THE REFRACTORIES ENGINEER

September 2016 www.ireng.org THE OFFICIAL JOURNAL OF THE INSTITUTE OF REFRACTORIES ENGINEERS

Institute of Refractories Engineers Conference and Training Day 2016

Annual Conference Wednesday 12th October

SILVER LININGS, ADDING VALUE

Programme

ArcelorMittal Dofasco – Tom Vert, Vice President Manufacturing – *What do Steelmakers really want... how refractory suppliers can add value*

British Steel / LISI – Dave Collins / Stuart Woodliffe – *Queen Anne Blast Furnace Reline*

UK Steel-EEF/ISSB – Richard White – *UK Steel Industry and its future*

Pahage – Ashley Webster, Director – topic to be confirmed

Almatis – Sebastian Klaus, Application & Market Development Engineer – *Fused & Sintered Aggregates*

Elkem – Dr Hong Peng, research Scientist – *Cement Free Castables*

Dupre Minerals – Andrew Baylay – *Perlite & Vermiculite, Sources, Quality & applications*

Kerneos – Fabien Simonin

PLACES STILL AVAILABLE

See inside

Training Day Thursday 13th October

HEAT FLOW AND THERMAL EXPANSION

Elkem Silicon Materials

- not a conventional raw material supplier ….

Elkem's mission is to contribute to a sustainable future by providing advanced silicon and carbon solutions, creating value for our stakeholders globally.

Elkem has been a proud supplier to the refractory industry for more than 40 years. Our main product families, Elkem Microsilica®, Si-NINE (silicon powders) and recently the SioxX®-range, are well known to the industry.

But, we offer more….

- **R&D and application technology provider**
  - Competent technical staff, 100 technical papers presented at international refractory conferences
  - Core competence in micro-particle technology, high temperature processes and equipment, material characterisation and refractory technology
  - Laboratories in Norway, China and India for local adaption
  - Joint development projects with customers and academia
  - Technical support in product development

- **Production, processes & supply chain - Optimised value chain**
  - 110 years of experience in electro-smelting technology and production
  - In-house key raw material sources
  - Highest level of quality maintained through SPC and extensive QC testing in “real” refractory formulations
  - JIT delivery through optimised logistics solutions

- **Caring for the environment**
  - Smelting plants run on 100% renewable electric hydro-power
  - Heavy investments in heat recovery systems
  - Rebuilding to reduce NO_x emissions

Elkem’s future is carbon neutral production – an ambitious project with the goal to produce without net CO_2 emissions and without a net supply of energy is on-going

For more information, please contact us:

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Elkem
A Bluestar Company

THE REFRACTORIES ENGINEER

The Institute of Refractories Engineers is dedicated to fostering the science, technology and skills of refractories engineering and to serving the needs of refractories engineers worldwide.

Aims: To raise the standard of ability and training in this field of science and technology. To promote and maintain the character, status and interest of members of the Institute. To disseminate information, facts, ideas, news or suggestions that may be of interest to members. To encourage the exchange of ideas and information among members to their benefit and to the benefit of the industries they serve.

The Institute is a non-profit making body and its entire income is applied solely to the promotion of these aims.

General Secretary's Report

Dear Members

By the time this journal reaches you I am sure you will all be refreshed from your summer holidays.

This journal is being distributed at Aachen, the 7th international symposium on refractories in China and our own Annual Conference and Training Day. We are printing almost a 1000 extra copies of this journal.

Representatives from the Australian Branch will be manning a small stand at symposium on refractories, where we hope we can raise our profile in Asia and recruit some new members, considering the size of refractory production and sales markets in Asia our membership levels are very low. If you are attending this event please call at the stand.

If you have not booked for the Annual Conference and Training Day please book ASAP to avoid disappointment we have some excellent speakers this year and it would be a shame to miss out.

There has been a much high demand for places this year. We have been able to advertise the conference in several other journals that are connected with our industry this year as well as our own journal

I am still trying to put together a contact directory for our members but still need of a lot of email addresses from yourselves, please send me your email addresses then I will send you your invoice to make a card payment in the future, please email me at secretary@ireng.org if you have not already done so.

The journal is always on the looking for technical papers for publishing in the journal so if you are interested in having a paper published please contact me on my usual email.

We are busy getting the conference organised, there are still some spaces for both conference day and training day, we also have spaces for some small stands in the reception area if you or your company would like to advertise, Jon Masding's team will be selling this space, so please contact Imedia if you would like to buy some advertising space.

I hope to see you at the conference.

Jayne Woodhead,
General Secretary & Treasurer
Institute of Refractories Engineers

President's Column

Hello Members and Colleagues

Welcome and I hope you have had a good summer and hopefully enjoyed your holidays.

I have previously spoken about the many varied end products where refractories are used in the manufacturing process, from glass to wind farms and plastics to paper. I've also spoken about the wonder that children have at how things are made, the processes used for high technology items and the history behind it all. Something that we should remind ourselves of from time to time. Recently I was reminded of this by two examples at opposite ends of the scale. One was during a visit to an aluminium foundry that was making high technology components for luxury vehicles, including the new Aston Martin DB11. It really was refreshing to see refractories being used to help make things which can only be described as cool. Fancy that, refractories can be cool! (I know, I know, I'm still a child when it comes to anything with an engine). At the other extreme it was fascinating to watch a documentary with my son about the humble baked bean can where the steel making process featured prominently but also the secondary and forming processes which rely on the quality and type of metal used. The look of awe on both the presenters and my son's face from when the BOS was running all the way through to processing at the sheet plant, reminded me of the faces of visitors and new starters that I used to take around the steel works. Perhaps every steel worker and refractory engineer has had that look and feeling of wonder on their first day. It does us no harm at all to remind ourselves that even the most mundane items which we may think are simple to produce, have a huge amount of effort and technology put into them. After all, the humble tin can is often the base load for many integrated steel plants.

As you return hopefully refreshed from your summer holidays, thoughts turn to the remainder of 2016 for many of us and what 2017 will bring whether it's planning your next holiday, working on your next project or starting to think about pulling next year's budgets together.

This is no different for the IRE and whilst we don't have holiday plans we've been working on the future.

In August a very positive meeting was held with the North West branch committee to explore where the executive / council could assist the branch more effectively. It was agreed that the branch would be supported better not only from the executive / council but also from neighbouring branches during 2017. The branch is looking for people to help on the committee so if you are interested please contact one of your branch officials or the General Secretary for more details.

By the time you read this the Sheffield branch AGM should have been held after several delays. Hopefully this important branch will have had new life breathed into it. The next step will be to look to the next year's branch program and how the branch will function. I dare say that some of the ideas that were discussed with / raised by the North West branch committee could also be applied in the Sheffield branch, and I will be raising these points at the Sheffield branch AGM.

Support for local and national events is vital, not only for and from the membership but also from the executive / council. Local branches around the world represent the grass roots of the IRE and we should be doing everything we can to support them. The IRE is here for you, the members, and I would like to again encourage all members to get involved, go to technical meetings, go to social events, pass the journal around and please book your place at the conference and / or the training day.

Speaking of conference and the training day, it's almost here and I'm looking forward to meeting faces old and new. If you haven't booked yet there is still time and you can contact Jayne Woodhead to ensure your place as soon as possible. Remember that the training day is on a separate day to conference so you can easily attend both.

See you there!

Callum Arthur
President
Institute of Refractories Engineers

Company News

Management Team changes at Ancorite

Ancorite Surface Protection Ltd, specialists in refractory and process linings, coatings and finishes, have announced the recent retirement of Managing Director, Neil McConnell. Neil joined Ancorite as Contracts Manager in 1988, before becoming Operations Director and then Managing Director in 2013. Ancorite has grown substantially under Neil's leadership and the team wishes him a long and well-earned retirement.

Andy Cummings, formerly Contracts Director, has been appointed Managing Director, with Anthony Frain and David Clegg joining the board alongside Financial Director, Alison Smith. The new team has recently been strengthened by securing Gary Doran as Senior Contracts Manager. Gary also brings with him a wealth of industrial experience.

Andy Cummings paid tribute to Neil's contribution to the company's success, during his twenty eight years with Ancorite, commenting that the new management team is looking to build on strong foundations and to continue Ancorite's development in the coming years.

Pictured here (left to right) are Alison Smith - Financial Director, Andy Cummings - Managing Director, Anthony Frain - Contracts Director and David Clegg - Sales Director

MAYERTON

Mayerton celebrates 25 years of trading

Established in 1991, Mayerton is celebrating 25 years of trading.

Mayerton Refractories is a leading global manufacturer and supplier of high quality refractories and tailor-made refractory solutions for the iron and steel industry and other refractory consuming industries worldwide including India/Asia; China; UK & Europe; Russia/CIS and Mexico.

The Company was established by Dieter Beckmann and is jointly run today by his son and daughter, Christopher Beckmann & Corinna Beckmann-Clarkson.

A family business that has evolved into a renowned quality refractories supplier, having its own manufacturing plant in China and long serving employees, agents and consultants across the globe forming the company today that we are all very proud of.

We have loyal and valued Customers who appreciate the difference that Mayerton makes, with our strong technical knowledge; our desire to cater for our clients' bespoke requirements and ability to offer value engineering solutions from our highly competent and skilled global technical team, engineers, site services and sales staff, backed by our highly dedicated and experienced support staff.

Institute News

Institute of Refractories Engineers Conference and Training Day 2016

Venue: Tankersley Manor, Church Lane, Tankersley, Barnsley, South Yorkshire S75 3DQ. Tel: 01226 744 700

Annual Conference Wednesday 12th October

SILVER LININGS, ADDING VALUE

Conference Day Member £95.00
Conference Day Non Member £115.00
Conference Dinner including VAT £32.00
Training Day Member £70.00
Training Day Non Member £95.00
1 Night Bed & Breakfast £84.00

Additional nights accommodation can be booked at £84.00 per night.

To make bookings please contact Jayne Woodhead on secretary@ireng.org or telephone 01782 310234.

Places are limited so please book early.

Institute of Refractories Engineers Conference and Training Day 2016

Training Day Thursday 13th October

HEAT FLOW AND THERMAL EXPANSION

Refractory materials are used to provide containment for high temperature processes. An understanding of how heat flows through a refractory lining and the thermal expansion of the refractory lining is critical to safe and effective design and operation of process plant.

This course will provide a working knowledge of the calculation of thermal gradients and thermal expansion allowances and is aimed at personnel who design linings and select and specify materials of construction. No knowledge of refractory materials is required.

Course content

- **Introduction**
- **What is Thermal Conductivity and Thermal Expansion**
- **Thermal Gradient Calculation and Heat Transfer**
- **Thermal Expansion Calculation and Allowance**
- **Application of Thermal Calculations**

The course will be made up of lecture and small group problem solving sessions which will reinforce the key points.

Conference and Training Day Booking Form

Name..Company ....

Tel.................................Fax.................................Email.................................

Postal Address..

....

Conference Fees Members .... ☐ £95.00

Wednesday 12/10/15 Non Members.......... ☐ £115.00

(Includes lunch) Student/Retired .... ☐ £50.00

Conference Dinner All Welcome .... ☐ £32.00

Wednesday 12/10/15 7-00 for 7-30pm

(Including wine)

Training Day

Thursday 13/10/14 Members .... ☐ £70.00

(Includes lunch and refreshments) Non Members.......... ☐ £95.00

1 Night Bed & Breakfast .... ☐ £84.00

Total Payable..

I enclose a cheque payable to

INSTITUTE OF REFRACTORIES ENGINEERS ☐

Visa/Mastercard/Switch/Delta ☐ Please tick

(delete as necessary)

Card No ....

Expiry Date ....

Valid From ....

Issue No..

Security Code ....

Signature..

Places are limited

To reserve a place please contact the IRE General Secretary - email secretary@ireng.org or send the attached form to **Mrs J. Woodhead, General Secretary & Treasurer, The Institute of Refractories Engineers, 575 Trentham Road, Blurton, Stoke-on-Trent, Staffs ST3 3BN. Tel/fax 0044 (0) 1782 310234**

INSTITUTE OF REFRACTORIES ENGINEERS
www.ireng.org

APPLICATION FOR MEMBERSHIP

Name	
Tel	Fax
Email	Date of birth
Full postal address	
Company	
Address	
Business of Company	

Details of past and present employment in connection with Refractories.
Information given in this section is to enable Council to assess your experiences in the Design, Erection or Maintenance of Refractory Structures. Please give full details of each position held stating the number of years served and indicating where supervisory duties were involved.

If necessary, continue on a separate page

Training – in order to support your application please add details of examinations passed, courses attended, or memberships of any other Institutes or other Professional bodies.

Declaration
I declare that the details given above and on any attachments hereto are correct in every respect. I agree to be bound by the rules of the Institute, and understand that the grade of membership to which I shall be offered admittance shall be the decision of the Council.

Signature	Date

We declare that the details submitted by the applicant are, to the best of our knowledge, correct.

