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Steel Ladle Lining Management: A Comparison Between Different Maintenance Technologies to Increase Performance, Reduce Refractory Consumption and Waste Disposal of Used Materials

Optimum management of steel ladles plays a crucial role for efficient and sustainable steel production. Regarding ladle wear linings, steelmakers typically have two main approaches. The most common is a fully bricked lining, offering advantages such as slag and high-temperature resistance, along with reliable campaign lifetimes. An alternative, which has demonstrated many benefits in recent years, is monolithic technology based on alumina spinel. However, whichever lining concept is used, performance can be further improved with intermediate repairs of high-wear areas using shotcrete. This article presents results collected over multiple years at different steelworks, all of which benefited from this type of repair method. For example, savings in the quantity of refractories used were observed, as well as reductions in waste and CO_2 emissions.

Introduction

Over many years, ample proof has accumulated that zoning different areas of the steel ladle with specific refractory materials is the most effective and safe approach to optimise service life. Currently, steelmakers generally rely on one of two concepts for the ladle refractory wear lining. While the majority trust bricks, which provide good high-temperature resistance, excellent slag protection, easy heat up, and reliable service life, others have already switched to monolithic solutions based on alumina spinel, with high thermal stability, good hot strength, excellent resistance to thermal spalling, as well as low carbon pickup and decreased thermal conductivity, which are important for the production of ultra low carbon steels and energy saving, respectively. However, since both concepts see uneven refractory wear in different zones, repair of these regions with sprayable materials has emerged as a solution to increase the number of heats before complete relining is required.

Comparison of Two Standard Lining Concepts

Steel ladles play a critical role in steel production, serving as vessels for transporting and refining steel through various stages of secondary metallurgy. The refractory lining of these ladles is subjected to chemical, thermal, and mechanical wear. For these reasons, it is essential to carefully select the type of refractories, installation technique, and maintenance to provide as long a service life as possible. Due to the wide-ranging requirements, there is no one-size-fits-all solution. Steel shop managers need to balance different parameters, such as durability, balanced performance, low consumption, resistance to slag attack, safety, ease of installation, quick heating up, capacity optimisation, insulation properties, flexibility, and cost effectiveness. Finding the best compromise among these complex requirements is a continuous challenge. While MgO-C bricks have long been favoured for the ladle wear lining, due to their high-temperature resistance and reliable service life, the steel industry is increasingly recognising the potential of alumina spinel monolithic refractories. For example, research conducted over two decades ago revealed that these monolithic products not only compete with traditional lining materials, but also offer additional benefits, such as increased ladle capacity and reduced thermal losses [1].

Recent reports and articles have further supported these findings, highlighting the advantages of alumina spinel monolithic refractories [2–5]. Lower operating costs and improved consistency in the steel carbon content, make these refractories appealing to steelmakers seeking enhanced efficiency and higher quality steel production. Furthermore, transitioning from MgO-C bricks to alumina spinel monolithic refractories can contribute to a reduction in CO_2 emissions, both during refractory production and operation, making them an environmentally sustainable choice. Another advantage of monolithic refractories is their ability to minimise waste generation by enabling targeted repairs instead of complete demolition and relining, thereby optimising resource utilisation in the steelmaking process.

Introduction to Cyclic Shotcrete Repair

A previous article presented at the 63rd International Colloquium on Refractories showcased an innovative cyclic shotcrete repair technique for steel ladle management [6]. The following summary provides an overview of the repair cycle and calculations for long-term analysis after multiple years in use. Cyclic shotcrete repair involves applying protective layers of monolithic castable onto an existing brick lining in a repetitive manner. By combining the advantages of monolithic and brick linings, this method offers a flexible and reliable solution for ladle lining repair.

The shotcrete technique, known for its flexibility and ability to create refractory linings with similar technical features as traditional casting methods, is utilised in this application. A castable mix is sprayed at high pressure onto the surface, where it rapidly sets, allowing for targeted repairs without complete demolition and relining. A comparison between the typical brick lining cycle and the cycle with shotcrete repair reveals the advantages of shotcrete application (Table I). Without steel zone repair, the slag line can only be replaced once before complete relining becomes necessary. However, with shotcrete repair in the steel zone, the slag line can be changed multiple times before complete relining is required.

Table I.

Comparison of a standard steel ladle life cycle and one with shotcrete repair.

