Well and truly anchored

Until a decade ago, the role of refractory anchors was undervalued, but the higher use of alternative fuels has seen them increase in importance in the cement industry. Now they are key in preventing refractory lining failure, and their design and manufacture have developed rapidly.

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The increase of alternative fuel use has led to the emergence of new issues in many areas of cement production, which have affected different parts of the production line. Refractory materials have to face new challenges, including the need for resistance to very specific chemical environments – in coolers, precalciners, smoke chambers and lower stages of the preheater tower.

At high temperatures and during long-term exposure, the presence of chlorine and sulphurs in different states damages the ceramic of the lining. Therefore, many of the major refractory producers have created new castable compositions with particular properties of resistance to the corrosion of alkaline salts. As a result, there are a lot of new materials on the market containing zircon, silicon carbide and specific alumina content.

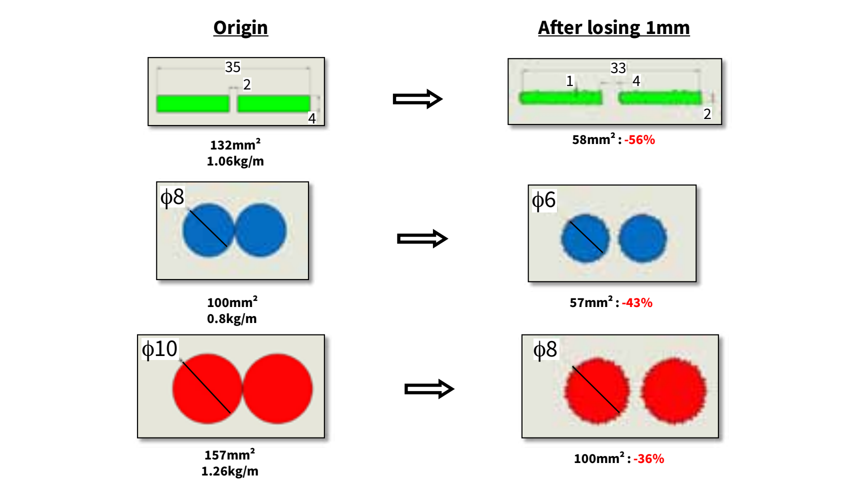

Figure 1: nominal surface comparison under service of flat and round anchors

However, very few precautions have been taken in terms of the refractory anchors that will retain the lining on the steelwork, resulting in lining failure.

While for a long time considered as a simple piece of steel, refractory anchors

Table 1: nominal room temperature mechanical property ranges*

Form and condition	Tensile strength		Yield strength (0.2% offset)		Elongation (%)	Hardness (Rb)
	(kmi)	(MPa)	(kmi)	(MPa)		
Rod and bar						
Hot-finished	85-120	585-825	35-100	240-690	60-15	65-95
Annealed	80-115	550-790	30-00	205-415	70-40	60-80
Plate						
Annealed	80-100	550-690	30-45	205-310	65-45	60-75
Sheet						
Cold-rolled	115-190	790-1310	100-175	690-1205	20-2	-
Annealed	85-100	585-690	30-50	205-345	55-35	65-80
Strip						
Cold-rolled	115-190	790-1310	100-175	690-1205	20-2	-
Annealed	85-100	585-690	30-50	205-345	55-35	65-80
Tube and pipe					-	
Cold-drawn						
Annealed	80-110	550-760	30-60	205-415	65-35	70-95
Wire						
Cold-drawn	120-205	825-1415	100-195	690-1345	20-3	-
Annealed	90-115	620-790	35-70	240-480	45-35	-
All forms						
Solution-treated	75-110	515-760	25-55	160-380	75-40	55-95

**Values shown are composites for various product sizes and therefore are not suitable for specifications.*

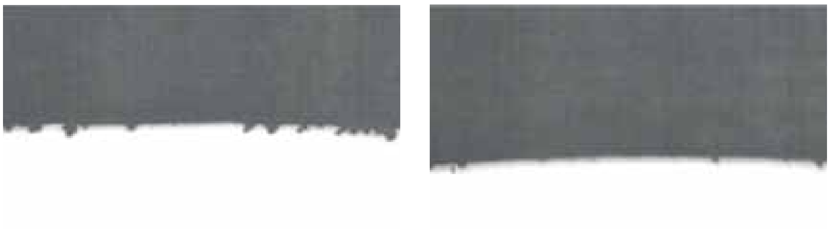

Figure 2: comparison of surface defects between a wire of average quality (left) and one for anchoring purposes

have become valued as a research and development topic in their own right.