Name
Position
Company
Name
Position
Company

This Application form should be signed by an Executive of your own company, and a member of the Institute and submitted to:-
Mrs J. Woodhead, General Secretary and Treasurer,
575 Trentham, Road, Blurton, Stoke on Trent, Staffs ST3 3BN
Tel/fax 0044 (0) 1782 310234
email jaynewoodhead@ireng.org
www.ireng.org

Notice is hereby given that the

55th Annual General Meeting of the Institute of Refractories Engineers

will be held at 12.30 on WEDNESDAY 12th October
at Tankersley Manor, Church Lane, Tankersley Barnsley S75 3DQ UK

President Mr C Arthur will preside
By order of the General Council

AGENDA

1. To receive apologies

2. To approve the Minutes of the 54th Annual General Meeting held on 7th October 2015 at Tankersley Manor Barnsley.

3. To approve the General Council's appointment of Officers of the Institute for the year 2016/2017

President	2015/2017 Mr C Arthur
Senior Vice President	2016/2017

4a. To re-elect Members of Council.

4b. To elect any other members of Council nominated prior to the meeting date.

5. To receive a joint report from the Chairman of the Executive Committee and the General Secretary on the Management and Operations of the Institute.

6. To approve General Council's recommendation that the published audited accounts for the period ended 31st December 2015 to be accepted.

7. To approve the General Council's recommendation that the subscriptions for 2017 is as follows

Full Members	£68.00
Members under 25 undergoing training (UK based)	£25.00
Members under 25 undergoing training (overseas based)	£34.00

Full time students under 25 year on qualifying courses and residing in the UK are proposed to be admitted free of charge.

8. To appoint Short's Accountants (Sheffield) as the Institute's accountants for the financial year 2017

Any amendments to this agenda will be posted on the Institute's website www.ireng.org not later than two weeks prior to the meeting

Members who wish to record votes on any item on the Agenda and who cannot themselves be present at the Annual general Meeting may arrange with the General Secretary, or with any members of the Council, to vote on their behalf by proxy.

If it is any member's intention to vote they should furnish the General Secretary with instructions, in writing, giving full details of the item on the Agenda they are concerned with. And whom they wish to appoint as their proxy.

Any member not attending the Annual General Meeting, and not arranging such a proxy vote, will be deemed to be in favour of all resolutions, approved at the Annual General Meeting by the members there present.

DRAFT INCOME AND EXPENDITURE ACCOUNT
YEAR ENDED 31 DECEMBER 2015

	Note	2015 £	2015 £	2014 £	2014 £
INCOME					
Subscriptions and entrance fees			18,474		20,060
Journal advertising			48,664		45,484
E-directory			4,662		3,345
Conference fees			13,179		3,341
Training			1,655		1,976
Bank interest received			953		1,072
Branch social fund raising			17,195		9,930
			104,782		85,208
EXPENSES					
Meeting expenses		933		998	
National Dinner Dance		-		100	
Branch social events		16,142		11,503	
		17,075		12,601	
Journal					
Journal printing and distribution		39,187		40,557	
Journal e-directory		-		30	
Editorial costs		9,438		9,442	
		48,625		50,029	
Depreciation					
President's regalia		-		-	
		-		-	
Other expenses					
Telephone		458		420	
Computer expenses		793		1,590	
Printing, stationery and postage		3,345		1,112	
General Secretary and office expenses		3,970		5,189	
Insurance		1,012		1,088	
Conference and exhibition costs		14,749		4,184	
Credit card and bank charges		1,103		1,058	
General Secretary		11,566		11,144	
Branch Secretaries' honoraria		100		525	
Presidents honoraria		850		-	
Marketing costs		462		475	
Training		215		1,453	
Accountancy support fees		350		462	
Audit & accountancy fees		2,380		2,297	
Bad and doubtful debts		2,048		6,330	
Mileage		1,294		937	
Exchange rate difference		2,554		1,205	
		47,249		39,469	
			112,949		102,099
NET DEFICIT FOR THE PERIOD			(8,167)		(16,891)

DRAFT BALANCE SHEET 31 DECEMBER 2015

	Note	2015 £	2015 £	2014 £	2014 £
FIXED ASSETS	2		-		-
CURRENT ASSETS					
Debtors	3	13,921		16,358	
Bank deposit accounts		105,448		110,712	
Cash at bank		43,983		40,525	
		163,352		167,595	
CURRENT LIABILITIES					
Creditors	4	5,020		3,117	
NET CURRENT ASSETS			158,332		164,478
NET ASSETS			158,332		164,478
FINANCED BY:					
CAPITAL ACCOUNT					
Original balance brought forward			164,478		181,369
Net deficit for the period			(8,167)		(16,891)
			156,311		164,478

These draft financial statements were approved by Council for circulation to members pending final audited approval.

The Members of the Council acknowledge their responsibilities for:

(i) ensuring that the Institute keeps proper accounting records which comply with the Rules; and

(ii) preparing financial statements which give a true and fair view of the state of affairs of the Institute as at the end of the financial year and of its surplus for the financial year in accordance with the requirements of the Rules.

These financial statements have been prepared in accordance with the Financial Reporting Standard for Smaller Entities (effective April 2008).

The finalised audited accounts will be published in the September 2015 issue of The Refractories Engineer.

P Bottomley. Chairman of the Executive Committee

NOTES TO THE FINANCIAL STATEMENTS
FOR THE YEAR ENDED 31 DECEMBER 2015

1. **Accounting policies**

Basis of accounting
The financial statements have been prepared under the historical cost convention, and in accordance with the Financial Reporting Standard for Smaller Entities (effective April 2008).

Cash flow statement
In the opinion of the Council the Institute qualifies as a small entity and accordingly a cash flow statement is not required.

Income
The subscription and entrance fees income represents the amounts due from members for the period after adjusting for subscriptions in advance.
The journal advertising income represents the amounts due for the period for services provided, exclusive of Value Added Tax.
All other income represents amounts due for the period for services provided.

Depreciation

Depreciation is calculated so as to write off the cost of an asset, less its estimated residual value, over the useful economic life of that asset as follows:

Presidents regalia - 5% straight line basis

Stocks

Stocks are valued at the lower of cost and net realisable value, after making due allowance for obsolete and slow moving items.

UK Branches

All income, expenses, assets and liabilities for the UK branches for the year ended 31 December 2015 and year ended 31 December 2014 are recognised in full within the financial statements.

Australia Branch

All income, expenses, assets and liabilities for the Australian branch for the years ended 31 December 2015 and 2014 are recognised in full within the financial statements after being translated at the appropriate exchange rate

South Africa Branch

The net contribution paid to the UK is recognised as income. No assets or liabilities of the branch are shown within the financial statements.

2. Tangible fixed assets

	President's regalia
	£
Cost	
At 31 December 2014 and 31 December 2015	788
Depreciation	
At 31 December 2014 and 31 December 2015	788
Net book value	
At 31 December 2014 and 31 December 2015	-

3. Debtors

	2015	2014
	£	£
Trade Debtors		
Advertising debtors	9,322	11,566
Subscriptions overdue	1,507	439
Buyers Guide debtors	1,135	1,134
Conference fees debtors	44	1,648
	12,008	14,787
Provision against bad and doubtful debts	-	-
	12,008	14,787
Other debtors	1,913	1,571
	13,921	16,358

4. Creditors: Amounts falling due within one year

	2015	2014
	£	£
Creditors and accrued charges	5,020	3,117

5. Contributions in the event of a winding up

Every member of the Institute undertakes to contribute to the assets of the Institute in the event of its being wound up. This applies while he is a member or within one year afterwards for payment of the debts and liabilities of the Institute contracted before he ceases to be a member and of the costs, charges and expenses of winding up and for the adjustment of rights of the contribution amongst themselves such amount as may be required not exceeding one year's annual subscription.

6. Taxation

The Institute's mutual income (subscriptions and conference fees) is not chargeable to corporation tax.

No tax charge arose on the remaining income in the year and as at 31 December 2015 corporation tax losses carried forward totalled £118,227.

BRANCH INCOME AND EXPENDITURE ACCOUNTS 2015

	Main Institute	NW Branch	Sheffield	Stoke	Australia	Cons.Adj	Total
	£	£	£	£	£	£	£
INCOME							
Subscriptions and entrance fees	18,205				2,969	(2,700)	18,474
Journal advertising	48,664						48,664
E-directory	4,662						4,662
Conference fees	2,150				11,029		13,179
Training	1,655						1,655
Bank interest received	93				860		953
Branch social fund raising	5,638	9,270	1,228	1,059			17,195
Total Income	81,067	9,270	1,228	1,059	14,858	(2,700)	104,782
EXPENSES							
Meeting expenses	757		176				933
National Dinner Dance							-
Branch social events	5,474	8,819	1,103	746			16,142
Journal							
Journal printing and distribution	39,187						39,187
Journal E-Directory	-						-
Editorial costs	9,438						9,438
Other expenses							
Telephone	458						458
Computer expenses	793						793
Printing, stationery and postage	3,276			69			3,345
General Secretary and office expenses				60	3,910		3,970
Insurance	577				435		1,012
Payments/Grants to branches					2,700	(2,700)	-
Conference and exhibition costs	2,719				12,030		14,749
Credit card and bank charges	1,103						1,103
General Secretary	11,566						11,566
Presidents honoraria	850						850
Branch Secretaries' honoraria	100						100
Marketing costs	462						462
Training	215						215
Accountancy support fees	350						350
Audit & accountancy fees	2,100				280		2,380
Bad and doubtful debts	2,048						2,048
Mileage	1,294						1,294
Exchange rate difference	-				2,554		2,554
Total Expenses	82,767	8,819	1,279	875	21,909	(2,700)	112,949
NET SURPLUS/ (DEFICIT) FOR THE PERIOD	(1,700)	451	(51)	184	(7,051)	-	(8,167)

Improving the performance of a lime kiln burning zone with a layer of structural refractory insulation

By Mario Taddeo * Michael Dubokovich **

Synopsis:

The burning zone of rotary lime kilns produces the highest process temperatures for the dissociation of calcium carbonate. This region also has the highest shell temperatures, which is increased further with the selection of higher quality brick to cope with higher thermal, mechanical and chemical stresses. The resulting excess shell temperature can cause shell deformation, loosening of the refractory lining, rotational and migration issues concerning the tyre as well as increased energy consumption.

This paper addresses the above problem of significantly reducing heat loss of the kiln shell by selecting a 13mm thick, dense, structural insulation refractory board to be installed between the wear lining and the shell to maintain vessel capacity or open cross-sectional area while reducing shell temperatures.

An insulation lining trial was carried out at Boral Cement (Marulan South, NSW Australia) Lime Operations and included comparative assessments of; shell temperature, tyre migration, ovality, wear lining erosion rate and energy consumption.

The data shows a sustained shell temperature reduction greater than 60°C over 2.5 years, without any adverse effect on refractory wear or kiln operations. Based on this, the calculation of saving 0.3GJ/tonne looks achievable when up to 55% of the kiln's length has insulation. Greater thermal energy retained within the kiln also allows for the option of increased throughput.

This work is significant in proving a twin lining system incorporating a thin refractory insulation board of special thermo-mechanical properties offers sustained shell temperature reduction and energy savings without affecting refractory erosion or operational performance.

Key Words: ISOMAG® 70XCO; Structural Insulation Board; Working Lining Brick; Refractory; Shell Temperature Measurement; Lime Kiln, GJ/t Reduction;

* Sales Manager (ISOMAG®) Asia Pacific - Pyrotek Canada. (Wollongong, NSW Australia).

** Refractory Project Engineer- Boral Cement. New Berrima, NSW Australia.

1. Introduction

Boral Cement in Marulan South, NSW (Australia) operate a lime kiln of 3.35m diameter by 84 metres long. It is lined with refractory brick up to 220mm thick. The kiln is supported by 3 riding rings (tyres) each in contact with carrying rollers supported by concrete piers. The typical daily production rate converts 800 tonnes of limestone ($CaCO_3$) to 400 tonnes of lime (CaO).

The performance of this kiln has been improved in part through the selection of better quality refractories. For the hottest zones with most chemical reactions occurring, Magnesia-Alumina spinel brick has been selected. This material has higher chemical inertness and refractoriness, at the expense of higher thermal conductivity.

As a result, burning zones with excessive high shell temperatures can produce the following issues:

- Potential to cause shell deformation and premature replacement,
- Loosening of the refractory lining as a result of shell deformation,
- Over-expansion of the shell and necking within the Tyre,
- Heat stress exposure to plant, equipment and personnel, and
- Higher than normal energy consumption and or green-house gas emissions.

In the case of Boral Cement Marulan, shell temperatures exceeding 450°C were regularly experienced in the Burning Zone, No.1 Tyre Area, and action was required to reduce the shell temperature and related high energy consumption.

The lime and cement producers have limited options to reduce heat loss through the refractory lining, and any changes can have an adverse effect on productivity, operations or refractory performance.

Also, the rotary kiln refractory lining represents the most extreme of dynamic mechanical, thermal, chemical and fatigue forces not seen in any other industry- particularly in the burning zone region.

