TECH FRONTIERS

Improving performance in metal pouring/transferring ladles

The authors offer several refractory solutions for improving the performance of metal pouring/transferring ladles, discussing the advantages and limitations of each

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LADLES are used for holding iron alloys, mild steel, and various alloys of steels in foundries. Traditionally, refractory for the ladle is not given high importance as a part of the operational process. A foundry consumes more and spends more for the ladles than for the furnaces if an appropriate refractory is not used. Price per tonne of metal melted can be greatly reduced by using a ladle lining system that runs longer with less patching and saves energy.

The quality of casting is more dependent on ladle refractory than furnace lining. Over the years, severe problems of rejection due to inclusions in the castings have been observed.

Since every foundry is unique, the material recommendation is handled on a case by case basis. There is no single product that can be used for all applications. Even though this has been done for decades, new and better technology exists for various applications which engineer a system that will last longer, run safer and cost less money per tonne of metal melted. This is an extremely easy concept to prove. Quantity of material will be reduced greatly, less downtime for ladles, less re-heats required thereby lowering the fuel cost, lower surface defects (lowering the time and money needed for welding and grinding repairs of castings) dramatically less rejection of casting due to inclusions.

Ladle refractory selection criteria

• Chemistry of the metal being transported
• Any alloying done in the ladle
• Kind of inclusions in the castings
• Is heat loss an issue while transportation?
• Do the ladles use a cover? If no, can the process be operated with the use of a cover?
• Is there purging plug being used in the ladle?

Various refractories for iron and steel ladles

Traditionally bricks, moulding sand, silica sand, etc have been used to line ladles but gradually they are being replaced by high quality monolithic refractories which can either be dry vibratables, castables, plastics, or precast shapes. All these refractories have their own advantages and limitations.

There are certain refractory additives which are added to the refractory aggregates. These additives are used to improve the characteristics of the base refractory aggregate. Compounds such as silicon carbide (SiC) provide excellent non-wetting properties, Fused silica is thermally stable and chromium oxide enhances the corrosion resistance in the refractory. There are others as well but these are the more common additives.

We will discuss the advantages and limitations of bricks, castables, and the dry vibratables will be discussed one by one.

Modern iron foundries experience several daily challenges while handling and

BRICKS

Advantages	Limitations
High hot strength	Slow installation time
Resistant to acid and alkali attack	Requires skilled labour
Good abrasion resistance	Not monolithic – multiple joints in lining construction
Fast drying cycle – pre-fired	More prone to thermal shock

CASTABLES

Advantages	Limitations
Very good resistance to chemical attack	Need special equipment for installation like mixer
Monolithic – no joints in lining construction	Need to be installed using skilled worker
Very high hot strength	Longer dry out time
Very tight grain structure, therefore high density and low porosity	Requires a heavier and more reinforced form
Quick installation time	
Forms are removed and re-used	
Can be repaired with same material	

DRY VIBRATABLES

Advantages	Limitations
Very few equipment needed for installation	Low resistance to chemical attack
Can be installed by inexperienced workers under proper supervision	Difficult to have repaired
Can be sintered rapidly	Lower strength at operating temperatures
Better thermal shock resistance	Takes more time for the installation
Long shelf life	Higher porosity and lesser density

Figure1: Magnesia-based sacrificial coating

pouring molten iron and steel, including the continuous battle of keeping ladles clean, maintaining the original ladle capacity and minimising the heat loss. Reduced ladle capacity from slag build-up directly translates into reduced production rates. For example, in ductile iron production, maintaining 'the pocket' in the treatment ladle is critical for the proper treatment of the iron, as well as maintaining the original capacity of the ladle. The slag generated is very high and tends to adhere naturally to the refractory. The right selection of the refractory can help increase the performance, and reduce the operation cost and casting defects.

Importance of advanced coating technology over the monolithic lining

- It reduces time for cleaning ladle
- It makes the cleaning job easier
- Longer lining life of working lining
- In some cases, less heat loss

Magnesia-based sacrificial coating is designed for high contraction upon cooling. This refractory coating is applied over the main working lining of the ladle to combat build-up. As shown in **Figure1**, this coating cracks upon cooling of the ladle which makes cleaning easy, thereby significantly reducing slag build-up and maintenance time to clean the ladle.

Carbon-based sacrificial refractory coating is applied over the main working lining of the ladle. It can be thermal shocked and re-used. In foundries where thermal cycling often takes place this coating will help during the slag removal.

CASE STUDY 1

This is a case study involving the transfer ladle used for pouring the liquid iron metal in the pressure pour. This is a focus area in many foundries because improper ladle refractory can cause build-up in the receiving spout and the uppercase of the pressure pour furnace, thereby leading to build-up and reduced capacity.

