THE PRODUCT DEVELOPMENT AND CONTINUOUS IMPROVEMENT PROCESS FOR REFRACTORIES IN THE BASE METALS INDUSTRY
A TEXT BOOK AND PRACTICAL PERSPECTIVE

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Vereeniging Refractories (Verref)

Abstract
The paper explores the practical experience that Verref has had with the development and continuous improvement of refractory products used in the Base Metals industry. It describes the value add to Base Metals’ producers through customer interaction and improvements to the products delivered to customer requirements. It includes the practical in-house testing of raw materials and products (Rotary slag testing and subsequent microscope analysis of wear mechanisms) and how laboratory results have been borne out in refractory performance. This is further described in case studies.

It is concluded that the product development and continuous improvement process for refractory products utilized in the Base Metals Industry, can only be effective with close, continuous customer interaction.

Keywords: Product development, Continuous improvement, Convertor refractories, Furnace refractories, rotary slag test, microscope analysis, wears mechanisms

1. Introduction
Refractories are predominantly based on six high melting point metal oxides together with carbon and some carbides and nitrides. The oxides used are those which are reasonably abundant, of reasonable price and alone or in combination give brick and monolithic products the thermal, mechanical, physical and chemical properties required for a particular application. To meet the varied demands of the major metallurgical and heat containment industries the “big six oxides” expand to a range consisting of approximately 400 chemically or physically distinct brick and monolithic products. If we consider brick shapes, individual items number in excess of 5 000.

Development of improved and new refractory products is an ongoing process critical to both manufacturer and user. The combined effect of developments in refractories and metallurgical processing is reflected in the specific consumption in the steel industry, which over the last four decades has fallen from 35 kg/t to 10kg/t in the Western World\(^1\). When specific consumption was high refractories were regarded as an auxiliary raw material rather than a component of the production equipment \(^2\), which they now are. Specifically for Copper operations the consumption for conventional operations is 15 – 20 kg/ton of Copper and this has been reduced to lower than 10 kg/ton for newer technologies.

A new product progresses through a sequence of stages from introduction to growth, maturity and decline. This sequence is known as the product life cycle and is a process involving both technical development and marketing strategy and decisions.
This product life-cycle model is used to describe the value add to Base Metals’ producers through customer interaction and improvements to the products delivered to customer requirements. It includes the practical in-house testing of raw materials and products (Rotary slag testing and subsequent microscope analysis of wear mechanisms) and how laboratory results have been borne out in refractory performance. This is further described in case studies.

2. The Product Life Cycle
Product life-cycle stages and sales volume can be presented as the well known Life Cycle Curve, an example of which is shown in Figure 1.

![Figure 1- Product life cycle curve]

2.1 Concept, R&D and Introduction Stage
Concepts for refractory development derive from in house ideas, examination of used materials, licence agreements, technical literature, customer requirements, consultants and existing commercially available products.

Preliminary work based on concepts frequently does not go ahead, but forms the springboard for successful development when an idea’s time arrives or associated process technology is introduced and often work that is started for one industry will find its main application in a totally different area. Surprisingly development is not always logical and occasionally there is sometimes a pleasant element of serendipity.

During the development and introduction stage, product quality standards are firmly established and product awareness is developed. Marketing targets innovators and early adopters and pricing may be low to rapidly increase production volume, or higher to recover research and development costs. During this stage of the product development the testing processes with customers and their feedback is extremely important.
2.2 Growth Stage
In the growth stage, product preference is established, market share increases and the first competition from similar products is encountered. An important aspect during this stage is that the lessons learned in the previous stage are expanded into the broader customer base.

2.3 Maturity Stage / Market Saturation
On product maturity, growth in sales starts to decrease due to competition from similar materials and marketing effort moves increasingly from promotion to defence. Long term proven performance and unique product features are emphasized and improved if possible. Pricing incentives may have to be introduced.

2.4 Decline Stage
Volumes continue to decline during this stage for typical fast moving products and the only options are to further decrease price or to discontinue the product. It is however important to recognise that refractories is not a fast moving industry and that a significant portion of refractory volume sits in the so called “Mature/Decline” categories. Despite that these products continue to have a very important role to play. Close technical collaboration between the end user and supplier will ensure maximum life and cost effectiveness for even these mature refractory products. In fact for many refractory products the sales volume curve flattens out in this stage.

