Integrity Evaluation Procedure of an Incinerator Treating Explosive Wastes (Case Study)

ENKELEJDA KONDA[1], MIGENA ZEQO[1], DHIMITRAQ SOTJA[2,*]
[1]Department of Production and Management, Faculty of Mechanical Engineering,
Polytechnic University of Tirana,
ALBANIA

[2]Department of Mechanics, Faculty of Mechanical Engineering,
Polytechnic University of Tirana,
ALBANIA

Corresponding Author

Abstract: - Military munitions undergo both chemical and mechanical degradation over time, rendering them unsafe for use or storage. This degradation underscores the urgent need for demilitarization through methods such as physical destruction. Incineration, a key demilitarization technique, involves burning munitions at high temperatures in specialized facilities. This process effectively destroys the chemical components of explosives, reducing them to ash and gases, which can be further treated to minimize environmental impact. Albania, heavily militarized until 1991, faced significant safety and stability risks due to vast stockpiles of weapons following the collapse of its dictatorship. Incineration was chosen as an effective method for demilitarization. To ensure the safe and efficient operation of incineration facilities, adherence to international standards and European regulations is critical. Scheduled inspections and maintenance are essential for maintaining safety and operational efficiency. This article evaluates the integrity of an incinerator at the Military Explosive Plant of Mjekes in Albania, focusing on the cylindrical shell of the rotary kiln furnace, surface conditions, internal structure, and deformation. We propose the implementation of specific non-destructive testing (NDT) methods, including surface and volumetric testing of the rotary kiln furnace shell. These methods enhance integrity evaluation protocols, enabling early identification of potential issues and contributing to the safety, efficiency, lifespan, and regulatory compliance of waste incineration operations.

Key-Words: - Demilitarization plant; hazardous waste incineration; rotary kiln furnace; non-destructive testing (NDT); structural discontinuities; material defects; wall thickness loss; structural integrity assessment; periodic inspection protocols

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1 Introduction

The Military Explosives Plant of Mjekës, founded in 1962, is a state-owned facility situated in the village of Mjekës, within the Municipality of Shirgjan, Elbasan District, Albania. Initially established to supply explosives to the Albanian Armed Forces, the plant expanded its operations over time. In 1982, it began producing high-powered explosives under license from the Swedish defense company BOFORS. Its production portfolio has included dynamite, ammunition, black powder, slow-burning safety fuses, TNT, DNA, RDX, single- and double-base propellants (NG/NC), and nitrocellulose.

After the fall of the communist regime, the facility shifted its focus toward demilitarization. Through the NATO-led Trust Fund Concept under the Partnership for Peace—supported by countries such as Canada, Austria, Belgium, the Netherlands, Norway, Switzerland, and the United Kingdom—the plant was restructured to dismantle approximately 1.6 million anti-personnel landmines (APL).

In addition to neutralizing munitions, the process recovers explosive compounds and recyclable metals for civilian applications, contributing to environmental sustainability, [1].

To ensure safe and responsible operations, international bodies such as NAMSA and the European Union require compliance with strict pollution control standards. These include ISO 14001 for environmental management, AQAP

2130:20 for quality assurance, and the EU Directive on Waste Incineration (2000/76/EC) , [2].
Compliance with these regulatory frameworks safeguards facility operations and contributes to environmental protection.
The industrial demilitarization process involves:
a) Separating all ammunition components.
b) Removing explosives and pyrotechnic elements from other components (metallic, plastic, etc.).
c) Destroying propellants and explosives with no recycling value and pyrotechnic elements.
d) Demilitarizing ammunition components (rendering them unsuitable for military use); and
e) Packaging and storing explosive residues with potential recycling value for civilian industries or local markets. Mjekës Plant was responsible for approximately 60% of the industrial demilitarization load (Table 1), [3].

