When considering the cost of refractory linings, including materials, labor and downtime, investing in proper anchorage is a relatively small expense with a huge potential return. Harbison-Walker Refractories Company offers a wide variety of anchoring products. However, in both Cement and Lime processes, there are several application variables to consider before selecting the best anchors. These include: the process conditions such as chemical attack; vessel temperature and geometry; lining thickness; monolithic installation type; and where in the vessel the material will be located. Anchors used in Cement and Lime applications are either metallic or ceramic, or a combination of both. But with so many options and combinations available, making the best selection can be difficult.

THE WRONG WAY

Making the wrong anchor selection can be quite costly and could result in premature or catastrophic failure of the refractory lining. Refractory failures can endanger the integrity of the vessel by exposing the shell or structure to conditions and temperatures beyond their design limits. The failure shown in Figure 1 could have been avoided by proper selection of products and anchorage for this application.

Figure 1. Example of end result when improper selections are made in anchorage and refractory material for the operating conditions.

THE RIGHT WAY

Optimizing the selection of refractory products and anchorage, as shown in Figure 2, results in a well supported refractory lining. In this case, the materials and anchorage are well suited to the operating conditions resulting in outstanding refractory performance.

WHAT ANCHORS ARE RIGHT FOR MY APPLICATION?

With all of the process variables and design issues to consider, the daunting task of anchor design must include understanding of the following criteria:

- Appropriate metallic alloy selection.
- Conditions necessitating ceramic anchors.
- Proper anchor pattern selection for the application area, i.e. roofs versus walls.
- Anchor design considerations based on installation method, such as gunning and shotcreting, pouring or ramming.

Please read on to find out what options are available and to understand how and when to use them.

Figure 2. Improved refractory life utilizing ceramic and wire anchors in cooler hot end bullnose.

VESSEL TEMPERATURE

Application temperature is usually the most important criteria for choosing between ceramic and metallic anchors. For all areas where process temperatures approach or exceed 2000°F (1090°C), H-W Refractories Cement and Lime group suggests incorporating ceramic anchors into the lining design.

METALLIC WIRE ANCHORS – ALLOY SELECTION

Harbison-Walker Refractories uses 310SS alloy for most metallic anchor applications in the Cement and Lime industries. To understand why 310SS is often the alloy of choice for wire anchors, one must first understand temperature limits of the available stainless steel alloys, 304SS, 309SS and 310SS, as well as the most common failure mechanisms. Three of the most prevalent failure modes for stainless steel anchors are sigma phase formation, oxidation and sulfidation.

THE CASE FOR 310 SS

Steel manufactures use the chromium content as an indicator of the oxidation resistance of an alloy. Increasing the nickel content of the alloy also improves the high temperature properties of a SS alloy. Compared to 304 SS and 309 SS, 310 SS contains the highest amount of both chromium and nickel. The effect of composition on maximum service temperature can be seen in Table 1 below.

Maximum Service Temperature (Intermittent/Continuous)	Anchor Alloy	Chromium Content	Nickel Content
1500°F (816°C) / 1650ºF (899°C)	304 SS	17.5% – 19.5%	8.0% – 10.5%
1800°F (982°C) / 2000°F (1093°C)	309 SS	19% - 21%	12% - 15%
1900°F (1038°C) / 2100°F (1149°C)	310 SS	24% - 26%	19% - 22%

Source: www.matweb.com

Table 1. Maximum Service Temperature versus Chromium and Nickel Content of Three Stainless Steel Alloys

In general, as chromium and nickel content increases, so does the temperature resistance. In most cases, the maximum service temperature is dictated by a number of factors. Among those are tensile strength and oxidation resistance. Tensile strength is shown in Table 2 below.

Tensile Strength of Three Stainless Steel Alloys (psi / MPa)			
Temperature	**304 SS**	**309 SS**	**310 SS**
77°F (25°C)	90,000 / 620	90,000 / 620	89,500 / 615
1500°F (816°C)	23,000 / 160	28,500 / 195	30,300 / 210
1800°F (982°C)	No data	10,000 / 70	11,000 / 75

Source: Allegheny Ludlum

Table 2. Tensile Strength of Three Stainless Steel Alloys at Varied Temperatures

While the strength of all three alloys decreases significantly at elevated temperatures, the 310 SS possesses the highest strength at 1500°F (816°C) and 1800°F (982°C). However, even though the 310 SS possesses the highest measured strength at 1800°F (982°C), the remaining strength is still only 12% of its room temperature strength.

Oxidation resistance is also key to service temperature limits of stainless steels. In general, increased chromium content improves the oxidation resistance of stainless steel because it promotes the formation of a protective layer of chromic oxide under service conditions. For the 309 and 310 stainless steels, Figure 3 illustrates the oxidation rate in terms of weight change at elevated temperatures. An increase in weight indicates increased oxidation.

