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INDIAN REFRACTORY MAKERS ASSOCIATION
Duckback House, Flat No. - 2B, 2nd Floor,
41, Shakespeare Sarani, Kolkata 700017
Phone: 033 4003-2748
E-mail: support@irmaindia.org
Website: www.irmaindia.org

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MESSAGE FROM THE CHAIRMAN

Dear Colleagues,

What absolutely fascinating days they were! The colours, the vibes, the ecstasy conjured an incredible atmosphere where a super enthusiastic stream of denizens soaked in the warmth of the Congress!! All of them united with a single strand ie love for the subject of refractories and strong optimism about its future especially in India.

IRMA feels humbled, honoured to provide platform to such luminaries and takes this opportunity to reaffirm its pledge to put Indian refractory industry in world centre stage.

Judging by the response of the participants, it is fair to conclude that the conference was a great success! So many people have contributed in so many ways to turn this event into a smoothly running meeting with many very interesting technical presentations, case studies, vibrant exhibition area and a stimulating environment for discussion and networking. I owe much gratitude to the Mr Sameer Nagpal, Chairman, IREFCON22 Organizing Committee, Mr Sunanda Sengupta, Co-Chairman IREFCON22 Organizing Committee and Dr I N Chakraborty, Chairman IREFCON22 Technical Committee did an exemplary job for giving structure to the programme and fine tuning it to the minutest details. A programme of grand scale like IREFCON needs resources and I thank the sponsors for spontaneously coming forward to provide the much needed input. I also take this opportunity to thank the sincere efforts taken by IRMA Secretariat in organizing the entire event.

Finally you as a participant have been the core of our story since the beginning and we solicit your kind presence when we will again be celebrating our togetherness in 2024.

Ish Garg
Chairman

ASSOCIATION ACTIVITIES

IREFCON 2022

14th India International Refractories Congress was successfully organized at kolkata from16th-18th November 2022. The detailed report has been provided in the journal.

WRA Board Meeting & General Assembly

World Refractories Association organized its Board of Directors meeting and General Assembly on the sidelines of IREFCON22 on 17th November 2022 at Kolkata. The event was hosted by IRMA and a significant number of Directors and other members attended both the functions.

IRMA ISA White Paper on Refractories Raw Materials

IRMA had prepared a white paper on refractories raw materials in association with ISA outlining the need to create a strong backward linkage of refractories raw materials to support the vibrant domestic refractories industry. The report underlines the possible areas of support from Government and other stakeholders in this regard. The report was published by Mr Piyush Goyal, Union Minister for Commerce and Industries at a function on 22nd November. Mr Sameer Nagpal, Deputy Chairman IRMA represented the Association in the programme.

IN THE NEWS

Hindustan Zinc

Hindustan Zinc'ss mined metal output registered a marginal rise of one per cent to 2,54,000 tonnes in the third quarter of the current fiscal. The company's mined metal production was 2,52,000 tonnes in the year-ago period.

India's Coal Production

The country's coal output went up by 16.39 per cent to 607.97 million tonnes (MT) during the April-December period of the ongoing fiscal. India's coal production was 522.34 MT in the corresponding period of previous fiscal. The coal production by state-owned Coal India -- which accounts for over 80 per cent of domestic output of the fossil fuel -- was at 479.05 MT in the April-December period, registering a rise of 15.82 per cent, the coal ministry said in a statement..

RINL

Rashtriya Ispat Nigam Limited (RINL)-Vizag Steel Plant (VSP) registered the record of producing 5.773 million tonnes of hot metal, 5.272 million tons of Crude steel, and 5.138 million tons of saleable steel which is the best ever produced. RINL also registered the best-ever sales turnover of Rs.28,008 crores which is 56% higher than the corresponding period last year.

JSPL

Jindal Steel and Power Limited (JSPL) will spend Rs 7,930 crore under the PLI scheme for specialty steel. The amount will be used to manufacture eight types of high-end alloy in India. The company is one of the qualifiers of the government's production linked incentive (PLI)

scheme and aims to increase the output of value-added steel using new age technologies in the domestic steel sector.

Baldota Group

Aaress Iron and Steel, a subsidiary of the Vijayanagar-based Baldota Group, has proposed to set up and operate an integrated steel plant of 3.5 million tonnes per annum (MTPA) capacity with an investment of Rs 18,000 crore. The plant will come up at Halavarthi village in Koppal district.

Dalmia Cement

Dalmia Cement (Bharat) Limited (DCBL), wholly owned subsidiary of Dalmia Bharat Limited has entered into a binding Framework Agreement for the acquisition of Clinker, Cement and Power Plants from Jaiprakash Associates Limited and its subsidiary / associate having total cement capacity of 9.4 MnT (along with Clinker capacity of 6.7MnT and Thermal Power plants of 280MW) at an Enterprise Value of Rs 5,666 Cr. These assets are situated in the states of Madhya Pradesh, Uttar Pradesh & Chhattisgarh. The acquisition will enable Dalmia to expand its footprint into the Central Region and will represent a significant step towards realization of its vision to emerge as a Pan India Cement company with a capacity of 75 MnT by FY27 and 110-130 MnT by FY31.

Hindalco

Hindalco Specialty Alumina Chemicals team has solved a 130-year-old problem and turned Red Mud waste into an alternative raw material for the cement industry replacing finite mined minerals. Hindalco achieved 100 percent Red Mud utilisation at thee of its alumina refineries saving 4.5 mn tonnes of natural resources.

OVERSEAS NEWS

Shinagawa Refractories

Shinagawa Refractories Co. has agreed with Saint-Gobain S.A. to complete the acquisition of the Brazilian Refractories business and the Alumina-based Wear-Resistant Ceramics business in the United States from Saint-Gobain S.A. on December 29, 2022.

Sinosteel

Beijing-based Sinosteel Corp. was restructured and merged into China Baowu Steel Group Corp. Ltd. as per the the country's State-owned Assets Supervision and Administration Commission (SASAC). The deal will elevate the global competitiveness of Baowu Steel Group, which is already the world's largest steelmaker, across the industrial chain, in particular in overseas mineral resources.

Harbison Walker International

Platinum Equity, the Los Angeles-based private equity firm, is set to buy the Coraopolis-based manufacturer sometime in the first half of 2023 for an undisclosed sum from the two asbestos trusts that own HWI. HWI is a major presence in North America with the manufacturing of high-temperature refractory bricks and other supplies for the steelmaking industry. It has 16 manufacturing facilities and sales all over the world, as well as a strong position in North America.

Puyang Refractories

In the first half of 2022, Puyang Refractories (PRCO, the company) achieved revenue of 2.538 billion yuan, a year-on-year increase of 15.75%, and realized a net profit attributable to shareholders of the listed company of 169.3036 million yuan, a year-on-year increase of 41.76%. Among them, the steel business realized an sales of 2.257 billlion yuan, a year-on-year increase of 16.28%; the raw material business realized an sales of 219.7 million yuan, a year-on-year decrease of 11.69%. Overseas sales accounted for 32.47%, compared with 20.96% in the same period last year, mainly due to the increase in overseas sales orders.

MEMBERSCAN

RHI Magnesita India Ltd

RHI Magnesita has announced the acquisition of the Indian refractory business of Dalmia Bharat Refractories Limited ("DBRL"). The acquisition will significantly increase RHI Magnesita's presence in the fast-growing Indian refractory market, with forecast steel production growth in India of 12% in 2022 and a 7-8% compound annual growth rate until 2030. The acquisition will take place via a Share Swap Agreement in exchange for 27 million shares in RHI Magnesita India Limited. In October 2022, RHI Magnesita India Limited had acquired the refractory business of Hi-Tech for Rs 621 crore.

IFGL Refractories Ltd

IFGL Refractories Ltd has lined up a capex of Rs 160 crore by FY'24 to ramp up its capacity and debottlenecking of its plants. The SK Bajoria group company will invest Rs 50 crore in its Odisha plant including the Research & Technology Centre at Kalunga, at an estimated cost of Rs 20 crore. The R&D centre will help develop new products for steel and other sectors. The Kandla plant will attract a capex of Rs 44-45 crore and Rs 65 crore in the Vizag facility.

TRL Krosaki Refractories Ltd

TRL Krosaki Refractories Ltd is to set up a refractory manufacturing unit for the Metal Ancilliary and Downstream industry in Dhamra. The unit is being set up at an investment of Rs 650 crores and is expected to generate employment opportunities for over 700 people in the state.

Almatis Alumina Pvt Ltd

Almatis, a member of OYAK Group Companies, has recently integrated the tabular alumina plant in the Falta region of India with its global operations. OYAK will grow in the south east Asian market with the Falta facility, where semi-finished products will be produced from now on. OYAK expects its Falta facility to contribute 40 million dollars to its turnover in the first stage.

