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Refractories Applications and News

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Technology Bimonthly for the Global Refractories Industries

From the Editor . . .

Jeffrey D. Smith, Editor, *jsmith@mst.edu*

Jeffrey D. Smith

My editorial for this issue is very brief, not because I don't have a great deal to say (anyone who knows me knows that is very rarely the case) but because I want to stress the importance of the editorial topic.

As the refractory industry goes, so goes advertising support for *RAN*. I thought very seriously about starting and ending my editorial with that sentence and not including anything in between, but I feel like I ought not be quite so cryptic.

The tough times have hit the industry hard and everyone is doing what they can to survive. Many see better times within a year but others expect a longer downturn. Of course, cost cutting is just part of the process that companies must go through and who could blame anyone for reducing or eliminating their support for *RAN*. The real question that comes to mind is "Is a journal like *RAN* critical to the health of the refractory industry in the US?" I have always used advertising support as my gauge on that question; but then do the recent drops in advertising revenue reflect a reduced perception in the value of *RAN* or is it just that times are tough and tough decisions have to be made?

A great deal of time goes into an endeavor such as this and I wonder if we at *RAN* are providing an appropriate, valuable product to the industry. I guess I will leave it up to the industry leaders to make that call.

CONTENTS

Refractories Applications *and News*

Refractories Applications *Transactions*

ADVERTISING INDEX

Refractories Applications
and News

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Technology Bimonthly for the Global Refractories Industries

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REFRACTORIES RELATED MEETINGS

2009

August 29-September 2, **The 30th International Thermal Conductivity Conference and the 18th International Thermal Expansion Symposium,** Seven Springs Mountain Resort near Pittsburgh, PA. The conference will be hosted by Anter Corporation (Pittsburgh, PA, USA) and the University of Lisbon (Portugal), www.thermalconductivity.org.

September 23-24, **52nd International Colloquium on Refractories 2009**, Aachen, Eurogress, Germany, Forschungsgemeinschaft Feuerfest e.V. – Feuerfest-Kolloquium – An der Elisabethkirche 27, 53113 Bonn, Germany, Tel:+49-(0)228-91508-45, Fax:+49-(0)228-91508-55, E-Mail: info@feuerfest-kolloquium.de, www.feuerfest-kolloquium.de.

October 13-16, **UNITECR 2009 - 11th Biennial Worldwide Conference on Refractories**, Pestana Bahia Hotel, Salvador, Brazil, www.unitecr2009.org/.

October 25-30, **Materials Science & Technology 2009 Conference and Exhibition - MS&T '09** combined with the **ACerS 111th Annual Meeting**, David L. Lawrence Convention Center, Pittsburgh, PA.

2010

January 24-29, **34th International Conference and Exposition on Advanced Ceramics and Composites**, Hilton Daytona Beach Resort and Ocean Center, Daytona Beach, FL.

Feb. 21-24, **Materials Innovation in an Emerging Hydrogen Economy,** 2010 Hilton Cocoa Beach Oceanfront - Cocoa Beach, FL.

May 3-6, **AISTech 2010 The Iron & Steel Technology Conference and Exposition,** David L Lawrence Convention Center, Pittsburgh, PA., USA

October 17-21, **Materials Science & Technology 2010 Conference and Exhibition - MS&T '10 combined with the ACerS 112th Annual Meeting,** George R. Brown Convention Center, Houston, TX.

Nov. 14-18, **3rd International Congress on Ceramics**, Osaka International Convention Center, Osaka, Japan.

Send meeting announcements to Mary Lee at: leemj@mst.edu
Announcements must be received a minimum of four months prior to the meeting date.

Rob Crolius

TRI SPRING MEMBERSHIP MEETING

An energized group of TRI members met in Ponte Vedra Beach, FL, April 29 – May 1, 2009, to discuss the difficult issues facing the refractories industry.

Attendees heard a number of presentations from TRI officers and staff on the state of the Institute and its priorities, as well as from a number of guest speakers. Dina Daniele from The Graham Company provided an informative overview of how to manage the cost of risk in a company through a close, hands-on relationship with insurance providers. The discussion was particularly invaluable in a time when companies must find every possible savings while weathering the economic downturn.

Two speakers discussed the state of the economy. David Huether, chief economist of the National Association of Manufacturers, provided a detailed analysis of how the economic downturn has impacted the manufacturing sector. John Nolan, vice president and general manager of the Structural and Rail Division of Steel Dynamics then discussed the dismal state of the steel industry, particularly as it has been impacted by China.

Both Huether and Nolan expect modest improvements in the economy beginning in 2010, but suggest that the recovery will be slow and may not reach its full potential until 2012 or beyond.

Participants also saw a rough cut of the TRI video under development, "Taming the Flame: The Story of Refractories."

Another positive highlight of the Spring Meeting was the awarding of the 2009 William T. Tredennick Award to Dr. Charles Semler, long time industry consultant and mainstay of the refractories community.

TRI SAFETY AWARDS

Three TRI member companies were recipients of TRI Chairman's Awards at the TRI Spring Meeting for reporting the best overall company-wide safety records for 2008. A perennial winner, The Nock and Son Company, won in the small company category, Allied Mineral Products took the honors for the mid-size company category, and Unifrax Corporation came in first in the large company category.

TRI President's Awards were also announced for TRI member company production facilities that operated in 2008 without a lost work time accident. They are:

- Allied Mineral Products, Brownsville, TX.
- ANH Refractories, Fairfield, AL; Fulton, MO, Mexico, MO; Middletown, PA; Minerva, OH; Pryor, OK; West Mifflin, PA; Windham, OH.
- Christy Refractories Company, Christy Refractories, Christy Industrial Services, Christy Catalytics, St. Louis, MO.
- LWB Refractories, Engineered Ceramics, Greenville, PA.
- Minteq International, Baton Rouge, LA; Bryan, OH; Old Bridge, NJ.
- Missouri Refractories Company, Pevely, MO.
- The Nock And Son Company, Oak Hill, OH.
- Resco Products, New Cumberland, WV; Oak Hill, OH.
- Riverside Refractories Canada, Nanticoke, Ontario.
- Thermal Ceramics, Burlington, Ontario; Canon City, CO; Elkhart, IN; Girard, IL; Morgan Insulation, Erwin, TN.
- Unifrax Corporation, Sanborn, NY; New Carlisle, IN.
- Whetstone Technology, Cabot, PA.

POWER, PIERCE ASSUME LEADERSHIP ROLES FOR TRI ASSOCIATE COMMITTEE

Leslie Power, Almatis, was elected chairperson of the TRI Associates Committee at the recent membership meeting. She replaces Nancy Bunt of Kerneos who completed a successful two-year term. Mike Pierce, C-E Minerals, was elected vice chairman to fill the vacancy created by Ms. Power moving up. The associate chair and vice chair also serve on the TRI Board of Directors during their terms of office on the committee.

TURNER, KANIUK RETIREMENTS

John L. Turner has retired from Allied Mineral Products after more than thirty-eight years of service. A past TRI chairman and President of UNITECR 2005 in Orlando, Turner has been a fixture in the refractories community and will be missed. John will consult with Allied through October to complete projects and facilitate the transition of top management responsibilities.

John Kaniuk has retired from Zircoa. John will continue in his role with BJR Sensors and as the current president of The American Ceramic Society, bringing a supportive industry perspective to an important organization.

NEW SAFETY AND ENVIRONMENTAL MANAGER FOR RESCO PRODUCTS

Clem Cicconi is Resco Products new Safety and Environmental Manager. Mr. Cicconi previously worked at United Refractories as the Operations Manager and prior to United Refractories was at the Timken Company. He has an extensive background in safety, having previously worked as the Safety Coordinator for the Timken Company at the Canton, Ohio location. Mr. Cicconi is a graduate of Youngstown State University with a B. S. Degree in Business Administration.

REGULATORY

IARC Drafts Silica Monograph Revision

The International Agency for Research on Cancer (IARC) at its meeting in France in March, approved a draft change to its monograph on the carcinogenicity of crystalline silica. In unwelcome news, the new language, when published, eliminates the current caveat that "inhaled" crystalline silica "from occupational sources" is a known human carcinogen. By eliminating the words inhaled and from occupational sources, IARC has significantly broadened the definition of potential exposures. The proposed revision also contains the sentence, "Quartz and cristobalite dust cause cancer of the lung."

Continued on Page 25

DESIGN AND FAILURE OF MONOLITHIC REFRACTORY STRUCTURES – PART 2*

Greg Palmer and K. C. Tan, Palmer Technologies Pty Ltd, Australia, *greg.palmer@palmertechgroup.com*

INTRODUCTION

Part 1 of this paper highlighted the errors with existing refractory design methodology and a general methodology for the design of monolithic refractory structures was presented. In particular it has been shown that traditional concepts or guidelines are erroneous, not based on engineering science and can leave open the risk for catastrophic failure.

The fact that there are no prescriptive procedures, e.g. engineering standards, to follow means that detailed engineering analysis is required to support a refractory lining design as this is normal engineering practice when there are no Standards to follow. Also in our opinion the practice of simply following what may have been done in the past, while important, cannot be considered an engineering analysis. While refractory lining design has posed significant engineering challenges the understanding of failure mechanisms and the availability of advanced engineering software means refractory structure design can be supported by engineering analysis. Until Standards can be developed it will be necessary to undertake more detailed engineering analysis to support the design. The benefit in the medium to longer term is that this will lead to improvements in refractory lining life and the development of standards.

Previous research [1] has shown that failure of refractory linings due to creep rupture of the steel anchor at or near the interface zone[1] is the major failure mechanism. This is because gravity and thermal loads induce low stress (<10 MPa) at high temperatures. However, the thermal strain loads on steel anchors only occur during heat up and at low strain rates ($\dot{\varepsilon}$) typically about 10^{-7} s^{-1}. At this strain rate the yield stress of the anchor steel is low and depending on the grade of steel alloy used will be <50 MPa and permanent plastic deformation of the anchor can occur. If residual yield stress remained after deformation then creep rupture failure could be expected to occur in less than 100 hours at 1000°C. However, this obviously does not occur in practice, as refractory linings would catastrophically fail during heat up. The reason is that the thermal load (from thermal expansion) is not continually applied to the anchor. Once the refractory stops expanding the strain has reached its maximum thermal strain value and the stress in the anchor will have reached its maximum stress state which may or may not be plastic yield. From this point forward the anchor stress will start to decrease due to a stress relaxation mechanism, essentially due to creep at temperature. This is not comparable to constant load, or stress creep rupture strength tests, which are used to measure the creep strength of anchor materials.

[1]The interface zone is that area between the hot-face and insulation layers.

Design and Failure of Monolithic Refractory Structures – Part 1 of this article appreared in the previous issue of this journal (Refractories Applications &News),* ***14* *[3] 19-26 (2009).*

The current approach to anchor design and spacing, which have been developed from experience and applied "rules of thumb" are considered inadequate and fundamentally incorrect. This paper discusses the analysis of failed refractory structures and the numerical analysis used to predict anchor stress. Our research has shown that numerical analysis techniques can be used to predict and design refractory structures. The numerical analysis when compared to real structures shows that the results are in-line with observed failure modes. It is also clear that non-linear numerical analysis is required when designing refractory structures.

This paper shows how numerical analysis should be used in the design of refractory structures.

CREEP RATES AND STRESS RELIEF ON STEEL ANCHORS

Field observations have found that on some occasions steel anchors can be displaced by large amounts, i.e. 10-20 mm, without failure. While it is obvious that these deformations are due to plastic yielding it also means that if the stresses were continually maintained then the anchor would fail by creep rupture in very short time frames. Thus, it is safe to conclude that relaxation of axial or bending stresses due to thermal strains must occur in steel refractory anchors during high temperature operation.

It is also important to be aware that once the refractory stops expanding the maximum strain has been reached and there will also be a maximum stress regardless of the value of strain. In a refractory system this means the maximum stress value due to thermal expansion will start to decrease due to creep at temperature, until reaching an equilibrium residual stress (dependent on temperature and creep rate).

This creep is a relaxation process, often labeled stress relief, and the majority of stress reduction occurs very quickly typically less than 30 minutes at temperatures >550°C (See **Figure 1**). Unlike creep rupture strength tests are carried out at constant loads. This means once a refractory system is at steady state the anchor stress will not be maintained and start to decrease due to creep.

It should be noted that depending on the temperature of operation the anchor is exposed to; residual stresses may not be fully removed. However, at the lower temperatures where this occurs the creep rate is reduced anyway. The amount of strain consumed by stress relief is also limited at essentially that of the elastic strain limit at the temperature of operation (e.g. up to 0.2% or 1.0% plastic strain). As anchor materials are ductile at the expected temperatures of operation, this strain is readily accommodated by further (limited) deformation of the anchor until either an equilibrium creep rate is reached, or the residual stress is essentially zero (i.e. the elastic residual stress has fully converted to creep deformation).

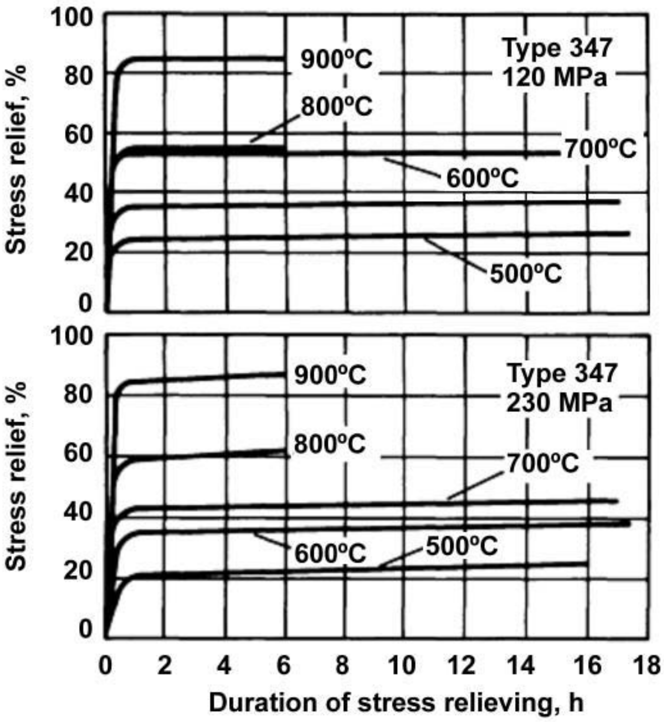

Figure 1. Typical stress relief curves for an austenitic stainless steel. Note majority of stress relief occurs during initial exposure. From ASM Handbook Vol. 4 - Heat Treating [2].

