MANUAL

INSULATING AND DENSE REFRACTORY CONCRETE LININGS

DEP 64.24.32.30-Gen.

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DESIGN AND ENGINEERING PRACTICE

PREFACE

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Shell International Exploration and Production B.V. (SIEP)
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The Hague, The Netherlands,

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They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Group Operating companies. Where appropriate they are based on, or reference is made to, national and international standards and codes of practice.

The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual operating companies to adapt the information set forth in DEPs to their own environment and requirements.

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APPENDICES

1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the design, supply and installation of insulating and dense refractory concrete linings, and for the design and installation methods for the anchoring which retain the linings on the wall of the equipment.

This DEP is a revision of the DEP of the same number dated November 1991 and also incorporates DEP 30.48.60.34-Gen. which is now withdrawn. Hence, this DEP now covers refractory linings for fired equipment as well as monolithic (erosion-resistant), insulating and dense refractory linings in units such as fluidised catalytic cracking units (FCCUs).

Requirements of the refractory Manufacturer shall apply if they are more stringent than those of this DEP.

Refractory bricks and special shapes in insulating, dense or acid-resistant refractory are excluded from the scope of this DEP, for which reference is made to DEP 30.48.60.13-Gen., DEP 30.48.60.33-Gen. and DEP 44.24.90.31-Gen.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group company, and to Contractors nominated by them (i.e. the distribution code is "C", as described in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, gas plants, chemical plants and, where applicable in exploration and production facilities and supply/marketing installations.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project, or operation or maintenance of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

The definition of terms relating to unshaped refractory materials shall be in accordance with ISO 1927.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced by this DEP are listed in (11).

2. FUNCTIONS AND TYPES OF REFRACTORY MATERIALS

2.1 FUNCTIONS

Dense and/or insulating refractory linings protect equipment from process conditions (e.g. radiant and convection sections of furnaces, waste heat boilers, sulphur recovery units and fluid-bed installations such as FCCUs and Gasification units).

Refractory linings are used:

- to enclose a space in which processes take place at high temperatures, giving protection to the steel enclosure and the environment (e.g. furnaces, kilns, (fluid-bed) incinerators, reaction chambers, (waste heat) boilers, ducts and steel stacks);
- in installations in which solids or gases are separated or contained at high temperatures (e.g. cyclones, reactors, strippers and regenerators).

The application of an erosion-resistant refractory lining is to be considered if the process conditions inside the equipment are of an extreme nature in terms of highly abrasive flows and solids-containing fluids.

Refractory materials should have:

- resistance to high temperatures and temperature fluctuations;
- chemical/mechanical resistance against those substances which come in contact with the refractory material (e.g. gases, slags, catalyst);
- sufficient mechanical strength to form part of the load-bearing structure and withstand loads during maintenance operations.

The specifications governing refractories greatly depend on the location(s) where they are to be used. A substantial investment in refractory products designed to handle high temperatures and destructive operations can be wasted by inadequate design or careless construction/installation.

2.2 UNSHAPED REFRACTORY MATERIALS

Unshaped refractory materials are mixtures of aggregates and binders, prepared ready for use either directly in the supplied condition or with the addition of a suitable liquid, and having a Pyrometric Cone Equivalent (PCE) of at least 1500 °C.

These mixtures are either dense or insulating refractories. The true porosity for insulating refractories is not less than 45%. The materials shall meet the specifications in Appendix 1.

NOTE: Even though some insulating refractories have a PCE lower than 1500 °C, they are still considered as refractory materials.

Refractory materials for monolithic construction and repairs can be further divided into the following subgroups:

2.2.1 Mouldable refractory materials (mouldables and plastic ramming mixes)

These are materials which are either supplied already moist and ready to use or require moistening into a workable consistency. They are prepared for direct installation as bulk or in cakes.

According to the type of product the binder may be ceramic or chemical (mineral, organic-mineral or organic). They are placed by manual or mechanical ramming or by gunning and hardened by the subsequent application of heat.

2.2.2 Castable refractory materials

These "ready mixed" materials are delivered dry and require mixing with water or other liquids. They are placed by pouring or self-flowing, troweling, vibrating, rodding, tamping or pounding, and harden at ambient temperature.

Castable refractories can be supplied with three main types of bonding:

a) *Hydraulically bonded castables*, containing cement but without deflocculant;

b) *Chemically bonded castables*, containing one or more chemical bonds (e.g. phosphate, sodium-silicate or no-cement). Calcium silicate binders shall not be used.

c) *Deflocculated castables*, hydraulically bonded castables containing cement, a minimum of 2% by weight of ultra-fine particles (< 1 µm) and at least one deflocculating agent.

2.2.3 Gunning refractory materials

These are "ready-mixed" mixtures which are non-coherent before use and specially prepared for placing by pneumatic or mechanical projection, and which belong, by virtue of their properties, to one of the two preceding groups (2.1.1 or 2.1.2).

2.3 EROSION-RESISTANT REFRACTORY MATERIALS

Erosion-resistant refractory materials are essentially unshaped refractory materials but the mixtures consist of special, hard and dense aggregates, generally with a high alumina content, in order to improve resistance against abrasion. Consequently they have a high density and poor insulating capabilities.

The selection of a material is amongst other things based on and depends upon the erosive effects mainly caused by the velocity and/or angle of impact of a solids-carrying fluid stream, the solids loading and the nature of the solids.

Depending on the process conditions and the abrasive nature of flows or solids-containing fluids, aggregates will be selected to combat erosion for example: tabular alumina, corundum, silicon-carbide or nitrides, tungsten-carbide, zirconia, etc.

Erosion-resistance is generally classified as:

Extremely erosion resistant	if loss of volume of the specimen is less than	4 cm^3;
Extra erosion resistant,	if loss of volume of the specimen is less than	12 cm^3;
Moderate erosion resistant,	if loss of volume of the specimen is less than	20 cm^3;

NOTE: Specimen and testing according to ASTM C 704.

3. QUALITY ASSURANCE/QUALITY CONTROL

The required properties of refractory materials and of the applied refractory are specified in (Appendix 1).

Sampling and testing requirements are specified in (Appendix 2).

Requirements regarding the Applicator's Procedure Qualification are specified in (Appendix 3).

Requirements for the anchor materials are specified in (Appendix 4).

The application of refractory lining is a multi-stage process, covering stages such as material manufacture and selection, anchoring system design, refractory application and curing. Omissions or lack of quality control at any stage could lead to complete failure of the lining. It is therefore of vital importance for a quality control procedure to be established for each refractory lining application, covering all aspects from refractory material selection up to and including final inspection of the lining.

The principal quality control aspects which should be covered as a minimum are as follows:

Refractory material selection	Requirements, inspection and testing
Design	Design requirements for achieving a sound refractory lining
Refractory shipment and storage	Requirements, inspection, certification
Welding of anchoring systems:	
- Surface preparation	Requirements, Inspection
- Weld procedure	Procedure, Certification Inspection, Testing
- Welding	Requirements, Inspection, Testing
Installation/Application equipment	Requirements, Inspection
Installation/Application crew	Applicator’s Procedure Qualification
Refractory mixing and installation	Requirements, Inspection, Testing
Curing and drying	Requirements, Inspection
Completed lining	Inspection
Lining repairs	Methods, Requirements, Inspection

The Contractor shall assure that all relevant parties have QC procedures in place which address at least all the steps described above and shall verify their application.

The Contractor shall provide refractory suppliers and applicators with sufficient detailed specifications for each of their specific activities.

In particular, the demarcation of responsibilities and the smooth hand-over between parties involved should be duly covered in the quality control programme.

Lining details not covered by this specification shall be included, if necessary, on drawings or in requisitions. They may also be required to be developed by equipment suppliers.

Any conflicting requirements between documents covering refractory systems shall be thoroughly investigated by the Contractor and referred to the Principal for resolution before bidding or proceeding with the refractory work involved.

Table 3-1 Reference table for testing

Properties of refractory materials	Available test methods according to:			
	ISO	**EN**	**ASTM**	**JIS**
Classifications	1109, 1927 2245, 10080	1094-2 1094-3 ENV 1402-1 12475-1 12475-4	C 155, C 401 C 467, C 673	R 2541 R 2561 R 2641
Refractoriness (PCE)	528, 1146	993-12 993-13	C 24	R 2573
Refractoriness under load	1893	993-8	C 16	R 2209
Creep	3187	993-9	C 546, C 832	
Permanent Linear Change (PLC)	2477 2478	993-10 1094-6	C 113, C 179 C 210, C 605	R 2554 R 2576 R 2654
Thermal expansion			C 832, E228	R 2555 R 2577
Thermal shock resistance		ENV 993-11	C 38, C 1100 C 1171, C 1211	
Thermal conductivity	8894	993-14 993-15	C 201, C 417 C 1113	R 2616 R 2618
Density (bulk, true)	5016, 5017 5018, 8840	993-1 993-2 993-17 993-18 1094-4 1094-7	C 135, C 357 C 493, C 604 C 830, C 914	R 2655 R 2205
Cold crushing strength	8895 10059	993-5 1094-5	C 93, C 133	R 2553 R 2575 R 2653
Modulus of rupture	5013 5014	993-6 993-7	C 133, C 583 C 1161	R 2553 R 2575 R 2653
Abrasion resistance			C 704	
Porosity (apparent, true)	5016 5017	933-1 1094-4	C 493, C 830	R 2205
Young's modulus			C 885, C 1198	
Sieve analysis	565		C 92	R 2552 R 2652
Chemical analysis	10058	955-2 955-5 ENV 955-4	C 560 C 571, C 572, C 573 , C 574, C 575, C 576	
Workability, moisture content (ball-in-hand)		prENV 1402-4	C 92, C 181 C 860	R 2553 R 2572 R 2574
Gas permeability	8841, 8842	993-4	C 577	
Resistance to slag, liquids, gases, vapours	8890, 12672	993-16	C 288, C 621 C 622, C 768 C 874, C 987	R 2214
Sampling and preparation	5022, 8501 8656	ENV 955-4 ENV 1402-2 prENV 1402-3 prENV 1402-5	C 862, C 865 C 1054	R 2551 R 2571 R 2651
Installation			C 903	
Dimensions	5019, 5417 9205, 12678		C 899, 1095	
Vocabulary	R 836	1094-1 ENV 1402-1	C 71	

NOTE: Testing shall be performed in accordance with the relevant ISO standard where available or with the standards shown above or the equivalent AS, AFNOR, BS or DIN.

4. HEALTH, SAFETY AND ENVIRONMENTAL (HSE) ASPECTS

Refractory materials are chemical composites and the mixtures can contain or form hazardous chemical components. These can occur both in freshly produced mixtures as well as in use, and during removal of aged materials.

With respect to man-made mineral fibres reference is made to the publication “Man-made mineral fibres” issued by the Shell Safety Committee.

Local HSE regulations shall be met. In the absence of such regulations, PRE/R50 and PRE/R51 shall apply.

5. DESIGN

5.1 DESIGN PARAMETERS

Besides operating conditions, the design of linings shall also take into consideration construction and maintenance aspects.

Linings can be single or multi-layered, depending on operating temperatures. Maximum allowable surface temperatures of refractories may, for instance, necessitate the use of a hot face layer backed up by an insulating layer (multiple lining). Lining thicknesses are determined by strength, method of application and insulation properties. Attention shall be paid to proper detailing of joints to compensate for thermal expansion and drying shrinkage.

The traditional method of retaining thin-layer erosion-resistant refractory linings to the substrate has been to use continuous armour such as Hex-metal (normal or off-set) or, for highly curved surfaces, Flexmetal. The use of this type of armour is now discouraged as it tends to be very time consuming in terms of application and maintainability. Instead, Speedcells, Tacko anchors, Hexcels and Y studs should be used because they have equivalent fixing capabilities and are easier to install.

NOTE: Speedcell is a registered trademark of Silicon BV, NL. Tacko is a registered trademark of Plibrico Japan. Hexcel is a registered trademark of Causeway Products Ltd.

Table 5-1 summarises the relation between operating/lining design conditions and refractory characteristics and should be used as guidance in lining design.

For materials specifications and anchor materials, reference is made to Appendices 1 and 4 respectively.

Table 5-1 Lining design factors and the related refractory characteristics

Lining Design Conditions	Lining Design Factors	Refractory Characteristics
Operating temperature	Refractoriness of the materials	Maximum service temperature
	Degree of the crack appearance	Linear change
	Necessity of the expansion joint	Thermal expansion
	Strength of the lining	Modulus of rupture or compressive strength
Outer shell temperature and heat loss	Type and thickness of the lining	Modulus of rupture or compressive strength and thermal conductivity
Operating pressure	Tightness to the shell	Linear change and thermal expansion
	Strength and type of the lining	Modulus of rupture or compressive strength
Frequency and degree of temperature variation. Batch Process	Influence of thermal shock	Spalling resistance
Gas composition	Corrosion of refractory	Corrosion resistance (chem. composition, porosity)
	Influence onto thermal conductivity	Thermal conductivity and porosity
Substances contacting the lining (flue gases, slags, catalysts, etc.)	Corrosion of refractory	Corrosion resistance (chem. composition, porosity)
	Influence due to mechanical forces such as erosion	Erosion resistance and modulus of rupture or compressive strength
Mechanical forces against lining (rotation, vibration, abrasion, etc.)	Resistance against mechanical impact	Modulus of rupture or compressive strength
Furnace weight limit	Refractory weight after installation	Bulk density
Initial heating up schedule	Explosion, spalling, cracks, etc. due to steam pressure generated in the lining during heat-up	Porosity, strength and binder characteristics
Installation method	Adaptability for specified. Installation method	Installation feature

5.2 TYPES OF LINING

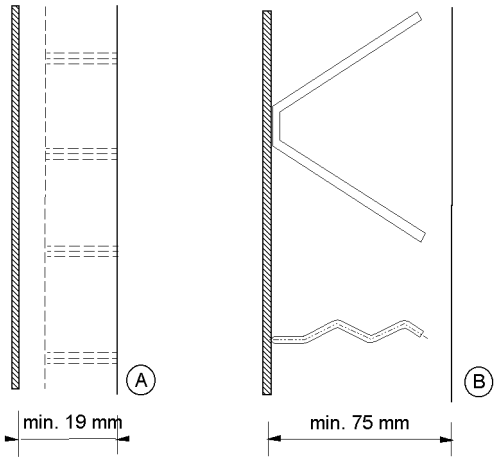
The following types of lining can be identified:

- unshaped refractory ([vibra] cast, self-flow, moulded, rammed, gunned);
- pre-shaped refractory, e.g. bricks, pre-cast monolithic special shapes;
- ceramic fibres.

The types of monolithic refractory lining described below provide a common basis for identification:

- Single-layer linings, consisting of dense or insulating refractory or ceramic fibres (Figure 5-1);

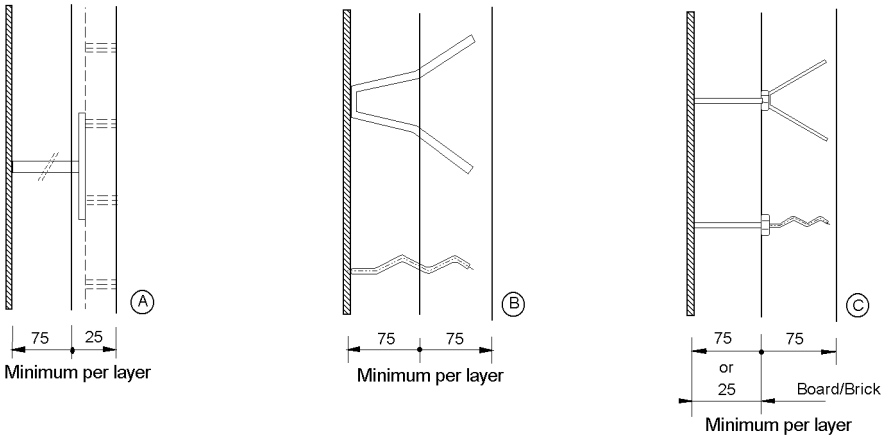
Figure 5-1 Single Layer Linings



- Multi-layer linings (commonly 2 or 3 layers), consisting of layers of insulating refractory protected by a layer of medium weight or dense refractory (Figure 5-2);

  Backup layers may consist of either monolithic materials, bricks or fibrous and/or semi-rigid boards.

Figure 5-2 Double Layer Linings



Linings of fired equipment shall be designed so that the outer wall temperature is between 60 °C and 80 °C at the average ambient temperature and wind velocity, which shall be specified by the Principal.

If the fluid in contact with the refractory contains sulphur the first line of defence should be to ensure that the outer wall temperature is well above dew-point (typically 25 °C higher), taking into consideration the level of SO_3 and the internal atmosphere. The process technologist should be consulted for this data. If this margin cannot practically be achieved (e.g. for FCCU regenerators and fired heaters), the wall temperature may be designed at, or even below, dew point if SO_3 vapours migrating through the lining are expected to be largely neutralised by the lime content in the refractory concrete.

5.3 SELECTION OF UNSHAPED REFRACTORY MATERIALS

Selection of the correct refractory material is normally a multi-stage process. Table 5-2 gives guidance for the selection. For material limitations reference is made to (Appendix 1; 4.3).

Proven material properties shall be used in the design and determination of lining thickness and stresses. The chemical and mineralogical composition shall be selected so as to

minimise the effect of prolonged exposure in service to reducing atmospheres predominantly composed of hydrocarbons and/or carbon oxides.

For erosion-resistant refractory materials the bond mechanism is a very important factor and their maximum strength shall already be effective at temperatures of approximately 500 °C, yet they shall not react adversely with the aggregate or other raw material should the temperature rise above sintering temperature.

Anchor specifications and methods of installation are described in (Appendix 4).

Table 5-2 Performance review of unshaped refractory materials (not applicable to thin, erosion-resistant refractory linings)

PERFORMANCE PROPERTIES	TYPE OF MATERIAL		
	Mouldable Refractory	**Dense Refractory**	**Insulating Refractory**
Bulk Density	High	High	Low
Strength - Impact	Very good	Good	Poor
- Abrasion	Moderate to very good, depends on type of aggregate	Moderate to very good, depends on type of aggregate	Poor
Thermal Shock Resistance	Excellent	Very Good	Good
Thermal insulation	$^1/_2$ to $^1/_3$ that of firebrick	$^1/_2$ to $^1/_3$ that of firebrick	$^1/_2$ to $^1/_5$ that of firebrick
Slag resistance	Increases with Al_2O_3 content	Increases with Al_2O_3 content	Poor
Minimum section thickness	90 -100 mm	75 mm	75 mm
Storage life	6 - 12 months	6 - 12 months	6 - 12 months
Site mixing required	No	Yes	Yes
Installation method	Ramming	Casting, Gunning or Troweling	Casting, Gunning or Troweling
Curing	None required	24 hours	24 hours
Air drying	None required	24 - 72 hours	24 hours
Heat drying 100 -130°C	6 - 8 hours	6 - 8 hours	6 - 8 hours
Initial heating rate	50 °C/h	25 °C/h	25 °C/h
Wall Shuttering	None required	Casting -Yes Gunning -No	Casting -Yes Gunning -No
Roof Shuttering	Yes	Casting -Yes Gunning -No	Casting -Yes Gunning No
Installation rate -Walls	Moderate	Fast	Fast
-Roofs	Slow	Fast	Fast

5.3.1 Mouldable refractory materials

Ramming is a particularly useful method of application for burner walls, burner throats and special roof constructions.

Rammed lining thickness should be between 100 mm and 250 mm. If abrasion, melting or spalling of the surface is explected, additional thickness may be required.

Standard anchors for rammed constructions consist of special shaped ceramic anchor bricks fixed to the casing with cast or welded stainless steel claws. Below 800 °C stainless steel "Bell" type or cast-hooks may be used instead.

5.3.2 Castable and gunned applied refractory materials

The thickness of a single layer in the lining shall be between 75 mm and 150 mm. If abrasion, melting or spalling of the surface is expected, additional thickness may be required.

Erosion-resistant and armoured linings may be thinner, generally 19 mm or more.

The standard for anchorage in dense or insulating refractory concrete linings are V-anchors, double shaped V-anchors or Y-anchors which are corrugated and have equal length prongs suitable either for hand welding or stud welding (Appendix 4).