ECONOMY AT A GLANCE

- India recorded a growth of 9.7 per cent in the first half of 2022-23 (April-September), as against 5.6 per cent in Indonesia, 3.4 per cent in the UK, 3.3 per cent in Mexico, 3.2 per cent in the Euro area, 2.5 per cent in France, 2.2 per cent in China, 1.8 per cent in the USA and 1.7 per cent in Japan.
- The World Bank has revised its 2022-23 GDP forecast for India upward to 6.9 percent from 6.5 percent (in October 2022), considering a strong outturn in India in the second quarter (July-September) of the 2022-23 financial year.
- Growth in the output of the core sector, comprising eight infrastructure industries, rebounded sharply in November to increase at 5.4 per cent, owing to a lower base and double-digit expansion in four of the eight areas.
- India is set to post a balance of payment deficit for the second straight year in the next fiscal, which would be the first such instance in two decades, Standard Chartered Bank said on Friday. The foreign bank expects the country to record a BoP deficit of $24 billion this fiscal year and $5.5 billion in the next, against a surplus of $47.5 billion last year.
- Inflation was one of the major factors that affected the Indian economy in 2022. The country's retail inflation measured by the Consumer Price Index (CPI), dropped to an 11-month low of 5.88% in November 2022 after RBI raised the repo rates several times since April.

Table 1: Key projections

Indicator (percentage)	FY21/22	FY22/23	FY23/24
Real GDP Growth, at constant market prices	8.7	6.9	6.6
Private Consumption	7.9	9.4	6.7
Government Consumption	2.6	4.1	5.1
Gross Fixed Capital Formation	15.8	9.5	8.2
Exports, Goods and Services	24.3	10.4	9.0
Imports, Goods and Services	35.5	15.4	10.2
Real GDP Growth, at constant factor prices	8.1	6.6	6.4
Agriculture	3.0	3.4	3.6
Industry	10.3	5.0	5.8
Services	8.4	8.4	7.6

Source: National Statistics Office and World Bank forecasts for FY22/23 and FY23/24

IREFCON22 REVIEW

14th India International Refractories Congress (IREFCON22) was organized at Hotel Westin, Kolkata from 16th – 18th November 2022. The theme of the Congress was *Indian Refractory's Big Leap: Opportunities & Challenges*. The theme was selected keeping in mind the fact that India has emerged as a key player in global refractory market in recent times and offers sustainable growth in future. It is also world's second largest crude steel producer which provides ample scope of growth for the refractory makers.

IREFCON22 Organizing Committee comprised:

Sameer Nagpal (Chairman)	(Dalmia Bharat Refractories Ltd.)
Sunanda Sengupta (Co-Chairman)	(TRL Krosaki Refractories Ltd.)
Parmod Sagar	(RHI Magnesita India Ltd.)
Ish Mohan Garg	(Calderys India Refractories Ltd.)
Arup Kumar Chattopadhyay	(National Refractories)
Udaya Shankar	(Refratechnik India Pvt Ltd)
Kamal Sarda	(IFGL Refractories Ltd)
Nitin Jain	(Vesuvius India Ltd.)

IREFCON22 Technical Committee comprised:

Indra Nath Chakraborty (Chairman)	(Calderys India Refractories Ltd)
Saumen Sinha	(Calderys India Refractories Ltd)
N.K. Mishra	(RHI Magnesita India Ltd.)
Sheik Basir Mohammad	(Dalmia Bharat Refractories Ltd)
H S Tripathi	(Central Glass & Ceramic Research Institute)
S.Adak	(Mahakoshal Refractories Pvt. Ltd.)
S. D. Majumdar	(IFGL Refractories Ltd)
Shankha Chatterjee	(Almatis Alumina Pvt Ltd.)
Goutam Bhattacharya	(Imerys)
Ujjal Sengupta	(Refratechnik (India) Private Limited)
Brijender Singh	(Tata Steel Limited)
Premanshu Jana	(Vesuvius India Limited)
Arup Samanta	(TRL Krosaki Refractories Ltd.)

There were **three keynote speeches**-on Technology, Tools & Talent. They were

Organization	Title	Speaker
Shinagawa Refractories	Technology for Refractory Industry	Masakazu Iida
Tata Steel Europe	Tools for Refractory Industry	Rinus Siebring
Refratechnik	Talent For Refractory Industry	Rainer Gaebel

The **Theme lectures** that were given were:

Organization	Title	Speaker
Calderys India Refractories Ltd	Overview of Indian Refractory Industry	Ish MohanGarg
Vesuvius	Safety Aspects for Refradory Industry	Patrick Bikard
RHI Magnesita India Pvt Ltd	Refractory 4.0	GustavoFranco
Hindalco Industries Ltd	Sustainability efforts taken by Hindalco and ensuring supply security for Alumina	Saurabh Khedekar

There were 21 case studies and 29 technical presentations in the Congress. In fact it was first time that collaborative case studies as an organized format was presented at IREFCON and was well accepted by all the participants. The collaboration was between raw material supplier – refractory maker or refractory maker – user industries. The case studies mandatorily had joint presentations.

The following companies displayed their products and services at IREFCON22 exhibition:

- Almatis Alumina
- ALTEO India Aluminas Pvt Ltd.
- AMI Refractrahold
- Arcum Engineering (P) Limited
- Autosys Engineering Pvt Ltd
- Carborundum Universal Limited
- Dalian Xihua Refractory Material Co.,Ltd
- Eirich Transweigh
- Elkem S.A.
- Forace Polymer
- Fused Minerals International
- Gautam Zen International
- Hebei North Kiln Engineering Co.,Ltd.
- Hindalco Industries Limited
- Indaid Engineers Private Limited, Chennai
- ISGEC Heavy Engineering Ltd
- Imerys
- KPL International Limited (Budenheim)
- LAEIS GmbH (Luxembourg)
- Lanexis Enterprises Private Limited
- Liaoning Yuxin Hi-tech New Material Co.,Ltd
- Minchem Impex
- Neptune Industries Limited
- NY Two Global Pvt. Ltd.
- Orient Abrasive Limited (Ashapura Group)
- Pennekamp Middle East (L.L.C)-Dubai-UAE
- Romco Aluminates
- SACMI Imola S.C. (Italy)
- Saint Gobain
- Thyme Corporation
- Totale Global Pvt Ltd
- Zhengzhou Fang Ming high temperature ceramic new material co Ltd.
- Zhengzhou Haloong Machinery Manufacturing Co.,Ltd

The juries selected the following companies for the IREFCON22 Exhibition Awards:

- 1st Prize : Totale Global Pvt. Ltd
- 2nd prize : Almatis Alumina Pvt. Ltd
- 1st Consolation Prize : ISGEC Heavy Engineering Ltd
- 2nd Consolation Prize : Romco Aluminates Pvt Ltd.

Sponsors who provide support are:

Sponsorship Title	Company
Cultural Nights Sponsor	RHI Magnesita India Ltd
Bar Sponsor	Dalmia Bharat Refractories Ltd
Welcome Dinner Sponsorship	Maithan Ceramic Ltd
Diamond Sponsor	Almatis Alumina Pvt Ltd
Platinum	Calderys India Refractories Ltd Refratechnik India Pvt Ltd Vesuvius India Limited
Gold	Imerys IFGL Refractories Ltd. TRL Krosaki Refractories Limited Global Monarch FZC
Silver	Heatworks Pvt Ltd Totale Global Pvt Ltd Hitech Chemicals Pvt Ltd Noble Refractories Sarvesh Refractories
	Elkem S.A. Orind Special Refractories Pvt. Ltd. Mahakoshal Refractories Pvt Ltd Viswa Vishal Refractory Ltd Hindalco Industries Limited

On the opening day noted orator Mr Devdutt Patnaik gave a lecture on “India Is Not Chaotic” followed by a lecture on Indian Economy by Mr. Prasenjit Chakravarti, partner, Khaitan & Co. Overall 608 delegates from 200 companies participated in the 3 days Congress.

IREFCON 2022 PHOTO GALLERY

Welcome Gate - IREFCON 2022

Sponsors' Signage

IRMA Chairman Mr. Ish Garg delivering his Address

Section of Delegates

WRA Chairman Mr. Parmod Sagar addressing the delegates

Mr. Sameer Nagpal addressing the Delegates

IREFCON 2022 PHOTO GALLERY

Mr. Masakazu Iida giving his Keynote Speech

Mr. Rainer Gaebel giving his Keynote Speech

Mr. Rinus Siebring giving his Keynote Speech

Mr.Devdutt Pattanaik giving Lecture 'India Is Not Chaotic'

Mr.Prasenjit Chakravarti giving lecture on' India - A Bright Spot Amid Global Economic Turmoil'

The Organizers

IREFCON 2022 PHOTO GALLERY

View of Exhibition

The Interactive CEO Meet

Thanking the Participants of CEO Meet

Entertainment Program

Totale Global Pvt Ltd receiving the First Prize in the Exhibition

Concluding Cake cutting Ceremony

BUSINESS SECTION: IREFCON22 SPECIAL

UNICORN HUNTING: FINDING TALENT FOR THE REFRACTORY INDUSTRY

Rainer Gaebel, Corinne Fields, Sahaja Balla - Refratechnik Holding

Just a few years ago, the industry's focus was on coping with various temporary crises such as the financial crisis or the various raw materials crisis'. Most recently, the pandemic and the resulting supply chain crisis have particularly challenged the industry. The refractory industry has largely mastered these challenges successfully. Why is this the case? Our industry is indispensable. Without refractories, basic industrial processes are inconceivable. This is certainly a comfortable situation for companies in our industry. However, this should not lead us to conclude that the refractories industry is also well prepared for all of the challenges ahead.