This conversion of residual stresses to small permanent deformations would have little effect on the service life of the anchor, unless the anchor was exposed to numerous thermal cycles, i.e. thermo-mechanical fatigue (TMF). Then the affect of accumulated creep strain from relaxed thermal loads can reduce the creep life of an anchor under constant loading. Depending on the temperature, type of alloy, cyclic strain range, and microstructure, the interaction between constant load creep and TMF can result in a linear or highly non-linear reduction in service life, as shown in **Figure 2**. The combination of any cyclic accumulation of damage and time dependent damage (e.g. creep or corrosion) should be addressed by detailed engineering analysis to avoid either unexpected reductions in service life, or improper operation causing a reduced service life.

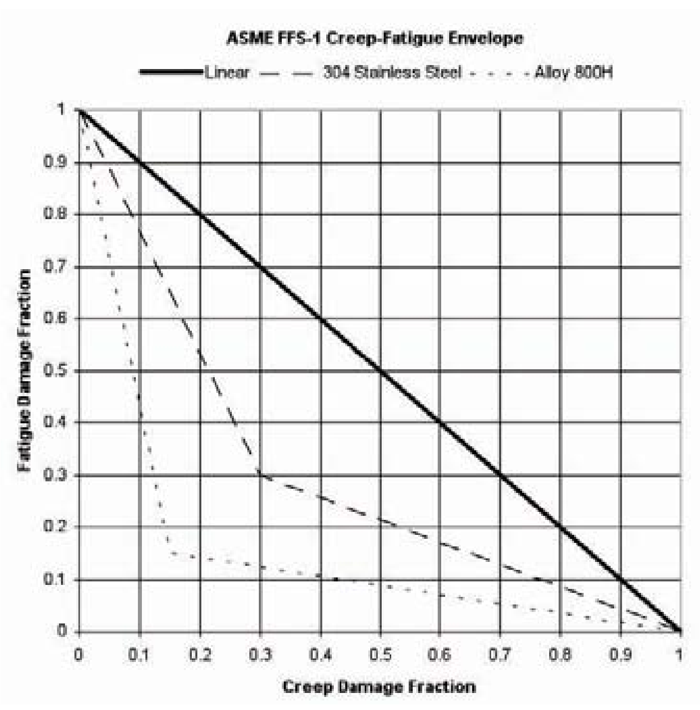

Figure 2. Creep-fatigue interaction design envelope, after ASME/API FFS-1 [3].

ROOF LINING FAILURE

The failure of a refractory lined roof was investigated after the center section of the hot-face collapsed as shown in **Figure 3**.

After inspection it was found that:

- The center disc hot face layer was completely missing but the majority of the anchors (Alloy DS) were intact.
- The remaining hot face panels (closest to the center of the roof) had all moved away (dropped) from the insulation layer by approximately 50 to 110 mm.
- Approximately 40% of the anchors were damaged at various locations along the vee.
- Some of the anchors had signs of creep rupture, though had not yet failed.

Of the 43 anchors in the center disc area four (4) had failed completely at the interface and another twelve (12) had one part of the anchor missing or 37% of the anchors in the center zone were severely damaged.

Two anchors were taken for metallurgical analysis and detailed as follows:

- Anchor center zone
  - (a) Service life approximately 14,000 hours
  - (b) Small cracks visible near base of vee
- Anchor outer zone
  - (a) Service life approximately 7,000 hours
  - (b) Small cracks visible near base of vee

One of the "as-received" refractory anchors is shown in **Figure 4**. Inspection of anchors from the center of the roof revealed a large number of obvious cracks in both arms of the anchor above the vee, as seen in **Figure 4**. These were located on one side of each of the bars, but on opposite sides, indicative of bending stresses either spreading the arms of the anchor or twisting the arms of the anchor. The anchor from the outer zone was noted to have a (barely visible to the naked eye) crack above the vee. The surface of both anchors had

Figure 3. General view of damaged roof showing missing center panel.

Figure 4. Center anchor as received.

a scaly, corroded appearance, with white deposits, presumably from the refractory material.

The examination of the anchors from the center and outer zone indicates that oxidation occurred. The arms of the center anchor were cracked because of a stress being applied to each arm, which resulted in creep cracking. The outer anchor having been in service for approximately 7,000 hours did not have as extensive cracking and the small cracks observed were adjudged oxide driven rather than creep driven. Some voiding, possibly creep, was observed in the outer sample away from the surface. The location of the voids would suggest a tensile load would have to have been applied to the anchor for those voids to be creep voids.

It was concluded that the cause of the cracking in the center zone was creep and the creep cracking was exacerbated by metallurgical deterioration leading to intergranular oxide attack initiating cracking, due to the presence of coarse, chromium rich, second phase precipitate.

ANALYSIS OF REFRACTORY CONCRETE STRUCTURES

The most prudent design method for refractory structures is by using numerical analysis techniques with non-linear functionality. ATENA [6], Advanced Tool for Engineering Non-linear Analysis, has been developed to analyze reinforced concrete structures [7]. ATENA allows the user to use both linear and non-linear solutions. The linear case can be characterized by a linear constitutive equation, a linear geometric equation and both loading and boundary conditions are conserved. In many cases it is possible to use linear equations but the user needs to realize that linear solutions are only permissible in the case of small strains. In the non-linear case where the solution is not closed an iterative approach is required. The analysis is characterized by non-linear material behavior; deformations are such that equilibrium equations must use the deformed structure shape and where both non-linear material and geometric equations are used.

Refractory structures are highly non-linear due to the anchoring system and the material characteristics with temperature, though at low temperatures it is possible to assume, under some conditions, those material temperature properties are relatively constant after first firing. ATENA is well suited for refractory structures because it incorporates non-linear functionality and temperature dependent material properties. This means complex non-linear analysis can be undertaken relatively quickly. Refractory anchors (or steel reinforcement in civil concrete) are modeled as truss elements and bond slip between the anchor and concrete can be included, which has been shown to be critical when analyzing anchor stresses. Thus the use of truss elements is particularly useful in 2D analysis where an approximation to anchor stresses can be obtained in a relatively short period of time compared to 3D analysis. The software also includes solutions for non-linear material property. This is because during load increments the forces can be out of balance, i.e. the total load after applying the loading increment less the internal forces at the end of the previous increment. In the case of linear analysis the stiffness matrix deformation dependence is neglected. The use of this analysis technique coupled with field observations has allowed good validation of the numerical models.

ANCHOR BONDING

When undertaking numerical modelling the concept of perfect bonding between materials must be considered as this rarely simulates reality. This is particularly true for steel anchors in refractory concrete. In civil engineering, it is well known that bond slip occurs with reinforcement steel [British Standard BS 8110 Part 1 (1997) Clause 3.12.8.3 "Design Anchorage Bond Stress"]. Cervenka [5] has shown that bond slip in steel reinforced structures is an important modelling criterion. Our analysis of refractory anchor under thermal load shows it is equally important that anchors stresses will be unrealistically high, >1000 MPa, if bond slip is not applied.

Analysis shows that anchors, when confined in concrete under thermal load, are placed in compression, which is logical. However, poor densification of the concrete around the anchors can result in increased bond slip and the potential for localized bending stresses thus the installation of refractory concrete quality is very important.

The bond between refractory anchors and the surrounding concrete is very important for the mechanical system. Too much slip can result in excessive movement of the refractory lining and too little slip can result is creep rupture failure. Most computer codes assume perfect bonding and it has been found that this argument is in contradiction to experimental observation [5]. The numerical software ATENA [6] allows engineers to use bond slip in the analysis or design process and our research has shown that when undertaking numerical analysis of refractory structures that bond slip must be taken into consideration.

While there is no, as yet, direct evidence that the current wavy shape anchor, see **Figure 8**, impedes bond slip it does raise concerns about the degree of bond slip that can occur between the refractory concrete and the anchor particularly for materials of very high refractoriness. However, this needs to be balanced against refractory shrinkage dilation in the green state. It is known that refractory monolith when green behaves in a plastic manner under load at temperatures lower than that associated with creep. The fact that the anchors shown in **Figure 4** and **Figure 5** had the vee angle reduced indicates that there has been considerable slip between the anchor and the refractory concrete and this is not typical as the analysis presented below shows that the anchor when encased in the concrete will be placed in compression at temperature.

Figure 5. Center anchor cracks near base.

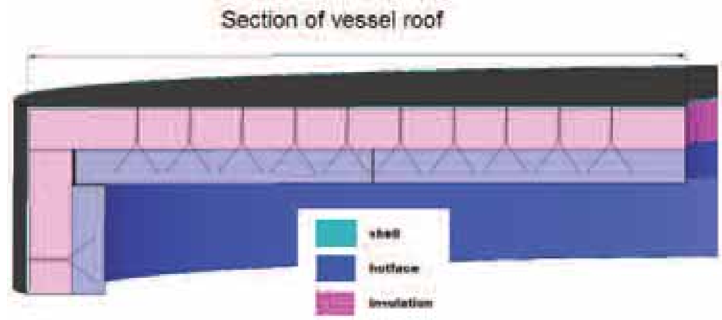

Figure 7. ATENA model of typical roof section showing the refractory layers and anchors layout.

Figure 8. A typical wavy vee anchor.

NUMERICAL ANALYSIS

Figure 6 shows a typical vessel roof composed of a steel shell, insulation layer and the "hot face" and **Figure 7** shows a typical section with the anchor layout. Refractory anchors are typical "wavy vee", see **Figure 8**, shaped and the length and diameter vary according to lining thickness.

In ATENA, the anchors are modelled as two wire rods 8 mm in diameter. The joint between each layer is modelled as an interface, which considers cohesion, tension and friction. Gravity and thermal forces can be applied to each material along with refractory concrete plastic behavior, crack softening and shrinkage.

Figure 9 shows the results for a 1 m length of refractory roof. The material characteristic for the concrete can be automatically determined by using the input compressive strength of f'_{cu} = 70 MPa for the hot-face concrete and adjustment for density, thermal expansion, elastic modulus and fracture energy can be made by the user. In this case, the hot-face density is 2200 kg/m^3. The shell is 10 mm thick, the insulation is 100 mm thick and the hot-face is 130 mm thick. The refractory anchor is a standard Y anchor diameter of 8 mm with 200 mm spacing. Gravity load only is applied in this model. The insulation/hot-face and the insulation/shell are able to debond at the interfaces which is sometimes observed in the field though the degree of adhesion to the shell varies depending on the grade of insulation concrete used.

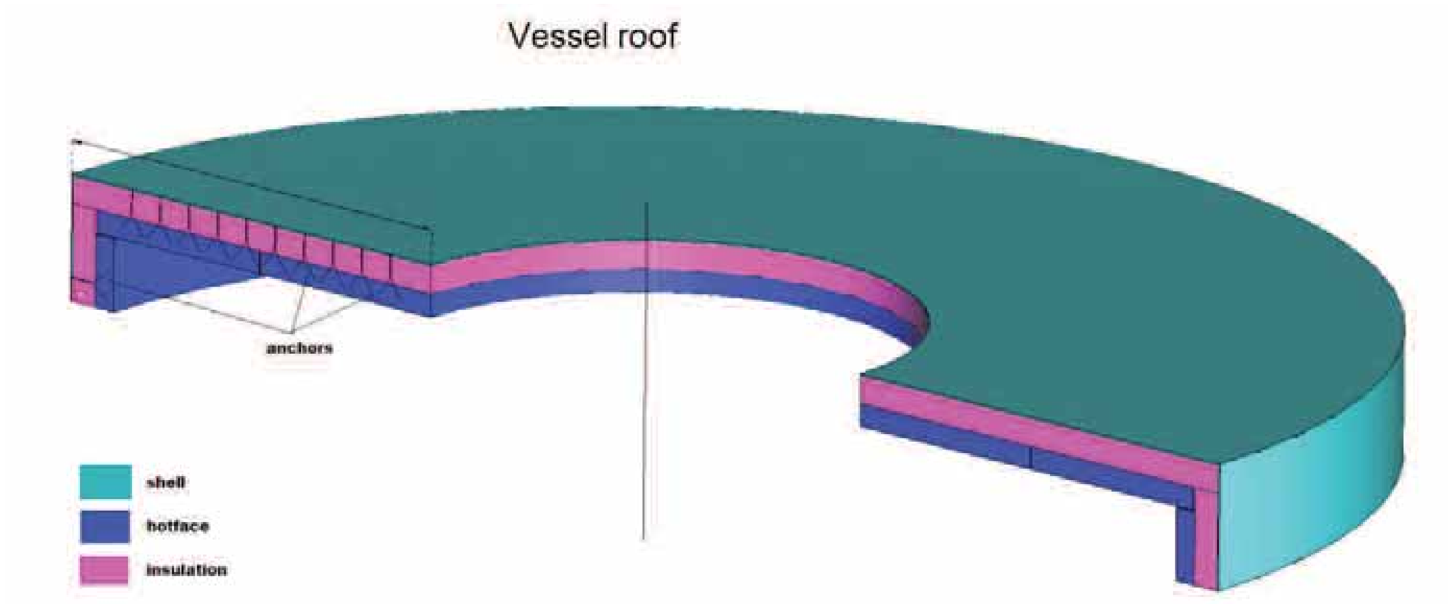

Figure 6. Graphical image of half a vessel roof showing different refractory layers and general anchor arrangement.

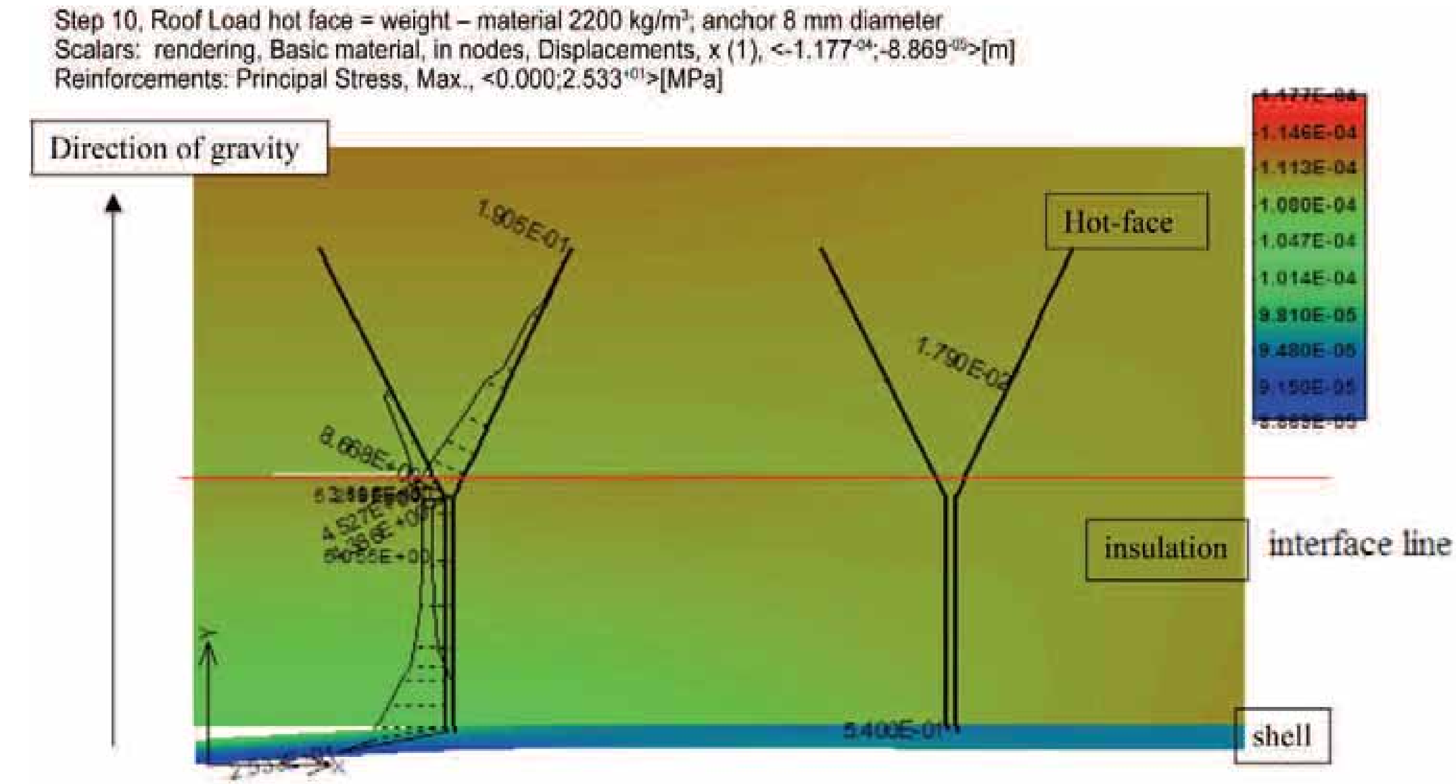

Figure 9. Close-up of ATENA model for a typical 1 m section of the refractory lining, density 2200 kg/m³ with anchor diameter of 8 mm, showing displacements and anchor stresses due to gravity load (upside down).