5.3.3 Stainless steel fibres in applications

Metal fibres manufactured as plain chopped wire shall not be used. If stainless steel fibres are to be included in the refractory lining, this shall be specified in the lining design documentation, but only steel fibres of hooked ended drawn wire fibres or melt-extract types, approx. 25 mm long, shall be used (Appendix 4).

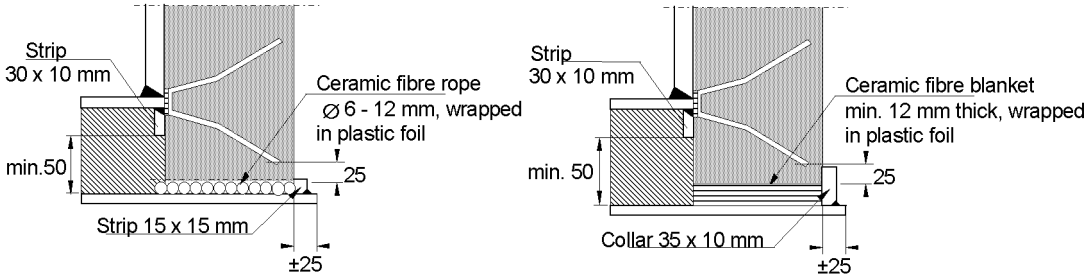
The Contractor shall provide for the Principal's approval, the Supplier's technical details covering bond enhancement, improved lining properties, additional costs and test results to demonstrate the performance of the fibres to be used in the design.

5.4 CERAMIC FIBRE PACKING

The choice between ceramic or anorganic fibres depends on the service temperature and the atmosphere in which the fibres have to function. Anorganic fibres have a temperature of use below 800 °C and a limited chemical resistance.

Ceramic fibre packing is required in expansion joints in order to keep them free of extraneous matter; ceramic fibre packing is required in nozzle neck regions in monolithic linings as typically shown in Figure 5-3 below. See also (8.7.2).

Figure 5-3 Ceramic fibre around nozzles



100 mm < NOZZLES < 600 mm

(Nozzles < 100 mm wrapped with 3 mm ceramic fibre paper)

NOZZLES > 600 mm

Fibres shall be packed to a density of 150 kg/m^3 (i.e. hand tight). The typical thickness shall be checked against or based on calculation of the resulting differential thermal expansion of the materials and the operating temperature.

Wraps of ceramic fibre shall be securely attached to avoid movements during refractory application. The ceramic fibre composites should not absorb moisture from the applied refractory concrete or packed wool shall not be wetted. Water repellent ceramic fibre materials should be used or the packing should be wrapped in thin plastic foil, e.g. polyethylene foil. The leachable chloride content shall not exceed 10 mg/kg. Chloride-containing foils such as PVC shall not be used.

5.5 PROTRUDING NOZZLES AND COLLARS

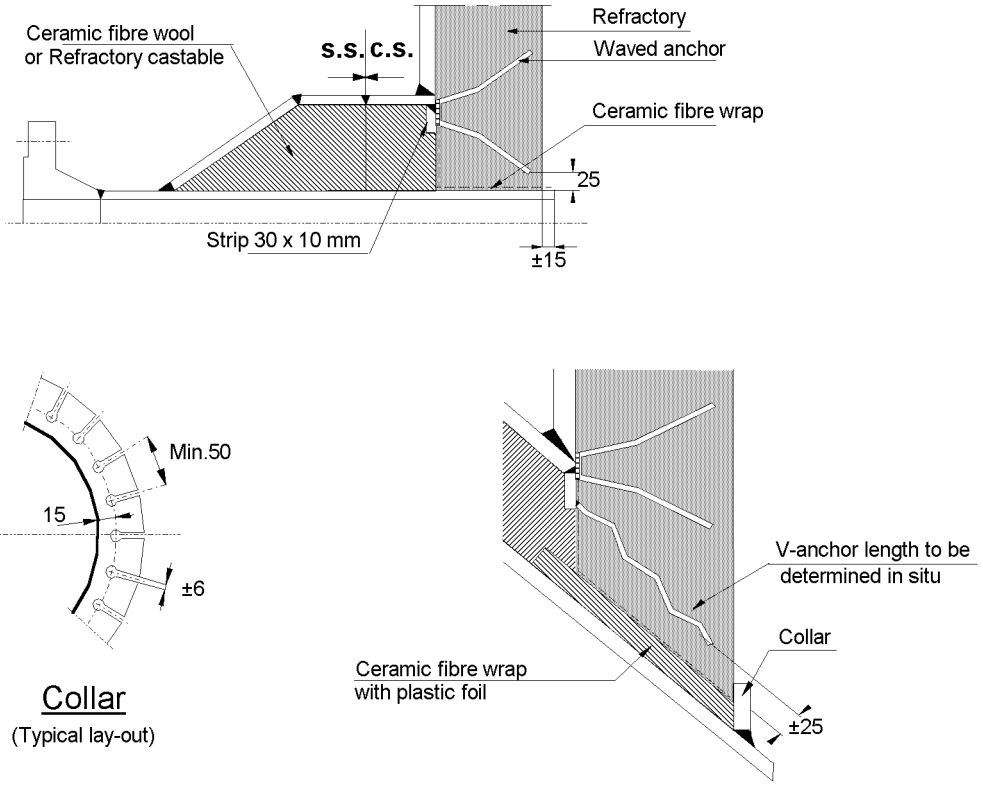
Stainless steel nozzles protruding through (insulating) gunned refractory linings shall be designed according to figures 5-3 and 5-4, e.g. with an internal and externally placed nozzle. The refractory lining is not allowed deeper into the external nozzle than 15 mm, and the remaining space shall then be filled with ceramic fibre wool as shown in (5.4).

Depending on the nozzle's diameter, small strips or collars shall be welded onto the nozzle in front of the lining to prevent the ceramic fibre wraps from shifting forward out of the joint. Collars shall be provided with cuts at regular distances depending on the operating temperature, according to figures 5-3 and 5-4.

If nozzles protrude at an angle through the refractory lining, it shall be ensured that surrounding anchors will adequately support the refractory linings including those neares to the nozzle. If required, extra anchors shall be fitted or strips shall be welded laterally into the external nozzle, without obstructing expansion allowances, to allow extra anchors to be fitted.

For nozzles which protrude through 'cold wall' linings (e.g. those mainly lined with dense refractory and/or vibrated castables) the ceramic fibre wool stuffing in the external nozzle is not required.

Figure 5-4: Typical nozzle layout



5.6 STANDARD DRAWINGS

Standard drawings in Group 24 of DEP 00.00.06.06-Gen. reflect experience acquired during design, construction, operation and maintenance, and should be considered as guidance.

6. SUPPLY

6.1 MANUFACTURE OF REFRACTORY MATERIALS

Refractory Materials shall comply with the materials specification in (Appendix 1). Sampling and testing shall be in accordance with (Appendix 2).

6.2 PREPARATIONS FOR SHIPMENT

Each shipment shall be clearly identified according to the requirements of (Appendix 1).

Each pallet or container shall be clearly identified with the batch number and shall be waterproofed.

6.3 REFRACTORY SHIPMENT AND STORAGE

The Manufacturer's instructions for storage, handling and shipment of materials shall be followed. Shipment of refractory should be scheduled so that it will be **installed** within its specified shelf life. Material which has been in store longest shall be used first.

Some Manufacturers, aware of the limited storage problems, have anticipated this by formulating special (unshaped) refractory materials which are supplied with the agents limiting shelf life kept separate from the main aggregates/mixtures. For example, insulating or dense refractory materials are supplied with suitable quantities of the cement separate, so that the proper mixtures can be made when required by adding the necessary amount of potable water.

For ramming mixes this gives a practically unlimited shelf-life with no wastage because only the required quantities are mixed. Potable water is required to make it ready for use and installation.

Refractory materials shall be protected during storage from extreme weather conditions and exposure to sun. In winter, plastic mouldable refractory materials may freeze and must be thawed before use. This is done by removing only the outside packaging, not the foil, and storing them in a warm place. Thawing may take several days; the material is ready when it can easily be shaped by hand.

All hydraulic setting refractory materials shall be protected from moisture absorption during shipment and storage. Air-tight and moisture-tight polythene bags shall then be used.

Refractory that shows signs of having set (hard or unbreakable lumps in the dry mixture) prior to installation shall be rejected and removed from the job site. Left-overs from previous jobs as well as damaged bags shall also be immediately removed from the job site.

7. TRANSPORT AND HANDLING OF REFRACTORY LINED EQUIPMENT

Refractory installation in furnaces, process equipment, ducting etc. normally takes place on site. It is advantageous to install refractory linings as one major exercise, which allows sound preparation and proper execution; no extra precautions (e.g. for transport or critical jointing) are then required. However, it is recognised that prefabrication of equipment linings can save both time and money, and can provide acceptable results. In such cases the Contractor shall submit procedures covering the design, manufacture and transportation for approval by the Principal.

The procedures shall address at least the following:

- *Maximum weights and overall dimensions* in view of transport facilities, access to the site/plant, and final erection.
- *The shape* of the equipment and/or pieces of equipment. These should be as "compact" as possible since protuberances, small radii or awkward dimensions may give rise to damage in handling and transport.
- *Binding and securing methods*. Portable sections should be sufficiently bound or secured so that loading and unloading from barges, railroad cars or trucks will not crack the refractory lining. Rigid box forms are preferred. Lighter bindings consisting of sheets and T-sections should only be used together with an adequate (diagonal) bracing. Rigging should therefore be such that flexure and distortion do not have an impact on the integrity of the lining. Stiffening rings or structures should be applied where necessary.
- *Time of moving.* To prevent possible cracking, deformation or distortion of the lining, the equipment should be left idle until the lining has been completely cured and air-dried (and ‘water-free’-dried, if this is done at the prefabrication stage rather than at final installation on site). Refractory materials which remain hygroscopic shall be fired.
- *Inspection.* The installed refractory linings shall be inspected prior to shipment and upon arrival at site, see (10).

8. INSTALLATION OF UNSHAPED REFRACTORY MATERIALS

Reference is made to BS 7335-1 and BS 7335-2 for working procedures in the installation of refractory linings by casting and/or gunning techniques.

8.1 GENERAL

The Applicator shall have successfully passed the Applicator's Procedure Qualification (APQ) as specified in (Appendix 3), for the installation of the actual lining. An APQ is required for each crew and type of installation .

The Applicator shall verify that the anchorage and cleanliness of the surface to be lined are adequate before starting the lining activity. Requirements for anchor installation are specified in (Appendix 4).

Depending on the abrasive nature of the refractory material, it is recommended to perform the test procedure in (Appendix 3; 5), in order to ensure the proper working/mixing of the refractory material components.

It is recommended that during refractory installation all nozzles or small openings protruding through the refractory lining be closed by means of plugs (of polystyrene, wood, etc.), slightly tapered for easy removal afterwards.

Provisions shall be made to maintain the refractory materials and equipment to be lined at a moderate temperature (10 °C to 25 °C) until curing is complete. The refractory and steel temperatures shall be continuously monitored and recorded until curing is complete. Thereafter, the lining shall be protected from exposure to water, frost, condensation or extreme heat until commissioning of the lining.

Because refractory materials may contain aggressive chemical substances, safety regulations shall be strictly adhered to . When working with the materials, personnel shall wear masks, rubber industrial gloves and eye protection.

8.2 INSTALLATION OF MOULDABLE REFRACTORY MATERIALS

8.2.1 Preparation

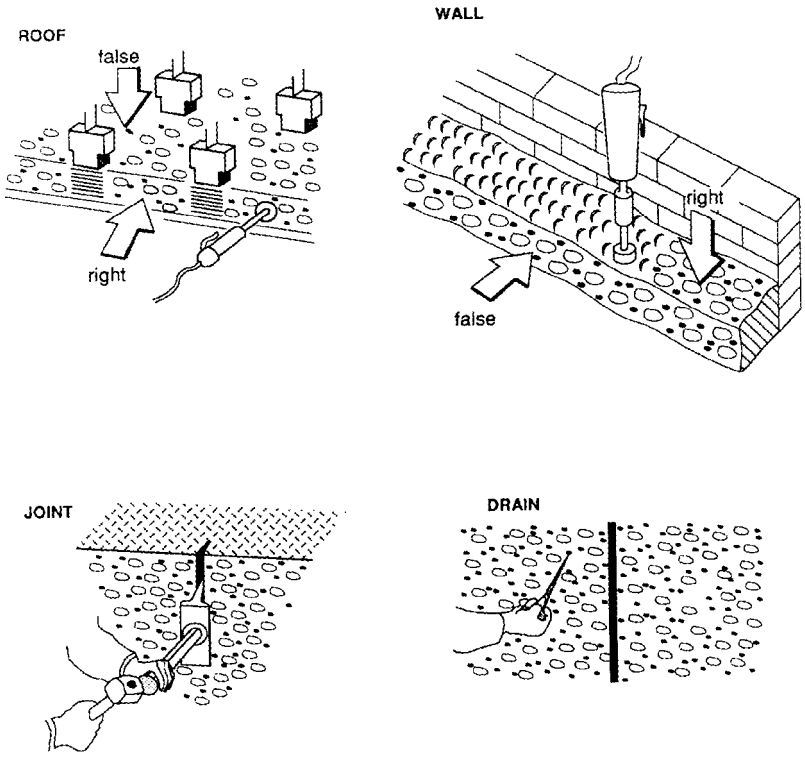
Mouldable, plastic refractory materials are generally supplied ready-to-use, so no special preparations are necessary before the start of the work.

8.2.2 Installation

Mouldable, plastic refractory materials are normally supplied in cartons and packed in foil as cakes, already sliced into approx. 60 - 65 mm thick slices. Otherwise, such slices shall be cut and then broken into small, hand-size pieces. The first layer may be applied as slices; subsequent small pieces shall be placed one after the other and rammed home. A layer thicker than the slice thickness shall not be rammed at one time.

Compacting shall be executed with pneumatic hammers having a frequency of 900 - 1200 blows/min., using as few strokes as possible to avoid the formation of layers.

Figure 8-1 Ramming methods



Ramming shall be in the direction shown in Figure 8-1, gradually shifting the hammer sideways, providing uniform and thorough compacting and knitting all parts monolithically together, leaving no voids. The rammed refractory surface should not be smooth; it should show hammer impressions (which indicates a good knit with the next material). When ramming refractory in overhead positions, before continuing the next layer, a roughened surface is required to achieve an intimate bond.

To save time and material, rammed refractories should be placed behind form work (e.g. shutter boards, forms, etc.) to prevent loss of compacting force, ensure firmness, minimise cracks and ensure the specified lining thickness.

In rammed applications, tile anchors shall be placed after pre-moulding with dummy tiles; alternatively, a tile anchor may be used as a dummy. When fixing the anchor tiles, proper engagement with the anchor jaws and adequate expansion allowance with intersected layers shall be assured.

Only in large applications may the use of plastic, mouldable refractory materials suitable for gunning be considered. These products are supplied in a moist state and gunned by special

rotor gunning machines. Unlike normal gunning, such an application requires dedicated skills and much higher capacity equipment, e.g. rotor gun, air pressure and capacity, etc.

The main advantage is the uniform application that is possible and the re-use of non-polluted, rebound material.

8.2.3 Trimming

After the refractory has been compacted, the surface shall be trimmed with a scraper before the material hardens. In thick applications (over 100 mm), venting holes shall be provided having a diameter of approximately 3 mm, a spacing of 100 mm to 150 mm, about two-thirds depth and pointing slightly upwards, as required.

Uniformly compacted and installed plastic and mouldable refractory materials will often show cracks after drying and firing. Especially in burner walls/throats, score lines 30 mm to 50 mm deep and 2 mm to 3 mm wide (Figure 8-1) shall be used to direct crack formation in a desired direction.

When halting application for short periods, the finished area shall be cut at right angles to the shell and the surface roughened and covered with plastic sheets to ensure that the refractory material remains moist. Longer halts are only permitted if marked-off sections have been finished, adequately secured against collapse or damage, and covered with plastic sheets.

8.3 INSTALLATION OF CASTABLE REFRACTORY MATERIALS

8.3.1 Preparation

Castable refractories are normally supplied in bags and are mixed with potable water on site and poured in place. The amount of potable water to be added depends on the type of the castable and the consistency required during installation. The minimum amount of castable to be mixed shall be one bag and/or the minimum capacity of the mixer.

The materials shall be mixed in suitable mixers, preferably fed through a 10 mm mesh screen to separate any unwanted matter. The castable material may have compacted somewhat during transport and storage; such lumps may be broken and used. For much larger and continuous mixes, mixers of treble paddle (preferred) or the rotary bowl type may be employed.

During mixing, the consistency shall be checked by the "ball-in-hand" method in accordance with BS 1902-703 or ASTM C 860.

8.3.2 Installation

Castable refractory materials shall be installed behind form work (e.g. shutter boards, forms, etc.). Form work shall be stable and rigid and shall be constructed from wood or metal. They shall be treated to avoid water absorption. Form work height should not exceed ten times the lining thickness, with a maximum of 1000 mm, unless specifically designed and detailed for greater height and approved by the Principal.

Each batch of the mixer shall be cast over the full thickness and distributed level. Once application has started it shall proceed without intervals until the entire scheduled lining has been completed. If an unavoidable interruption occurs, the wet ending of the lining shall be cut back at right angles to the surface. All material ahead of the cut shall be discarded.

Compacting may be done using rods or vibrating pokers of suitable size and capacity. Poker vibrators shall not be used with castables having a bulk density less than 1750 kg/m^3. The Contractor shall demonstrate the proper handling during the AQP procedure (Appendix 3).

Horizontal linings shall be cast continuously without layering. Partitioning into suitable parts may be necessary; if so, the layout shall be agreed by the Contractor.

When casting multiple or thick layers, embedded, wetted woollen threads (forming drains) may be used to enhance evaporation of excess water from the refractory.

Special attention shall be paid to dense, high quality and low-cement castables. They normally require small amounts of mixing water, are sensitive to temperature conditions and shall be treated as specified by the Manufacturer.

8.3.3 Trimming

When casting horizontal areas (without form work), the finished surface shall be levelled off with a scraper or screed only; slurry shall not be visible after finishing the surface.

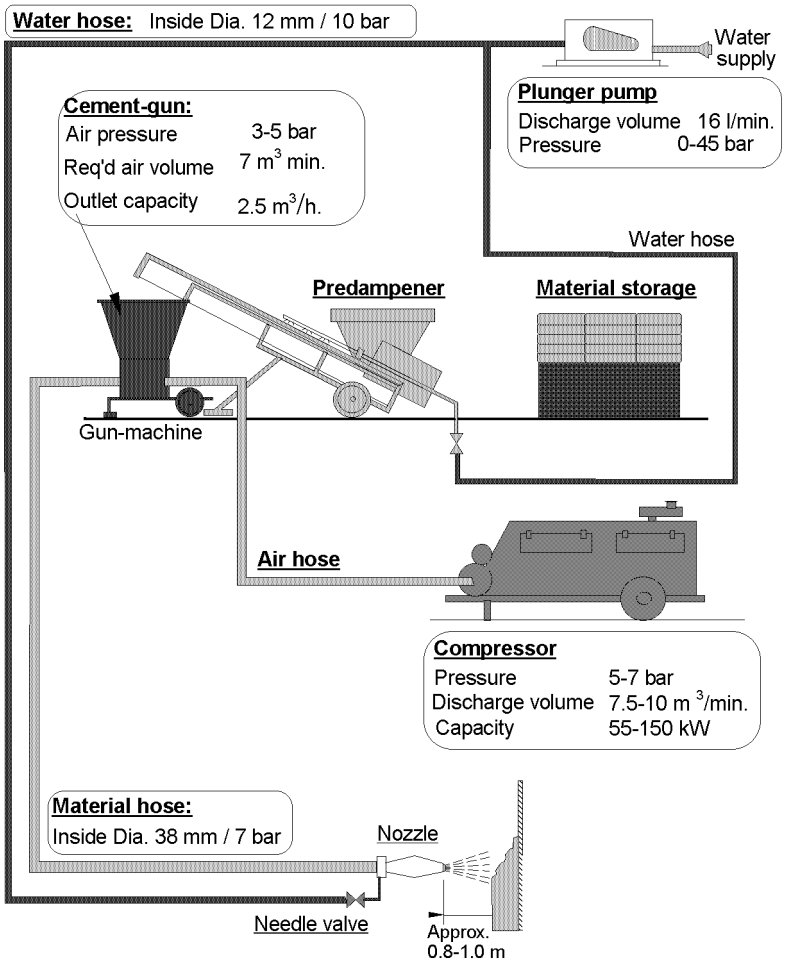
8.4 INSTALLATION OF GUNNING REFRACTORY MATERIALS

8.4.1 Preparation

Gunning refractory materials are normally supplied as ready-mix, packed in moisture proof bags. The contents of one or more bags shall be dry-mixed in a paddle mixer in order to reverse possible segregation during transport.

