Campaign life extension of COREX furnaces

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Refractory materials or heat resistance complex ceramics are designed to protect the structural integrity of metallurgical furnaces and process vessels from extreme thermochemical and thermomechanical changes. These refractories typically come as prismatic blocks like masonry bricks, coarse-grained and heterogeneous. During the smelting process, the hot face of the refractory lining faces abrasive turbulence and extreme temperatures over 1500°C.

The patented Acousto Ultrasonic-Echo (AU-E) technique has been developed to non-destructively inspect metallurgical furnaces and process vessels. This technique detects changes or chemical alterations in the refractory lining and measures the remaining refractory thickness. AU-E has been successfully applied to blast furnaces and electrical smelting furnaces. Recently, AU-E has been used on COREX furnaces to determine the remaining refractory thickness and estimate the remaining campaign life. This paper showcases this application, benchmarking the results with other furnaces globally. Comparisons can also be made for different sections of the furnace and with previous campaign lives, providing insights into furnace operation parameters.

KEYWORDS: ACOUSTO ULTRASONIC-ECHO (AU-E), REFRACTORY MONITORING, CAMPAIGN LIFE EXTENTSION, REMAINING CAMPAIGN LIFE

INTRODUCTION

Refractory linings in COREX furnaces deteriorate over time due to thermo-mechanical conditions, similar to blast furnaces. Common issues include cracking, chemical degradation, and loss of heat transfer capability. Traditionally, thermocouples and heat transfer analysis have been used to determine refractory wear. However, there is a need for non-destructive testing (NDT) and monitoring techniques to assess COREX lining conditions. NDT results aid in safe operation, production optimization, campaign life extension, and better maintenance scheduling.

Hatch developed an NDT technique known as the Acousto Ultrasonic-Echo (AU-E) (1, 2). It has been used for the determination of remaining refractory thickness, build-up thickness and location of cracks and chemical alterations in electrical furnaces, smelting furnaces and blast furnaces. In recent years AU-E has also been applied to COREXES for lining condition monitoring.

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THEORY

AU-E is a stress wave propagation technique that uses time and frequency data analysis to determine refractory thickness (3), and detect anomalies such as cracks, gaps metal penetration within the refractory lining. During an AU-E inspection, a mechanical impact on the surface of the vessel shell generates a stress pulse which propagates into the refractory layers. Once there is a change in acoustic impedance due to material change, the AU-E stress waves reflect. The degree of energy reflection depends on the acoustic impedance between the two materials (4). The acoustic impedance, Z, is defined by equation 1. The changes in material properties along the wave path may include gaps, cracks, and chemically altered refractory and build-up interfaces. Most of the wave energy propagates through the full lining thickness. The reflected compressive waves are then received by the receiver and the signals are analyzed for refractory quality and thickness assessment.

$$Z = \rho \times V_p \tag{1}$$

where **ρ** is the density and V_p is the P-wave velocity.

When the AU-E signals travel from less density, softer and lower stress wave velocity of material 1 to denser, harder and higher stress wave velocity of material 2, the acoustic impedance relationship between the two layers is described as $Z_1<Z_2$. When the two materials have similar acoustic impedance, i.e. $Z_1=Z_2$, no signal reflections will be observed at the material interface. Finally, when the relationship between the two layers is described by $Z_1>Z_2$, a total signal reflection will be observed at the material interface. This often happens at refractory and build-up interface, good refractory and impregnated/altered refractory interface, or refractory and air/fluid interface.

The stress wave velocity is governed by equation 2:

$$V_p = \sqrt{\frac{E_d(1-\upsilon)}{(1+\upsilon)(1-2\upsilon)\rho}} \tag{2}$$

where E_d is the dynamic Young's modulus of elasticity, V_p is the P-wave velocity, **ρ** is the density, and **υ** is the Poisson's ratio.

Based on the two equations, we can conclude that the AU-E waveforms are sensitive to material changes within the refractory. When refractory is exposed to an intense thermal and chemical environment, the chemical and physical properties of the refractory may be altered. Since the AU-E waveform is sensitive to material changes, the refractory lining areas that are affected by chemical changes can be identified and mapped by the AU-E inspections. However, the reflected AU-E signals from the brittle zone may be misinterpreted as the full remaining lining thickness. This error can be eliminated when both thermal analysis and AU-E thickness measurement data are used for the interpretation of the remaining lining thickness and lining condition. In the case that both the AU-E and thermal analysis indicated similar results, the confidence level of the assessment increases. However, if the results of the two assessment methods showed significant differences, then it may suggest that the lining has undergone severe chemical alteration, and further analysis will be required.