To reduce the risk of rapid anchor failure, some basic requirements have to be met. The anchor has to be chosen with care in terms of shape, type and the way it is produced.

The round anchor – the flat anchor's alternative

While flat anchors are cheap, simple to manufacture and readily available, and therefore often used, they have some major disadvantages and are regarded by some as even inappropriate for use.

The intrinsic mechanical characteristic of the anchor will impact on its life span. Corrosion will have some effect on the microstructure of the steel and negatively impact its mechanical behaviour, leading to the partial or total destruction of the anchor. Therefore, it is necessary to select a product that will retain its mechanical properties for as long as possible in the intense physical and chemical stresses that occur.

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Flat anchors show poor behaviour as the shape of the object is a key reason. Figure 1 shows a comparison of nominal surfaces to evaluate the evolution of the relative tensile strength. A typical 35x4mm flat anchor has a higher surface area than the commonly-used 8mm round anchor. However, after losing 1mm, due to the prevailing conditions, the former surface area is reduced. The so-called mechanical advantage of the flat anchor is then a weakness. The round anchor, due to its shape, will keep its form and its mechanical tensile strength longer.

There are few comparisons in literature, but Table 1 shows the nominal difference between the flat and the round, cold-drawn anchors in the nickel alloy Inconel 601. Therefore, with corrosion present and rapid weight loss, the flat anchor is not the first choice.

The choice of the alloy

Once the type of anchor has been chosen there are several other considerations that still need to be made. The raw material choice is obviously critical, because the reliability and consistency of the quality are important for the stability of the anchoring during its lifespan.

Moreover, the choice of alloy is of paramount importance, particularly in terms of corrosion. When the concept of alternative fuel-induced corrosion first became apparent, IRIS started to investigate the alloy choice for this specific matter. Table 2 shows a comparison of different stainless steels and their corrosion rates under sulphur attack.

AISI 309 and 310 steels are very often used in cement plant applications. Due to their chromium content, they create a protective, corrosion-resistant and passive chromium oxide layer. The nickel content in the steel enables mechanical properties to be retained effectively, even at high temperatures.

However, where chlorine or sulphur attack the steel, this chemical composition is not advantageous. The high nickel content (without any special additives in the alloy) makes the steel highly sensitive to sulphidation (the combination of sulphur with the nickel) and chlorine, in any case, is a tough opponent to steel.

This led to the development of new alloys that contained specially-added components. Additional corrosion resistance is provided by the rare earth elements (eg, cerium, lanthanum), silicon, aluminium, nitrogen and molybdenum as the most common. Indeed, literature underlines two different kind of alloys: the austenitic stainless steel (eg, AISI 308) and the nickel alloys (eg, Inconel 800H).

Table 2: corrosion of stainless steels in sulphur vapour at 1060°F (571°C)

AISI type	Corrosion rate based on 1295h test (mpy)
314	16.9
310	18.9
309	22.3
304	27.0
302b	29.8
316	31.1
321	54.8

In the environment of a cement plant, the first micro-alloy commercialised steel grade, 253MA, (see Table 3 for its chemical composition) has shown it benefits. This type of steel exhibits favourable characteristics when compared with 310S and 309 steel types. Table 4 shows a comparison of weight loss between these three types.

Thanks to the addition of silicon (that can also be found in the AISI 314), cerium and of nitrogen, 253MA has been used in cement plants for many years now. Major global contractors and refractory suppliers to the cement industry have seen the interest of using such an alloy when conditions demand it. In France Prevel, an engineering company specialised in cement plant revamping, and refractory castable producer Hepha have been installing this material with positive feedback.