Figure 8-2 shows the layout and specifications for castable gunning equipment, as further elaborated below:

Figure 8-2: Typical set-up of gunning equipment



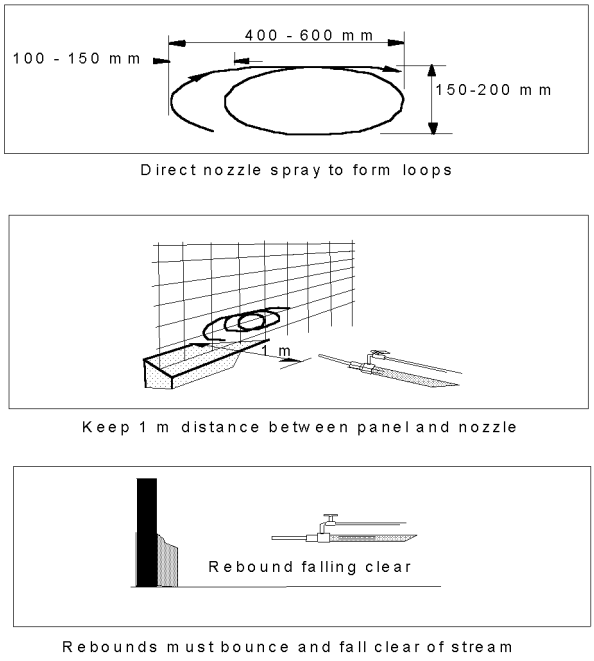
- for large jobs, "Big Bags" (150-200 litres) may be used, depending on the capacity of the mixer;
- a paddle mixer, mixing horizontally or vertically;
- a closed screw conveyor or belt with a small hopper under the outlet of the mixer and the top above the hopper of the gun-machine (compact set-up);
- the gun-machine, preferably with a pressurised chamber system;
- a suitable air compressor, equipped with a well-functioning water separator;
- purpose built hoses (for material as well as water), loop free and as short as practical from gun-machine to work site;
- a gun-nozzle with sufficient spares;
- a remote radio control between the machine operator and the nozzle-operator;
- a remote machine actuator or "dead man's handle" for the nozzle-operator.

All the equipment should be placed as close as practicable near the area to be lined, including intermediate storage of materials to facilitate an easily controlled, continuous

operation.

8.4.2 Installation

Figure 8-3 Typical installation procedure



The appearance of the gunned refractory surface is the best indicator of a correct water/mix ratio. The amount of water shall be controlled so that the gunned surface has a wet, silky sheen and coarse aggregates make craters on the gunned surface upon impact.

A sandy or gritty surface means that too little water has been used. Slumping, ripples or a washboard effect indicates that too much water has been used.

The material shall be applied by moving the gun in small circles and progressing in a 'L'-shaped manner as is typically indicated in Figure 8-3.

Care shall be taken to ensure that rebounds fall or bounce clear of the target and are not entrapped. Entrapment of rebounds by the fresh stream from the nozzle can lead to laminations or spots of low density in the application.

8.4.3 Trimming

When finishing gunned refractory materials, the surface shall be scraped, not trowelled. Excess trowelling works the binder into the surface, seals the surface and restricts the escape of moisture during drying and firing. It may also create a thin crust of pure binder which will flake off when subjected to heating and cooling.

The surface should be left rough, but excessively built-up lining, mud-like spots, tears and dry spots shall be removed and anchors, if present, cleaned.

Finishing of the surface and checking of the nominal thickness should be done directly after a part is ready but before 'setting' starts. The thickness shall be checked either with a ruler or a marked awl. The frequency of required measurements depends on the skill of the nozzle-operator. The specified minimum thickness shall be applied; material in excess of 15 mm over the specified minimum thickness shall be removed.

8.5 INSTALLATION OF VIBRACAST, PUMPABLE AND SELF-FLOW REFRACTORY MATERIALS

Vibracast, pumpable and self-flow refractory materials are the same as conventional materials except that they contain ultra-fine components (from 0.1 µm to 10 µm) and appropriate dispersants, which affect the fluidity and working time.

Preparation and installation of self-flow refractory materials require special attention and the Manufacturer's recommendations shall therefore be followed.

8.5.1 Preparation

The preparation of refractory materials for vibration and/or pump casting are very similar to that for conventional casting except that the water ratio is much lower and the mixture remains very stiff and will not flow without significant vibration (except for pump-cast). Often use is made of low cement type castables with flow enhancing additives.

Mixing of the refractory materials generally takes much longer (up to and over 10 minutes) then conventional mixing and the mixture remains very 'dry' for inexperienced observers. After the appropriate mixing time the mixer operator waits for the mix to change consistency which indicates that it is ready to use.

8.5.2 Installation

Items to be lined shall be placed in a vertical position and major sections shall be cast in one continuous pour. Time between consecutive pours shall be as short as possible, but at least long enough to allow the escape of all captured air before the refractory material sets.

If an item being lined is more than 3 m long, form work shall be installed with temporary windows at approx. 3 m intervals to observe the progress of the installation.

The windows shall be welded shut, or otherwise adequately secured, at the appropriate time during the pour.

All openings, nozzles, etc. shall be closed by means of wood or metal-jacketed plugs, slightly tapered and of a size such that they will fit snugly into the openings. Plugs shall be coated with a suitable release agent.

8.5.3 Trimming

In general no trimming shall be required.

As a result from the heat liberated by the hydration reactions it may be necessary to water spray the form work during initial setting of the refractory lining. After removal of the form work the lining surface shall be kept moist until final setting has occurred.

Form work shall be removed as soon as the castable has developed sufficient strength to allow removal without causing damage. Plugs shall preferably be left in the lining until final setting has occurred. Burn-out of forms is not permitted.

Immediately after the form work has been removed, the surface shall be checked by gently knocking for hidden voids and laminations. Fringes and other protrusions, which can still be removed, shall be treated carefully.

8.6 INSTALLATION OF EROSION-RESISTANT, CHEMICALLY BONDING REFRACTORY CASTABLES

8.6.1 General

Erosion-resistant refractory castables are generally chemically bonding, high purity alumina, plastic refractory mixes with outstanding erosion resistance.

Note: The liquid component of such castables may include others mono-aluminium-phosphate.

Standard delivery is recommended in either plastic drums or in cardboard containers. In view of the limited 'pot-life' of these materials, package is generally such that approx. 11 kg (25 lb) of ready mix can be prepared at a time.

The following precautions are recommended: safety glasses, heavy duty rubber gloves, an eye rincer within reach of the mixer and near to the work location, and compliance with the safety procedures of the Company concerned.

If the addition of stainless steel fibres is required, approximately one percent by weight of AISI 304 stainless steel drawn wire fibres (length 18 mm, diameter 0.4 mm) with hooked ends (Bekeart Dramix or equivalent) may be added through a 10 mm sieve during mixing of the dry refractory material and thoroughly mixed before any liquid is added.

8.6.2 Preparation and mixing

To achieve optimum results, it is advisable to adhere to the precise application methods given by the Manufacturer.

A bowl type mixer (e.g. Hobart) of 15 - 25 litres capacity should be used.

A brief description of the mixing procedures is given below:

Mix thoroughly for at least 1 minute on speed '1' to make the mix lump free (maximum 2 minutes).

If applicable, add stainless steel fibres to the mix by gentle hand spreading or by means of an appropriate sieve and continue mixing on speed '1' for another 30 seconds. Then pour the whole liquid content of the bottle or measuring-glass gently into the mix.

Continue mixing at speed '1' for 3 to 5 minutes until 2 or 3 "balls" are formed of a homogeneous putty-like consistency and material no longer adheres to the bowl.

Pot-life of this mixture is normally between 15 - 45 minutes.

Note: Speed '1' is based on the use of a 'Hobart D300' mixer or equivalent.
The use of water is never allowed for addition to a two-component mix, unless approved by the Manufacturer in the case of water-based mixtures.

8.6.3 Installation

Refer to (Appendix 5; 1.4 - 1.6).

8.7 SPECIAL ARRANGEMENTS FOR INSTALLATIONS

8.7.1 Joints

In refractory applications the use of joints shall be minimised; if joints are unavoidable they shall be made at calculated and practical locations. In general these locations are at corners, edges, changes of material quality and, for example, where a mechanical joint is designed (i.e. permanent flanged joints excluded). Practical locations are entailed by the application procedures, such as scaffold platforms and changeovers of application equipment.

Distinction shall be made between expansion joints and butt-joints. Butt-joints are used when joining materials in the process of application. They are treated with the ordinary surface finish and may be filled with a 1 mm layer of ceramic fibre paper.

Expansion joints are not usually required in monolithic refractory linings due to the shrinkage of the refractory being greater than its expansion. However, consideration shall be given to joints which compensate for constructional/material movements. They shall be designed for the width, shape and type of filling and made at the appropriate locations, i.e. not interfering with attachments in the lining or openings in the equipment.

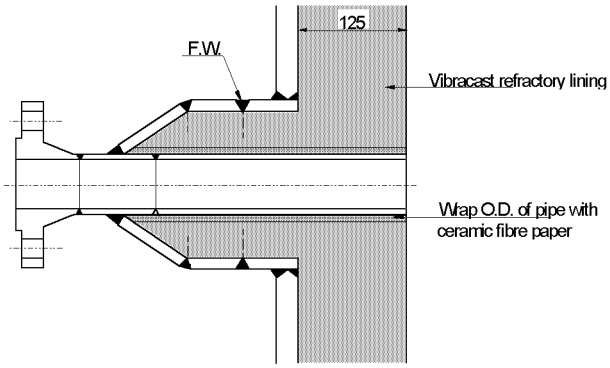
Expansion joints shall normally be straight-through. In multi-layer linings labyrinths shall be formed by shifting joints approx. 35 - 50 mm, or at least twice the joint thickness. Only pre-compressed ceramic fibre blankets or semi-rigid ceramic fibre board shall be used as joint material.

8.7.2 Internals

All nozzles and other fittings which protrude through or intersect the lining shall be wrapped over the full lining thickness with ceramic fibres as described in (5.4).

Figures 5-3 and 5-4 show the principle arrangement for nozzles, etc. which are fitted in insulating refractory linings. Figure 8-4 below shows the principle arrangement for nozzles, etc. in dense vibracast refractory linings.

Figure 8-4: Typical nozzle for dense (vibra-)cast refractory linings



CERAMIC FIBRE PAPER:

Type 1260 °C, 0.192 g/cm3

(all wrapped in PE-foil or paper tape)

Thickness:

DN 50 < NOZZLE < DN 125: 2 mm

DN 125 < NOZZLE < DN 300: 3 mm

DN 300 < NOZZLE < DN 600: 6 mm

DN 50 < NOZZLE < DN 600

Unless it is used in butt-joints, ceramic fibre paper in cast or gunned linings may be treated with a non-absorbent coating or foil.

Anchors for refractory materials, (e.g. V-anchors or Y anchors) and anchor bricks shall not be wrapped or coated, unless specifically required by the design.

9. STARTUP AND OPERATION

Refractory lined equipment shall not be operated until the lining has completely cured and has been formally accepted by the Contractor and Principal.

To avoid damage to the lining, the equipment shall be brought into service in accordance with an approved drying and firing procedure. Critical limitation of temperatures during start-up and/or operations shall be submitted to operator personnel in order to avoid possible refractory damage in the start-up process. Detailed specifications for curing, drying and firing are given in (Appendix 6).

The equipment shall also be taken out of operation in a controlled manner (Appendix 6).

Reports on completion of dry-out/heat-up schedules shall be prepared.

Refractory lined equipment standing idle should be protected against frost and water ingress, especially where moisture can accumulate in the lining.

10. INSPECTION AND MAINTENANCE

10.1 RESPONSIBILITIES

The Principal shall have final responsibility for the acceptance of newly installed linings and repaired linings.

Based on visual inspection, hammer testing and further examination, including laboratory analysis, it shall be determined whether damage or irregularities are the result of material selection, materials supplied, design of equipment and/or lining, specifications, protection of materials during storage and installation, curing and heating or operation.

10.2 INSPECTION

Refractory lined equipment shall be inspected by experienced personnel approved by the Principal. The inspection may be restricted to the reporting of visual observations. Inspection reports shall indicate areas which need immediate or postponed (to scheduled shutdown) repairs.

10.2.1 After drying of the lining

The installed lining shall be inspected immediately after drying. This inspection offers the opportunity to establish the condition of the newly installed lining and to specify necessary repairs.

The inspection may be combined with the supervision of the final preparations for the firing/start-up operations. At random (as agreed by the Inspector), areas of the total lining shall be tested by striking with a ball-peen hammer (approx. 500 g) at approximately 30 cm intervals.

Any voids or dry filled areas will produce a dull sound. Such areas shall be brought to the Inspector's attention for further investigation of the quality of lining installation.

10.2.2 During operation

If access is available prior to start-up/operation for other reasons, the refractory lining may be inspected after completion of the entire drying out and firing procedure; otherwise inspection is not required at this stage.

During operation, infrared thermography on the outer surface of the steel casing should be used to ascertain the condition of the lining. Other means of temperature measurement are contact thermometers and temperature indicating markers on the steel casing, but these are much less accurate and not particularly suitable for overall condition monitoring.

10.2.3 During a shutdown

During a shutdown of the unit, refractory linings shall be inspected, paying attention to the following aspects:

- General *condition* of the refractory lining;
- *Discoloration* of the lining;
- Regular *shape* of the lining (disbonding of butt joints can cause irregularities);
- *Cracks* (deformation of equipment due to lack of or improper pre-treatment can cause irregularities);
- *Spalling.* General spalling could result from incorrect composition and porosity characteristics, or too severe operating conditions such as frequent or major temperature/pressure changes.
  Local spalling could result from direct impact or liquid or vapour jets causing rapid temperature changes or the effect of boiling at the interface level;
- Location and *condition of ceramic fibre* material in the joints (pollution, erosion, dissolving or washing out caused by steam, water, solids or chemical attack);
- Lining in and around *burners, nozzles and manholes* (when design, location, material selection, installation, special treatment and operation are done correctly, only minor repairs should be expected).

If disbonding and spalling of the lining is noticed, this should be further investigated by careful hammer testing. If defects are detected (e.g. leakages, disbonding, wide cracks, severe spalling, material reduction or open joints) by visual inspection or hammer testing, a further thorough examination is necessary; it is advisable to seek specialist advice in such cases.

10.2.4 Inspection of FCC-regenerator linings

The thickness tolerance for the installed refractory concrete shall be at least the specified thickness up to 15 mm plus.

For (gunned) refractory linings that have been allowed to air dry under ambient conditions, random shrinkage cracks (hair-cracks) up to 25 mm long and up to 0.1 mm wide are normal. The total width of cracks which are individually more than 0.2 mm but less than 0.5 mm wide, totalled over a distance of 1 m on the surface, shall not exceed 1 mm.

The individual length of these (shrinkage) cracks may not exceed 150 mm. Larger cracks wider than 0.5 mm and/or areas containing a larger crack density are considered defective. Moreover, large/long cracks are in many cases not due to shrinkage but may well be caused by external forces. It is recommended to seek specialist advise in such cases.

Core samples may be cut from the lining if the quality of the lining is questionable The location of the core samples and repair procedure shall be agreed before samples are taken. Core samples may be used to prepare test specimens for further testing.

For core samples reference is made to (Appendix 7).

10.2.5 Inspection of erosion-resistant refractory linings

The entire refractory lining shall be hammer tested after air drying. The sound should be similar to that produced by hammering bare steel. Dull sounding areas shall be brought to Inspector's attention for closer examination.

The refractory material shall show no voids adjacent to armour or cells, etc., and the surface shall show a closed smooth appearance.

10.3 REPAIR OF VIBRACAST REFRACTORY LININGS

No 'cosmetic' repair of lightly damaged linings shall be allowed. Repair of deeper and localised damage shall be avoided, because they will adhere poorly to the existing refractory and may obstruct expansion during subsequent operation.

In the event of more serious damage, the following repair procedure may be executed:

- The minimum required thickness of the new top layer shall be 25 mm, when in pipes with an internal diameter up to approx. 1.5 m. Where required the existing refractory shall be cut back to the minimum thickness as well, in order to form a complete cast 'cylinder'.
- In larger diameter pipes or on flat surfaces the minimum thickness shall be 25 to 50 mm with preferably a number of anchors pulling through. Boundaries shall be cut back to form a rectangular recess.
- If so desired the refractory material may be mixed with 2 %wt stainless steel needles 15 mm in length.
- The surface to be cast shall be made as rough as possible and free of adhering and loose remnants. Preferably the surface shall be (grit-) blasted. No additional wetting or re-activating of the surface shall be allowed.
- After thoroughly placing and securing the form work, a self-flowing castable of equivalent quality to the existing refractory lining shall be cast.

10.4 MAINTENANCE

To avoid mechanical damage, special protective provisions shall be made for cleaning, scaffolding and lining repair activities. Nozzles and manholes shall be opened only when required for access, or to provide for the appropriate working climate.

For the execution of local repairs, the remaining lining shall be properly supported, and shocks and vibrations to the surrounding lining shall be avoided. Loose debris and dust

shall be removed by vacuum cleaning.

Minor defects in refractory linings should be repaired at an early stage in order to prevent defects spreading to deeper layers of the lining. 'Cosmetic' repair and patchwork repair should be avoided. The extent of area to be repaired shall be determined by inspection. If inspection reveals a defective area requiring extensive repair, the area shall be replaced up to the natural limits of the section in which the defective area is located. All surfaces which will be in contact with the repaired lining shall be thoroughly cleaned and subsequently pre-moistened before any replacement work commences.

Surface defects in refractory linings shall not be filled by wash-coating with a mortar layer. This includes even those of a minor nature since the closure of the hair cracks and/or openings of joints will, due to reversible thermal expansion, inevitably cause more damage during subsequent operation.

11. REFERENCES

In this DEP reference is made to the following publications:

NOTES: 1. Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

2. This list does not include the standards contained in Table 3-1 of this DEP, all of which shall also be considered as references.

SHELL STANDARDS AND PUBLICATIONS

Index to DEPs and Standard Specifications	DEP 00.00.05.05-Gen.
Index to standard drawings	DEP 00.00.06.06-Gen.
Design and calculation of chemical-resistant brick linings for process equipment	DEP 30.48.60.13-Gen.
Requirements for chemical-resistant brick lining materials	DEP 30.48.60.33-Gen.
Refractory bricks and shapes	DEP 44.24.90.31-Gen.
Man-made mineral fibres	Shell Safety Committee
Curing, drying and firing of refractory linings	Memorandum SIOP-MFE No. 003-96

AMERICAN STANDARDS

Liquid membrane-forming compounds for curing concrete	ASTM C 309
Abrasion resistance of refractory materials at room temperature	ASTM C 704
Determining and measuring consistency of refractory concretes	ASTM C 860

Issued by:
American Society for Testing and Materials,
1916 Race St., Philadelphia,
PA 19103, U.S.A

ASME Boiler and pressure vessel code, Section IX: Qualification standard for welding and brazing procedures, welders, brazers and welding and brazing operators	ASME IX

Issued by:
American Society of Mechanical Engineers,
345 East 47th Street,
New York, NY 10017, U.S.A

BRITISH STANDARDS

Preparation of test pieces from dense castables by vibration	BS 1902-703
Installation of monolithic refractories.	
Part 1: Code of practice for installation by casting	BS 7335-1
Part 2: Code of practice for installation by gunning	BS 7335-2

Issued by:
British Standards Institution
389 Chiswick High Road
London W4 4AL
UK

EUROPEAN STANDARDS

Recommendation for the compilation of safety data sheets for refractory products	PRE/R50
Information on health, safety and environmental aspects for the user of refractories	PRE/R51

Issued by:
PRE European Federation of Refractory Manufacturers,
Rue de Colonies 18 - 24 Bte 17,
B-1000 Brussels
Belgium

INTERNATIONAL STANDARDS

Classification of prepared unshaped dense and insulating refractory materials	ISO 1927
Preparation of steel substrates before application of paints and related products, visual assessment of surface cleanliness	ISO 8501-1

Issued by:
International Organisation for Standardisation,
1, Rue du Varembe,
CH-1211 Geneva, Switzerland

APPENDIX 1 SPECIFICATION FOR UNSHAPED REFRACTORY MATERIAL

1. APPLICATION

This appendix specifies the properties required for unshaped insulating and dense refractory materials which are used in vessels, heaters, reactors, ducts and stacks, or other equipment to be internally protected from process conditions.