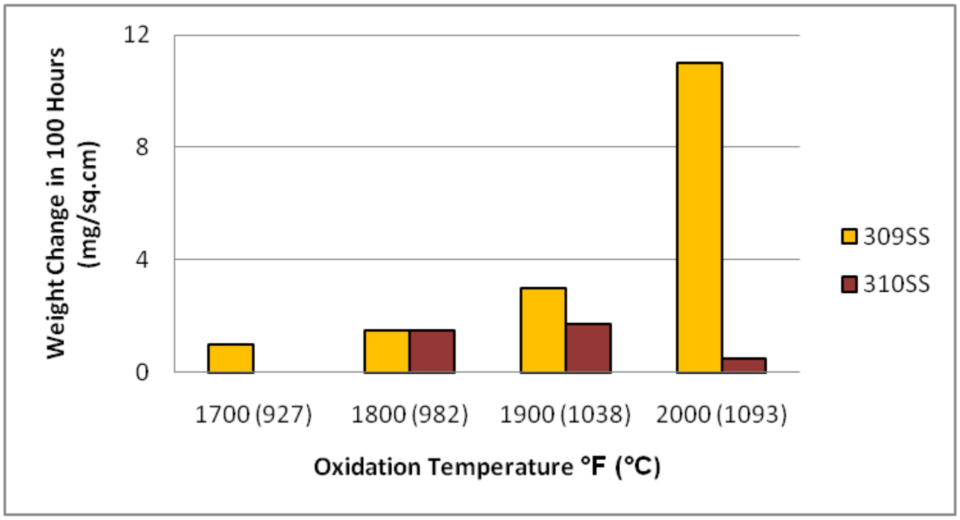

Figure 3. Oxidation of 309 SS and 310 SS Measured by Weight Change

For temperatures exceeding 1800°F (982°C), the oxidation resistance of the 310 SS alloy is clearly superior to the 309 SS as shown by the increased weight of the 309 SS. Compared to the other common anchor alloys, the benefits of 310 SS alloy anchors are numerous, particularly for the conditions present in Cement and Lime applications.

BENEFITS OF 310 SS

1. Rated for applications with continuous service up to 2100°F (1149°C).
2. Rated for intermittent service temperatures up to 1900°F (1038°C).
3. High hot strength.
4. High chrome content develops protective chromium scale to resist oxidation at elevated temperatures.

WEAR MECHANISMS: SIGMA PHASE, OXIDATION AND SULFIDATION IN STAINLESS STEEL

All stainless steel anchors are susceptible to sigma phase formation; a non-magnetic, inter-metallic material composed primarily of iron and chromium which leads to embrittlement. Most metallic anchors fail due to the development of sigma phase, especially when combined with temperature cycling during service. Sigma phase forms in austenitic stainless steels when exposed to temperatures between 1050°F (566°C) - 1800°F (982°C). Temperatures near 1600°F (871°C) are optimal for sigma phase formation. Sigma phase is believed to have little effect on properties as long as the material remains at elevated temperatures. However, as application temperatures cycle, sigma phase causes loss of ductility and brittleness at temperatures lower than approximately 1100°F (593°C).

Sigma phase formation is reversible, however, in anchoring applications, it is only partially reversible. Each time the stainless steel anchor is exposed to temperature cycling, its oxidation resistance is reduced, eventually causing failure. In applications where continuous service temperature is maintained, sigma phase alone is not likely to cause a failure of the anchorage and refractories. Nonetheless, increased embrittlement of the anchors, combined with other failure mechanisms, and stresses, may eventually cause the anchors to fail and potentially result in the failure of the refractory lining.

Chromium is one of the constituents of sigma phase; however, its presence in stainless steel alloys is necessary to improve other properties of the steel. Optimal chromium content, as well as nickel in austenitic stainless steels improves corrosion resistance, resistance to oxidation, and increases hot strengths compared to carbon steel alloys. All metals react with the atmosphere to form oxides and other compounds. Chromium in the alloy reacts with oxygen to form a thin layer or scale of chromic oxide on the surface of the anchor. The chromic oxide layer effectively seals off the other metals in the alloy from the atmosphere, preventing further oxidation, improving the high temperature properties of the alloy.

However, oxidation of stainless steel anchors in refractory applications is a complicated issue. Conditions can develop leading to the rapid growth of the oxides of chromium, iron and nickel, a process known as breakaway oxidation. Figure 4 to the right, shows the effect of severe oxidation and sigma phase on metallic anchors. Note the heavy chromic oxide scale and evidence of embrittlement of the anchor remnants.

Figure 4. Chromic Oxide Scale and Sigma Phase.

