FOUNDRY WORKS

Level-II

Based on December 2021, Curriculum Version 1

Module Title: Refractory Lining and Repair

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Acknowledgment

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Acronym

TTLM	Teaching, Training, Learning Materials
TVT	Technical and Vocational Training
LAP	Learning Activity Performance
RCF	Refractory Ceramic Fibre
(RPE)	Respiratory Protective Equipment
(ASRs)	Air-Purifying Respirators
OHS	Occupational Health and Safety

Introduction to the Module

In the field of foundry, A refractory lining is a safety protective layer in industrial furnaces, pipes, or equipment that provides high-temperature resistance and protects the structure from thermal shock, wear and erosion. The refractory lining protects the pipe or equipment material from direct exposure to heat from fire or fluids. They are very important components for boilers, furnaces, and certain pipes. The correct installation of refractory is essential to ensure the safe and efficient operation of furnaces and boilers. In this article, we will learn about the materials, selection, and procedure for the refractory lining. Let's dive into the subject starting from its definition.

Refractory lining is basically a protective layer installed inside the furnace to protect the steel structure from high temperatures. Refractory bricks or monolithic refractories can be used for refractory lining. This selection is determined by the indented heat levels of the furnace and/or the chemical structure of the material being processed inside. Refractory lining is one of the most important things to look for during the installation. A professionally placed lining will increase the lifetime of the furnace and lower the energy costs. In general, refractory lining thickness is in between 80 mm and 300 mm. However, the thickness should be determined for each project differently.

Refractories come in all shapes and sizes. They can be pressed or molded for use in floors and walls, produced in interlocking shapes and wedges, or curved to fit the insides of boilers and ladles. Some refractory parts are small and possess a complex and delicate geometry; others, in the form of precast or fusion-cast blocks, are massive and may weigh several tons.

Figure 1 refractory brick

This module is designed to meet the industry requirement under the foundry works occupational standard, particularly for the unit of competency: **Refractory Lining and Repair**

This module covers the units:

- Inspect refractory
- Knock out refractory
- Refractory materials
- Installation of refractory

Learning Objective of the Module:

At the end of the module the trainee will be able to:

- Inspect refractory lining on its specification
- Knock out refractory
- Identify the Refractory materials and their applications.
- Install refractory using deferent technics.

Module Instruction

For effective use this modules trainees are expected to follow the following module instruction:

1. Read the information written in each unit
2. Accomplish the Self-checks at the end of each unit
3. Perform Operation Sheets which were provided at the end of units
4. Do the "LAP test" giver at the end of each unit and
5. Read the identified reference book for more resources and Examples and exercise

Unit One: Inspection of Refractory

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- Safety (OHS) requirement
- Interpretations of refractory specification.
- Specific areas of refractory.

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this unit, you will be able to:

- Apply refractory Safety (OHS) requirement
- Interpret the refractory specifications.
- Identified the Specific areas of the refractory for repair or replacement.

1.1. Safety (OHS) requirement

Information, instruction and training

All workers should be given the appropriate information, instruction and training to enable them to appreciate the hazards and risks from RCF and why it is important for them to observe the correct precautionary measures, e.g. wearing respirators and maintaining good standards of housekeeping and hygiene.

Hygiene/welfare

Eating, smoking and drinking in areas where there is risk of contamination by RCF should be prohibited. Breaks for food and drinks should be taken in a separate, designated 'clean' area and overalls should be removed and hands washed before eating.

Washing facilities and, where necessary, showers should be provided to enable workers to maintain an appropriate standard of personal hygiene.

When contractors are carrying out work, arrangements should be made between their employer and the person in charge of the site for adequate welfare facilities to be made available.

Protective clothing

Protective overalls should be worn when handling RCF. For dusty operations, loose-fitting one-piece disposable overalls, preferably with a hood, should be used, and disposed of at the end of each shift. Thought should be given to minimising exposure to any residual dust clinging to overalls when they are being taken off. Wearing gloves when handling RCF will help prevent skin irritation.

Personal protective equipment (PPE) for Refractory lining

In Refractory lining and repair work a number of PPE are used to protect us from deferens hazards. Those are:

1. Chemical prof full clothing
2. Long and chemical proof shoe
3. Chemical proof glove
4. Eye protection goggle
5. Hard hat or helmet and use additional suitable PPE for better safe.

Respiratory protective equipment

As exposure to RCF must be reduced to the lowest level reasonably practicable, appropriate respiratory protective equipment (RPE) will need to be used when maintenance, wrecking, or any other job likely to result in significant levels of dust is being carried out (this will be the case despite the above precautions being taken).

There are two main types of respiratory protection—**air-purifying respirators** (APRs) and **atmosphere-supplying respirators** (ASRs). Each respirator type provides a different level of protection based on its design. Therefore, it's important to choose the right type of respirator for the specific exposure.

Figure 1.1 utilization of Respiratory protective equipment

1.2. Interpretations of Refractory specification

1.2.1. Refractory Lining

Refractory Lining is a layer of material which can resist high heat temperature in the kiln or furnace. The refractory lining can also resist thermal shocks, erosion, physical attack and chemical attack.

Figure 1.2 Refractory Lining

Refractory lining is a kind of refractories, composed of refractory bricks and monolithic refractory materials. Refractory lining is used in the inner of kiln, furnace, incinerator, and oven and so on. The commonly used refractory bricks in refractory lining are high alumina bricks, silica carbide bricks, silica mullite brick, etc. The widely applied monolithic refractory lining is aluminum silicate castable.

1.2.2. Purpose of Refractory Lining

Refractory lining is widely used in very high-temperature services in order to

- Serve as a thermal barrier between the pipe/equipment wall and hot medium.
- Withstand physical stresses.
- Protect against corrosion and erosion.
- Provide thermal insulation

As a reason refractories are found in various useful applications. They are extensively used in furnaces, kilns, reactors, fired heaters, hydrogen reformers, ammonia primary and secondary reformers, cracking furnaces, utility boilers, catalytic cracking units, air heaters, sulfur furnaces, and various other vessels handling hot mediums such as metal and slag.

1.2.3. Refractory Lining Properties

1. Heat damage resistance.
2. Slag erosion resistance.
3. Chemical corrosion resistance.
4. Physical corrosion resistance.
5. Wear resistance.
6. Thermal storage

1.2.4. Application of refractory lining

a. Refractory Lining of Blast Furnace

During the production of blast furnace, series of severe physical and chemical reactions are taking place. These reaction cause serious corrosion to refractory lining, particularly when these erosion occur under the high temperature or violent temperature fluctuations. Common chemical erosion are gas erosion, alkali metal erosion, slag erosion and molten iron erosion. There are also some mechanical wear. These erosion occur at the same time and promote each other. None of the refractories has comprehensive advantages over others to solve the erosion problem in a round way. Considering the variety and the performance of refractory material used in blast furnace lining, the corresponding material should be selected for different parts due to the erosion reason in order to get the suitable performance. In the Construction Refractory Lining for Blast Furnace the following are used:

- **Hearth and hearth bottom:** carbon brick, micro-pore carbon brick, aluminum carbon brick and mullite masonry.
- **Belly and bosh of blast furnace:** Si_3N_4-SiC brick, aluminum carbon brick.
- **The middle and upper part of the furnace body:** aluminum carbon brick and fire-clay brick (resist the mechanical wear of the furnace material and gas flow).

Figure 1.3 Construction Refractory Lining for Blast Furnace

b. Refractory Lining in Cement Rotary Kiln

The cement rotary kiln is one of the most important core equipment in the building industry. The length of its service life depends on the quality of the refractory lining brick, which is the key to ensure continuous production and the calcination quality of the products.

Figure 1.4 Rotary Kiln Hoods Refractory Lining

Figure 1.5 Cement Kiln Refractory Lining Construction

The function of the refractory lining brick in the cement rotary kiln are follows.

- To prevent the direct damage of the high temperature flame or air flow damage to the kiln body and protect the kiln barrel.
- To prevent harmful substances (CO, SO2) from eroding the kiln.

- To prevent the erosion of the kiln body by material and air flow.
- To reduce kiln temperature and prevent kiln body from being oxidized and eroded.
- To preserve heat.
- To improve the coatability.

The silica mullite wear-resistant brick, made of high alumina bauxite clinker and silicon carbide, is mainly applied in building refractory lining in cement rotary kiln, especially in the transition zone, cooler and kiln eye. It has the characteristics of high pressure strength at normal temperature, high structure strength at high temperature, good thermal shock stability and so on. In the course of using, the protective layer is gradually formed, which has good abrasion resistance and strong peel resistance.