The materials specified are mouldables, plastics, (vibra-)castables, self-flow castables or gun mixes, depending on their method of application.

2. SCOPE

Installation or repair of refractory linings can normally be executed with standard manufactured refractory materials. Their properties shall at least meet the requirements of the Manufacturer's data-sheet with respect to sieve analysis, true density, moisture content and workability etc. (Appendix 2; 4.2).

Because normal operating conditions are commonly lower than the classification temperature the APQ and installation testing shall correspond with these operating conditions.

There are a number of special applications where standard specifications do not cover the specific requirements. Examples are: fluidised catalytic cracker (FCC) units (regenerator and reactor sections), calciners (rotating), fluidised bed combustors (FBCs), combustion chambers in sulphur recovery units (SRUs), burner parts, etc. In these cases, one or more properties have to be specified more accurately due to structural related or operational conditions.

3. DOCUMENTATION

3.1 Applicable Standards

Testing shall be performed in accordance with the standards shown in (Table 3-1).

The test results shall be reported on forms having the minimum content of those shown in (Appendix 2; Tables 3 and 4).

The Contractor shall submit to the Principal the Manufacturer's certificates for all refractory materials supplied.

Certificates shall attest that the materials comply with the Manufacturer's data sheets and shall include the following information:

- Name of Manufacturer;
- Name of material*;
- Dates of manufacture/pre-shipment tests*, combined with batch identification numbers*;
- Order number;
- Shelf life and storage precautions;
- Recommended water/liquid quantity;
- Pre-shipment test results of the batches and specifications with which these test results comply.

Note: * these data shall also be identified on the packaging

The Contractor shall supply the Principal with the following additional information on the refractory material:

- Material make and data sheets;
- Recommended method for preparing and mixing of all refractory components;
- Recommended method for the installation, curing and subsequent drying, initial and subsequent firing of the lining.

4. SPECIFICATION OF UNSHAPED REFRACTORY MATERIALS

Designation of materials shall be in accordance with ISO 1927. For the applications covered by this DEP the classification of unshaped refractory materials is based on the bulk density

as follows:

• Extra-light weight (XLW) refractory materials;	less than	800	kg/m^3
• Light weight (LW) refractory materials;		800 - 1250	kg/m^3
• Medium weight (MW) refractory materials;		1250 - 1750	kg/m^3
• Dense refractory materials; (including mouldable and plastic ramming mixes)	over	1750	kg/m^3

These classifications are used in Tables 1a and 1b in (Appendix 1, 4.1).

4.1 Classification of insulating and/or dense refractory castables, mouldables and plastic ramming mixes on the basis of the maximum temperature of use and permanent linear change in dimensions.

The classification into the groups is based on a maximum temperature of use:

- For mouldables and plastic ramming materials, the **sum** of the linear drying and firing shrinkage after testing for a soaking period of five (5) hours at this temperature shall not exceed the specified value;
- For insulating and dense refractory castables, the permanent linear change (PLC) after testing for a soaking period of five (5) hours at this temperature shall not exceed the specified value.

Table 1a Classification of unshaped refractory materials

GROUP	Temperature (°C), at which the PLC test is carried out and the PLC is ≤ 1.5% after 5 hours			Temperature (°C), at which the PLC test is carried out and the **sum** of drying and firing shrinkage is ≤ 3% after 5 hours
	INSULATING CASTABLE	Regular	**DENSE CASTABLE** Regular	**MOULDABLE AND PLASTIC**
080	XLW	800	800	
090		900	900	
100		1000	1000	1000
105	LW	1050		
110		1100	1100	1100
115		1150		
120		1200	1200	1200
125		1250		
130		1300	1300	1300
135		1350		
140	MW	1400	1400	1400
150		1500	1500	1500
160		1600	1600	1600
170		1700	1700	1700
180		1800	1800	1800

Table 1b Classification of sub-class 'L'

Insulating Castables belong to sub-class "L" if the Bulk Density (kg/m^3) is less than the values below					
Group	kg/m^3	Group	kg/m^3	Group	kg/m^3
080	700	115	1100	140	1450
090	800	120	1250	150	1500
100	900	125	1350	160	1550
105	900	130	1350	170	1600
110	1000	135	1400	-	-

Examples showing the application of Tables 1a and 1b are as follows:

1. LW 110 is a light weight refractory material which is tested for PLC at 1100°C and has a bulk density of 1000 kg/m^3 or over.
2. LW 110-L is a light weight refractory material which is tested for PLC at 1100°C and has a bulk density of less than 1000 kg/m^3.

NOTE: 1. The temperatures are for classification purposes only.

Although not standard 'Group xx5' classifications may also be used for Dense and Mouldable materials.

2. The temperature of the groups correspond to the limiting temperatures of use in a non-corrosive oxidising atmosphere.

It should be noted that the behaviour of the products depends not only on the temperature but also on the conditions of use.

3. The classifications may be preceded by the terms 'Group' or '(ISO)', e.g. (ISO) MW 135.

4.2 Designation of Insulating, Dense castables, Mouldables and plastic ramming mixes

The designation of an unshaped refractory material shall include the following information:

- type;
- class;
- principle raw material of the aggregate;
- nature of the bond;
- condition in which it is delivered;
- method of placing;
- particle size;
- yield by volume.

Example of an order description:

Insulating castable, Class II, Group 105-L, vermiculite based with hydraulic binder, dry, placed by casting, yield by volume 0.6 t/m^3, maximum particle size 8 mm.

4.3 Material Limitations

4.3.1 Exposure to Sulphur and Vanadium Components

If the fuels fired in equipment contain ≥ 0.5% (weight) sulphur or ≥ 400 mg/kg vanadium, the unshaped refractory materials shall comply with the following limitations:

For fuels containing ≥ 0.5% (weight) sulphur:

- the 'facing' material shall be 1250 kg/m^3 or denser;
- the binder shall be Calcium Aluminate Cement with ≥ 50%(weight) Al_2O_3;
- the 'facing' material shall belong to the 'Low-Iron' class of materials, i.e. Fe_2O_3 < 2% (weight).

For fuels containing ≥ 400 mg/kg vanadium:

- the 'facing' material shall be 1250 kg/m^3 or denser;
- the Al_2O_3 content shall be not less than 40% (weight).

4.3.2 Other Limitations

If fired equipment is designed for water washing of tubes, e.g. in waste heat boilers, 'facing' materials shall be 1250 kg/m^3 or denser.

In these cases the design should be a multi-layer system consisting of a layer of dense refractory bricks, backed up by an insulating brick layer or concrete which is not lighter than Group LW 110-L and of 'Low-Iron' class (Appendix 1; Table 1b).

If fired equipment is not protected against acid corrosion on the casing, the 'facing' material shall also be 1250 kg/m^3 or denser, with a minimum thickness of 75 mm, and in direct contact with the casing.

If fired equipment is not gas-fired and/or reducing operating conditions may occur frequently, the 'facing' material shall have an Fe_2O_3 content of < 2% (weight).

4.4 Burners

The specification of refractory materials used in burners, is divided into two main groups:

- oil fired or dual fired burners;
- gas fired burners.

Burners are designed for long operational service with low maintenance. The refractory lining of oil-fired or dual-fired burners consists of bricks or special shapes, or occasionally pre-cast and pre-fired (low cement) castables.

Mouldable plastic refractory materials can be considered in case of complicated layouts.

The refractory lining of gas fired burners consists either of bricks, pre-cast or pre-fired castables, plastic refractory materials, or pre-fired, vacuum-formed modules of ceramic fibres. Refer also to DEP 44.24.90.31-Gen.

4.5 Furnaces

The lining of furnaces may consist of bricks, cast or gunned refractories.

In view of the operational conditions and the possible presence of slags, vapours or other contaminating agents, only a brief summary is given of refractory materials used in furnace linings:

Table 2 Refractory materials for furnaces

TYPE	GAS-FIRED	OIL-FIRED
Walls	Group MW 130 (-L) castables by casting/gunning, or as dual type lining with Group LW 110 backup	
Roofs	same as furnace walls	same as furnace walls, except that bricks are used around uptakes
Floors	Group MW 130 (-L) castables plus 30% Al_2O_3 bricks protection layer	
Hot Ducts	same as furnace walls	same as furnace walls, except that refractory bricks (>30% Al_2O_3) are used for areas around uptakes and other areas susceptible to erosion damage
CONVECTION BANKS: Roofs	same as furnace walls	same as furnace walls; or as dual type lining with Group LW110 backup
Walls	Group MW 130 (-L) castables by casting/gunning	Same as gas-fired except for soot-blower and/or bullet cleaning: Group FC30 refractory bricks, with Group LW 110 castable backup

4.6 FCCUs

Table 3 Refractory materials in FCCU, regenerator and reactor sections

Material Description		(ISO) MW 135 Medium Weight Insulating Castable	(ISO) Dense 140 Dense Castable	(ISO) Dense 150V Dense, Vibrated Castable	(ISO) Dense 165ER Dense, Erosion-resistant Castable
Bulk Density (dried at 110°C)	kg/m^3	1350 - 1550	1900 - 2100	2100 - 2450	2650 - 3000
Maximum Temperature of Use	°C	1350	1450	1500	1650
Grain size	mm	max. 6	max. 4	max. 4	max. 4
Type of Binder		Hydraulic	Hydraulic	Hydraulic	Chemical
Permanent Linear Change	% % max.	-0.10 at 800 °C -0.15 at 800 °C	-0.2 at 800° C	-0.2 at 800 °C	-0.5 up to 350 °C -0.2 at 1000 °C
(Cold) Crushing Strength	MN/m^2 (min.)	10 at 110 °C 15 at 800 °C	20 at 110 °C 18 at 800 °C	30 at 110 °C 70 at 800 °C	>90 at 110 °C >120 at 800 °C
Erosion Loss	cm^3	> 20 cc	max. 15 cc	max. 6 cc	max. 3 cc
Thermal Conductivity	W/mK	0.30 at 25 °C 0.35 at 400 °C 0.55 at 800 °C	0.65 at 25 °C 0.70 at 400 °C 0.75 at 800 °C	1.05 at 800 °C	2.5-4 at 800 °C
Application		Regenerator	Regenerator Overhead Line Spent cat.risers Catalyst coolers Cold-wall reactor	Cold-wall Liftpot Cat.piping	Cyclones Liftpots Cat.piping Reactors

4.7 Sulphur recovery units (SRUs)

The lining of the various equipment may consist of bricks, or unshaped refractories.

Because SRUs may differ in layout and type, only a brief summary is given of refractory materials used in linings.

Table 4 Refractory materials for SRU equipment

Equipment	Refractory lining
Main reaction chamber:	
burner	Refer to DEP 44.24.90.31-Gen.(4), minimum Group 160 plastic/mouldable + Group 140 IFB,
reaction chamber baffle wall tube sheet	minimum Group 160 castable/plastic + Group 140 IFB, Group HA70 bricks, minimum MW 175-1.4-L, bubbled alumina castable or Group 165 castable/plastic, with HA70 ceramic ferrules + c.f.paper wrap
1st and 2nd line-burner:	
burner body	minimum MW 180 castable, minimum Group 160 castable/plastic + Group 140 IFB,
Incinerators:	
burner body	minimum MW 180 castable, minimum Group 160 castable/plastic + Group 140 IFB
Reactors:	MW (acid-resistant) 125li-L castable
Hot ducts	MW (acid-resistant) 125li-L castable
Flue gas ducts	Carbon steel, externally lagged
Sulphur pit	Group HA45 acid-resistant bricks (+ cellular glass backup)

4.8 Flare tips

External flare tip refractory linings operate under very widely varying thermal conditions, e.g. thermal shock or instant heat-up after being wetted by rain, which often results in a limited service life. Hence, the appropriate choice of refractory material, a suitable anchoring layout especially at corner transitions and around nozzles, etc. and initial curing drying and firing procedures are required.

Curing, drying and firing shall be at least up to approx. 400 °C, or in accordance with the Manufacturer's recommendations, for proper mixing water/moist removal and for control of the initial material shrinkage.

A brief summary of refractory materials for various types of flare tips is given below:

Table 5 Typical refractory materials for flare tips

Equipment/Types	Refractory lining
Ground flares, e.g. John Zink Multi-jet	minimum (ISO) Dense 135 acid-resistant castable or Group FC30 bricks, with improved acid-resistance or HT vacuum-formed ceramic fibres, pre-fired.
Elevated flares, e.g. John Zink Airoil Flaregas /Flaroil SIOP (no refractory)	minimum (ISO) MW 175-L castable, with Rapid-Fire-Technology enhancement, and depending on: type of gases or liquids, corrosion/abrasion resistance, thermal shock behaviour, layout or HT vacuum-formed ceramic fibres, pre-fired, coated.

APPENDIX 2 SPECIFICATION FOR SAMPLING AND TESTING OF UNSHAPED REFRACTORY MATERIAL

1. INTRODUCTION

This Appendix specifies the testing and acceptance criteria for unshaped insulating and dense refractory materials.

Testing shall be performed in accordance with the standards shown in (Table 3-1). The tests shall be performed by a laboratory (the selection of which is subject to agreement by the Principal) which is experienced in testing refractory materials.

The data resulting from regular tests will develop into a pattern which will facilitate future assessment of material properties. The specific properties to be controlled will depend on the field of application or the operating factors on the basis of which the refractory material is chosen.

2. DOCUMENTATION

The test results shall be reported on forms having the minimum content of those shown in (Appendix 2; Tables 3 and 4)

3. SAMPLING FOR TESTING OF SUPPLIED REFRACTORY MATERIALS

Sampling shall be executed on all supplies of refractory materials according to (Appendix 2; Table 1). In the case of urgent supplies and/or limited quantities, reduced sampling and testing may be performed if approved by the Principal. A sample shall contain the appropriate amount of refractory material to produce the required specimen for testing according to the relevant standards.

Table 1 Number of samples for testing

Bulk Density kg/m^3	**Material** Group	**Number of samples**
Less than 1250	Up to LW-120	Minimum 2, plus 1 for every 12.5 tonnes (or part thereof) (Note: 12.5 tonnes is approximately equivalent to 100 m^2 or 10 m^3)
1250-1750	LW120 - MW 180	Minimum 2, plus 1 for every 25 tonnes (or part thereof)
Over 1750	Over MW 180 including Mouldables, Plastic	Minimum 2, plus 1 for every 10 tonnes (or part thereof)
Erosion-resistant linings for FCCU	Over Dense 150	Minimum 2, plus 1 for every 2 tonnes (or part thereof) (Note: 2 tonnes covers approximately 30 m^2)

Each sample of refractory material shall be clearly stamped with a day code and a code for the sequence of production. The coding shall be unique, and traceable to the Manufacturer or Contractor's test report.

4. MANUFACTURER'S ACCEPTANCE SAMPLING AND TESTING

4.1 Sampling of refractory materials

Prior to shipment of the refractory materials, the Manufacturer shall regularly and at random check uniformity and granulometry during the production of the batches, according to (Appendix 2; Table 1).

The Manufacturer shall take one sample per day's production or batch for testing in the test laboratory and the remainder of the samples shall be stored for subsequent (if necessary)

re-testing in air-tight plastic bags. The Contractor is responsible to ensure that the samples are regularly delivered for testing to the test laboratory.

4.2 Testing of material properties

Testing shall be conducted to determine the

- Sieve analysis; ⎫ informative instead of chemical analysis.
- True Density; ⎭

Note: XLW-type materials may show a larger bias than ± 20% per retainment (Appendix 2; Table 2). Manufacturer shall then confirm the material's normal bias for use of control.

- Water content (1x per batch/day's production)*;
- Spectrometric Chemical analysis (1x per order)*;
- Erosion-resistance test according to ASTM C-704*.
- Moisture content (plastic and mouldable materials only);
- Workability test (plastic and mouldable materials only)

A day's production or batch of refractory of which the test results do not meet the tolerances specified in (Appendix 2; 4.4) shall be re-tested, using the stored reference samples. Re-testing shall additionally be performed for:

- Cold Crushing Strength, dried at 110°C;
- Permanent Linear Change, fired at appropriate temperature.

Any failure in this testing shall mean rejection of the day's production or batch.

Note: * for information purposes only, not subject to acceptance criteria.

4.3 Testing of erosion-resistant refractory linings

Refractory material classed as extra erosion resistant or extreme erosion resistant (see 2.3) shall be tested on a set of test specimens as follows:

Six 50 x 50 x 50 mm cubes for bulk density (BD) and cold crushing strength (C.C.S) testing (i.e. minimum 3 x C.C.S 110 °C and 3 x C.C.S 815 °C), and

Two 115 mm x 115 mm x approx. 25 mm plates for ER and PLC testing.

For PLC testing of chemically bonded erosion-resistant castables/mouldables the following procedure shall be adhered to:

Measure and record the average of the longest dimension of one side of the form work. Record the same dimension of the specimens after air drying and removal out of the form work. Record the same dimension of the specimens again after firing and subsequent cooling. Calculate the subsequent percentages of PLC.

4.4 Acceptance criteria for refractory materials supplied

The refractory materials shall meet the requirements of the Manufacturer's data sheet with a tolerance (for sieve analysis) and a range of tolerances for other characteristics as stated in (Appendix 2; Table 2). The Manufacturer's requirement as well as 95% of tested results shall fall within the range of tolerance.

Table 2 Acceptance criteria

PROPERTY	TOLERANCE	
Sieve analysis, per retainment	± 20% of the specified percentage	
True Density:		
less than 1250	50 kg/m^3	
1250-1750	35 kg/m^3	
over 1750	20 kg/m^3	
Bulk Density (BD):		
less than 1250	125 kg/m^3	
1250-1750	150 kg/m^3	
over 1750	175 kg/m^3	
	Individual	Total
Cold Crushing Strength:		
for BD less than 800	2 MN/m^2	1 MN/m^2
800-1250	6 MN/m^2	3 MN/m^2
1250-1750	12 MN/m^2	8 MN/m^2
over 1750	20 MN/m^2	15 MN/m^2
PLC:		
for BD less than 1250	150%	75%
1250-1750	200%	100%
over 1750	200%	100%

NOTE: A test method includes requirements for the test apparatus and a well-defined procedure for using it to measure some property of a material. The precision and accuracy refer statistically to the degree of mutual agreement between individual measurements, derived from a product, from one or more laboratories or from a group of equivalent materials.

Basically no absolute values can be established regarding the properties of unshaped materials. Since there is no general statement of accuracy which can be universally recommended and no justifiable statement can be made regarding the bias of the results, an index of precision is applied: the Standard Deviation (Sigma).

For unshaped refractory materials a Two-Sigma Limit is normally used, and about 5% of the measurements can be expected to differ beyond these limits.

The tolerances/range of tolerances introduced in (Appendix 2; Table 2) are based on a limited number of collected test results. They have been interpreted on the basis of long term experience.

If no relevant data are available or the Manufacturer has not yet collected sufficient data for a bias, he shall present data based on his actual (e.g. yearly average) performance for approval prior to production.

5. INSTALLATION SAMPLING AND TESTING

5.1 Prior to installation

Prior to the installation of a lining, the Applicator shall perform procedure tests to demonstrate that his working methods, equipment and operators can produce refractory linings in accordance with the design requirements. A successful test qualifies the procedure and the operators for the installation of the actual lining. Refer to (Appendix 3) for details of the Applicator's Procedure Qualification (APQ).

The Applicator shall verify that the anchorage and cleanliness of the surface to be lined are adequate before starting the lining activity.

