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Review paper

NDT METHODS FOR MONITORING DEGRADATION OF REFRACTORY LINING FOR BLAST FURNACE AND CONVERTER

Tatjana Volkov Husović[1a], Ana Alil[2a], Sanja Martinović[2b]

[1] Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4,Belgrade, Serbia
[2] Institute of Chemistry, Technology and Metallurgy-National Institute of the Republic of Serbia University of Belgrade, Njegoševa 12, Belgrade, Serbia

[1a] tatjana@tmf.bg.ac.rs, 0000-0002-2667-5802
[2a] ana.alil@ihtm.bg.ac.rs, 0000-0001-7153-0621
[2b] sanja.martinovic@ihtm.bg.ac.rs, 0000-0001-8040-407X

Abstract

Refractory materials are most often used as walls of various devices in metallurgy that, as a rule, work at high temperatures. Devices in which refractory materials are installed can work continuously and discontinuously. Monitoring the behavior of refractory material in working conditions is very important, because it affects the quality of the material produced in the device, as well as the operation of the device itself. Part of the control of the refractory wall is performed during regular and extraordinary repairs of the device. The paper will present various methods for monitoring the properties of refractory walls during work in the iron and steel industry.

***Keywords**: refractory lining, monitoring, NDT methods*

1. INTRODUCTION

Refractory degradation is the primary cause of significant overhauls and relines in metallurgical and process vessels. This is why it is necessary to know the state of the refractory lining in furnaces and process vessels. Brick gaps may allow liquid metal or chemical leaks to penetrate, and a significant breach may cause a run-out, in which an unmanageable amount of molten material or undesirable chemicals spills into the environment, necessitating costly repairs and replacements as well as most importantly prolonged vessel downtime. Tons of refractory materials are dumped in landfills every year. Recently, there has been an attempt to recycle the refractory materials and repurpose them for different use [1-5]. However, a significant amount of refractories are impregnated with dangerous and aggressive compounds that have gone into the refractory pores from the process host and are unable to remove. Therefore, expensive and stringent monitoring systems are needed in landfills that contain refractory waste materials to ensure that hazardous, unstable substances won't seep into groundwater systems. Therefore, it would be ideal to reduce the amount of contaminated refractory debris at the source, through extending the campaigns for refractory lining. The NDT methods that have been applied to the inspection and monitoring of metallurgical furnaces and process vessels are briefly reviewed in the section that follows. These consist of discrete measurements like temperature analysis, infrared thermography, radioactive tracing, and refractory sounding, based on electromagnetic radar systems, magnetic-based systems, low frequency pulse ultrasonic, Acoustic Ultrasonic-Echo, and conventional thermocouple or fiber optic data. Additionally, the acoustic emission approach can be used as a continuous, long-term refractory monitoring method.

2. NON DESTRUCTIVE METHODS FOR BLAST FURNACE

Using mathematical models based on thermocouples and process-related furnace temperature measurements is the most popular method for figuring out the remaining refractory thickness in a furnace [2]. The precision and forecasting of heat transfer models and computational fluid dynamics (CFD) using finite element analysis (FEA) and other numerical techniques are predicated on the precision of the temperature data, the assumptions, the uniformity, and the accuracy of the thermal characteristics in the inner hot face, skull, and refractory. Although the thickness profiles produced by the mathematical models are essential and typical, errors are always produced when relying solely on temperatures and homogeneous parameters for heterogeneous media.

The use of ultrasonic waves to identify the remaining refractory lining is another developed method. Since the frequency of ultrasonic waves is higher than 20 kHz, their wavelengths are modest and their frequencies are typically set at the frequency of transmission. Because of their high frequencies, ultrasonic waves have a shallow penetrating depth. Furthermore, the ultrasonic waves attenuate quickly due to temperature, the multi-layered vessel cross section, and the heterogeneous refractory material properties. At most, a high energy pulser with a voltage between 2,000 and 10,000 volts or an extremely powerful energy source are needed.