1.2.5. Selecting Refractory Lining

Selecting a refractory lining is not easy and straightforward. The selection of refractory lining depends on various factors like:

1. **Thermal Requirements**: The refractory lining material chosen must meet the maximum operating and design temperatures that they will be subjected to. The material must have high thermal shock resistance, and be strong against thermal fatigue, excessive expansion, etc.
2. **Life Span**: During operation, the refractory material is bound to experience mechanical and thermal loads which may cause wear and failure. So, the selected material must be able to absorb dynamic loads, mechanical impacts, severe erosion and corrosion, tensile loads, large hydraulic loads, pinch spalling, etc. to increase its lifespan.
3. **Chemical Attack:** There could be the possibility of a chemical reaction with the content at high temperatures. So, the refractory material selected should be inert against them.

Installation: The refractory lining material must be easily available and installed. The chosen refractory material must be quickly delivered to the required location during repair or maintenance times.

4. **Cost:** Finally, cost or economy governs all decisions. The chosen material must be economic for the range of services.
5. **Refractory Lining Thickness**

Depending on the type of the furnace and the substance of the smelting, the thickness of the refractory lining is usually between 80mm-300mm.

In certain applications, there may be two layers of refractory lining of different materials. For example, the refractory lining of the converter has two layers. The outer layer consists of magnesium refractory of 50-100mm thickness and the inner layer is composed of magnesium brick with 300-500mm thickness.

1.3. Specific areas of refractory replacement

A refractory failure is the number one cause of boiler inefficiency and a major contributor to boiler shut-downs. Refractory that is properly selected and installed will always last longer, help minimize the amount of shutdowns required, and lead to savings in annual fuel cost.

Refractory is an integral part of boilers. In the steam-generating industry, refractory materials are used to fill gaps and openings (to help keep the fire inside the firebox), to line wet and dry hoppers for collecting ash and slag, and to protect the lower furnace wall tubes inside fluidized-bed and cyclone-fired boilers and boilers fired by refuse-derived fuels.

Refractory failure is a major cause of boiler energy losses as well as a major contributor to boiler outages. Understanding why a refractory material fails requires a complex analysis of many interrelated factors: materials that don't match the operating environment, incompatibility with the by-products of fuel combustion, and improper installation techniques (Figures below).

Figure 1.6 Unprotected section. A wet bottom-ash hopper with areas of missing refractory

Figure 1.7 Fly ash inside a penthouse between the screen, super heater, and re-heater.

1.3.1. Common Causes of Refractory Failure

2. Fiber Modules Fallen from the Roof
3. Failing Brick Walls
4. Bridge wall/Tunnel Wall Issues
5. Castable Cracking
6. Floor Cracking/Heaving
7. Convection Castable/Corbel Damage
8. Mating Dissimilar Materials

1. Fiber Modules Fallen from the Roof

When fiber modules fall from the roof of a kiln, the issue is often material, design or installation related. If the modules and support anchoring are missing, the most likely cause is an installation issue, insufficient stud welding, or excessive corrosion from the shell caused by sulphur or rust. If most of the fiber is missing but the support anchoring is intact, it is more likely to be a result of mechanical abuse (e.g., water placing excess weight on the fiber). Since fiber is 90% porous, it absorbs many times its weight in water.

Make sure you check the fiber to see if it was torn off the anchoring, or has signs of water damage. It is always important to look at the area affected and take note of what it is telling you. Can you see gaps in the fiber? Is a hot spot associated with the gaps? Always check the fiber chemistry and design to ensure you can quarantine fallen fibers before the issue spreads.

Figure 1.8 Fiber Modules Fallen from the Roof

2. **Failing Brick Walls**

Insulating fire bricks (IFBs) are commonplace in many furnaces and, like any lining, require good materials, design, and installation to give good life in service. Upon examining IFB linings closely in the event of failure, you may be able to determine if they were the root cause. Look for hot spots outside the unit. If the wall is in bad shape, this may indicate issues with the backup lining. To address voids, pump hot spot repair materials in from the outside of an operating unit. Make sure you also look at the face of the brick. It may have melted or cracked, which indicates higher furnace operating temperatures, possible fuel impurities, or the wrong grade brick being used. If the hot face brick is in good shape but the wall is bowed, this could be due to inadequate thermal expansion provisions, which can also be a result of changing operating conditions and higher outputs or box temperatures.

Figure 1.9 Failing Brick Walls

3. **Bridge wall/Tunnel Wall Issues**

It is not uncommon to see walls lean to some extent. However, if they lean too much, which could be a result of the floor not being level, it can cause failure. A lot of wall issues are also due to inadequate expansion provisions (design), particularly if you increase operating conditions to higher temperatures than expected. Increased temperatures can also cause slumping over time.

Remember, not all firebrick are created equal. They differ in formula, firing and high-temperature properties. The key to making the best selection is investigating both the ambient and hot strength properties. Don't focus too much on cost, but on reliability—the best products for the job are typically not the cheapest.

Figure 2 Bridge wall/Tunnel Wall Issues

4. Castable Cracking

Castable linings are unique in that they are not in a finished state when they leave a manufacturing facility. This means that the final quality is dependent on the installer.

Materials must be mixed with clean water of the correct temperature range, and installed and cured before water is removed during the dry-out. If dry-out is not done in a slow and controlled manner, the castable can explosively spall. Some shrinkage cracking is normal. If it becomes excessive, however, it could be a consequence of poor installation and may indicate that too much water was used.

5. Floor Cracking/Heaving

Issues with the furnace floor cracking or heaving are common when temperatures increase after the original design. Provisions for reversible thermal expansion or expansion joints in the floor should be protected, as they can easily be filled with debris during normal operation, limiting the gap's movement capability. It's good practice to regularly vacuum gaps to avoid debris buildup.

Floor cracking is also common when dissimilar materials are used. If you have a floor-fired unit, you will have castable burner blocks of a certain material grade and a different floor material surrounding the burner. It's common to see cracks appear at the corner of the burner blocks if adequate expansion joints are not installed.

6. Convection Castable/Corbel Damage

Castables are prone to damage during the construction and shipping process. This often manifests itself in the form of visual cracks, typically through the entire thickness. You may also notice some pinch spalling at the surface, which indicates directional mechanical flexure of the steel. Corbels may also be susceptible to damage as they protrude from the base lining. Any apparent damage should be quickly repaired, and the affected portion of the lining removed and replaced to avoid damaging surrounding materials.

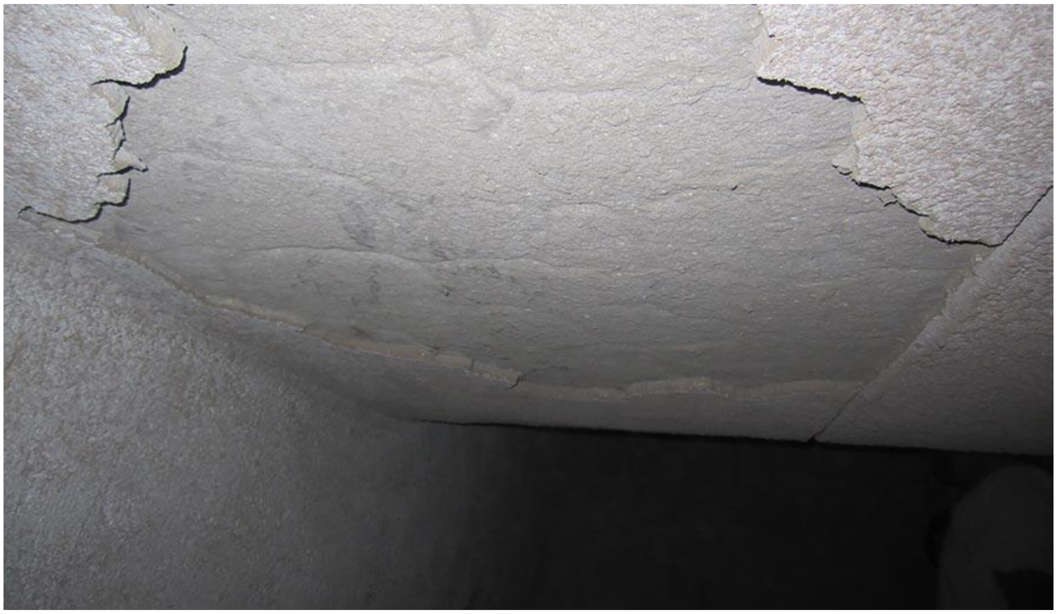

Figure 1.10 Convection Castable/Corbel Damage

7. **Mating Dissimilar Materials**

Dissimilar refractory materials adjacently located are common, particularly surrounding openings such as doors (fiber and brick), peep sights (IFB, castable, fiber modules), burner blocks and pressure-relief doors. Because dissimilar materials have different refractory properties at elevated temperatures, this makes a homogenous design difficult.

In many cases, the hot effluent gases will make their way through the compromised refractory lining, resulting in hotspots on the outer casing. If these surround peep sights and door openings, it's possible that the interface designs are inadequate. In the case of the peep sight, you should use similar refractory materials to those surrounding the opening to avoid design issues and to create the best possible seal.