The analysis predicts, using a refined mesh at the interface, an anchor stress on the outer two anchors of approximately 8.8 MPa due to gravity only load. This level of stress is because the insulation and hotface are not bonded to each other or the shell enabling the material weight to deform the shell and thus stress the anchor.

The same analysis was carried out for the case when a higher grade of refractory concrete is used, which is very frequently the case.

Figure 10 shows the same section of refractory roof but with the hot-face material density of 3000 kg/m³ and the concrete compressive strength, f'_{cu} equals 100 MPa. The anchor diameter and spacing remain the same, i.e. 8 mm diameter and 200 mm. Again, there is no thermal load applied. In this case, the anchor stress on the same anchor stem has increased to approximately 10.7 MPa for gravity only load. The same anchor stress increases for the same reason as described above. The same anchor stress increases due to the same reasons as previously described.

At ambient temperature, these axial stresses would be of little concern. However, given that the total stress on an anchor is the sum of gravity and thermal stress,

$$\sigma_{total} = \sigma_{gravity} + \sigma_{thermal}$$

then unless the thermal load changes the stress distribution then an Inconel 601 anchor with a stress of 10.7 MPa will fail under creep rupture in approximately 1700 hours and an Alloy DS anchor will fail under creep rupture in approximately 1000 hours at a temperature of approximately 980°C.

Further analysis shows it may be possible to reduce the stress on the anchors by increasing the anchor diameter but analysis shows that for a dense material of 3000 kg/m³ the anchor diameter would have to be increased to more than 20 mm. This is impractical from an application and economic perspective. The stress could also be reduced by increasing the number of anchors per m² but it is not possible to reduce the spacing much less the 200 mm center to center without significantly increasing the risk of voids and laminations in the concrete during installation. Also it will not reduce the bending stress on the outer lying anchors.

A gravity and thermal load case similar to the dimensions used above was carried out. The shell thickness has been reduced to 6 mm, the insulation layer is 110 mm and the hot-face is 130 mm thick. An interface is included between the hotface and insulation and between the shell and insulation layers, which debonds due to the thermal load. The anchor diameter is 10 mm with bond slip applied. The thermal load applied is 154°C at the shell and 1093°C at the hot-face. **Figure 11** shows the results for the gravity and thermal load case for a 2D axi-symmetric 1.0 m long roof section allowed to freely expand.

The analysis shows the anchor stress profile for the applied gravity and thermal loads. When temperature and gravity load are considered the anchor stress at the left hand side is approximately 8.8 MPa at the interface. An Inconel 601 anchor at 980°C with an axial stress of this magnitude will fail due to creep rupture in <4400 hours. The fact that one anchor arm is preferentially stressed is often encountered in the field.

Figure 12 is of failed anchors on a vertical wall and shows a number of anchors with one anchor arm broken. The anchors were fabricated from Alloy DS and they had failed in less than 10,000 hours. This failure pattern is in line with that predicted by the numerical modelling.

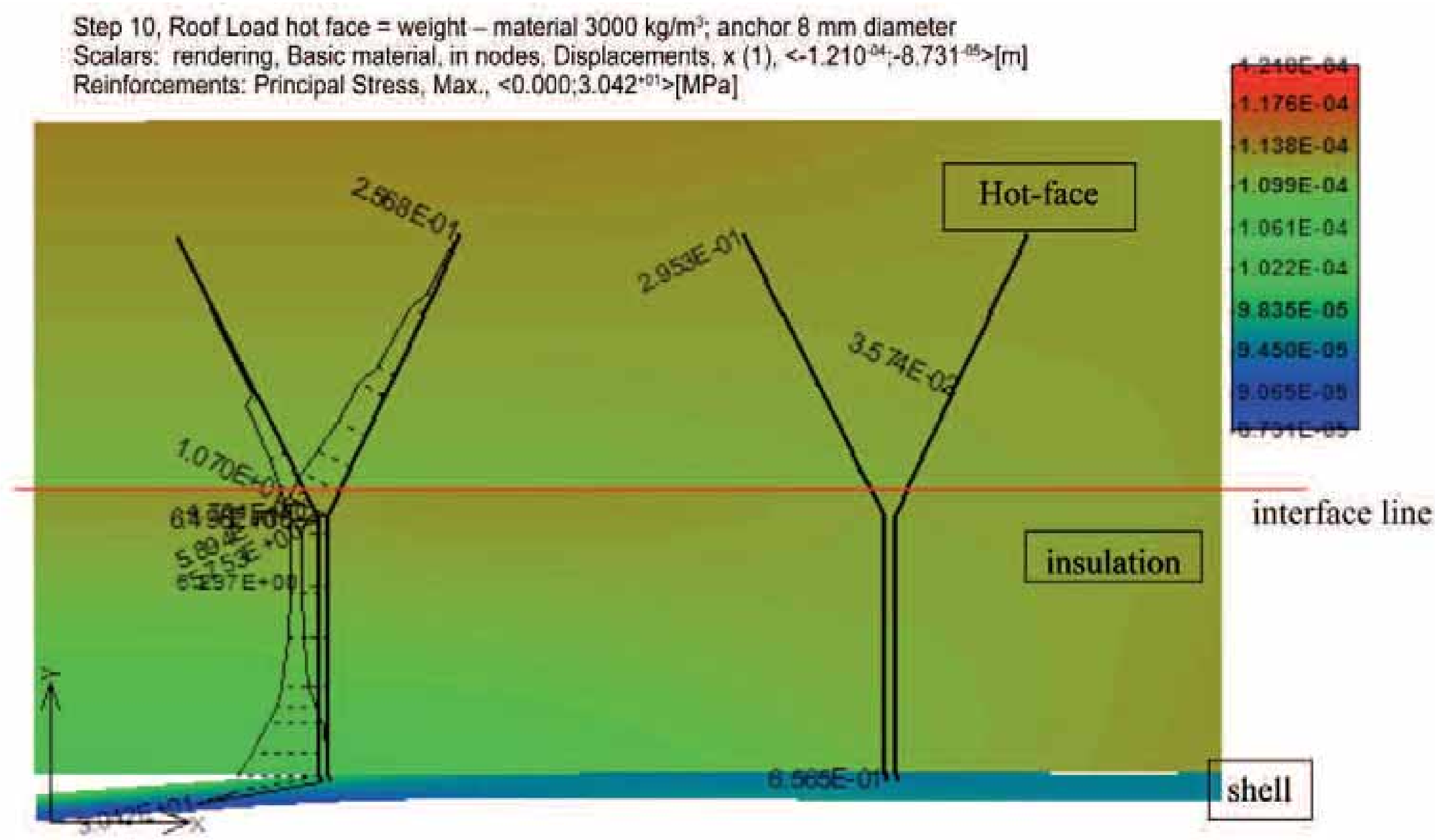

Figure 10. Close-up ATENA model of typical 1 m section of the refractory lining showing displacements and anchor stresses due to gravity load. Material density 3000 kg/m³ and anchor diameter 8 mm.

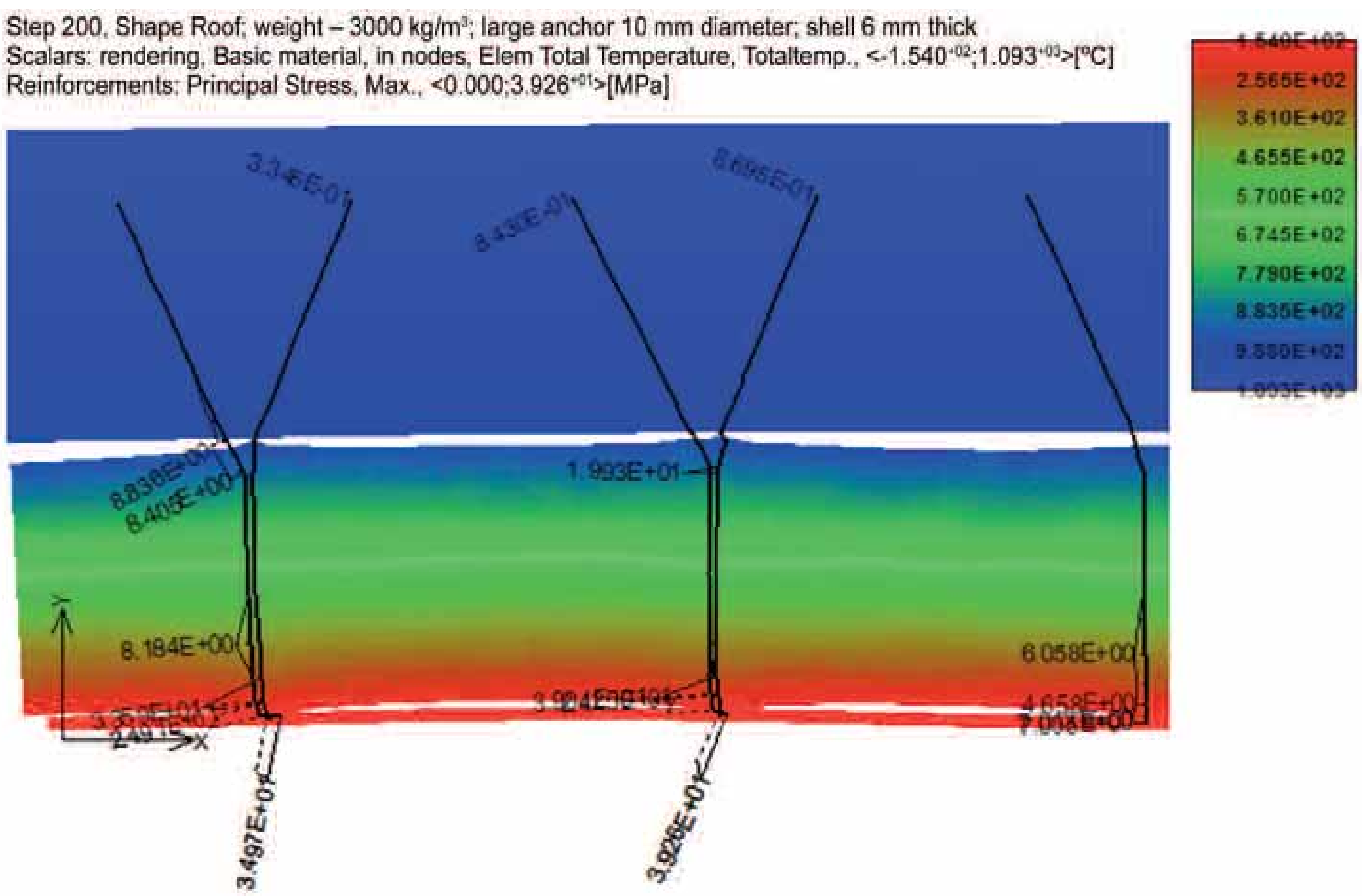

Figure 11. 2D axi-symmetric model of typical 1 m section of the refractory lining showing temperature and anchor stresses due to gravity and temperature. Material density 3000 kg/m³ and anchor diameter 10 mm.

Figure 12. View of failed anchors (10 mm diameter) showing one stem of the vee missing.

Clearly the 2D model does not allow for variations in the anchor orientation as most anchor patterns position the anchor at 90° to each other. To account for this a 3D model was carried out.

The 3D analysis model is shown in **Figure 13**. The model has hexahedra mesh elements and the anchors are orientated 90° to each other and spaced at 200 mm center to center. The hot-face is 130 mm thick and the insulation is 100 mm thick. The anchors are 10 mm diameter and the section is 1 m x 1 m in length. Bond slip has been applied to the anchors in accordance with CEB-FIP model code, 1990. The anchor was modelled as a cold drawn wire in confined concrete with a poor bond quality. The thermal boundary conditions were 95°C at the shell and 980°C at the hot-face. The shell has springs on each side and the insulation and hot-face are allowed to freely expand. There is a contact interface between the insulation and hot-face layers but not at the shell insulation interface nor between the shell and insulation. **Figure 14** shows the temperature profile of the anchors and of the interface plane.

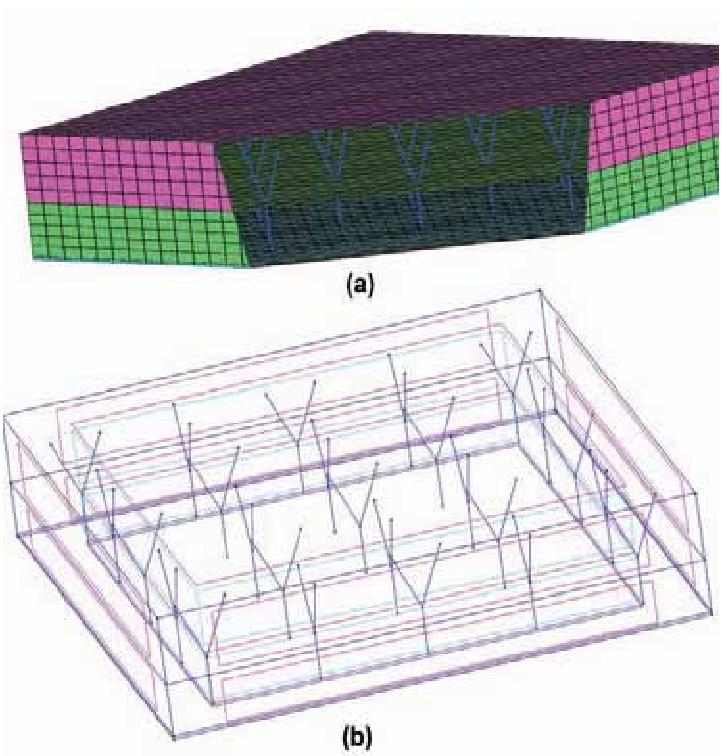

Figure 13 a and **b.** - 3D roof model showing mesh and anchor orientation. Model has free expansion of hot-face and insulation layers, shell with spring restraint.