It is the reason two lining systems in the burning zone operate under high risk and any dedicated insulation lining must have a series of properties that offer complete resistance to the thermo-mechanical-chemical forces.

The potential for failure of an insulation lining would result in loosening and collapse of the lining, causing significant production losses and high costs to repair and restart the Kiln.

ISOMAG® 70XCO Structural insulation board was offered by Pyrotek to Boral based on its unique properties in maintaining its integrity in the rotary kiln environment and its proven history at other Lime producing plants. At 12.7mm in thickness it also did not compromise lining thickness or installation procedure and calculations indicated significant shell temperature reduction was possible.

Assuming this dual lining design has the durability and compatibility to maintain shell temperature reduction and lining stability over the full campaign other potentially adverse effects; such as increase in ovality, refractory spalling, and increased chemical attack will be reviewed during the trial.

2. Rotary lime kiln process & refractory trial

Rotary Lime Kilns are large steel tubes that are lined on the inside with refractory bricks. They are slightly inclined and ride on a set of riding rings (tyres). Limestone rock is introduced at the uphill feed end and slowly makes its way to the discharge end, due to the inclination and rotation of the Kiln. A burner is installed at the discharge end where fuel is burned to form a cylindrical flame. Heat transfer from this flame and the hot combustion gases that flow up the kiln – dries, heats and calcines the counter flowing lime solids. [1]

Rotary Lime recovery kilns typically have four zones (Discharge, Burning, Preheating, Charging) to convert calcium carbonate into calcium oxide, or lime. Refer to Figure 1.

Figure 1: Refractory Zones in a Lime Recovery Kiln

Of these zones the burning and discharge zones are the hottest and thermovision reports prior to the insulation trial also show these zones have very high shell temperatures. This is consistent with both higher quality/ conductive refractories and burning temperatures. As the wear lining erodes, shell temperature becomes more excessive, particularly under the No.1 Tyre at the Burning Zone.

To address the imbalance is problematic; ideally a dedicated insulation lining of minimal thickness and excellent thermo-chemical-mechanical strength must be selected. [2]

An insulating board may seem to be the answer however none so far have offered the exquisite balance of properties required at elevated temperatures including; chemical inertness, thermal elasticity, high hot strength and low conductivity.[2]

3. ISOMAG® 70xco - back up refractory insulation board

As the foundation of the refractory lining, an insulation material must have structural integrity at service temperature. At minimal thickness it maintains vessel operating capacity. A low insulation value also allows for premium or more conductive refractory linings to be selected whilst maintaining low shell temperature.

ISOMAG® 70XCO is a phosphate bonded MgO-SiO_2 structural insulating board, specifically designed for back up refractory lining for demanding thermo-mechanical applications such as beneath the tyre of a Rotary Lime Kiln Burning Zone area . It is unique in having the required properties at elevated temperature including:

- Minimal Shrinkage, with
- High strength, whilst
- Maintaining low thermal conductivity, and
- Thermal elasticity. [3]

Figure 2 below shows ISOMAG® 70XCO has the right the combination of properties and was the reason for its selection in this application.

4. Installation & test procedure

in reviewing all of the above data, ISOMAG® 70XCO 12.7mm board was installed at the No. 1 Tyre Burning Zone of BC (Boral Cement) Marulan's No. 2 rotary lime Kiln shown in figure 3.

The comparison of refractory linings is shown in Table 1.

Tyre No. 1 centre-line is about 8.84m from Kiln discharge end of shell, Figure 3.

The trial area of 3.8m in length (3 rows of 1265 x 76 x12.7mm board) by the full circumference in the burning zone either side of the tyre centreline was selected as shown in figures 4, 5, 6 and 7.

ISOMAG® 70XCO board was installed between 6.4m and 10.2m axial metres, mortared to the shell beneath the 220mm VDZ B222-B422 Magnesia Spinel brick – as shown in figure 5.

The Mag-Spinel Wear Lining bricks were "radially mortared" (with 1mm magnesite mortar joint) on the brick-to-brick faces around the ring for

Product	Max. Service Temp. Limit	Shrinkage at 900°C	Cold Crushing Strength	Hot Crushing Strength at 5% Strain at 500°C
ISOMAG® 70XCO	1050°C	1.64%	15 MPa	17 MPa

Figure 2: Physical properties of ISOMAG® 70XCO. [4]

Lining Material	Standard Lining	Insulated Lining	K Value-600°C	Density
Wear Lining Brick	220mm MgO-Spinel	220mm: MgO-Spinel	3.25 W/m.K	2880 kg/m^3
Insulation Board	-	**13mm ISOMAG®70**	0.31 W/m.K	1250 kg/m^3

Table 1: Refractory Lining - Burning Zone Trial: Standard v/s Insulated Practice

Figure 3: No.1 Tyre in Burning Zone of BC Marulan No.2 Kiln

Figure 4: Picture inside the kiln showing removal of worn brick and shell preparation

Figure 5: Installation of the insulation board across the shell bottom half

Figure 6: Installation of the Mag-Spinel brick on the insulation board below spring line

Figure 7: Installation of the insulation board above the spring line

Figure 8: Installation of the brick on the insulation board completed

added mechanical flexibility in the rings of bricks to aid in resistance of ovality stresses under the tyre at operating temperatures, refer to Figure 6.

Figures 7 and 8 show the final stages of installation of both ISOMAG® 70XCO board and Wear Lining brick. Figure 8 shows the completed installation, with the bricks in the burning zone standing 13mm proud, accommodating the insulation board.

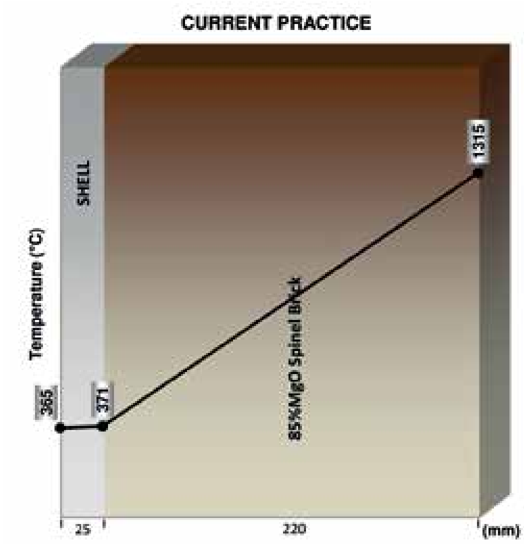

Figure 9: Heat loss calculation: Standard lining, NEW wear lining brick

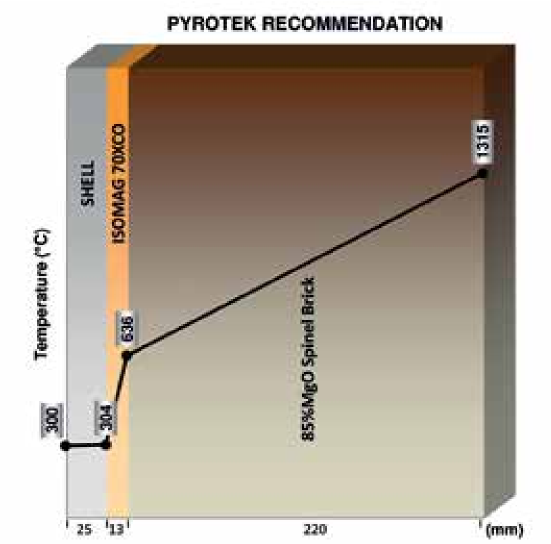

Figure 10: Heat loss calculation: Insulated Lining New wear lining brick. 66°C saving

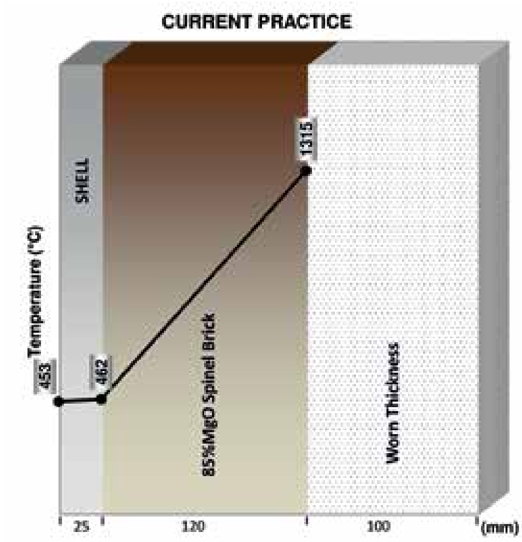

Figure 11: Heat loss calculation: WORN wear lining brick

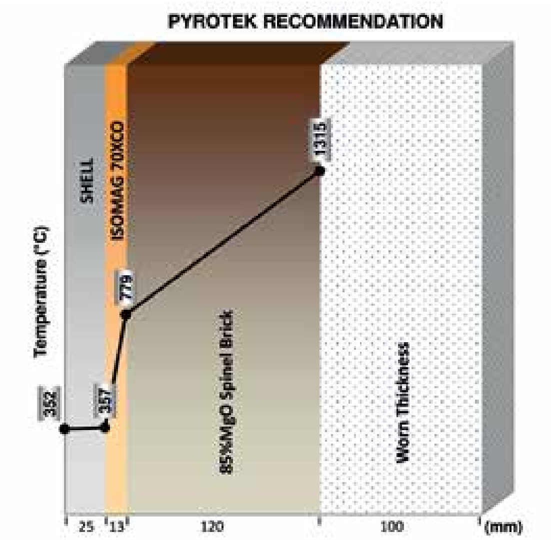

Figure 12: Heat loss calculation: Insulated Lining: WORN wear lining brick. 101°C saving

5. Results & discussion

5.1 Theoretical Calculation Comparison

Figures 9, 10, 11 and 12 show a calculated 1D (steady state) heat loss comparison between the standard lining and insulated lining; with the Wear lining in the new and worn condition. [5]

The calculations measured through conduction represent the major mechanism of heat transfer through the wear lining. The convective heat transfer between brick joints has a minor role and is not included in these calculations.

Figure 9 shows the standard lining in the new condition. The calculated shell temperature is 365°C with an energy loss of 10.5kW/m^2. With 13mm of ISOMAG®70XCO insulation board, the shell temperature and heat loss is calculated to 300°C and 8.1kW/m^2 respectively. This is 66°C cooler and based on a typical heat consumption reduction, they represent a 32% reduction in heat loss from the kiln shell in this zone.

Figures 10 and 11 show the same condition except that the Wear Lining brick is now worn to120mm thick, which simulates end of campaign or high erosion area. With less thickness, the calculated shell temperature is now 453°C. The insulation board proves an even greater benefit in this situation lowering this figure by 101°C to a more tolerable shell temperature of 352°C, with an equivalent 50% energy loss saving.

The above graphs show the calculated effect an insulation board has on the thermal gradient.

Since it is a barrier to heat loss, the Wear Lining brick has a flatter thermal gradient, representing hotter refractories and more retained energy within the refractory lining.

As a result, the wear lining brick accommodates a much higher heat load, having a more uniform temperature throughout its thickness. This results in a more uniform thermal expansion that should promote lining tightness as well as minimize thermal shock and fatigue.

These properties could result in extending its life however it is suspected the chemical and thermo-mechanical operational effects are a greater factor in determining the rate of erosion.

Given the strength and insulating properties of ISOMAG®, a series of shell temperature tests and wear erosion measurements were carried out to confirm the above calculated data.

5.2 Actual Shell Temperature Comparison

Actual field temperature measurements confirm a 25-35% reduction in shell temperature throughout the trial zone relative to those areas which were left as controlled or standard lining practice.

Figure 13 below is a thermograph taken in March 2011 of the burning zone (Pier 1) and tyre section which was toward the end of the refractory campaign. It shows large areas of the kiln shell exceeding 485ºC under the No.1 Tyre, albeit with a refractory approaching its minimum thickness. This value is consistent with the theoretical calculation of 453ºC as shown in Figure 11.