Tube seals also provide personnel protection, encouraging an influx of ambient air into the furnace. For peep sights and walls, always use a high-temperature fiber expansion joint, as this will avoid the issue of having to mate an expanding material (IFB) with a material that expands and shrinks differently.

Other causes of refractory installation failure

- Chosen refractory material does not fit the environment
- The burned fuel damages the refractory monolithic
- Improper handling of refractory materials (mix, install, dry out and store)

- The selected refractory product does not fit the environment after the burning process

1.3.2. Inspection method to refractory repairs

- Datasheets of current refractory brick or refractory lining
- Samples of heated materials
- Location of refractory materials storage
- Refractory products date of manufacture
- Conditions during previous refractory installation
- Quantity of installed refractory insulation
- Previous installation and dry out process

Self-Check-1

Direction I: True or Fouls

Instruction1- Say True or Fouls to the following questions.

1. Eating, smoking and drinking in areas where there is risk of contamination by RCF should be prohibited.
2. Refractory Lining is a layer of material which can resist high heat temperature in the kiln or furnace.
3. Air purifying respiratory equipment is one of RPE.
4. Identify the location of refractory materials storage is the inspection method to refractory repairs.
5. Improper handling of refractory materials (mix, install, dry out and store) may not causes of refractory failure.

Direction II: Multiple Choice

Instruction1I- Choose the best answer from the given alternatives.

1. One of the following is true about OHS
   A. Orientation of health and safety
   B. Occupational health and safety
   C. Operations to hand safety
   D. All of the above
2. What is mean by RPE
   A. Range of proper equipment
   B. Respiratory protective equipment
   C. Repair protective equipment
   D. All
3. Of the following is PPE for refractory lining and repair
   A. Chemical prof full clothing
   B. Long and chemical proof shoe
   C. Chemical proof glove
   D. Eye protection goggle
   E. All
4. Of the is Common Causes of Refractory Failure
   A. Fiber Modules Fallen from the Roof
   B. Failing Brick Walls
   C. Bridge wall/Tunnel Wall Issues
   D. Castable Cracking
   E. All

5. Refractory Lining Properties
   A. Heat damage resistance.
   B. Slag erosion resistance.
   C. Chemical corrosion resistance.
   D. Physical corrosion resistance.
   E. All

Direction III: Short answer items

Instruction III- Briefly answer the following questions

1. What are the purpose of refractory lining?
2. What are the selection criteria for refractory lining?
3. Write and explain the common Couse of refractory failure.
4. Write the appropriate PPE for refractory lining.
5. What should be inspect to repair the refractory materials?

Unit Two: Knock Out Refractory

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- Operation sequences of refractory removal
- Appropriate tools and equipment
- Disposing of damaged refractory
- Housekeeping procedures

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this unit, you will be able to:

- Determine sequence of operations to remove refractory
- Select appropriate tools and equipment.
- Remove and dispose damaged refractory.
- Implementing OHS procedures and measures.
- Perform housekeeping procedures.

2.1. Operation sequences of refractory removal

Refractory demolition or removal can be done by high pressure water – hydro demolition, by robotic breakers, or manually with handheld chipping hammers. The size of the vessel and environment can be a determining factor into which method is best. When possible hydro demolition is the preferred method.

Figure 2.1 manual refractory removing

Manually removing of refractory lining

In refractory installation and maintenance, failed refractory part can be removed manually with handheld chipping hammers.

Operation sequence of manual refractory removal:

- Identify the part of refractory to be removed
- Prepare appropriate tools and equipment's.
- Full fill the necessary safety equipment's.
- Study the fuller type.
- Prepare lay out on the on part of refractory to be removed.
- Using hammer and chisel remove the refractory part properly.
- Clean the removed part of the refractory.

2.2. Appropriate tools and equipment

We have deferent tools and equipment's in refractory lining and repair. Some tools and equipment's that are appropriate in refractory installations listing below:

- Cold chisels — Flat cold chisels
- Conventional truck cranes — Boom trucks; Lift trucks
- Front end loaders — Wheeled front-end loaders
- Furnaces — Feed fired heaters; Rotary kilns
- Helical blade mixer — Horizontal helical blade mixers
- Power grinders — Cordless power grinders; Rotary tools
- Power saws — Brick cutting saws; Cordless saws
- Stonemason hammer — Brick hammers
- Trowels — Masonry trowels
- Wet scrubbers — Acid scrubbers
- Paint brush
- Brooms
- Steel pipe
- Mixer

Figure 2.2 refractory Mixer machine

2.3. Disposing of damaged refractory

Refractories are ceramic materials used to protect equipment in industries working at high temperatures. They contain compounds like aluminium silicates, magnesium, dolomite, chromite, zirconium, carbides, nitrides and oxides. Steel production is the main user of these materials, consuming around 70% of their total production.

The waste refractory brick/mould and ash may be a **hazardous** waste due to high concentrations of chromium in the stainless steel. Consequently, these wastes must be treated as hazardous waste unless laboratory analysis demonstrates the wastes as being non-hazardous.

Damaged and demolished refractory materials should be managed and properly disposed to the separate prepared area or place.

Figure 2.3 Disposing of damaged refractory materials

2.4. Housekeeping procedures

Housekeeping and waste disposal

A good standard of housekeeping should be maintained to prevent secondary exposure from settled dust. Waste and off-cuts should be removed frequently. Cleaning should be carried out by a method which does not give rise to dust, i.e. not dry sweeping. Any residual material should be vacuumed with a suitable industrial vacuum cleaner fitted with high efficiency (HEPA) filtration. Wherever possible, waste materials should be wetted.

Waste fiber should be carefully placed directly into heavy duty plastic bags (NB If the material is thrust too vigorously into the bag, dust will be blown back out). All waste should be double-bagged in heavy-duty plastic bags and clearly labelled to indicate the contents.

From the date of classification as a carcinogen, RCF will be a 'special waste' and will need to be disposed of accordingly, i.e. with a consignment note and at a licensed disposal site
Refractory ceramic fiber being transported on the road will not be subject to regulations concerning the carriage of dangerous goods as these regulations apply to materials which could cause immediate danger to the emergency services and other road users. (The fact that a material is classified as toxic under the Chemicals (Hazard Information and Packaging for Supply).

Steps of housekeeping operation

Housekeeping should be implemented after the removal of refractory part and after refractory lining and repair. These are the steps to housekeeping:

1. Prepare housekeeping tools and equipment's
2. Wear the necessary PPE and RPE
3. Identify the property of the waste material
4. Take the necessary safety measure
5. Prepare waste disposal area
6. Clean and dispose the refractory waste.
7. Clean tools and equipment's

Self-Check-2

Direction I: True or Fouls

Instruction1- Say True or Fouls to the following questions.

1) Refractory lining can be removed using hand held chipping hammer.
2) Flat cold chisel is a manual refractory removing tools.
3) Damaged and demolished refractory materials can be disposed wherever in the field of free space.
4) Waste fiber should be carefully placed directly into heavy duty plastic bags.

Direction II: Multiple Choice

Instruction1I- Choose the best answer from the given alternatives.

1. Of the followings are refractory demolishing or removed method
   A. High pressure water –
   B. Hydro demolition,
   C. Robotic breakers
   D. All
2. Of the following is tools and equipment's used in refractory lining and repair.
   A. Cold chisels
   B. Power saws
   C. Brick hammers
   D. Mixer
   E. All

Direction III: Short answer items

Instruction III- Briefly answer the following questions

1) Write the operation sequence to remove refractory lining.
2) Write the appropriate tools and equipment's to refractory lining and repair.
3) How can dispose damaged refractory
4) Write the steps for housekeeping.

Operation sheet 1

Operation Title: remove refractory

Instruction: Remove the damaged refractory part

Purpose: To Remove the damaged refractory part from the furnace.

Required tools and equipment:

- Hand glove
- Clothing
- Shoes wear
- Chalk
- Flat chisel
- Broom
- Wire brush
- Brush

Precautions:

- Dust inclusion to lung
- Hand injury

Procedures:

Step-1: Identify the part of refractory to be removed

Step-2: Prepare appropriate tools and equipment's.

Step-3: Full fill the necessary safety equipment's.

Step-4: Study the fuller type.

Step-5: Prepare lay out on the on part of refractory to be removed.

Step-6: Using hammer and chisel remove the refractory part properly.

Step-7: Clean the removed part of the refractory.

Step-8: clean tools and equipment.

Quality criteria:

- Good finished component

LAP Test	Practical Demonstration

Name: ___________________________ Date: _____________

Time started: _____3:00________ Time finished: ____8:00___

Instruction I: Given necessary templates, tools and materials you are required to perform the following tasks within 4-5 hours.

Task 1: Remove the damaged refractory part of Furness.