The new challenges facing the global refractories industry are a result of the need to protect resources and drastically reduce CO_2 emissions. The refractory industry, as well as our customer industries, are facing an enormous task as the demand for steel, cement, glass and aluminum and other basic materials will continue to grow. The world population will also continue to grow, with many more millions of people striving for prosperity. India will soon replace China as the most populous country, and must create the infrastructure for future growth. This means that without innovative technological changes, CO_2 emissions will continue to increase.

While processes such as the reduction of iron ore with hydrogen, or the capture andutilization of CO2 are already being developed in the steel and cement industries in Europe and elsewhere, most companies in the refractories industry still find it difficult to similarly challenge their own processes. The refractory industry's contribution to global emissions is of course lower than that of some of the refractory users. However, assuming that an integrated steel mill converts its hot metal production to hydrogen reduction, refractory wear products will be one of the largest remaining contributors to CO_2 emissions in the overall steelmaking process.

Whether the statement made above; that many industrial processes are inconceivable without refractories will hold true, in this generalization in the future is not certain. The need to reduce emissions will almost certainly lead to many technological upheavals in the next 20 years, which may in part call into question the current business model of the refractory industry. What is certain, however, is that if the refractories industry does not succeed in reducing its own emissions, the pressure to avoid traditional refractoriesconsuming technologies will grow.

What lies ahead of us is not just mastering crises or difficult economic phases - it is the fundamental reorganization of our customer industries and our own processes in the direction of increased sustainability and CO_2-neutral production and application of our products.To make this change, we have to both: develop new technologies and tools that can be applied by a new generation of employees. We need the classic skills, of course, which are already becoming increasingly difficult to find, but we also need generalists and specialists, developers, engineers and application technicians who, together with digital specialists and program developers, can break new ground in research and development. Process engineers who develop new high-temperature firing techniques. Engineers who are driving the automation of assembly processes. Logistics specialists who optimize the flow of goods with digital systems, and specialists for the necessary networking with customers.

It follows that the most important raw material we need to mine for the future of the refractory industry, is no longer just minerals. "Talent mining" is becoming the most urgent task for the industry.

All of the qualifications needed in our industry are also in demand in other industries. At the same time, the number of students in the

traditionally relevant natural sciences and engineering such as metallurgical engineering, geology or mineralogy is gradually declining in many important economic regions.

In Germany for example, none of these subjects is in the top 20 (Fig.1). Although there are many good ideas and research topics where funding is not a problem, open PhD positions are often difficult to fill.

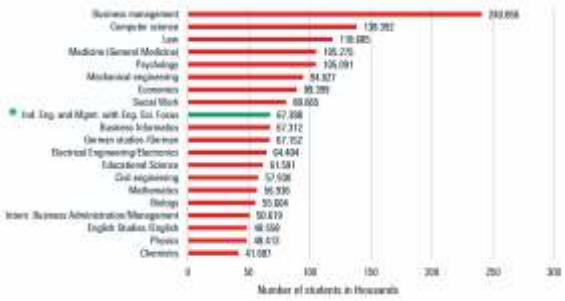

Fig.1: Number of students at German universities in the 20 most popular subjects in the winter semester 2021/2022 (Source: Statista 2022)

Even in India with its' rapidly growing heavy industry, the number of students graduating engineering every year is approx.1.5 million, with metallurgical and mining engineering graduates to approx. 8,000 - 9,000 as per 2022 which is relatively very small. Based on the demands placed on us and the reported study numbers, it can only be concluded that we need to attract talent from all disciplines. At this point, it should be noted that talent does not only refer to academics, but to all levels of education.

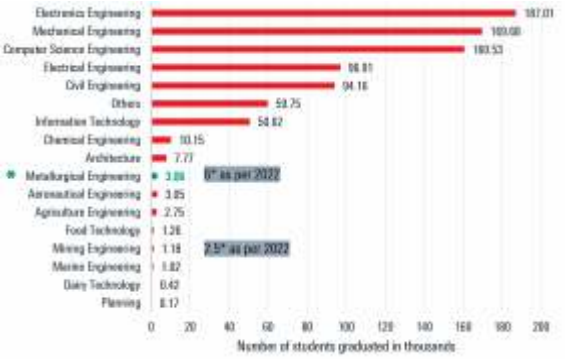

Fig. 2 Number of students who graduated in Engineering stream across India in FY 2016 (Source: Statista 2022)

The situation may vary from country to country, but of today's college graduates, independent of the study subject, at best only a tiny fraction worldwide dream of or plan a career in the refractory industry.

Our industry is known to only a few, our companies are sometimes negatively perceived because of our smoke stacks - even if the emissions comply with all legal requirements. Not all factories in the industry look modern and contemporary. Overall, we are simply not very attractive for young graduates. We should start sooner rather than later to increase the attractiveness of a career in the refractory industry and promote a correspondingly positive image of our industry. Internationally, the World Refractory Association (WRA) has already begun to raise awareness of the refractory industry by portraying it on social media as essential to everyday life.But that will not be enough. Individual companies must also contribute to increase their attractiveness to applicants. The more companies succeed in increasing their attractiveness, the better it is for the image of the entire industry.

While we can spend a lot of time discussing what motivates Baby Boomers versus Millenials and Generation XYZ, today's recruiting process is actually the opposite of the recruiting process most of us experienced when we entered the job market.In short, we competed with our peers for the best career opportunities, where today companies have to compete with other employers for the best talent. We now find ourselves in the new and uncomfortable position of having to cater to the demands of potential employees.

You will often hear hiring managers complain (in most parts of the world, but perhaps not yet in India) that new recruits just don't want to work hard anymore, and are looking for work life balance, that they demand flexible work conditions and remote office options. The business they choose to join must have clearly defined growth opportunities and be a fun place to work. Additionally, they want to be part of a

dynamic team and a socially and environmentally responsible corporation.

Could it be that potential employees have become more demanding than our customers? Could it be that we should approach potential employees in the same manner that we approach customers? Could it be that recruiting now requires that we sell the potential benefits of our joining organization in order to attract the best talent? The answer is plain and simple: yes. Consequently, modern companies do the following: They

1. Check their company culture
2. Update their job requirements
3. Invest in digital tools
4. Make training and development their biggest priority
5. Revise their marketing and advertising strategy

Nothing speaks louder than your employees talking about how „this is a great place to work", grass roots, unscripted messages have the strongest effect. When new employees are made to feel left out until they „pay their dues", and there is a strong „ old guys" versus „young guys" dynamic, retaining new talent is negatively impacted. The highest potential new employees will be hungry for information whenever and wherever they can get it, information hoarding and barriers to access will quickly demotivate even the most eager and dedicated. One of the most prevalent complaints of entry level and mid-career professionals is focus on title and position rather than performance and contribution. They are absolutely unimpressed and not intimidated by fancy titles and seniority. Most young people are less patient and more prone to job hopping, while those who are not and whom you want to keep must be rewarded by the employer for their commitment to the company.

When your job requirements are too focused on the right university degree or relevant industry experience, you are likely to reduce the pool of potential candidates and could miss out on some excellent talent simply because they don't fit in a neat box. I would propose that some of your own top performers are not always fitting a traditional mold. Personality testing and a more interactive interviewing process can help identify the best suited candidates.

Anyone currently entering the job market has grown up in a digital world. Provide digital tools that make your employees experts, with quick and relevant information available at their fingertips. Listen to the wishes of entry level employees and make them part of developing digital solutions.

If talent is hard to find, then provide an infrastructure to develop your own talent by offering:

1. Comprehensive and structured programs, teaching basics, intermediate and expert skills and knowledge.
2. Recognition: Certificates, Internal Diplomas etc. that celebrate success and advancement.
3. Career long program: No employee, no matter how senior should ever be finished with training and development.
4. Involvement: Work with local schools and higher learning institutes to support their efforts while exposing students to your business. (Example: Organization of a seminar or exhibition to educate our business, internship or project opportunities, offer of one day industrial tour for the students)

If people are your most important resource, then your landing page should reflect this.

We tend to focus our marketing and advertising on what we do and sell, how big or global we are, how innovative we may be, but rarely do we advertise WHY we do what we do, if we want to attract talent, the WHY is going to be the biggest „ hook".

The refractory industry has a wealth of WHY to offer. It is a worthwhile goal to transform the refractory industry, which is essential for the development of society, into a greener, more sustainable industry and enable our customers to do the same. If we succeed in actually putting the WHY in the foreground, we only have to define the goals. Our talented employees will find the way to the goal themselves.

TECHNICAL SECTION

GHG EMISSIONS SURPRESSING TECHNOLOGIES OF THE REFRACTORY INDUSTRY

Masakazu Iida Research Center, Shinagawa Refractories Co., Ltd., JAPAN Corresponding author's e-mail: m_iida@shinagawa-ref.com

Abstract:

In 2016, the world emitted 49.4 Gt of anthropogenic greenhouse gases (GHG), of which, the industrial sector occupies 26.4 % according to "Our World on Data" [1]. As suggested in the report of the Intergovernmental Panel on Climate Change (IPCC) [2], furnace insulation and recycling are effective options to mitigate GHG emissions. These are measures to which refractory industry can contribute. According to the articles presented in Unified International Technical Conference on Refractories (UNITECR), it is obvious that refractory-related industries have been developing many technologies in these two fields. In some cases, industrial application of these technologies is costly and risky at the initial stage of deployment, thus, large industrial scale implementation by a single company is difficult. To motivate ambitious investment and purchasing of these technologies, establishing a standard for GHG emission evaluation and fair ruling for a carbon pricing mechanism are necessary.