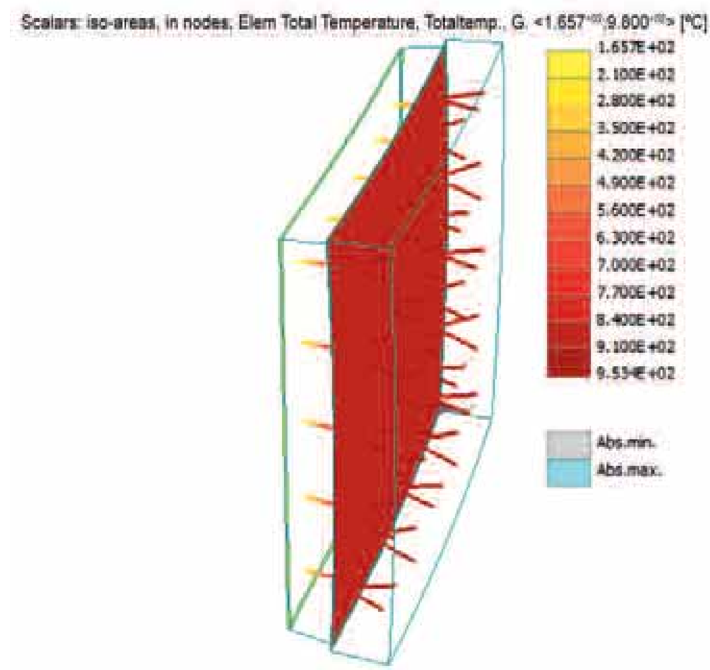

Figure 14. 3D model 1 m x 1 m showing deformed shape and temperature profile.

The maximum anchor stresses are shown in **Figure 15**.

The analysis shows the tensile stress along the perimeter anchors, in particular those with the vee at right angles, of the panel edge, varies from 30 to 160 MPa at the interface zone. Thus, some sections of the anchor will be at the plastic yield stress which means some small sections of the anchor will permanently deform. The refractory anchor encased in hot-face is in axial compression of approximately 160 MPa which is due to the thermal expansion of the anchor and the refractory concrete. The stress at the anchor base, at or near the shell, varies from -20 to -100 MPa (compression). The temperature of the anchors at the interface is predicted to be approximately 850ºC.

At this temperature, the predicted anchor life for different alloys at 850°C and 9.95 MPa is:

Alloy type	Predicted anchor life
253MA	~520,000 hours
310 stainless steel	~11,000,000 hours
DS Alloy	~16,000 hours

With no corrosion

The analysis shows that ATENA can be used to predict refractory anchor stresses and the results from our research are in line with plant observations.

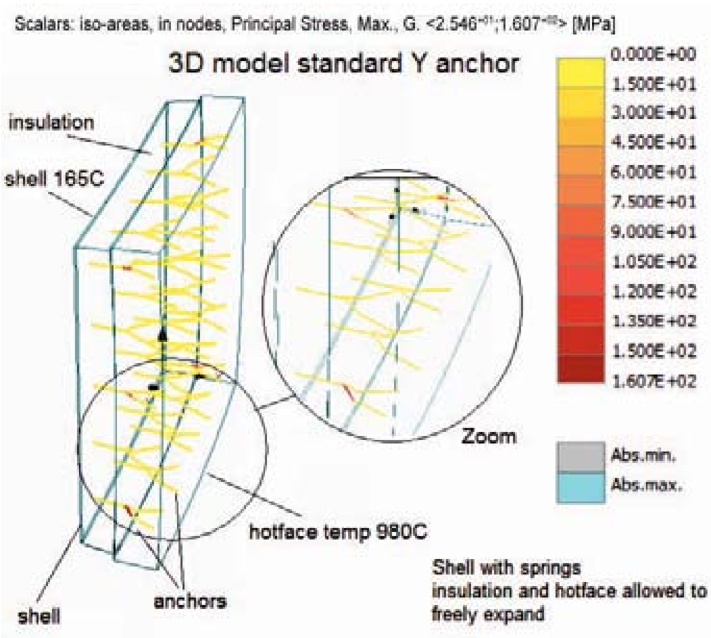

Figure 15. 3D model showing deformed shape and maximum axial stress in anchors.

It is also concluded that it is possible to validate numerical models by plant observations though careful observation and interrogation of the refractory condition is required.

ANCHOR STRESS DUE TO CHANGING ANCHOR SPACING

One common question often encountered is the spacing of anchors from the edge of a panel.

A 1 m section of a typical roof was modelled in 2D with anchor spacing of 200 mm and 250 mm. The model material thicknesses are 6 mm shell, 100 mm insulation and 130 mm hotface. The anchor vee is 10 mm diameter cold drawn wire and the anchor base is 20 mm diameter cold drawn wire both with poor bond slip. **Figure 16** and **Figure 17** shows the gravity only result for a 1 m roof section with anchor spacing of 200 mm and 250 mm spacing, respectively. In this case, the insulation is bonded to the shell.

The analysis shows the inner arm of the outer lying anchors have a maximum tensile stress of 1.64 MPa and 2 MPa for the 200 m and 250 mm spacing, respectively. Further analysis found that if the insulation is not bonded to the shell, which may occur, then the stress on the outer anchor arms would increase to approximately 3.3 MPa and 4 MPa for the 200 mm and 250 mm spacing, respectively.

DEFECTS AROUND ANCHORS

One of the most common defects found in refractory concrete are "honeycombs" or voids around anchors. In a typical concrete structure, the presence of any void or honeycomb will cause a weak point where structure failure is likely to occur (See **Figure 18)**.

In a refractory structure, cracks through the hotface can also cause a passage for the process gas to penetrate and attack the steel, which will accelerate corrosion and anchor failure. The other problem that could occur is a crack through the hotface, which crosses an anchor, can increasing the bending stress due to both gravity (a shift in the center of gravity) and thermal load.

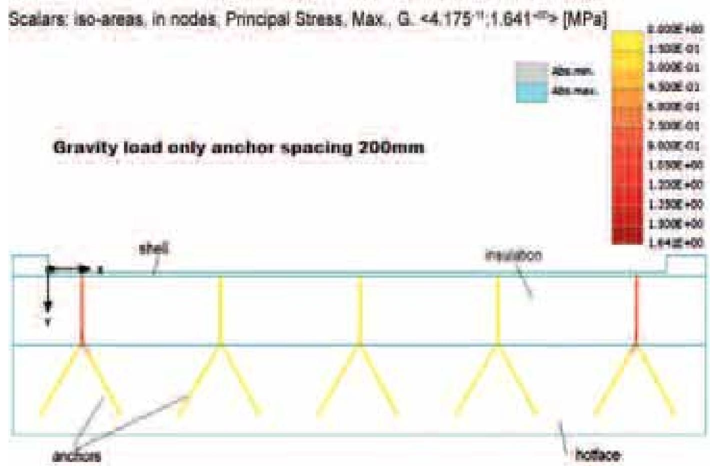

Figure 16. ATENA model of roof section with 10 mm diameter anchors at 200 mm spacing.

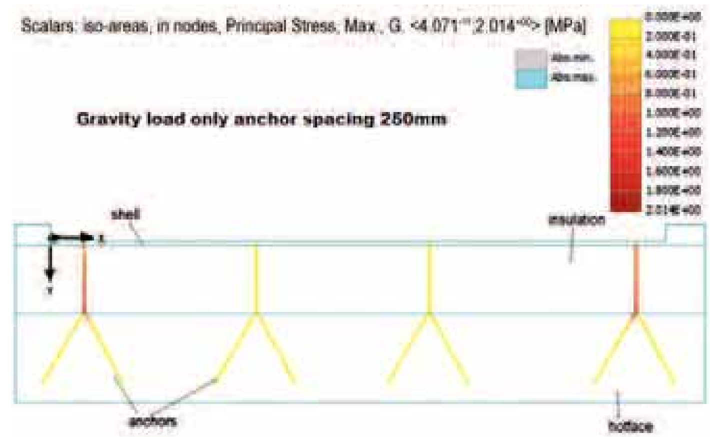

Figure 17. ATENA model of roof section with 10 mm diameter anchors at 250 mm spacing.

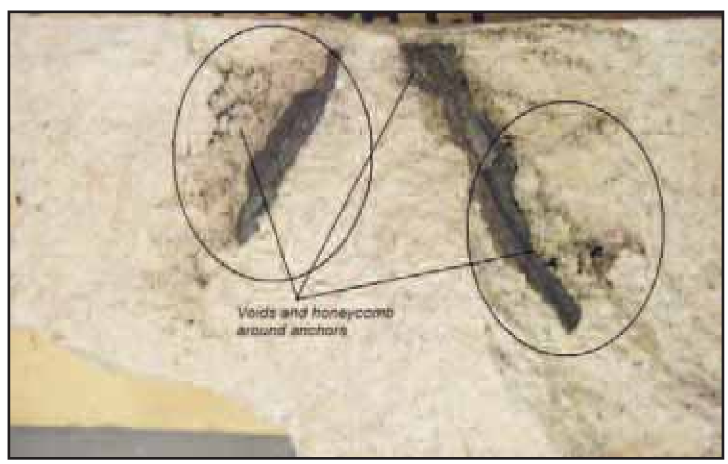

Figure 18. Defect in the hotface around the anchor locations.

The effect of defects was studied by including a void in the model around the base of one of the anchor vees as shown in **Figure 19**. The model has both thermal and gravity load applied. The temperature is incrementally increased by 1.8°C per step until 1000°C then held for another 300 steps to achieve steady state. The anchor base is 20 mm diameter and the anchor vee is 10 mm diameter. The analysis shows the effects of thermal load on anchor stress as the temperature of the structure increases to a point where the hotface fracture energy (Gf) is exceeded and small crack develops in the hotface. The analysis

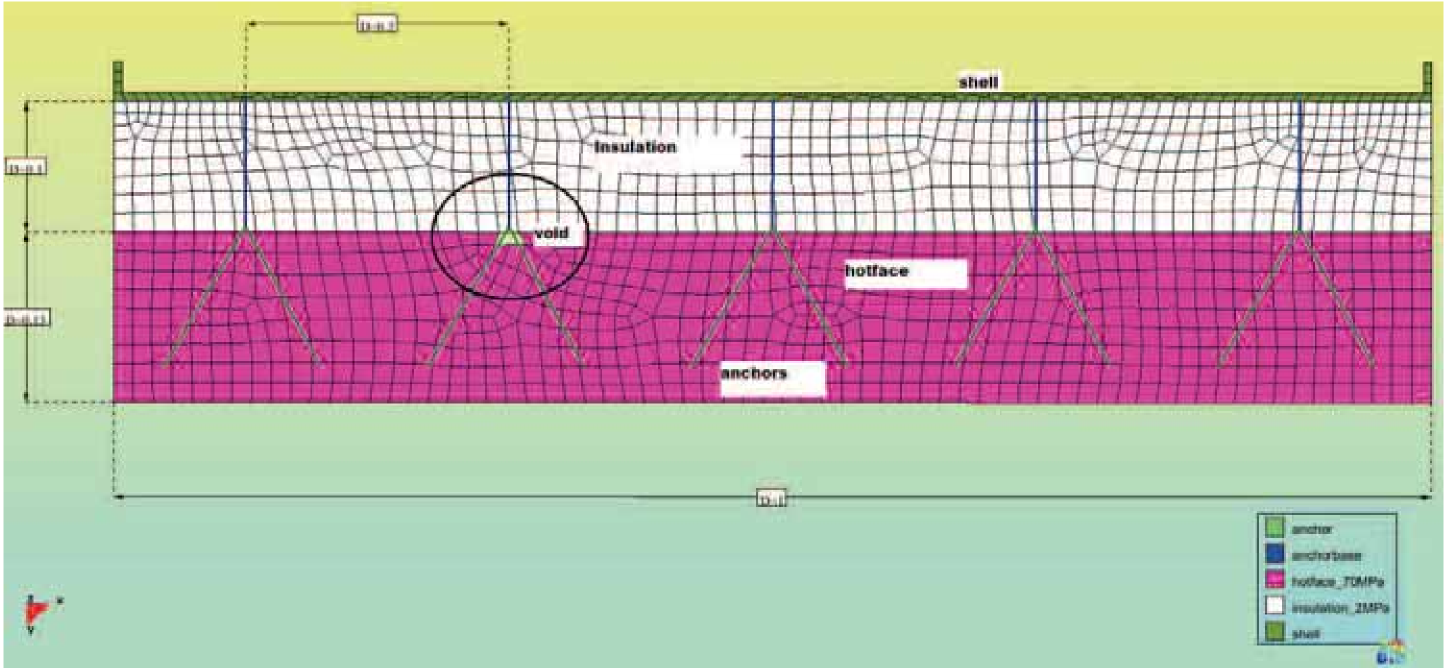

Figure 19. ATENA roof model with void defect around one anchor at the interface.

shows that as the hotface cracks propagate across the middle anchor vee then the anchor stress at those location increases, due to bending.

Figure 20 shows the gravity load anchor stress at ambient temperature. The anchor stress in the truss elements varies from approximately 0.5 MPa at the void to 2.56 MPa at the extremities of the panel.

As the thermal load is increased, the anchor stress in the defect void also increases. At step 400, the hotface surface temperature is 800°C and the calculated anchor stress on one arm is approximately 90 MPa at the void. The anchor stress at the extremities of the panel also increases (See **Figure 21**).

As the hotface temperature is increased to 1000°C at step 600 a crack starts to form near the center of the hotface panel as shown in **Figure 22**. At this stage, the stress in the outer most anchor has increased due to bending and the stress in one of the middle anchor arms has increased slightly to approximately 8 MPa. The anchor stress in the void has decreased from approximately 90 MPa to approximately 21 MPa (See **Figure 22**).