Another very important issue with the ultrasonic wave is that the wave path “bends” due to high temperatures. This means that the reflections from the refractory hot faces will not echo directly back to the source. This deviation angle depends on the signal frequency, medium material properties, and temperature of the hot face [3-12].

The differences between ultrasonic and acousto ultrasonic-echo (AU-E) techniques are the followings:

- Impact produced Compared to ultrasonic pulses produced by piezoelectrics,

- AU-E pulses have a higher energy.
- Ultrasonic transmissions are narrowband, whereas AU-E signals are broadband.
- Several reflections from the surfaces aid in determining the refractory in the AU-E approach parameters, while numerous echoes and ultrasonic ringing are regarded as noise.

-The low frequency displacement Heat does not cause AU-E signals to bend, but ultrasonic waves do.

The most thorough method of keeping an eye on the status of the refractory liner in an operational blast furnace would be to combine thermal modeling based on the furnace temperature readings with a stress wave propagation methodology.

2.1. Ultrasonic

The mid-1980s saw the introduction of low frequency "Ultrasonic Pulse Velocity" (UPV) technologies like PUNDIT and V-Meter for assessing refractory quality. A refractory with a predetermined thickness is positioned between a transmitting and receiving transducer at opposite ends of the refractory sample using UPV systems. In general, low porosity, high density, and a high modulus of elasticity are indicated by high ultrasonic wave speed. In order to detect the thickness of refractory in a running furnace, "Ultrasonic Pulse-Echo" (UPE) systems are necessary. The transducers used for transmission and reception are positioned on the same surface in UPE systems. There should be very little space between the transducers used for sending and receiving. Parker et al. [13] showed that while the acoustic impedance in liquid is usually 13–15% lower than for a solid refractory or molten metal, the interface between the two produces a distinct reflecting surface accumulation, indicating that the wall is reflecting at least 10% of the waves. They showed in their research that temperature and porosity cause a significant amount of ultrasonic energy to attenuate within the solid refractory. As the sample was heated to higher temperatures, a decrease in the amplitude of reflected ultrasonic signals was observed. The travel route of an ultrasonic waveform in a solid is likewise influenced by temperature [14]. The longitudinal or P-wave path widens with increasing temperature, leading to increased attenuation and a shift in the reflection angle.

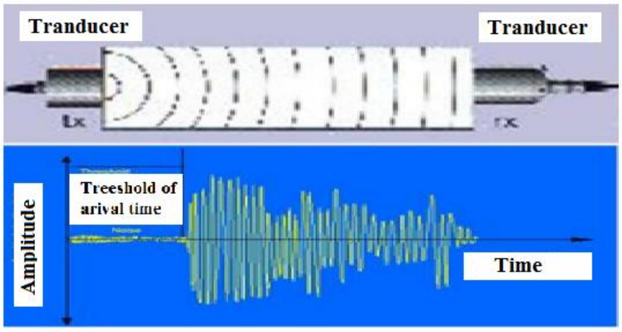


Figure 1. Ultrasonic through transmission method to determine wave speed in refractories and evaluate their QA based on longitudinal (P-wave) speed, dynamic modulus of elasticity and Poisson's ratio [7]

2.2 Acousto Ultrasonic-Echo (AU-E) Technique

In order to quantify the refractory thickness in operational metallurgical process vessels, like furnaces, the AU-E technique was created in the late 1990s. The theory and practical advantages of this non-destructive testing technique have been described in more than 80 papers to date, and it has received international patents.