Keywords:

Refractories, GHG, Insulation, Recycling

1. Introduction

For several decades, refractory manufactures have been promoting the developments of heat insulation and refractory recycling technologies with confidence that these measures will improve energy efficiency, resulting in mitigating greenhouse gases (GHG) emission that causes global warming. It seems though, that no significant reduction of GHG has been achieved yet. One reason is assumed to be cost ineffectiveness. In some cases, the adoption of these technologies raises refractory prices, which in turn reduces competitiveness of the final products in their market. The other reason is considered attributable to global economy expansion. Even if implementation of individual technologies could reduce GHG emission per unit refractory consumption or final product production, total emission would increase due to global production expansion and world exceed the summation of the reduced amount. These examples indicate that ending up with an economical advantage has been being prioritized. Thus, for ambitious deployment of these developed environment protecting technologies, prioritization of GHG gas emission reduction is necessary. In order to prioritize the reduction of GHG emissions, setting a target with an appropriate index is an effective method and a GHG footprint may be a strong candidate for this index.

Most people are probably aware of the above dilemma, however, many, including the author, have had only a vague understanding. In this article, therefore, a general perspective on global GHG gas emission and mitigating options will be reviewed followed by exemplifying technical papers on the topic of heat insulation and refractory recycling presented in a recent Unified International Technical Conference on Refractories (UNITECR). Lastly, global implementation of GHG gas mitigation measures in refractory-related industry will be discussed.

2. GHG emissions overview

Figure 1 shows anthropogenic GHG emissions by sector in 2016 summarized in CO_2 equivalents (CO2eq) by "Our World on Data" [1]. That year, 49.4 Gt of CO_{2eq} was emitted globally, of which, the industrial sector was responsible for 26.4 % energy consumption and process emissions. Although detailed classification differs among data sources, it provides a holistic projection of the GHG emission. Obviously, iron & steel is the largest emitter in the industrial sector. Emissions from the refractories and refractory raw materials producing process may be included in "other industry". "European Industrial Production Information Exchange" estimated GHG emission from global ceramic industry

including refractory as 15,671 kt of CO_{2eq} in 2017 [3]. Thus, ceramic industry occupies only a tiny fraction of global GHG emission. However, **Fig. 1** also indicates that there's no giant in GHG emitter. This means that every sector including the refractory industry should be responsible for reducing global GHG emission.

Figure 2 is a sanky diagram showing an intersectional relationship of GHG emission proposed by Bajželj et al [4] cited from the Intergovernmental Panel on Climate Change (IPCC) report [2]. Relation and contribution of each category is well-expressed.

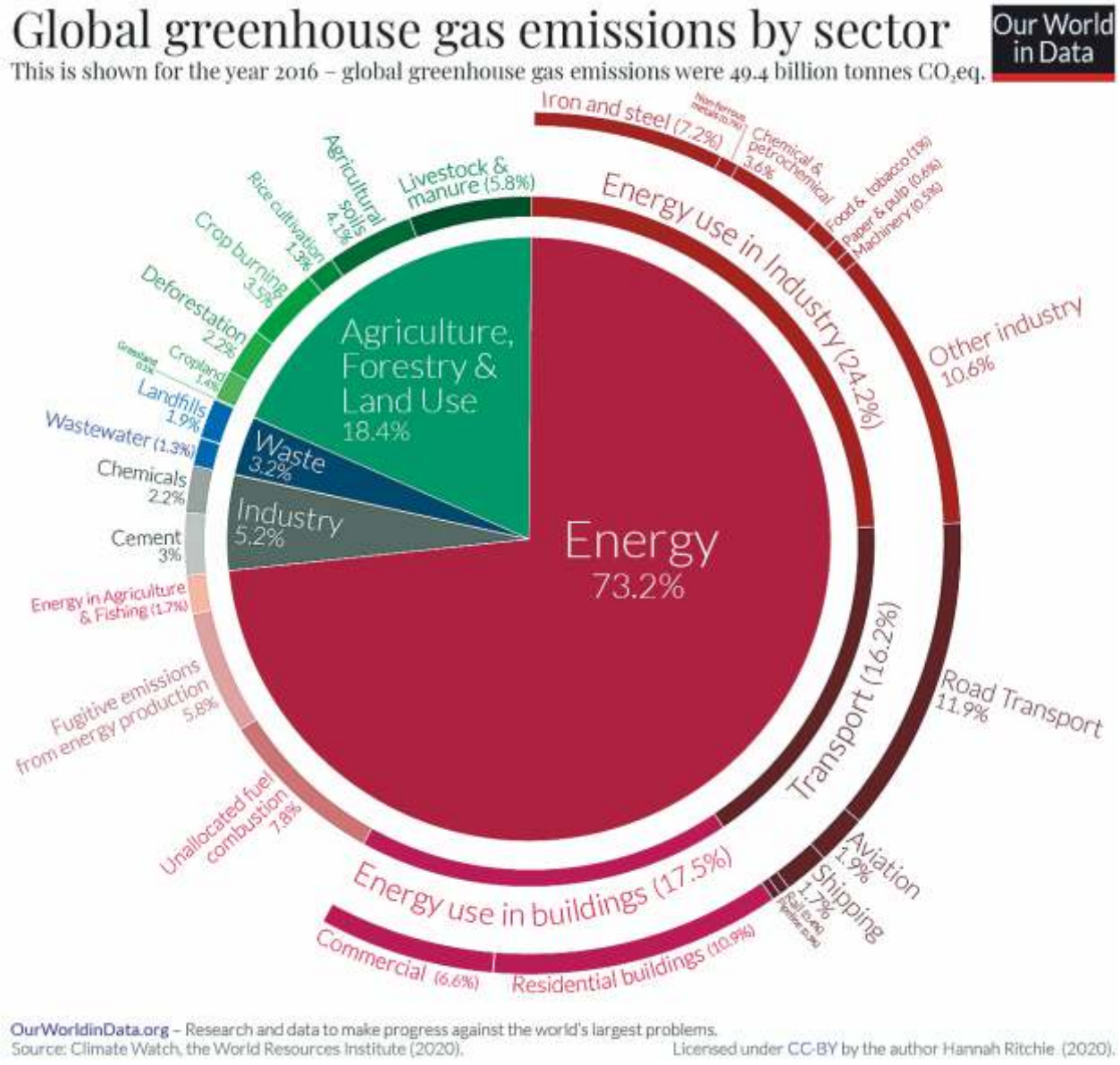

Figure 1 Global GHG emissions by sector [1].

