded, so that step in the process was investigated. A case where all the sand falls but results in an NFO may have been an issue with the ladle bottom being cold; thus processing times and heating steps were reviewed. But based on Nucor Steel–Berkley's experience, a NFO was rarely related to one single variable and that is the reason why NFO root causes are challenging to determine.

Other major activities undertaken to improve root-cause investigation were:

- Automated tracking of caster tundish fill time to auto assign NFOs to heats. This activity was implemented to ensure that all NFOs were correctly assigned to heats for investigation.
- Ladle sanding cameras were added to investigate ladle sanding quality.
- Ladle sand tracking was implemented to input how much, which type, which operator, etc., was used in sanding a ladle to better track trials and ladle sanding variables.

Figure 1

Free open rate over time at Nucor Steel–Berkeley.



- Consistent communication between all teammates in the meltshop on NFO performance, trials, and feedback implemented to ensure successes and failures were well documented and understood.
- Benchmarking within other Nucor divisions and white papers to best capture all known NFO reasons to date.

Improvements

After initial investigations and data gathering, major variables correlating to NFOs were determined and expectations were set for the meltshop team. The following expectations were developed from the investigations:

- All NFO heats are to be investigated.
- All ladles should be cleaned of loose slag/steel before sanding.
- Minimize number of ladles in operation.
- Ensure thorough heating of new ladles put in service.
- Ensure thorough heating of ladle repairs.
- Ensure thorough heating of the ladle well block area on cold ladles.
- Store ladle sand in a dry area.
- Thoroughly inspect ladle bore before sanding for obstructions.
- Apply the proper sand type and amount based on ladle conditions.
- Apply the proper sand type for specific process routes.
- Ensure adequate distance from tapping stream to the sand mound.

- Make all reasonable efforts to minimize sanding to tapping time.
- Ensure proper sanding of ladle.
- Minimize time of depart LMF to open at caster time.

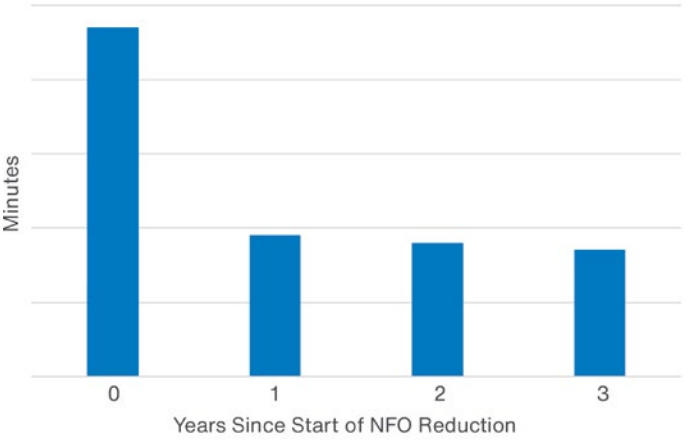
The details of how and why these major variables were determined is not as important as having a way to gather data on NFO heats and free open heats to determine and measure variables for each specific shop's operating condition. To achieve a best-in-class free open rate, each specific shop's operating condition and philosophy will need to be evaluated to set meaningful expectations on operating variables to achieve low NFO rates.

Specific Actions

- The last stir at the LMF to open at caster time was determined to be a major factor in NFOs at Nucor Steel–Berkeley. This was noticed by many NFO heats showing all the sand dropping from the well block but the ladle experiencing an NFO. Efforts were put in place at the LMF to reduce the time a ladle sits with no bottom stirring to keep the ladle temperature more homogenized, especially on the bottom of the ladle.
- The first heat of a new ladle (ladle with new refractory repairs) was seen to have a much higher occurrence of NFOs than subsequent heats.

Figure 2

Last stir at the ladle metallurgy furnace to caster open time improvements.



Practices were put in place to improve ladle well block heating conditions, including implementing a venturi system to draft heat from the horizontal ladle wall heating lid through the well block of the ladle. Nucor Steel–Berkeley preferred to use this venturi system on new ladles and ladle repairs.

- Ladle sanding quality was determined to be a significant factor in NFOs. This was inferred from a high number of NFO heats showing some ladle sand fall and then the steel stream stopping.

Figure 3

Venturi system to heat ladle well block.

