METAL ANCHORS: AN ABBREVIATED REVIEW

R. Engel
Refractory Consulting Services, Oxford, Ohio, USA

ABSTRACT

Metal anchors have been used to hold monolithic refractories in place for a long time. Nevertheless, many challenges remain as metallurgical, environmental conditions like temperature and atmosphere, parameters pertaining to lining design: joints, refractory material and others all have to be addressed for the installation to be successful. In this review some of the above-mentioned parameters will be discussed with emphasis on the effect of the environment on anchor dimensions, metallurgy, and on their interaction with the refractory.

INTRODUCTION

The use of anchors to hold monolithic refractories in place is more challenging than generally stated as many different and opposing demands have to be addressed concurrently. Among the most basic are: which type to select, metallic or refractory based on temperature of exposure, environmental conditions, how to accommodate the dimensional changes of the refractory monolith and anchor as a function of temperature and so on.

Anchor type and other refractory decisions are made when designing and installing the lining and the determination of the correctness of these decisions is evaluated at the time of the planned or unplanned removal of the lining.

BACKGROUND

The role of an anchor is to hold the refractory lining against the steel shell or support system so as to "prevent major movement" of the lining. Some movement will take place as a result of curing / drying / firing of a liquid containing monolith, castable, or of a plastic and also because metal anchors undergo expansion as a function of temperature. What needs to be avoided is the "major movement" that leads to a section of refractory dislodging from the location where it was installed or, in the extreme, falling out and leaving a major gap or hole in the lining.

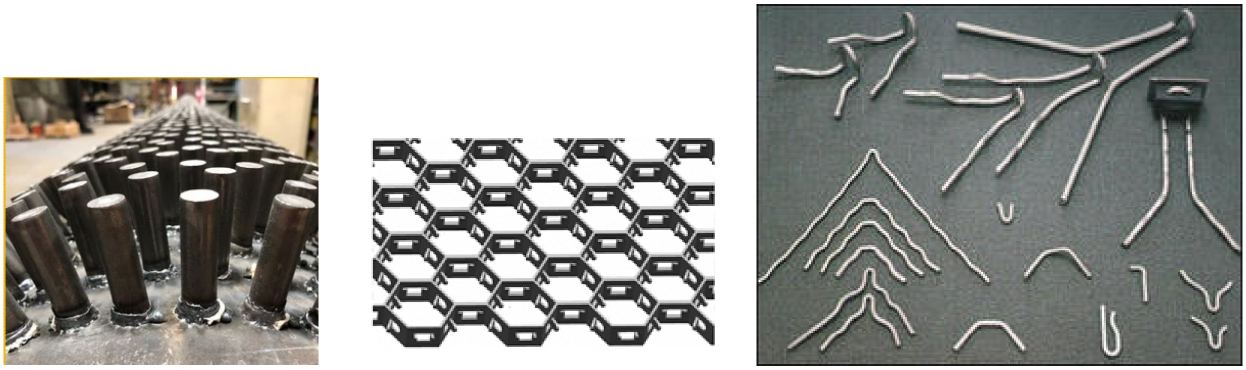
The literature presents different estimates on the percentage of monolithic structural failures resulting from a lack of proper anchor design and installation. One author claims greater than 60%[1] while another puts the number at 40% or less[2]. This work will focus on metal anchors and the effect their location, environment, metallurgy and refractory installation can have on each other.

ANCHORS

Anchors can be divided into two major groups depending on the base material used for their production: metal or refractory. Within each of these categories there are many different subgroups which take into account the composition, shape, length and so on of an anchor. For metal, the type or shape of the anchor(s) are often industry specific. Fig. 1 shows examples of metal anchor systems typically found in specific industries. The information presented will mostly apply to the type of anchors shown in Fig. 1c. These anchors are mainly used with castable, gunning and/or shotcrete applications.