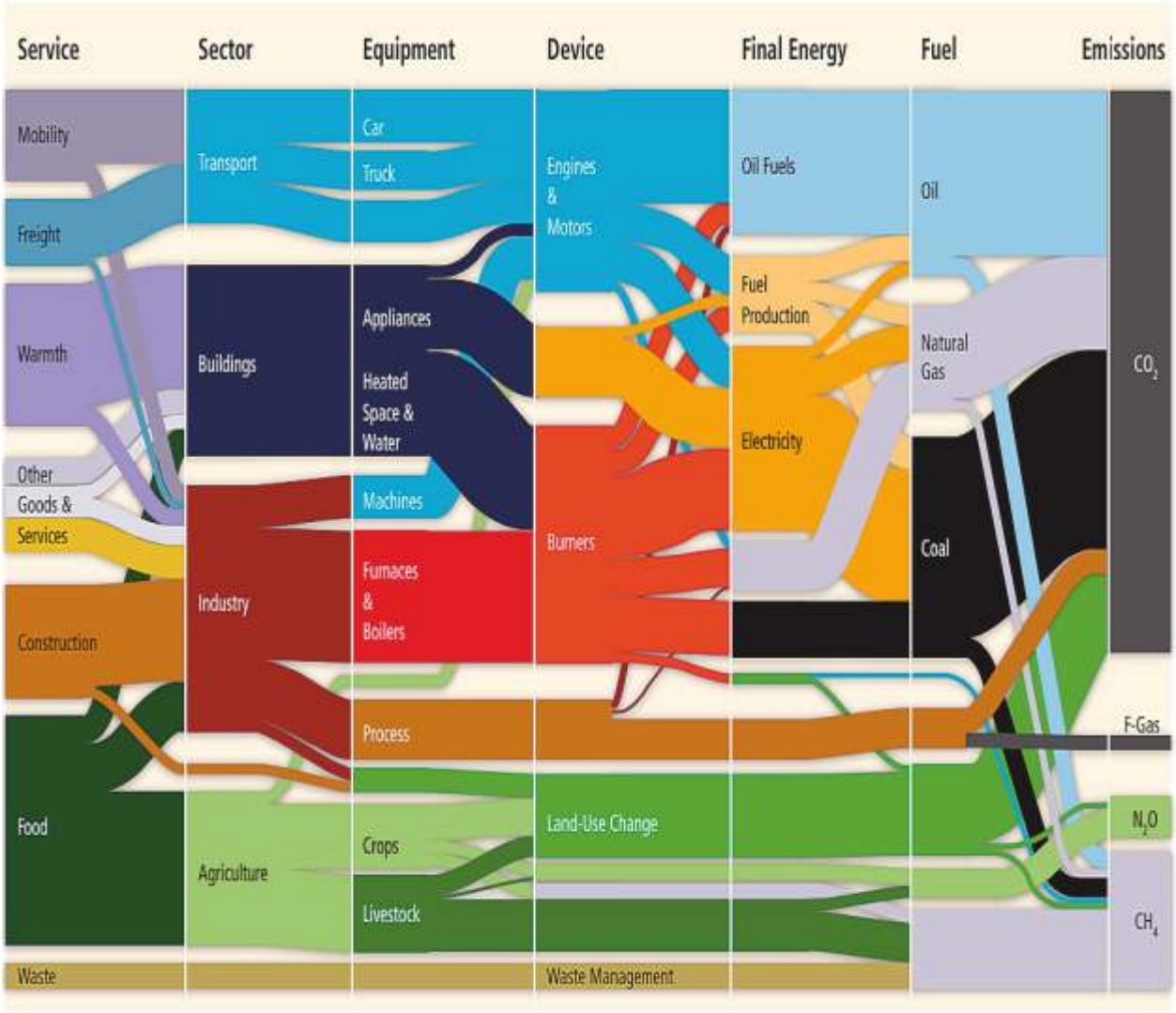

Figure 2 Intersectional relationship of GHG emissions [4].

Figure 3 shows energy use and GHG emissions through industrial process schematically [2]. The darkened circled numbers indicate suggested options for emission mitigation. As exemplified in option (1), furnace insulation and material recycling are listed as effective methods for mitigating GHG emissions by improving energy efficiency. These are what the refractory industry has been pursuing. In addition, improvements of durability and resulting reduction in refractory unit consumption correspond to options (3b): Material efficiency in product design and (5): (Service) demand reduction. If reduction of high-grade steel yield losses can be achieved by optimization of submerged entry nozzle design, it is a refractory technology contribution to mitigating GHG emissions in the manner of option (3a). Therefore, the refractoryindustry itself has been a great contributor to building an ecological society.

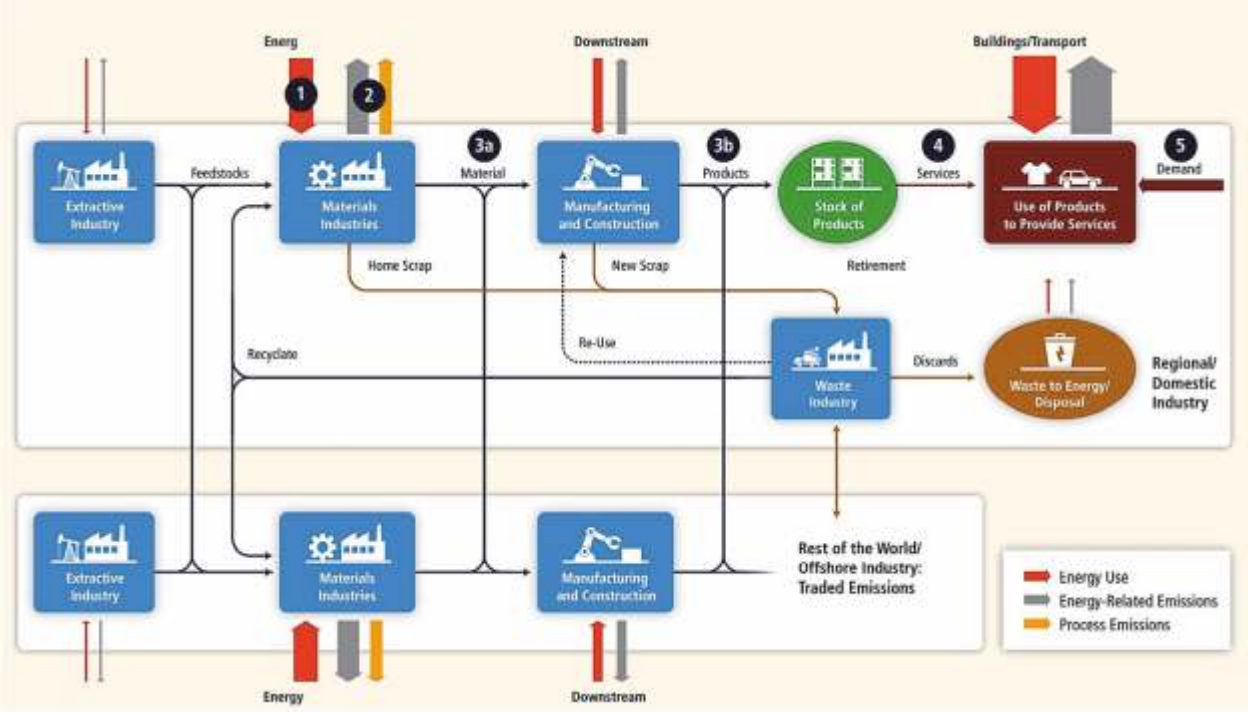

Figure 3 Schematic illustration of energy use and GHG emissions through industrial process [2].

Darkened circle numbers indicate emission mitigation options as follows.

(1) Energy efficiency (e.g., through furnace insulation, process coupling, or increased material recycling);

(2) Emissions efficiency (e.g., from switching to non-fossil fuel electricity supply, or applying CCS to cement kilns);

(3a) Material efficiency in manufacturing (e.g., through reducing yield losses in blanking and stamping sheet metal or re-using old structural steel without melting);

(3b) Material efficiency in product design (e.g., through extended product life, light-weight design, or de-materialization);

(4) Product-Service efficiency (e.g., through car sharing, or higher building occupancy);

(5) Service demand reduction (e.g., switching from private to public transport).

In terms of refractory technology, biannually-held Unified International Technical Conference on Refractories (UNITECR) has been a world-wide platform for exchanging technical information as well as building personal relationships since its establishment in 1987. Thus, reviewing articles that have been presented at UNTECR is a reasonable way to follow the trends of refractory-related technologies.

Figure 4 summarizes numbers of articles concerning insulation and recycling presented in 21st century UNITECR (there might be an oversight because it is according to the author's counting). Technology developments for both fields have been presented consecutively. In the following two sections, recent developments of these fields presented in UNITECR will be exemplified.

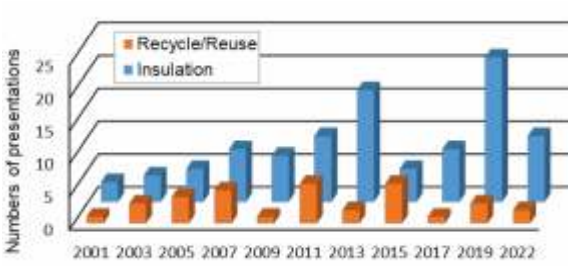

Figure 4 Numbers of papers concerning insulation and recycling presented in UNITCR.

3. Thermal insulation technologies presented in recent UNITECR

As shown in **Fig. 5**, a variety of topics concerning thermal insulation were presented in this century. Traditional fiber insulation materials are still under development and some new insulation materials have been presented.

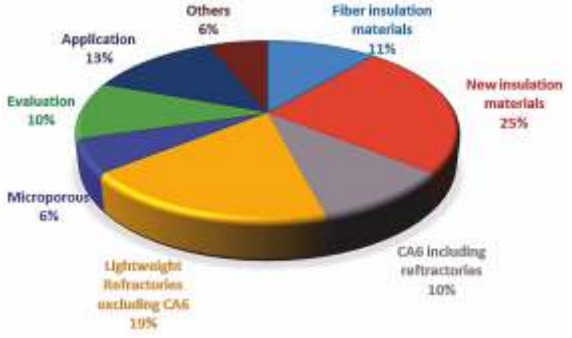

Figure 5 Topics concerning thermal insulation presented in UNITCR from 2001 to 2023.

In **Fig. 5**, category "evaluation" includes evaluation of insulation material properties and computer simulations relating to furnace thermal insulation. Thanks to the rapid developments and affordable circulation of high-speed computer and calculation software, proposals of optimal applications of refractories and insulation materials with high accuracy became possible.

Focusing on heat retention in the working lining during the heating period and heat emission from the working surface during the emptying period, the effectiveness of application of low thermal conductivity working lining refractories to steel making facilities was demonstrated taking unsteady state heat transmission into account [19], [20]. **Figure 6** shows the influence of the thermal conductivity of the working lining on temperature distribution of steel ladle lining schematically. The solid and dotted lines are assumed temperature distributions of conventional material and lower thermal conductivity material, respectively, and the red and light blue indicate highest and lowest temperature period in operation, respectively. When the ladle retains molten steel, the refractories are heated by molten steel and the inner temperature rises according to thermal conduction. If lower thermal conductivity material is applied, the inner temperature becomes lower. This indicates that less amount of heat is retained in working lining. When the steel ladle is emptied for steel casting, heat retained in the working lining is emitted from the working surface and the inner temperature lowers. If lower thermal conductivity material is applied, the temperature drop in the inner part becomes smaller, thus, less heat is emitted.