Table 1. Data on industrial demilitarization repartition according to initial destruction plan, [3]

Ammunition	Mjekes Plant	Others Plants	Total (tonnes)
7.62–14.5 mm	9,920	7,011	16931
20–160 mm	21,417	14,032	35449
Total	31,337	1,283	52380

To destroy the extremely widespread light weapons ammunition 7,62 mm and anti-personnel landmines used by the Albanian army and which are in a very large stock, a special military incinerator (EWI) is used, which force them to explode inside a metal cylinder (Figure 1).

Fig. 1: Explosive Waste Incinerator (EWI) – Mjekes

2 System Description

The Explosive Waste Incinerator (EWI) system consists of a Rotary Kiln Furnace and an Air Pollution Control System (APCS), which includes an afterburner, gas cooler, baghouse filter, and a stack fan (Figure 2).

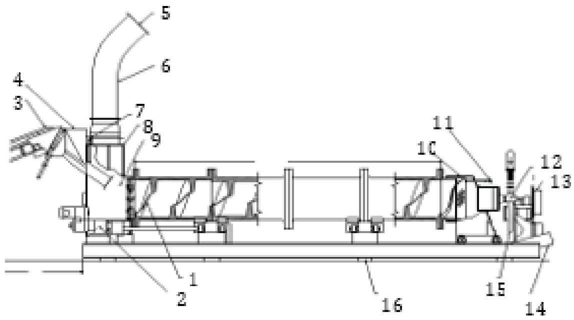

Fig. 2: Explosive Waste Incinerator (EWI), [4]
1- spiral flighting; 2-varidrive motor; 3-upper feed conveyer. 4-upper feed chute; 5-air pollution control system; 6-exhaust duct; 7- thermocouple; 8-feed end Assy; 9-lower feed chute. 10-discharge end Assy; 11-burner end thermocouple; 12-burner; 13-aux control panel; 14-discharge conveyer; 15-combustion air blower; 16-concrete pier foundation)

2.1 Rotary Kiln Furnace

The main part of the Explosive Incinerator System is the Rotary Kiln Furnace (RFK). The rotary kiln furnace, as shown in Figure 1, consists of four sections. Each section is about 1.5 meters long.

The two midsections where most of the detonation blasts occur are 82 mm thick, and the other two end sections 58 mm thick.

Each section features internal spiral flighting to facilitate the movement of explosive waste materials through the furnace. The explosive wastes stay inside the furnace for a total of eight revolutions. The furnace rotates at adjustable speeds, controlling the duration of waste exposure to elevated temperatures. This controls how long the explosive wastes stay in the furnace and when they start to burn or detonate.

The burner unit, located at the discharge end, operates on fuel oil with a maximum heat capacity of 1.8 million BTU per hour. The burner is equipped with a flame detector that shuts off the fuel. supply and triggers an audible alarm if the flame extinguishes. If the flame goes out, the fuel supply to the burner will shut off, activating an audible alarm at the control panel.

2.2 Feed Conveyer System

Feed Conveyer System (FCS) is a metal pan-type conveyor moving approximately 13 meters per minute. As shown in Figure 2, the FCS is used primarily to destroy ammunition. The FCS is inclined and 20 cm wide. The conveyor moves the explosive waste (ammunition) from the feed room through the barricade wall, then drops them into the feed chute and to the rotary kiln furnace.

2.3 Discharge System

Metallic materials recovered after incineration are discharged onto a conveyor, which transports them through a concrete barricade window to a holding wagon for collection.

3 Integrity Evaluation of Rotary Kiln Furnace through life service

The evaluation of the integrity of a rotary kiln furnace within the demilitarization sector is crucial for maintaining safe and efficient operations throughout its operational lifespan. The controlled detonation process necessitates the introduction of light weapons ammunition and anti-personnel landmines into the furnace, where they primarily detonate in the second and third sectors, which are characterized by the most substantial wall thicknesses. The combustion process of the ammunition within the furnace is marked by cycles of intense explosions that exert significant force on the furnace walls, generating high pressure and extreme heat.