Unit Three: Refractory Materials

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- Appropriate refractory materials
- Mixing of refractory media
- Determination of installation and repair of refractory

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this unit, you will be able to:

- Select appropriate refractory materials.
- Mix refractory media depending on specifications.
- Determine installation and repair of refractory

3.1. Appropriate refractory materials

A refractory material or refractory is a material that is resistant to decomposition by heat, pressure or chemical attack and retains strength and form at high temperatures. They are inorganic, non-metallic, porous and heterogeneous. They are composed of oxides of materials like silicon, aluminum, magnesium, calcium and zirconium.

These materials are used in furnaces, kilns, incinerators and reactors. They are also used to make crucibles and molds for casting glass and metals and for surfacing flame deflector systems for rocket launch structures. In today's date, the iron and steel industry and metal casting sectors use approximately 70% of all refractories produced.

These materials must be chemically and physically stable at high temperatures. Depending on the operating environment they must be resistant to thermal shock, be chemically inert and have specific ranges of thermal conductivity and coefficient of thermal expansion. The oxides of aluminum (alumina or Al2O3), silicon (silica or SiO2) and magnesium (magnesia or MgO) are the most important materials used in the manufacturing of refractories. Other oxide found is of calcium (lime or CaO). Fire clays are also widely used in the manufacture of refractories.

Refractory materials are useful in many ways as given below:

- Serving as a thermal barrier between hot medium and the wall of a containing vessel
- Withstanding physical stress and preventing erosion of vessel walls due to hot medium
- Protecting against corrosion
- Protecting thermal insulation

What are the types of refractories?

Depending on temperatures and service conditions of the applications such as boilers, furnaces, kilns, ovens etc. different types of refractories are used.

- Fireclay refractories.
- Silica brick.
- High alumina refractories.
- Magnesite refractories.
- Chromite refractories.
- Zirconia refractories.

Refractories have multiple useful applications. In the metallurgy industry, refractories are used for lining furnaces, kilns, reactors, and other vessels which hold and transport hot mediums such as metal and slag. Refractories have other high temperature applications such as fired heaters, hydrogen reformers, ammonia primary and secondary reformers, cracking furnaces, utility boilers, catalytic cracking units, air heaters, and sulfur furnaces.

Refractory Lining Materials

The common materials that are used as refractory lining materials are:

- Alumina or Aluminum oxide (High Alumina bricks)
- Silicon oxide
- Magnesium oxide
- Calcium oxide
- Fire clays (Clay bricks)
- Zirconia
- Silicon carbide
- Tungsten carbide
- Boron nitride
- Hafnium carbide
- Molybdenum disilicide
- Tantalum hafnium carbide
- Corundum bricks
- Plastic refractory

Refractory lining material consists of refractory aggregate, admixture, powder, binder, water, or other liquid, made of amorphous refractory products or fixed refractory products

Classification of refractory materials

Refractories are classified in multiple ways, based on:

1. Chemical composition
2. Method of manufacture
3. Fusion temperature
4. Refractoriness

5. Thermal conductivity

1. **Based on chemical composition**

   a. **Acidic refractories**

Acidic Refractory or acid refractory is a kind of refractory material with silica as its main component. Acidic refractory can resist acid slag erosion, but it can easily react to alkaline slag erosion at high temperature environment. Acidic refractory is widely used for coke oven, open hearth regenerator and furnace roof, refractory firing kiln and glass tank furnace in metallurgical industry.

Figure 3.1 Acidic Refractory Brick

Acidic Refractory Definition

Acidic refractory usually refers to refractory material with more than 93% SiO_2 content. The main characteristic of acidic refractory is to resist the erosion of acid slag at high temperature, but it is likely to react with alkaline slag. Acidic refractory is mainly made of quartz glass, fused silica re-bonded products, silica bricks and amorphous silicon refractory. Semi siliceous refractory products are generally attributed to this kind. As for clay refractory, it is classified as semi acidic or weakly acidic refractory. In addition, zirconium carbide refractory and silicon carbide refractory are used as special acidic refractory.

Acidic refractory is the refractory material that is not affected by acidic materials at high temperature. But acidic refractory reacts with basic slags easily. Acidic refractories contain alumina, silica zirconia refractories and fire clay bricks refractory.

Figure 3.2 Acidic Fire Clay Bricks

Acidic Refractory Classification

According to acid strength, there are mainly: (1) strong acidic silica brick, amorphous silica refractory, quartz glass products, fused silica recombination products; (2) moderately acidic semi-silica refractory and pyrophyllite refractory; (3) weak acid clay refractory. The main property of acidic refractory its strong resistance ability to the corrosion of acid substance (or acid slag) at high temperature, but it tends to react with alkaline substance (or alkaline slag). Zirconium quartz refractory and carbonized silicon refractory as special acidic refractory are also included in this category.

1. Strong acidic refractory refers to siliceous materials with silica content more than 93%, such as silica refractory brick. Strong acidic refractory is used for glass kiln, acid furnace, coke oven, etc.

Figure 3.4 silica refractory brick

2. Semi-acidic refractory contains a lot of silica and alumina refractory. Semi-acidic refractory is one of the refractory materials. The main purpose of semi-acidic refractory is to make semi-silica bricks. In order to alleviate the thermal expansion of silica brick and to compensate the shrinkage and softening properties of clay brick, more clay fired refractory brick was added into quartz.
3. Fire clay brick belongs to weak acid refractory. Fire clay brick is made of refractory clay with 30%~46% content alumina. This brick also has good thermal shock resistance and acid slag resistance. This kind of acidic refractory brick is widely used with large amount of production.
4. Zircon and SiC refractories are also classified as acidic refractories because of SiO_2.

Figure 3.5 Monolithic Acidic Refractory

Acidic Refractory Uses

Because the properties of acidic refractory are quite different from basic refractory, the acidic refractory uses are also different from that of basic refractory. The anti-slag corrosion performance, refractoriness under load, the volume change at high temperature burning and thermal shock resistant ability determines the using temperature of acidic refractory.

Acidic refractory is not resistant to alkaline slag and alkaline flux and is mainly used in coke oven, open hearth regenerator, furnace top, acid furnace, refractory kiln and glass kiln.

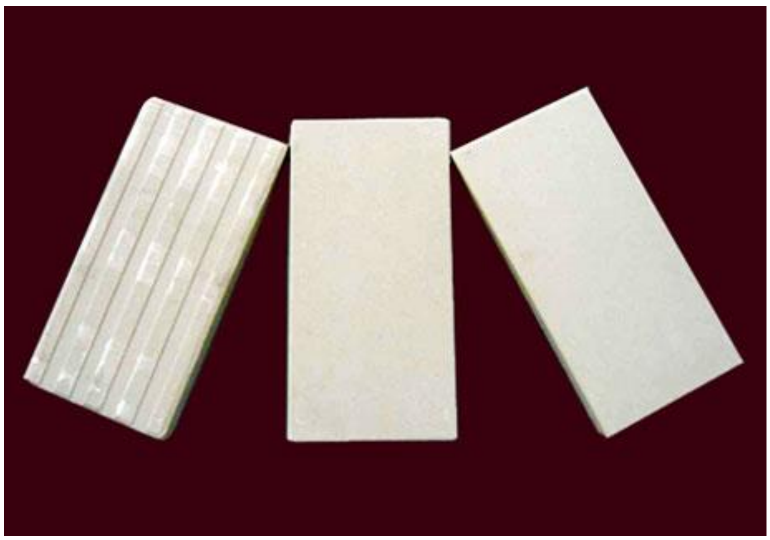

Figure 3.6 Acidic Brick

It is of great significance to classify refractory materials according to their acid and alkali properties. We can choose the corresponding refractories according to the acidity and alkalinity of the working environment, which can improve the service life of refractories and reduce production cost.

Differences between Acidic Refractory and Basic Refractory

The raw material of acidic refractory is silica with SiO2content more than 93%. Acidic refractory can resist the slag erosion and react with alkaline slag. While the basic refractory is on the contrary side. The basic refractory is made of magnesium oxide and calcium oxide with strong alkaline resistance. Basic refractory is mainly used in basic steelmaking furnaces and non-ferrous metal smelting furnaces, and often used in cement industry. The main products of basic refractories are magnesia, magnesia chrome, magnesium olivine, and dolomite and limestone refractories.

Magnesium, dolomite and limestone refractories are strongly alkaline refractories, while chrome-magnesia, magnesia-chromium, forsterite and spinel-limestone are weakly alkaline refractories.

b. Basic refractories

Basic Refractory is refractory material contains magnesium oxide and calcium oxide. Basic refractory has high refractoriness and strong alkaline slag resistance. The major basic refractory is the refractory with the content of magnesia, dolomite and limestone. The most commonly used basic refractory brick is magnesite brick with the strong resistance to alkaline slag and iron slag. The basic refractory is applied in converter lining and hearth furnace bottom.