SELECTION CRITERIA

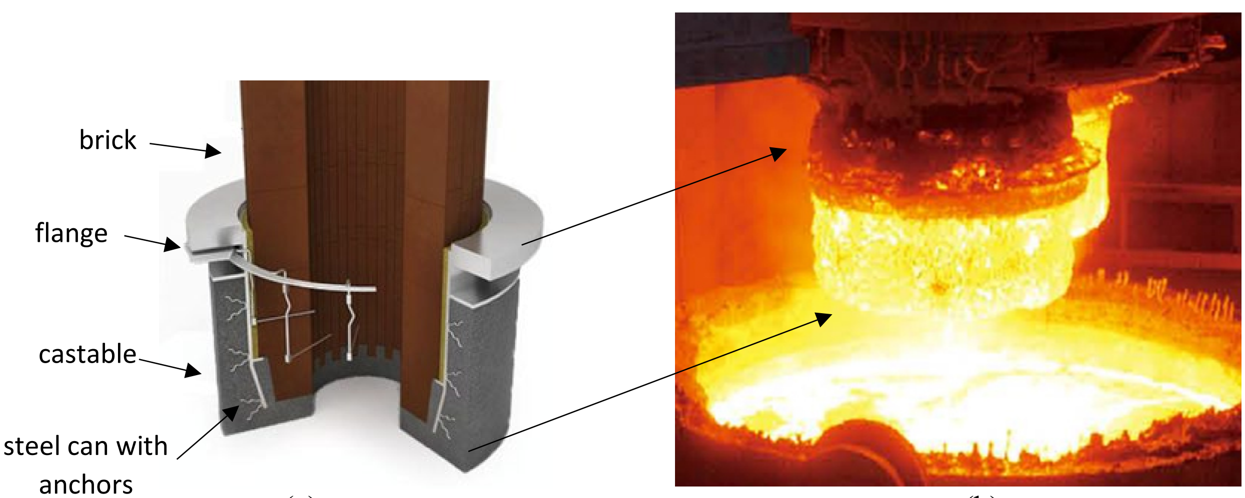
The type of anchor selected for use in a specific application should be based on the refractory lining characteristics, the expected environmental conditions to which the lining will be exposed to and the anchor's location within a unit. These will determine the requirements it needs to meet and also affect its length, shape, installation density, lay out pattern, steel/alloy type and quality and, welding procedure.



(a) (b) (c)

Fig. 1**.** Different metal anchor shapes (not to scale): (a) pin studs found in boilers[3], (b) hex-mesh often used in petrochemical installations[4], (c) various metal "wire type" anchors[5] found in steel, aluminum, alloys, cement, etc. industries.

The literature often states that metal anchors should be reserved for linings that are less than 230 mm in cross section and are exposed to lower temperatures which are defined as less than approximately 1090ºC[6,7,8]. This criteria neglects to acknowledge that metal anchors are also used in applications where the monolith's hot face greatly exceeds these temperatures; for example, when it is contact with molten steel expected to be at least at 1600ºC i.e., injection lances, CAS-OB bells, degasser snorkels (Fig. 2**)**, etc.



(a) (b)

Fig. 2. Degasser snorkel found in some steel making operations: a) schematic of snorkel lining design**[26]** b) snorkel after removal from the molten steel**[27].**

The lining characteristics encompass such items as the total refractory thickness, the lining design which could be a single material for the full thickness or consist of two or more refractory layers each with their own chemical, thermal and mechanical characteristics. In addition, the installation methods could be gunning, shotcreting, casting or a mixture of these. The lining configuration will determine the shape, length and thickness of the anchors so they are able to support the weight of the installation, prevent refractory movement while bringing the unit to operating temperature and resist deformation or creep as a result of the stresses exerted on them during operation.

Often only some of the environmental conditions are accounted for, but all are of critical importance for the long term success of an installation. The unit's expected operating temperature is always assumed to be known and to be taken into account in the lining design, but exposure to oxidizing or reducing conditions, the presence of an atmosphere containing carbons, chlorine, sulfur or, steam, the heating fuel type in use or the one expected to be used and so on are often not given the weight they deserve. These operating conditions will determine the steel or alloy type best suited for anchor use so it can properly carry out its function and will also impact the refractory selection so it is compatible with the environment.