Sulfur is often present in cement and lime applications as an impurity which can lead to sulfidation attack of stainless steel anchors. Sulfidation of stainless steel is a complex process, highly dependent on the relative levels of oxygen and sulfur, as well as the form of the sulfur, whether elemental vapor, oxide or hydrogen sulfide. Chromium in stainless steel alloys forms stable oxides and sulfides. In the presence of both oxygen and sulfur, the chromium usually combines with the oxygen to form the stable chromic oxide (Cr_2O_3) layer. As previously stated, this protective layer forms a barrier against chemical attack, including sulfidation. However, sulfidation attack can still occur if the chromic oxide layer spalls off or is damaged. Under certain conditions, sulfur can transport across the chromic oxide scale to form internal chromium sulfide phases. The tendency to form sulfides increases in alloys containing high amounts of nickel. Nickel and nickel sulfide form a low temperature melting phase that can cause failures in metallic anchors.

EXTREME APPLICATION STRESSES: ALKALIES, CHLORIDES AND/OR SULFIDES

High temperatures combined with exposure to corrosive atmospheres can necessitate the use of special alloys. In applications where the anchorage is exposed to high temperatures, as well as sulfur and/or alkali chloride attack, special alloys may be required. One particular material containing a solid solution of nickel-cobalt-chromium-silicon, is known for its resistance to sulfidation and alkali chloride attack in both reducing and oxidizing atmospheres.

Figure 5. Metallic Anchor Exhibiting Sulfide Crack and Embrittlement

Figure 6. Remnant of Metallic Anchor Exhibiting Sulfide Attack

In service, sulfur and chlorine, if present, can volatilize and combine to form alkali salts and corrosive sulfides attacking the refractories and the metallic anchors. This can result in anchor failures similar to those shown in the photographs, Figures 5 and 6, above.

In special alloys, with the chromium content greater than 25% and the nickel content exceeding 30%, the iron content is low. This prevents the formation of sigma phase at elevated temperatures seen in stainless steel alloys. However, these alloys are expensive and should be limited to problematic areas where ceramic and metallic anchorage is not possible. Suggested applications include burner pipes, nose ring anchoring systems and other areas where thin walls, high temperatures and/or severe thermo-chemical attack are present.

TEMPERATURE PROFILE – SELECTING THE RIGHT SIZE ANCHOR AND MATERIAL

H-W Refractories Cement and Lime group has established guidelines regarding anchor length versus lining thickness. The following graph, Figure 7, illustrates some of the principles behind those guidelines, showing the temperature profiles of three 10” (25.4 cm) refractory linings in a 2000°F (1093°C) application. In this example, a 60% alumina high density, low cement castable has been used for all the configurations. In the dual component linings, an insulating gunning castable has been chosen for the back-up. In one case, the dense hot face lining is 6” (15.2 cm) thick with a back-up of 4” (10.2 cm) and in the other the hot face lining is 7” (17.8 cm) thick with a back-up of 3” (7.6 cm).