Figure 3.7 Basic Refractory Brick

What Basic Refractory Material Is

Basic refractory means refractory made of magnesium oxide and calcium oxide, including magnesite brick, magnesia alumina brick, magnesia chrome brick, dolomite brick, etc. This kind of basic refractory material has the characteristics of high refractoriness and strong alkaline slag resistance and is widely used for open hearth, oxygen converter, electric furnace, non-ferrous metal smelting equipment and other heating equipment.

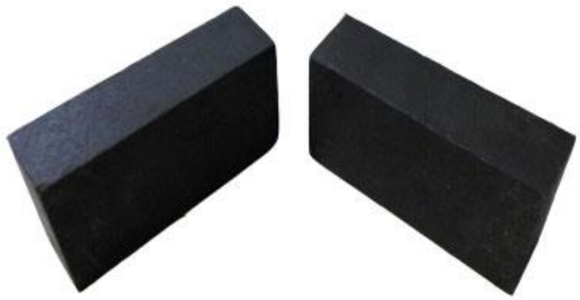

Figure 3.8 Basic Magnesia Chrome Brick

Basic Refractory Raw Materials

Roughly, the raw materials of basic refractory are dolomite, magnesite, and olivine and serpentine whose useful components are MgO, CaO, $MgCO_3$, and SiO_2 and so on. Specifically, the raw materials of basic refractory are magnesia, magnesia spinel, magnesia calcium sand, magnesia chrome sand and magnesia zirconium sand.

Basic Refractory Properties

1. High refractoriness, above 2000℃.
2. Good resistance to alkaline slag.
3. Good hydration resistance.
4. Good vacuum resistance.
5. Strong resistance to basic flux.
6. Purifying molten steel function.
7. High thermal expansion rate.
8. High thermal conductivity.
9. Large heat capacity.
10. Poor thermal shock resistance.

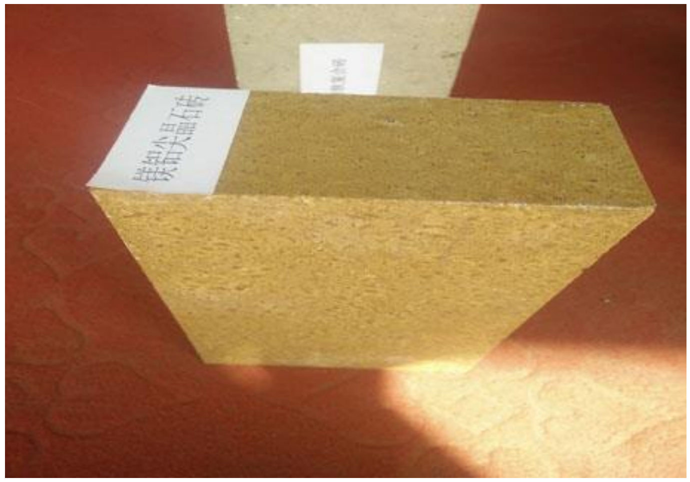

Figure 3.9 Basic Refractory Spinel Bricks

Basic Refractory Uses

Basic refractory is used in the following equipment.

1. Oxygen converter furnace lining.
2. Electric furnace lining permanent layer.
3. Glass kiln heat storage room.
4. Non-ferrous metal smelting equipment.
5. Heating equipment.
6. Open hearth.
7. Rotary cement kiln.
8. Mix iron furnace.

Figure 3.10 Alkali Resistant Castable Refractory

Types of Basic Refractory

a. According to the content

- Magnesium basic refractory: MgO≥80%, made of periclase, includes magnesite brick, magnesia silicon brick and magnesia calcium brick.
- Limestone basic refractory: CaO≥95%, calcium stone, includes lime brick.
- Magnesium spinel basic refractory: MgO(Al2O3/Cr2O3/Fe2O3), includes magnesia alumina brick, magnesia chrome brick and chrome magnesia brick.
- Forsterite basic refractory: 2MgO.SiO2, includes forsterite brick.
- Dolomite basic refractory: includes dolomite brick, magnesia dolomite brick and stabilized dolomite brick.
- Tar combined basic refractory.
- Bituminous basic refractory.

b. According to the shape

- Basic refractory bricks.
- Basic amorphous refractory.

Figure 3.11 Basic Refractory Castable

Basic Oxygen Furnace Refractory Lining

The oxygen top blown converter (Basic Oxygen Furnaces) is blown by industrial pure oxygen furnace. The lining of the furnace is mostly alkaline, like a straight bucket. The oxygen is injected into the surface of metal liquid by the water-cooled nozzle at the top of the furnace at a high speed of Mach 3/h. Because of high furnace temperature, waste steel or ore can be smelted.

The advantages of using the basic oxygen furnace refractory are:

- High quality of steel products, low content of phosphorus, sulfur and nitrogen.
- Suitable for various products, like carbon steel and alloy steel.
- High efficiency of production.
- Refractory saving.
- Applicable to the blowing of different components of iron liquid.

c. Neutral refractories

These are used in areas where slags and atmosphere are either acidic or basic and are chemically stable to both acids and bases. The main raw materials belong to, but are not confined to, the R2O3 group. Common examples of these materials are alumina (Al2O3), chromia (Cr2O3) and carbon.

- **Carbon graphite refractories** mainly consist of carbon. These refractories are often used in highly reducing environments, and their properties of high refractoriness allow them excellent thermal stability and resistance to slags.
- **Chromite refractories** are composed of sintered magnesia and chromia. They have constant volume at high temperatures, high refractoriness, and high resistance to slags.
- **Alumina refractories** are composed of ≥ 50% alumina (Al2O3).

2. Based on method of manufacture

1) Dry press process
2) Fused cast
3) Hand molded
4) Formed (normal, fired or chemically bonded)
5) Un-formed (monolithic-plastic, ramming and gunning mass, canstables, mortars, dry vibrating cements.)
6) Un-formed dry refractories.

3. Based on fusion temperature

Refractory materials are classified into three types based on fusion temperature (melting point).

- Normal refractories have a fusion temperature of 1580–1780 °C (e.g. Fire clay)
- High refractories have a fusion temperature of 1780–2000 °C (e.g. Chromite)
- Super refractories have a fusion temperature of > 2000 °C (e.g. Zirconia)

4. Based on refractoriness

Refractoriness is the property of a refractory's multiphase to reach a specific softening degree at high temperature without load, and is measured with a pyrometric cone equivalent (PCE) test. Refractories are classified as:

- Super duty: PCE value of 33–38
- High duty: PCE value of 30–33
- Intermediate duty: PCE value of 28–30
- Low duty: PCE value of 19–28

5. Based on thermal conductivity

Refractories may be classified by thermal conductivity as either conducting, non-conducting, or insulating. Examples of conducting refractories are silicon carbide (SiC) and zirconium carbide (ZrC), whereas examples of non-conducting refractories are silica and alumina. Insulating refractories include calcium silicate materials, kaolin, and zirconia.

Insulating refractories are used to reduce the rate of heat loss through furnace walls. These refractories have low thermal conductivity due to a high degree of porosity, with a desired porous structure of small, uniform pores evenly distributed throughout the refractory brick in order to minimize thermal conductivity. Insulating refractories can be further classified into four types:

- Heat-resistant insulating materials with application temperatures ≤ 1100 °C
- Refractory insulating materials with application temperatures ≤ 1400 °C
- High refractory insulating materials with application temperatures ≤ 1700 °C
- Ultra-high refractory insulating materials with application temperatures ≤ 2000 °C

How to Handle Refractory Materials Properly

- Use fresh materials and follow proper storage methods.
- Refractory material manufacturers suggest using drinkable water for mixing.
- Use the right type of mixer, follow the set mixing process, and take note of the material’s pot life.
- Ensure the final mix temperature is in a specific range.

- A proper curing process allows proper chemical action to happen and helps the refractory reach its maximum strength when dried.
- Remove all mechanical and chemical water to reach its desired strength by drying out the cured refractory.
- Know the exact quantity of materials to ensure the refractory is not too thick or too spars

3.2. Mixing of refractory media

Mixing refractory properly means using the exact amount of water–not guessing or approximating. Proper mixing means mixing for the correct amount of time, providing the refractory to the point of installation in the right consistency, and having the mix retain its consistency until the installation is complete. Anything less is an improper mix and is usually the root or contributing cause of refractory failure.

Mixing refractory is not only about adding water to the mix using a hose and mixing it just enough until it looks wet—like mixing concrete. Mixing refractory requires a bit more.

