

# Improving slag detection

We look at the issue of slag detection in the steel making process and how thermal imaging cameras are helping to reduce its impact and improve efficiency. By **Peter Unwin\***

STEEL slag, a molten liquid melt of silicates and oxides, is a by-product of the steel-making process, which is produced during the separation of molten steel from the impurities that are found in iron ore and scrap metal. The slag solidifies upon cooling.

Slag needs to be removed as its impurities degrade steel. For example, slag will pull phosphorous from iron and, if not removed, the phosphorus reverts back into the steel, lowering its quality. It also causes substantial wear and tear on the vessels involved. Removal of slag can require huge effort and expense on the part of steel producers. Recent advances in detection, however, now mean that slag can be more reliably and effectively managed.

The disadvantages of slag carryover include:

- Longer processing time
- High inclusion formation and steel cleanliness challenges
- Difficulty in ladle desulphurisation
- Caster nozzle clogging
- Ladle refractory wear

There are many grades of steel that can be produced, and the properties of the steel slag can change significantly with each grade. Grades of steel can be classified as high, medium, and low, depending on the carbon content of the steel. High-grade steels have a high carbon content. To reduce the amount of carbon in the steel, greater oxygen levels are required in the steel-making process. This also requires the addition of increased levels of lime and dolime (flux) for the removal of impurities from the steel and increased slag formation.

There are several different types of steel slag produced during the steel-making process. These different types are referred to

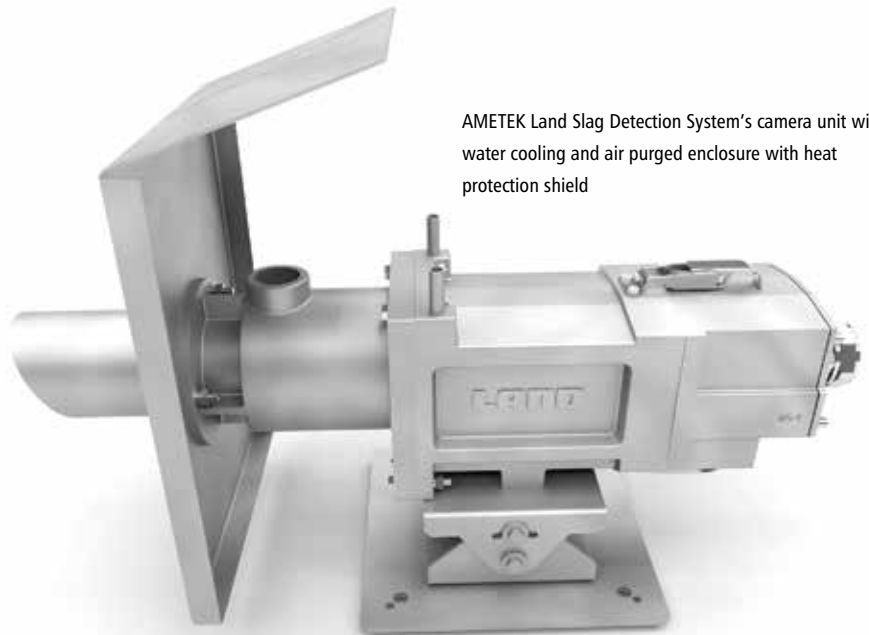
as furnace or tap slag, raker slag, synthetic or ladle slags, and pit or cleanout slag.

The steel slag produced during the primary stage of steel production is referred to as furnace slag or tap slag. This is the major source of steel slag aggregate. After being tapped from the furnace, the molten steel is transferred in a ladle for further refining to remove additional impurities still contained within the steel. This operation is called ladle refining because it is completed within the transfer ladle. During ladle refining, additional steel slags are generated by again adding fluxes to the ladle to melt. These slags are combined with any carryover of furnace slag and assist in absorbing deoxidation products (inclusions), heat insulation, and protection of ladle refractories. The steel slags produced at this stage of steel making are generally referred to as raker and ladle slags. While slag can be used in the aftermarket for a variety of applications, its presence as a result of the steel-making process involves a great deal of time and expense to remove it. Slag also can lead to equipment damage.

## How steel is produced

Steelmaking starts with iron in a furnace, with the two most common furnace types

AMETEK Land Slag Detection System's camera unit with water cooling and air purged enclosure with heat protection shield



being a basic oxygen furnace (BOF) and an electric arc furnace (EAF).