As the crack continues to propagate during the temperature transients (i.e. the refractory lining temperature increases to reach steady state) the anchor stress decreases at the void but increases in the anchor, which is in the crack path. This anchor

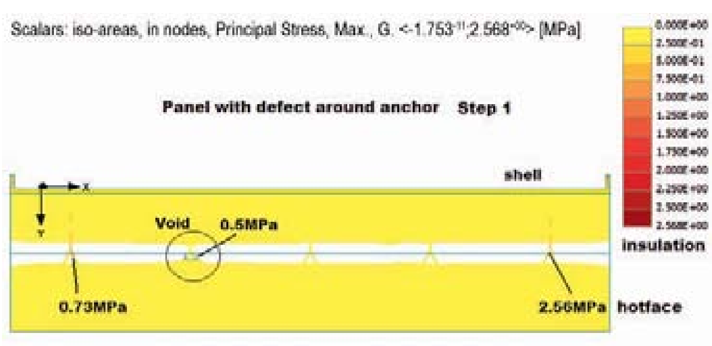

Figure 20. Defect roof model step 1 anchor max. principal stress at ambient temperature.

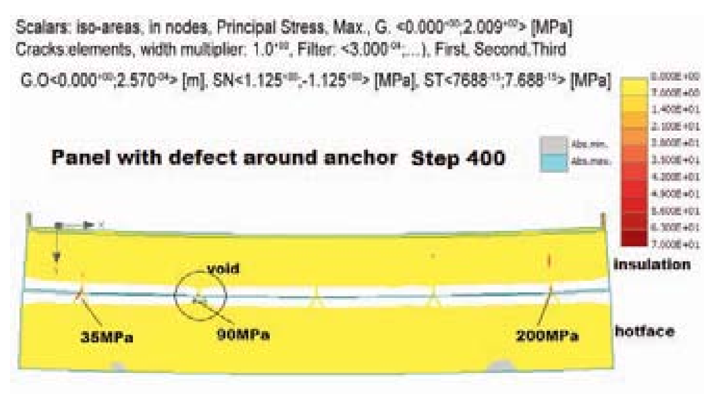

Figure 21. Defect roof model step 400 anchor max. principal stress at void, hotface temperature 800°C.

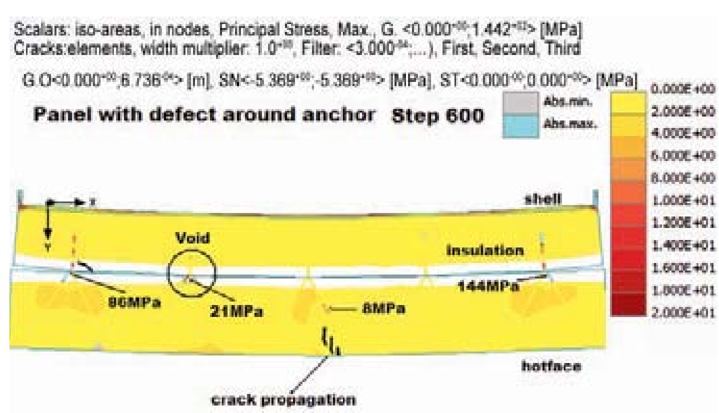

Figure 22. Defect roof model step 600 showing crack propagation and anchor max. principal stress at void, hotface temperature 1000°C.

stress increase is due to an increase in the bending of the hotface panel. When the hotface is not cracked, it resists the thermal bending induced by the insulation layer but with a crack that crosses an anchor the stress in that anchor is seen to increase.

The analysis shows that defects in the refractory concrete can result in increased anchor stress at that location and defects as in voids around anchors can result in cracks at those locations. The analysis also shows that cracks that propagate across an anchor can increase the anchor stress at that point. Thus, it is concluded that the installation of refractory concrete requires the utmost care and defects, particularly in the hotface, need to be avoided.

ENCAPSULATION DESIGN

The corrosion of refractory, anchors and the steel shell poses additional problems when trying to improve refractory longevity. This is especially so in processes like cement kilns which have high alkali (chlorides or sulphates) feed materials. Chlorides at temperature can be particularly aggressive to refractory anchor steel with metal wastage being greater than 50% in less than 12 months and sulphates can be aggressive to both the refractory and shell steel causing accelerated metal thickness loss and refractory spalling. One concept has been to encapsulate the refractory insulation in the hotface to try to reduce corrosion of the anchor and steel shell [7].

The principle of the encapsulation design is to try to prevent corrosive gases and alkali vapors, e.g. NO_x, $H_2O_{(vap)}$, SO_2 and Cl^-, tracking through expansion joints or cracks and along the interface between the insulation and hotface. The elimination of gas tracking is reportedly achieved by wrapping the hotface at the corner of a panel to the shell as shown in **Figure 24** and **Figure 25**.

However, part of the theory leading to encapsulation design appears to be based on the premise that process gases can track between the hotface and insulation layers causing anchor corrosion and failure. However, our research has shown there is no scientific evidence to support the gas tracking at the interface theory. If gas tracking does occur then corrosion of the metal anchor by the process gas is rapid and anchor failure can be expected to occur within months. In addition, numerical analysis using ATENA shows that the hotface and insulation can separate by 0.5 mm towards the center of a panel and approximately 1 mm at the edge of a panel.

Thus our experience is that diffusion of chloride and sulphate ions through the refractory concrete is dominated by a mass transfer mechanism, particularly when there is a network of open pores left from the polypropylene fiber used to control steam spalling. Controlling diffusion of these elements or compounds through refractory concrete is near impossible as concentration gradients will drive these compounds into the refractory (Le Chatelier's principle). However, densification during sintering will assist in closing some pores. In one example, see **Figure 26**, a sample of 1600 grade hotface was sectioned and inspected microscopically. The observations are summarized as follows:

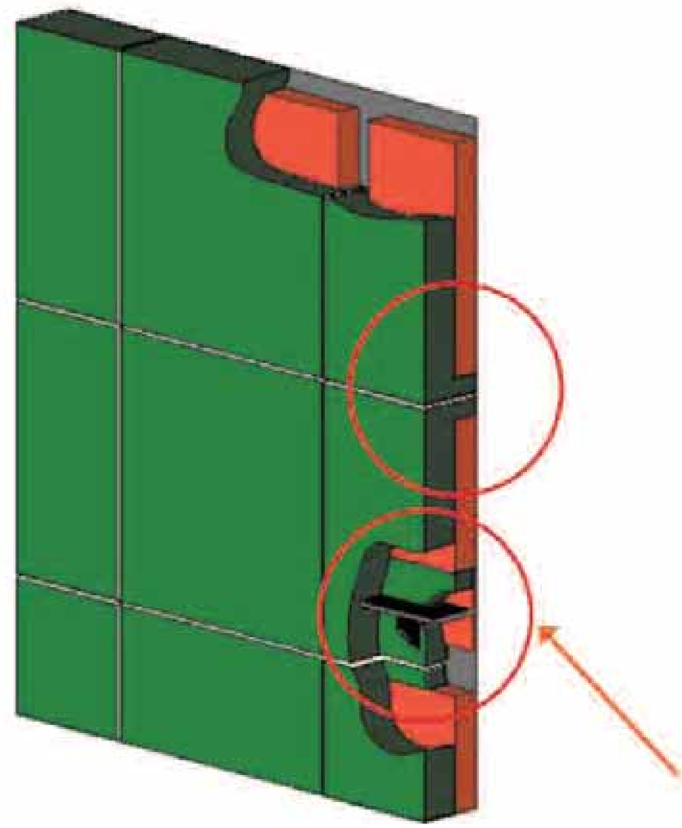

Figure 24. Gas tight capsulated monolithic lining design according to Baatz [7].

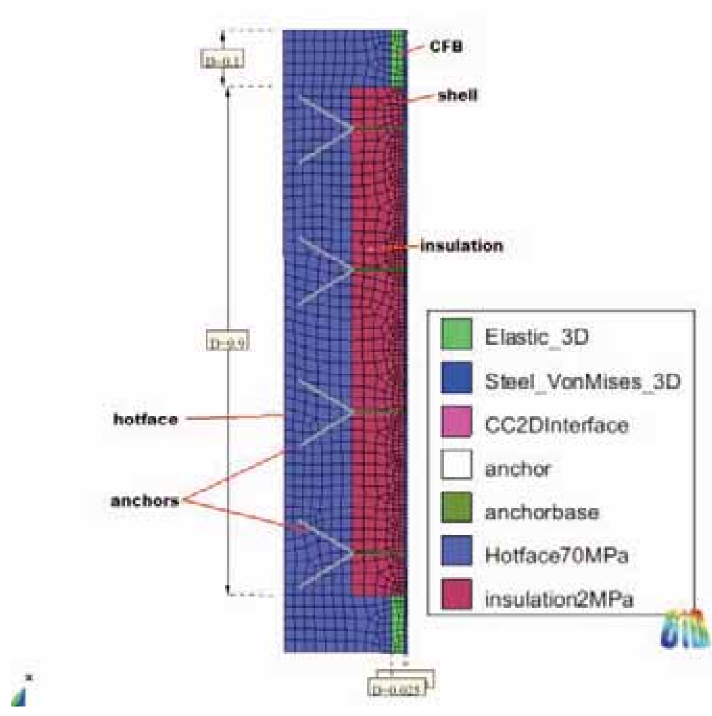

Figure 25. Cross section of encapsulation design.

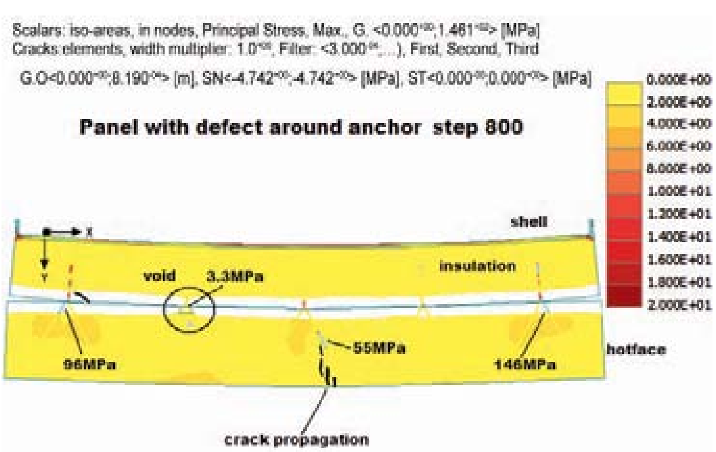

Figure 23. Defect roof model step 800 showing crack propagation and anchor max. principal stress at void, hotface temperature at steady state of 1000°C.

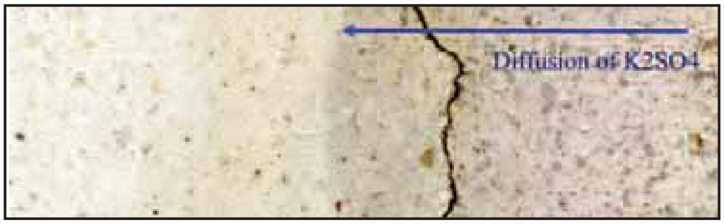

Figure 26. Sample of 1600 grade refractory from a cement kiln showing band of K_2SO_4 (yellow) and crack just above the diffusion line.

> The sample shows two distinct zones and the area closest to the hot face was grey in colour. The upper zone (hot face) was diffusely micro-cracked with zones of spalling. The aggregate had changed colour from a cream to grey. After washing, the sample a yellow zone appeared near the diffusion boundary. This was interpreted as K_2SO_4.

The lower zone (cold face) was white in colour and the aggregates were cream to fawn in colour. The body of this zone appeared sound (as new) with no visible cracking or spalling.

A plot of the percentage K_2O through the refractory sample is shown in **Figure 27**. This figure shows that the concentration of K_2SO_4 decreases the further the distance from the hotface.

The chemical analysis found the refractory has been impregnated with K_2SO_4 and mineralogical analysis has identified feldspathic minerals - kaliophilite, nepheline and lucite in the samples. These minerals are expansive in nature and can increase the original volume

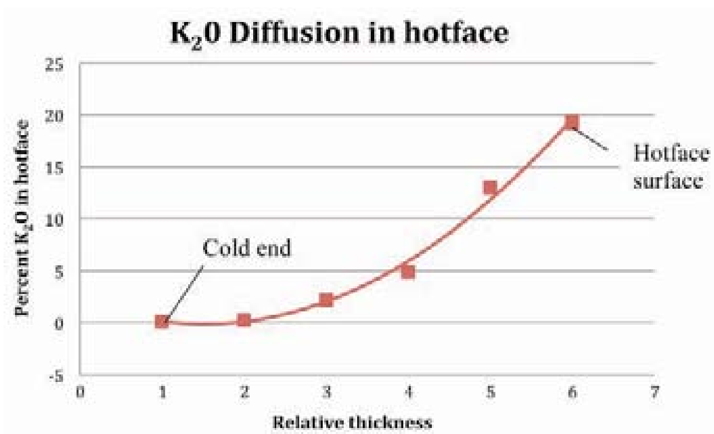

Figure 27. Variation in K_2O% with thickness in refractory hotface sample.

by 45%, which is in line with Baatz [7]. Site observations have found that the refractory concrete spalls (bursts) in thin small sheets. The best solution to solve this problem appears to be careful selection of the refractory material, which is less susceptible to corrosion by sulphates.

The encapsulation design, as shown in **Figure 25**, was analyzed with ATENA to evaluate the anchor stresses. The model has both thermal and gravity load applied. The temperature is incrementally increased by 1.8°C per step until 1057°C then held for another 300 steps to achieve steady state. The anchor base is 20 mm diameter and the anchor vee is 10 mm diameter with a poor bond slip applied. The vertical interface between the insulation and hotface has bonding, cohesion and friction applied. The density of the hotface was 2300 kg/m³. The final steady state temperature profile is shown in **Figure 28**.

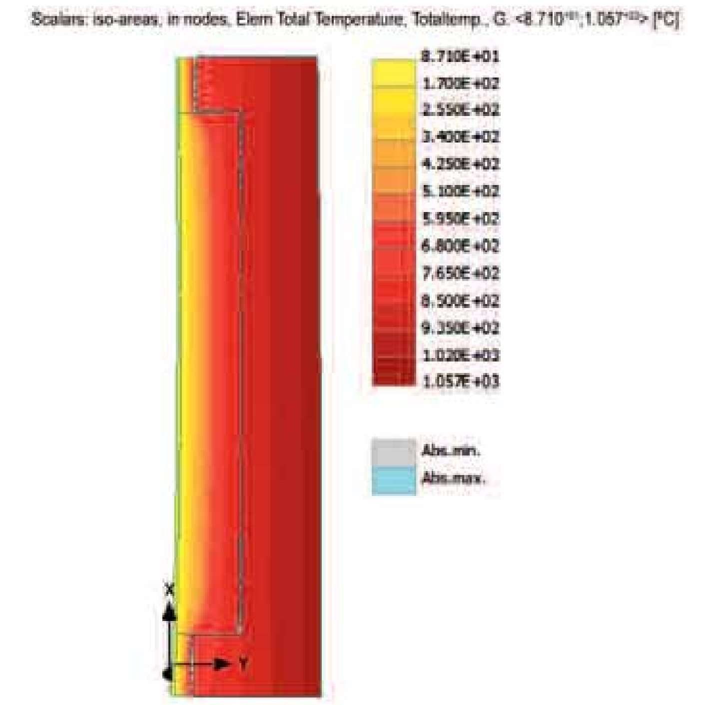

Figure 28. Final steady state temperature profile at step 900, hotface temperature of 1057°C.