AU-E APPLICATION

The monitoring of the condition of a COREX hearth was made available by doing regular AU-E measurements on the furnace. The studied furnace was divided into sections and each section consists of a line of measurement points. The furnace can be divided into tuyere level, cast level and lower hearth level. An example of the remaining thickness profile is shown in Fig. 1. In the example, the cross-section showed the current measurement worn profile in blue. The accretion in front of the remaining refractory was shown as green triangles, while the location of anomalies was shown by red squares, which can be interpreted as gaps, cracks or chemical attacks within the refractory.

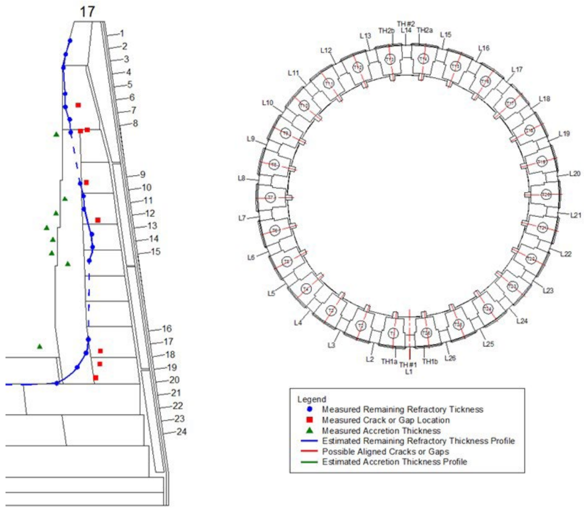

Fig.1 - Typical Remaining Refractory Profile at Different Elevations of a COREX.

The overall average thickness profile was also plotted by averaging the AU-E results of the 26 sections at each elevation (Fig. 2). The wear is also illustrated by a contour plot illustrated in Fig. 2. This analysis is particularly useful for identifying weak regions such as the formation and severity of elephant foot. AU-E data can also be grouped and analyzed as taphole and non-taphole regions, or at different elevation ranges, such as bosh, tuyere and lower hearth regions to provide further insight into the furnace conditions and weak spots.

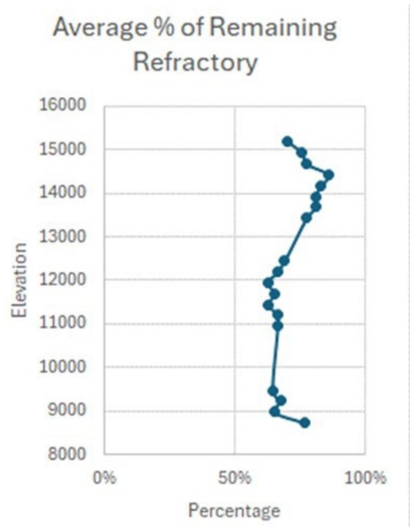

Fig.2 - Average Circumferential Remaining Refractory at Various Elevations of the COREX.

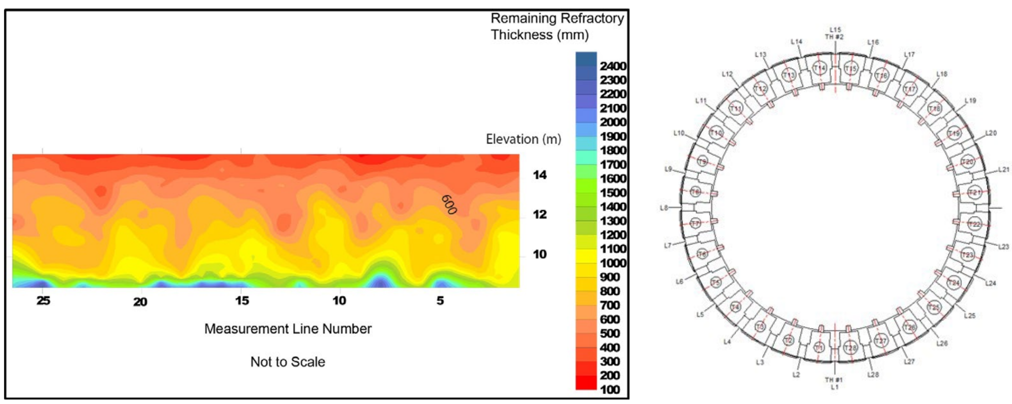

Fig.3 - Corex Remaining Refractory – Contour Plot.

