João Pedro Santos, Julia Macedo, Haylander Ávila, Gilcimar Lima, Everton Arruda and Anderson Lazaroni

Innovative Refractory Wear Measurement Method for Steel Ladles Using 3D Laser Scanning

Determining the steel ladle refractory wear profile is a process used to ensure efficient and safe operation of the equipment throughout its campaign. Despite being an essential practice for steel ladle performance, the creation of this report is still done in an obsolete way, which includes exposure of the operator to hazardous conditions. This article describes the implementation of an innovative method that generates postmortem data using a portable 3D laser scanner. The solution creates and compares measurement models at two points in time: One before and another after the metallurgical process. This advancement can safely generate the residual lining thickness of the entire steel ladle, ensuring accurate and rapid refractory wear profiles at the end of campaigns.

Introduction

Refractory wear profile generation is an important practice used, among other things, to determine for a specific equipment how various regions of the lining are impacted by the metallurgical process. Since it is possible using this approach to monitor performance of the lining material in each specific situation and context, refractory suppliers are constantly developing innovative methods to carry out these measurements, with the focus on safety and efficiency.

This article presents a method that can be used in various scenarios and at different time points for steel ladle inspection using a portable, accurate, and safe 3D laser scanner. While the first 3D laser scanning technology was developed in the mid-twentieth century to recreate the surfaces of objects [1], it was only in the early 2000s that it started to be refined for the steel industry and is now a robust solution to rapidly generate refractory lining wear reports.

Wear Profile Measurement Technologies

Commonly, wear profile measurements are performed manually, with an operator inside the equipment using a tape measure to generate a report detailing residual measurements of the refractory lining at the end of a campaign. Although recently metallurgical companies have started using advanced technologies to perform hot equipment measurements during the campaign, manual measurement is still necessary to obtain actual values required to validate such tools. Therefore, to improve operational safety and decrease operator exposure to hostile environments, RHI Magnesita is now offering the metallurgical industry the ability to generate measurement reports at the end of an equipment campaign in a quick and accurate way using contactless cold scanning.

3D Laser Scanning

A common problem faced during the development of new methods for steel mills is the appropriate technology format, since each customer has a different plant layout, operating procedures, and challenges. In this regard, innovative solutions created to fulfil the diverse needs typically take two different directions: A specific and unique application or a more general, scalable technology. The path taken usually depends on how generic the issue is being solved and what benefits must be reached during the implementation.

In line with these considerations, it was determined that a quick and efficient solution to safely generate an accurate refractory wear profile in a generic way while not limiting the specific needs of each client was 3D laser scanning, a technology that can take measurements of various pieces of equipment and generate useful, dynamic, and crucial information for the plants.

The scan can be controlled remotely and due to its portability the operator can put the scanner in more than one position around the ladle to capture the lining perfectly. The method is used before the campaign starts, during the campaign when needed (e.g., during slag line renewal), and at the end of the process. Following the measurements, software generates a comparison between the reference and the worn refractory in a highly accurate report, containing valuable information such as the remaining thickness, wear index, potential according to a critical limit, and the equipment internal volume, with and without considering a free board [2].

Steel Ladle Scanning and Point Cloud Generation

The steel ladle is key for transferring liquid metal from the basic oxygen furnace to the continuous casting machine. Due to its crucial importance and the need for continuous operation, measuring the refractory lining thickness is a constant challenge during and after its campaign, but also essential to maximise plant safety and efficiency [3]. Although hot measurement is a very interesting tool for this application, since it is possible to follow the development of the equipment throughout the campaign and monitor its wear, it requires high investment costs to apply such technologies.

Aiming to achieve better results, greater accuracy, measurement agility, and above all, to protect the operator from risks related to manual measurements, the 3D laser scan provides a solution for our customers. To ensure success of this approach, several developmental processes were carried out including:

- Validation of the programming code and results generated.
- Validation of the generated point clouds.
- Comparison of values generated by the scan and actual measurements in the steel plant area.
- Software development and report automation.