Four months later the burning zone was relined with 220mm of Magnesia Spinel brick and 13mm of Magnesia-Silicate structural insulation board (ISOMAG®70XCO[4]). The effect according to the thermography report is shown in Figure 14. The thermography company stated: "Pier 1 showed a steep decrease with an even distribution of temperatures around the circumference in the range of 355 - 365ºC. This is a decrease of 90 - 120ºC below the previous survey." [6]

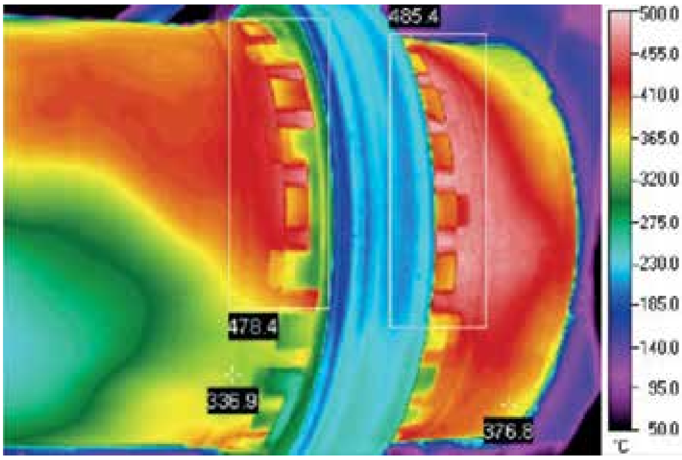

Figure 13: Infrared Thermography picture of burning zone [5] – No Insulation. Temp at 485ºC exceeds control limit. Brick worn to 110mm *Photo taken: March 2011*

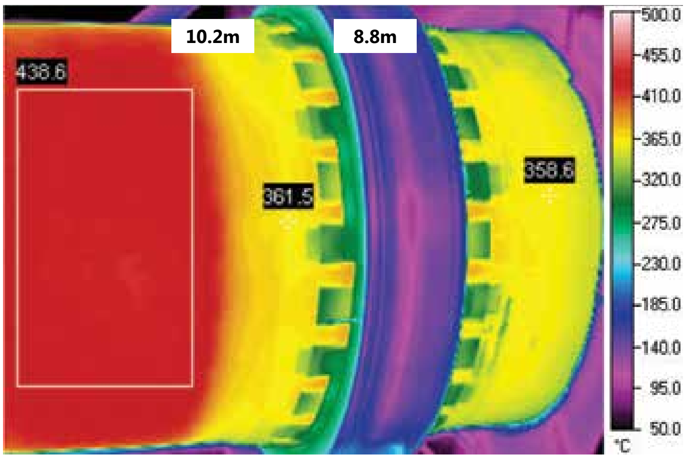

Figure 14: Infrared Thermography picture of burning zone [6] - 13mm ISOMAG Insulation with new Mag Spinel brick (220mm)
Photo taken: September 2011

Figures 15 and 16 showed after 28 months of stop start operation, the shell temperature under the Tyre in the burning zone (6.4 to 10.2m region) has been maintained at an average of 360-370ºC, where the ISOMAG insulation has been installed compared with 420-440ºC without insulation.

The area upstream to this, 10.2 – 13m region, had the same Mag-Spinel brick installed, as new and without insulation, averages 425ºC. As the wear lining becomes more worn, (without insulation) is likely the Shell temperature will exceed the control limit set at 470ºC as shown in Figures 13 and 14, requiring constant vigilance and may result in premature reline.

The shell temperature saving with 13mm ISOMAG®70XCO is therefore calculated to be 75 ºC.

High shell temperatures are also an indication of excessive energy loss.

Figures 16 shows the regions beyond the 13m mark having considerably reduced shell temperature, comparable to the insulated tyre area. This region also contains similar Magnesia spinel and was relined in December 2013 including 12.7mm ISOMAG®70XCO insulation board.

5.3 Reduced Shell Distortion and Necking Risk

Section 5.2 has proven 12.7mm ISOMAG®70XCO insulation board has offered sustained shell temperature reduction over the No.1 Tyre in the central burning zone for more than 2 years.

Lowering the shell temperature will result in less shell distortion. This results in a more uniform or circular shell profile that allows for better keying in of refractories for a more secure lining throughout the campaign.

Also a lower shell temperature also reduces the risk of necking; where expansion of shell exceeds the tyre diameter. Necking can cause catastrophic refractory failure and operational issues as well as potential shell repair/replacement.

Finally, lowering the shell temperature protects surrounding equipment like bearings, drives and also aids operator comfort and safety.

5.4 Potential Effect Insulation can have on Ovality and Migration

Reducing the shell temperature may have adverse consequences in terms of Ovality and Migration.

Ovality is the relationship between the vertical (b) and horizontal shell diameters (a); refer to Figure 17, which also shows the corresponding effect on the trunnion rollers. The kiln is designed so that shell expansion at operating temperature results in the least ovality.

Reducing the shell temperature results in less shell expansion; and may affect ovality and migration. As shown in Figure 18, a less circular shell, due to less expansion, results in potentially greater pinch spalling effect highlighted by the red circles (10 and 2 o'clock positions) and loosening highlighted by the blue square (12 o'clock position).

Lime Kilns typically rotate at 1-2 revolutions/minute and are up to 4.5 metres in diameter, as a result the wear lining refractory undergoes several thousand cycles of compression and loosening per year. Therefore controlling the expansion of the kiln shell is important for a stable refractory lining and process operations.

Figure 19 shows the refractory spalling due to ovality, when Ovality exceeds the specification. Holderbank offers further guidelines in showing the safe working relationship between % Ovality and Kiln diameter – refer to Figure 20.

Prior to installation, Boral Cement and Pyrotek calculated the reduction in kiln expansion to be within the acceptable range according to Holderbank.

Insulation increases the thermal loading and therefore thermal expansion of the wear lining brick causing extra compression along its through

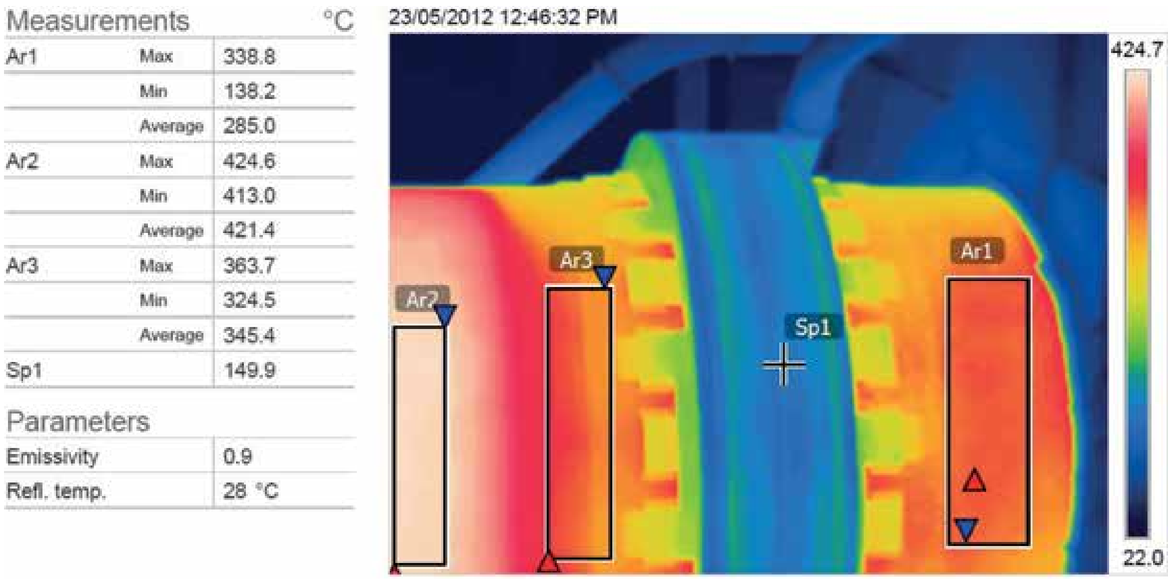

Figure 15: Infrared Thermography picture of burning zone – 13mm ISOMAG Insulation *Photo taken: May 2012 (E60 FLIR Camera – M Taddeo)*

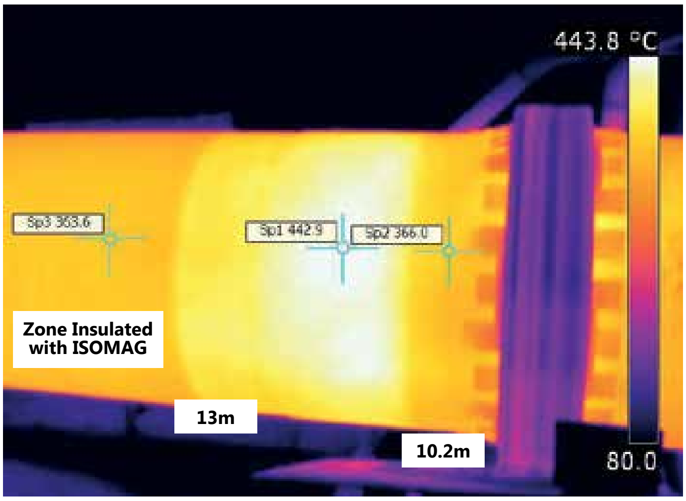

Figure 16: Infrared Thermography picture of burning zone [5] – 13mm ISOMAG Insulation *Photo taken: January 2014 (FLIR T250 Michael Dubokovich)*

thickness. As a result the recommended expansion joint and installation brick procedure must be strictly adhered to as specified by the wear lining brick supplier. The 13mm ISOMAG® 70XCO results in a minimal reduction to shell internal diameter and does not greatly affect bricking installation procedure.

Related to ovality is tyre migration. Lower shell temperatures result in less thermal expansion, with the potential to increase the migration (rolling distance) of the tyre in relation to the shell.

Where possible these affects should be recorded prior to and after any trial to guide any adjustments in tyre to shell clearance that may be required to be made during a suitable shutdown.

Hence, the insulation lining must be designed to achieve the right balance of shell expansion but to also optimise the increased heat containment within the refractory lining with no effect to kiln operations.

For the trial at Boral Cement; Migration or Ovality was not strictly recorded, although there were no related adverse consequences on refractory wear and kiln operations reported. It was therefore considered the insulation lining had minimal effect on Migration and Ovality.

5.6 Chemical Attack on Refractories due to higher thermal load

The major factor of wear lining erosion in a rotary kiln is of thermo-chemical origin.

It is important to note ISOMAG® is a basic material and offers resistance to

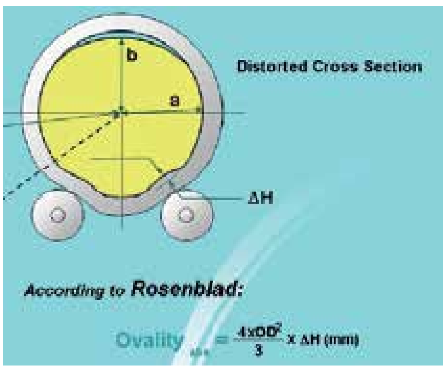

Figure 17: Ovality according to Rosenblad [7]
Note: %Ovality = 2 x (a-b)/D x 100

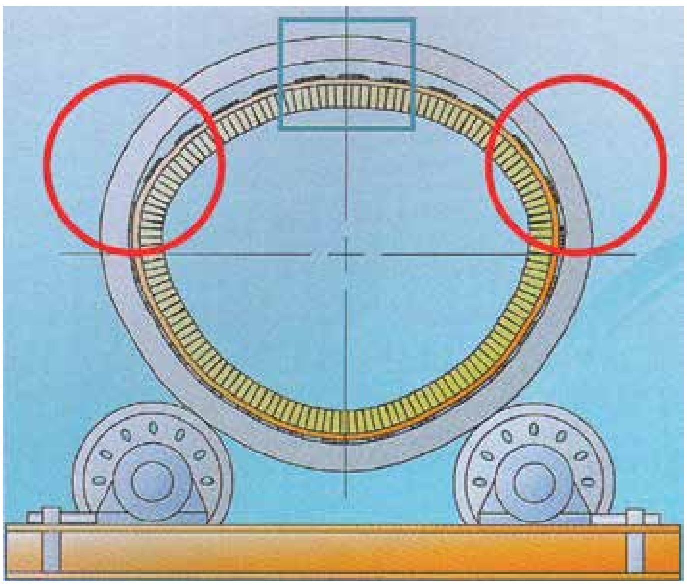

Figure 18: Kiln Maximum Stress Zones [9]

Figure 19: Spalling due to Ovality [9]

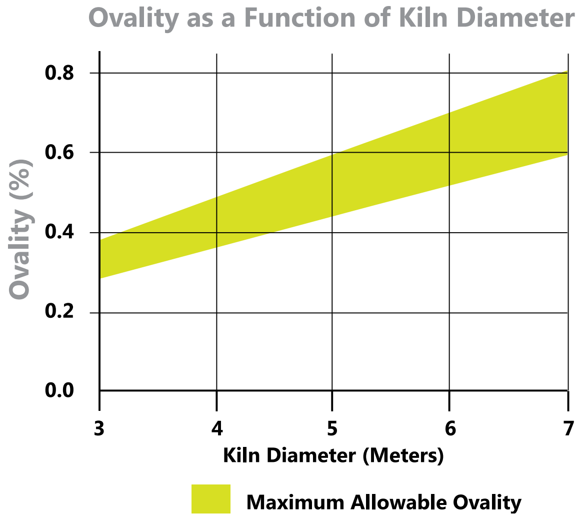

Figure 20: Maximum Ovality – Holderbank [8]

alkali attack (it contains up to 3% alkalis in its structure). The lime producing environment is more benign on chemical attack when compared to clinker production, though lime build up on refractories is common.

The concern for insulation is that it may increase the penetration depth of chemical attack through the refractory due to its higher heat or thermal loading (refer to Figure 12).

A signal for this would be a localised wear pattern or increased (alkali) spalling in the Insulation region.

Section 5.7 below, investigates further any chemical related attack due to the insulation lining in the burning zone. A post-refractory analysis on the Insulation Board and Wear lining brick (with and without insulation) are required to quantify this effect.