Where the refractory is to be installed, its location within a unit, will determine the required anchor density to properly hold it in place and this, in turn, will be different if it is a furnace roof, or covering a steel pipe for use as an injection lance into molten steel.

Development of appropriate procedures for preparation of the support surface and the welding parameters may be required. Because it is impossible to visually determine a weld's integrity a test for checking should be in place.

ANCHOR LENGTH or DEPTH

Publications from various refractory and anchor manufacturing sources provide "rules of thumb" on the length of the anchor, how close to the hot face it should reach. One of the most common ones is that the anchor should extent up to approximately 65% to 80% of the lining thickness[6]. In 1966, Crowley[9] suggested that anchors should extend 66% to 75% of the thickness, and a shorter anchor should be added when installing a 2 component lining[9] to keep the "lining snug against the wall". Others also propose a 2 anchor design[10]. Several authors state that the anchors should not come closer than 25 mm or their tips be restricted to 25 to 30 mm from the hot face[7,11,12,13].

ANCHOR LAY OUT / SPACING

Some analysis has been carried out on the anchor lay-out pattern as it pertains to their orientation and spacing. Palmer and Tan[14] refer to empirical formulas or personal opinions which tend to space them out in the range of 200 to 350 mm. Goulart et. al.[6] discusses the widespread approach presented by several companies to make the anchor spacing a function of the total refractory thickness regardless of the lining material(s) and environmental conditions it will be subjected to. Based on the perceived shortcomings of these approaches they developed a new model accounting for the observed crack pattern and providing a more realistic anchor lay-out, but in most cases the lay-out is still determined based on prior experience.

METAL PROPERTIES

The type of metals most commonly used to fabricate anchors are stainless steels and alloys due to their resistance to chemical alteration at temperature. The exact type selected will determine the metal's chemistry which not only affects the maximum temperature to which it can safely be exposed to before it loses strength, but also its rate of corrosion.

Although published tables of maximum service temperature for metal anchors are widely available, a comparison amongst them shows a wide range in maximum service temperatures for the same steel types (Table I). In addition, most omit the conditions, reducing or oxidizing, used to determine these values. Generally, the stated temperatures are applicable for installations in oxidizing environments.

Table I.- Ranges of maximum allowable temperatures for selected steel grades

Steel grade	Stated Max. Service Temperature (ºC)		
Carbon steel	450[11]	260[6]	
304	900[11,20]	815[6]	760[24]
310	1000[11]	1150[20]	925[6,24]
316	815[6]	760[24]	
Inconel 601	1200[11]	1095[6]	

The physical integrity of metal anchors can be compromised due to corrosion as a result of chemical reaction with gases, solid or molten salts or, molten metals. This phenomena takes place at temperatures greater than about 400ºC[15]. The corrosion can manifest itself in various forms, the main ones being carburization and oxidation. Others are sulfidation, chlorination and nitridation. Other gaseous species can also attack and react with the metallic anchor thereby detrimentally affecting its properties.

In carburization, carbon from gas mixtures containing CO or hydrocarbons enters the steel/alloy structure via solid state reaction at temperatures >400ºC. This carbon reacts with the metal's chromium forming carbides, specially at the grain boundaries which leads to embrittlement of the anchor and reduces its resistance to oxidation and sulfidation. The extent of the reaction will depend on C and O levels in the gas and the metal composition. The extreme case of carburization is metal dusting[16].

In oxidation a reaction layer is formed on the surface of the anchor as a result of its exposure to the oxygen in the air. As long as this layer is continuous it acts as a barrier to further reaction until the maximum service temperature, the scaling temperature, is reached whereupon it will start to crack and the metal beneath it is no longer be protected leading to further reaction and corrosion. Luckily, metal types with high resistance to carburization are also highly resistant to oxidation[15].

Many stainless steel compositions are also susceptible to form sigma phase particles when the anchor is exposed to temperatures between approximately 560º - 980ºC for extended periods of time. The fastest rate of formation takes place close to 870ºC. Its effect is a loss of ductility or embrittlement which results in the anchor becoming strain intolerant at low temperatures (<~150ºC). This is problematic when a unit is cooled and the anchor is impact loaded or stressed[17]. Although sigma phase can be dissolved, the process is not practical for an anchor embedded in a refractory lining.