The time scale from initial concept to decline and eventual discontinuation of the product differs widely with industry and application. For a steel plant ladle which is of relatively small capacity, is part of a multi-stream process and where life is measured in weeks, production and commercial losses associated with an unsuccessful trial are relatively low and market saturation can be reached in 18 to 24 months\(^3\).

This paper examines the development and introduction of four generations of products for base metals converters. These campaigns are typically 6 to 12 months. Risks are high and procedures during the development and introduction stages are rigorous, time consuming and costly. Simulative testing which is used as an indicator of service performance is an integral part of the development process.

3. Destructive Service Factors
Destructive service factors include the following:

- Thermal Shock Spalling
  This is highly unlikely for refractories used in continuous processes (smelting furnaces) where commissioning and cooling times are measured in weeks. The crack pattern is different for heating and cooling spalling. Refractories used in batch processes within the base metal’s industry are exposed to thermal shock spalling in combination with structural spalling.

- Pinch Spalling
  Associated with lack of expansion allowance or filling of open joints during cooling down and heat up of a vessel. It is difficult to differentiate between pinch spalling and thermal shock spalling. Generally, pinch spalling (See figure 2) causes the loss of corners and arises on the exposed face of the refractory brick, whilst thermal shock tends to involve complete shearing (spalling) of the hot face.
Structural Spalling
This is the peeling off of the densified hot face during thermal cycling, that has been penetrated by metal, slag or matte in a metallurgical process, and is brought about by a chemical/structural change of the densified hot face zone leading to a difference in thermal expansion, as well as in other physical properties, between the original refractory and the infiltrated area. This is prevalent in batch furnaces such as Pierce Smith converters and is accelerated by thermal cycling leading to a combination of structural and thermal spalling. See figure 3.

A further severe example of structural spalling is shown in figure 4. The upper left side is the working face of the tuyere, characterised by a lighter blue/grey densified zone heavily cracked into segments which are about to peel off. Behind this working face copper metal has infiltrated the matrix and is dissected by further cracks containing metal and matte. On the bottom third of the plate, towards the centre a large crack has developed into which copper metal has flowed.
Figure 4 - Structural spalling of a tuyere – Showing severe metal penetration

- Chemical Attack
The following are all chemical attack mechanisms:

Hydration. (See figure 5)
The basic oxides of magnesia (MgO), lime (CaO) are both susceptible to hydration. If moisture is present in a refractory lining from installation, or formed during heat from the use of fuel oil, it will move back through the lining in front of the 100°C isotherm. If the isotherm is held at any stage during heat up for an extended period of time, especially if the lining is thick, moisture will react with magnesia. MgO readily reacts with moisture at temperatures around 80°C forming the hydroxide, MgO+H₂O →Mg(OH)₂ with an associated large volume expansion that can disrupt both refractory and furnace structure. Cracking and disintegration of the brick and damage to the furnace structure results.
Attack from Sulphur compounds.
Typically this is SO₂ and elemental Sulphur attack of the brick especially magnesia in brick.

Carbon monoxide attack.
This type of attack is prevalent in CO rich atmospheres.

- Slag Attack
  In this paper only slag attack is examined.

Slag compositions in Base Metal operations are mostly silica rich fayalite (2FeO.SiO₂), which rapidly attacks and deeply penetrates aluminosilicate refractories. Basic materials, are also attacked as indicated by the simplified phase diagram FeO-MgO-SiO₂ shown as Figure 6.

Depending on the industry, slag compositions may lie either on the SiO₂ or MgO/FeO side of the Pyroxene field. The former slags are more aggressive as solution of magnesia reduces slag viscosity, increasing the volume of fresh slag in contact with the refractory surface. Viscosity changes and amount of magnesia dissolved is dependant on the initial slag composition and operating temperature.

Typical stresses on Base Metal refractory lining are chemical, thermal and mechanical and Chromag and Magchrome refractories have become the materials of choice for non-ferrous applications due to the following characteristics:

- Compatibility with highly aggressive siliceous (Acid) slags that contain FeO. Generally fayalitic slags. (2FeO.SiO₂).
- Resistant to attack by metal (Cu, Ni), mattes (xCu₂S. FeS, xNiS. FeS) and metal oxides (Cu₂O). (Matte and metal highly mobile – See figure 10)
- Highly Refractory. Refractory phases MgO, Spinels (RO. R₂O₃), Forsterite (2MgO.SiO₂). Excellent hot strength. Low SiO₂ - less liquid phases. (Direct bond & Rebonded).
- Excellent resistance to thermal cycling – converter practice. (Mechanical, structural spalling.)