5.7 Actual Wear Lining Erosion Comparison

Section 5.3 to 5.6 highlighted the range of potential adverse issues on wear lining erosion and spalling associated with a 2 lining system. That is assuming the insulation lining has the extreme durability to maintain its integrity throughout the wear lining campaign over the Tyre in the Burning Zone.

Though the shell temperature reduction has been maintained throughout the campaign that does not suggest the wear lining has remained unaffected. Given the performance of the insulation, shell temperature increases resulting from spalled refractory will be less noticeable. The

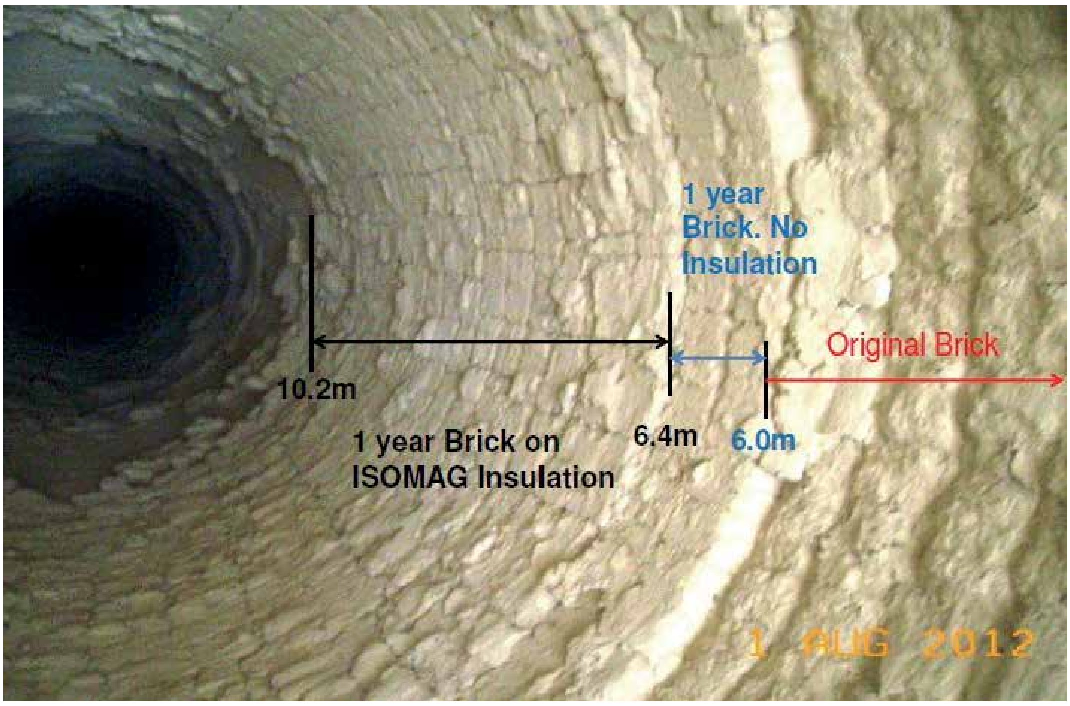

Figure 21: Insulation of Wear Lining Brick – 11 months

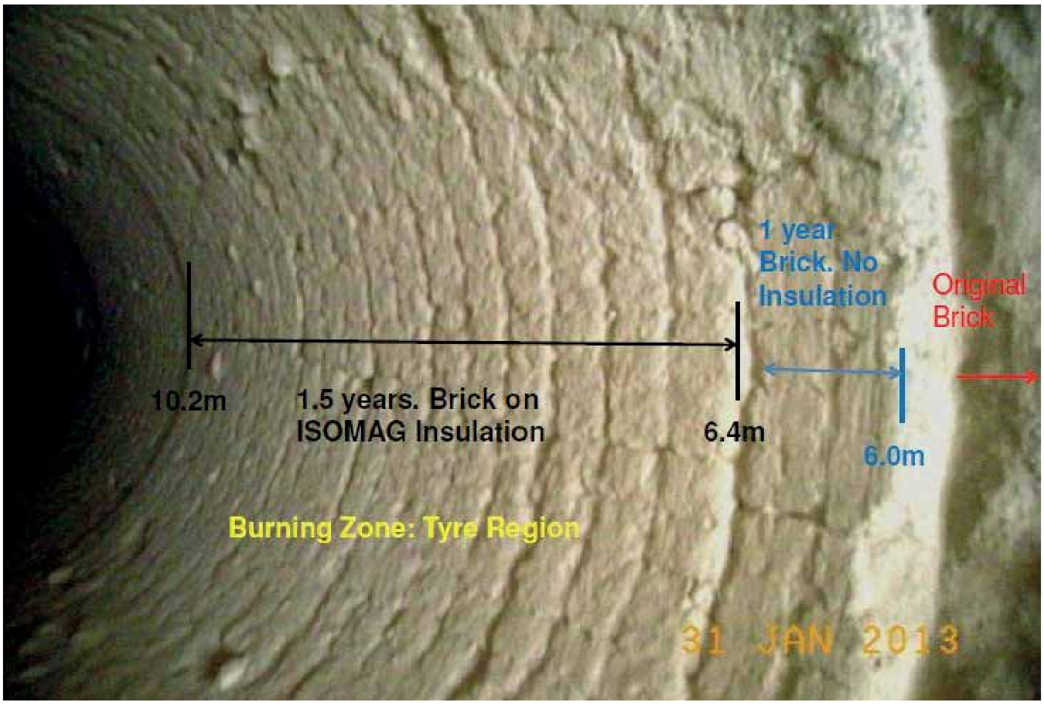

Figure 22: Insulation of Wear Lining Brick – 16 months

best measure is to wait for a scheduled shut down and carry out physical inspection.

Figure 21 shows the performance of the working lining after 11 months of stop start operation.

The 3 zones show the following:

1. Old Mag-Spinel Brick. (1st 4 circumferential courses) In service for approximately 6 years has shown about 80mm of wear in comparison to the adjacent newer Mag-Spinel Brick (11 months). Shows highest degree of "cobble-stoning" wear but still in reasonable condition.
2. New Mag-Spinel Brick. (Next 2 circumferential courses: 6.0 – 6.4m from discharge end) in service for 11 months shows minor signs of wear and build up.
3. New Mag-Spinel Brick with 13mm ISOMAG70XCO. (19 circumferential courses: 6.4 – 10.2 m from discharge end) in service for 11 months. Shows comparable performance to the adjacent brick (without insulation) installed at the same time.

Figure 22 shows the performance of the working lining after 16 months of stop start operations. Accordingly there is no difference in wear patterns or lining integrity between bricks that have the insulation or not. The distinct 13mm ridge between the adjacent linings also shows the refractory board has maintained its dimensional integrity and strength.

Figures 23, 24 below show evidence of a process related event that resulted in build-up and spalling of the refractories. Despite the subsequent loss of the 12.7mm step, refractories placed on the insulation lining were equally affected to those placed directly on the shell. Despite the damage to

Figure 23: Wear Lining Brick – 19 months

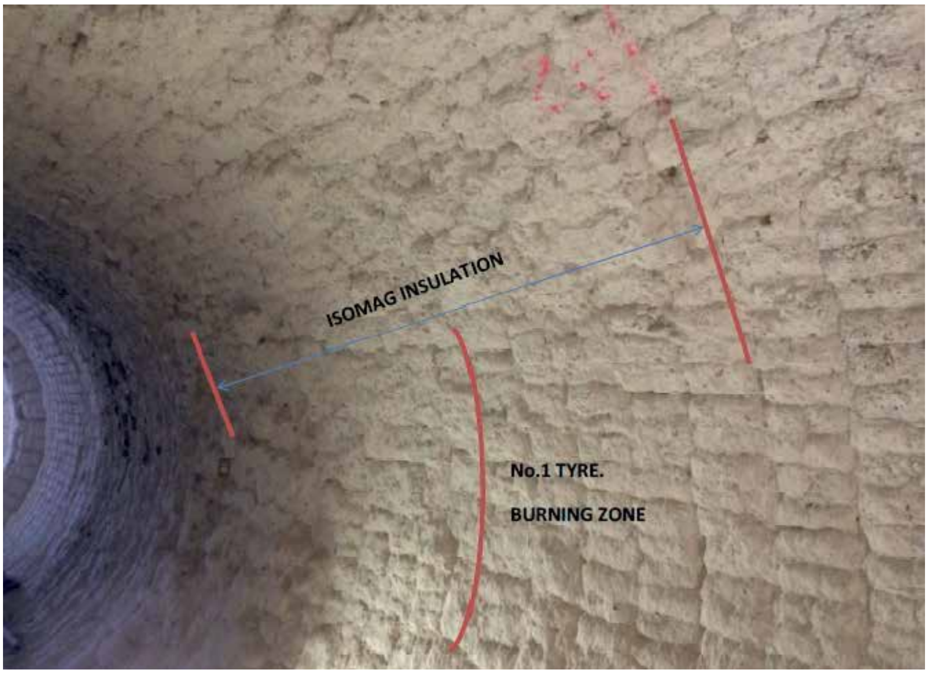

Figure 24: Wear Lining Brick – 28 months

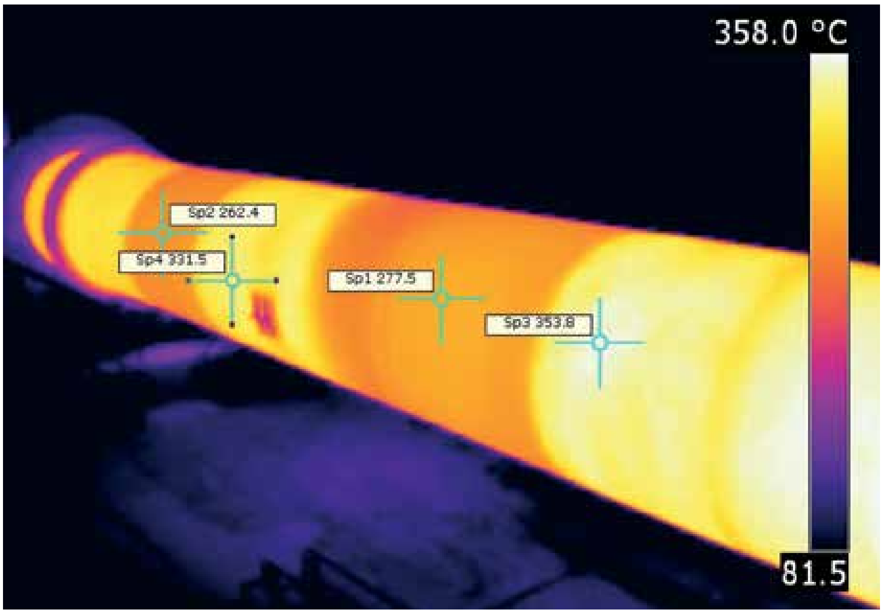

Figure 25: Kiln Shell Thermovision showing regions with and without ISOMAG insulation
Photo taken: January 2014 (FLIR T250 Michael Dubokovich)
9th January 2014 – View from Burning Zone uphill to 2nd Tyre – shows 2 zones of new 220mm 80% alumina brick installed over 12.7mm Isomag 70 XCO insulation board – indicates about 60°C to 70°C shell temperature reduction.

the refractories, the ISOMAG continued to maintain its reduction in shell temperature and lining stability for more than 28 months campaign life.

5.8 Potential Effect Insulation can have on Energy Consumption

The previous sections have shown the ISOMAG® insulation lining offering continuous shell temperature reduction and lining stability in the burning zone over the No.1 Tyre for a campaign exceeding 30 months.

It was then subsequently installed in the transition zone sections containing either Magnesia Spinel or high alumina brick. Figure 25 shows (with an infrared camera) the regions of high and low shell temperatures are consistent with the placement of the insulation lining.

Figure 26 is a picture taken looking inside the furnace 20 minutes after a "flame out". The bands of hotter or glowing brick are consistent with the location of the insulation lining, preventing the according heat from escaping through to the shell. When insulated, these bricks have a higher thermal load as calculated in figures 9-12, and particularly on cool down this heat is clearly seen to be retained.

Therefore, Figure 26 represents the inverse of Figure 25. Having greater heat contained within the lining, or less energy escaping through the shell results in reducing the energy consumption.

Figure 27 below is a theoretical calculation measuring the energy savings in GJ per tonne of Lime produced. The data originates from the heat loss calculation shown in Figures 9 – 12 and other inputs from the plant.

Zone 1 is comprised of Magnesia Spinel brick (discharge, burning and upper transition).

Zone 2 is the transition (preheating) zone toward the tumblers, with an 80% alumina wear lining brick. Zone 3 (charging zone) is comprised of a firebrick and "tumbler rows" construction.

As shown, the hotter areas also have more conductive brick and are therefore the regions of highest energy loss. The prediction of 82°C µΔT (average shell temperature difference) in Zone 1 is consistent with the actual measurements. It yields a calculated energy saving of 0.21GJ/t.