Properly mixed refractory must:

1. Have a carefully calculated, measured, and/or weighed amount of water
2. Never have water added directly from a water hose
3. Be mixed for a certain amount of time
4. Be mixed in a paddle mixer or by hand, vigorously
5. Be mixed to the consistency matching the application of usage

These general mixing and installation instructions apply when installing refractory by troweling, casting, or pouring. The cast or pour method is defined as installing refractory when filling seal or wall boxes, or when installing a large amount of refractory, with the use of forms to retain and hold the refractory. The trowel method is defined as installing thin refractory linings by hand, or when the location is not readily accessible for other applications. The consistency of the refractory mix will vary not only by the characteristics of the refractory material, but also by the application requirements. The following steps should be taken as minimum requirements for properly installing refractory when using these types of applications:

1. Read the refractory material data sheet before using any refractory material.
2. Read the information on the back of refractory bag, taking note of the following:

- Percentage or range of water recommended (range usually applies to application needs)
- How long to mix the refractory material
- Date the refractory material was made
- Pot life of the refractory

3. For proper mixing, remember the following points:
    - The amount of water required for mixing will vary by the characteristics of the refractory material and application requirements.
    - Add just enough water to meet the application requirements (such as being sticky and capable of staying in place for troweling, or in a fluid state for pouring and casting-see ball-in-hand, Item 5, below).
    - The water source for mixing refractory should be potable (drinkable) or treated water–never river water.
    - The final mix temperature should be between 50°F and 90°F.
    - A wetter mix may handle more easily, but it robs the refractory material of its needed strength.
    - A mix that is too dry is difficult to place and may set to a weak, porous, “popcorn” structure.
    - A proper refractory mix usually will seem on the thick side, as compared to mixing conventional concrete.
    - All tubes or penetrations located inside a refractory seal area should be coated or sealed with a parting agent (such as white latex barn paint) prior to installing refractory.
4. Calculate and fill the required water amounts into clean containers (pails) prior to mixing the refractory. The water amount initially will be based on the refractory manufacturer’s recommendations, found on the back of the bag, and the size of the mixing device being used (a two-bag paddle mixer). Also remember the following:
    - Always use clean containers, and periodically rinse them.
    - Never pour water directly into the refractory from a water hose.
    - Adjust the water amounts during the first two mix batches for mix consistency and workability at install, then add holes in the container just at the water lines of each container. This will ensure that the water amounts will be the same from one mix batch to another.

- Use a device (a wrist watch with a second hand, or a stop watch) to accurately record the length of time the refractory is mixed.

5. Use the ball-in-hand method to test the consistency of the refractory before using and installing a refractory mix. Make a small ball of refractory mix (2 to 3 inches in diameter) and toss it 12 inches into the air, taking note of the condition of the ball as it hits the flat palm of the hand that catches it. Follow these rules of thumb:
   - If the ball breaks, it is too dry for all applications.
   - If the ball flattens out, it is too wet for troweling but acceptable for pouring and casting.
   - If the ball retains its size and approximate shape, it is acceptable for troweling.
   - The ball-in-hand method should be done after every batch.
6. Place the mixed refractory into clean pails and transport to the work location, making sure to put equal amounts into each pail for ease of installation and for monitoring material quantities and labor productivity.
7. Do not over-trowel the finished surface of the refractory. Over-troweling will bring the cement to the surface and will seal the refractory surface, restricting the escape of water vapor (which occurs during dry out).
8. Vibrate all cast or pour applications to remove all air bubbles trapped inside the refractory.
9. Properly prepare the surface of the refractory after installation is complete by taking the following steps:
   - Hand brush or curry comb the surface of all exposed refractory to keep the surface open to promote proper dry out.
   - Keep the surface of the refractory moist, or the surrounding atmosphere humid, for a minimum of 24 hours to cure the refractory. This can be accomplished using a fine mist of water (but not soaking), covering the refractory with wet canvas bags, or spraying the surface with a manufactured curing compound.
   - Protect freshly installed refractory from freezing (if applicable) for a minimum of 48 hours using external heat.

Most refractory projects are small in size and do not require much heavy equipment. The most commonly used and preferred method of mixing is either using a paddle mixer or using a pan or tub for mixing by hand. The following are general instructions for their use:

General Instruction for Using a Paddle Mixer (Two-Bag Paddle Mixer)

1. Turn mixer on before adding water or refractory.
2. Add half the water amount required into the mixer before adding refractory.
3. Add up to the two-bag limit of the desired refractory material.
4. Add the balance of the required water slowly to achieve proper consistency for the application desired, checking consistency throughout the process.
5. Paddle mix refractory for 3 minutes after all the water and refractory have been added to the mixer. Over-mixing tends to speed up the setting rate. Never remix.
6. Test for proper consistency using the ball-in-hand method before removing refractory from the mixer.
7. Clean mixer every two to three batches to prevent clogging and paddle jamming.

General Instruction for Hand Mixing Using a Pan or Tub

1. Add half the water amount required into the pan or tub before adding refractory.
2. Add up to two bags only of the desired refractory material.
3. Add the balance of the required water slowly to achieve proper consistency for the application desired.
4. Hand-mix refractory thoroughly for 4 minutes after all the water and refractory have been added to the pan or tub. Over-mixing tends to speed up the setting rate. Never remix previously mixed or partially mixed refractory.
5. Test for proper consistency using the ball-in-hand method before removing refractory from pan or tub.
6. Clean the pan or tub after every mix to remove old material. Never re-use old material.

Figure 3.12 hand mix of Heat resistant refractory concrete

Example: for hand mix of Heat resistant refractory concrete

Materials

- River gravel or crushed fire bricks
- Sand
- Calcium Aluminate cement. (Best grade available)
- Lime
- Water (h2O)

Mixing ratio

Mixture: (parts ratio is 3 x 2 x 2 x 0.5, plus water)

- 3 shovels of the gravel or crushed firebricks.
- 2 shovels of sand.
- 2 shovels of the cement.
- Half shovel of lime.
- This amount will require approximately 6-7 liters of water to mix the concrete.

Mixing method

1. Refractory concrete dry ingredients

Figure 3.13 Refractory concrete dry ingredients

2. Mixing dry refractory concrete ingredients

Figure 3.14 Mixing dry refractory concrete ingredients

3. Adding water to refractory concrete

Figure 3.15 Adding water to refractory concrete

4. Semi dry refractory concrete

Figure 3.16 Semi dry refractory concrete

5. Adding more water to refractory concrete

Figure 3 adding more water to refractory concrete

6. Refractory concrete of good consistency

Figure 3.18 Refractory concrete of good consistency

3.3. Determination of installation and repair of refractory

To Determination the installation and repair of refractory it should identify the root cause of a refractory failure, the five-step process outlined below should be closely followed while paying attention to the amplifying comments and suggested best practices.

Step 1: Begin the discovery process

The process begins with the collection of basic technical information about the failure, followed by interviews of plant and installation personnel. Document the following:

- Material samples and data sheets of the existing brick or refractory lining.
- Material samples of ash clinkers and slag.
- Chemical analysis of the fuel being burned.
- Where and for how long the refractory material was stored prior to installation.
- When it was manufactured.
- Its condition at the time of installation.
- How much material was installed?
- How it was installed or applied (pneumatically, toweled, poured, shotcrete, etc.).
- How it was cured and/or dried, using which procedures.

Step 2: Examine the Existing Material and Test

The existing material (or the lack thereof) should be examined for signs that may indicate the root cause of the failure. When looking at an existing refractory lining or photos of the existing lining, keep these questions in mind:

- Did the material fail due to thermal shock, usually indicated by large sections of the top surface being sheared away (Figure 2)?
- Is there any evidence that the materials had been exposed to excessive temperatures (such as excessive shrinkage or glazing)?
- Is there any evidence of mechanical abuse (broken and jagged edges or holes)?
- Did the material fail due to the operation of the equipment, furnace, or boiler?
- Was the refractory material installed improperly (does it have a porous or popcorn-like texture)?

Figure 3.19 A typical slag sample from a coal-fired steam generator.

Samples of the existing refractory material should be gathered and sent out for a cold crush test. This test will verify the strength of the installed material. The results can then be compared with the manufacturer's material data sheets. If the strength of the existing installed material is low, the mix probably was too wet when installed.

Samples of the existing slag and ash clinkers should also be gathered and sent out for chemical analysis. The slag samples should also have a PCE (pyro-metric cone equivalent) test performed to verify the minimum temperature that the refractory may have been exposed to.

Step 3: Calculate the Base-to-Acid Ratio

The next step is to document the environment that the refractory material was exposed to. One way to do this is by calculating the base-to-acid ratio (B/A, values taken from the information received from the chemical analysis test mentioned in Step 2). This B/A ratio will give an indication of what type of refractory material should have been chosen in the first place.

Here is one way to calculate the base to acid ratio, based on the mass fractions of the following compounds, determined by the laboratory data results:

$B = Fe_2O_2 + CaO + Na_2O + P_2O_5 + MgO + ZnO + MnO$

$A = SiO_2 + Al_2O_3 + TiO_2$

A base-to-acid ratio less than or equal to 0.25 indicates an acid condition. An acid condition would indicate that a SiO_2 type refractory should have been used.