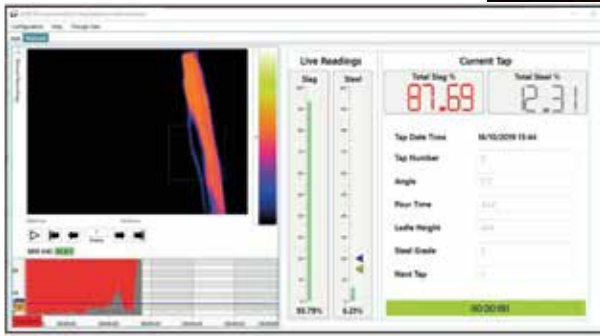
The two vary as follows:

### Basic Oxygen Furnace

A basic oxygen furnace is a refractory-lined and tiltable converter. When steel is made in a basic oxygen furnace, molten iron and scrap are heated. Oxygen is then blown through nozzles into the charge via a water-cooled oxygen lance. The BOF is able to rotate, enabling it to charge raw materials and fluxes that are used to remove impurities. That also allows it to sample the melt and pour the steel and slag out of the furnace. The oxygen converts the pig iron, which accounts for approximately 94 per cent of the volume. The remaining six per cent is composed of impurities, including manganese, carbon and silicon. By the end of the steel-making process, steel made via BOF will have impurity levels of approximately one per cent.

In the basic oxygen process, hot liquid blast furnace metal, scrap and fluxes, consisting of lime and dolomitic lime, are charged to a furnace. A lance is lowered into the converter and high-pressure oxygen is injected. The oxygen combines with and removes the impurities in the charge. These impurities include gaseous carbon monoxide,

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AMETEK Land IMAGEPro-SDS advanced image processing and application software

silicon, manganese, phosphorus and liquid oxides that combine with lime and dolomitic lime, forming steel slag. At the end of the refining operation, the liquid steel is tapped (poured) into a ladle. The steel slag remains in the vessel and is subsequently tapped into a separate slag pot.

The steel-making steps in a BOF include:

- Charging the scrap
- Adding pig iron to the furnace
- Charging the fluxes
- Oxygen blowing
- Sampling
- Tapping
- Ladle refining
- De-slagging

The molten steel is removed from the furnace when the steel is at its optimal consistency, through the tapping hole. During the steel manufacturing process, the tapping hole remains plugged to keep heat from escaping the furnace.

### Electric arc furnace

In comparison, an electric arc furnace (EAF) creates steel from scrap and direct-reduced iron (DRI). It uses three vertical graphite electrodes to charge the iron and scrap via electric current. This furnace is analogous to a wok with a lid. Metal is added, the lid is closed, and an arc is created between the electrodes. A huge amount of power is used to melt 100 per cent of the steel scrap.

At this point, limestone flux is added. A hole in the base of the "wok" opens and a ladle is positioned underneath. The molten steel exits into the ladle, and the hole closes when slag is detected.

The steel making steps for an EAF are:

- Charging scrap metal, iron and limestone



Molten iron is tapped at regular intervals

An operator carrying out a visual slag detection inspection

- Lowering the electrodes, melting the metal with electric current
- Oxidation
- De-slagging
- Adding new fluxes for reducing stage to eliminate sulfur and oxide absorption
- Tapping
- Lining maintenance to eliminate molten steel breakouts from excessive lining depletion.

With both types of furnaces, molten iron is tapped at regular intervals. Accurate temperature monitoring ensures steel quality is consistent and improves process efficiency. While it seems that the steps are straightforward, detecting slag and keeping

it from degrading the steel is an art and a science, and the detection methodology has evolved significantly over time.

### Slag detection – measurement methods

When slag begins to exit along with the steel, the pour is stopped. The early method of detecting slag was visual. An operator wore a dark viewing shield, or visor, to observe the colour of the pour. Since slag has higher emissivity, it looks brighter than the steel preceding it. Once the slag was spotted, the operator signalled for the molten steel vessel to tilt, preventing it from pouring out.

There are several downsides with this method – a major one being safety, as

the operator's eyes could be damaged while observing the steel. Repeatability is a major issue, as reliability varies from operator to operator. Fumes often cloud the environment so that complete accuracy is impossible. While this visual method is still used in some areas of the globe, its use prevents improvements to the process.