A comprehensive integrity assessment of a rotary kiln's metallic structure requires a multidisciplinary approach, incorporating visual inspections, non-destructive testing (NDT) techniques, structural analysis, and thorough documentation. Establishing a systematic evaluation protocol is essential for early detection of defects, thereby enhancing operational safety and extending the service life of the kiln. Prioritizing safety and performance through regular assessments is fundamental to effective kiln management.

The rotary kiln furnace is fabricated from cast steel, a material whose complex casting process demands rigorous quality control. In this context, NDT methods play a critical role in verifying structural soundness and detecting casting-related discontinuities. Typically, a combination of radiographic tests (RT), magnetic tests (MT), penetrant tests (PT), and ultrasonic tests (UT) are employed. Defects arising from foundry manufacturing can generally be classified into surface defects, mold-related defects, and metal related defects.

Surface defects manifest in several forms, [5], [6]:

a. Porosity. This can be further classified based on the characteristics of the internal surface. Common types include cracks, pinhole porosity, and large gas porosity:
b. Skin Defects. These may include wrinkles, poor surface finish, vitrification, burn-on and metal penetration, [7].
c. Inclusions: These are particles of foreign materials embedded within a metallic matrix. According to industry standards, inclusions may include dross, slag Inclusions, sand drops, graphite, metallic inclusions.
d. Thermal expansion defects: Resulting from the thermal expansion of silica, these defects include scabs and buckles, erosion scratching, rattails, veining, [8], [9].

The classification of surface discontinuities in cast structure is done by utilizing visual-tactile comparators, and according to the standards two sets of patterns are commonly used, [10], [11], [12]:

- BNIF No 359
- SCRATA ASME 802

Acceptance levels utilize these comparators for the visual determination of surface roughness and surface discontinuities described as follows:

- Surface roughness
- Thermal dressing
- Mechanical dressing
- Nonmetallic inclusions
- Gas porosity
- Fusion discontinuities
- Expansion discontinuities
- Metal Inserts
- Welded surfaces

Mold-Related Defects

Mold-related defects can arise from three primary sources associated with the molding process.

a. Molding defects: These encompass issues such as mold breakage, sinking, mismatch, swelling, mold breakdown, mold lifting.
b. Mold-metal reaction defects: these occur due to reactions between the mold and the molten metal, leading to issues such as shrinkage, graphite precipitation, carbide formation, cold shot.
c. Cracks or iron oxides in the internal surface of the defect.

Metal-Related Defects

The classification related to cast alloy are shrinkage, graphite precipitation, graphite degeneration, carbides formation and cold shot.

An inspection of the furnace was conducted to assess the structural integrity of the rotary kiln,

focusing on identifying discontinuities or defects caused by thermal or mechanical stresses. This evaluation was particularly challenging due to the absence of an initial assessment prior to operation, as well as the lack of periodic inspection records and regular maintenance documentation.
The inspection process included the following steps:
Visual inspection: Examination of surface conditions, discontinuities, deformations, and any deviations from the cylindrical shape of the kiln shell.
Ultrasonic inspection: Ultrasonic testing to measure the thickness of the kiln shell, detect internal discontinuities, and identify areas where material loss (thinning or erosion) had occurred because of the incineration process (Figure 3).

Fig. 3: Ultrasonic thickness measurements and volumetric scan conducted on the rotary kiln shell

3.1 Visual Inspection

Visual inspection remains the most immediate and practical method for assessing structural condition during production. Beyond its efficiency, it plays a critical role in verifying structural integrity throughout operational life. The process focuses on tracking the evolution of existing discontinuities and identifying new defects, particularly those exacerbated by thermal or mechanical stress.
The acceptability of observed discontinuities is determined through expert judgment, consultation with the manufacturer, and compliance with EN 1370:2012, [13]. This standard defines criteria for evaluating surface irregularities in castings, offering a structured approach to distinguish between acceptable and non-acceptable defects based on their type, size, and location.
According to that standard, surface discontinuities are classified by:
1. Dimensional characteristics (height H and length L, see Fig. 4);
2. Visual-tactile comparators, specifically for steel and iron castings.