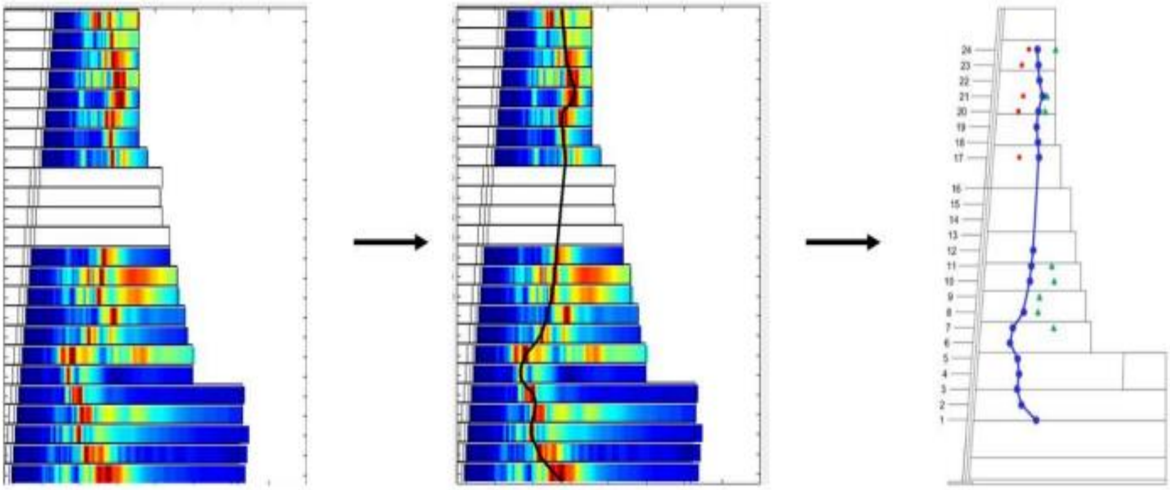


Figure 2. A typical AU-E thickness spectra accumulation for a blast furnace wall and its 2D interpretation on a furnace sidewall drawing [1,2,7]

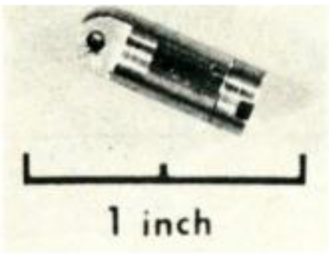
This approach was used in developing several testing methods, such are:

- Refractory Oxidation or Brittle Zone Detection

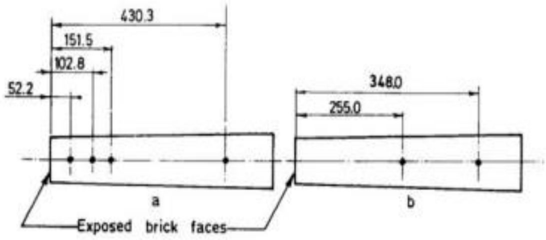
- Sidewall Refractory Wear

2.3. Radioactive traces

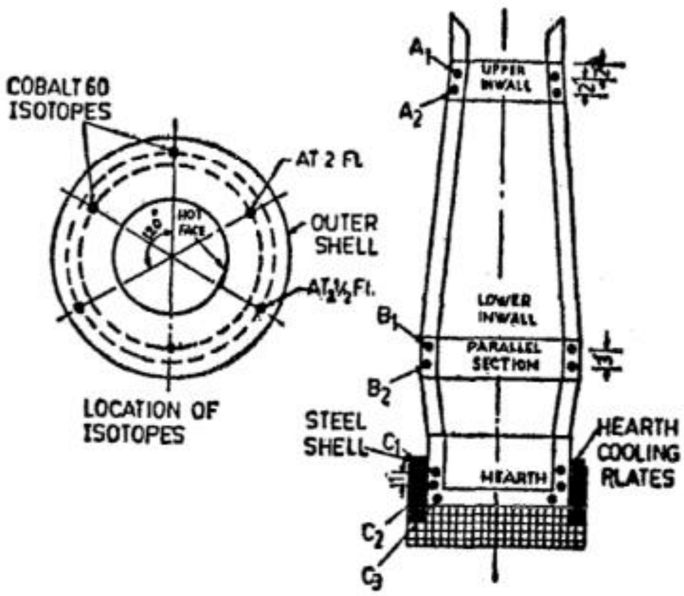
In the 1960s and 1970s, refractory thickness in blast furnaces was measured using radioactive tracers. The employment of tracers in blast furnaces has been the subject of several published works of literature [15-19]. This technique makes use of short-lived radioactive isotope tracers. The radioactive tracers were first used in previous studies to the blast furnace's top. The receiver, tracer counter, or Geiger counter measured the radiation that traveled through the build-up, refractory, and shell as the tracers moved downward with the load.