5.2 During installation

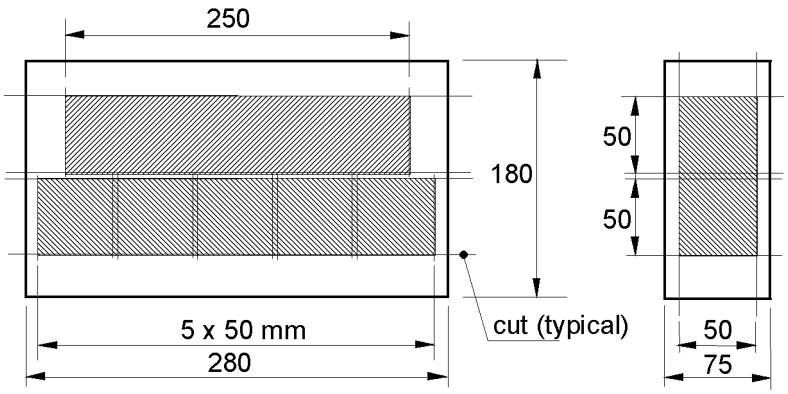
At randomly selected times during each shift, the Applicator shall prepare a number of samples (panels) using the same refractory materials being installed. The minimum number of samples is shown in (Appendix 2; Table 1). Preparation of the samples shall be witnessed by the Contractor. Depending on the type of refractory material, samples shall be either:

- **standard shape**: 230 mm x 114 mm x 64 mm;

  NOTE: Filling shall be done with the dimension of 114 mm upright.
  Alternatively a small case of expanded metal can be used which can be placed over an anchor.
  Minimum dimensions shall then be 300 mm x 200 mm x 125 mm.

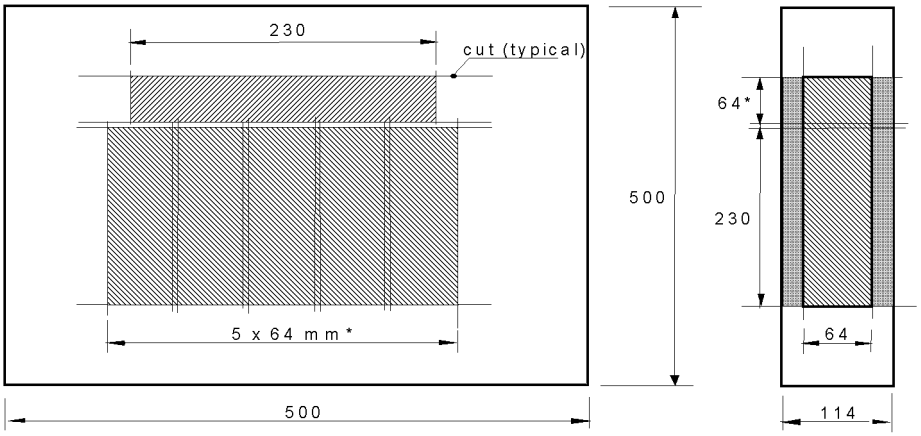
- **box**: 280 mm x 180 mm x 75 mm, for mouldable and/or ram-mixes and poured castables;

Figure 1a Test box for cast/ram mixes



- **panels**: 500 mm x 500 mm x 114 mm, for gunned refractory materials.

Figure 1b Test box for Gunned mixes



Each sample shall be clearly marked with the Contractor's code numbers for that day/shift/crew and for sequence of production. Each code shall be unique, and traceable to

the locations where refractory has been applied by that crew during that shift.

The Contractor is responsible for ensuring that the samples are regularly delivered for testing to the test laboratory. Test specimens shall be cut from the samples at the laboratory, after being prepared, cured and air-dried at the work site.

If samples have to be taken from the installed lining (e.g. loss or damage of samples), refer to (Appendix 7).

Note: Dried samples from ramming mixes cannot be cut in the normal way; they shall first be fired.

5.3 Testing of refractory materials

For each sample, the following properties shall be tested:

- Bulk Density;
- Apparent Porosity;
- Water content (1 per shift)*.
- Cold Crushing Strength, dried at 110 °C;
- Permanent Linear Change, fired at the appropriate temperature.

Note: * for information purposes only, not subject to acceptance criteria.

The acceptance criteria for these tests shall be as stated in (Appendix 2; Table 2).

If the test values do not meet the specification, new samples from same panel or, if necessary, from the associated lining section, shall be re-tested for:

- Bulk Density;
- Cold Crushing Strength, dried at 110 °C;
- Permanent Linear Change, fired at the appropriate temperature.

If the retest results do not meet the specification, the lining section related to the tested samples shall be rejected.

Table 3 Preshipment test report

PRESHIPMENT TEST REPORT			Manufacturer:			Product Name:			Date:			
			Order number:			Identification Number*:			Serial number:			
Remarks:			Mixing water % (wt)		Chemical Analysis % (mass)							
					SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O
				Mean								
			SIEVE ANALYSIS									
Number	Date	True Density, ρ_t (kg/m^3)	< 0.063	0.063 - 0.125	0.125 - 0.25	0.25 - 0.5	0.5 - 1 mm	1 - 2 mm	2 - 4 mm	4 - 8 mm	8 - 16 mm	
MEAN												
STANDARD DEVIATION, σ												

Table 4 Test report

TEST REPORT			Type **:** ☐ **Application** ☐ **Re-testing application** ☐ **Re-testing pre-shipment**					
Product Name:		Manufacturer :						
Manufacturer's Logo		Contractor :						
		Applicator's code : (stated after sample number)						
Date :		Order number :				Serial number :		
Sample Number	**Mixing water**	**after drying at 110 °C**				**after firing for 5 hr. at *x* °C**		
		ρ_s	π_a	**C.C.S**	**PLC**	π_a	**C.C.S**	**PLC**
	% (wt)	kg/m^3	%	N/mm^2	%	%	N/mm^2	%
MEAN								
2 x Standard Deviation								

ρ_s = bulk density

π_a = apparent porosity

x = test temperature

APPENDIX 3 APPLICATOR'S PROCEDURE QUALIFICATION (APQ)

1. SCOPE

This Appendix specifies the procedure for the qualification of Applicators for the installation of unshaped refractory materials. This procedure is divided into three main parts, namely:

- The qualification of Applicator's personnel for all monolithic refractory materials commonly used in refinery equipment, for which a certificate shall be issued with one year's validity;
- The qualification of Applicator's personnel to execute a specific job, in conjunction with the equipment to be used for that job;
- The testing procedure for mixing equipment which shall be used for a specific job.

2. PROCEDURES

Prior to the installation of a lining, the Applicator shall perform procedure tests to demonstrate that his working methods, equipment and team of operators can produce refractory linings in accordance with this specification.

A successful test qualifies the procedure and the equipment operators for the installation of the actual lining. A record shall be made of the complete test procedure, including:

- Details of the test pieces, set-up, equipment and equipment settings,
- Names of the equipment operators;
- Refractory batch identification;
- Mix details and temperatures;
- Test data and results;
- Acceptance by Contractor.

3. PREPARATION AND SETUP OF EQUIPMENT

Prior to APQ testing, the Applicator shall make arrangements to perform tests without interruptions, taking into account the use of tarpaulin covers, storage of materials and set-up of equipment. Supply of materials and disposal of waste and litter are essential parts of the preparations.

The Applicator shall provide all materials for proper execution of the tests, such as tools, boxes and panels, and shall line up facilities as required. The application of refractory materials shall reflect actual installation conditions as much as possible.

If use is made of gunning equipment, at least half the required hose length for the production application shall be used. Mixers and equipment for pre-moistening and conveying shall be checked and tested by the Contractor prior to qualification to confirm that they are working satisfactorily.

4. APPLICATOR'S QUALIFICATION

4.1 APQ for mouldable refractory materials

The Applicator(s) shall prepare a 280 mm x 180 mm x 75 mm (minimum dimensions) sample in a hardwood box, pneumatically rammed, placed in approx. 25 mm thick layers, to demonstrate accurate filling and workmanship. (Appendix 2; Figure 1a)

From the finished and trimmed sample the apparent density shall be calculated and shall meet the value specified on the Manufacturer's data sheet with the tolerances for true density as specified in (Appendix 2; Table 2). The APQ test shall then consist of removing the sample from the box and visually checking completeness of the filling, the compacting, and the "knitting" by breaking the sample into small pieces.
A transparent material (e.g. Plexiglas) may be used for the bottom of the hardwood box so that the filling rate can be visually checked immediately.

Although some porosity is inevitable, it must be evenly distributed. Satisfactory knitting is considered achieved if the sample breaks into small pieces, i.e. no flaws present which cause major fractures when breaking.

4.2 APQ for castable refractory materials

Each team of mixer operators and applicators shall prepare either a standard shape (230 mm x 114 mm x 64 mm minimum dimensions) or a box specimen (280 mm x 180 mm x 75 mm minimum dimensions) in a hardwood box. The specimen shall be placed by hand in approximately 25 mm thick layers, subsequently poked to achieve accurate filling and good workmanship. Poker vibrators shall not be used with castables having a bulk density of less than 1750 kg/m^3.

During installation of dense and medium weight refractory materials, the Contractor shall check the consistency of the ready mixed refractory material using the "Ball-in-Hand" method (8.3.1).

Applicator's test samples shall be stored to set and dry. From the sample, test specimens shall be cut and tested as described in (Appendix 2).

4.3 APQ for gunning refractory materials

Each team of mixer and/or gun machine operators, nozzle-man and helpers shall prepare a panel, approx. 1.5 m x 1.5 m, provided with standard anchoring, V-shape, diameter 6 mm, height 100 mm, pitch 150 mm. Minimum application thickness shall be 120 mm. The test panel should be a reflection of the anticipated production job.

Additionally, each team shall prepare test specimens by gunning one or more panels sized 500 mm x 500 mm x 114 mm minimum dimensions without anchoring, as shown in (Appendix 2; Figure 1b). As an alternative to wood, these small panels may be formed from (stainless steel) expanded metal.

Rebound samples shall be taken for calculation purposes and for information on gunning performance.

During the preparation of the panels and test specimens the nozzle-man shall not change the settings for gunning, water quantity and pressure level. Gunning shall continue until the panels are ready; after trimming, the panels are left to set.

The test panels shall then be stored for further drying. From the samples, suitable test specimens shall be cut according to (Appendix 2; Figure 1a and 1b) and tested as described in (Appendix 2).

Before the panels harden they shall be visually examined by the Contractor; gentle knocking shall not reveal any air inclusions or voids. Pieces taken from the sample shall show an even distribution of the granulates and shall demonstrate the absence of laminations.

4.4 APQ for vibra-cast refractory materials

Vibration cast ("Vibracast") linings may be installed only by an Applicator who has had specific experience with this type of lining and anchoring system in similar thicknesses and quantities.

For each job, the Applicator shall supply technical qualifications and references of installed vibration cast linings with the quantity of refractory materials involved.

Furthermore he shall present a description of the method showing all necessary requirements, such as arrangement and fixation of vibrators, their capacity, arrangement of form work, arrangement of work site, etc.

4.4.1 Mock-up testing:

The refractory Applicator shall demonstrate, by means of a mock-up arrangement which accurately resembles the equipment to be lined, that the form work is properly designed and manufactured fit-for-duty and that the proposed vibra-casting procedure is suitable.

Mechanical vibrators shall preferably be used on the outside of the shell to eliminate voids or dry filled spaces during the casting operation. Proposals to use vibrators inside the forms are subject to approval by the Principal.

The vibrator arrangement shall demonstrate that air bubbles are removed evenly over the thickness and circumference of the freshly cast lining.

Vibrators shall have a total mechanical force of at least 100 % of the total mass being vibrated, including form work and refractory material. The vibrator frequency shall be adjusted to suit the mass and size of the item being cast. Vibrators shall be securely attached by bolting to the item being vibrated; clamping or chains are not permitted.

Specimens shall be core drilled 48 hours after casting and air drying the lining to demonstrate the homogeneity of the lining over its thickness and circumference. The number of specimens is dependent on the size of the equipment and shall be established by mutual agreement between the Applicator and the Principal and/or Contractor, but shall be at least three. From these specimens the bulk density, cold crushing strength and permanent linear change shall be determined by the methods described in this specification.

5. PERFORMANCE TESTING OF MIXING EQUIPMENT

The correct working/mixing of refractory materials shall be tested at regular intervals if specified by Principal or Contractor.

A small amount (e.g. 5 kg) of a dry refractory material shall be mixed according to the applicable work procedure, but instead of adding liquid or water, the same amount of a suitable liquid paint or dye, contrasting with the colour of the refractory material, shall be used.

After spreading out the mixed material on a flat clean area, an even coloration shall be visible and concentrated lumps or "dry nests" shall not be visible. After completion of the test, the mix shall be removed and all equipment and tools used shall be thoroughly cleaned.

Should the test fail, then corrective action is required on the mixing equipment and a re-test made.

APPENDIX 4 SPECIFICATION FOR METAL AND NON-METAL MATERIALS FOR ANCHORS

1. APPLICATION

This Appendix specifies the requirements for (stainless) steel single-point anchors, continuous armour and ceramic anchors for retaining unshaped refractory materials in equipment.

2. DESIGN

Monolithic refractory linings use metal and/or ceramic anchors in various types and shapes to retain the lining firmly to the steel work to be lined. The type of anchors can have multiple forms, like V-anchors, Y-anchors, Speedcells, Hexmetal, Hexcels, Tacko anchors, special anchors bricks, etc. The ultimate choice shall depend mostly on the location and the type of refractory lining applied.

3. MATERIALS, LABOUR AND EQUIPMENT

If supply of material forms part of the contract, the Contractor shall obtain the Manufacturer's test certificates for the actual material to be used. These shall be submitted to the Principal for acceptance prior to the commencement of the work. Welders and welding procedures shall comply with (Appendix 4; 6.1.3).

4. MATERIALS

4.1 Properties

The selection of anchorage material depends on the operating temperature and shall be confirmed by calculations. Tables 1a and 1b summerise the selection criteria.

Table 1a Reinforcing metallic materials selection for erosion resistant linings

Base Material (1)	Offset Hexmetal Anchoring (2) and Floor Steel		Single Point Anchoring (4)	
	Hexmetal Material	Welding Consumable	Anchor Material (5)	Welding Consumable
Carbon Steel or 0.5Mo Steel	12Cr SS (6)	309L SS	12Cr (6) or 18-8 SS (7)	309L SS
Low Alloy Steel (3) (8)	12Cr SS (6)	309L SS	12Cr (6) or 18-8 SS (7)	309L SS
12 Cr Clad SS (CS, 0.5Mo or Low Alloy Base Material) (8)	12Cr SS (6)	309L SS	12Cr (6) or 18-8 SS (7)	309L SS
18-8 Austenitic SS (Clad or Solid)	18-8 SS (7)	308 SS	18-8 SS (7)	308 SS

NOTES:
1. Base material refers to either pressure retaining components or internals, welded with or without PWHT.
2. Offset Hexmetal welded directly to base material without spacer bars.
3. Low Alloy steel refers to 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, 5Cr-0.5Mo or 9Cr-1Mo materials
4. Single point anchoring refers to Speedcell, Hexcel, Tacko anchors and Y anchors.
5. Anchor material refers to the part of the anchor welded to the base material, e.g. threaded stud.
6. Fully annealed Type 410S or 405 SS material.
7. Fully annealed Type 304, 304H or 321 SS material.
8. For maintenance applications on Low Alloy or 12Cr clad base materials the preferred anchoring method is Single point. If Hexmetal is to be used the Principal shall be contacted for a fitness for service evaluation.

Table 1b Anchor materials selection for other refractory linings

Base Materials (1)	Anchoring Material Selection		Welding Consumable
	Temperature of Anchor Tip	Type of Anchor Material	
Carbon Steel, 0.5Mo or Low Alloy Steel (2)	< 450 °C < 800 °C < 1100 °C ≥ 1100 °C	CS 18-8 SS (3) 310 SS Ceramic	CS 309L SS 309L SS N/A
18-8 Austenitic SS	< 800 °C < 1100 °C ≥ 1100 °C	18-8 SS (3) 310 SS Ceramic	308 SS 308 SS N/A

NOTES: 1. Base Material refers to either pressure retaining or internals, welded with or without PWHT.

2. Low Alloy Steel refers to 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, 5Cr-0.5Mo or 9Cr-1Mo materials

3. Fully annealed Type 304, 304H or 321 SS material.

For visual recognition of special alloys the tips of anchors with qualities other than SS304 shall be dipped in paint: min.10 mm, i.e. SS309 - light blue, SS310 - red, SS330 - yellow, or if not possible, shall be suitabley marked in some other way.

4.2 Types of anchors and their layout

4.2.1 Anchors

The anchors are placed in square or chequered pitches, staggered perpendicularly to each other, with dimensions as given in (Appendix 4; Table 2):

The pitch dimensions are projected to the inner surface of the refractory lining, particularly for ducting (square or round), piping and the outside of curvatures. Consequently the pitches are equal to the dimension chosen in flat applications, larger when welded on inner surfaces and smaller when welded on outer surfaces.

In general the largest matching length shall be chosen, unless extra protection against high temperature chemical corrosion will be required.

Table 2 Anchor spacing

Anchor Location	Refractory thickness 'L' mm			
	150	125	100	75
	Anchor spacing 'D'			
Top head of vertical vessels Furnace roofs	175	150	125	100
Shells of vertical vessels Furnace walls Plenums Thermal transitions	175	175	150	125
Horizontal cylindrical shells (0 > 2500 mm)	200	175	150	100
Horizontal cylindrical shells (≤ 2500 mm) Ducting (all shapes) Bottom head of vertical vessels	250	200	200	150

The spacing of Speedcells is given in Appendix 4; 6.2.1 and the spacing of Y-studs is given in Appendix 4; 6.2.3.

The refractory thickness 'L' relates in principle to the thickness of the hot face layer irrespective of the total lining thickness.

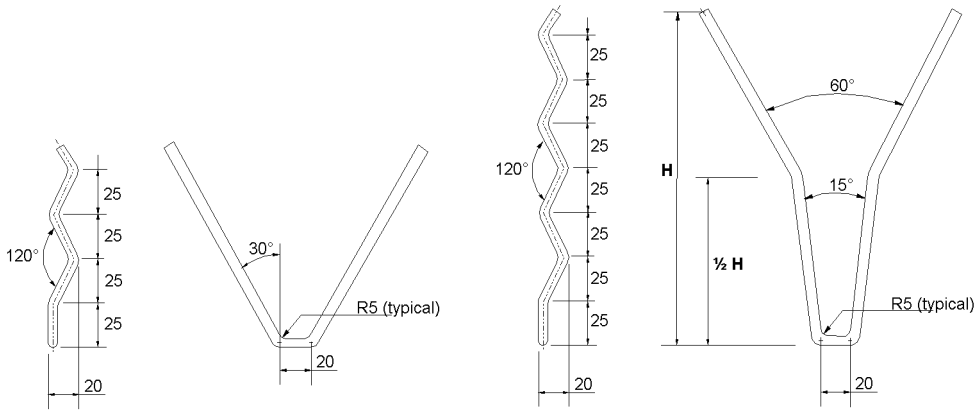
Note: Especially in multi-layer linings the anchor tips tend to diverge too much resulting in insufficient retention of the refractory materials

The lining system anchoring components shall be one or more of the following types:

a) **V-anchors** are made of 6 mm diameter wire, V-shaped with equal prongs and corrugated ("waved"). They are available in heights from 40 to 250 mm.

The anchor height shall be 10-15 mm less than the nominal thickness of the refractory layer to be placed:

Figure 1 Dimensions for V-anchors for single and double layers



Anchor diameter 6 mm.

Length 'H' mm	Code
40	A4
50	A5
60	A6
70	A7
80	A8
90	A9
100	A10

Type A

Anchor diameter 6 mm.