Another method involves a ceramic ball, or dart, that is shot into the molten steel. The stem of the dart is visible as it floats on top of the steel. Once slag begins to flow through the tap hole, the flow density lowers and the dart sinks into the tap hole, reducing slag flow until the operator reverses the tilt. Inserting the dart is often problematic, so much so that, in many cases, it requires an expensive machine run by a highly trained operator. The darts are also consumable and add costs to the process.

A third method is to use a circular induction coil that is wound around the tap hole in a refractory. Current passes through the coil, and the induction field varies based on the material composition of the flow. When slag is present, a signal from the induction coil determines the time when reversal should occur.

This method actually works well. The coil, however, does not last as long as the vessel. When the coil fails, it means casting a new coil into the hole or waiting for a reline and moving to manual slag detection in the interim. Accuracy over time is another major issue. Again, the coil is consumable, so using this method also adds an ongoing expense.

Two decades ago, thermal imaging cameras were introduced to help improve the process of slag detection. They had major advantages, including being non-contact, which meant they did not wear out or add consumables to the bottom line. Their detectors were an optical or infrared detector array that featured an electronic processor and repeatability was greatly enhanced.

Advances over time

included long-wavelength thermal imagers with an 8-14  $\mu\text{m}$  response. The results were good, as the emissivity between steel and slag is accentuated by the long wavelengths. There was still fume obscuration and the optical materials used in these thermal imagers were not sufficiently durable for the harsh environment, requiring frequent protective window or lens replacements.

### An atmospheric window

Although long wavelengths were problematic, mid-wavelength thermal imagers offered several possibilities. A thermal imager working at a narrow waveband could see through hot  $\text{CO}_2$  and hot water vapour. This atmospheric window was first documented in NASA test data more than five decades ago. The shorter 3.9  $\mu\text{m}$  waveband also enabled extremely durable optical systems, including sapphire protection windows with good transmission characteristics from ultraviolet to approximately 5.5  $\mu\text{m}$  in the infrared.

These capabilities are built into AMETEK Land slag detection system (SDS), which deliver improved yields, higher-quality steel and reduces costly downstream processing for BOF and EAF steelmaking operations. It is specially designed to withstand the harsh conditions of continuous operation in a steel plant, with minimal maintenance requirements.

The AMETEK Land SDS has an industrial thermal imaging sensor, which is housed in a rugged, water-cooled and air-purged enclosure that continuously views the tapping area. As the tap begins, dedicated software automatically records the tap, producing a log and graph of the relevant steel and slag data. When the slag reaches a pre-determined level, an alarm

is generated to stop the tap. Full access to the tapping data is available to the operator for quality control purposes.

The SDS' high-resolution thermal imaging camera detects the transition between steel and slag with a particular wavelength, reducing "blackouts" caused by smoke and fumes. The data it presents in real time enables the operator to make informed decisions about the tapping process. By warning the operator in a dependable, repeatable and timely manner to stop the tap before slag is carried over, the SDS improves production yields and ensures a lower slag content, therefore improving the steel's quality, reducing energy costs further along the process and lowering overall maintenance on the furnace vessel.

Using an SDS has been shown to improve operator response time and consistency at the end of each tap. This results in a typical reduction in slag depths of up to 25%, compared to traditional methods for monitoring slag.

The SDS represents a major innovation in slag detection and thermal imaging, providing a man-machine interface for the steel industry. The system offers improved operator safety, quick response times and consistent results. It is very durable and will normally be expected to last longer than the vessel as the system is designed to withstand the harsh conditions of continuous operation inherent in steel production. It reduces slag carryover in steel production facilities, saves money and improves operator safety.

### Summary

Although measurement methods have evolved over the past few decades, the quality of metallic scrap and iron feed stocks have simultaneously deteriorated; this results in greater slag generation and increased slag-related challenges for the steel industry. The existence of slag causes substantial processing time, lower steel quality, difficulty adding alloys and conditioners and substantially higher processing and treatment costs.

The cost of additional downstream processing time and materials can be a significant burden for an operating plant. By controlling slag carry-over, these costs can be reduced or eliminated, improving plant throughput and operating margins. ■