In the first process step, the equipment, for example a ladle with a newly installed wear lining, is scanned before any metallurgical operations are carried out to establish reference data for comparison at the end of the campaign (Figure 1a). The 3D laser scanner is positioned around and inside the ladle to generate point clouds that include reference points for aligning the images (e.g., steel ladle trunnions), as well as the refractory lining surface. After the ladle has been measured with the intact refractory components, it is released for operation. The scanning process is then typically repeated at the end of the campaign to get the final postmortem results (Figure 1b).

Point Cloud Preparation

Once a ladle has been scanned in multiple positions, the following steps are required to generate a point cloud that can be used for subsequent comparative analyses:

- Combine multiple point clouds of the same ladle into a single point cloud.
- Optimise the point cloud using image alignment.
- Remove points of the image unrelated to the ladle.
- Separate the steel shell from the refractory lining, while retaining the trunnions and other reference points.
- Export the refractory lining point cloud in a defined file format.

Figure 1.

Steel ladle 3D laser scanning on site. Refractory lining (a) prior to use and (b) at the campaign end.

(a) (b)

Point Cloud Comparison

Currently, two approaches can be used to compare point clouds and generate lining wear data: A guided mode in a software requiring specific know-how and powerful computing capacity, and a RHI Magnesita Web-based solution.

When using the software to compare point clouds from different time points of an equipment campaign, it is possible to achieve two main analyses: The wear measurements depicted as a coloured image (Figure 2) and a report detailing the actual values as well as the limiting values, wear rates, and potential heats (Figure 3). In this respect, the results not only visualise the ladle lining wear but also provide essential information in a user-friendly way.

Figure 2.

3D laser scan image showing the wear colour scale that indicates lining wear and slag/steel adhesions in comparison to the ladle profile at the beginning of the campaign.

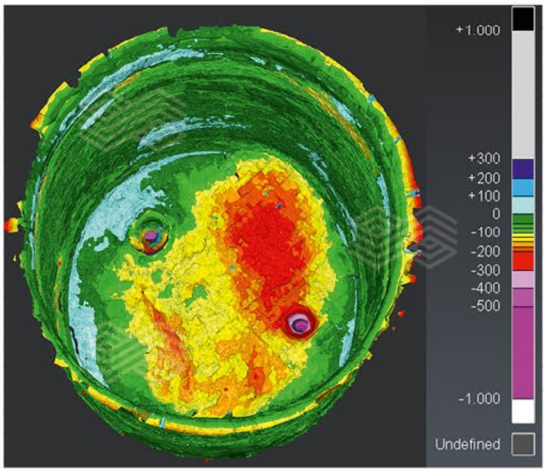

Figure 3.

Detailed wear profile report.

WEAR PROFILE - STEEL LADLE

RHI MAGNESITA

Client	Companhia Siderúrgica Nacional						
Ladle	30	Campaign	109	Heats	92	End Date	
New Ladle - Full Capacity	236 t	End Of Campaign Ladle - Full Capacity	247 t				
New Ladle - Capacity with 44 cm of free edge	204 t	End Of Campaign Ladle - Capacity with 44 cm of free edge	211 t				