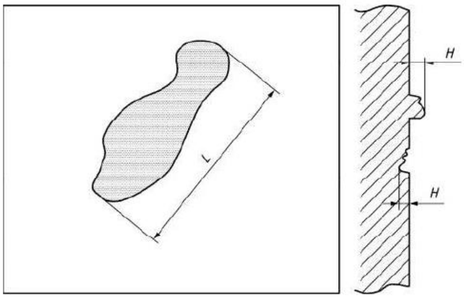

Fig. 4: Size of discontinuities L and H

EN 1370 [13] defines eight severity grades, from VD1 for precision castings to VD8 for large-scale cast components, each outlining acceptable surface discontinuity limits based on casting size. The term "VD" refers to the **V**isual examination of discontinuities in **D**imensions. The rotary kiln furnace, classified as a large casting, will be assessed at intervals VD7 and VD8. Specifically, the height (H) for VD7 is set between 1.5 mm and 3 mm, while for VD8, it ranges from 2 mm to 4 mm. Additionally, the minimum and maximum lengths within the height range are established at 15 mm and 20 mm, respectively.

The visual inspection indicates the following findings:
1. The outer surface of the rotary kiln furnace generally presents a rough texture resulting from the casting process, characterized by small pores and localized voids. Typically, the surface exhibits a metallic gray hue, which over time has developed an oxide scale layer due to prolonged exposure to high temperatures and oxidizing environments within the kiln. This oxide scale manifests as a dark, flaky layer (Figure 5).

Fig. 5: Rotary kiln furnace surface appearance

2. Localized porosity was identified as a significant cluster in the first cylindrical section of the furnace body. The dimensions of this porosity exceed the

acceptable limits for surface defects as outlined in standards such as EN 1370 [13] and other relevant guidelines. This porosity cluster has created a vulnerable zone within the material, increasing its susceptibility to cracking or failure under mechanical or thermal stress. Consequently, it poses a risk to the structural integrity and corrosion resistance of the furnace (Figure 6).

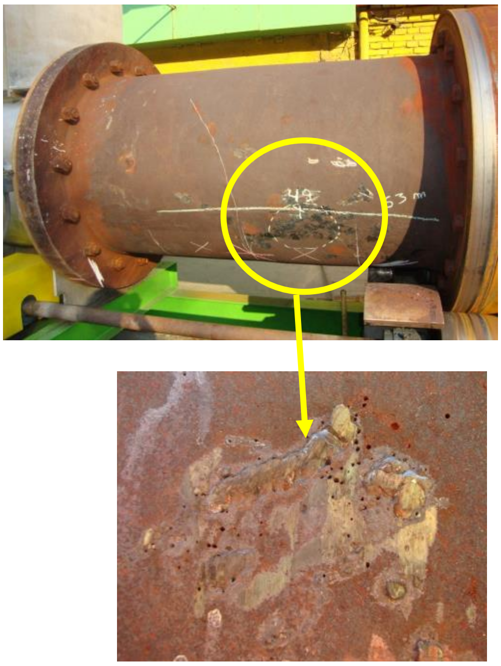

Fig. 6: Porosity cluster on the first section

3. A discontinuity measuring 18 mm in longitudinal extension and 7 mm in depth was identified on the outer surface of the second cylindrical section of the kiln rotary furnace body (Figure 7). This section is recognized as the most heavily utilized part of the furnace. The depth of the discontinuity was identified and found using the ultrasonic testing method (UT). Given the dimensions of this discontinuity on the surface of the furnace shell, it is likely that it could potentially compromise the integrity of the furnace as a whole, particularly under operational stresses in a high-temperature and high-stress environment typical of rotary kiln furnaces (Figure 7).

4. Several localized delaminations were identified on the external cylindrical surface of the furnace shell. The depth of these discontinuities was evaluated through Ultrasonic Testing (UT) and determined to be within the range of 4 to 6 mm. (Figure 8).