Length 'H' mm	Code
110	B11
130	B13
150	B15
170	B17
190	B19
210	B21
230	B23

Type B

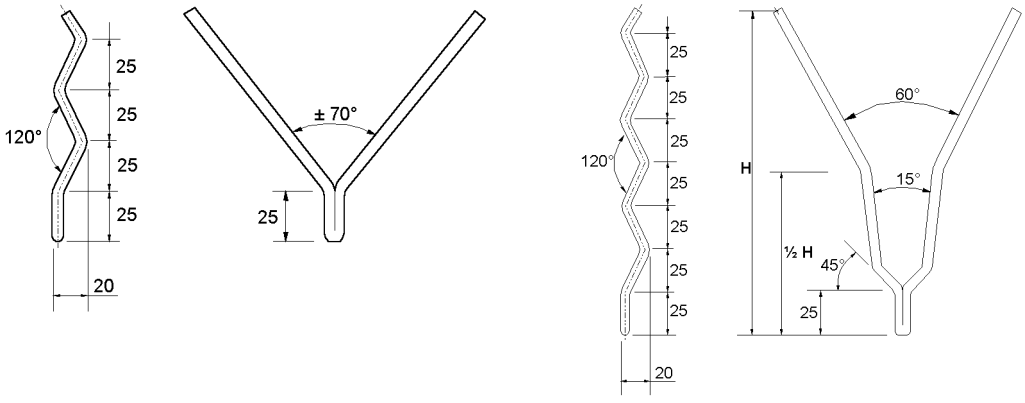
NOTES: 1. A4 - A6 not corrugated, but straight.

2. For lining thickness (refer to table 2) 'L' < 125 mm: Type 'A',
'L' ≥ 125 mm: Type 'B'.

3. For anchor lengths 'H' > 250 mm: 8 mm diameter

In double layer systems, or thick layers (over 175 mm), the anchor tips tend to widen out too much, so double shaped (type B) or Y-anchors shall be used. Such Y-shape anchors are preferably assembled from V-anchors type A, welded on 6 mm diameter studs.

Figure 2 Dimensions of V-anchors for stud welding only



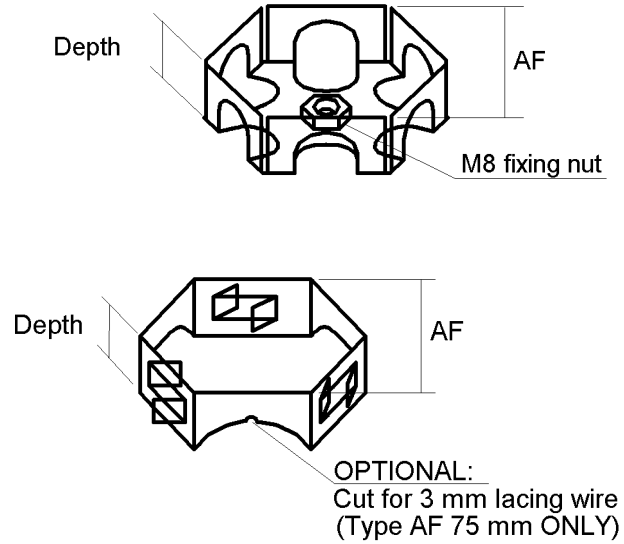
Type A **Type B**

V-anchors suitable for stud welding are basically ordinary V-anchors, adapted to stud

welding equipment. They shall be supplied with the required ceramic ring for proper fitting.

b) **Speedcells**, **Hexcel** anchors and **Tacko** anchors, are prefabricated and are supplied according to the licenser's standards. Only the height for these types of anchors needs to be specified. Tacko dimensions are not given and shall be in accordance with the Manufacturer's standard. The spacing of Speedcells and Hexcel anchors is given in Appendix 4; 6.2.1.

Figure 3 Dimensions of Speedcells and Hexcel anchors



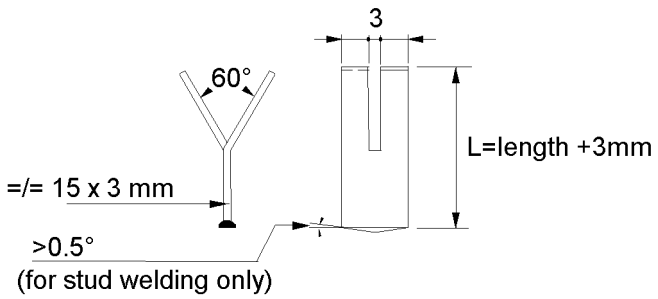
	Speedcell	Hexcel			
AF	50 mm	50 mm	75 mm		
Standard depth	15 mm	25 mm	25 mm	38 mm	50 mm
Standard thickness	1 mm	1.5 mm	2.0 mm		2.5 mm

c) **Y-anchors** should be stud-gun welded. If this process is not possible, hand-welding is permitted. Depending on the height and make, the anchors are already split in two sections or have to be spread apart after welding.

A typical notation for ordering anchors for a 25 mm lining is as follows:

CY(A/S)	**15/3(60)**	**025**	**304**
type (flat/spread)	strip (angle)	height, excluding weld	alloy type

Figure 4 Typical "Y" anchor



d) Special shaped **ceramic anchors** are available in a wide variety. The supplier shall provide detailed design drawings and test results or other data to support the

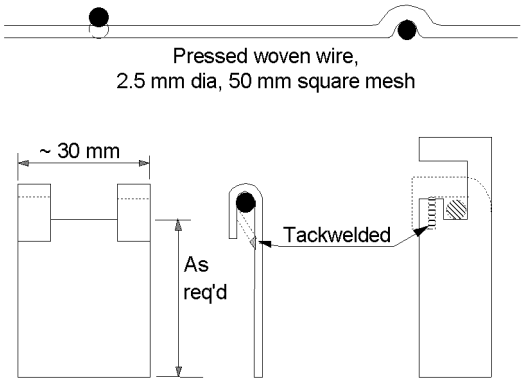
performance of the anchoring system used.

The anchor pitch should be as shown in (Appendix 4; Table 2). However for ceramic anchors "D" is the distance between the edges of adjacent anchors, with a minimum distance of 150 mm.

The material of the anchor claws shall be in accordance with (Appendix 4; Tables 1a and 1b).

e) Compressed woven **wire mesh**, mesh width 50 mm and wire diameter 2.5 - 3 mm, may be used in thin monolithic linings up to 60 mm, apart from typical erosion-resistant refractory linings, as an alternative to a densely packed V-anchor arrangement. A typical arrangement is given in (Appendix 4, Figure 5):

Figure 5 Typical wire mesh arrangement



Typical mesh retaining studs
(suitable for stud gun)

5. COMPARISON OF ANCHOR SYSTEMS IN FCCU EROSION-RESISTANT REFRACTORY LINING

Because the various types of anchor system each require a specific installation, removal and installation time especially when used for thin erosion-resistant linings in FCCUs, (Appendix 4; Table 3) compares three typical fixing systems.

Any of these anchor fixing systems (Hex-metal, Y-anchors, V-anchors Speedcells) may be used for new constructions. Specific systems to be used will be specified on detail design drawings. Any anchoring applied to equipment that requires Post Weld Heat Treatment (PWHT) shall be applied prior to the final PWHT, so that the anchoring welds are also PWHT. This eliminates the need for spacer bars in Hex-metal systems.

For maintenance of and repairs to anchoring welded directly onto low alloy steel base metal without subsequent PWHT, the anchoring system should be semi-automatically welded Y-anchors, V-anchors or Speedcells.
Alternatively, if manual welding is used for either a single point anchoring system or Hex-metal anchoring, welded directly onto low alloy steel without subsequent PWHT, a fitness for service assessment shall be performed to determine whether defects introduced by welding pose any risk to base metal integrity.
See paragraph 6.1.3 for specific welding requirements. The Principal shall be contacted for details of the fitness for service methodology which should be applied.

Table 3 Comparison of fixing systems used in FCCUs

Description of operation	Hex metal	25mm Y-anchors	Speedcells
Break out of 'old' steel parts and refractory material: a] Regenerator cyclones and cat. Piping b] Reactor liftpot, riser, and cyclones	20 manhours/m2 60 manhours /m2	8 manhours /m2 12 manhours /m2	4 manhours /m2 8 manhours /m2
Transport into position	Very difficult	Very easy	Very easy
Positioning and marking	Very difficult	Very easy	Easy
Forming operations	Required Difficult	Bending out of tines on non-preshaped Y-anchors	None
Welding (see NOTE)	Approx. 12 m/m2	Approx. 4 m/m2	Approx. 4 m/m2
Installation time steel parts a] Cat. piping, cross-overs b] Cyclones	*Hand welding* 60 manhours /m2 60 manhours /m2	*Stud welding* 5 manhours /m2 5 manhours /m2	*Stud welding* 2.5 manhours /m2 2.5 manhours /m2
Steel wastage during placement (non-designed)	20 - 30%	1 - 5%	1 - 3%
Steel fibres	Not necessary	1 - 2%, optional	None
Method of application	Ramming Hand packing	Vibration Hand packing	Vibration Ramming Hand packing
Refractory application time	10 manhours /m2	5 manhours /m2	6.5 manhours /m2
Reparability	Fair	Excellent	Excellent
Lining outside of pipes	Only large diameter	Easy	Easy
Lining heights	Hexmetal to be placed on stud and plate; up to 200 mm	Only longer fins (up to 50 mm, above change to V-anchors)	Only longer M8 stud (up to 150 mm)
Height adjustability	Difficult	Change the fin angle	Rotate Speed cell, Use longer M8 stud
Lining of shapes	Difficult	Easy	Easy
Duplex linings	Extra threaded stud and plate piece required	Not applicable	Use longer M8 stud
Lining cracks	None	Fine non-continuous cracks	Few and non-continuous
Combination with different anchors	Not applicable	Easy	Easy
Thermal shock resistance	Satisfactory	Excellent	Good
Chances of application errors	*Hex metal* : Large *Refractory*: Medium	*Studs* : Small *Refractory*: Small	*Studs* : Small *Refractory*: Small
Qualified operators/installers	Qualified welder and experience in hex-metal installation	Welders	Welders
Delivery time	3 - 4 weeks	1 week	1 week

NOTE: Figures are aggregate weld length in each square metre of applied system.

6. INSTALLATION OF ANCHORING SYSTEMS

6.1 General

6.1.1 Inspections and approvals

All work shall be subject to inspection and approval by the Principal. The Contractor shall not apply any metallic materials to surfaces without prior approval by the Principal.

6.1.2 Surface preparation

The surface on which any anchor component is to be welded shall be cleaned free of grease, mill scale, loose rust or other foreign materials prior to installation of anchoring. To achieve this, blast cleaning per ISO 8501-1 (grade SA-1), followed by cleaning with an air jet (dry and oil free) shall be executed.

6.1.3 Welding

For new construction either manual or semi-automatic stud gun welding may be used.

For maintenance welding involving the direct welding of an anchor system onto low alloy steel base metal without subsequent PWHT semi-automatic stud welding should be used. If manual welding is used for direct welding of an anchor system onto low alloy steel, a fitness for service assessment may be required (see Section 5).

The welding consumables used shall be compatible with both the base metal and the anchor material. Tables 1a and 1b shall be used as guidance in the selection of the consumable type.

All welding procedures used for the welding of anchoring systems, including semi-automatic stud welding, shall be qualified in accordance with ASME IX procedure requirements (11).

Welders and welding operators shall be specifically trained to make proper anchor attachment welds and qualified in accordance with ASME IX performance requirements. Each welder or welding operator must be tested on an actual anchor in all positions to be used on the job. Any other training or qualification requirements proposed by the Contractor shall be approved by the Principal.

Any anchor welds on low alloy steel (with or without PWHT) require the following minimum pre-heat temperatures:

Table 4 Pre-heat temperatures (without PWHT)

Base Material	Thickness (mm)	Minimum preheat (°C)
0.5 Mo	>20	100
1Cr-0.5Mo or 1.25Cr-0.5Mo	All	150
2.25Cr-1Mo	All	200
5Cr-0.5Mo or 12Cr	All	250

6.1.4 Testing of anchors and their welds

Anchors and welds shall be such that an anchor can be bent through 90° and returned to its original position without failure of anchor or weld. This testing shall be executed at random during anchor installation on at least 5% of the anchors.

Anchor welds shall be visually inspected. Manual stud welds shall be fully fused over 360°. Semi-automatic stud welds shall show a 360° flash. Weld undercut on the anchor exceeding one-eighth of the anchor nominal diameter or thickness shall be repaired or the anchor shall be replaced.

Prior to the application of refractory, all anchors shall be hammer tested to ensure sound welding. A light hammer (approximately 200 g) shall be used to tap each anchor end sharply, without bending it. Each anchor having a dull, flat sound shall be replaced.

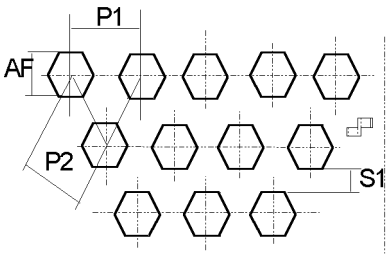
6.2 Installation

6.2.1 Installation of Speedcells

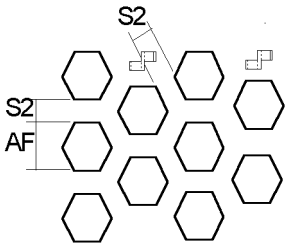
Speedcells consist of a threaded M8-stud and a hexagonal cell. After (stud) welding the appropriate stud, a cell is attached to the required height and tack welded to avoid loosening.

Speedcells shall be installed as indicated in (Appendix 4; Figure 6). In circular vessels or equipment the cells shall be evenly divided over the circumference. The use of a template is recommended.

Figure 6 Arrangement of Speedcells



PATTERN A



PATTERN B

	AF	50	75
	P1	100	130
	P2	87	112
	S1	37	37
	S2	21	28
Approximate number of cells per square metre	Pattern A	115	69
	Pattern B	229	109

The same cell patterns shall be used in conjunction with Hexmesh armouring, either in the design or in repair areas. However, a clearance of 10 mm to 20 mm between the panel and the first row of cells shall be made.

The last panel strip shall be welded on both sides of the cells. If the panel strip ends perpendicular to the joint, then all ends shall be welded, either together and/or to the substrate.

In larger 'voids' between the cells and the panels or at boundaries where the cell patterns will end, either ½ cells or Y-studs shall be placed.

6.2.2 Installation of Hexcel anchors

Hexcel anchors are available in two cell dimensions, AF 50 mm and AF 75 mm. The Contractor shall submit detailed drawings showing the size of Hexcel anchors used and the configuration according to pattern A or B (Appendix 4; 6.2.1). Hexcel anchors shall be welded at three alternate sides with a single weld with a minimum length of a weld of 20 mm, leg-length 2.5 mm.

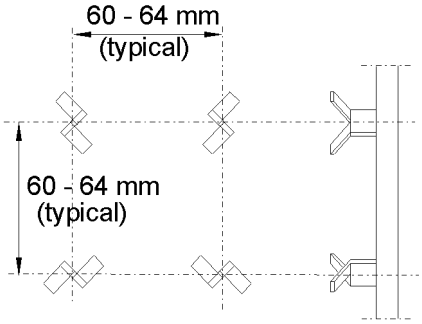
The layout of Hexcel anchor patterns is as mentioned in (Appendix 4; 6.2.1).

6.2.3 Installation of Y-anchors

Y-anchors shall be installed as indicated in (Appendix 4; Figure 7).

The Contractor shall submit detailed drawings showing the configuration of Y-anchors.

Figure 7 Typical installation detail of "Y" anchor



6.2.4 Installation of Hexmesh panels

The installation of hexmesh panels, consisting of plain or off-set type panels, shall comply with the Manufacturer's procedures with regards to welding and joining of panels.

A typical weld pattern valid for both types is shown in (Appendix 4, Figure 8).

If panels are installed on spacer bars or studs, the panels shall be joined (by using 'punched-tabs' if necessary).

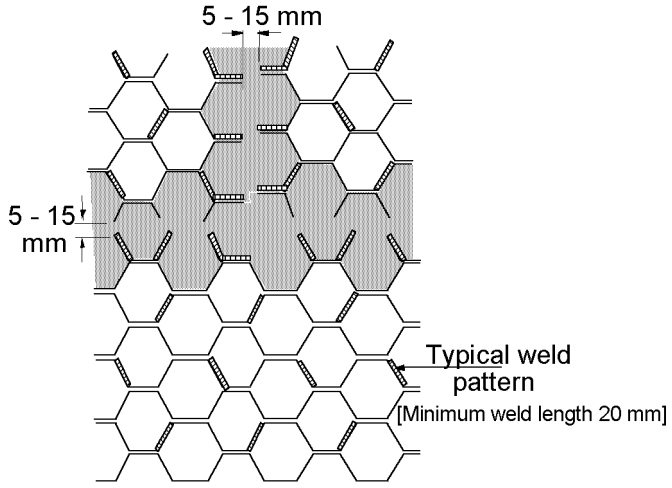
All punched tabs and/or strip ends shall be cut to size and welded over their entire height.

Punched tabs shall be omitted if strips of joining panels can be rearranged so that gaps can be bridged. In principle spacing shall comply with the following:

- any dimension, including AF, shall be larger than 25 mm;
- the surface of individual spaces shall be maximum: 'Length' x 'Width' $\leq$ 225 mm^2.

However, if whole panels are placed directly and fully against the substrate they may be joined together without the use of punch-tabs. In that case installation shall be executed as indicated in (Appendix 4; Figure 7) and shall be subject to Principal's approval.

Figure 8 Typical panel-to-panel alignment



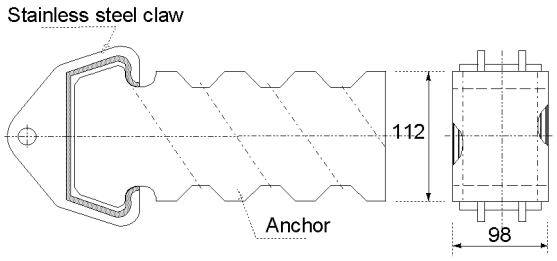
7. CERAMIC ANCHORS

Ceramic anchors used in rammed plastic refractory linings shall be placed after pre-moulding with dummy forms located in square pitches. The anchor claws shall be placed so that expansion movements of the inserted anchor bricks are not restricted.

Special care shall be taken to prevent damage when handling the anchor bricks. Broken

anchor bricks shall be replaced.

Figure 9 Typical ceramic anchor and claw



8. METAL FIBRES

Metal fibres manufactured as plain chopped wire are not acceptable. Should stainless steel fibres be required in the refractory lining, this will be stated specifically in the lining design documentation.

In that case, approx. 1%w stainless steel fibres of hooked ended drawn wire fibres, 0.4 mm diameter by 18 mm long, or as melt-extract type, 0.5 mm diameter and 25 mm length, both to AISI 304 or 310 selected in accordance with (Appendix 4; Tables 1A and 1B), shall be added as described below.

Refractory materials with metal fibres should be ordered already premixed by the Manufacturer to save time at the work site. If metal fibre is to be added at site the Manufacturer shall advise the optimum percentage to be added. A small vibrated hopper shall be mounted on top of the paddle mixer to evenly feed the proper quantity of fibres into the dry mix.

The addition of metal fibres shall be executed simultaneously with dry premixing and this dry mixing shall then be continued for a further 1 to 2 minutes to prevent metal fibres from forming lumps or accumulating in the mixer.

Small vibrators shall be installed on the gun-machine hopper particularly when using premixed stainless steel fibres. This should minimise the formation of lumps of moist material during pre-damped mixing and allow a more evenly distributed filling of the machine.

APPENDIX 5 REFRACTORY LININGS FOR FCCUs

1. GENERAL

In view of the special character of refractory linings in FCCUs, it is necessary to specify additional design requirements. Special material property requirements are given in (Appendix 1; 4.7).

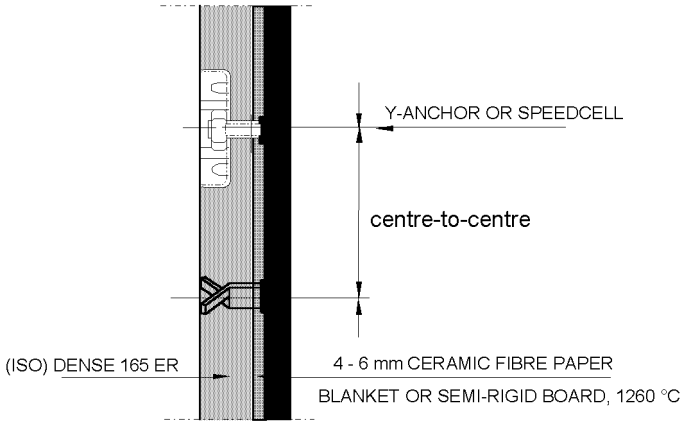
Traditionally, erosion-resistant refractory linings are placed directly on the substrate, i.e generally pressure parts, in conjunction with external thermal insulation. Such lining is called ***hot-shell*** design. Both the lining and the substrate are at approximately the process temperature.