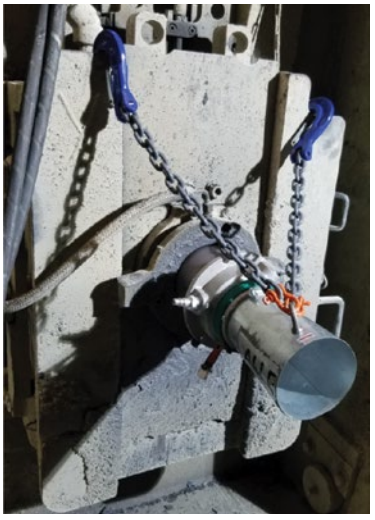
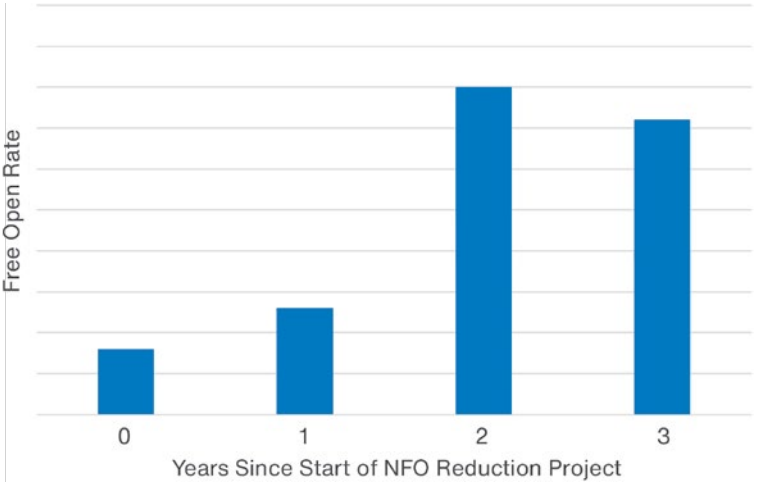


Figure 4

Free open rate improvement on new ladles.



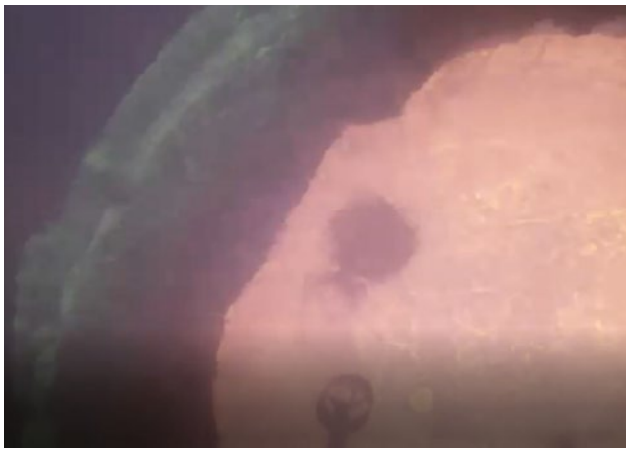
Subsequent investigation of the ladle well block condition typically showed a mixture of ladle sand and slag/steel clogging the well block area. A ladle sanding camera was implemented to view ladle sanding activities, especially on NFO heats. The sanding system was redesigned to ensure the sanding path was aligned with the well block, and the sand amount was set to account for well block wear as the ladle aged. The ladle sanding camera was of particular use to look for debris that may have entered the well block and sand mound integrity.

Many other activities were undertaken in attempts to improve NFO rate at Nucor Steel–Berkeley. This article does not do justice to all the work put in by the Berkeley team and suppliers on this critical topic. The involvement of the entire meltshop team was crucial to driving improvement ideas. Some of the other projects implemented to improve NFO rate include:

- At least eight different ladle sands tested for NFO performance.
- At least four different well block designs tested for NFO performance.
- Slidegates trialed with plates of different diameters.
- Slidegate opening speeds at the caster were investigated.
- Ladle sand moisture content was monitored.
- Ladle sanding station improvements.

Figure 5

Ladle sanding camera view.



Conclusion

Improving NFO rate is not a simple activity. All areas of the meltshop are involved in a ladle free opening and a disciplined approach to each heat is necessary to give each ladle the best chance to free open. Improving the NFO rate is not one person's or one operating group's job; it is a collective effort from every member of the meltshop to maintain a world-class NFO rate with the desire to improve to the goal to 100% free open rate. There are many factors that can combine to cause an NFO and establishing a culture throughout the meltshop to prevent/eliminate one NFO at a time is paramount. The effort involved in improving NFO rate is justified as a mitigating step against potential quality issues inherent on NFO heats.

References

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This paper was presented at AISTech 2024 — The Iron & Steel Technology Conference and Exposition, Columbus, Ohio, USA, and published in the AISTech 2024 Conference Proceedings.