A base to acid ratio greater than 0.25 but less than 0.75 indicates a neutral condition. A neutral condition would indicate that an Al2O3, SiC, or chrome-type refractory material should have been used.

A base to acid ratio greater than or equal to 0.75 indicates a basic condition. A basic condition would indicate that an MgO, or a Dolomite-type refractory material should have been used.

Step 4: Review the Collected Data

Now it is time to analyse all the information gathered in Steps 1 and 2. All of the service conditions must be reviewed and analysed thoroughly in order to see how they could affect the installed/failed material. This includes the fuel or raw materials being burned, the start-up fuel that was used, the ash and slag content, gas temperatures, and the plant operations and procedures.

Among the technical factors that could have contributed to a refractory failure are the following:

- The combination of a high (>15%) moisture content in a fuel and a reducing atmosphere can cause a separation of silicon carbide base materials (grain).
- Certain fuel constituents (iron oxide, potassium, or sulphur) found in fuel, slag, or ash could react with cements (calcium-aluminate) present in cement-bonded refractory—especially in the presence of a reducing atmosphere.
- In some plants, liquid start up fuel may contain vanadium. Vanadium could react with the silica and lime in the cement that is found in a cement-bonded type refractory. When vanadium is present, it can cause a chemical attack and surface failure or cause a complete refractory failure.

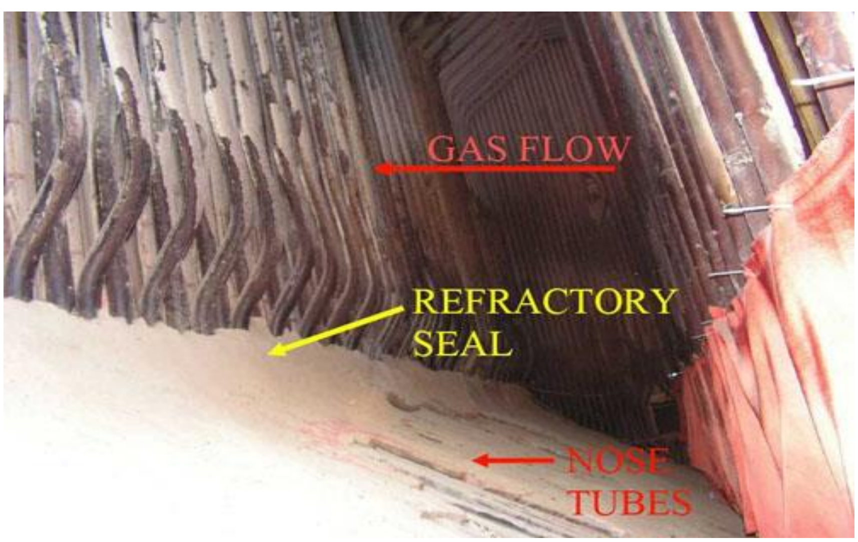

Figure 3.20 A superheated box where the refractory is missing, viewed from above.

Figure 3.21 The refractory seals inside this furnace failed and must be replaced.

Figure 3.22 Another view of refractory seals that must be replaced. Courtesy:

Step 5: Review the Installation Procedures

Assuming the right refractory material was selected for the given boiler, the next step is to review and determine if the proper installation procedures were used. A number of installation factors can prevent a refractory material from reaching its proper strength. A refractory material that is unable to reach its designed strength has the highest potential for failure. Consider asking the following questions.

- Was the material fresh, and were the proper storage procedures followed?
- Was the proper water used for mixing?
- Was the right installation equipment used and the recommended pot life followed?
- Was the refractory installed during the recommended ambient conditions?
- Were the correct curing procedures followed?
- Were the correct procedures followed? The dry-out or bake-out of the refractory will take place after the curing period. This process removes all mechanical and chemical water left in the installed material and allows the refractory material to reach its proper strength.
- Were the correct quantities installed? Finally, to help ensure that the refractory material was not installed too thick or too thin, it is important to know the quantity of material required for a proper installation.

Questions when inspecting damaged refractory materials:

- Was the material damaged due to thermal shock?
- Did excessive shrinkage due to high temperature cause the rupture?
- Was the refractory material installed improperly?
- Did the equipment operation damage the material?
- Are there any mechanical injuries?
- After answering these questions, the refractory engineer will collect material samples to test.

First, it will go through a cold crush test. Then, the strength of the refractory material will be analyzed. Afterward, compare the results with the datasheets. Lastly, the results will show whether the refractory mix was too wet or too dry.

Self-Check-3

Direction I: True or Fouls

Instruction1- Say True or Fouls to the following questions.

1) A refractory material or refractory is a material that is resistant to decomposition by heat, pressure or chemical attack and retains strength and form at high temperatures.
2) Furness is not the application area of refractory.
3) Alumina or Aluminum oxide common materials that are used as refractory lining materials.
4) Acidic Refractory or acid refractory is a kind of refractory material with silica as its main component.
5) Basic Refractory is refractory material contains magnesium oxide and ferrous oxide.
6) Poor thermal shock resistance is one of Basic Refractory Properties.
7) In mixing refractory, carefully calculated, measured, and/or weighed amount of water.

Direction II: Multiple Choice

Instruction1I- Choose the best answer from the given alternatives.

1. Of the following is the use of refractory materials
   A. Serving as a thermal barrier between hot medium and the wall of a containing vessel
   B. Withstanding physical stress and preventing erosion of vessel walls due to hot medium
   C. Protecting against corrosion
   D. Protecting thermal insulation
   E. All
2. Of the following is not the refractory material.
   A. Zirconia
   B. Silicon carbide
   C. Ferrous oxide
   D. Boron nitride
   E. Hafnium carbide
3. Of the following is Classification of refractory materials
   A. Chemical composition
   B. Method of manufacture
   C. Fusion temperature
   D. Refractoriness
4. Of the following is Basic Refractory Raw Materials
   A. Dolomite
   B. Magnesite

C. Olivine and serpentine
D. All

5. Of the following is property of basic materials.
   A. Good vacuum resistance.
   B. Strong resistance to basic flux.
   C. Purifying molten steel function.
   D. High thermal expansion rate.
   E. All
6. Of the following is the Basic Refractory Uses
   A. Oxygen converter furnace lining.
   B. Electric furnace lining permanent layer.
   C. Glass kiln heat storage room.
   D. Non-ferrous metal smelting equipment.
   E. All

Direction III: Short answer items

Instruction III- Briefly answer the following questions

1) Write the types of refractories.
2) Write the common materials that are used as refractory lining materials.
3) Write Classification of refractory materials and discuss in detail.
4) Define Acidic Refractory.
5) Write the use of acid refractory.
6) Define Basic Refractory Material.
7) Write the Types of Basic Refractory.
8) Write the advantage of properly mixed refractory.
9) Write the general instruction for hand mixing using a pan or tub.
10) Write the steps to determine the installation and repair of refractory.

Unit Four: Installation of Refractory

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- Operations sequence of installing refractory
- Technique of refractory installation
- Techniques of refractory curing

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this unit, you will be able to:

- Determine operations sequence of refractory installation.
- Identify techniques of Installing refractory and select appropriate tools and equipment's.
- Identify Techniques of refractory Curing

4.1. Operations sequence of installing refractory

Good refractory practices are necessary to achieve proper refractory installation. It all begins with mixing.

REFRACTORY INSTALLATION PROCEDURE

1. Installation
2. Curing
3. Temperature Control
4. Water Removal
5. Drying Out

1. INSTALLING THE REFRACTORY LINING

After consulting with the hired refractory contractor, industrial refractory installation is conducted. This process is the mixing of a certain amount of water with a fixed amount of refractory castable. If not, the incorrect amount of water can spoil the refractory lining. Among these are lower strength, longer time to set, and more water to remove during the dry out process.

2. CURING THE REFRACTORY LINING

The castable refractory curing procedure is the process where the water reacts with the refractory cement. It is completed when the refractory material has hardened to its final form.

However, it is an intricate process. This is because the temperature of surroundings and castable can impact curing success.

Thus, curing needs a precise temperature range for it to work. Lower temperatures can weaken the curing. This will lead to lower permeability and longer curing time.

Comparably, higher temperatures will set the refractory product too quickly. Hence, it will affect the densification, making the refractory lining unfit for application.

3. REFRACTORY INSTALLATION TEMPERATURE CONTROL

Temperature is a major part when installing refractory. So store all refractory materials and equipment under a controlled setting. If they are cold, you will lose precious time waiting for them to reach the desired temperature. Thus, refractory contractors put heaters surrounding the curing process depending on the ambiance.

Store material and equipment in a controlled atmosphere. Cold refractory material can take several days to stabilize to the desired temperature. Use heaters in cold conditions to apply heat to the vessel or space around the curing refractory. Heaters should not be pointed directly at refractory surfaces.