Equipment: Equipment is a 1-tonne lip pouring transfer ladle for iron casting production. The subject ladle is lined with mould sand and fireclay directly against the 8 mm mild steel shell. Processing temperature is 1450-1500°C.

Original lining design: The original lining was 50 mm of fireclay and mould sand directly against the steel shell, no insulation was utilised. The total consumption of sand and fireclay for lining the ladle was 300 kg. The throughput taken from the ladle was 25 MT of liquid metal before it was removed in two days with an operation of 24 hours per day.

The erosion observed in two days of operation was around 15 percent of original lining thickness, i.e. 45 kg sand eroded per 25 MT of molten metal transfer.

It is very hard to remove 100 percent sand before pouring into pressure pour. There is always a possibility of some percentage of sand going to pressure pour. Since erosion is fast, there is higher chance of sand going to the pressure pour along with liquid metal.

New lining design: A general improvement was considered using 3 mm insulating paper against the steel shell followed by installing the Allied's castable directly against the paper. The total consumption of Allied's castable to line the ladle was 350 kg.

The throughput taken from the ladle was 1500 MT of liquid metal transfer against 25 MT throughputs taken in the ladle lined with mould sand and fireclay.

The erosion observed after 1500 MT throughput of liquid metal was around 15 percent of original lining thickness, i.e. 51 kg castable eroded per 1500 MT of molten metal transfer.

Results: By simply changing the ladle lining from sand to Allied's castable, the performance of the ladle increased thereby reducing the number of linings and amount of build-up in the pressure pour.

Heat loss reduction through advanced lining configuration

A general refractory design and heat loss analysis can be broken down into four components:

1) The primary metal contact refractory chosen for the equipment
2) The refractory insulation component(s)
3) The environment, including the metal processing temperature and the emissivity of the steel shell
4) Type of coating used over the metal contact refractory.

Metal contact refractories: These refractory grades are designed to have direct contact with molten metal and slag components within the process. The refractory products, having a maximum exposure temperature above the molten metal processing temperature of the ladle, will possess enough strength to resist mechanical abrasion.

Insulation components: In general, most metal contact refractories have a thermal conductivity that result in significant heat transfer to the shell of the transporting equipment. To reduce the shell temperature and the resultant heat/

energy loss, insulative refractories are utilised. General categories of these insulation products are listed here.

• *Insulating firebrick* is a common refractory insulator for many applications. These are highly porous, lightweight aluminosilicate bricks; they are installed with mortar, like dense bricks and are available in many common shapes. The high porosity and low weight of these bricks results in a low thermal conductivity and minimal heat capacity. IFBs are available in many temperature ratings, with the normal range being 1100-1540°C. As with most metal contact refractories, as the temperature rating of the IFB is increased, the resultant density is higher, resulting in reduced insulating properties.

• *Insulating ceramic board or paper* is thin, lightweight, board or paper, consisting of processed aluminosilicate refractory fibres that offers minimal structural strength but do provide excellent thermal insulation. This is a very common material type that can be placed quickly, with an adhesive, against the steel shell of vessels. Thicknesses can vary from 3 mm paper to 25-50 mm thick ceramic board. Temperature rating is generally 1100-1260°C. Ceramic paper is often used in ladles as a relief membrane for improved lining removal.

• *Microporous insulation*: For areas that demand a very low shell temperature, a commonly used material with a very high insulative value is referred to as microporous insulation. This contains a high SiO_2 encapsulated sphere type base structure, extremely lightweight with a very low thermal conductivity. The maximum used temperature is generally about 1000°C, slightly lower than ceramic board or paper.

• *Insulating castable*: Insulating or lightweight castables are similar in consistency to insulating firebricks but are supplied in a cement bonded form to be mixed, cast, and formed in the same method as a traditional castable material. These materials are available in multiple grades ranging from 1000-1650°C. Insulating castables can be cast, trowelled, or gunned into place before the dense castable is installed in the vessel at the metal contact surface. Like most insulation materials, the higher the temperature rating, the denser the product is, providing a lower insulation value.

Environment is a general term for the non-refractory factors that affects the thermal conductivity and shell temperature of the metal processing equipment. The environment includes the actual melting or holding temperature of the molten metal, the velocity of the air surrounding the vessel, and the emissivity of the metal shell. The metal temperature and the velocity of the air around the vessel are self-explanatory, while the emissivity is the efficiency that heat is radiated from the steel shell surface (generally referenced as a ratio).

To demonstrate the material options available while designing an optimal refractory system and to document the influence that insulation has on the resultant shell temperature, several case studies are detailed:

CASE STUDY 2

This is a very simple case study involving the most common example of foundry equipment – the pouring ladle. This is a focus area in many foundries where temperature consistency of the metal is critical but heat loss if often not adequately addressed.