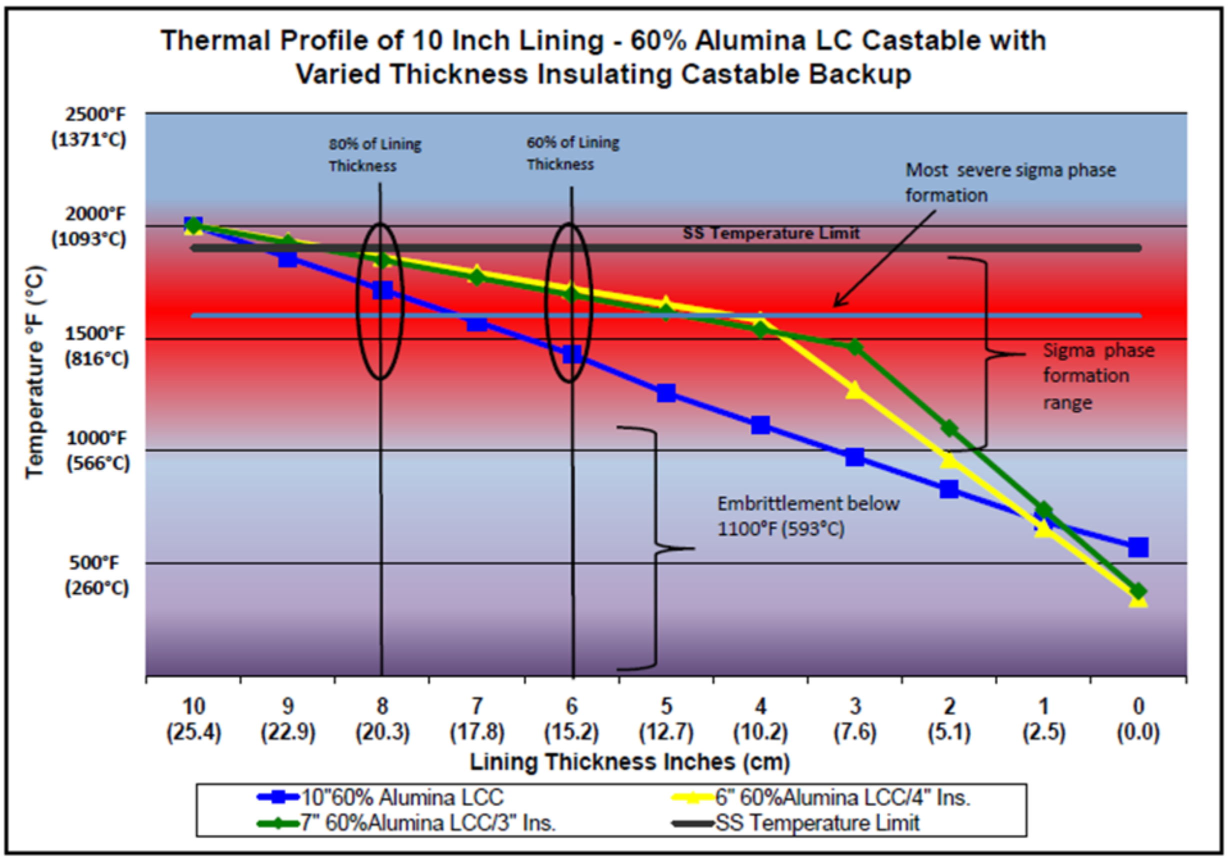

Figure 7. Thermal Profile of Refractory Linings Illustrating Internal Refractory Temperatures

The temperature limit for 310 SS in intermittent applications, 1900°F (1038°C), has been included on the graph, as well as 80% and 60% of the lining thickness measured from the cold face of the lining. These depths were chosen to illustrate the recommended anchor lengths for Cement and Lime applications. Additionally, the temperature ranges for sigma phase formation and embrittlement are shown.

This example demonstrates the effect of insulating back-up on shell temperature and internal refractory temperature. Insulation reduces the shell temperature, holding the heat inside the vessel. This improves the efficiency of the process and also increases the internal temperature of the refractory lining.

When designing anchorage remember that the operating temperatures provided often represent predicted normal values and may not take into consideration temperature excursions due to upset conditions. It is advisable to design linings and anchorage with a margin of safety.

The thermal conductivity of the metallic wire anchor is much higher, roughly six times that of the ceramic refractories. In the examples above, a metallic anchor exposed to approximately 1900°F (1038°C) at 80% of the lining thickness conducts heat deeper into the lining compared to the refractory materials. This heat sink effect results in the anchor temperature being much hotter at any given depth compared to the surrounding refractory. At 60% of the total lining thickness, the hot end of the metallic anchor is exposed to lower temperatures. However, note the sigma phase formation range. In dual linings, more of the metallic anchor will be exposed to temperatures favorable to sigma phase formation. In the case of the lining with 4” (10.2 cm) of back up insulation, the interface between the insulation and the working lining is approximately 1600°F (871°C), the temperature where sigma phase formation is the most severe. In applications similar to the one depicted, ceramic anchors are recommended, often with wire anchors in between. The ceramic anchors extend through the entire lining thickness, while the wire anchors should only extend to 60% of the lining thickness, due to the internal temperature conditions described above.

It should be noted the example in Figure 7 is based on a complete lining thickness, with no wear taken into account. As the refractories wear, the thermal profile also changes, increasing the internal temperature of the anchors. The increase in exposure temperatures will increase the rate of anchor deterioration, yet another reason to design linings and anchorage with a safety margin.

GENERAL LENGTH RECOMMENDATIONS FOR METALLIC ANCHORS

When using metallic anchors for applications below 2000°F (1093°C), H-W Refractories Cement & Lime group recommends lengths up to 80% of the total monolithic lining. For most dual component linings, H-W L-Clips are used in conjunction with the proper Y or V wire anchors shown below in Figure 10. The H-W L-Clips afford the lining flexibility at the interface between hard face lining and the back-up lining. This is because the anchor is not welded to the clip, but snaps onto the slotted end of the clip. Anchors that are welded to the shell of a vessel form a rigid framework for a single component lining. The L-Clip is welded at the foot to the shell to form the framework for the insulating back-up. The V type anchor forms the framework for the hard face, while the flexible connection between the two allows stress relief between the two components of the lining should they expand or contract at different rates.