Radioactive tracer pod



Placement of pods in carbon refractory blocks at different thicknesses



Placement of the pods in different refractories at various locations in the blast furnace

Figure 3. Radioactive tracers for refractory thickness measurements in blast furnaces [1, 15]

2.4. Thermocouple or RTD

In order to forecast the refractory and/or skull thickness in operational furnaces and process vessels, refractory thickness assessments based on thermal analysis extrapolate thermocouple or resistance temperature detector (RTD) data [1,21]. This technique uses thermocouples or RTD temperatures at predetermined points in the water and refractory. The heat flux out of the furnace is computed using a one-dimensional steady-state heat transfer calculation using the stave temperatures. It is assumed that the refractory acts as a uniform heat conductor between the furnace shell and the hot inner face in these simplified thermal calculations. The heat flux is therefore taken to be constant throughout the refractory. The information for thermal calculations and thickness measurements is gathered using thermocouples or RTD and the water temperature in cooling blocks. Figure 4 shows an example of a standard thermocouple.

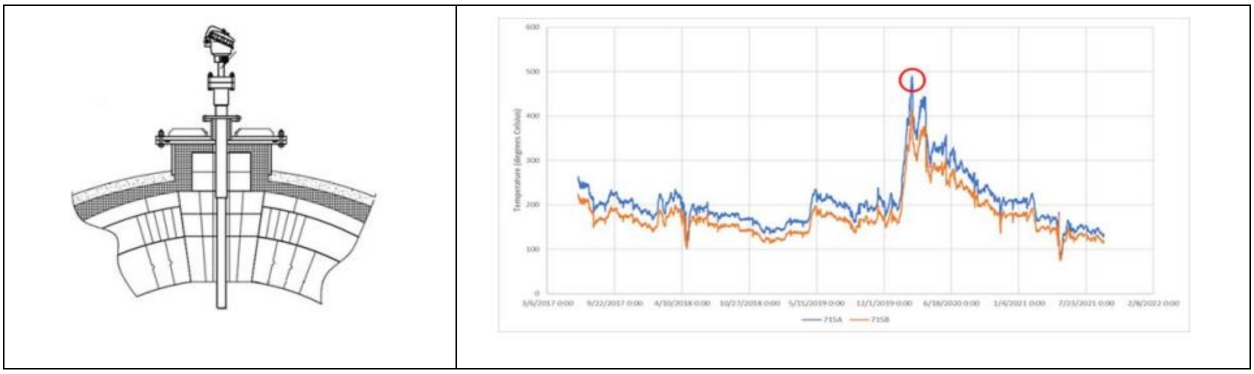


Figure 4. A typical thermocouple embedded and installed into a refractory lined vessel and Example of paired thermocouple data with analysis temperatures (degrees Celsius) highlighted in red [1]

2.5. Fibre optics

In single or multiple lined process vessels, such as kilns, reactors, and converters, magnetic systems are employed to measure the thickness of the residual refractory. The refractory strength can be ascertained using a device called a Covermeter, which is based on electromagnetics and was initially intended to detect the position of rebars in concrete elements. An electric current, also known as pulse-induction, regularly charges two coils, producing a magnetic field that produces an eddy current. A secondary, opposite field direction eddy current field is produced in the ferromagnetic body if one is close by, or more accurately, within the range. The distance between the coils and the ferromagnetic body can be ascertained by the strength of the secondary eddy current field that results. The converter probe can be positioned on the surface of the kiln or converter once the inspectors are inside. Refractory and gauge how far away the ship's shell is. Measurements are precise, especially in containers with brick linings, and many places can be measured quickly without drilling or lining removal. In Refractory anchors in castable lined vessels may pose problems if they are recognized instead of the shell; therefore, it is important to identify their position and take readings in between anchor positions (see Fig. 5) [1]