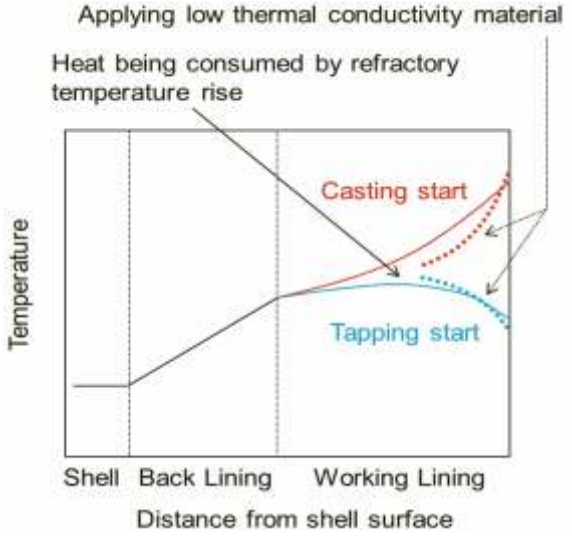

Figure 6 Conceptual image of the heat being consumed by temperature rise of lining refractory of steel ladle.

"Others" in **Fig. 5** includes surface coating technologies. Surface coating with emissivity-varied materials is effective for controlling heat emission from the surface [21], [22]. Therefore, it is expected that suitable applications of the above technologies will improve the thermal efficiency of high temperature facilities, resulting in a reduction of global GHG emissions.

However, for implementation of strong thermal insulation to high temperature vessels, temporal acceleration of the corrosion rate of the working lining refractories is a concern since the temperature of the working surface rises as a result of thermal insulation. Theoretically, the surface temperature rise is compensated by lowering operating temperature. This is the ultimate purpose of insulation. However, low temperature operation is thought to be difficult at the initial stage of industrial application according to lack of experience. Additionally, unexpected troubles such as sudden deterioration are also a concern for unprecedented trials.

4. Refractory recycling technologies presented in recent UNITECR

Recycling is one of the promising options for reducing industrial waste, consumption of natural resources and energy since modern high-performance refractories require purified raw materials which are produced through an energy intensive process. Hence, promoting refractory recycling contributes to the reduction of global GHG emission.

For recycling, it is important to reject altered zone, in which impurities such as slag have penetrated during furnace operation. In practice, impurities can be contained in various materials to some extent inevitably and its quantities and composition varies according to the variations in furnace operation. Since many of the rejection and separation processes are carried out by operators manually, process automation is necessary from an industrial point of view. Currently, available technologies have been adopted for suitable separation and new recycled material treatment technologies are under development. A color-sorting device (**Fig. 7**), which is used widely in the food industry to sort beans according to color contrast, has been applied to the commercial recycled refractory sorting system[23]. It allows sorting of black colored aggregates, which are derived from the altered zone, and white colored aggregates, which are derived from the unpenetrated zone, successfully. A Laser-Induced Breakdown Spectroscopy (LIBS) sensor enables sorting according to chemical analysis [24]. Utilizing high voltage pulse power fragmentation method, separation of magnesia and graphite of post-used MgO-C brick became possible [25]. In order to use recycled materials as refractory raw materials, long distance transportation, which emits GHG, is necessary. Thus, using them in a refractory user's plant without bringing them back to a refractory manufacturing plant is a better option. In a steel plant, subsequent to on-site treatment, crushed recycled materials are charged into castable during mixing for installation[23]. Continuous addition of grains and/or powder derived from used brick to the gunning repair process through a special providing device is another option[26]. Using crushed recycled refractories in the reheating furnace hearth to form a ballast barrier structure is effective for preventing hearth brick damage caused by mill scale [27].

As described above, various methods are available for refractory recycling. Among those, down graded application, in which high grade refractory scraps are used for lower grade refractories, is easier and cost effective. However, annual usage of this kind of refractories is quite small since only slight damage is occued there. Hence, to promote refractory recycling, expansion of the application to corrosive zone refractories is necessary. To accomplish this, accurate treatment, intensive elimination of contamination and/or further purification is demanded. However, this is costly and risky in terms of economy and safe furnace operation, respectively.

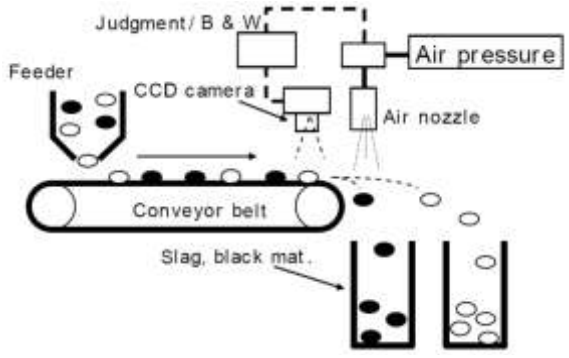

Figure 7 Schematic illustration of color-sorting device [23]

5. Other measures

Naturally, refractory manufacturers and refractory raw material producers must reduce GHG emissions from their own manufacturing process. As listed in (1) to (5) in **Fig. 3**, Every possible measure, such as improving thermal insulation efficiency of brick burning kilns, changing burner fuel to non-fossil fuels, using green electricity, improving overall productivity by suitable adoption of artificial intelligence (AI) technologies, and so on, should be taken. Furthermore, reduction of transportation by utilizing on-line tools and/or Virtual Reality technologies mitigates GHG emissions from all economy aimed activities. Particularly, sufficient distribution of green electricity is crucial. Currently, many of these measures are still under development and they are costly.

For refractory manufacturers, lowering burning temperatures and an increase in the monolithic products share is effective for reducing GHG emissions. However, if those alternatives use highly purified raw materials and/or specific additives, which are produced though energy intensive process in order to secure sufficient durability, global GHG emissions increase. Hence, careful assessment is necessary from a holistic point of view. Therefore, Life-cycle Assessment (LCA) is important.

Based on careful research and appropriate hypothesis, Strubel[28] calculated CO_2 emission from the refractory manufacturing process. In the paper, carbon footprints of 41 commercially-available refractory raw materials are assessed as the emission factor in the unit of kg-$CO_{2/t}$-raw material. Some of them are shown in **Fig. 8**. Selection of lower GHG footprint raw materials according to qualified accurate evaluation is also important.

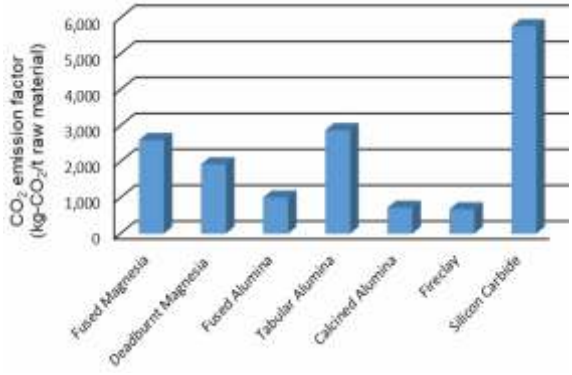

Figure 8 Carbon footprints of refractory raw materials [28].

6. Implementation of actions for global GHG emissions mitigation

While Strubel[28] carried out the estimation under the appropriate hypothesis, the emission factor might differ from plant to plant corresponding to the production system and energy efficiency of facilities. Principally, if all industrial members disclose their GHG footprint product by product, the GHG footprint of each industrial product can be documented by the summation of GHG footprints of raw materials and GHG emitted from own manufacturing process. Individual GHG emission mitigation efforts should be acknowledged, thus, it is desirable to establish an international standard for a GHG footprint evaluation method and let the GHG footprint be one of the important indices for purchasing.

As mentioned in sections 3 to 5, many GHG emission mitigation measures are cost intensive and sometimes risky. Since investment and purchasing for these measures reduces cost competitiveness, large scale implementation of these measures by a single company is difficult.

To motivate ambitious investment and purchasing for GHG emission mitigation measures, carbon pricing based on the GHG footprint is considered to be an effective option since it allows the evaluation of GHG emissions as financial impact.

There is no single decisive measure to reduce GHG emissions, hence, every available effective measure should be taken. Ultimately, extra cost for GHG emission mitigation will be paid by general consumers. Therefore, fair international ruling and improving common awareness is important.

7. Conclusion

The refractory industry has been developing thermal insulation and recycling technologies consecutively. Although these technologies contribute to the mitigation of GHG emissions, large scale industrial implementation is costly. Thus, establishment of a GHG footprint evaluation standard and fair ruling of a carbon pricing mechanism are important in order to motivate implementation of GHG emission mitigating measures.

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TECHNICAL SECTION

TOOLS TO ENSURE AND TO IMPROVE REFRACTORY PERFORMANCE AT TATA STEEL IJMUIDEN

Rinus Siebring, Tata Steel IJmuiden, Centre of Expertise Refractories

Refractories expertise is seen as a core competence at Tata Steel IJmuiden. A systematic approach is used to optimise the refractories to the requirements of the different production facilities. The primary focus of the Centre of Expertise Refractories of Tata Steel located in IJmuiden is to find the best Value in Use refractory solution for every installation. Taking the health, safety and environmental regulations as boundary conditions, different refractory solutions are considered using Value in Use tools to calculate the most economical solution. Improved measurement tools and tools for better understanding of the wear mechanism are developed and several examples are presented. Besides this collaboration with universities and refractory institutes (for developing more fundamental understanding andspecial tools), other steel plants (via benchmarking) and suppliers (for developing solutions based on the wear mechanism) are an essential part of the refractory improvement strategy in IJmuiden.