1. Metallic wire anchors are available in several sizes, alloys and designs. Harbison-Walker Cement and Lime Group requires the alloy stamp on every metallic anchor as shown in Figure 8.
    a. 1-A Series Anchors, ¼” (6.3 mm) wire, are generally used for single component linings less than or equal to 4½” (11.4 cm) thickness.
    b. 3-A series anchors, 5/16” (7.9 mm) wire, are used for single component linings greater than 4½” (11.4 cm) thickness.

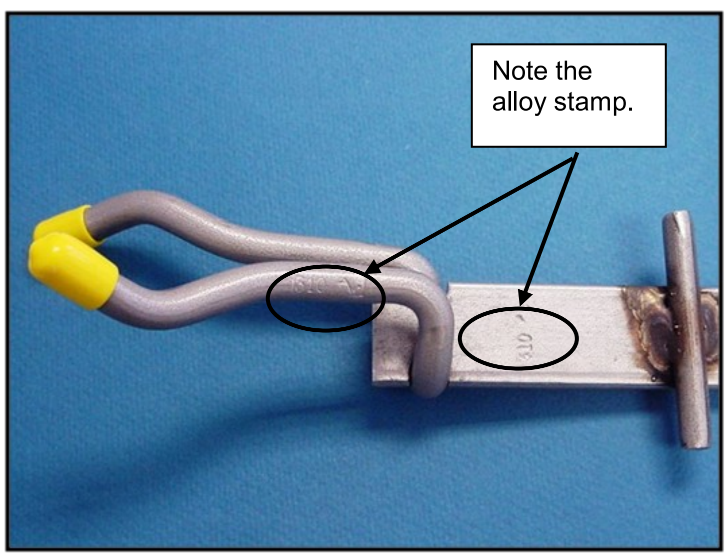

Figure 8. Look for the Alloy Stamp on Each Anchor and Clip

2. Metallic wire anchors may be welded directly to the vessel for single component linings or may be combined with clip designs for two component linings.
    a. When welding the anchor foot to the vessel shell care must be taken not to overheat the anchor, causing embrittlement.
    b. Keep the weld at least ¼" (6.4mm) away from any vertical bends as welding changes the structure of the metal and could weaken the bend of the anchor. See Figure 9, below.

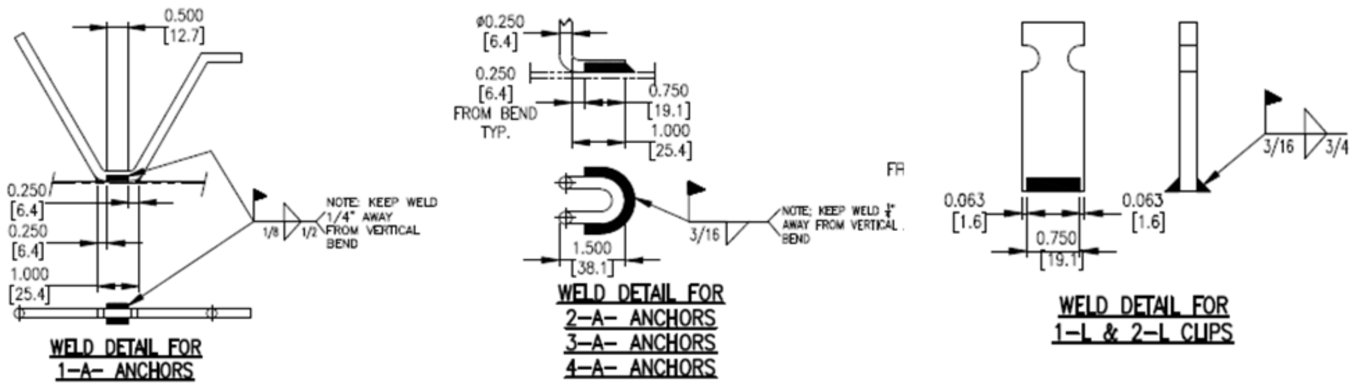

Figure 9. Weld Details for Anchors and Clips Commonly Used in Cement and Lime

3. All two component linings will use either 3-A or 2-A series wire anchors with 1-L or 2-L series L-clips with T-bar, depending on total lining thickness.
    a. 3-A series, 5/16" (7.9 mm) wire anchors, are generally used in dual component linings, except when the hot face lining is proportionally thin compared to the back-up lining.
    b. 2-A series, ¼" (6.2 mm) wire anchors, are generally used for proportionally thin hot face linings.
4. When using L-clips in conjunction with metallic anchors, the V-anchors are attached after the back-up lining is applied. Figure 10 shows how the design of the L-clip indicates the proper back-up lining depth, as well as attachment of the V-anchor to the L-clip.