Regions	Sign	Angle	Depth	Limit (mm)	Residual (mm)	Location of the Residual	Wear Rate (mm/heat)	Potential (heats)
Slag Line SW	!	1° a 90°	2.91m a 3.93m	50	56	88.08° a 3.59m	1,876	95
Slag Line NW	✗	90° a 180°	2.91m a 3.93m	50	34	154.02° a 3.64m	2,122	84
Slag Line NE	!	180° a 270°	2.91m a 3.93m	50	62	241.09° a 3.64m	1,811	99
Slag Line SE	!	270° a 0°	2.91m a 3.93m	50	64	274.09° a 3.59m	1,789	100
M. L. SW 10 and 11	✓	1° a 90°	2443m a 2.9m	30	83	35.02° a 2.53m	0,960	147
M. L. NW 10 and 11	✓	90° a 180°	2443m a 2.9m	30	86	123.00° a 2.51m	0,922	153
M. L. NE 10 and 11	✓	180° a 270°	2443m a 2.9m	30	117	269.05° a 2.58m	0,585	241
M. L. SE 10 and 11	✓	270° a 0°	2443m a 2.9m	30	93	301.04° a 2.60m	0,843	167
M. L. SW	✓	1° a 90°	1095m a 2443m	30	82	76.00° a 1.82m	0,967	146
M. L. NW	✗	90° a 180°	1095m a 2443m	30	-219	170.03° a 1.27m	4,034	30
M. L. NE	✗	180° a 270°	1095m a 2443m	30	-50	180.00° a 1.59m	2,192	56
M. L. SE	✓	270° a 0°	1095m a 2443m	30	90	315.01° a 2.29m	0,884	159
M. L. SW 2 and 3	✓	1° a 90°	0.64m a 1095m	30	79	20.09° a 0.66m	1,005	140
M. L. NW 2 and 3	✗	90° a 180°	0.64m a 1095m	30	-273	173.05° a 0.88m	4,615	26
M. L. NE 2 and 3	✓	180° a 270°	0.64m a 1095m	30	60	213.01° a 0.92m	0,998	122
M. L. SE 2 and 3	✓	270° a 0°	0.64m a 1095m	30	87	320.07° a 0.91m	0,910	155
1st Row SW	✗	1° a 90°	0.356m a 0.62m	100	95	20.08° a 0.40m	1,454	89
1st Row NW	✓	90° a 180°	0.356m a 0.62m	100	173	102.06° a 0.41m	0,611	211
1st Row NE	✓	180° a 270°	0.356m a 0.62m	100	158	243.05° a 0.56m	0,768	168
1st Row SE	✓	270° a 0°	0.356m a 0.62m	100	165	358.01° a 0.53m	0,699	185
General Bottom	✓	0° a 0°	0.00m a 0.344m	100	192	36.01° a 0.19m	1,639	148
Channel Bottom	✓	0° a 0°	0.00m a 0.382m	100	214	42.03° a 0.21m	1,811	155
Impact Bottom	✗	0° a 0°	0.00m a 0.306m	100	71	320.08° a 0.06m	2,546	81

Legend:
M. L. = Metal Line; SW = South-West; NW = North-West; NE = North East; SW = South East.

Observations

Before the wear profile analysis tool is brought into routine use at a particular steel plant, it is necessary to determine the system accuracy and make any necessary adjustments regarding possible sources of errors. This is achieved by installing new refractory linings in numbered steel shells, performing a 3D laser scan before use, and then measuring the lining wear at the campaign end using both the 3D laser scanner and manually at specific positions. It is essential that the same ladle is used for a comparison between the beginning and end of the campaign because the deformations specific to each steel shell must be taken into consideration.

Following data collection, deviations between the scanned and manual measurements for specific positions are calculated (Table I) and if necessary operational adjustments are performed (e.g., ensuring reference points are clean) to achieve an average error of <2% with a standard deviation <1.7%. These errors are often related to some particularities of the assembly (e.g., application of backfill with a greater or lesser thickness) or deformation of the steel shell that has happened during the campaign. Following verification that the setup is appropriate, the system is put into standard operation with the knowledge that the data can be trusted and used to support the decision-making process [4].

Web Interface

In parallel with the development of this new measurement method, a fully interactive and automated platform was also created to streamline and facilitate easy generation of the refractory wear profile.

The platform features a portal where the point clouds can be uploaded individually according to the type of lining and the lining campaign. This information is then used to create a database of all the campaigns analysed.

Once the images are uploaded, a comparison is automatically performed using parameters previously programmed for the alignment and within just a few minutes all the data related to the wear profile of the analysed equipment is available. Furthermore, it is also possible to visualise and analyse an image of the ladle lining after the upload, because the platform generates an interactive 3D image that can be rotated (Figure 4).

Figure 4.

Interactive 3D ladle image with the wear colour scale indicating the residual lining thickness.