Table 3: nominal chemical composition of 253MA steel

Chemical element	Content (%)
C	0.08
Ci	1.6
Mn	≤0.8
P	≤0.040
C	≤0.030
Cr	21
Ni	11
N	0.17
Ce*	0.08

**To cerium should be added the quantity of other rare earth models since the additive takes the form of a metal containing about 50% Ca.*

Table 4: 253MA resistance to corrosion compared to 310S and 309

Product	Exposure time (h)	Mechanical resistance – Rm (MPa)	Elongation – Z (%)
253MA	12	748	–
	48	649	14
310S	12	448	20
	48	428	21
309	12	506	61
	48	619	21

A recent analysis made by the research centre of Ugitech France, on IRIS initiative, has shown the superior resistance to corrosion by sulphur and chlorine salts of this alloy against the commonly-used 310S and 309 (see Table 4). The analysis of the mechanical characteristics after exposure to a corrosive environment provides a good preliminary evaluation of the effect of corrosion on the alloy. Nevertheless, each plant has its own service conditions and other alloys can show better results. The final choice must be made after further investigations.

Round anchor and cold-drawn CNC bended round anchor

The anchor manufacturing process is also important. Manufactured from steel, the process impacts on the mechanical and chemical characteristics of the anchor as the steel structure differs in state depending on whether it has been cast, worked, cold-drawn or annealed.

For this purpose, cold-drawn annealed wire provides the best results. Homogeneous, accurate, stable and ductile – the wire obtained by a cold-drawn process has all the appropriate properties to form a steel round product. This manufacturing process enables a very defect-controlled surface state and a constant nominal diameter. Those two parameters are crucial in the anchor's life. The defect-controlled surface is a basic requirement to avoid micro-cracks and reduce the penetration of corrosion in terms of depth and speed (see Figures 1 and 2). In comparison, the basic 'wire rod' has poor corrosion resistance and low mechanical properties (350MPa vs up to 750MPa for a cold-drawn wire).

The cold-drawn wire needs to be shaped into an anchor in the most suitable way of three options: by hand, by press or by robotic machine. The aim is to keep the wire integrity, keep the obtained charactericstics intact and avoid damage before use. While bending by hand or with a press is an easy option, these techniques substantially impact on the wire characteristics.

Figure 3 shows the difference between bending the wire by press (top) and robotic machine (bottom). Using the former, it is almost impossible to obtain a bent wire free of micro-cracks. The pressure on the steel while bending is so high that it cracks at the surface at the macro/microscopic scale. These cracks can reduce the corrosion resistance by 20 per cent (see Figure 4). As a result, in the bottom area of the precalciner or in the cooler anchors often break at the first bending point.

In addition, there will be a diameter reduction on the bending, thus locally decreasing the mechanical properties.

Conclusion

Cement production faces many issues and has to remain competitive, which means running an efficient production line. Cement production efficiency relies in part on the reliability of the installed refractories and the prevention of refractory issues. This must include not only the dense layer of the lining but also the anchors as both are tightly linked with the refractory lifespan. Paying attention to the choice of anchor in terms of raw materials, alloys, type and manufacturing process is a key requirement in this prevention process. ■

Figure 3: the upper anchor has micro-cracks after being shaped by a press. The lower anchor has been bent with a robotic machine

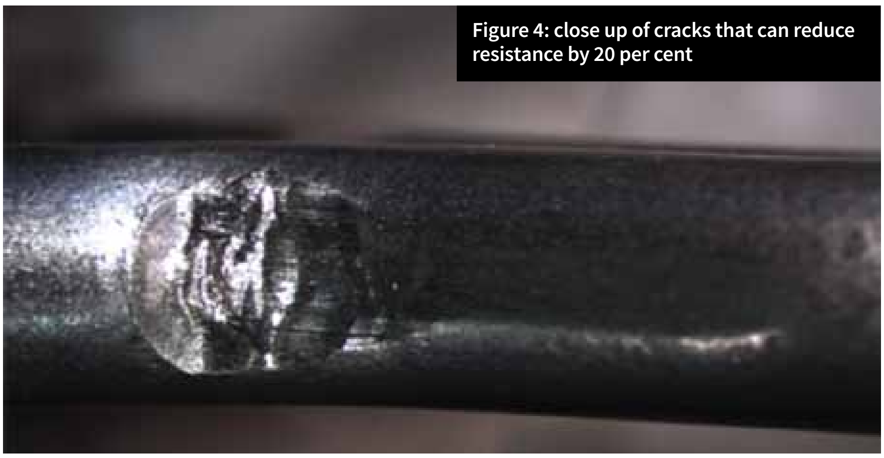

Figure 4: close up of cracks that can reduce resistance by 20 per cent