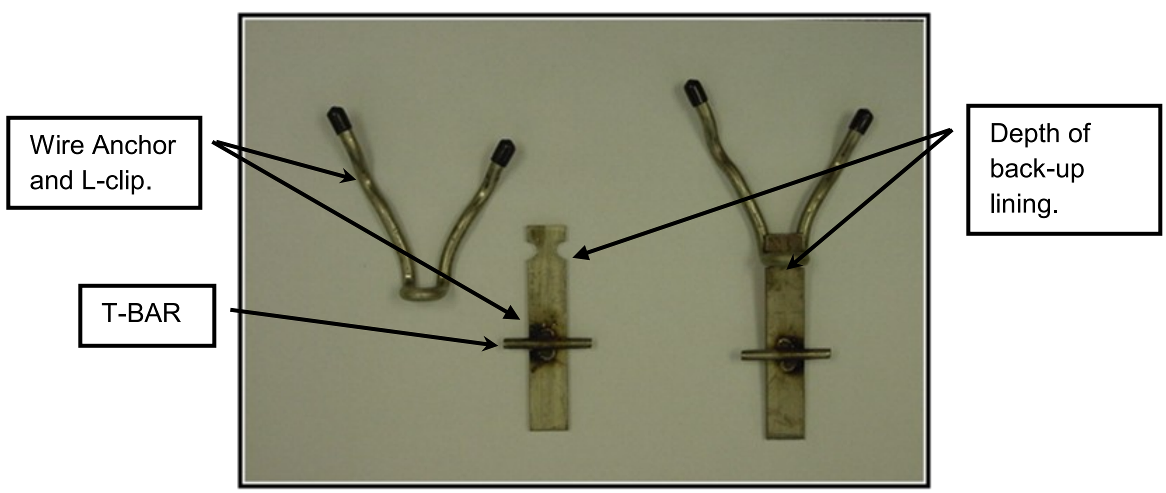

Figure 10. Example of Wire V Anchor and H-W L-clip with T-bar for use with two component linings.

CERAMIC ANCHORS

When application temperatures exceed 2000°F (1093°C), H-W Refractories Cement & Lime group recommends the use of ceramic anchors, generally in CORAL BP, although other options exist that can be investigated for certain problematic areas. CORAL BP is a burned, high alumina, phosphate bonded refractory brick with excellent hot strength and abrasion resistance. Because it is a ceramic product, the maximum service temperature is well above that of stainless steel or most other alloys.

CORAL BP anchors are manufactured in many configurations. For cement and lime applications, RAS configurations work well due to their shape. During installation, monolithic refractories conform to the contours of their shape. As the monolithic sets or develops strength, the ceramic anchor becomes part of the lining. C-Clips are used to attach the anchors to the vessel. This allows some flexibility in the anchorage to "give" rather than break.

When choosing ceramic anchors:

1. Harbison-Walker generally recommends CORAL BP quality ceramic anchors due to the superior physical properties of this brand, particularly hot strength.
2. Choose RAS series ceramic anchors, as shown in Figure 11, with C-Clips attached to the vessel shell.
3. C-Clips should be CCH series, 3/8" (9.5 mm) thick 304 SS*.
4. Install C-Clips so the anchors will be installed in the same direction as gas flow through the vessel.

Figure 11. RAS Anchors in CORAL BP with CCH C-Clip

*Note: The C-Clip alloy of choice is usually 304 SS. This is because the clip, made from 3/8" (9.5 mm) thick steel, is installed next to the shell where the temperatures are much lower than the internal refractories. At the shell, the less costly 304 SS alloy retains its strength and is typically not exposed to temperatures where oxidation or sigma phase formation will occur. For severe service conditions, 310 SS alloy is also available.

When ceramic anchors are installed using C-Clips, Figure 12, there will be a space between the top of the anchor and the C-Clip. A shim, usually of wood or plastic, should be used in this space to help hold the ceramic anchor in place. The C-Clip should then be filled with foam or covered in some other manner to keep any refractory material from filling this void. Duct tape or plastic wrap may also be used as a seal around the C-Clip and ceramic anchor prior to monolithic installation. The ceramic anchor itself should also be covered with plastic during installation of any back-up lining and then removed prior to wear face installation.