Zone 2 has a lower process temperature and a refractory brick more insulating that Zone 1. The calculated shell temperature improvement (µΔT) is lower at 65°C, consistent with actual measurements, and results in a 0.09GJ/t calculated energy saving.

Zone 3, representing the lowest process temperatures with the wear lining of highest insulation shows modest improvements. The calculated µΔT here reduced by 36°C and subsequent 0.07GJ/t energy saving due to the larger surface area.

Since life of these bricks can be more than 10 years, rather than the 3 -5 year of its respective upper zone, does result in a respectable ROI.

Given the higher shell temperature reductions, if the first 46m of the rotary kilns length (or 55%) has insulation, it is calculated 0.3GJ/t energy saving will be achieved.

There are a number of process variables that affect the GJ/t energy efficiency. As more of the kiln becomes insulated with ISOMAG, subsequent measurements will be carried out to determine the energy savings, and will likely be the topic of another paper.

6. Conclusions

The decision to insulate a rotary kiln is usually done to reduce excessive heat loss. The burning zone is the region of highest thermal, chemical and mechanical stress. The shell temperature in the Burning Zone, under No.1 Tyre at Boral Cement Marulan Lime Kiln exceeded 480°C, above steel design limit and action was required to reduce this.

This paper compared and examined the initial and long term effect of incorporating a 13mm structural insulation board beneath the refractory wear lining in the Burning Zone. This maintained the kiln's capacity and refractory installation procedure whilst significantly reducing the shell temperature.

Region	HF Brick	Lt m	Kiln ID	Surface Area ID	Shell µ Δt	ΔHL kW/ m2	MWh day gain	t/day	GJ/t gain	Nett (Energy) Savings pa	ISOMAG ROI
Zone 1 (0-25m)	85% Mg-Spinel	25	3.34	262	82	3.87	24.4	420	0.21	$191,355	14
Zone 2 (25-46m)	85% Alumina	21	3.34	220	65	2.09	11.1	420	0.09	$86,098	12
Zone 3 (46-84m)	43% Alumina	38	3.34	399	36	0.80	7.7	420	0.07	$57,455	8
TOTALS		**84**		**881**	**61**	**2.26**	**14.4**		**0.37**	**$334,908**	**12**

Figure 27: Energy Savings Calculations with ISOMAG insulation in the Lime Kiln

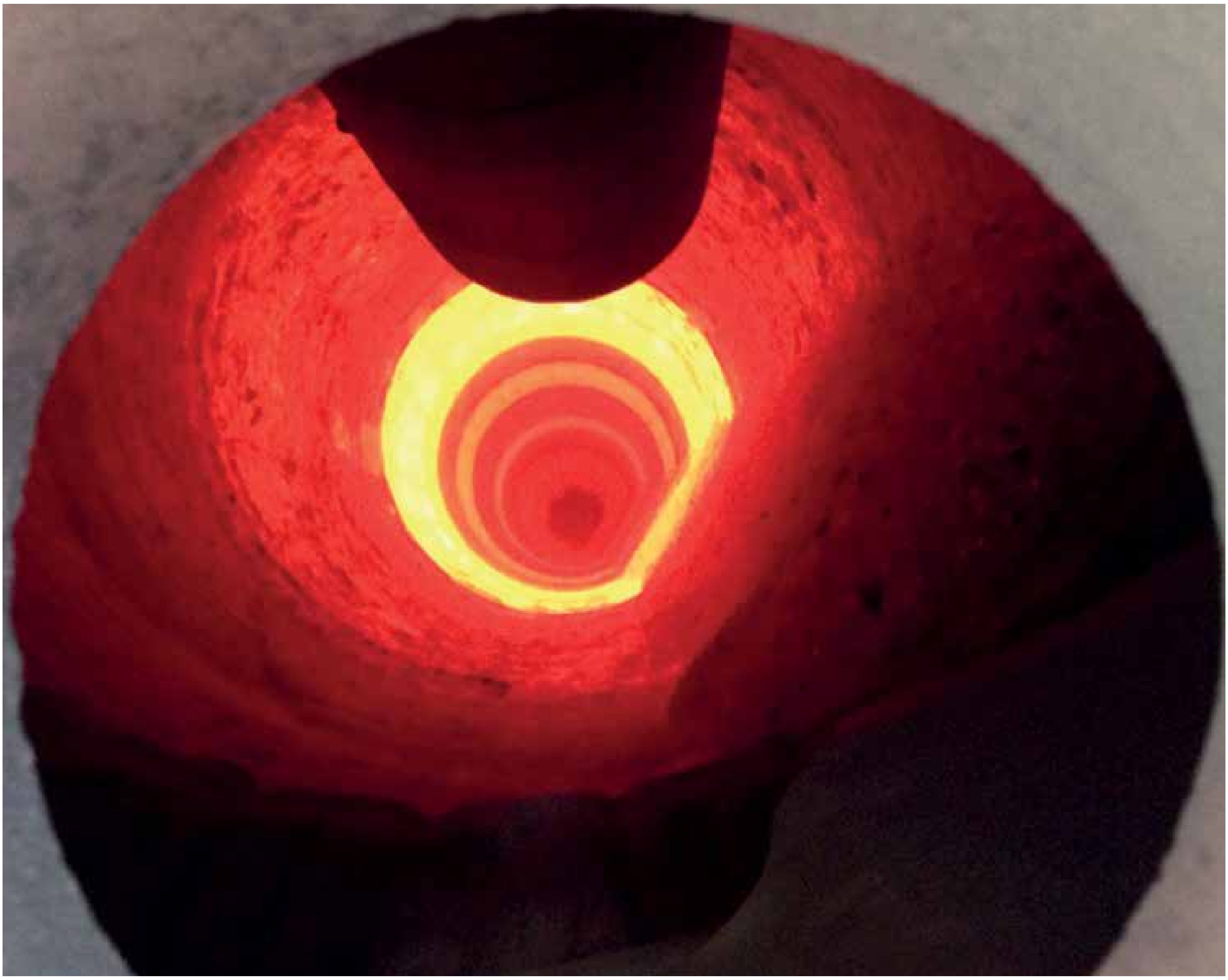

Figure 26: Insulated Brick lining comparison 20 minutes after flame out
Photo taken: 16 January 2014 (Boral Cement Marulan Sth)

A deformed shell can compromise the tightness of the lining which increases the risk of further operational issues. The refractory insulation lining incorporating insulation board showed no evidence of degradation throughout the campaign. This had the following results:

- 70°C shell temperature reduction maintained for at least 30 months of stop start production;
- Operator comfort adjacent to the burning zone is noticeable when walking past the kiln;
- No effect on Wear Lining Erosion;
- Potential to reduce shell repair costs by being well under design limit temperature;
- Enhances productivity/costs by prolonging the life of the shell, and
- Potential to reduce at least 0.3 GJ/tonne energy consumption if insulation installed 55% of the length of the kiln from the discharge end.

6. Acknowledgments

The Author would like to thank the cooperation of Boral Cement Australia, and others in the cement industry for their cooperation.

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Thermal Shock Resistance of Ladle Castables

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Abstract

High purity alumina-spinel (A-MA) and alumina-magnesia (A-M) castables are widely used in steel ladles due to their resistance against slag penetration and corrosion. With a calcium magnesium aluminate bond (CMA) excellent slag penetration resistance can be achieved which results in high wear resistance due to reduced structural spalling. This paper investigates the impact of matrix compositions and CMA-binder content of A-MA and A-M castables on thermal shock resistance (TSR). Standardized thermal shock tests have been applied with sample quenching from 950°C down to room temperature. Results show that all castables are significantly damaged after 5 cycles despite their differences in microstructure. However, the mix with 12% CMA gave TSR that is at similar good level as the reference mix with 6% CAC (70% alumina cement). While a similar strength level was achieved before and after the thermal cycling, the formulation with 12% CMA contains 0.6% less total CaO. The A-MA castables perform better on average than the A-M mixes with this test method. Within the group of A-M castables the mix with 18% CMA and 0.5% SiO_2 gave superior TSR, similar good as castables of the A-MA group. The introduction of CMA in a A-M castable allows reduction of free MgO and SiO_2-addition. The reduction of SiO2 has been found beneficial for the TSR. This was also found during a thermal cycling trial at high temperature between 1100 and 1500°C. Here the A-M mix with 18% CMA and 0.5% SiO_2 performed better than the SiO2-free A-MA castable.

Key words: thermal shock, ladle castable, calcium magnesium aluminate binder.

1. Introduction

Both alumina-spinel and alumina-magnesia castables are widely used in steel ladles and achieve excellent performance especially in ladle bottoms [1]. Recent publications have also demonstrated that these high-tech castables can further be optimized. The development of the calcium magnesium aluminate binder CMA 72 (CMA) enables excellent slag penetration resistance. As consequence better wear resistance is observed due to reduced structural spalling [2, 3, 4]. With the introduction of CMA into a castable matrix typically the strength increases at equivalent total lime content in the castable compared to a castable bonded with a 70% or 80% alumina cement and added spinel powder. While the CMA increases the resistance against slag penetration and corrosion, it is important to keep a good balance with the thermal shock resistance (TSR), especially for the ladle bottom castable, well block, gas purge plugs, lances etc.

2. Experimental Procedures

2.1 Starting Materials

Model formulations as shown in **Table 1** have been used to determine the TSR. As reference formulations an A-MA (A-MA-CAC6) and an A-M castable (A-M-CAC6-1S), both bonded with 6% Secar®71 (CAC) have been chosen. The impact of CMA on TSR of the A-MA castable has been evaluated with the formulation A-MA-CMA18 (18% CMA). In the A-M system CMA has been tested with the formulation A-M-CMA-1S (18% CMA and 1% SiO_2). The CMA containing formulations have equal chemistry and equal mineralogy after firing compared to their references A-MA-CAC6 and A-M-CAC6. But they have a different distribution of spinel, calcium aluminate phases and micro-pores which gives them their superior slag penetration resistance. Detailed information about the composition of CAC and CMA and the microstructures, penetration and wear resistance of castables formulated with both binders can be found in Wöhrmeyer et al. [2].

Since CMA achieves higher strength than CAC at constant total CaO content in the castable [4], formulations with a lower CMA content have been tested to compare similar initial strength. In the A-MA system the recipe A-MA-CMA12 with 12% CMA has been evaluated and in the A-M system the formulation A-M-CMA10-0.75S that contains 10% CMA and 0.75% SiO_2. In case of the A-M castables the impact of the silica fume content has been studied with the formulation A-M-CMA18-0.5S that contains 18% CMA and 0.5% SiO_2 and A-M-CMA10-0.75%. Silica is used to control the expansion related to the in-situ spinel formation. Previous studies [4] have shown that with the introduction of the micro-spinel through CMA the amount of free MgO in the formulation can be reduced and as consequence also the amount of silica as less in-situ spinel will be formed. Furthermore CMA has a strong sintering activity which also contributes to a better control of the Permanent Linear Change (PLC).

	Alumina-Magnesia model castables			
	A-M-CAC6-1S	A-M-CMA18-1S	A-M-CMA18-0.5S	A-M-CMA10-0.75S
Tabular Alumina 0-6mm	75.5	70	70.5	74.75
Reactive Alumina	11	8	8	10
MgO UBE95 0-0.07 mm	6.5	3	3	4.5
Elkem Microsilica® 971U	1	1	0.5	0.75
Secar® 71	6			
CMA 72		18	18	10
Peramin® AL200	0.15	0.1	0.1	0.15
Water	4.5	4.5	4.5	4.5

	Alumina-Spinel model castables		
	A-MA-CAC6	A-MA-CMA18	A-MA-CMA12
Tabular Alumina 0-6mm	60	61	62.5
Reactive Alumina	11	11	11
Spinel AR78 0-1 mm	23	10	14.5
Secar® 71	6		
CMA 72		18	12
Peramin® AL200	0.1	0.1	0.1
Water	4	4	4

Table 1: Model A-MA and A-M castables

The formulation A-M-CMA10-0.75S contains only 10% CMA which results in a reduction of total CaO in the formulation to 1% compared to 1.8% for the other A-M formulations. To keep the same total amount of spinel after firing the free-MgO content has here been increased to 4.5% and 0.75% silica has been added to control the PLC.

2.2 Thermal Shock Test Methods

The thermal shock resistance (TSR) tests have been performed according to the procedures describes in EN-993-11. Four 230x55x65 mm standard prisms of each castable have been prepared for measuring the thermal shock damage. This test was conducted by quenching a sample 5 times into air pressure of 1 bar. Prior to quenching, samples were either pre-fired for 5h at 950ºC, or 6h at 1600°C (A-MA castables), resp. 3h at 1550°C (A-MA and A-M castables) and after cooling, reheated at 950°C for 1h before each thermal shock.

The Cold Modulus of Rupture (MOR) has been tested before and after 5 thermal shocks. The Elastic modulus has been determined by GrindoSonic equipment.