Additionally, uncontrolled storage and mixing temperatures will disrupt further steps to refractory installation methods. Hence, causing severe spalling to the refractory lining.

Figure 4.1 Failure to properly mix, place, and cure refractory materials along with using improper dry out schedules or practices can result in severe spalling

4. WATER REMOVAL OF REFRACTORY INSTALLATION

After the castable has been installed and hardened, there are two types of water remaining: physical water and chemical water. Both must be removed before the refractory material can be used in service.

Physical Water: enables the castable to flow, and is also referred to as "free water" because it sits in the pores of the castable and is not bound by any hydrate phases.

Chemical Water: chemically combined water tied up in various cement hydrate phases.

Heat needs to be applied to remove both types of water. The physical and chemical water is released at certain critical temperatures during the dry out which are as follows:

- Removal of free water: 212°F (100°C)
- Dehydration of major cement phases: 440°F (227°C), 530°F (277°C), and 1020°F (549°C)

All water must be removed in a controlled manner and dry out schedules should pay attention to these critical temperatures.

When water turns to steam there is a volume expansion of approximately 1,600 times. This increase in volume causes high pressures within the lining. At each critical temperature there is a high potential for developing internal pressures that could exceed the strength of the refractory castable and cause the material to spall.

5. DRYING OUT PROCESS

Lastly, conduct the drying out process for the refractory castable lining.

The dry-out process requires expertise from the right refractory. If done improperly, the refractory lining will crack and weaken quickly. Also, the steam explosion might happen, risking the workers and the refractory project.

Steps to repair refractory materials

- Cut materials according to specifications or needs.
- Measure distances or dimensions.
- Repair worn, damaged, or defective mechanical parts.
- Seal gaps or cracks to prevent leakage or moisture intrusion.
- Adjust the tension of nuts or bolts.
- Fabricate parts or components.
- Repair structural components.
- Assemble mechanical components or machine parts.
- Clean equipment, parts, or tools to repair or maintain them in good working order.

4.2. Technique of refractory installation

The proper installation of refractory castables includes mixing, placing, curing, and drying.

Careful attention must be paid when adding water and mixing castable materials. Excessive amounts of water can negatively impact the refractory – lower strength, longer set time, and more water that must be removed during dry out. Lower strength and excessive water to remove can make for a higher-risk dry out. Use the proper water target, which can be found on the product datasheet.

The lining acts as insulation to withstand extremely high temperatures, and also helps protect the structure from abrasion and thermal shock. Here's a summary of the best ways to install monolithic refractory linings

1. Casting
2. Ramming
3. Shotcrete
4. Gunite

1) Shotcrete

Shotcrete is typically a low-cement, low-moisture refractory that is fully tempered and mixed with water and special binding additives, and then projected at high velocity onto a surface. With shotcrete, the concrete is already mixed in a cement truck before you shoot it out of a hose,

2) Gunite

Gunite is a dry monolithic refractory designed for use with dry gunning equipment. It uses compressed air to send the dry material to the nozzle, where it mixes with water. Then it sprays out at super high velocity, which compacts the material on placement.

3) Ramming

Ramming plastics and castles is perfect for allowing workers to hand-ram them into place. Lining-support fittings are attached to the shell (metal anchors or ceramics tile anchors for the wall). The material is quite literally rammed into place using a pneumatic hand hammer. Forms may or may not be used, depending on the situation.

4) Casting

Casting refers to pouring wet castables into forms. Castables can be poured into forms to achieve whatever shape is desired or even molded by hand. Once the cement in the mix is hydrated and completely secure, the forms can be removed.

Choosing an installation method

Proper refractory installation is vital to achieving a quality refractory lining. Choosing the right installation method comes down to several factors, including:

- **Site Conditions:** Is the site at a high elevation? Will you be able to set up near the work site? Will you need to stop and start several times?

- **Volume**: Gunite and shotcrete methods deliver high volumes in a short amount of time (upwards of 5 tons per hour), so you must be prepared to handle that in your installation planning.
- **Budget:** Even when the price doesn't vary much between materials, installation methods that lead to more waste will generally end up costing you more.
- **Installation Team's Skill Level:** Whether shotcreting, guniting, ramming or casting, an inexperienced crew can directly affect the amount of refractory material waste, and therefore the total job cost.
- **Bake out:** Different refractories have different bake out times and these should be considered in your project schedule.

Figure 4.2 refractory lining installation

4.3. Techniques of refractory curing

The curing process begins when the water is added to the castable and begins to react with the cement. The process ends when the material is hard and has achieved its final set. Curing behavior is directly impacted by both the ambient and castable temperature. The ideal curing temperature range is between 70°F and 90°F. Curing at temperatures below 70°F can produce negative effects: lower strength, lower permeability, and extended curing time.

Conversely, excessively hot conditions can cause the material to set too quickly, resulting in poor densification or even render the material unable to be put in place.

4.3.1. Ladle Refractory Lining

With the increasing demand for clean steel, the development of ladle defining and continuous casting technology, the function of ladle is expanding. The ladle refractory lining seems significant for its good function performance.

Figure 4 Ladle Refractory Lining

Refractory lining used in steelmaking are used in harsh conditions which includes higher temperature and thermal shocks when the temperature changes abruptly. When molten steel is pour in from a converter or electric arc furnace, the temperature sometimes reaches an extremely high value 1700°C. Before the pour in of molten steel, the temperature of the lining of the ladle is usually between 800°C-1200°C, which causes stress in the lining layer, and this may lead to the stripping of the working layer.

It is well known that the reaction of slag at high temperature can cause erosion of refractory materials. The change of slag composition mainly depends on the smelting process. In the existing smelting process, it is mainly related to alkaline slag, which is likely to react with corundum brick lining. At present, corundum magnesia brick or corundum spinel brick is often used in the entire lining of ladle.

When castable refractory containing spinel (10%-25%) is used for a ladle lining, its resistance to damage is particularly important because its crystalline structure helps to capture a series of two or trivalent cations (Fe^{2+}, etc.). Refractories containing spinel have very low porosity and excellent mechanical properties. However, Magnesium Oxide's materials are replacing these spinel refractories now, because of cost reduction. But it is also because of its good anti permeability.

The preheating of the permanent layer of the ladle lining is an important factor which affects its performance. This phase is also a very important. At this time, any deviation from the ideal heating curve will cause greater stress in the lining, and sometimes may cause the mechanical stress on the burst layer, which are the most dangerous cause of the lining use. Prime. The sequence of thermal cycling during the treatment of molten steel and during the use of ladle will also cause some lining to become fragile and spalling.

4.3.2. Refractory Lining Drying-out Design

Speaking of the refractory lining design, the drying-out process is the most important step concerning the service life of a new lining. In the process, when the heating temperature exceeds 100 degrees Celsius, free water will leave the lining. But the chemically bound water in the plastic refractories won't leave until the temperature reaches 500 degrees Celsius. And the installation of a new lining shouldn't be heated up so quickly or it may cause steam explosion. After 24 hours of initial maintain, the lining should be heated to 550 degrees Celsius. During the period of temperature rise, the proper temperature gradient is maintained and the main burner should be directly applied to the drying process. Once lighted the fire, it shouldn't be suspended. The lining temperature rises by 15℃/h to 150℃ and it should be maintained for 24 hours. Then the temperature increases by 25℃/h to 350℃, keeping it for at least 12 hours. After that, the temperature continues to go up at the same speed and reaches the temperature of 550℃.

Self-Check-4

Direction I: True or Fouls

Instruction1- Say True or Fouls to the following questions.

1. The proper installation of refractory castables includes mixing, placing, curing, and drying.
2. Excessive amounts of water can negatively impact on the refractory strength.
3. Curing means process begins when the water is added to the castable and begins to react with the cement.

Direction II: Multiple Choice

Instruction1I- Choose the best answer from the given alternatives.

1. ______ is typically a low-cement, low-moisture refractory that is fully tempered and mixed with water and special binding additives, and then projected at high velocity onto a surface.
   A. Casting
   B. Ramming
   C. Shotcrete
   D. Gunite
   E. All
2. _______is a dry monolithic refractory designed for use with dry gunning equipment. It uses compressed air to send the dry material to the nozzle, where it mixes with water.
   A. Casting
   B. Ramming
   C. Shotcrete
   D. Gunite
   E. All
3. ________plastics and castles is perfect for allowing workers to hand-ram them into place.
   A. Casting
   B. Ramming
   C. Shotcrete
   D. Gunite
   E. All
4. ______ refers to pouring wet castables into forms. Castables can be poured into forms to achieve whatever shape is desired or even molded by hand.
   A. Casting
   B. Ramming
   C. Shotcrete
   D. Gunite
   E. All

Direction III: Short answer items

Instruction III- Briefly answer the following questions

1. Write the and explain refractory installation procedure
2. Write the technique of refractory installation
3. Write the installation method of refractory materials.
4. What are the techniques of refractory curing?

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