The numerical analysis shows that the anchor stresses remain very low, less than 0.5 MPa, during all stages of the heating process. The low anchor stress is due to the support and friction that exists between the two layers and the fact that the returns at each end of a panel will help support the gravity load.

However, that analysis does show that fine cracks parallel to the hotface surface (<0.3 mm) can occur during the heating process due to the thermal gradient.

CONCLUSIONS

It has been shown that the current approach to refractory structure design, which has been developed from experience and applied "rules of thumb" while important, is inadequate in today's environment where designers are legally required to support their design.

Until the development of international standards for the design of refractory structures it means there is an obligation for engineers to carry out detailed engineering calculations. It has also been shown that traditional concepts and guidelines are grossly inaccurate and can result in unpredictable refractory failure.

Advanced engineering analysis of refractory structures can be carried out and the structure's behavior can be predicted. However, the paucity of engineering data on refractory material at temperature means material testing needs to be carried out. In comparison material property data for steel alloys used in refractory anchors is well understood and available from manufacturers.

In Australia the material properties available are generally: cold compressive strength, modulus of rupture, thermal conductivity, permanent linear change and abrasion index after firing to a specified temperature. Properties such as elastic modulus, tensile strength and fracture energy over a temperature range are very difficult to find. It is also realized that having to test materials to provide this data is expensive. However, when these advanced material properties are not available ATENA software assumes default values based on

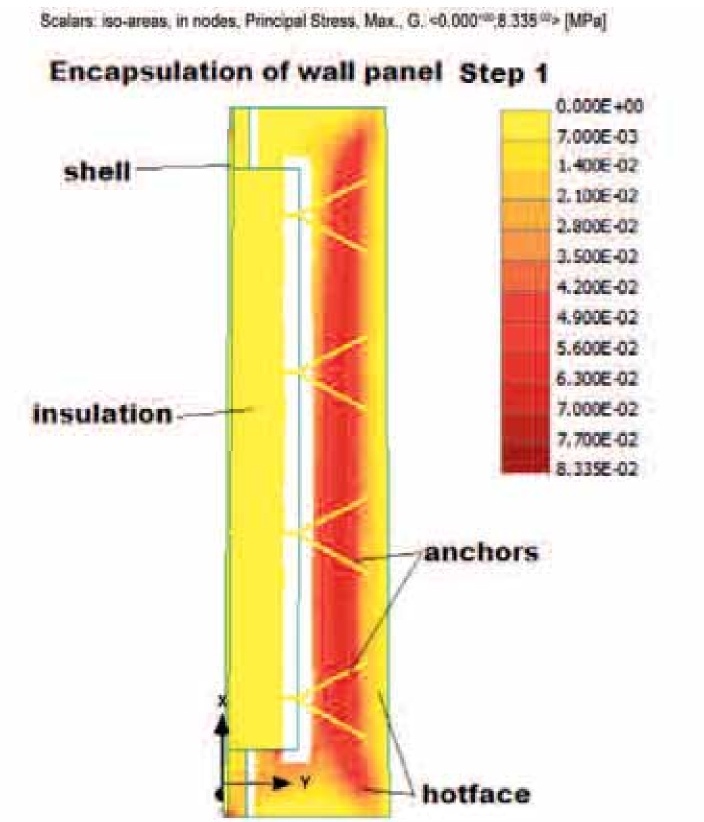

Figure 29. Wall encapsulation model step one showing anchor and refractory max. principal stress, hotface temperature at ambient temperature.

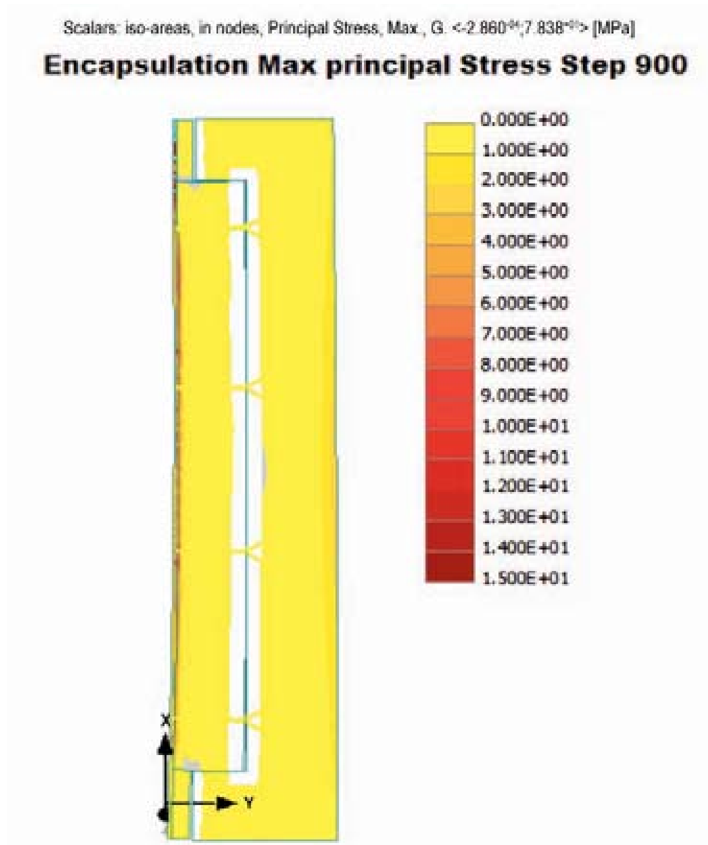

Figure 30. Wall encapsulation model step 900 showing anchor and refractory max. principal stress, hotface temperature 1057°C.

CEB-FIP model code 1990 formulas and their temperature dependence based on Eurocode 2 for fire analysis (EN 1992-1-2) for concrete or it is possible to calculate these parameters from a 3-point bend or compression tests by simulating the test results in ATENA.

One of the major failure mechanisms of dual layer refractory structures is due to creep rupture of the anchor at high temperature. It has also been shown that numerical analysis is required when designing refractory structures due to temperature material properties.

Analysis of a refractory structure shows that changing the anchor spacing from 200 mm to 250 mm under gravity load will increase/decrease anchor stress by approximately 22% under ideal conditions. More importantly it has been found that defect in the refractory concrete hotface will introduce weak points into the structure and increase the likelihood of cracking. Cracking of the hotface can lead to a passage for the process gas to penetrate and attack the steel, which will accelerate corrosion and anchor failure. In addition, cracks in the hotface, which crosses an anchor, can increase the bending stress on an anchor due to both gravity (a shift in the center of gravity) and thermal load.

It was found that the encapsulation design for walls could lower anchor stresses due to the panel returns at each end. However, this relies on the corners of a panel not cracking. In the overhead position the corner returns do not support the hotface and anchor gravity loads are not reduced. In addition, it is not clear if this design is any better than a standard straight panel shape.

On the subject of corrosive gases, we are of the opinion that encapsulation offers little advantage as ions like chlorides and sulphates have been found to diffuse through the refractory concrete.

Our research has shown that numerical analysis techniques are required for refractory design. We have also shown that numerical analysis can allow quick efficient analysis of refractory structures particularly when it comes to consideration of anchor type and spacing.

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UNIMIN CORPORATION YOUR PARTNER IN REFRACTORY INNOVATION

Chris Karr, Market Director, Refractory and Metallurgical Products, ckarr@unimin.com

Refractory selection is more than physical properties and delivered costs. It represents your selection of a technical partner in the shared pursuit of quality, productivity and environmental objectives.

Unimin Corporation is North America's largest producer of industrial quartz, olivine, nepheline syenite and microcrystalline silica, and a major supplier of feldspar, clays and kaolin, lime and limestone. International in its scope of operations, Unimin has established the quality and service standards in the many global industries it serves. A major market category served is refractory, where the company's industrial minerals provide high temperature performance in metal casting applications. By bringing together superior deposits, experienced technical managers, and process innovation in a single integrated system, the industry has easier access to refractory solutions. In North America, these products include VANGUARD® mineral refractory sands, flour and aggregates, VANTAGE® fireclay and kaolin binders and THERMTECH™ engineered basic refractories.

Personnel who represent the company's refractory portfolio come from diverse, and often multi-disciplined, backgrounds. Their expertise is applications oriented with special emphasis on function and performance in customer applications. With knowledge of our customer's objectives and continuous feedback from customer operations, our goal is to optimize our refractory product performance.

Unimin also operates research and development facilities in support of its refractory product line. Through programs of fundamental research and application-based product development the company is able to respond to evolving industry requirements. Initiatives reflect current commercial challenges and ongoing "green" compliance objectives; including projects designed to increase productivity, reduce cost, minimize emissions and eliminate wastes. By actively listening to our customers, and through continuous improvement and reinvestment, our objective is to supply proven refractory solutions.

The THERMTECH™ portfolio of engineered basic refractory shapes and monolithics is an example of customer-oriented problem solving. THERMTECH™ tundish refractory mixes include gunning, slurry and sprayable systems for both hot and cold tundish practices. With superior insulating properties, THERMTECH™ working linings are an integral part of steel production economics. Its forsterite bonding effectively resists thermal load and erosion from molten steel alloys to extend the lifetime of working linings and protect costly permanent linings. THERMTECH™ tundish linings are distinguished by their very low consumption per ton of liquid steel cast, extended cycle times before re-lining and prolonged safety lining life. All THERMTECH™ tundish systems produce a smooth surface to minimize reactivity, spalling and erosion at the metal interface.

THERMTECH™ EASYSET™. **Figure 1** is a cold setting tundish working liner designed to eliminate VOC emissions for a cleaner and safer workplace. An evolution of customer oriented problem solving, EASYSET™ is a versatile system, adaptable to the entire range of steel alloy systems and suitable for either cold or hot tundish practices. Supplied as a dry mix, EASYSET™ is activated on site with an inorganic environmentally friendly binder and hardener system using conventional equipment. Placed between the safety lining and a steel mandrel, EASYSET™ cures rapidly without an external heat source and without VOC emissions. Residual heat from the safety lining accelerates the process allowing mandrel removal within 10 minutes and because EASYSET™ does not use water there is no need for time consuming drying or preheating steps. The finished lining is smooth, fine grained and of low surface area to resist erosion.

THERMTECH™ EBT, **Figure 2,** offers steel producers a unique ability to achieve a controlled sintering in eccentric bottom taping EAF furnaces. An engineered balance of coarse and fine-grained particles, THERMTECH™ will improve the free-opening performance rate. Finer grain sizes in contact with the molten metal sinter quickly to form a reliable refractory plug required for ferrostatic loading. The coarser granules form a dense stratum that supports the thinner, sintered layer until the heat is tapped.

THERMTECH™ ALUBRICK™, **Figures 3** and **4,** cathode barrier brick is designed to increase productivity and performance in Prebake and Søderberg electrolysis cells. ALUBRICK™ thermal conductivity is equivalent to fireclay, but its higher heat capacity and greater bulk density can absorb 40 – 50% more excess cell heat. The benefit is a more uniform bath temperature, an increased current efficiency and a reduced cathode voltage drop. Production can be increased with greater amperage while still maintaining critical thermal balance. ALUBRICK™ is also more resistant to cryolite attack and remains dimensionally stable throughout its lifetime. In some installations a thin layer of OLIBAR™ is applied on top of ALUBRICK™ for leveling and height adjustment. (**Figure 5**)

The foundation of every THERMTECH™ product is VANGUARD®, a natural hard rock mineral composed of forsterite, magnesium orthosilicate, Mg_2SiO_4, and fayalite, iron orthosilicate,

Figure 1. Installing a new EASYSET™ low VOC tundish working lining.

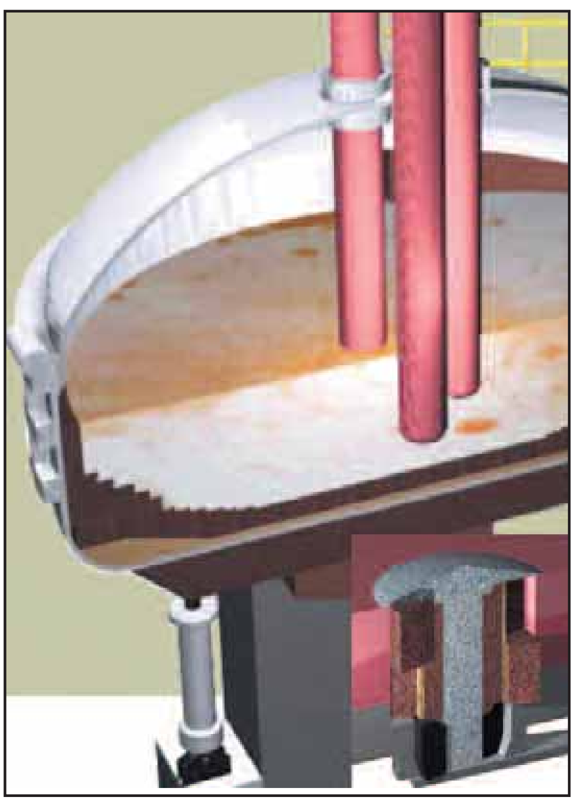

Figure 2. Schematic of Eccentric Bottom Tapping Electric Steelmaking furnace with EBT tap hole filler aggregates.

Fe_2SiO_4. It achieves a high refractory value of 1750ºC due to its effective oxide content of approximately 49% MgO, 42% SiO_2 and 7% Fe_2O_3. VANGUARD® finds application over the entire range of fired and chemically bonded basic refractory shapes, sprayable and ramming mixes, slurry systems, castables, dry vibratable mixes and mortars. VANGUARD® additions will help resist chemical attack, increase impact strength and thermal stability and improve insulating properties. Highly resistant to neutral and basic chemistry slags, and non-reactive with most molten metals, VANGUARD® is an excellent refractory aggregate in primary metals production.

VANGUARD® thermal conductivity is lower than comparable basic refractory raw materials such as dead burned magnesite or dolomite. This property makes it an ideal component in tundish working lining insulating mixes for continuous steel casting. When formulated with an excess of MgO, VANGUARD® will develop forsterite bonding in the refractory matrix. These two materials work synergistically to resist hot pressing and to maintain lower temperatures at the working lining - safety lining interface to extend service life by maximizing resistance to erosion and chemical attack.