Depending on the age and operation history of the furnace, more frequent AU-E inspections may be required. For a furnace that is in fair to good condition, an annual AU-E inspection is recommended. This allows the development of refractory deterioration trends and warnings for refractory lining maintenance or repair. For a furnace that has been inspected several times, a wear trend can be developed. This is illustrated by a blast furnace inspection example in Fig. 3. Assuming the furnace would be operated similarly, and that no intervention was introduced, the estimated average percentage of remaining refractory will reach a threshold of 25% remaining refractory by November 2028. However, this ideal situation may not happen. It is more likely that the variation in operation including ore materials, operation intensity, maintenance plans, shutdown periods, and ramp-up-ramp-down rates will all contribute to the variation in refractory wear. Thus, the wear trend must be updated based on further AU-E inspection results, and the frequency of the inspection may be increased toward the end of the furnace campaign life. Furthermore, the minimum remaining refractory thickness regions often dictate when the furnace needs to be relined and so the wear trend and location of the minimum refractory was also studied.

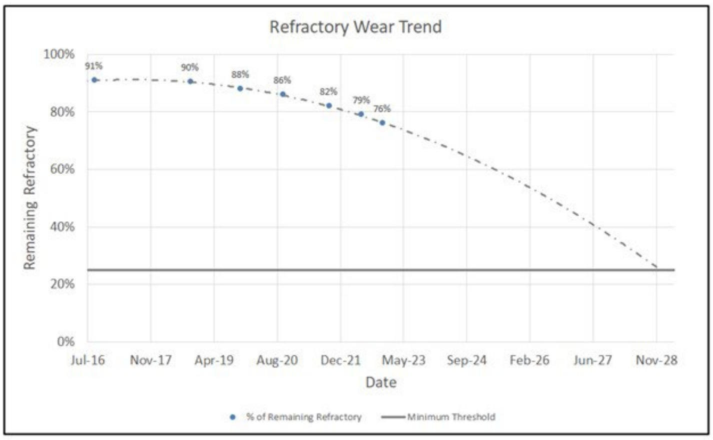

Fig.4 - Refractory Wear Trend Prediction of a Blast Furnace.

The AU-E inspection has been done for over a hundred vessels including blast furnaces and COREXES. Our catalogue information can be used to benchmark the performance of each furnace against some similar type and size furnaces worldwide, compare with the previous furnace campaigns, or compare with various furnaces within the same plant (Fig. 4). The AU-E results essentially provide a means for measuring the vessel's performance and can be a good indicator of any changes in operation parameters.

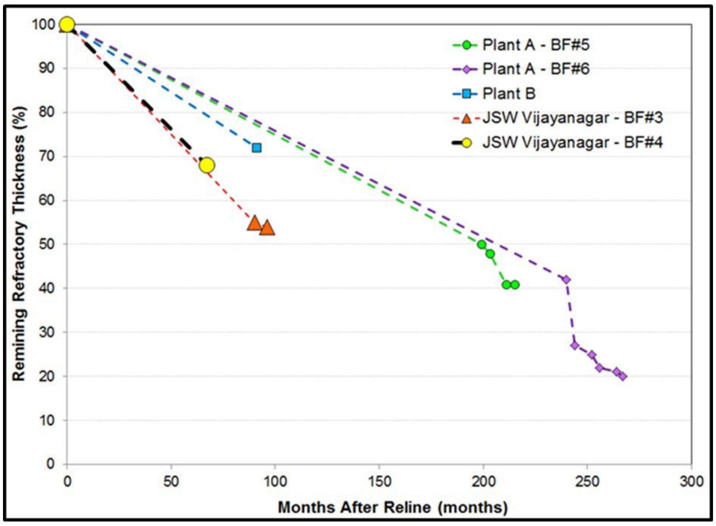

Fig.5 - Trend of Average Refractory Wear at the Lower Hearth Since the Startup of the Compared Blast Furnaces.

CONCLUSION

Iron-making vessels including blast furnaces and COREXES require regular inspection to determine the state of the vessel condition. This can optimize furnace campaign life, ensure safety, reduce the cost of maintenance, reduce furnace downtime; and hence, maximize production time. Regular AU-E inspection of the furnace not only provides a snapshot of the furnace condition but also the wear trend and end of campaign life estimates. Based on the results, plant managers can have better planning of relines and maintenance. Furthermore, the furnace campaign life performance can be benchmarked with other similar vessels or previous campaigns. This allows the study of the effect of operational parameter changes on the refractory lining.

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