INTERACTIONS OF ANCHOR(S) WITH REFRACTORY

Expansion

The thermal expansion of the anchors is much greater than that of the refractory in which they are embedded (average: 1.5 mm per meter per 100°C for the metal[18] or about 3 times the refractory). It also takes place at a much lower temperature than that of the refractory. These characteristics combine to apply stresses to the lining leading to crack formation and the possibility of refractory failure. To accommodate the differential expansion anchors are routinely covered, dipped into, wax or special parting agents which burn off at low temperature thereby providing a small space for the anchor/refractory to move without jeopardizing the integrity of the lining.

A commonly used method, assumed to address the differential expansion between the anchor and the refractory, is to install plastic caps at the anchor's tips. These caps, which will melt at about 150°C, are to provide a small space into which the anchor can grow (Fig. 3). Palmer and Smillie[13] carried out visual and metallographic examination of the anchors and their surrounding refractory upon its removal and found no difference in refractory damage, hot face cracks or pop-outs, as a result of the presence or absence of caps (Fig. 7a).

Fig. 3. Tear out of castable installation showing the imprint of an anchor with caps

Shadowing

A high anchor density can affect the refractory installation by interfering with its uniform densification. One of the most common problems is shadowing whereby the anchors block the uniform material flow leading to poorly consolidated areas or even voids in the lining. In addition, the refractory is not in intimate contact with the anchor leading to weak points. Fig. 4 shows poor refractory consolidation around an anchor and its, in service, oxidation.

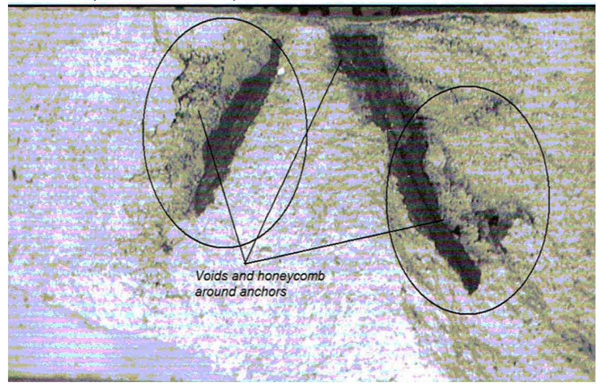


Fig. 4. Inconsistent / poor refractory densification around the anchor prongs and anchor oxidation[19]

Thermal Conductivity and Linear Change

Metal anchors have higher thermal conductivity than their surrounding refractories. Infrared thermography shows their shell weld points as distinct hot spots (Fig. 5). Wear of the refractory hot face will increase the anchor's temperature and can affect the weld or shell integrity.

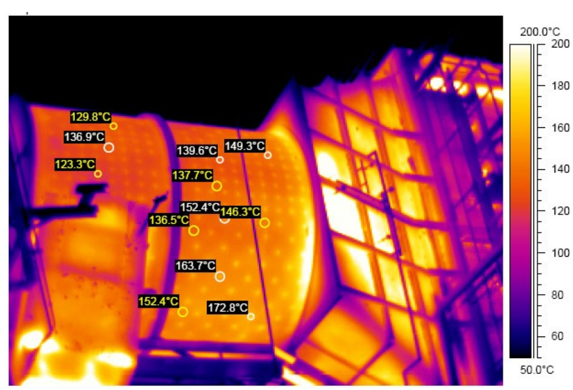


Fig.5. Thermovision survey of a furnace shell showing anchor bases as hot spots (regularly spaced light colored spots on the left half)[23]

The calculated thermal gradients through several different lining configurations are shown in Fig. 6 which graphically depicts how parts of an anchor could be exposed to the appropriate temperature regime for sigma phase formation. It also shows the effect of changing the insulation thickness from none to 76 mm and 102 mm.