Thermal cycling at high temperature between 1100 and 1500ºC has been conducted on cylinder samples with a diameter of 50 mm and a length of 96 mm. These samples have been pre-fired for 5h at 1500ºC and then slowly cooled down to room temperature prior to this high temperature thermal cycling test. Samples have then been heated from one end of the cylinder to 1100ºC while the other end of the cylinder heats up to approximately 400 ºC. Then the hot end of the cylinder has been rapidly heated to 1500ºC and then cooled down to 1100ºC again prior to the next cycle (**Figure 1**). After 9 thermal cycles the samples have been cooled with slow speed to room temperature.

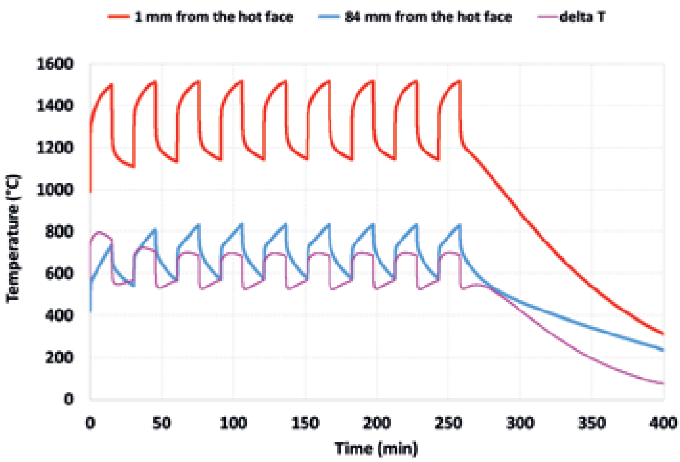

Figure 1: Temperature evolution at the hot and cold side of the sample during high temperature thermal cycling

The ultrasound velocity (v) has been measured parallel to the axis of the cylinder and at different distances from the hot face perpendicular to the axis. The damage parameter has been calculated following the equation of Kachanov [5]:

$$D = 1 - \left(\frac{v}{v_0}\right)^2$$

2.3 Laboratory corrosion tests

Corrosion tests have been conducted in a laboratory rotary kiln with slag and as well in an induction furnace with slag and steel. In both test equipment 2 different slags have been used, a FeO-rich BOF slag with 59% CaO, 19% FeO, 6% MnO, 15% SiO2, 5% MgO, and an Aluminium-killed calcium aluminate ladle slag with 57% CaO, 30% Al2O3, 7% MgO, 5% SiO2.

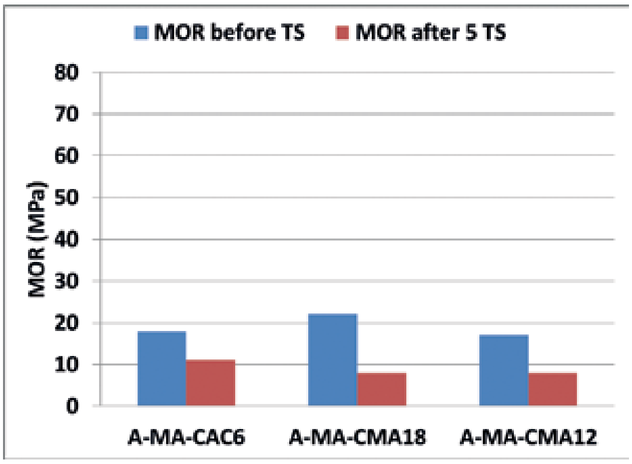

Figure 2: MOR of A-MA castables pre-fired 5h at 950ºC, before and after 5 thermal shocks

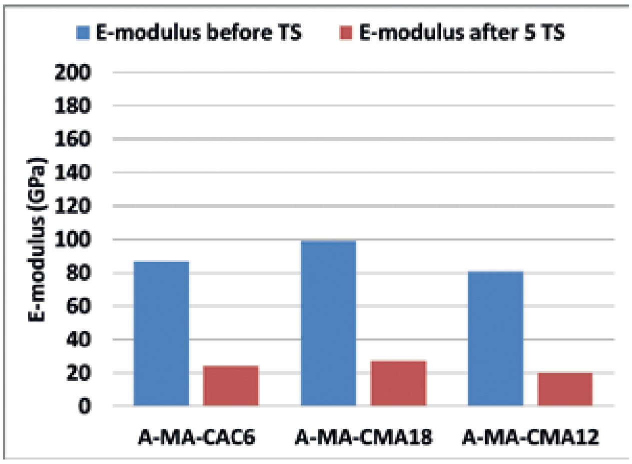

Figure 3: Elastic Modulus of A-MA castables pre-fired 5h at 950ºC, before and after 5 thermal shocks

3. Results

3.1 Resistance of A-MA Castables to Thermal Shocks from 950 to 20ºC

The pre-firing of castable A-MA-CMA18 at 950ºC results in a higher MOR and E-modulus compared to the chemically equivalent castable A-MA-CAC6 (**Figure 2-3**). After the thermal shock both castables have the same remaining E-modulus but A-MA-CMA18 has a lower residual strength. With A-MA-CMA12 the drop in MOR and E-modulus is lower than with A-MA-CMA18.

Samples pre-fired at 1600ºC have approximately a three times higher MOR and a two times higher E-modulus than those pre-treated at 950ºC (**Figure 4-5**). A-MA-CMA18 exhibits again the highest strength while A-MA-CAC6 and A-MA-CMA12 achieve similar strength. After the thermal shocks the MOR drops to values as low as in case of 950ºC pre-firing while the E-modulus after the thermal cycling remains two to three times higher for the 1600ºC. Although the differences are small, it can be seen that overall the A-MA-CMA12 and the A-MA-CAC6 have equal performance and slightly better than A-MA-CMA18 in terms of absolute values but also in terms residual values relative to the sample before the shock test (**Figure 6-7**). Nevertheless, the differences are very small and pre-tests have also shown that this is particularly true with a low pre-firing temperature (950ºC) where the repeatability of the test results is relatively low as at this stage the phase transformation in the binder and sintering reactions have not fully occurred yet. Therefore results after pre-firing at 1600°C seem to be more relevant and are also closer to the real ladle application.

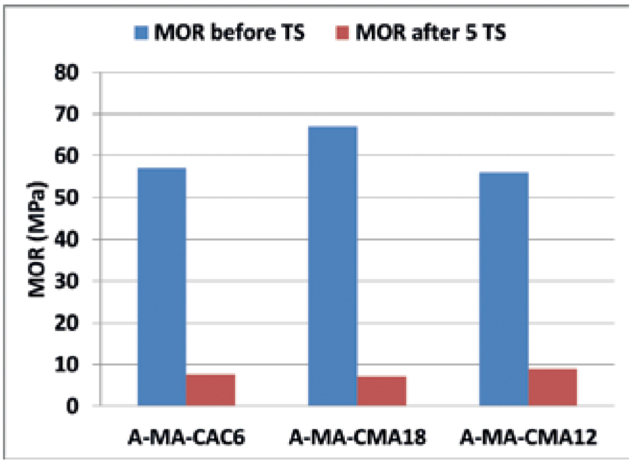

Figure 4: MOR of A-MA castables pre-fired 6h at 1600°C, before and after 5 thermal shocks

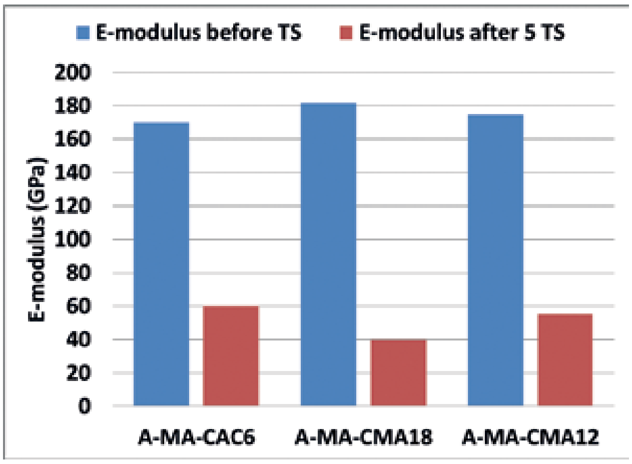

Figure 5: Elastic Modulus of A-MA castables pre-fired 6h at 1600°C, before and after 5 thermal shocks

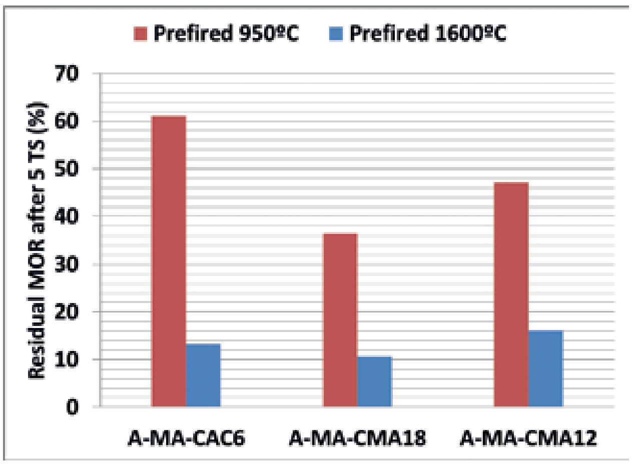

Figure 6: Residual MOR of A-MA castables after 5 thermal shocks

3.2 Resistance of A-M Castables to Thermal Shocks from 950 to 20°C

Compared to the A-MA castables the strength of the A-M castables before thermal cycling (pre-fired at 1550°C) is lower (**Figure 8**). This could be the consequence of the slightly higher water demand, but also the expansion caused by the spinel formation. Nevertheless, as in case of A-MA castables,

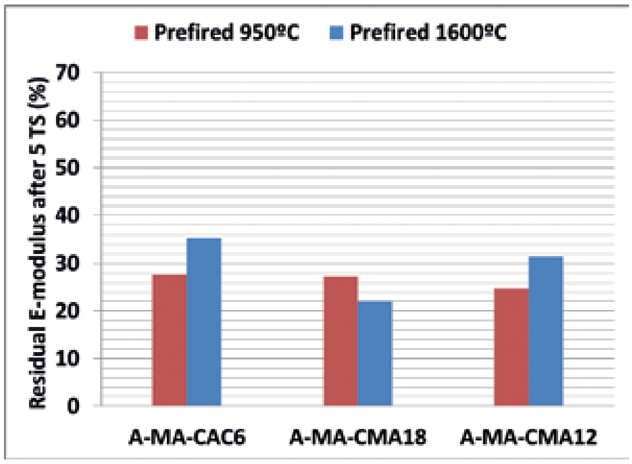

Figure 7: Residual Elastic Modulus of A-MA castables after 5 thermal shocks

those bonded with CMA achieve a higher strength than the CAC-bonded references. However, the residual strength is very low, with the exception of A-M-CMA18-0.5SCMA which achieves similar absolute and relative residual strength (**Figure 9**) and E-modulus (**Figure 10-11**) as the A-MA castables.

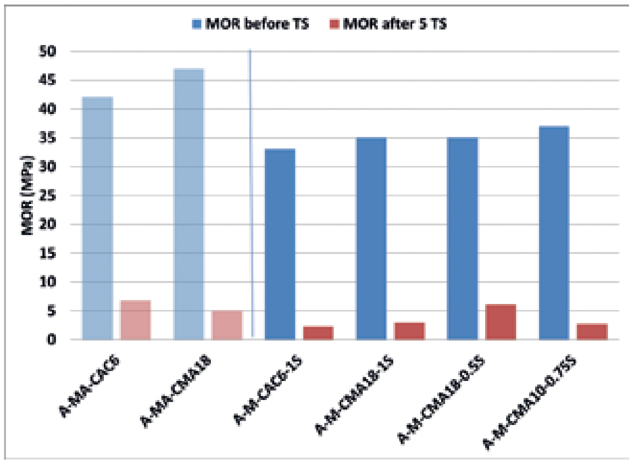

Figure 8: MOR of A-MA and A-M castables pre-fired 3h at 1550°C, before and after 5 thermal shocks

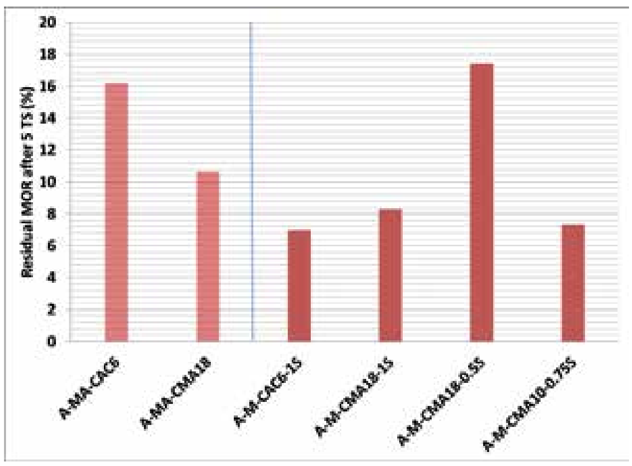

Figure 9: Residual MOR of A-MA and A-M castables pre-fired 3h at 1550°C, after 5 thermal shocks

3.3 Thermal Cycling between 1100 and 1500°C

First results with the thermal cycling tests at high temperature show some clear differences between the two materials that had been selected for this specific trial, the castables A-MA-CMA18 and A-M-CMA18-0.5S. While these 2 materials didn't show very big differences in the thermal cycling