On the other hand, ***cold-shell*** designs comprise a 100 - 150 mm thick erosion-resistant, insulating or dense refractory lining, resulting in typical shell temperatures of below 200 °C.

The ***warm-shell*** design is intended for use of shell temperatures between 200 °C and 350 °C, which is achieved by means of a dedicated thermal insulating layer between the thin erosion-resistant refractory layer and the shell.

The thermal insulating layer shall be chosen in accordance with the process conditions, but are typically semi-rigid, ceramic or graphite fibre board, paper or blanket. The thickness shall be designed for a shell temperature of around 300 °C during operation.

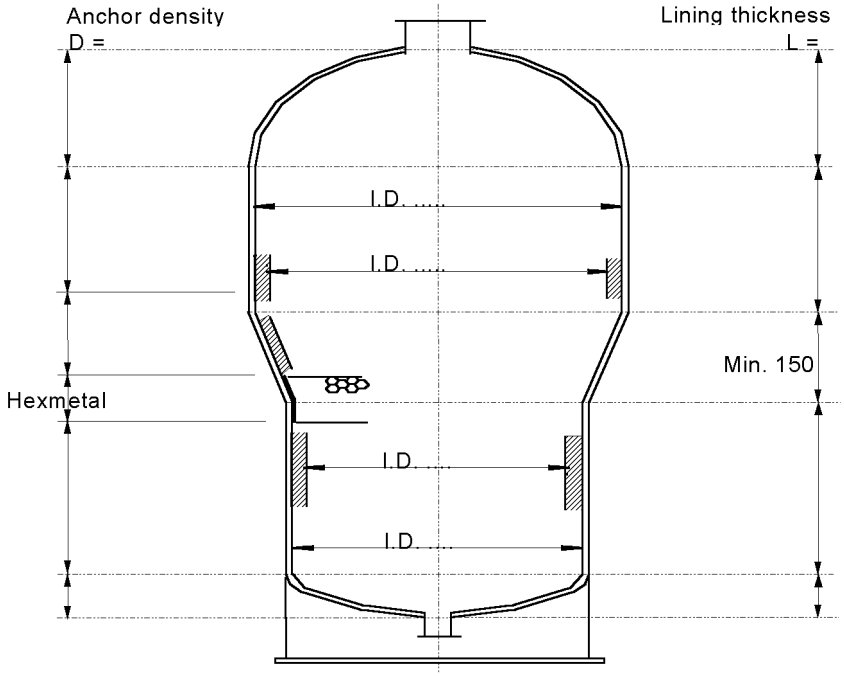
Figure 1 Typical detail warm-wall design



1.1FCCU Regenerator insulating refractory lining

The following design requirements shall be incorporated for the insulating refractory lining in the regenerator:

Figure 2 Anchors for FCCU Regenerator refractory linings (typical only)



Note: For each individual application the figure shall be completed with relevant data, e.g. Lining thickness "L", Anchor spacing "D" and 'Swage" layout.

- The thickness of the (medium weight) refractory lining shall be at least 125 mm;
- Under operating conditions at least 75 mm of the lining thickness shall remain under compression. This can be checked by means of the PLC value and the temperature profile over the lining thickness;
- The anchor density shall have a spacing of less than 1.5 times the lining thickness. Corrugated ("waved") anchors shall be used (refer to Appendix 4; 4.2);
- If applicable: at transitions between the swaged area and the cylindrical parts of the regenerator, a closer anchor spacing (< 120 pcs/m^2) is required due to the forces that occur.

These forces can also be reduced by having a rounding radius of at least 500 mm. The use of continuous armour, either complete or a section with hexmesh, shall be considered, if the forces exceed the highest practicable anchor density;

- The Contractor shall verify by calculations that the anchor slip and/or anchor density meets the requirements

1.2 Installation of FCC regenerator walls

Gunned linings in the regenerator or similar circular equipment shall be applied in horizontal circumferential bands, starting at the bottom and working upwards.

Bands shall be 1.5 to 2 metres high and the scaffold platform spacing shall coincide with these bands. Scaffold supports in front of the wall shall be arranged in such a way that at least a space of 750 mm remains between the shell and the scaffold structure. The use of a modular scaffold system is preferred. If so required, e.g. for anchor welding, the platform may be extended temporarily for ease of access to the wall.

Full 360° bands must be completed in one gunning operation. Therefore a "wet-to-wet" installation procedure is advisable, i.e. 2 nozzle operators starting one after another and continuing in opposite directions.

Interruptions during installation should be restricted to the bare minimum and should coincide with those locations where natural transitions in the lining already exist or where joints are planned.

If for any reason there is an interruption of installation the refractory shall be cut back to the shell wherever it does not reach full thickness, leaving a cold joint. Such joints between bands of refractory, with full thickness, are permissible providing the following conditions are met:

1) No interruptions or cold joints are allowed in the 'dense bed' area and transition areas unless unavoidable, i.e. near or around entrance/exit of cat piping or air-grid connections obstructing installation;

2) Where interruptions occur the concrete material shall be cut back to the shell leaving a straight but rough surface with an angle of 80° - 90° to the shell to form a key for subsequent refractory application.

3) Curing shall be performed if gunning interruptions, resulting in (vertical) cold joints, last longer than one hour.

   Note: Curing compound shall not be used in these 'cold' joints.

4) Cold joints in the conical section shall be at least 2 metres apart with no more than one joint in any 6 metres band.

   All cold joints and shot boards shall be cleaned carefully of debris and rebound material immediately installation is interrupted and the cleanliness must be verified before the resumption of installation.

5) All raked or combed material, rebound and removed (from the finished section) concrete shall be discarded and the shell and anchors shall be thoroughly cleaned from all refractory material as well as the surrounding area adjacent to the envisaged area of correction.

1.2.1 Installation of a refractory lining in the regenerator transition ("Swage")

In the transition area of the regenerator a minimum 150 mm thick lining, with a smooth transition into the designed thickness of the adjoining walls, shall be applied:

either consisting of a jointless continuous one-shot layer over the entire height of the transition area, including at least 500 mm below and above the tangent line;

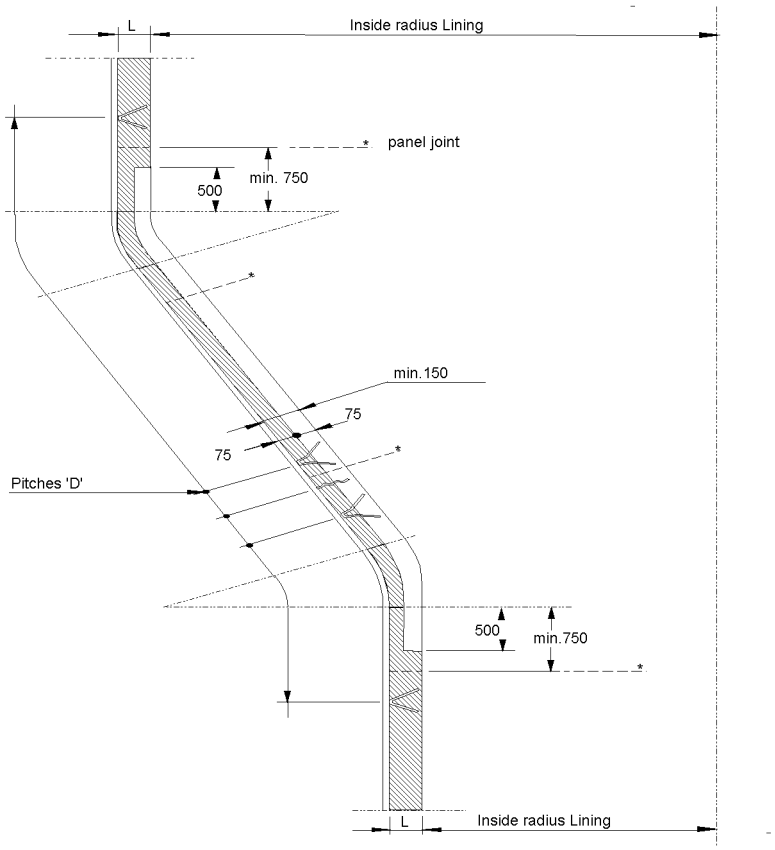
or consisting of two subsequent installed single layers of 75 mm medium weight insulating concrete with V-anchors (1.2.1.1 and Figure 3a);

or the 'hot face' layer incorporates a continuous Hexmesh armour, if a continuous jointless application over that height is not possible (1.2.1.2 and Figure 3b).

NOTE: Depending on the design of the transitions, i.e. radius and angle of slope, it may be decided to install a combination of the latter two options, yet still in compliance with (1.1).

1.2.1.1 Installation of a dual layered refractory lining with V-anchors

Figure 3a Lining detail for regenerator transitions



The refractory lining consisting of two subsequently applied layers of the same type shall be installed in the following manner:

a) The transition area can be anchored by either V-anchors or V-anchors on studs, placed on specific centres in and around the transitions. The anchors shall be indicated in (Appendix 5; Figures 1 and 3a);

b) The joint of the last applied full thickness band shall be located minimum 750 mm below the lower tangent line.

   The panel joint for the 'hot face' layer shall be applied so as to form a key in the backup layer and the next joint is at least 750 mm above the tangent line.

   Similar but inverted installation shall be used for the upper transition.

c) All protruding anchoring shall be thoroughly cleaned immediately after finishing the backup layer and all rebound removed.

d) After curing and air drying according to (Appendix 6), the 'hot face' layer of 75 mm thickness shall be applied continuously in the remaining section to be filled up. The backup layer of refractory shall be thoroughly dampened, but no free water should be visible prior to the commencement of the second layer.

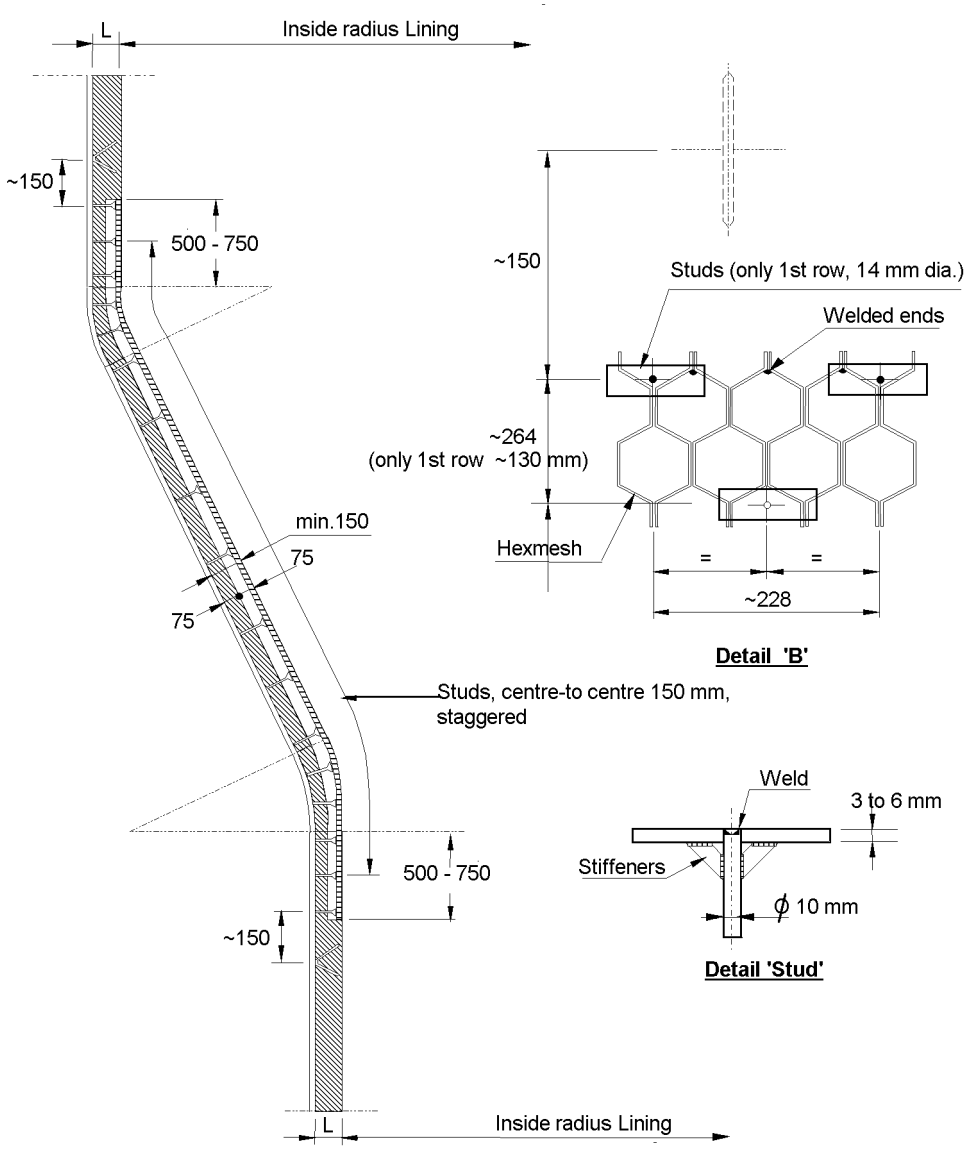
   Note: Curing compound shall **never** be applied on the surface of the first refractory layer.

1.2.1.2 Installation of a dual layered refractory lining with Hexmesh

The refractory lining consisting of two subsequently applied layers of the same type and with a retaining armour of Hexmesh (AF 75 mm) on studs and plates shall be installed according to (Appendix 5; Figure 3b).

The Contractor shall submit a detailed drawing of the exact configuration, taking into account the following guidelines:

Figure 3b Lining detail for regenerator transitions



a) Studs 10 mm diameter x 128 mm long, with a pitch of approx. 228 x 264 mm, are welded in the transition area, of which the first and last horizontal row shall be 14 mm diameter x 128 mm;a) Studs 10 mm diameter x 128 mm long, with a pitch of approx. 228 x 264 mm, are welded in the transition area, of which the first and last horizontal row shall be 14 mm diameter x 128 mm;

b) The backup layer of 75 mm thickness shall be applied equivalent to (Appendix 5; 1.2.1.1);

c) After finishing the backup layer, the stud tips shall be thoroughly cleaned before any welding and all rebound removed;

Note: If repairs are made, watch out for possible deposit of catalyst dust at all stages!

d) Weld the support plates, including the stiffeners, on the studs;

e) Install the Hexmesh panels, thoroughly welded to the support plates and joined together with use of punch-tabs, if so required;

f) Install the top 'hot face' layer of 75 mm thickness continuously in one normal gunning operation through the hexagons until full thickness is achieved.

Perpendicular gunning is of prime importance in order to avoid inclusions of rebound material and voids.

This procedure shall also be followed in other vessels where a high abrasive action of down falling catalyst is anticipated. By means of Hexmesh armour a "catalyst cushion" is created, which additionally protects the lining against the abrasive action of catalyst.

1.3 FCCU cyclones, reactor section and catalyst piping refractory lining

The traditional lining for cyclones, reactor sections and catalyst piping is a standard 25 mm thick Hexmesh armour, welded to the substrate and filled with erosion-resistant refractory castable.

Current practice is for linnings to consist of an erosion-resistant refractory layer (20 - 30 mm) attached to the substrate via Y-studs and/or Speedcells on M8 threaded-studs or similar retention devices, increasingly in conjunction with a thin thermal insulating layer (5 - 6 mm) between the refractory and the substrate. They can also be installed in conjunction with (existing) Hexmesh.

1.4 Installation of erosion-resistant castable on Y-studs or Speedcells and trimming

If there has been a delay after cleaning the equipment to be lined (whether or not armouring has been installed), the entire area should be re-cleaned, preferably by vacuum cleaning.

In order to maintain the required thickness during installation, wooden form work (i.e. gauges) should be placed beforehand.

Dimensions of areas to be installed each time shall be a multiple of whole pitches.

Note: Typical dimensions are 180 x 720 x 25 mm (i.e. 3 x 12 pitches), which could be dealt with by approx. 10 kg of mix. This is therefore the quantity of mix an applicator can handle within the pot life, allowing for wastage during placement.

Application shall be started against a solid part of the equipment, such as the form work or already set material. Hand pack the putty mix by thumbing or a choking tool, so that the material squeezes around and between the Y-studs, to achieve a proper key and to eliminate air bubbles and voids. The use of a small pneumatic roller vibrator (capacity 4 to 5 kN) on a base-plate will also give excellent compacted linings.

When using a rammer, the material shall be applied as gradually as possible in an adequate thickness (i.e. minimum 2 - 3 mm above the Y-tips), in order to avoid problems with levelling and finishing. Material shall always be cut back perpendicular to the shell.

Continue with thorough compacting of the material and level it off. Check before finishing the appropriate thickness with an adequate measuring device, i.e. a pointer/scraper. Vibration shall not cause segregation of the material's aggregates.

In the vertical direction, the refractory material shall be placed in bands of maximum 240 mm high. To avoid (forward) sagging, finish off at the top by forming a 75°- 90° angle. The same finish shall be applied if work is interrupted for a prolonged period, but before a final end is reached.

Y-anchors shall not be used in overhead applications ("10 to 2 o'clock" positions), because during installation and/or repairs there is too little anchoring present to keep the heavy, putty-like, erosion-resistant refractory material sufficiently in position.

Use heavy duty gloves. Moisten the gloves regularly with a thin potable water film by wetting and shake off the excess water.

To avoid adhesion of material to tools, it is recommended to coat their (working) surfaces regularly with some dedicated repair liquid. It has an advantageous effect on the smoothness and closure of the finished surface.

1.5 Installation of erosion-resistant castable in Hexmesh or Hexcels and trimming

The installation is basically the same as that given in (1.4).

Hand pack the putty mix by thumbing or a choking tool, so that the materials squeezes out and through the bonding holes, to achieve a proper key and to eliminate air bubbles and voids.

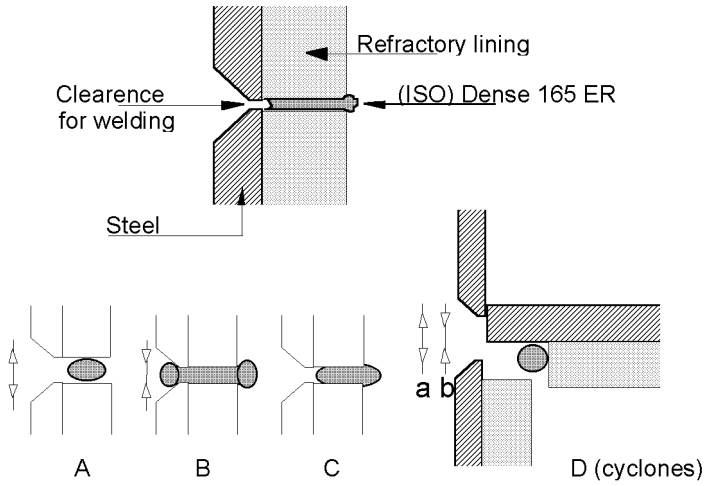
After proper filling the excess is cut off at the top of the armour, after which the surface is finished by planing with a hard rubber float or a block of wood.

Partly filled areas and loose crumbly material should be removed, prior to installing a fresh mix of material. Once a mix has started to set it should never be used or re-mixed with water. It must be discarded.

1.6 Installation of erosion-resistant castable in shop/field joints

In order to reduce end strips, bars, etc. in erosion-resistant linings which are subject to severe erosion, 'shop/field-joints' shall be designed and/or arranged as shown in (Appendix 5; Figure 4 and Figure 6). Guides should be used to achieve a good alignment and for the sawing tool when cutting sections.

Figure 4 Typical jointing detail of shop/field joints



NOTE: position and test fit steel parts before applying Curas joint material

- Finish the refractory lining at ends ⊥ and 1 - 2 mm short of flanges or edges;
- Position equipment parts adjoining to each other and test fit;
- Separate parts sufficiently again to lay a ribbon of erosion-resistant refractory material of adequate thickness (approximately 15 mm) to fill the joint after joining [A];
- Now squeeze both parts together up to the pre-set root gap [B];
- Clear and clean the root gap before welding [C];
- Remove the burr internally before final set, if access is feasible after welding.
- For 'field' joints in cyclones, e.g. connection of conical section to 'dust' collector, a similar procedure as described can be executed [D].