![Figure 6 - FeO-MgO-SiO₂ Phase Diagram](4)

4. Development Test Methods

4.1 Physical and Chemical
The routine test methods for the quality control of normal production are used to define the bulk properties of new products. These are density, porosity, mechanical strength and chemical analysis. For high risk and new applications additional simulative testing is required, some of these tests are, but not restricted to; hot strength, spalling resistance, Young’s modulus, hydration resistance, pot and rotary slag testing.

4.2 Simulative - Pot Slag Tests
Slag pot test samples consists of a 75mm cube which is core drilled, charged with crushed slag, fired and then cut as shown in Figure 7. Corrosion and depth of penetration of the sample are quantified if possible.
Pot testing is a useful and simple technique for the rapid initial evaluation of a large number of samples, but the results must be carefully interpreted considering both the limitations of the test and the chemical composition of the refractory sample and slag.

Limitations of the test are:

• No temperature gradient across the sample.
• No flow of slag in contact with the refractory surface.
• No fresh slag.
• The slag may quickly become saturated with refractory oxides which may change the viscosity and chemistry of the slag making it more benign.

All of the above are generally untypical of what occurs to refractories in service.

Figure 7 - Pot slag test sample

4.3 Simulative - Rotary Slag Tests
The rotary slag test method is described in ASTM C 774 – 75. Refractory specimens are cut from a 230 x 114 x 76 mm sample, assembled as a hexagonal cartridge and installed in the test furnace as shown in Figures 8 and 9. To reduce possible interactions between adjacent samples the Verref test piece hot face dimension is 56mm rather than the ASTM dimension of 44mm.

As the test gives the relative resistance of refractory materials against slag erosion a reference sample must be included to allow comparison of different runs. If the materials being evaluated are likely to give very different wear rates, then two samples of each should be included to minimize the effect of a high wear sample on those adjacent to it.
The rotating furnace is heated and charged with fresh slag, matte or a mixture of both at regular intervals, and spent slag removed, to ensure that the chemical composition of the liquid slag/mixture is close to the original composition. The test is run until significant differential wear on the specimens can be easily seen.

After removal from the furnace the samples are sectioned longitudinally as shown in figure 10 and the erosion and depth of penetration measured. XRD and microscopy can be carried out.
Compared with pot testing, rotary testing has the following advantages:

- There is a temperature gradient across the sample.
- Thermal cycling can be included.
- There is flow of slag across the face of the refractory.
- Slag composition remains close to original.
- The test can be run until there is significant differential wear.

A disadvantage is that atmosphere cannot be closely controlled.

![Figure 10 - Sectioned rotary slag test sample](image)

The test rig at Verref was originally constructed to evaluate materials for gasifiers and since then has been used in a wide range of development projects, including refractories for base metal applications. In all cases the test results are a very good indicator of actual performance.

### 4.4 Simulative - Hydration Resistance

Hydration resistance testing is a standard for basic (magnesia containing) lining materials for large smelters. Whole brick samples are placed in an autoclave and exposed to a steam atmosphere at a specified temperature and pressure. Visual appearance and residual physical properties are determined.

### 4.5 Mineralogical Examination

Mineralogical examination of raw materials, rotary slag test samples and field trial samples is an indispensable tool in the development of new raw materials or brick. The series of five photomicrographs below demonstrates the usefulness of the technique.

Figure 11 shows an example of a magnesia grain on contact with a silica rich fayalitic slag. At the bottom of the plate unaltered hexagonal magnesia (periclase) crystallites are clearly visible. On the working face magnesia has been transformed to an iron rich phase, which is disrupted and is floating into the slag. The reflective phase between the magnesia crystallites and seen as a channel at the lower left of the micrograph is copper/oxide, and though not reactive will cause structural disruption of the brick on thermal cycling owing to the differences in thermal expansion. Black holes are closed porosity.
Figure 11 - Attack on Magnesia by a silica rich fayalite slag. Field width 1000 µm

Figure 12 - Resistance of chromite to silica rich fayalite slag. Field width 1000 µm

Figure 12 is of the working face of a magnesia chrome brick and demonstrates the resistance of chromite over magnesia to silicate slag attack. The chromite grain in the centre of the field is standing proud of the surrounding and altered magnesia grains. At top left a second large chromite grain is floating out of the brick into the slag by slag silicate attack on and dissolution of the surrounding magnesia. To the right of the chromite crystal smaller angular chrome-rich fusion grains also exhibit the same resistance.
5. Magnesia Chrome Brick and Chromite Stabilization

Three approaches are employed for the manufacture of magchrome and chromag brick.