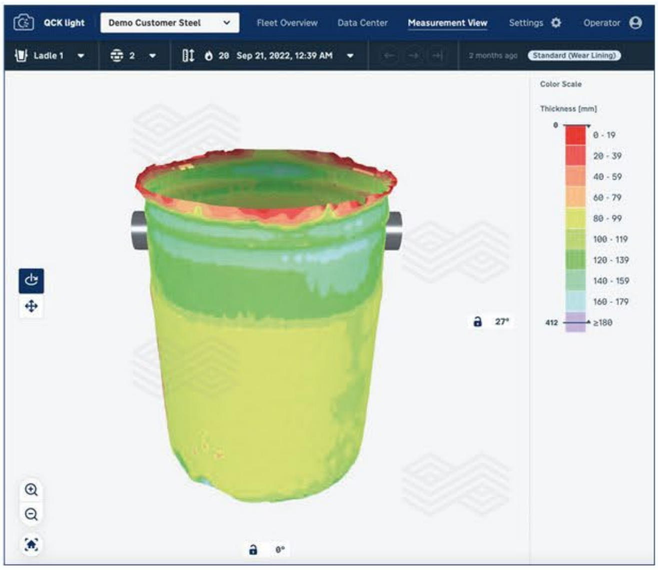

Table I.

Comparison of manual and 3D laser scan wear measurements for specific lining positions within a ladle, including the absolute deviations between the two measurement methods.

Position	Manual [mm]	Scan [mm]	Deviation [mm]	Deviation [%]	Absolute deviation [mm]	Absolute deviation [%]
1	155	155	0	0	0	0
2	135	133	-2	-2	2	2
3	100	97	-3	-3	3	3
4	90	89	-1	-1	1	1
5	105	110	5	5	5	5
6	110	112	2	2	2	2
7	115	117	2	2	2	2
8	115	119	4	3	4	3
9	105	105	0	0	0	0
10	120	119	-1	-1	1	1
11	95	94	-1	-1	1	1
12	95	96	1	1	1	1
13	60	63	3	5	3	5
14	75	72	-3	-4	3	4

Results/Conclusion

The main goal of the laser scanning technology is to achieve operational safety and ergonomics. By eliminating the need to remove the refractory material from the ladle to perform measurements, it is no longer necessary for personnel to stay inside the equipment for long periods in unsafe conditions. In terms of ergonomics, the operator can remain outside the ladle while monitoring progress of the scan, a process that typically takes around 5 minutes. In contrast, before using the measurement tool, exorbitant amounts of time were required for manual measurement. Steel ladles take about 48 hours to cool, then it is necessary to wait for demolition of part of the lining before finally allowing the operator to measure the ladle, totalling approximately 3 days to complete the measurement.

From a technical standpoint, it is possible to achieve many benefits by monitoring the ladle lining and understanding the entire wear profile. For example, it is possible to determine the process's influence on each region of the ladle. In terms of refractories, the technology enables areas that are more susceptible to wear to be identified, which provides the opportunity to address possible root causes with more certainty. Finally, the collected data can be used to develop models that predict refractory wear, which enables greater forward planning in the steel plant.

References

[1] Edl, M., Mizerák, M. and Trojan, J. 3D Laser Scanners: History and Applications. *Acta Simulatio - International Scientific Journal about Simulation.* 2018, 4, 1–5.
[2] Macedo, J.F., Ribeiro, A.S., Nonaka, F., Guimarães, B.F., Morais, V.L. and de Ávila, H.C. How 3D Laser Scan is Adding Value and Performance to Refractory Lining Inside Steel Industry. Presented at AISTech 2022 Technology Conference, Pittsburgh, USA, May 16–18, 2022.
[3] Vert, T. *Refractory Material Selection for Steelmaking;* John Wiley & Sons: New Jersey, 2016.
[4] Lamm, R. Laser Measurement System for the Refractory Lining of Hot Torpedo Ladles. Presented at AISTech 2012 Technology Conference, Atlanta, USA, May 7–10, 2012.

Authors

João Pedro Santos, RHI Magnesita, Rio de Janeiro, Brazil.
Julia Macedo, RHI Magnesita, Vienna, Austria.
Haylander Ávila, RHI Magnesita, Rio de Janeiro, Brazil.
Gilcimar Lima, RHI Magnesita, Rio de Janeiro, Brazil.
Everton Arruda, RHI Magnesita, Rio de Janeiro, Brazil.
Anderson Lazaroni, RHI Magnesita, Rio de Janeiro, Brazil.
Corresponding author: João Pedro Santos, Joao.Santos2@rhimagnesita.com