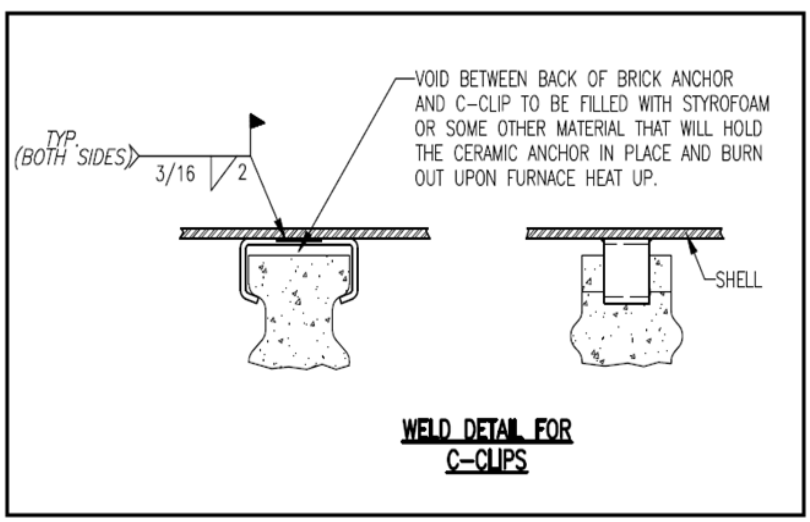

Figure 12. Weld Detail for C-Clips Showing Void Between Brick and Clip

SELECTING COMBINATIONS

Combining ceramic and metallic anchors is recommended for high strength support systems, in applications subject to high temperatures and chemical attack. Applications often requiring combined anchorage include calciner ducts, kiln inlets and risers, firing hoods, TAD connections, and hot zones of cooler walls, roofs and bullnoses.

1. Apply to dual lining systems with high temperature exposure.
2. Use in areas subject to excessive mechanical stresses or flexing.
3. Use Wire Anchors welded to shell or combine with L-Clips.
4. When combined with ceramic anchors, limit total wire length to 60% of the wear face lining thickness

Figure 13. Dual Lining Anchor Configuration Showing Castable Anchored with Ceramic and Wire Anchors and L-Clip.

SELECTING THE RIGHT ANCHOR PATTERN

Even after the anchors have been chosen; whether wire, ceramic or combined; it is extremely important to choose the correct anchor pattern and spacing. Proper spacing, orientation and installation optimize the support provided by the anchorage for the refractory lining. Insufficient anchorage, with too much separation between the anchors, risks inadequate load distribution and could lead to anchor failure. Spacing recommendations for anchor combinations vary depending on the installation method, application, wear face lining thickness, loading and orientation. However, the following general guidelines may be applied.

WIRE ANCHOR PATTERNS

1. Wear face linings ≥6” (15.2 cm)

   a. For vertical walls, sloped floors and overhead generally use 10” (25.4 cm) centers as shown in Figure 14.
   b. Note the orientation of the anchors at 45° from vertical and 90° from the adjacent anchor.
   c. Typically used for applications <2000°F (1019°C).
   d. Includes riser connections to cyclones, swirl entry to cyclones, floor riser connections to cyclones and cones and straight run sections of meal pipes.

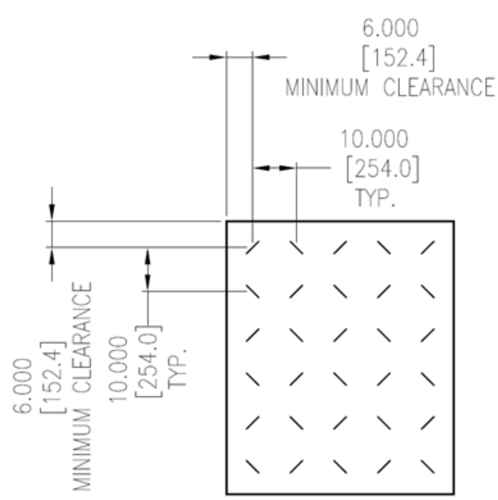

Figure 14. Example of 10”x10” (25.4x25.4 cm) Wire Anchor Pattern

2. Wear face linings <6"(15.2 cm)

   a. For vertical walls, sloped floors and overhead generally use 8"(20.3 cm) centers, similar to Figure 15.
   b. Again, note the orientation of the anchors relative to each other.
   c. Typically used for application <2000°F (1019°C).
   d. Includes riser connections to cyclones, swirl entry to cyclones, floor riser connections to cyclones and cones and straight run sections of meal pipes.

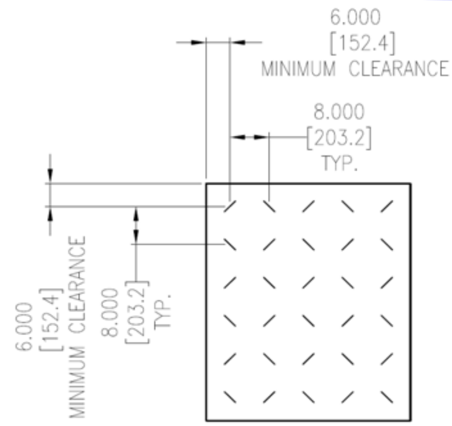

Figure 15. Example of 8"x8"(20.3x20.3cm) Wire Anchor Pattern

3. Examples of other wire anchor applications:

   a. Flat floors with <6"(15.2 cm) wear face linings generally require 10"(25.4 cm) centers
   b. Flat floors with ≥6"(15.2 cm) wear face linings generally require 12"(30.5 cm) centers.
   c. For other applications, such as meal pipes, burners, etc. contact your Harbison-Walker Technical representative for recommendations.