Equipment: Equipment is a 1-tonne lip pour ladle for iron casting production. The subject ladle is lined with a common, flexible high cement fireclay-based castable directly against the 6 mm mild steel shell. Processing temperature is 1400-1500°C (1450°C will be used for calculations within the case study). Air velocity is 2 m/second, common for ladle applications.

Original lining design: The original lining was 75 mm of fireclay castable directly against the steel shell; no insulation was utilised.

Environment

Metal temperature: 1450°C
Air velocity: 2 m/ws
Emissivity of steel shell: 0.82

Material	Lining thickness	Interface temperature
Fireclay castable	75 mm	1450°C
Steel shell	6 mm	428°C

Cold face temp 426°C
Heat loss 16,210W/m^2

New lining design 1: A general improvement was considered using 6 mm insulating paper against the steel shell followed by installing the fireclay castable directly against the paper. The change in heat loss is noted here to have decreased from 16,210 W/m2 to 10,920 W/m^2.

Material	Lining thickness	Interface temperature
Fireclay castable	69 mm	1450°C
Ceramic paper	6 mm	788°C
Steel shell	6 mm	428°C

Cold face temp 356°C
Heat loss 10920 W/m^2

Final lining design 2: A further improvement was considered using 12 mm of high strength insulating board against the shell and installing the fireclay castable directly on the ceramic board.

Material	Lining thickness	Interface temperature
Fireclay castable	75 mm	1450°C
Steel shell	6 mm	428°C

Cold face temp	289°C
Heat loss	7730 W/m^2

Results: By simply adding ceramic paper or ceramic board within the sidewall lining, the steady state steel shell temperature of the ladle was reduced from 426°C to 289°C, and the heat loss was decreased from 16,210 W/m^2 to 7730 W/m^2, a reduction of more than 50 percent.

Most of the foundries do not use cover/lid on the ladle which plays a key role in energy savings. A cover on the ladle can help save 8-10 percent of the heat loss thereby saving additional energy.

Controlling energy cost is one of the most significant factors in the profitability of foundries. Energy usage is necessary for the direct melting of metals to be poured into castings. The control and minimisation of heat losses through refractories in the melting, holding, and pouring process should be a key process goal. Employing optimal lining designs should begin with the purchase and sizing of melting equipment.

CASE STUDY 3

This is a case study involving the transfer ladle used for pouring the liquid iron metal in the pressure pour. This is a focus area in many foundries because improper ladle refractory can cause buildup in the uppercase of the pressure pour furnace, thereby leading to volume reduction in this equipment.

Equipment: The trial was planned in a 1.5-tonne lip pouring transfer ladle for iron casting production. The subject ladle is lined with mould sand and firebrick directly against the 8 mm mild steel shell. Processing temperature is 1450-1500°C.

Original lining design: The original lining was 50 mm of firebrick against the shell and 25 mm thick sand against the bricks. The total consumption of sand was 50 kg and firebrick (2 inches) was 40 nos.

The throughput taken from these ladles was 50 MT of liquid metal before it is brought down for repair. Normally these ladles are used for 24 hours to achieve this 50 MT throughput.

The erosion observed per day of operation was around 15 percent of original lining thickness, i.e. 45 kg sand eroded per 50 MT of molten metal transfer.

It is very hard to remove 100 percent sand before pouring into pressure pour. There is always a possibility of some percentage of sand going to pressure pour causing huge issues inside the pressure pour.

New lining design: The configuration followed was using 6 mm insulating paper against the steel shell followed by low cement castable lining for 70 mm thick. The total consumption of castable to line the ladle was 650 kg.

The throughput from the ladle lined with low cement castable was 1500 MT of liquid metal transfer (still running) against 50 MT throughput taken in the ladle lined with sand and firebrick.

The erosion observed after 1500 MT throughput of liquid metal was around 15 percent of original lining thickness, i.e. 51 kg castable eroded per 1500 MT of molten metal transfer.

Results: By simply changing the ladle lining from sand to castable the performance of the ladle increased thereby reducing the number of linings and amount of build-up in the pressure pour.

Conclusion

The most overlooked area in the foundry process is the ladle shop; yet it has the potential to save huge cost of foundries and steel mills than furnace refractory. By using the right product, the right quality of refractory and the right lining configuration, foundries and steel mills can save energy, reduce rejected castings, save money and reduce the carbon footprint. Ladles are not one type product fitting all. The operation of the ladle, the slag chemistry of the ladle, metal chemistry, the additions being made in the ladle and the distance the ladle travels all must be considered. In the competitive global market of today's foundry business, using the right products for the right applications can reduce the cost of foundry operations, giving the foundry a distinctive advantage over their competitors.

References

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