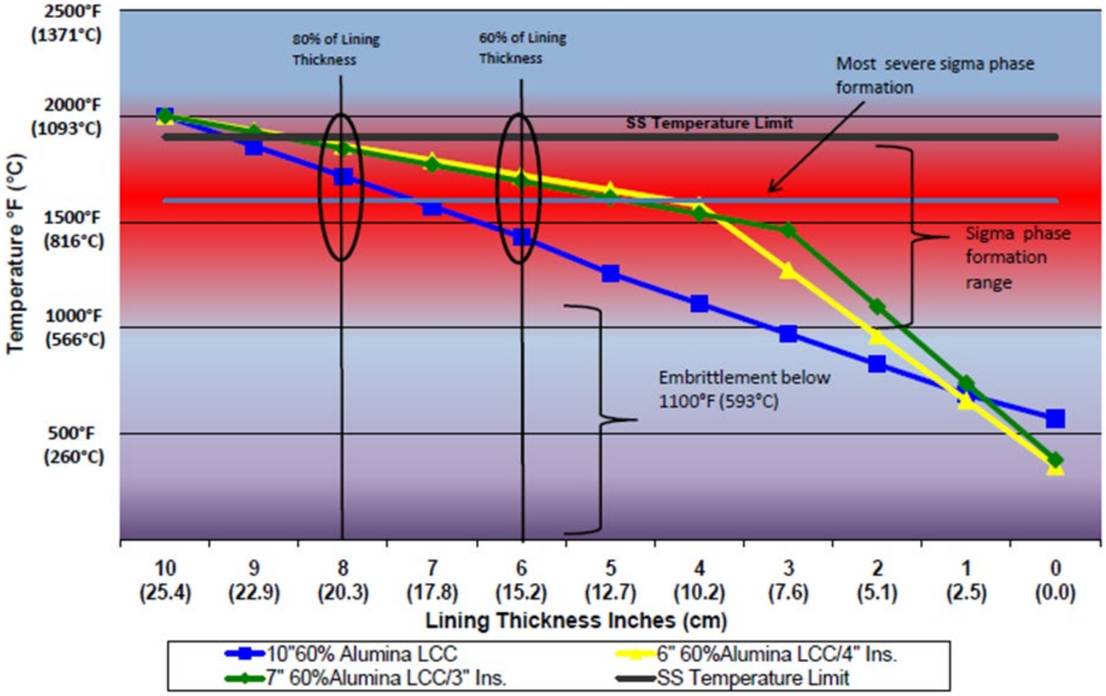


Fig. 6. Thermal profile of a 60% alumina LC castable with varying insulation thicknesses (lining thickness: 254 mm)[20]

The refractory's linear change, reversible and irreversible, should be considered when designing a lining to avoid shearing the anchors or splitting the shell. It will also affect joint design.

Most anchor failures take place at the interface between the dense, hot face, and the insulating layers. The reasons are localized higher temperatures and stresses due to the independent and distinct movement of each refractory layer, especially during initial drying and firing when their dimensional changes are most pronounced[13] and their effect on the anchor's thermal conductivity.

ANCHOR CORROSION

Carburization

Anchor carburization can be observed in petrochemical installations as they often operate with high carbon containing atmospheres. One of the suggested methods for preventing the carbon rich atmosphere from reaching the anchors or other metallic components is to cover them with refractory but, for this to be effective, there is an implicit requirement of no cracks.

Another carbon source are the plastic caps used to cover the anchor tips. Metallographic examination[13] showed that the cap's use provided the environment for localized carburization of the anchors leading to high wear rates of the tip (Fig. 7b). This phenomenon was also reported by Goulart, et. al[6].

Oxidation

Anchors can corrode while in service as a result of exposure to excessive temperature for the selected metal chemistry or environmental conditions. The reaction starts along the outside of the anchor and is expansive increasing the anchor's cross section. This exerts stresses on the refractory which can result in crack initiation. In addition, the physical properties of the oxidized layer are such that the anchor loses its holding ability (Fig. 8).