5.1 In Situ Reaction of Chromite and Magnesia

Magnesia chrome brick were first produced in Japan in 1925 and in the UK a decade later (2). Initially brick batches were based on magnesia and raw chromite with reaction taking place during kiln firing. Although still produced today redox reactions of unstabilized iron oxide from the chromite may give unpredictable expansions during manufacture and at times in service. In these refractories silicates are generally the primary bonding phase, and are subject to preferential attack by the silicate slag as are the residual magnesia grains.

5.2 Co-Sinter and Co-Clinker

Magnesia and chromite either as a blend of individual particles or briquettes are sintered in a rotary kiln at temperatures in excess of 1600°C. Iron oxide is stabilized, but there is still free magnesia present. At burning temperatures above 1550°C some direct bonding occurs, as the burning temperature is increased up to 1700°C and above, so the amount of direct bonding present increases and the silicate phase is confined to the interstices between periclase grains. (6) The attendant benefits of direct bonding are; increased thermal shock resistance, improved resistance to slag and matte penetration as well as corrosion and erosion, better hot strength and brick stability. As energy prices rise the energy inefficiency of small rotary kilns is making co-clinker increasingly uncompetitive.

5.2 Fused Grain

Reconstituted fused magnesia chrome refractories were introduced in the mid 1960’s with Verref being one of the first manufacturers, following the installing of a fusion plant in 1967. Since then fused magnesia-chrome products have been increasingly used in metallurgical applications ranging through lead, steel, ferroalloys, copper, cobalt, nickel and platinum. Industries where their use has largely been discontinued due to the high level of hexavalent chrome formed, are glass and cement.

Fused grain is prepared by fusing raw chrome together with magnesite, calcined or dead burnt, above 2000°C in either a Higgins or tilting electric arc furnace. This gives excellent bonding between the chrome and magnesia as well as distributing the chrome throughout the magnesia. Silicates are isolated within the interstitial crystal boundaries.

Benefits from the use of fused grain, over those listed under Co-Sinter - direct bonding are; very low open grain porosity, large crystal size with a concomitant lower surface area than found with smaller crystallite sizes. Both of these characteristics reduce the surface area available to slag corrosion and matte/slag penetration. In addition fused material is dimensionally stable and on refiring in a brick formulation the expansion generally found on raw chrome/magnesia brick is avoided.

Therefore, reconstituted fused grain brick have lower porosity, higher density and crushing strength which improve resistance to slag and matte ingress.

6. Fused Grain Compositions

For historical reasons most of the fused grain produced initially contained approximately 60% MgO and 22% Cr₂O₃. Composition can however be varied to meet application requirements, with a dramatic effect on the microstructure, refer figure 15 and 16.
Figure 13 shows a 22% Cr₂O₃ fusion. Hexagonal crystallites of magnesia containing white recrystallized chromite are clearly visible with some white recrystallized spinel along the magnesia crystal boundaries. The same recrystallized spinel (1) is seen as larger well-formed crystals at the top. Silicates are present at triple points and on crystal boundaries.

![Figure 13 - Fused magnesia-chrome grain - 22% Cr₂O₃. Field width 700 µm](image)

Figure 14 demonstrates that although fused grain products are more resistant to attack by silica slag than magnesia/chromite blends the primary wear mechanism is still dissolution of magnesia.

The lower part of the plate shows a particularly large crystal of fused magnesia-chrome with the flat uniform surface indicating rapid slag refractory reaction with solution of magnesia in a silica rich slag. No silicate penetration or reaction was apparent within the grain, as opposed to that of the magnesia found in figures 11 and 12. Recrystallized chromite within the crystal, although resistant to the slag, is released into the slag layer (O) and coalesces following solution of the magnesia component of the fused grain.

![Figure 14 - Crystal of 22% Cr₂O₃ fused grain showing dissolution of magnesia component. Field width 700 µm.](image)
The following two figures show the effect of increasing chrome content on the microstructure of fused magnesia-chrome.