VANGUARD® thermal expansion is low and uniform over its entire use temperature range because it does not undergo a phase change or crystallographic inversion nor does it require calcination prior to use. With the combination of low thermal expansion, high heat capacity, high refractoriness and particulate

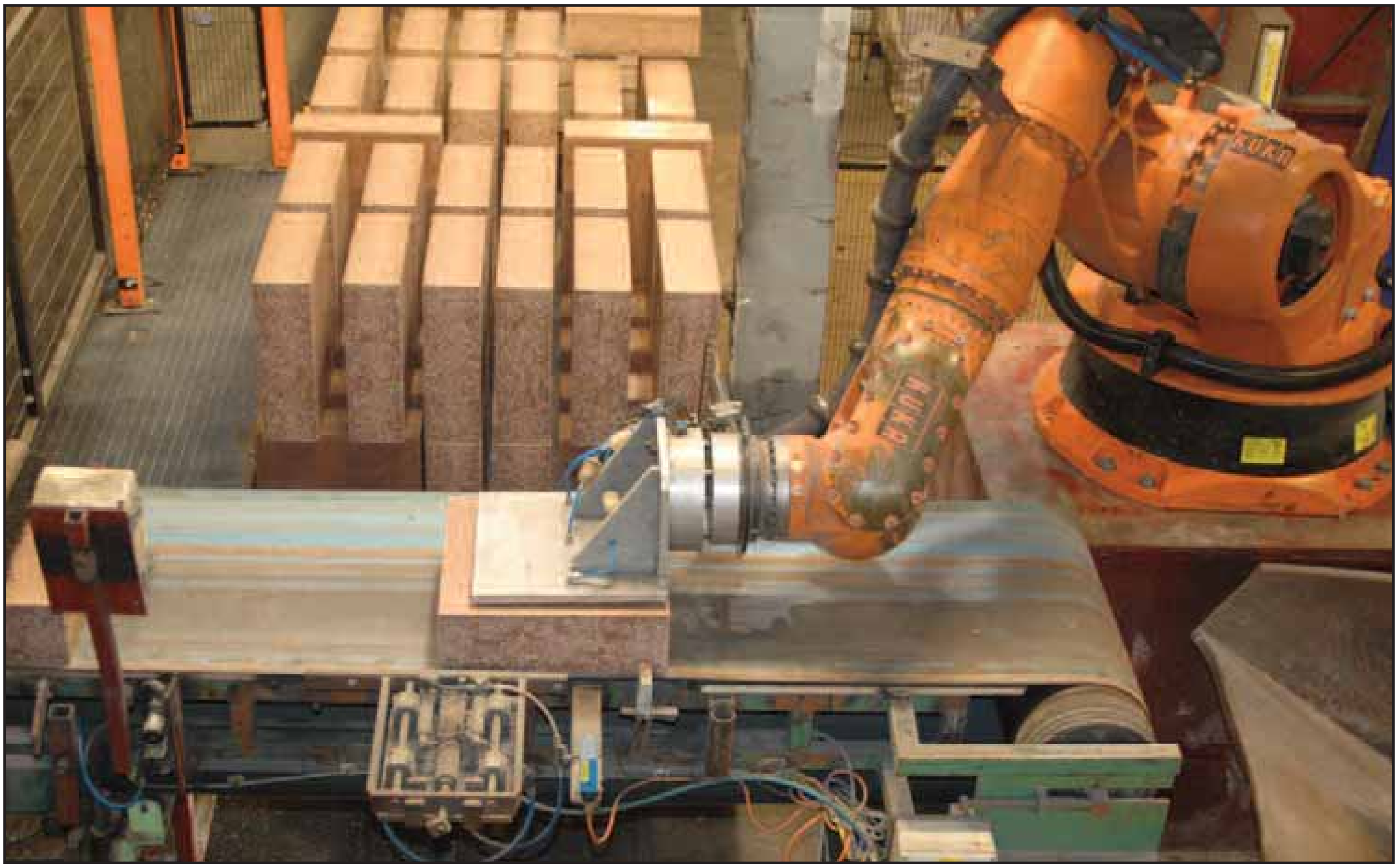

Figure 3. Setting of large format ALUBRICK™ on kiln cars for firing.

Figure 4. Relining an aluminum reduction cell with large format ALUBRICK™.

Figure 5. THERMTECH™ OLIBAR™ leveling compound over ALUBRICK™ cathode barrier bricks.

strength VANGUARD® sands and aggregates deliver substantial refractory performance in loose fill applications such as unbonded ferro-alloy casting beds, aggregates for lining soaking pits and media for fluidized bed bio-incinerators. In these applications VANGUARD® is noted for its low attrition rate, energy efficiency and general non-reactivity with molten metals, alkali impurities and slags.

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R2U CASTABLES: A NOVEL PLACING TECHNIQUE FOR BOF REMOVABLE BOTTOM

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ABSTRACT

In the steel industry, two typical BOF vessel designs are currently used despite the diversity of the production process: vessels with removable and fixed bottoms. Those with removable ones show severe wearing mainly of the bricks located around the tuyeres. Therefore, in order to keep the bottom blowing process working throughout the BOF campaign, the refractory bricks should be replaced. After new bottom replacement, the gap between bricks must be filled to assure that the vessel will end the campaign safely. Some steel shops present problems in installing monolithic refractories due to the difficult access to this region. As a result, bottom shell heating and/or metal infiltration are common problems which could prematurely halt the campaign.

A novel R2U (ready-to-use) MgO resin bonded castable was developed for application for BOF removable bottoms. The castable is delivered to the customers with all liquid incorporated only to be installed by a refractory castable double piston pump. All mixing procedures are carried out at the refractory producer, saving time and making pumping installation easy to be performed. The R2U castable is pumped from the bottom to the top of the converter. This new technology assures that all voids will be completely filled without any temperature restrictions. Field installations are performed as a routine procedure in an MPR-L converter in any remaining brick layer and temperature, with the same performance. An MPR-L converter is ready to resume operation in half the time than the usual installation procedure, with safety and reliability.

This paper reports the development of this novel self flow R2U MgO castable for installation in BOF removable bottoms. Product properties, field installation trials and performance are presented in order to highlight this novel technology.

INTRODUCTION

For each vessel, a typical wearing pattern of the refractory lining is related to a particular BOF operational method. The target is to match the different refractory quality bricks in order to present homogenous wearing, decreasing the refractory costs. Bottom blowing vessels show a very typical wearing area caused by turbulent flow pattern [1]. In some BOF processes, the service life of the bottom is not the same as the remaining area of the vessel. Therefore, a removable BOF bottom is used as a solution for increasing the campaign life.

The original version of the Metal Process Refining (MPR) converter has now evolved to the MPR-L process in which oxygen is top-blown and inert gas is injected through the porous elements in the bottom [2]. **Figure 1** shows a schematic view of an MPR-L converter used for stainless steel.

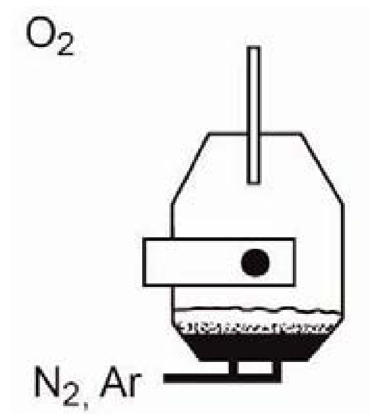

Figure 1. Schematic drawing of a MPR-L converter.

Each time the MPR-L bottom is changed, a gap between the new and used lining must be filled. Gaps can vary from 50 to 80 mm in a 75 t vessel, according to the wearing pattern. Plastic mortars or dry gunning mixes can not be installed due to the difficult access of the placing equipment inside the converter. As the converter must be kept in a vertical position, the only access is through its mouth.

Throwing type hot casting mix based on basic aggregates and organic binders can be used. The refractory composition is thrown into the vessel by a scrap shooter. Afterwards, the refractory is softened by the heat of the furnace, and it flows and hardens [3]. Usually the repairing time is longer than gunning and it is very hard to assure that all gaps will be completely filled. Bottom shell heating and/or metal infiltrations are common problems which could prematurely halt the campaign.

A R2U MgO resin bonded castable was developed for a bottom exchanging converter to replace a throwing type hot casting mix, assuring safety and reliability for the converter operation. The development of this novel product and field trials will be discussed in this paper.

R2U MgO CASTABLE DEVELOPMENT

This novel generation castable has been designed to be delivered to the customer as a R2U product and is applied by self flowing, pumping or shotcreting. All liquid is already incorporated into the mix in the refractory producer. No segregation is observed during storing and transportation due to grain size distribution and matrix viscosity [4].

A new challenge had to be overcome in the conception of this novel R2U castable. Long distance, vertical pumping and also very small gaps to be filled requires a minimum self flow index level of 90%. Taylor made matrix engineering was conceived to keep its original properties after 30 days. Sintered magnesia aggregates were used in all ranges to fit an Andreasen grain size distribution. Metallic additives and submicron MgO particles were incorporated and dispersed by a special additive for non-aqueous media. Phenolic resin was selected as the main binder due to various advantages:

- Low polluting organic binder
- Full compatibility with antioxidant additives
- Generation of carbon bonds after heat soaking
- Easy handling and pouring into the mix
- Phosphorous free binder required for MPR-L converter

Figure 2 shows the cross sections of the basic castable before and after the MRP-L campaign trial. The brick size sample was attained by self flowing as a quality control. A small sample was placed by pumping and withdrawn after the first trial. No significant differences were observed among the samples.

Table 1 shows the chemical and physical properties of the throwing hot casting mix and the novel R2U castable.

The chemical composition shows almost identical contents for the main oxides. Additionally, physical properties are similar for both materials after curing and coking. Improvements in the cold mechanical properties for the MgO castable resulted from better grain size distribution, additives and the resin binder type. Corrosion resistance was slightly superior mainly due to the better dispersion of basic fine particles in the matrix. HMOR improved nearly two-fold for the R2U castable due to stronger rigid carbon-carbon bonds and different metallic powders blend. Higher mechanical resistance did not offer extra labor during bottom replacing.

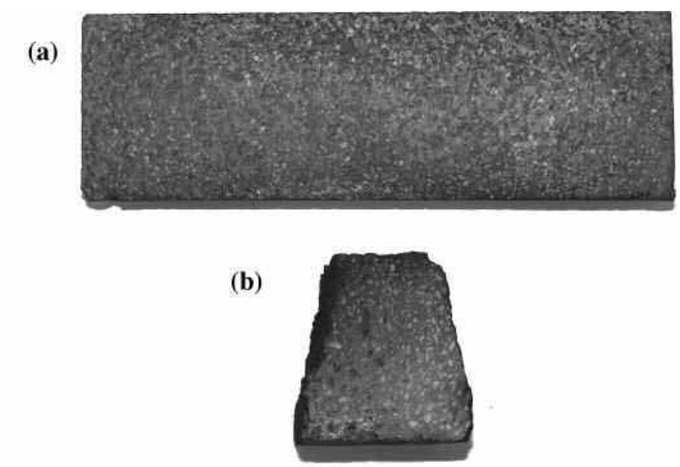

Figure 2. R2U MgO castable cross sections: a) Self flowing quality control brick, b) Pumped sample after first customer trial.

Table 1. Chemical and physical properties of throwing type hot casting mix and the novel R2U castable.

	Throwing mix	R2U castable
MgO (%)	90.8	90.8
Al_2O_3 (%)	3.8	3.5
Others (%)	5.4	5.7
After 200°C		
Density (g/cm³)	2.49	2.43
Porosity (%)	17.5	17.2
CCS (MPa)	15.4	26.5
HMOR (MPa)	1.5	2.3
Slag corrosion(1) (%)	39.7	32.5
After cooking at 1400°C		
Density (g/cm³)	2.51	2.43
Porosity (%)	24.9	21.3
CCS (MPa)	10.2	20.3
HMOR (MPa)	1.2	2.1

(1) Induction furnace – 1650°C x 3h, steel + 40% FeO slag

STEEL SHOP TRIALS

In-company Simulation

A partnership between a customer and Magnesita was the successful key to this project. A previous installation was performed inside the company simulating an MPR-L vessel gap to be filled with the R2U castable. Logistic installation was also simulated. All procedures and trials were followed by the customer. **Figure 3** shows the metallic vessel with a diameter very close to the original converter and a gap of 100 mm between the walls. The gap height of 1500 mm to be filled was similar to the actual brick converter dimension. The distance between the pump and the vessel was 7 m and a special bi-split pipe was used to speed up double pump installation. Hoses were attached to the vessel bottom by special open-close connectors. The R2U castable was pumped from the bottom to the top and the vessel was filled with a very low pump pressure.

Figure 3. R2U MgO castable installation simulation: Vessel simulating an MPR-L shell.

Figure 4. Double-split pipe.

Figure 5. Open-close connector.

Figure 6. Gap completely filled up by castable.

Bag transportation, pumping loading and pumping time were also recorded. This previous trial provided confidence for the field trials.

MPR-L Converter

The MgO castable was placed by pumping in a 75 t MPR-L converter using a refractory double piston pump. Material was delivered in a 1 t bag to optimize pump loading.

Figure 7 shows the sequence of the hot bottom exchange. A worn brick bottom was removed and a new one was already placed in the converter. **Figure 8** shows the same connecting system used in the company simulation. The attached connectors linked the pump hoses from the double-split pipes. Two pumps were used to speed up R2U castable installation and also to reduce converter downtime. Material was charged directly by a single lift car that fed the two pump silos. The R2U castable had to be transported 11 m through horizontal pipes and 5 m through vertical pipes. Nine t of castable were installed with a constant pump pressure of 1200 psi. This novel technology makes any pumping and shotcreting installation very simple and is suitable for confined rooms. **Figure 11** shows a converter mouth view. Installation was finished when the castable reached the upper part of the bricks at the new repaired bottom. The whole operation was carried out in 30 min. The R2U castable was set by the

Figure 7. MRP-L hot bottom exchange: Used bottom withdrawal.

Figure 8. New bottom lining with connectors attached to the pump hoses.

Figure 9. Double piston refractory pumps for installation.

Figure 10. Material loading into the silo.

Figure 11. Material reaching the upper part of the brick and ready to set.

heat generated by the oxygen lance. After two hours, the vessel could resume normal operation, half of the time for the usual installation procedure

The temperature of the remaining refractory lining region was measured using an electronic pyrometer and it was around 400°C. After 1614 heats, a complete relining was performed. The bottom was inspected and no infiltration or empty spaces were found, as shown in **Figure 12**. This new installation procedure was adopted as the routine for the MRP-L bottom replacement with safety and reliability.

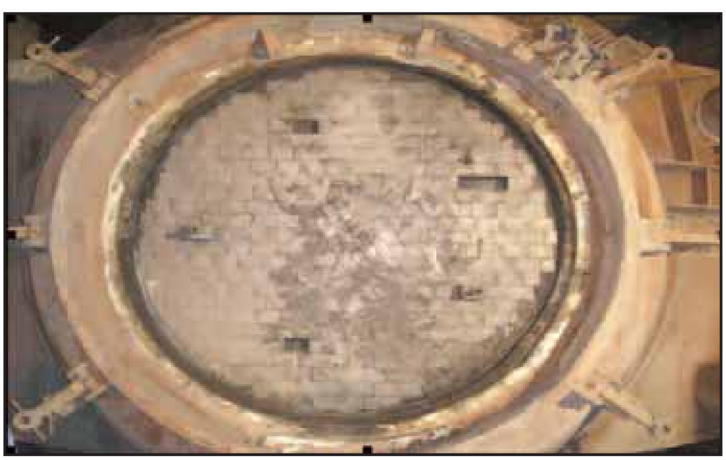

Figure 12. First inspection of the new R2U castable for removable bottom converter.