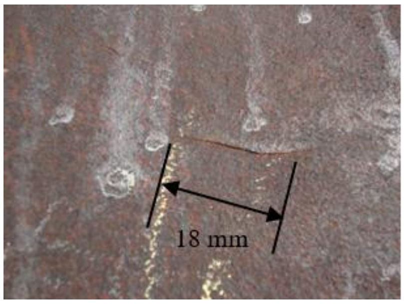

Fig. 7: Discontinuity identified on the external surface of the second section of the furnace shell

Fig. 8: Localized delamination on the external cylindrical surface of the furnace

5. Localized repairs through welding of previously damaged areas were identified. These areas correspond to surfaces that had been previously repaired, where scratches and chipping, deemed unacceptable, were addressed through welding. There is insufficient data regarding the type of filler used or the welding parameters, raising concerns about the quality of the welding and the mechanical properties of the affected areas. The visual inspection results for these areas were also considered unacceptable. The cavities created by the removal of discontinuities and the preparation process for welding have not been adequately filled with filler material, and proper fusion between the filler and the base material of the kiln rotary furnace has not been achieved (Figure 9).

Fig. 9: Localized repair of damage through welding

6. In the second section, a significant amount of welding has been applied along the corresponding internal spiral flighting flutes, indicating an effort to

repair or reinforce a heavily worn or damaged area. This region has experienced thermal expansion and fatigue. The absence of data concerning the overall dimensions, welding parameters, and filler wire utilized raises substantial concerns regarding the quality of the repair. The welding appears excessive and poorly executed, which may lead to additional complications. The weld seam surface displays irregularities, including uneven deposition of weld material and visible "start and stop" points, which are indicative of inadequate welding techniques and a lack of continuity in the welding process. Failed "start" and "stop" points can create weak zones in the weld, increasing the risk of cracking and failure. There is clear evidence of a lack of fusion between the weld consumable (filler material) and the base material. The welded areas have surface swelling with excessive deposition of weld material which illustrate the fact of using an inappropriate welding procedure (Figure 10).

Fig. 10: Welded repaired areas along the corresponding internal spiral flighting flutes

3.2 Deformation Issues in the Rotary Kiln Furnace Body Sections

The monitoring of structural deformations in a rotary kiln furnace shell is of particular importance, extending beyond mere routine maintenance. It plays a critical role in ensuring safety, optimizing operational efficiency, maintaining product quality, and adhering to regulatory standards. Significant deformations can compromise the structural integrity of the furnace, diminishing its capacity to endure operational stresses and potentially resulting in catastrophic failures.

Dimensional and shape deformations of the furnace body can lead to uneven heat distribution, decreased thermal efficiency, and the birth and creation of hotspots, all of which adversely affect operational performance. To evaluate structural deformation, they are measured geometric distortions along the generatrixes of the cylindrical furnace shell. In sections I, III, and IV, four generatrixes were considered at 90-degree intervals. In the second section, where deformation it is visually more noticeable, the number of generatrixes was increased to 14, each aligned with the bolt axis line of the furnace cylinder flanges, as illustrated in Figure 11.

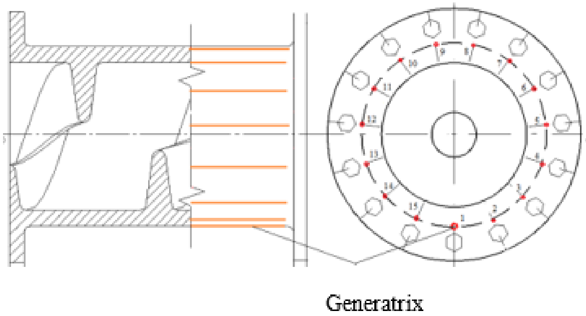

Fig. 11: Generatrix positions on Section II

The most significant deformations were identified in the second section, where deviations in generatrix linearity reached up to 22 mm, particularly in regions aligned with the corresponding internal spiral flighting flutes. These deformations were noted in the repaired weld areas and extended into the base material adjacent to these locations, where deviations from a cylindrical shape were evident. The observed deformation in this area is related to prolonged exposure to repeated thermal stress, which has led to metal fatigue and compromising the structural integrity.