Figure 15 - Fused magnesia-chrome grain containing 30% Cr$_2$O$_3$, Field width 700 µm

In figure 15 the recrystallized spinels (2) are larger and better defined than in figure 14, but still surrounded by periclase crystals. Silicates can be identified along crystal boundaries.

In figure 16 at 37% Cr$_2$O$_3$ recrystallized spinel is the major phase, and periclase occurs as isolated pockets. Silicates are apparent.

This composition would be expected to exhibit very much improved resistance to attack by silica rich fayalite slag owing to the encapsulation of the magnesia.

Figure 16 – Fused magnesia chrome grain containing 37% Cr$_2$O$_3$, Field width 700 µm
7. Base metals Convertor Lining Material Development

For the base metals industry the literature on refractories generally concludes that (5):

- Chrome containing refractories are more resistant to attack by fayalitic slags than magnesia.
- Grains of chrome-spinel are more resistant than periclase.
- SiO$_2$ content in the brick must be as low as possible to avoid slag penetration and improve the degree of direct bonding.

Verref’s own developmental work with rotary slag testing as well as microscopy on used samples from both rotary slag testing and customer’s vessels have borne out the above statements. In addition, moving to increasing levels of fused magchrome/chromag grain and enriching the matrix of the refractory with a sub-micron material has further enhanced slag resistance by corrosion/erosion of the refractory.

As a background to the development of refractories for Base Metals the nature of the chrome used in Verref’s magchrome/chromag refractories needs to be considered. Verref’s chrome is sourced from Marico Chrome Corporation which is a 50:50 joint venture between Vereeniging Refractories (Verref) and Samancor Chrome SA.

Whilst part of the Bushveld Igneous Complex, the Marico Chromitites do show some significant differences to the chromites of the main Bushveld complex and it is some of these differences in the nature of the Chromite that give Marico Chrome its superior properties in respect of refractory production.

Typically the Marico chromites are:
1. Higher in Cr$_2$O$_3$ content
   - Up to 49% for the refractory grade product
2. Lower in SiO$_2$
   - Typically below 1 %
3. Higher Cr: Fe ratio
   - Typically 2:1 compared to 1.6:1 in LG1.
4. Lower magnetite content
   - This results in more refractory MgO.Cr$_2$O$_3$ in the spinel phases and associated higher melting points.

The combination of these characteristics makes the Marico chromites extremely suitable for refractory applications due to the low impurities (SiO$_2$ & Fe$_2$O$_3$) and high relative content of chromium compared to iron which reduces the potential for iron oxide bursting and volume expansion at high temperatures and results in higher refactoriness (higher melting point).

However, one of the disadvantages is the sizing of the refractory chrome which is usually less than 2mm. As refractory brick mixes are generally formulated from various raw materials with the following fractions; 3-5mm, 3-1mm, 0-1mm and ballmill fines, this limits chrome use to the intermediate and fine fractions of a refractory brick mix and the benefits of chrome are therefore, unavailable throughout the entire refractory brick.
Product Improvement Cycle

Typical properties of the five generations of materials developed and introduced, together with one additional products still in development are given in Table 1.

7.1 Product C1 – Chrome-magnesia
(In situ bonded)
These were the first brick introduced based on in situ bonding of magnesia and raw chromite with reaction taking place during kiln firing. Although still produced today redox reactions of unstabilized iron oxide from the chromite may give unpredictable expansions during manufacture and at times in service. Residual magnesia grains are susceptible to silicate slag attack.

Verref produced an in situ bonded chrome-magnesia equivalent to the industry standard from the early 1960’s.

7.2 Product C2 – Chrome-magnesia
(Co Burnt. Lower SiO₂)
Verref developed their own co-burnt raw material for the production of chrome-magnesia brick. These brick were introduced from 1970 and had the further benefit of lower SiO₂ content. In product C1 and C2 the chrome could only be included in the finer fraction of the brick composition.

The introduction of a co-burnt sinter went some way to solving the chrome sizing problem in which raw magnesite and raw chrome were burnt together in a rotary kiln, the chrome sintering to the outside of the magnesite grain, stabilising the chrome and the sinter then screened into fractions and used in brickmaking. The benefits of this route on physical characteristics over the in situ firing of magnesia and chrome (C1), are given in Table 1, Product C2.