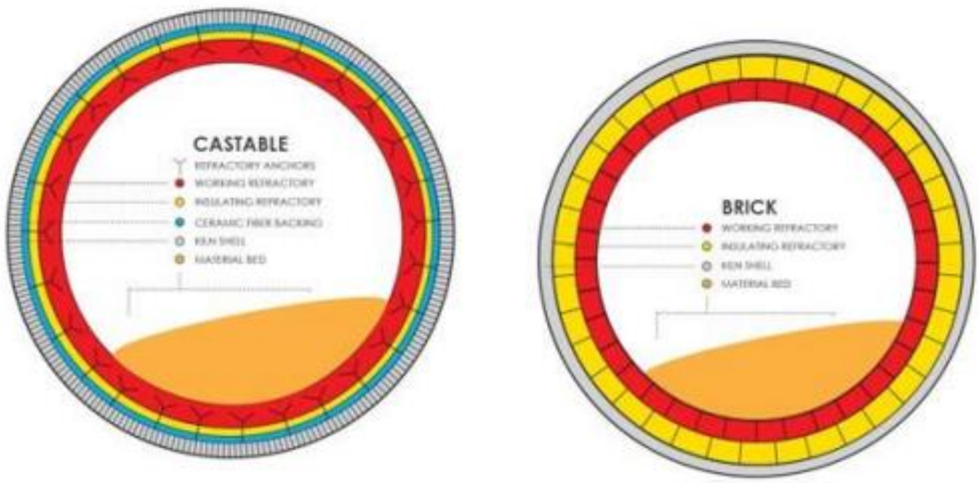


Figure 5. Castable and refractory lined kilns [1]

3. METHODS FOR CONVERTER

Many of the previously mentioned methods are available for other furnaces and devices in metallurgy, as well converter.

3.1. Laser method

A laser beam is utilized in this procedure to determine the thickness of the lining (Fig 6). The method involves bouncing a laser beam off of calibrated spots on the actual converter and comparing them to the points in the worn lining. The remaining lining thickness is then plotted using a computer analysis. Comparing the wear rates of various refractories and preventing shell damage are two other uses for this approach. This method is helpful in identifying and managing the necessary furnace maintenance through shooting. The locations that truly need gunning repair can be located and the necessary gunning maintenance can be performed by employing a laser beam.

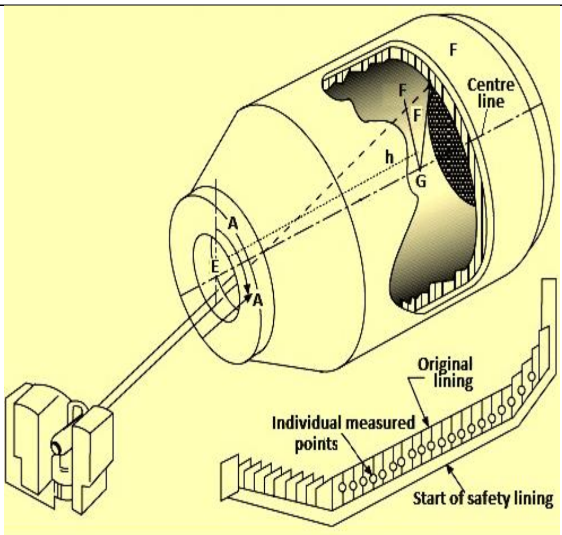


Figure 6. Measurements of refractory thickness using laser beam for converter [1,7]

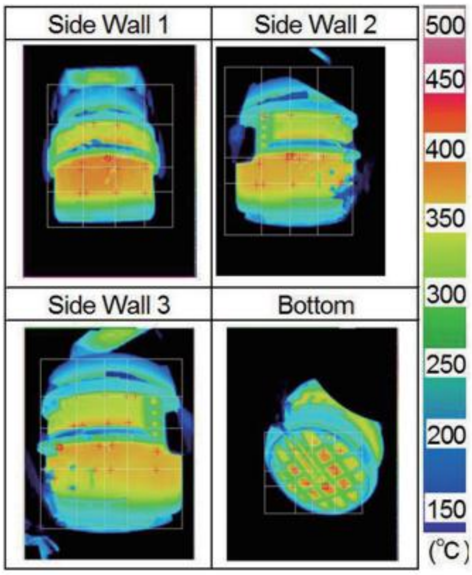


Figure 7. Picture of infrared thermography on hot metal ladle [1,20]