The first and final section demonstrated an average maximum linearity deviation of 8 mm, which it is considered within the acceptable parameters for iron-casting components which have dimensions of the range 1500 mm in length, [14]. Nevertheless, in localized regions at the extremities of these sections, where they join with the central section, are found deviations reaching up to 15 mm.

In the fourth section, geometric deviations were considered acceptable, exhibiting an average maximum linearity deviation of 7 mm, [15], [16], [17] (Figure 12). This indicate a relatively stable condition in comparison to the other sections.

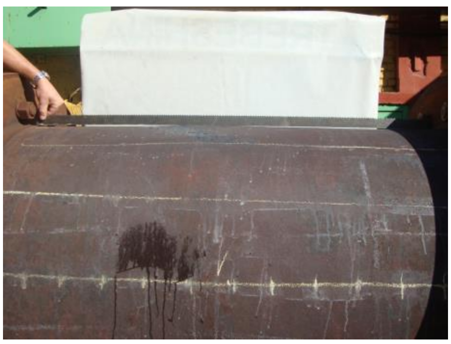

Fig. 12: On-site measurement of generatrix linearity

3.3 Ultrasound Thickness Measurement of Wall Thickness

Regular monitoring of the kiln shell's thickness is essential for maintaining structural integrity, preventing failures, and optimizing maintenance schedules. Ultrasonic testing (UT) is a well-established non-destructive method used to assess material condition. In this context, ultrasonic thickness measurement (UTM) offers a dependable way to monitor wall thinning and detect corrosion-related loss.

According to the technical specifications, section thicknesses vary: the first and fourth segments are nominally 58 mm thick, while the second and third measure 82 mm. Several factors influence UTM accuracy, including material type, surface condition, temperature, and accessibility.
Before conducting UTM, the kiln must be shut down and allowed to cool to a safe working temperature. The inspection area should be cleaned thoroughly to remove scale, oxidation, or debris. Calibration of the ultrasonic gauge is performed using a reference block of known thickness to ensure measurement reliability. The equipment utilized for thickness measurement is the OLYMPUS 650, a portable device equipped with a flexible cable to access difficult areas. Probe selection is determined by the properties of the kiln's rotary furnace material. We opted for a longitudinal wave probe with a frequency of 2 MHz and a crystal size of Ø20mm. Calibration of the equipment is performed on the IIW calibration block at three positions: A, B, and C (Figure 13).

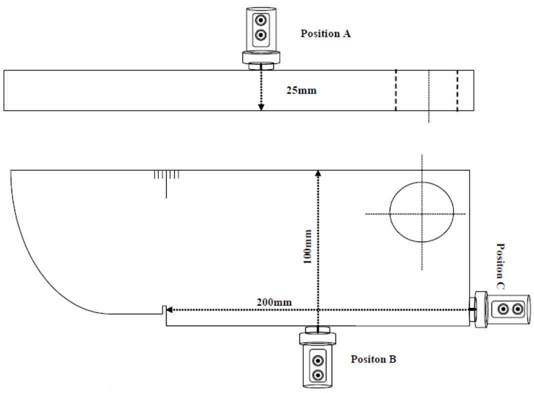

Fig. 13: Calibration of equipment in three positions

The calibration range scale has been established on a defect-free area of the material under examination. Specifically, a visually flawless section of the flange from the first segment was designated as the reference block for calibration range and sensitivity (Figure 14). The range scale should be selected to ensure that a minimum of two back-wall echoes (reflections) are consistently visible on the screen. The flange's thickness was measured using a calibrated caliper, with the back echo set to 80% of the screen height as the reference gain, with an additional of +12 dB for the ultrasonic thickness measurement (UTM) test, [18], [19].