Vibracast type joints may be installed by casting or ramming or by means of self-flow type refractory materials. Their quality shall be at least equivalent to the type of refractory material used as lining material. The method chosen depends mainly on the accessibility and shall therefore be agreed by the Principal.

Particularly for externally lined pipes with very small diameters, such as air-grid arms, steam rings, bracings, etc., instead of Floorsteel use may be made of Speedcells which are set in

a radius (approx. 70 mm for 4"-pipes and/or 100 mm for 6"-pipes). For larger diameters normal Speedcells can be used.

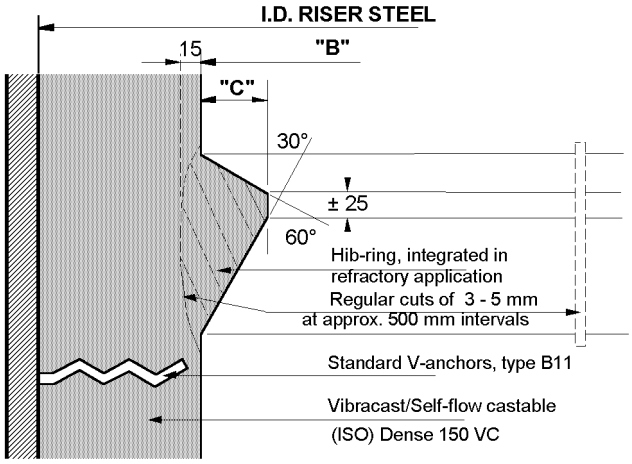
1.7 Installation of Hib-rings in (vibra)cast linings

If ***Hib-rings*** are required, their shape shall be incorporated in the form work necessary for and during the casting of the refractory material. The dimensions shall be as indicated in Figure 5. They can either be cast in-situ or made as prefabricated sections.

NOTE: '*Hib-rings*' are circular constrictions in a line or pipe, placed at regular distances to reduce laminar flows of gas/liquid or gas/solids mixtures along the wall.

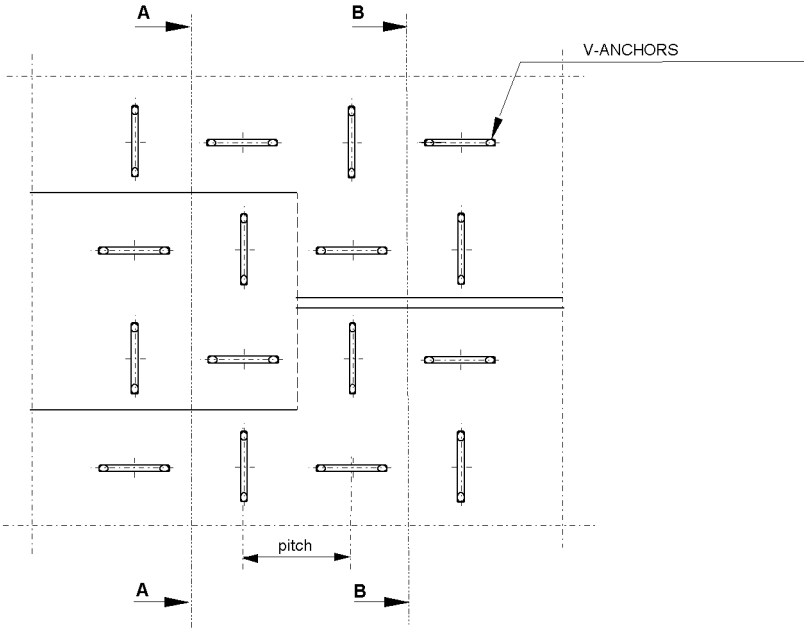
To accommodate for possible peak stresses in the top of the Hib-ring (e.g. smallest diameter) during operation, vertical cuts shall be made on regular intervals, but with a maximum of 500 mm. These cuts shall be made by means of a diamond saw but shall not penetrate deeper than 15 mm into the wall lining.

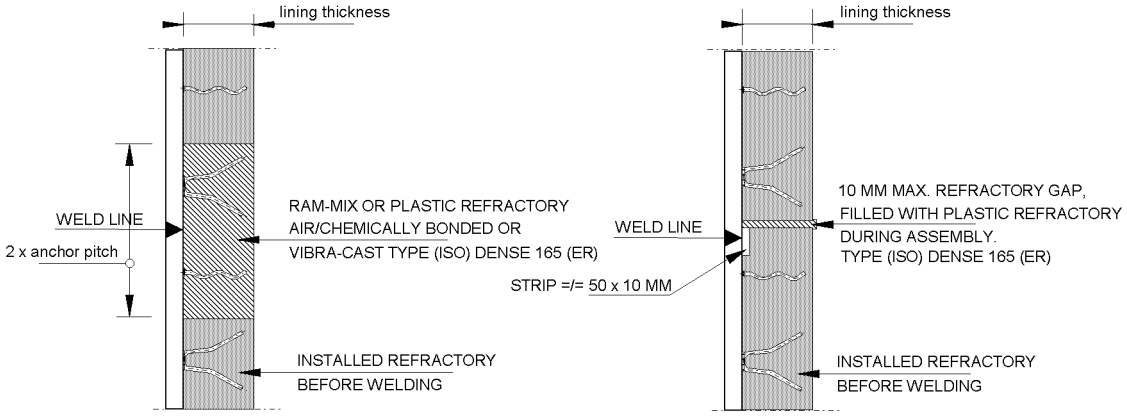
Figure 5: Typical detail of hib-ring in reactor riser



"B" Refractory I.D.	"C" Projection
1000	40
850	35

Figure 6 Refractory lining detail at field welds





REFRACTORY LINING INSTALLED AFTER WELDING AND POST-WELD TREATMENT

SECTION A - A: X-RAY

REFRACTORY LINING INSTALLED BEFORE WELDING, GAP FILLING ONLY.

SECTION B - B: NOT X-RAY CONTROLLED

APPENDIX 6 CURING, DRYING AND FIRING OF UNSHAPED REFRACTORY MATERIALS

1. APPLICATION

This appendix specifies the requirements for curing, drying and firing of newly installed monolithic refractory linings in equipment. It also applies to cooling and reheating, and to drying and firing after lining repairs.

Reference is made to Memorandum SIOP-MFE No. 003-96 in which all processes are discussed in more detail.

2. MATERIAL, LABOUR AND EQUIPMENT

The Contractor shall supply all material, labour and equipment necessary to complete the work.

3. CURING

3.1 General

After application, refractory materials shall be protected against freezing and extreme hot weather conditions (Appendix 6; 3.2.). During the curing period, installed hydraulic bonding refractories shall be kept moist to avoid cracking or other damage due to quick evaporation of the moisture needed for the hydration reactions of the refractory.

As an alternative to the moist-curing method, an impermeable organic resin type of membrane curing compound may be applied to the refractory surface (Appendix 8).

Curing compound shall not be applied to any refractory surface which will come into contact with refractory that will be applied later.

3.2 Temperature Conditions

For a period of at least 24 hours after refractory application, the shell and internal temperatures in the areas of newly applied refractory, resulting from ambient conditions and/or from heat of hydration, should be maintained between 10 °C and 25 °C.

If shell and internal temperatures higher than 28 °C are anticipated, the shell shall be cooled by clean water spray or by covering the outside with gunny bags which shall be kept wet. The internal temperature shall be reduced by forced air circulation when outside ambient conditions permit.

Because forced air circulation will also accelerate dry-out during curing, special treatment (e.g. fine water spraying of dry spots) may be needed for areas still in their curing stage.

Ventilation may have to be maintained in order to avoid condensation on parts to be subsequently lined.

If shell and internal temperatures lower than 4 °C are expected, the temperature of the shell shall be raised by applying an external insulating membrane and the internal temperature increased by circulation of warm air. Live steam shall not be used. The shell temperature shall be regularly measured and recorded during installation and curing.

3.3 Curing of plastic, mouldable refractory materials

These materials normally contain little free water and do not need a special curing period. Air-hardening plastic materials can normally be left for prolonged periods without firing, provided that sufficient precautions are taken when shell or internal temperatures are outside the range of 10 °C - 25 °C (Appendix 6; 3.2). Under those conditions, complicated applications should be left temporarily in their original form work.

Although minimum air ventilation is required to avoid condensation, it should not be such as to cause unacceptably fast dry-out.

Chemically bonding plastic materials are hygroscopic and shall either be fired up to 250 °C minimum immediately after installation, or adequately protected against moisture absorption

by, for example, using a curing compound (Appendix 8), or covering with plastic sheets.

Plastic foil or tarpaulins shall be used to minimise refractory damage. Water spray shall not be used on chemically bonding refractories.

3.4 Curing of chemically bonding castable refractory

The material shall be allowed to air-set and shall not be cured by water spraying. The use of an impermeable membrane, resin-type curing compound is also prohibited. The use of tarpaulins to protect the fresh refractory from dust and damage is allowed.

Temperature restrictions and monitoring requirements defined in the Manufacturer's workability guidelines shall be implemented during the curing period. Suitable means of heating or cooling the refractory lining during this period shall be provided if required.

3.5 Curing of hydraulically bonding castable refractory and gunned refractory

Hydraulically bonding refractory lining and gunned refractory lining shall be cured. The curing shall be started as soon as the exposed refractory surface appears dry to the touch (which is normally one to eight hours after application, depending upon atmospheric conditions). At this time a fine spray mist of clean, cool water shall be applied to the surface. The water spray shall be applied at sufficiently frequent intervals to preclude drying of the lining and shall continue for at least twenty four hours after the last portion of the lining has been applied. Adequate drainage shall be provided to allow excess water to run off without forming puddles.

If approved by the Principal, as an alternative to the water cure method, an impermeable organic resin type membrane curing compound (Appendix 8) may be applied to the refractory surface. The membrane curing compound shall be applied after the casting has achieved its initial set. It shall be non-flammable and its colour shall contrast with the colour of the refractory. The film thickness shall be 150-200 mm; one coat is sufficient. Adequate ventilation shall be provided to eliminate fumes.

An impermeable membrane shall not be applied to any surface on which refractory will be applied later.

For a period of at least 36 hours after refractory application, the shell and internal temperatures in the areas of the newly applied refractory (resulting from ambient conditions and/or from heat of hydration) shall be maintained between 10°C and 30°C. If necessary this shall be achieved by either cooling the shell with a water spray (and forced air circulation if ambient conditions permit) or raising the temperature by applying an insulating membrane and circulating warm air. The shell temperature shall be measured and recorded during the curing period.

Direct sunlight is not allowed on any fresh refractory within 36 hours of installation.

4. DRYING AND FIRING

The Contractor's detailed drying and firing procedures, including points of temperature measurement and full description of working methods, shall be submitted to the Principal for approval.

The Manufacturer should be consulted if deflocculated castable refractory materials are used. The Manufacturer shall then provide appropriate dry-out and firing procedures.

All refractory linings that will be subjected to sub-zero (°C) conditions (including prefabricated sections in storage) shall either have been fully dried and heat treated prior to exposure to such conditions or be kept warm during exposure to such conditions to avoid freezing of the refractory.

Freezing weather conditions are harmless to the refractory if it has been fully dried and heat treated.

4.1 Drying

After the curing period all refractory shall be air-dried for at least 24 hours by natural or forced ambient (minimum temperature 10 °C) air circulation before heat is applied. During

the drying period, adequate venting shall be provided for escape of moisture from the freshly installed material.

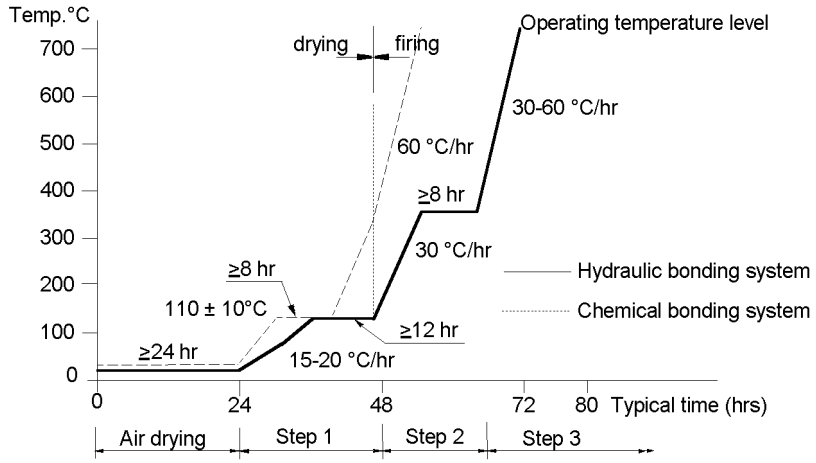
During and immediately after the drying out period is the appropriate moment for inspection of the completed refractory lining (10).

4.2 Firing of chemically bonding refractory

After air drying the chemically bonding refractories must be heated. The heat treatment is required to develop the chemical bond in the refractory, which is essential for good performance. Under atmospheric dry-out conditions the materials generally harden by air setting. This provides enough strength for transportation, handling and placing the lined equipment inside the unit.

Firing shall be carried out in accordance with the following typical main steps (Appendix 6; Figure 1):

Figure 1 Curing, drying and firing of unshaped refractory materials



Step 1:

The refractory temperature shall be increased gently (maximum 30°C per hour) by blowing hot air over the lining until all temperature monitoring points are between 90°C and 120°C. The temperatures shall be held in this range for at least 8 hours.

Step 2:

Subsequently the gas temperature shall be increased at a rate not exceeding 30°C per hour until all the gas temperature monitoring points and the equipment surface are at a temperature of 350 - 400°C. This temperature shall be held until the entire lining has a uniform temperature (i.e. within 10°C).

Step 3:

At the start of process operations the system should be brought to operating temperature at a rate not exceeding 60°C per hour.

External insulation may be used to promote dry-out.

The cooling rate after heat dry-out shall not exceed 60°C per hour.

4.3 Firing of hydraulically bonding refractory linings and plastic, mouldable refractory linings

The Contractor shall establish the dry-out requirements in accordance with the Manufacturer's recommendations and the requirements of this specification. The more stringent requirements shall prevail. After air drying the linings shall be heat treated.

Before the dry-out operation begins, sufficient temperature measuring devices shall be installed to monitor gas temperature throughout the lined area to be dried.

It is essential that these be located near or at the point of entry of hot gases, near or at the point of exit of the gases and at a sufficient number of intermediate points. In addition, temperature measurements at approximately mid-way inside the insulating refractory are required.

Heat dry-out shall be achieved by circulating hot air over the surface of the refractory. Items shall not be dried in a furnace. A minimum blower capacity of 30 m^3/hour at ambient temperature is required for each square metre refractory surface to be dried. A gas fired burner or steam coils may be used as heat source. Live steam is not permitted as it produces a much too high humidity in the hot air.

To ensure that any equipment failure causes no more than a very short disruption in the dry-out schedule, the Contractor shall ensure there are sufficient spare heaters and other items of equipment critical to the dry-out available at the job site.

If dry-out is interrupted for more than 15 minutes, the drying schedule shall be restarted at the temperature level of the point at the hot face of the lining with the lowest temperature and shall not be continued from the point of interruption.

The circulating hot air temperature shall be maintained at such levels that the metal shell temperature always remains at least 50°C below the metal design temperature at any metal temperature monitoring point. The controlling temperature in any drying activity shall be the temperature at the refractory hot face.

Heat shall be applied to increase the temperature in the following major steps (Figure 1):

Step 1:

The air temperature shall be raised gradually at a rate not exceeding 15°C per hour until all temperature monitoring points in the flue gas and at the refractory hot face are between 100°C and 120°C. This temperature range shall be held for at least 12 hours.

Step 2:

The flue gas temperature shall be increased smoothly at a rate not exceeding 30°C per hour until all the gas temperature monitoring points in the flue gas and at the refractory hot face are within 15°C of each other and are at a temperature between 300°C and 400°C. The gas temperature shall be held in this range for at least two hours per 25 mm of lining thickness (8 hours minimum).

Step 3:

The flue gas temperature shall be increased to operating temperature level at a rate not exceeding 30°C per hour until all the temperature monitoring points in the flue gas and at the refractory hot face show the same value (within 15°C). This temperature shall be maintained for 1.5 hours per 25 mm of lining thickness, with a minimum of 4 hours.

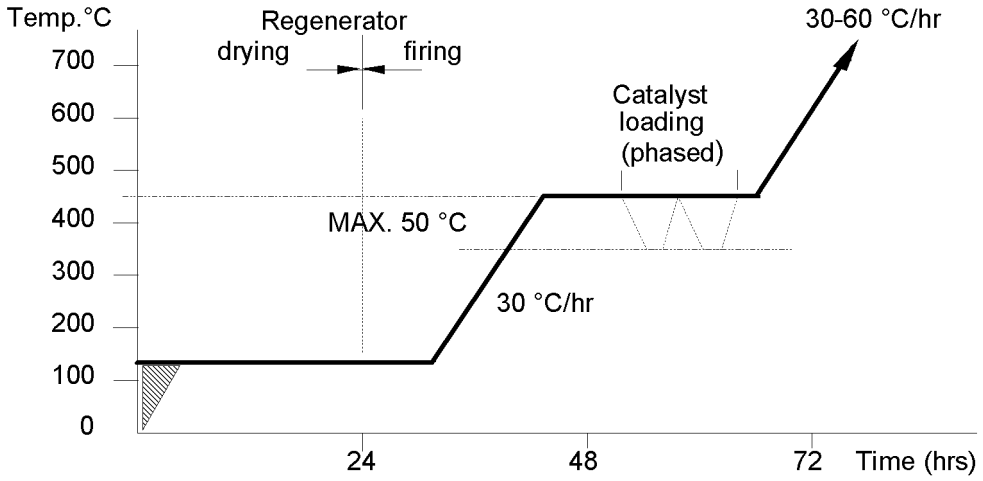
Step 4:

For systems which have previously gone through steps 1-3 (and for systems which are being restarted after a shutdown in which only minor refractory repairs have been effected) the system may be brought quicker to operating temperature (at a rate of 60°C per hour maximum).

In cooling after initial dry-out, a gas cooling rate of 60°C per hour should not be exceeded.

External insulation may be used to promote dry-out. An example of a typical drying and firing curve for an FCC unit is given in (Appendix 6: Figure 9b). Other dry-out rates may be acceptable subject to approval by the Principal.

Figure 2: Curing, drying and firing of FCCU unshaped refractory materials



5 AUXILIARY FIRING EQUIPMENT

Linings of complicated equipment or interconnected equipment may require to be dried and fired using an auxiliary burner unit. The Contractor shall install this unit as close as possible to the combustion air entry of the lined equipment. This may be the combustion air ducting, ensuring sufficient and intensive air circulation, and allowing temperature to be increased at a rate as described in (Appendix 6; 4.2, 4.3) and monitored accurately. It also provides adequate firing of refractory installed in burner throats and temperature control during start-up of the individual burners at minimum burner settings, without interrupting the firing schedule.

APPENDIX 7 CORE SAMPLES FOR QUALITY CONTROL OF REFRACTORY LININGS

1 REFRACTORY CASTABLES, RAMMING MIXES

Monolithic constructions consisting of dense castables, ramming mixes, either backed up or not backed up with rigid insulating firebricks. A water-cooled drill shall be used:

- Material control: 25 mm diameter cores;
- Application control: 50 - 100 mm diameter cores.

2 INSULATING REFRACTORY CASTABLES, ETC

Monolithic constructions consisting of light weight and medium weight insulating castables, gunmixes, either backed up or not backed up by a (X)LW-castable or equivalent insulating firebricks. An air-cooled drill shall be used:

- Material control: 75 - 100 mm diameter cores;
- Application control: 75 - 100 mm diameter cores.

Monolithic constructions of (X)LW-Castables, etc. used individually or in combination with back up insulating boards or ceramic fibre blankets. An air-cooled drill shall be used:

- Material control: 100 mm diameter cores;
- Application control: 100 - 150 mm diameter cores.

APPENDIX 8 CURING COMPOUND

The membrane curing compound should be in accordance with ASTM C 309 and shall be applied after the lining has achieved its initial set. The curing compound shall be non-flammable when dry and its colour shall contrast with the colour of the refractory material.

The film thickness should vary between 150 - 200 µm.

Adequate ventilation shall be provided to expel the fumes while the curing compound dries.