Introduction, needs of a steel producer

The steel industry is part of a rapidly changing society and it is struggling to manage all the necessary changes and demands on, for instance, the environment, variable process circumstances and political environment [1,2,3]. Refractories arean indispensable tool to produce steel. Optimising the steel production to the new demands means also adopting the refractories in the same pace to the new reality. Currently the changes in optimising refractories in the steel plants are going rather slow [4]. Within the Centre of Expertise Refractories, which is part of the Ceramics Research Centre of Tata Steel IJmuiden,a lot of tools have been developed or are under development to cope with these challenges. To understand the logic of the different developments it is important to start withthe needs of a steel producer like Tata Steel inIJmuiden (=TSIJ).

Fig.1: Tata Steel IJmuiden's perspective on refractories [4]

The demands on the refractories differ between steel plants. This has to do with the setup of the plant, the qualities to produce and different regulations. TSIJ produces around 7 mln tons of steel. The requirements on the refractories are given in fig.1.

Tools for refractory selection

TSIJ has developed/created several tools to optimise the selection of refractories. In the following sections we discuss tools to fulfil:

- Health, Safety and Environmental regulation,
- Economical, advanced analytical & thermalmechanical modelling,
- advanced monitoring
- QC system and laboratory testing

Boundary conditions

The choice for an optimal refractory design starts with the boundary conditions. The most important boundary conditions are the rapidly becoming stricter health, safety and environmental (HSE) regulations.Safety issues occur during building in and wrecking of the refractories and during service (breakouts).

Especiallyinavoiding breakouts, different tools like thermal couple measurements (e.g. blast furnaces, runners), laser measurements (torpedo cars, converters and steel ladles) and dashboards predicting 'thinnest point of the lining and the moment that the equipment has to be taken out of service' (steel ladles) are used.

Refractory materials may contain dangerous substances for health (CMR substances that arecarcinogenic, mutagenic or toxic to reproduction) orcan emit unhealthy gasses during heating (e.g. Polycyclic Aromatic Hydrocarbons "PAH", Phenol and/or formaldehyde) or can emit radiation (especially materials with Zr-components) or form dangerous phases during service (like crystalline silica). In all cases the Dutch legislation demands for a reduction, with as final goal to eliminate the use of such refractory materials.In many cases, suppliers give insufficient information to judge which material is favourable over another material and also the quality of the information on the safety data sheets (SDS) differs between the different suppliers. To get in controlTSIJ made a special questionnaire [5]. This questionnaire has to be filled by all suppliers and send to us including an applicable SDS.One of the future improvement goals is to harmonise this with other steel plants in order to set a new safety standard about information on refractory materials used in the steel industry.

Besides HSE boundary conditions, changes and improvements in refractories are also limited by the lay-out, process requirements and the logistics of the plant.

Selecting the optimal refractory solution

When boundary conditions are met, optimisation can start between costs of refractories, capacity utilisation, energy losses and effects on steel quality. Still, most steel producers have their focus on the cost/performance ratio when choosing refractories taking into account only the direct refractory costs of material and installation. Next to these cost, there are other refractory related costs (e.g. QC testing, breakouts, storage, heating, etc.) andalso steel producing benefits to consider (energy saving, capacity optimisation, etc.). These cost and benefits can be significant higher than the direct refractory costs [6]. Fig.2 shows besides the direct costs of refractories many other cost and possible benefits to consider.

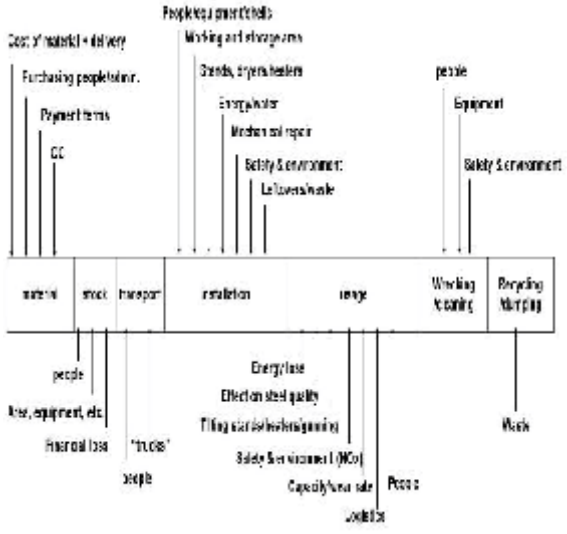


Fig.2: Different steps in the life cycle of steel ladle refractories and related costs/benefits [6]

For all equipment used in the steel plant such a scheme can be made, however influencing factors and benefits will be different. If we want to optimise the refractories in the equipment it is almost impossible to take all these factors into account with every change or decision. For this reason TSIJ developed for the steel ladle an economical model [6].

This model takes many of the factors into account
and also calculates with statistical supported wear rates and standard deviations. Calculations that took in the past several days now can be done in a few minutes with results that are much more accurate.

More important, it allows to play with different options/solutions and is therefore an essential basis for further refractory and construction developments. It enabled IJmuiden in the last 3 years significantrefractory savings, however the value of the benefits gained in steel production are at least a factor 4 higher.

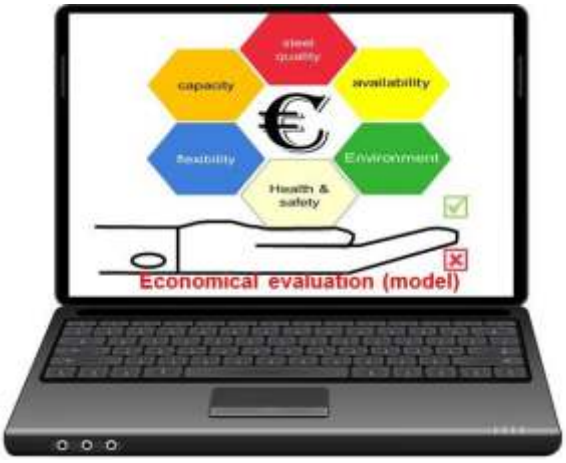


Fig.3: Economical evaluation computer model for the steel ladle. Since the model is in operation, developments are going much faster (at least 30% quicker), the number of trials are decreased and materials that were considered as too expensive in the past are now used successfully. The economic model facilitates the choices in improvements, but in itself it doesn't develop the equipment. Thereforereduction in wear rate and improved predictionof the wear of the refractories are the most important factors [4].

Factors in the wear of refractories

The wear/performance of refractory is depending on four interrelated factors: (steel) process, refractory materials characteristics, the chosen construction and the quality of the installation (fig 4).

In general more attention is paid to the interaction between steel process and refractory materials than to construction and installation. Based on the process circumstances and the refractory characteristics, materials are selected for a (shorter or longer) practice trial. In many cases the trial doesn't show the expected improvement [4].

There are several reasons for this:

- variable installation,
- variable refractory characteristics,
- insufficient knowledge about the interaction between (too many possible) process variables and refractory characteristics,
- insufficient accurate wear measurement,
- insufficient measurement systems to quantify the necessary refractory characteristics,
- insufficient knowledge about construction effect on refractory behaviour.

Fig.4: Factors affecting the performance of the refractories in the steel plant.

Variation in the installation of refractories and variation in refractory characteristics will have an influence on the refractory performance. Variation in the installation of refractories can have an effect on, as well as be caused by the refractory characteristics. With supervision the effect from installation on the installed refractory characteristics can be minimised. Changes or variation in refractory quality can have significant effects on the refractory performance Variation in the refractory material's characteristicscan come from variation in raw materials, variation in production, wear of pressing moulds, changes in raw materials and other production optimisation. To minimize this problem a refractory quality management system is in place at TSIJ with product definitions, test certificates and QC control [7].

Wear analysis tools

The relation between most of the process factors and refractory wear is still unclear. The reason for this is that there are hundreds of process variables that might have an effect on the performance of the refractory. These variables are often interacting with each other, it sometimes strengthen the effect, sometimes it reduces each other's effect. For the steel ladle, in the past the performance of the refractories was judge based on the life. With this very inadequate evaluation system it is almost impossible to find relations between process and wear. Since 2010 on a systematic and regular way the wear is calculated on the rest thickness per area resulting in a wear rate of 'mm/heat'or 'mm/time steel in the ladle' per refractory area [4]. This helped to pin point much better which processes were causing wear at which area. However it is still insufficient to find all relevant detailed relations, and the desired wear prediction is, based on this, still not possible. Recently TSIJhas started to use for the steel ladle "advanced analysis (AA)" to find relations between process and refractory wear [8]. The success of such a tool depends for a large part on the steel and refractory knowledge of the team using advanced analytics. Without knowledge about refractory wear this kind of tools are (for the time being) useless. AA helps to find possible relations, supports the discussion about the relations and based on this develops new hypotheses which can then be verified with the AA-tool.