(a) (b)

Fig. 7. (a) Samples of anchors removed from site showing the difference between anchor with and without plastic caps. The anchor with a cap is degraded and carburized[21], (b) Left side: as received anchor with cap, right side: 2 anchors showing the carburizing effect of the cap[13]

(a) (b)

Fig. 8. Oxidation: (a) effect of alternate fuels on anchor integrity: cast walls in the riser duct of a cement kiln[25], (b) highly corroded anchor (Cooler Bull Nose Section)[22]

CONCLUSIONS

An accurate knowledge of the environment in which the lining will operate is needed so as to select the appropriate anchors and refractories. Even with this knowledge there remain many parameters which need to be considered to achieve the expected installation longevity, but they have not been studied and are incorporated into the design using “rules of thumb” and experience.

Although many linings do last a long time in service, in order to meet expectations and reliability, a study of the technical reasons for their success needs to be undertaken so as to minimize catastrophic failures and provide guidance for new installations.

REFERENCES

1. "Proper Anchor Selection", http://fssperry.com/articles/proper-anchor-selection/ visited May 2020
2. D. Szynal, "Refractory Anchor Design: 3 Important Things You Need to Know", Heat Treat Today (2020)
3.www.newatudwelding.com/boilerdivision, visited April 2020
4. http://urc4u.com/refsource/products/tsi-39-5444.html visited Dec. 2020
5. www.pipetubeflanges.com/refractory-anchors.html, visited Dec. 2020
6. C.A. Goulart, M.A. Braulio, B.H. Teider, V.C. Pandolfelli, "A Critical Analysis of Anchor Spacing in Refractory Lining Design", RWF (2016).
7. Anchoring of Monolithic Refractories Design and Installation Manual, Thermal Ceramics (2002).
8. Harbison-Walker Handbook of Refractory Practice (2005).
9. M.S. Crowley, "Metal Anchors for Refractory Concrete", Am. Ceram. Soc. Bull., V 45, No. 7 (1966).
10. G. Bases, "Refractory Anchors - Keeping it Simple for the Power Generating Industry", preprint.
11. www.oster.co.za/refr_anc_3.htm, visited Febr. 2021
12. T. Dickinson, "Refractory Anchor Systems Part 2 of 2", linkedin, (2015).
13. G. Palmer, M. Smillie, "Selecting Steel Anchors for Monolithic Refractory Linings", Refr. Appl. And News, v 12, #5 (2007).
14. G. Palmer, K.C. Tan, "Design and Failure of Monolithic Refractory Structures – Part 1", Refr. Appl. And News, v 14, #3 (2009).
15. www.materials.sandvik/en/materials-center/corrosion/, visited Jan. 2020
16. H.J. Grabke, "Carburization, Carbide Formation, Metal Dusting, Coking", MTAEC, 36 (2002).
17. J. Hau, A. Seijas, "Sigma Phase Embrittlement of Stainless Steel in FCC Service", 61st NACE Int. CORROSION Conf. & Expo (2006).
18. www.anchorsforrefractory.com/wp-content/uploads/2015/10/information-castable.pdf, visited Jan. 2019
19. G. Palmer, K.C. Tan, "Design and Failure of Monolithic Refractory Structures – Part 2", Refr. Appl. and News, V 14, #4 (2009).
20. HWI Technical Bulletin: Anchor Selection for Monolithic Linings C&L, (2011).
21. G. Palmer, J. Millard, J. Cobos, "Refractory Concrete Behaviour for Anchored Systems under Load Induced Thermal Strain", RWF (2018).
22. 'B.' Ilano III, "Choosing and Installing Monolithic Refractories", slideserve, HASLE refractories, visited Febr. 2021
23. G. Palmer, T. Howes, "Heat Transfer Design Considerations for Refractory Linings with Steel Anchors, Part 2", RWF, 2 (2010).
24. "PIP RFSA1000 Refractory Anchor and Accessory Specification" (2015).
25.www.hoganasborgestad.com/wpcontent/uploads/2019/01/PRCorrosion_protection_and_energy_savings-min.pdf, visited May 2019
26. www.isco-europe.com/products/, visited Febr. 2021
27. www.osymen.com/rh-degasser-refractories-lining-recommendations.htm, visited Febr. 2021