	Standard procedure	Shotcrete repair procedure
1	• Complete new brick lining	• Complete new brick lining
2	• 1st part of the campaign • Number of heats = N1	• 1st part of the campaign • Number of heats = N1
3	• Ladle out of service • Replace the slag zone bricks	• Ladle out of service • Replace the slag zone bricks • Clean the application surface • Shotcreting on the steel zone brick lining • Heating up
4	• 2nd part of the campaign • Number of heats = N2	• 2nd part of the campaign • Number of heats = N2
5	• Ladle out of service • Total brick lining demolition • Complete new brick lining installation	• Ladle out of service • Replace the slag zone bricks • Clean the application surface • Shotcreting on the steel zone brick lining • Heating up and continue campaign • Avoid total brick lining demolition and new brick lining installation

The shotcrete application extends the ladle campaign life, reduces specific consumption and costs, while maintaining the use of traditional brick linings. Specifically, wear occurs to the shotcrete layer, while the original bricks remain intact. This technology offers significant benefits, including prolonged ladle campaign life, easy visual wear control, and reduced refractory lining waste. As a result, it leads to substantial reductions in specific refractory consumption and operational costs without compromising the ladle availability, reliability, and safety.

Analysis of Long-Term Cyclic Shotcrete Repair

Shotcrete repair is a standard maintenance solution, applied in numerous steelworks (Figure 1). The increased number of ladles repaired in this way has led to optimised cleaning techniques, installation, and heating curves, resulting in more reliable ladle management. This section presents long-term cyclic shotcrete repair results obtained from two steelworks. On average, the slag line bricks at Steelworks 1 were replaced after approximately 40 heats. The ladle then continued to operate for another 40 heats. However, at around 82 heats, the bricks in the steel zone became too worn to complete another slag zone cycle, resulting in the complete demolition of the ladle. In the new campaign life cycle, the introduction of two shotcrete repairs in the steel zone and two slag zone brick replacements has extended the ladle's campaign life by 50% (Table II).

Figure 1.

Shotcrete repaired steel ladle during operation.

Table II.

Average steel ladle performance without and with shotcrete repair at Steelworks 1 and 2.

Steel producing plant	Steelworks 1	Steelworks 2
Steel ladle capacity [tonnes]	350	160
No. of ladle campaigns (2020–2023)	350	690
Quantity of bricks for steel zone [tonnes]	26.5	16.0
Quantity of bricks for slag zone [tonnes]	14.3	6.3
Average quantity of shotcrete material per repair [tonnes]	4	3
Lifespan of slag line (heats)	40	60
No. of heats without shotcrete repair	82	100
No. of heats with 2 shotcrete repairs	123	185

Typically, the slag line bricks in Steelworks 2 were replaced after approximately 60 heats and the ladle was operated for a further 40 heats. However, at approximately 100 heats, the steel zone bricks became very worn, resulting in complete wear lining demolition. In the new campaign life cycle, implementing two repairs in the steel zone and two slag zone brick replacements has increased the ladle's campaign to an average of 185 heats, representing a 85% increase (see Table II). Using this data, the specific refractory consumption for the steel ladle walls per tonne of produced steel was calculated (Tables III and IV).

Using the annual steel production figure of 3.5 million tonnes at Steelworks 2, the number of ladle wear linings required per year was calculated. This enabled the annual amount of refractories needed for the steel ladle wall to be estimated for the standard practice and with shotcrete repair, and from this figure the amount of refractory waste, considering the ladle is demolished when the bricks reach 30% of their original thickness. These numbers reflect significant savings in refractory costs, increased steel ladle availability, reduced refractory waste, and lower CO_2 equivalent (CO_2e) emissions coming from refractory production when shotcrete repair is used. The latter was calculated assuming average cradle-to-gate product carbon footprints [7] of 2.472 and 1.344 tonne $CO_2e/tonne_{refractory}$ for the bricks and monolithic, respectively (Table V and VI).

Table III.

Specific refractory consumption ($kg_{refractory}/tonne_{steel}$) for the ladle walls at Steelworks 1 without and with shotcrete repair.

Steelworks 1 ladle capacity	350 tonnes	
Steel zone lining maintenance	Standard practice	Shotcrete repair
Quantity of produced steel [tonnes]	28700	43050
Tonnage of refractories used [tonnes]	55.1	77.4
Specific refractory consumption [$kg_{refractory}/tonne_{steel}$]	1.92	1.80

Table IV.

Specific refractory consumption ($kg_{refractory}/tonne_{steel}$) for the ladle walls at Steelworks 2 without and with shotcrete repair.

Steelworks 2 ladle capacity	160 tonnes	
Steel zone lining maintenance	Standard practice	Shotcrete repair
Quantity of produced steel [tonnes]	16000	29600
Tonnage of refractories used [tonnes]	28.6	40.9
Specific refractory consumption [$kg_{refractory}/tonne_{steel}$]	1.79	1.38

Table V.

Calculated annual figures for the number of ladle wear linings, refractory tonnage for the ladle side wall, refractory waste, and CO_2e emissions in Steelworks 2. The refractory production related CO_2e emissions were calculated assuming average cradle-to-gate product carbon footprints of 2.472 and 1.344 tonne $CO_2e/tonne_{refractory}$ for the bricks and monolithic, respectively.