3.2. Infrared thermography (IR)

The most popular NDT method for identifying hotspots and possible trouble locations in a process vessel is infrared (IR) thermography, provided that the refractory and shell are securely bonded. IR cameras produce a thermal image that displays an object's temperature on a color scale, with the darker colors are hot places, whereas the lighter areas are cooler. Surface temperature variations could be the consequence of subsurface flaws or variations in refractory thickness. The primary benefits of infrared cameras are their inexpensive cost, quick inspection and interpretation speed, lack of contact, and remote use, which improves inspector safety. A wide range of methods have emerged in recent years. The primary benefits of infrared cameras are their inexpensive cost, quick inspection and interpretation speed, lack of contact, and remote use, which improves inspector safety. Many different systems have become commercially accessible in recent years, offering a wide range of various prices and image resolutions.

3.3. Ferotron

Ferrotron's LaCam systems utilize laser technology for non-contact measurement of refractory lining thickness in steelmaking vessels, including converters, ladles, and electric arc furnaces. These systems are designed to provide steel producers with accurate data for optimizing maintenance, reducing costs, and improving safety.

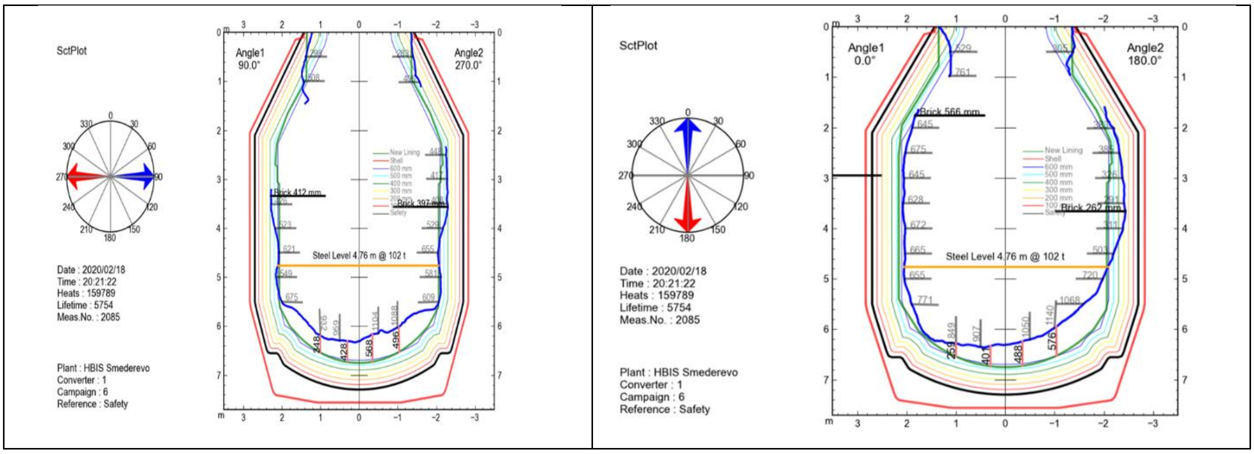


Figure 8. Ferotron measurement for converter [22]

3. CONCLUSION

The diagnosis technologies of refractories are essential in the manufacture of iron and steel production because they help to stabilize production equipment, reduce costs, and prevent issues like hot iron metal leaks and/or molten steel leaks. The use of refractory diagnostic technologies in blast furnace and converter in the steelmaking process that handles molten objects at high temperatures was the goal of this paper. Despite suggesting certain issues that need to be resolved, these diagnostic techniques are useful instruments for maintaining refractory-lined equipment. By implementing these advanced technologies on real equipment, it is crucial to improve the management accuracy of refractory-lined equipment.

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