SUMMARY AND CONCLUSIONS

A novel MgO castable has been developed and used for the converters hot bottom exchange. Easy and faster installation was attained with this technology. Trials conducted in steel shops showed safety and reliability with this new procedure.

A resin basic castable was installed by pumping from the bottom to the top of the converter and it was delivered as a R2U castable with no segregation. New rheology challenges had to be overcome to keep original properties after transportation and storing.

A new procedure for bottom exchanges was adopted by the customer with this R2U castable. R2U castables have also been applied for hot repairing of wells and plug blocks for steel ladles and BOF critical areas.

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Author's Note: This paper was previously presented in the proceedings of the 51st International Colloquium on Refractories, Aachen. Germany (2008).

TRI News Continued from Page 4

While the IARC proposal has no immediate effect on existing regulatory requirements, it clearly provides more impetus for OSHA to continue work on its pending crystalline silica regulation and opens the door for more scrutiny from EPA and other agencies concerned with silica exposures beyond the workplace.

REVISED STANDARD FOR NONMETALLIC MINERAL PROCESSING ANNOUNCED

EPA announced a final rule April 21 that will tighten limits on particulate emissions from new or modified nonmetallic minerals processing operations. The final rule amends the new source performance standards (NSPS) at 40 C.F.R. Part 60, lowering the particulate matter emissions standard for nonmetallic minerals processing plants to 0.014 grain per dry standard cubic foot (gr/dscf), down from the current 0.022 gr/dscf.

NSPS mandate the emissions control technology for new and reconstructed stationary sources of air pollution. The final rule would also lower the fugitive emissions opacity limit for crushers without emissions capture systems at the processing plants from 15 percent to 12 percent. For all other emissions sources, such as grinding mills, screening operations, bucket elevators, belt conveyors, bagging operations, storage bins, and enclosed truck or railcar loading stations, the opacity limit would be 7 percent, down from 10 percent previously.

The final rule would require periodic emissions monitoring of baghouses and water sprays used to control particulate matter emissions. Testing also would be required every five years to assure that fugitive emissions that are not being controlled by the water sprays are being reduced. Wet material processing operations are exempted from the final rule's emissions control requirements.

OSHA ACTING CHIEF NAMED

Secretary of Labor Hilda Solis has named Jordan Barab acting assistant secretary of the Occupational Safety and Health Administration (OSHA). Mr. Barab most recently worked for the House Education and Labor Committee. He spent sixteen years working as safety director of the American Federation of State, County, and Municipal Employees and also wrote a blog entitled "Confined Space" from 2003-2007.

Industry News

US DEMAND FOR SPECIALTY SILICAS

To reach $1.7 billion in 2013 US specialty silica demand is projected to increase 3.7 percent per year to $1.7 billion in 2013, led by healthy advances in the large precipitated silica segment. Overall volume gains are forecast to accelerate from the pace of the 2003-2008 period, benefitting from an expected rebound in nondurable goods output through 2013. Advances in market value will be limited by a significant moderation in specialty silica pricing. These and other trends are presented in Specialty Silicas, a new study from The Freedonia Group, Inc., a Cleveland-based industry research firm.

Precipitated silica accounts for the largest share of specialty silica demand in both volume and value terms. This silica type will also constitute the fastest-growing segment of the market, aided by above-average gains in its primary market -- tire rubber. Increasing use of precipitated silica as a replacement for carbon black in tire reinforcement applications in the US will offer significant opportunities for growth.

Fumed silica represents the second largest product type in value terms, owing to its higher price relative to other silica types. Demand for fumed silica is expected to be healthy, benefitting from gains in small volume markets such as plastics, adhesives and sealants, cosmetics and toiletries, and food and beverages. However, growth in the large electronics market -- where fumed silica finds use in chemical mechanical planarization slurries -- will slow significantly from the pace of the previous decade, restrained by changes in electronics technology, competition from nonsilica materials and greater electronics production in Asia.

The rubber industry is projected to remain the largest specialty silica market through 2013. All types of silica are used in rubber applications, but demand is dominated by precipitated silica, with fumed and fused types also accounting for appreciable shares of demand. Above-average advances will reflect greater use of precipitated silica in the production of "green" tires, which offer increased fuel efficiency and enhanced performance relative to conventional carbon black tires. The cosmetics and toiletries market, which represents the second largest market in value terms, will also advance at an above-average pace through 2013.

For further details, please contact Corinne Gangloff by phone 440.684.9600, fax 440.646.0484 or e-mail pr@freedoniagroup.com. Information may also be obtained through www.freedoniagroup.com.

US SPECIALTY SILICA DEMAND
(million dollars)

Item	2003	2008	2013	% Annual Growth 2003-2008	% Annual Growth 2008-2013
Specialty Silica Demand	1070	1420	1700	5.8	3.7
Precipitated Silica	446	590	740	5.8	4.6
Fumed Silica	318	425	510	6.0	3.7
Silica Gel	174	235	254	6.2	1.6
Silica Sol	89	117	137	5.6	3.2
Fused Silica	43	53	59	4.3	2.2

PUTZMEISTER CONCRETE PUMPS GMBH APPOINTS NEW CEO

Effective immediately, Ralf von Baer will oversee sales and marketing at PCP while simultaneously upholding his CEO responsibilities for Putzmeister Holding GmbH (PMH).

"With his five years experience at PMH Ralf will focus on the PM Group and their organizational methods while integrating effective management teams at different levels," says Karl Schlecht, chairman of the Putzmeister Supervisory Board and KS Foundation. "As Putzmeister's past has confirmed, our success is largely based on the innovative technology and the high quality of products we deliver. The drive and commitment behind our innovative technology must start from the top and I know Ralf will continue to help drive that."

DAN MARTIN NAMED WESTERN REGIONAL SALES MANAGER

Allentown Shotcrete Technology, Inc. announces the addition of Dan Martin as western regional sales manager. Martin's primary responsibility will be introducing core products and mortar equipment throughout the western United States. Martin will report directly to Allentown's president, Patrick Bridger.

"Allentown has been busy evaluating processes over the past few months with a goal of becoming even more efficient and to provide even better service to both Putzmeister and Allentown customers," says Bridger. "Dan has vast knowledge of Putzmeister's small line equipment and we have no doubt he will easily transfer that knowledge to the Allentown product line. We're thrilled to have him on our team," says Bridger.

JAMES ROGERS NAMED PUTZMEISTER AMERICA, INC.'S 2008 REGIONAL SALES MANAGER OF THE YEAR

Bill Dwyer, Putzmeister America's vice president – sales & marketing, presented the 2008 RSM of the Year award to James Rogers during the World of Concrete in February.

"James' commitment to Putzmeister America's customers is outstanding," says Dwyer. "From state to state within his region he diligently works with current customers to ensure their full satisfaction of equipment and support, while also prospecting new customers. His continuing customer dedication and service is why he continues to produce consistent sales within his region from year to year."

Employed by Putzmeister America since August 2006, Rogers handles concrete pump and Telebelt® sales within the company's Southeast region.

Dwyer adds, "Beyond his enthusiastic sales style, James is also a dependable and positive employee who is a strong team player."

For more information contact: Kelly Hayes, Marketing Services Manager, (262) 884-6387, www.putzmeister.com..

ASTM International Committee C08 on Refractories honors Louis J. Trostel Jr.

J.P. Willi and Louis J. Trostel Jr.

ASTM International Committee C08 held its 192nd meeting in St. Louis on March 24, 2009 prior to the 45th St. Louis Refractory Symposium. The highlight of the meeting was the recognition of Louis J. Trostel, Jr. for his fifty years of volunteer membership. Lou was presented with a mantle clock commemorating his membership from 1959 to 2009 and a framed congratulatory letter from the President of ASTM International. Throughout his fifty years of service, Lou has held several official positions on C08. Like his father before him, Lou was committee secretary and, also, served as chairman from 1994 to 2000. Lou is very active in international refractories standards having served as chair of C08's International Standards Committee from 1988 to 1994 and is currently a convener of a working group within ISO/TC 33 as part of the U.S. Technical Advisory Group to the International Standards Organization Technical Committee on Refractories. Lou was presented with the ASTM Award of Merit and made a Fellow of ASTM in 1976. In 2008, Committee C08 named its Distinguished Service Award after Lou to honor his outstanding contributions to the committee.

In addition to his service to ASTM, Lou has contributed much to the American Ceramic Society since joining in 1949. He has continuously served the Executive Committee of the Refractory Ceramics Division since 1981, as chairman in 1985-86 and as Trustee for the division from 1993 to 2002. Lou currently serves as the Division Councilor. Lou's other service to ACerS includes work on the Editorial Advisory Board and its chairman in 1980-81 and as chair of the Nomenclature Committee from 1985 to 1989. At home in Massachusetts, Lou is active in the New England Section of ACerS which he joined in 1955. Lou has served in all of the offices of the section including chairman and currently is the Section Councilor.

Among Lou's many awards he is a Fellow of ACerS, has received the New England Section's F.H. Norton Award for Distinguished New England Ceramist in 1982, the St. Louis Section's T.L. Planje Refractories Award in 1996 and The Refractories Institute's William T. Tredennick Award in 2002. In addition Lou was elected as a Distinguished Life Member of UNITECR.

For a man who has a humble disposition, Lou has distinguished himself as a servant of the refractories industry that deserves our great appreciation for all he has done.

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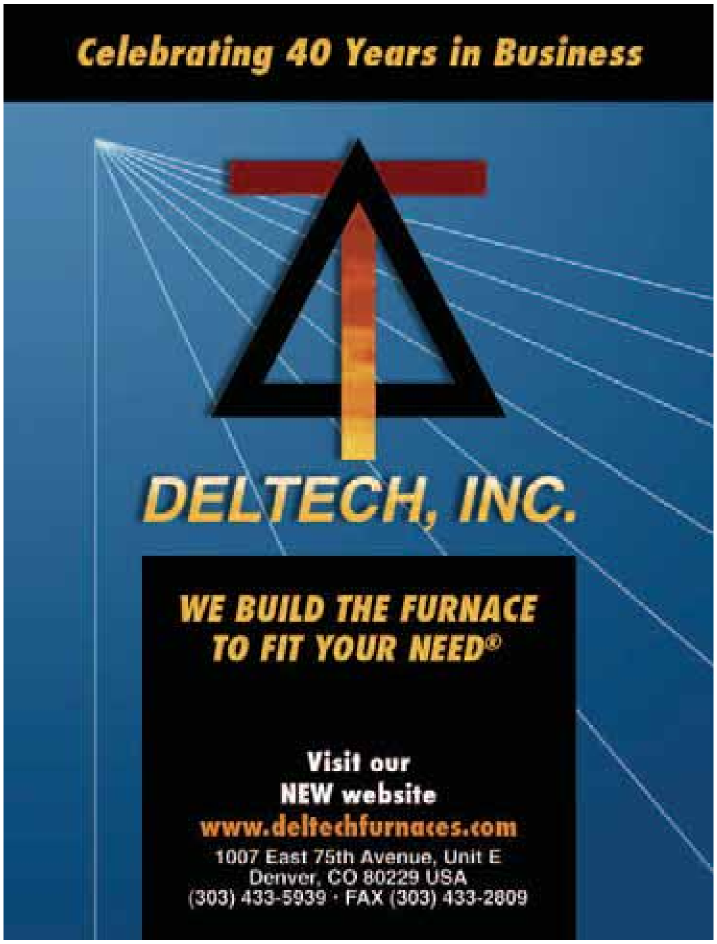
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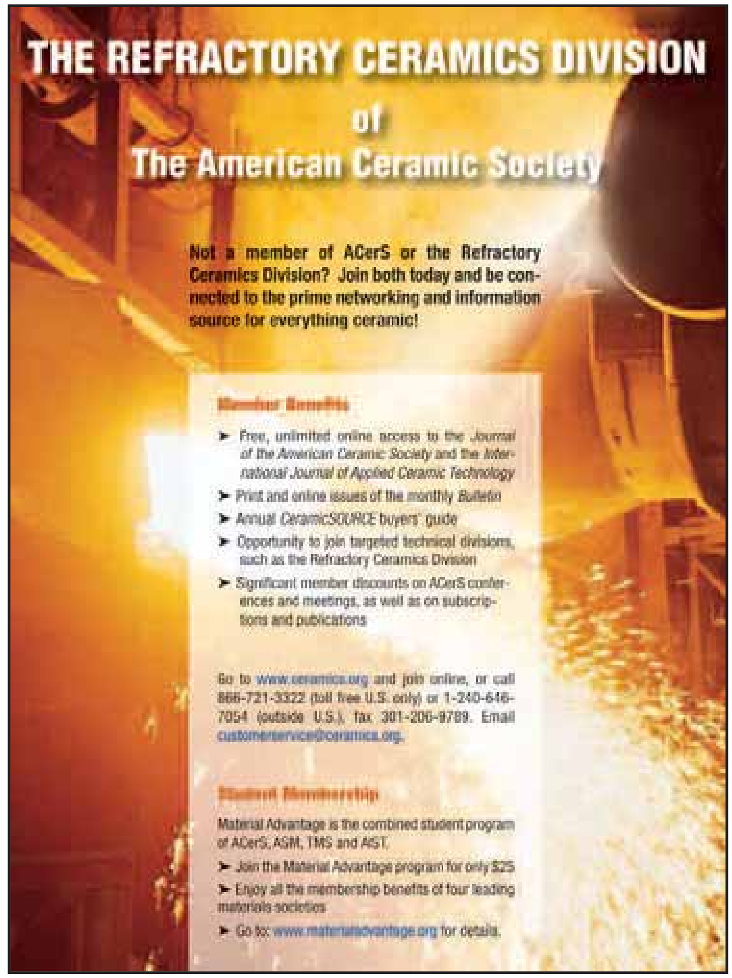
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Lecturer: **Prof. Dr. Victor C. Pandolfelli** - Tuesday 13 October, all day. Sponsors: **FIRE - ALAFAR**

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Attention UNITECR Attendees

We have been advised of an additional requirement to supplement the information in the January newsletter concerning Brazilian visas for UNITECR 2009. You must make entry into Brazil **within 90 days** of the date of the application approval. Therefore, you should not apply too early. Based on the October 13 date for the start of UNITECR, you may want to mark **July 15** on your calendars as the day to apply. That gives you the maximum time while meeting the 90 day requirement.