Annual steel production	3.5 million tonnes	
Steel ladle capacity	160 tonnes	
Steel zone lining maintenance	Standard practice	Shotcrete repair
No. of ladle wear linings per year	219	118
Annual quantity of refractories [tonnes]	6256	4836
Annual refractory waste [tonnes]	1877	1238
Annual refractory production related CO_2e emissions [tonnes]	21450	15720

Table VI.

Yearly savings calculated for Steelworks 2 using shotcrete repair compared to the standard practice.

	Annual saving [%]
No. of ladle wear linings	46.1
Used refractories	22.7
Refractory waste	34.0
CO_2e emissions	26.7

New Installation Method—SHOTGUN

Shotcreting is a versatile monolithic application technique where a castable mix is sprayed onto a surface at high pressure, rapidly setting in place. It offers exceptional flexibility, allowing it to be used in various locations regardless of complex geometries. Crucially, shotcreting achieves refractory linings with comparable technical features to traditional vibrating casting methods, particularly in terms of mechanical parameters. However, shotcrete is typically not used for small repairs due to the higher equipment cost, longer preparation time, and increased cleaning requirements after installation. These limitations are easily overcome by larger steelworks where the number of steel ladles and the quantity of installed material are high, and top-of-the-line performance is expected. On the other hand, for smaller steel mills, these limitations can be a dealbreaker, hindering them from modernising their steel ladle management. To assist them in moving into the greener future, a new installation technique and material that enables utilisation of gunning machines to apply similarly performing material as shotcrete have been developed. A schematic of this SHOTGUN system, which includes a modified gunning machine, high-pressure water pump, compressed air source, accelerator pump, and a special SHOTGUN nozzle (Figure 2), is depicted in Figure 3 [8].

Figure 2.
New SHOTGUN nozzle.

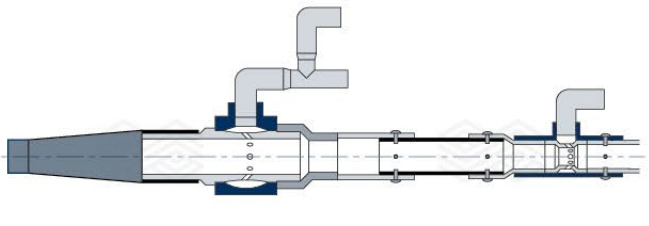
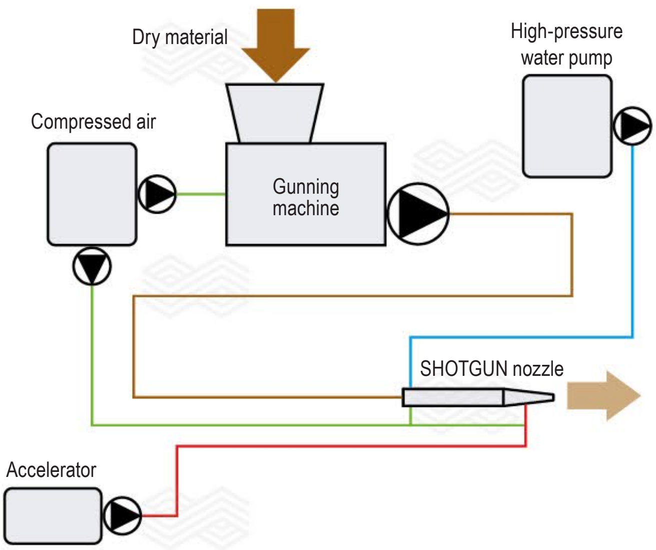


Figure 3.
Schematic of SHOTGUN system.



This system eliminates the need for a planetary mixer and shotcrete pump, which take up a lot of space and are costly, while also significantly reducing setup time and manpower. Since water is added at the nozzle, there is no need to clean the pipes, and no material is wasted that would normally remain in the mixer, pump, and pipes. As the existing shotcrete material (e.g., SEVEN SHOT 92 NR 08 Z) was not fully compatible with the new installation system, which requires a material that is dry pumpable without separation and can be wetted out in a short amount of time, the particle size distribution and additives were modified, giving rise to a new family of SEVEN SHOTGUN products.

A comparison of the SEVEN SHOT 92 NR 08 Z and SEVEN SHOTGUN 92 NR 08 Z physical properties shows that both have high cold crushing strength (CCS) values, especially at operating temperatures (Figure 4). Furthermore, the permanent linear change (PLC) is relatively constant for both products and far from the critical value of -1.5% (Figure 5). Although SEVEN SHOTGUN 92 NR 08 Z has slightly lower CCSs, the values are still sufficiently high, and the less negative PLC reduces the stress experienced by the material.