CERAMIC AND COMBINATION ANCHOR PATTERNS

1. Vibration Casting and Pumping

   a. For vertical walls in coolers, kiln inlets, firing hoods or sloped floors in ducts and risers, stagger ceramic and metallic anchors in horizontal rows on 15"(38.1 cm) centers and vertical rows on 7½"(19.0 cm) centers.
   b. Note the orientation of the wire anchors relative to one another and the adjacent ceramic anchors in Figure 16.
   c. For flat ceilings, such as closed cooler roofs, ceramic anchors or combinations of ceramic and metallic anchors are recommended to be staggered on 12"(30.5 cm) centers, both horizontally and vertically as shown in Figure 17.
   d. Ceramic anchor C-Clips should be oriented with the "C" profile in the direction of the gas flow so any vertical movement in the lining or ceramic anchor is not restricted.

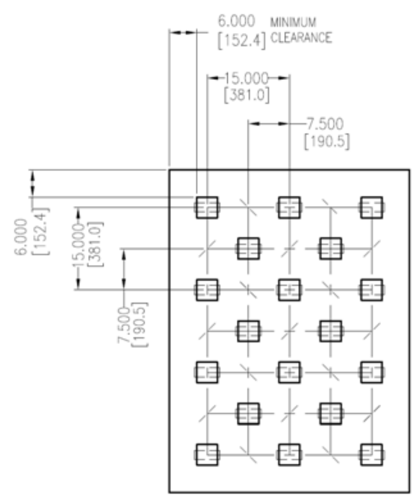

Figure 16. Example of 15"x7.5"(38.1x19.0cm) Anchor Pattern

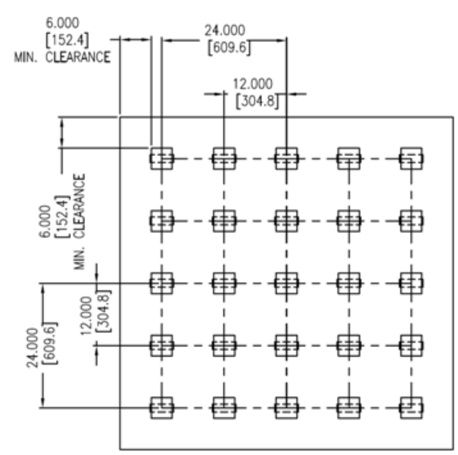

Figure 17. Example of 12"x12"(30.5x30.5 cm) Anchor Pattern

2. Gunning or Shotcreting

   a. For vertical walls in coolers, kiln inlets, firing hoods or sloped floors in ducts and risers, arched ceilings, such as firing hoods, TAD or Calciner roofs, stagger horizontal rows of ceramic and metallic anchors on 18"(45.7 cm) centers and vertical rows on 9"(22.9 cm) centers as shown in Figure 18.
   b. For flat ceilings, similar to casting, it is recommended to use 12"(30.5 cm) centers.
   c. Ceramic anchor C-Clips should be oriented with the "C" profile in the direction of the gas flow so any vertical movement in the lining or ceramic anchor is not restricted.

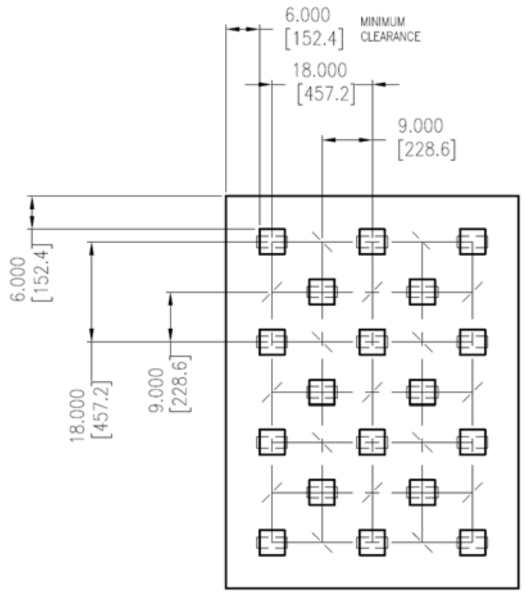

Figure 18. Example of 18"x9"(45.7x22.9 cm) Anchor Pattern

When questions arise regarding material selection, from products to anchorage and best installation practices, your H-W Refractories Sales representative and Technical Marketing Specialists are available to assist with technical solutions to meet your specific needs.