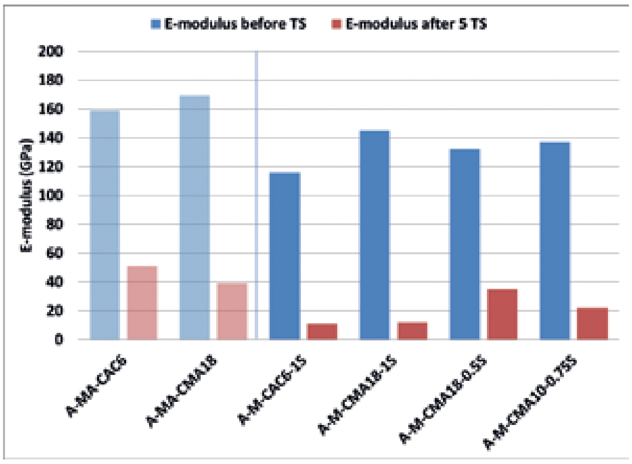

Figure 10: Elastic Modulus of A-MA and A-M castables pre-fired 3h at 1550°C, before and after 5 thermal shocks

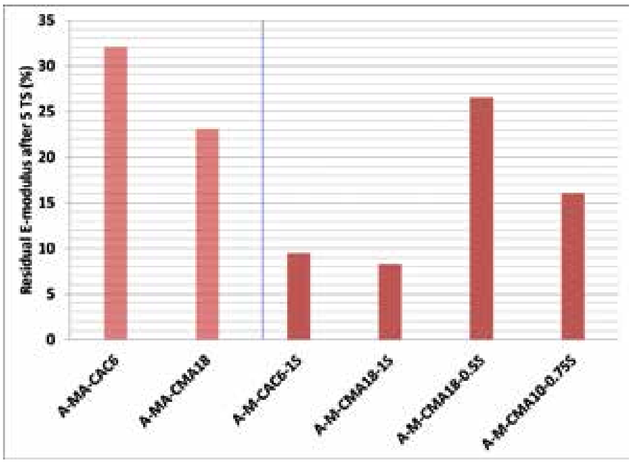

Figure 11: Residual Elastic Modulus of A-MA and A-M castables pre-fired 3h at 1550°C, after 5 thermal shocks

test from 950 down to 20°C, differences become more visible with cycling between 1100 and 1500°C. While both samples didn't have visible cracks before the cycling test, the A-MA-CMA18 showed relatively more cracks after the test. One important crack has been observed parallel to the hot face in a distance of approximately 40 mm from the hot face (N° 2 in **Figure 12**). One small crack is starting from the hot face and running more or less perpendicular to the hot face (N° 1 in Figure 12). In the A-M castable one small crack was observed macroscopically which is starting at about 20 mm from the hot face and running diagonally (see arrow on the right side of Figure 12).

The ultrasound measurements (**Table 2**) and the damage parameter (**Figure 13**) show quite clearly that the biggest damage occur about 25 to 50 mm behind the hot face. There the US-velocity is low and the calculated

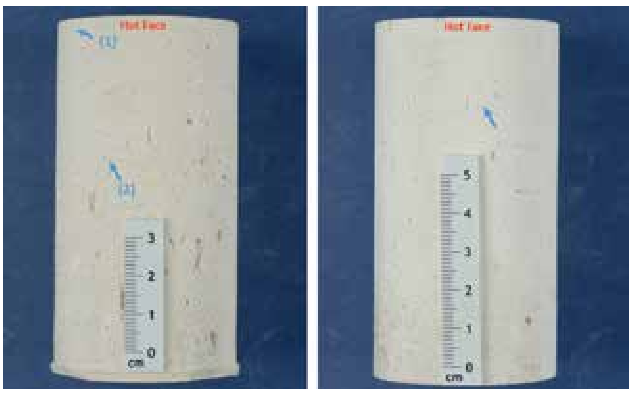

Figure 12: A-MA-CMA18 (left) and A-M-CMA18-0.5S after thermal cycling between 1100 and 1500°C

		A-MA-CMA18		A-M-CMA18-0.5S	
		Before Thermal Cylcling	After Thermal Cycling	Before Thermal cylcling	After Thermal Cycling
Along the thermal gradient (cylinder axis)		7.57	5.06	6.45	5.06
Perpendicular to the thermal gradient (distance to the hot face [mm])	10	7.65	5.85	6.42	6.34
	25	7.16	3.77	6.34	4.91
	50	7.59	4.32	6.17	4.72
	75	7.59	6.86	5.82	4.91
	90	7.28	7.38	6.10	5.89

Table 2: Ultrasonic velocity (mm/sec)

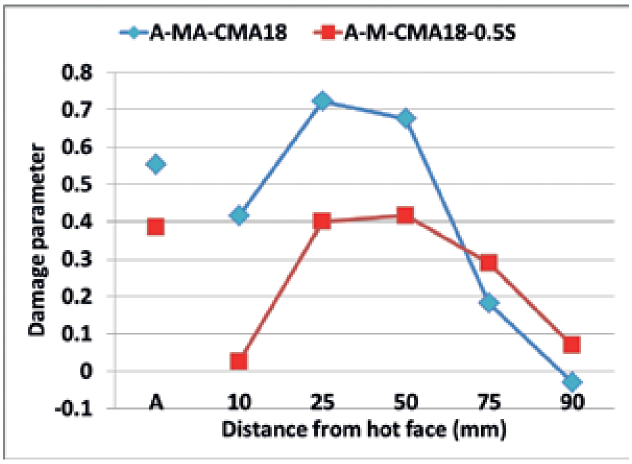

Figure 13: Damage parameter along the heat gradient of the cylinder (A) and perpendicular to the axis at different distances from the hot face

damage parameter high. The damage parameter shows as well that the CMA containing A-M castable performs better than the A-MA castable.

3.4 Corrosion Resistance of A-M castables

The corrosion resistance has been evaluated for 3 of the A-M castables to verify if a good compromise between thermal shock resistance and corrosion resistance can be achieved (**Figure 14**). Both CMA-containing mixes (A-M-CMA18-0.5S and A-M-CMA10-0.75S) show better corrosion resistance than the A-M-CAC6-1S reference castable. Especially in the induction furnace test the CMA-based castables show significantly better resistance against the FeO-rich BOF-slag. With the Al-killed ladle slag the 18% CMA containing A-M castable shows the lowest wear. With the rotary kiln the differences are less pronounced but still both CMA-based castables exhibit lower wear than the reference system A-M-CAC6-1S.

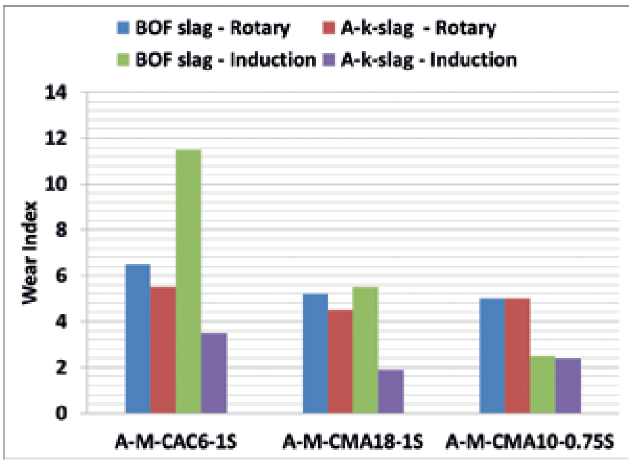

Figure 14: Corrosion resistance of A-M castables in laboratory rotary kiln and induction furnace tests

3.5 Discussion

High purity Alumina-Spinel castables have been proven to show high resistance against slag corrosion when high amounts of CMA are employed in the castable. With the introduction of CMA also the strength increases at equivalent total CaO content in the castable compared to a CAC based castable. This is positive for example for the abrasion resistance but not necessarily for the thermal shock resistance. The formulation with 12% CMA represents a good compromise and achieves approximately the same thermal shock resistance as the CAC-based reference mix.

The thermal shock resistance of the tested A-M castables shows a quite strong dependence on the amount of added silica fume. With the reduction of silica fume the thermal shock resistance seems to improve to levels achievable by A-MA castables. The use of CMA as binder in A-M castables makes it easier to work with lower silica contents as micro-spinel is brought into the matrix through CMA. Then less free-MgO need to be added to achieve the same quantity of total micro-spinel in the formulation. As less in-situ spinel need to be formed, also less expansion will occur and as result less silica need to be added to control the expansion. The A-M castable with 18% CMA and 0.5% SiO_2 has shown the best compromise between thermal shock and corrosion resistance. It has also performed well in the thermal cycling at high temperature. This test supplies more relevant information for ladle operations than the classical shock test from 950ºC to room temperature.

4. Conclusions

The A-MA castable with 12% CMA provides thermal shock resistance as high as the reference formulation with 6% CAC. At the same time it provides similar strength at reduced total CaO content. The thermal shock resistance of A-M castables depends on the SiO_2 content in the formulation. An excellent compromise between thermal shock resistance and corrosion resistance has been achieved with the formulation that contains 18% CMA and 0.5% SiO_2 in the A-M castable. The comparison between the standardized thermal shock tests that quench samples from 950ºC to room temperature with a thermal cycling test at high temperature between 1100 and 1500ºC show that the shocks towards low temperature result in only small differences between the different materials as all materials become severely damaged after only 5 shocks. The high temperature cycling is better able to simulate real ladle conditions and allows a more clear differentiation between different materials.

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Unifrax Ltd
Mill Lane, Rainford, St. Helens, WA11 8LP.
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CERAMIC FIBRE FIXINGS

Mach One (International) Ltd
Unit 8, Norfolk Business Park, Foley Street, Sheffield S4 7YW.
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CERAMIC FIBRE FREE BOARDS

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CERAMIC FIBRE PAPERS (1250°C AND 1400°C)

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CERAMIC FIBRE SOLUBLE

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CERAMIC FIBRE (ROPES)

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Website: www.unifrax.com

CERAMIC FIBRE (VACUUM FORMED)

Unifrax Ltd
Mill Lane, Rainford, St. Helens, WA11 8LP.
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Website: www.unifrax.com

CERAMIC WELDING

Chapman Brack Contractors Ltd
Faith Works, Clubmill Road, Sheffield S6 2FH.
Tel: 0114 232 4155.
Website: www.chapmanbrack.co.uk

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Email: enq@dysontc.com
Website: www.dysontc.com

DEMOLITIONS

Gnat (UK) Ltd
5 Jackson Close, Olympic Way, Gallowfields, Richmond, North Yorks DL10 4FD.
Tel: 01748 826046. Fax: 01748 826056.

DIAMOND PRODUCTS

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DRY VIBRATION RAMMABLE REFRACTORIES

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Website: www.capital-refractories.com

DRYING AND CURING OF PRE-CAST REFRACTORY BLOCKS UP TO 1250°C (IN HOUSE)

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Website: www.thermalhire.com

Irisndt Ltd
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Website: www.irisndt.com/uk/heat-treating/

DRYING AND CURING OF REFRACTORIES (ON SITE)

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Tel: (01909) 731959. Fax: (01909) 731579.
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Website: www.shl-refractories.co.uk

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Croker Mixers - Winget Ltd
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Markham (Sheffield) Ltd
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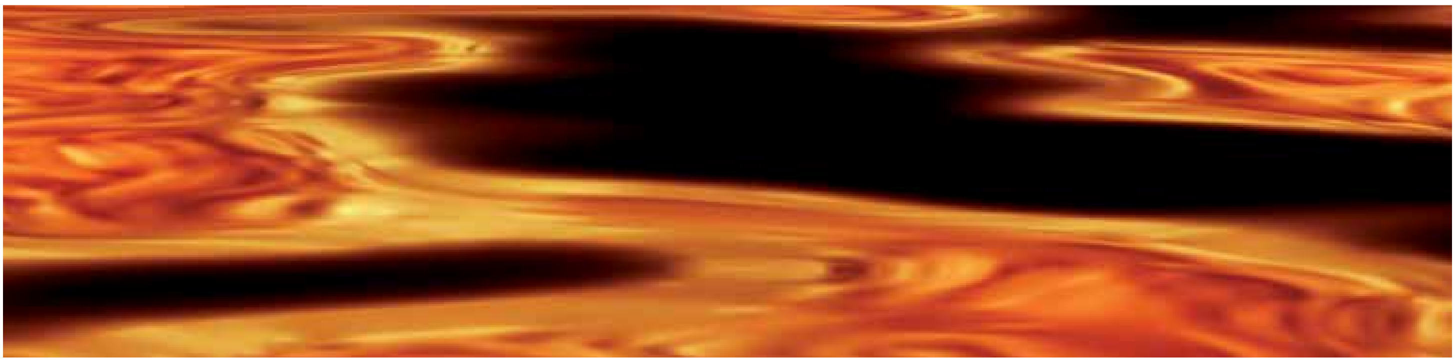

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