Figure 4.
Comparison of the CCS for SEVEN SHOT 92 NR 08 Z and SEVEN SHOTGUN 92 NR 08 Z.

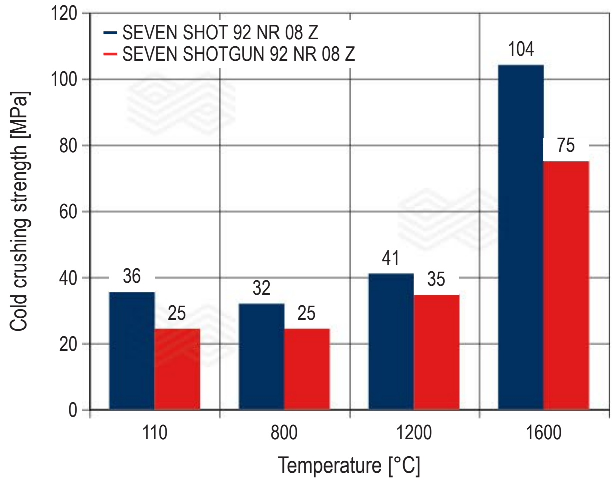
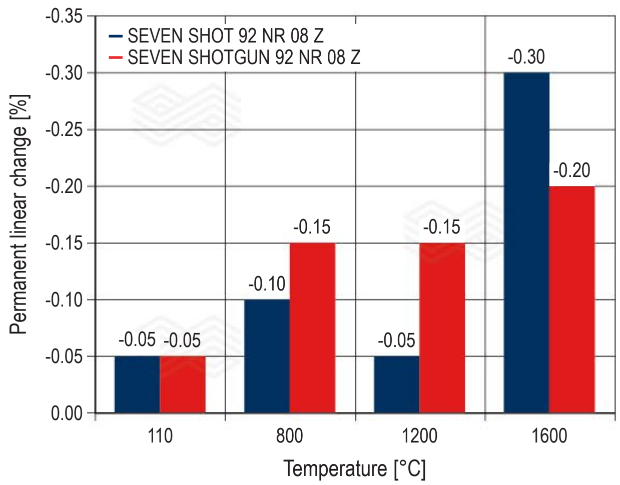


Figure 5.
Comparison of the PLC for SEVEN SHOT 92 NR 08 Z and SEVEN SHOTGUN 92 NR 08 Z.



Industrial Trials of SHOTGUN at Steelworks 3

At Steelworks 3, a bottleneck during the standard campaign was wear in the ladle steel zone lining. The application of SEVEN SHOTGUN 92 NR 08 Z during replacement of the slag zone bricks extended the campaign until the bottom and slag zones became limiting factors for the steel ladle's life cycle. This has been confirmed in several steel ladle campaigns. With this solution, all zones reach their end of life at the same time, which is a crucial parameter in economical calculations for all refractory linings and significantly reduces the amount of wasted material.

The introduction of the new SHOTGUN solution has made these benefits more accessible and easier to implement. Laboratory tests have shown only minimal reductions in physical values of the SEVEN SHOTGUN 92 NR 08 Z compared to the standard shotcrete material, ensuring high-quality repairs and the feedback from initial field trials has been positive. It is expected that this solution will be particularly useful for smaller steel mills seeking to optimise their steel ladle performance. RHI Magnesita is confident that further industrial trials will establish SHOTGUN as a reliable installation technique, enabling steel producers to transition towards a greener and more efficient future.

Conclusion

Shotcrete repair has proven to be an effective solution to improve steel ladle performance. These repairs extend the ladle service life, reduce waste, and decrease refractory consumption per tonne of steel. As a result, operating costs are lowered, and the environmental impact is reduced. Furthermore, the repair process helps equalise the life cycles of different zones within the ladles, resulting in further refractory waste reductions.

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Cover picture: The image depicts the lower section of a RH degasser, a secondary metallurgical unit used in steel plants. In the RH degassing process, snorkels are submerged into liquid steel contained in the casting ladle. Argon gas is purged through the inlet snorkel, creating a suction effect that draws liquid steel into the lower vessel of the RH degasser, where a vacuum is applied. The steel treated in the lower vessel flows back to the ladle through the outlet snorkel, creating a continuous steel circulation between the ladle and the RH degasser. The strong negative pressure (vacuum) within the RH degasser facilitates various metallurgical processes that enhance steel quality, with the key process steps including degassing, decarburisation, deoxidation, and alloying under vacuum. Rail steel, flat steel for the automotive industry, and steel plates for shipbuilding are just a few examples of products that benefit from the RH degasser. Prefabricated snorkels, which RHI MAGNESITA manufactures ready for use and delivers to our globally operating customers, are essential components of the RH degasser.