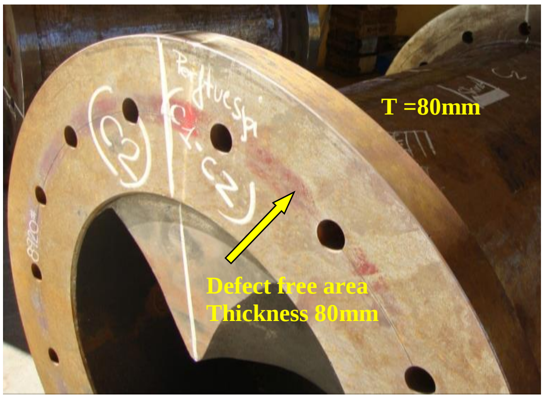

Fig. 14: Flange of the first section, which serves as the reference block for calibrating sensitivity

The procedure for measuring wall thickness using Ultrasonic Testing (UTM) includes measuring the thickness along the generatrixes as specified in section 3.2 of this article. Measurements were conducted at intervals of 100 mm along four generatrixes for sections I, III, and IV, positioned at 90-degree angles to one another (Figure 15), and along fourteen generatrixes for section II (Figure 10).

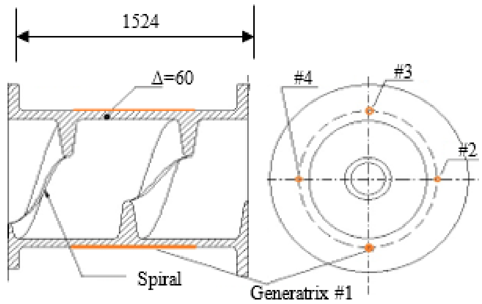

Fig. 15: Generatrix positions on Section I, III, and IV

The data collected are presented in Figure 16 in four sections.

Additionally, thickness measurements serve as a partial scan of the rotary kiln furnace wall. It is important to note that only discontinuities oriented perpendicular to the probe's axis can be detected. The discontinuities identified during the wall thickness assessments were considered as acceptable. The evaluation of the size and typology of these defects was conducted in accordance with the established UT inspection standards, [20], [21]. According to the acceptable level standards evaluation of this furnace, the reductions in the thickness of the walls for the three sections I, II, and IV of the kiln furnace shell are completely acceptable.