7.3 Product CF1
(Chrome-magnesia - 40% fused grain)
Verref produced fused chrome-magnesia grain raw materials from 1967. Verref was already producing a 100% reconstituted (rebonded) fused grain magchrome brick with approximately 60% MgO and 20% Cr₂O₃ for smelter applications. A refractory brick based on 100% fused grain is expensive and is mainly reserved for special applications where the expected life outweighs the cost. The aim at this stage of development was to add the chrome containing fused grain into the coarser aggregate where it would be most beneficial, the less expensive raw chrome could still be used in the intermediate and fine fractions.

As the advantages of using fused grain were known and the positive effects of higher chrome in the refractory, on resistance to fayalitic slags, were becoming apparent from our microscopy investigations, development was undertaken on high chrome containing fused grain, approximately 38% Cr₂O₃, which could be incorporated into chromag brick. This also gave the opportunity to increase the chrome content of all the fractions in the brick composition.

Product CF1 in Table 1 outlines the properties of this product. Porosity and density have changed and are similar to C1, but slag resistance has improved owing to the use of fused grain.
Owing to the high chrome content and the accompanying higher iron and therefore, lower magnesia, the product was not fully stabilised, and a further refiring process was required on the fused grain, prior to brickmaking, to remove volume expansion when the refractory bricks were tunnel kiln fired. With ever increasing energy and maintenance costs this process became untenable.

7.4 Product CF2
(Chrome-magnesia - 50% fused grain, Lower SiO₂)
Further development was required to replace the high chrome fused grain in all products using it, with a similar fused grain which would not require a post firing process after fusion. The level of chrome in the fused grain had to be reduced by around 5.0% to achieve this. To incorporate the required quantity of chrome within the coarser aggregate the level of fused grain was increased in the various brick mix formulations.

Product CF2 in Table 1 lists the improved physical properties. Additionally, at this stage in development the level of silica was reduced to improve refractoriness. Rotary slag testing performed in 2006 against a fayalitic slag type indicated an improvement of wear for a brick based on this composition. Mean wear % from 16.8% to 8.6%.

7.5 Product CF3
(Chrome-magnesia - 80% fused grain, Enhanced matrix type 1)
Microscopy has continued to highlight the matrix of the refractory as the weak point in resisting slag attack and matte infiltration and development work has continued along the route of enhancing the matrix to extend refractory performance by the use of a sub-micron material. The Cr₂O₃ content was also raised in order to increase the proportion of the more refractory spinels in the matrix.

Product CF3, Table 1 shows the effect of this additive with the laboratory rotary slag testing indicated a slag resistance factor increase of 1.2.

7.6 Product CF4
(Chrome-magnesia, Enhanced matrix type 2)
CF4 is in the early stage of development and destructive service factors in addition to slag attack are to be included in the development and evaluation programme. This stage CF4, Table 1 aims to continue this work by evaluating other sub-micron materials in conjunction with decreasing the pore size diameter, reducing permeability and improving resistance to slag erosion and corrosion as well as matte and metal penetration.
Table 1 – Product features, physical and chemical properties and performance ratios

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8. Conclusion

In this paper a 50 year period over which the introduction of an initial product, equivalent to the then Chrome-magnesia quality, followed by four improvements has been examined.

Key factors in minimizing the acceptance period for a new product and showing early volume growth are a track record in the industry and a simulative laboratory test method that is a good indicator of service performance.
Products could not be developed without the close collaboration with customers. The process is a continuous improvement cycle, its effectiveness and benefits only realised through continuous and constructive partnerships between Verref and its customers. A typical example of this is the collaborative process with a leading Platinum producer. This process included exchange on:

- Mineralogical examination
- Raw materials into products
- Visual aspects
- Sizing aspect
- Grading
- Product development aimed at improvement in refractoriness and permeability

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References

Niell John McEwan, Group Technical and Business Development Manager, Vereeniging Refractories

Niell started his working career at Samancor in the Chrome division in 1993 and fulfilled the positions of Metallurgist, Production Engineer and Production Superintendent at Middelburg Ferrochrome and Ferrometals. Achievements included commissioning and operating the first charge chrome furnace with Outokumpu pelletising and preheating technology in South Africa. In 2002 Niell joined Vereeniging Refractories and fulfilled the positions of Operations Manager, Technical Manager, Business Development and Project Manager.