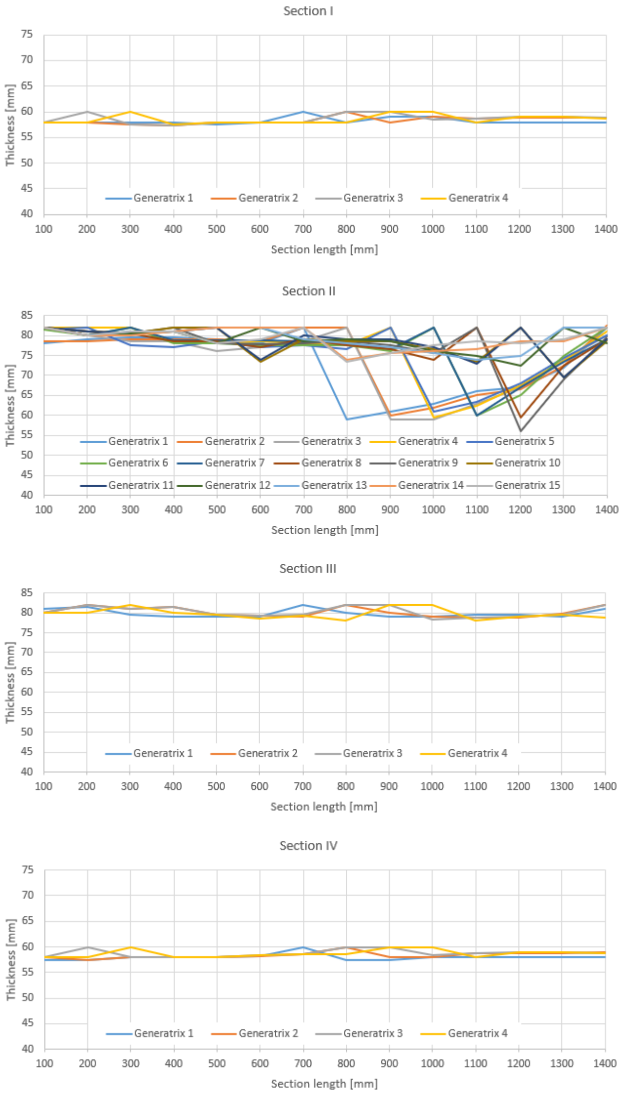

Fig. 16: Wall Thickness measurements on four sections

The second section of the furnace body, which, according to the manufacturer's drawing, should have a wall thickness of 82mm, is the part that has the most significant loss in thickness. This area of reduced thickness aligns with the deformed zone identified in the previous section, where notable deviations from its cylindrical shape were also observed. Furnace shell wall thickness reductions result in strip shapes approximately 40 to 50mm wide, with the most pronounced reduction occurring near the spiral flute, an area prone to increased explosive activity. In these regions, wall thickness has diminished to values ranging from 59 to 64 mm, representing a consumption level of approximately 17% compared to the initial thickness of 82 mm, a critical factor to be considered (Figure 17).

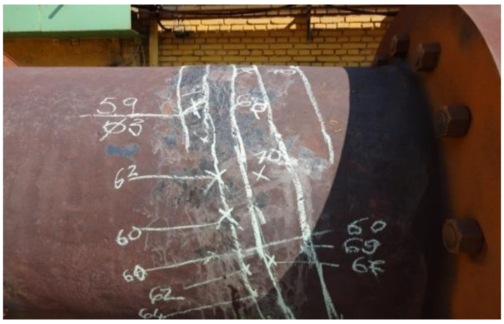

Fig. 17: Wall thickness measurement in the repaired area in the second section of the furnace body shell

4 Results of the Inspection

The inspection procedure conducted on the rotary kiln furnace body provide comprehensive data to evaluate its structural integrity. Delamination, predominant cluster porosity, and areas of substandard welding repairs were identified in the first, third, and fourth sections. It is advised that these defects be rectified in accordance with welding standards to ensure a quality weld. Additionally, other surface discontinuities in these sections should be monitored to assess their progression throughout the operational lifespan of the furnace.

In the second section, various issues were noted, including surface defects, deformation, non-compliant welding practices, and a reduction in wall thickness. A substantial area being repaired through welding has been observed, which raises significant concerns regarding the quality of the weld and its potential effects on the mechanical properties of the surrounding area. Significant wall thinning has been observed, along with deformations from the original cylindrical profile, reaching up to 22 mm. These changes are attributed to internal pressure effects, which have compromised both thickness and geometry. Based on these findings, replacement of Section II is recommended.

5 Conclusion

The combined application of visual inspection and ultrasonic thickness measurement (UTM) has proven effective for monitoring the structural condition of rotary kiln shells used in explosive waste incineration. The evaluation revealed significant material loss, particularly in Section II of the kiln, where deviations from the ideal cylindrical geometry were most pronounced. A clear relationship was observed between the extent of wall thinning and the degree of structural deformation, underscoring the cumulative impact of thermal and mechanical stresses over the kiln's operational lifespan.

The integrity assessment procedure developed in this study serves as a foundation for maintenance planning. By identifying critical areas in advance, the approach supports risk mitigation, extends equipment longevity, and promotes safe, efficient operation.

Looking ahead, future efforts will focus on optimizing inspection intervals, implementing a centralized data management system for comparative analysis, and tracking structural evolution over time. Emphasis will also be placed on temperature monitoring in zones exhibiting deformation or advanced wall loss, offering deeper insight into the kiln's behavior under thermal load. Collectively, these strategies aim to establish a more predictive and resilient maintenance framework for long-term kiln reliability.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors wrote, reviewed and edited the content as needed and verifies that none utilised artificial intelligence (AI) tools were used. The authors take full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Enkelejda Konda formulated the problem and carried out the investigation process and data collection.
- Migena Zeqo, Dhimitraq Sotja applicated formal techniques to analyse study data and prepared the draft

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