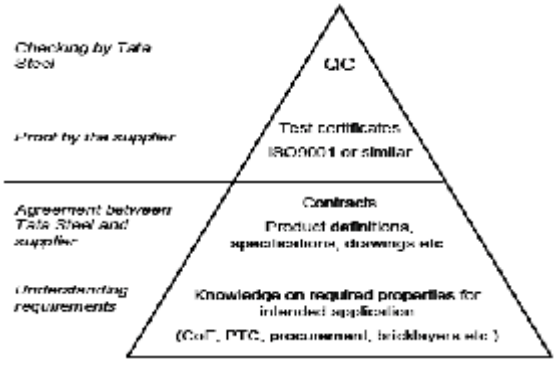


Fig.5: Refractory quality management /control system in place at Tata Steel IJmui - den [7]

Another very important aspect in finding a relation between process and refractory wear is the preciseness of the laser scanner. During a Six Sigma analysis it was found that the current preciseness of the scanner in IJmuiden is insufficient to do analysis based on a heat to heat basis, because the laser is not precise enough in its position in relation to the position of the ladle. This is mainly caused by the fact that the laserneeds to know the exact position of the ladle and the current methods used in IJmuiden are insufficient.

Despite of this, the AA (based on thousands of measurements data points) showed some clear directions for improvement. This proves that after the preciseness of the scanner is improved, much more detailed relations will be found. This is necessary because the final goal of project is to go to a prescriptive ladle logistics model (fig.6). For the time being the analysis are already used for the development of a dashboard which predicts during the life of the ladle at which moment and at which point the ladle will come out of service, helping the ladle coordinators to use the ladles more efficiently.

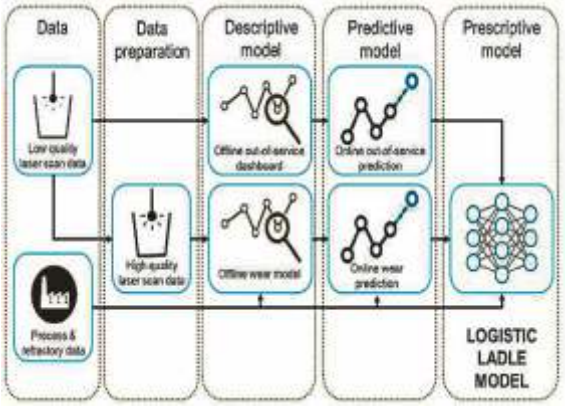


Fig.6: Steps to realize the logistic ladle model at Tata Steel IJmuiden [8]

An important side effect of the AA tool is the significant improvement in the time to find a cause of problems in case of high wear/incident. Could an investigation in the past in such a case take months or even up to a year [4], nowadays

these analysis are done within maximum a few weeks resulting in quick measures and a much more constant life (and lower cost).

More and more relations between process variables and refractory wear are found, but it is at the moment not possible to link this wear to the refractory characteristics. For this the refractory production batch should be linked to the ladle and also the right characteristics should be measured. It is at the moment unclear if data delivered by suppliers (chemistry, density, CCS etc.) will be sufficient. However TSIJ has a still significant advantage over many other steel plants, because it has its own refractory bricks producing plant for MgO-C, AMC and ASC bricks. With this material all production variables of the bricks are known, in the Ceramics Research Centre the important refractory parameters can be measured and therefore relation between refractories characteristics and process variables can be found.

The presence of its own refractory production facility will help IJmuiden in developing a self-learning refractory wear monitoring system for the steel ladle. This will reduce in the future development time, prevent breakouts and will significantly improve the logistical performance because of its predictability. Refractory measurement tools If the exact relation between process variables and refractory characteristics is not known, other approaches to get a performance improvement have to be used. Good cooperation between refractory supplier and steel plant speeds up this process. Having our own refractory production facility is a significant advantage. A good example is the development of improved refractories for the surrounding of the tuyeres of the converter [9].

Different plants use different materials (fig 7) and suppliers and have different wear patterns. A combination of thermal-mechanical modelling, hot compressive testing and creating a theoretical wear model, a clear relation between the flexibility of the refractory material and performance and pattern in practice was found (fig 8).

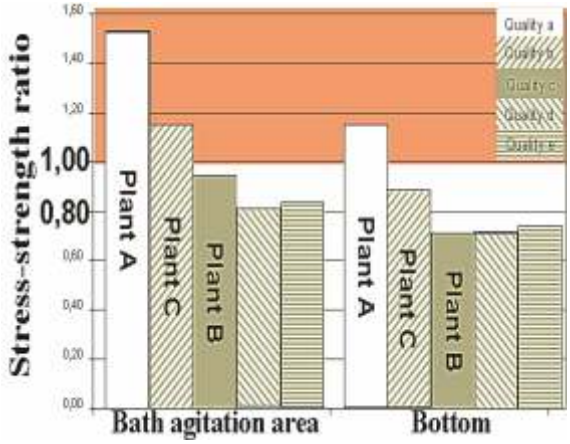


Fig 7: Stress-strength ratio of 5 different material (different suppliers) at 3 different steel plants around the bath agitation and bottom area.

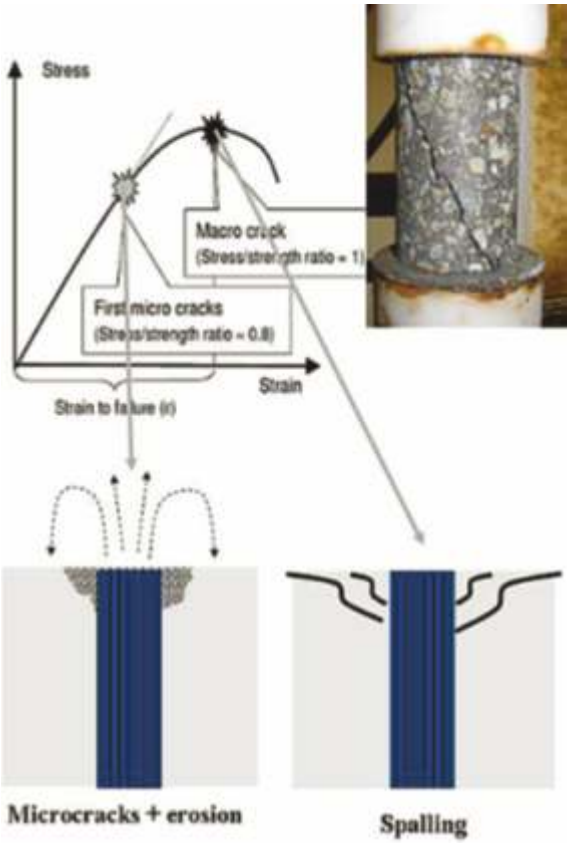


Fig 8: Material characteristics linked to the wear around the bath agitation

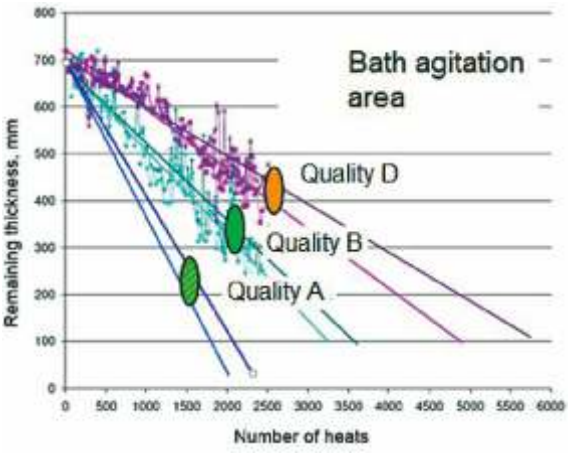


Fig 9: Rest thickness measurements of different qualities used around the bath agitation

With the above knowledge of the important required refractory characteristics a development trajectory was set up with different suppliers. Because of the inhouse production facility for MgO-C bricks very quick an improved brick was developed and put in for trials at the converter resulting almost complete disappearance of the problem (quality D compared to quality B in fig 9). Solutions from external suppliers came after several months or not at all.

Not in all cases existing measuring techniques give sufficient information to understand or solve a problem. In those cases new tests or measurements tools can be developed. The scrap impact panel in converters is a critical area, which often limits the life of the converter and reduces the availability of the vessels. Since the impact panel has to bear the brunt of heavy scraps of different shapes and sizes, it is important that the refractory brick qualities have good high temperature impact resistance. This requires a refractory brick with high strength and/or flexibility. Since the fundamental properties (like density, porosity, HMOR strength, epsilon etc.) of a material do not always have a visible correlation with the performance in reality, it is imperative to use a test designed in alignment with the application in practice. A hot temperatureimpact test was developed in order to simulate the impact behaviour of MgO-C bricks at a high temperature [10]. Balls of steel are shot with a special in-house build device (fig 10) at refractory materials at high temperature under nitrogen atmosphere with an impact energy that is in the same order as that of falling scrap in the converter. The HMOR strengths as well as epsilon (Strain to failure) and other tests were correlated to the impact test results.

Supported by the HT Impact test, HMOR strength ata particular temperature has a direct correlation withthe impact property of the material at thattemperature. Other relations (also for the flexibility) were much more weaker. This helps again forselecting improved materials for this area without doing a lot of trials in the converter that might have a negative effect on the availability.

Fig 10: High temperature impact test shooter [10].

In many installations it is not possible to do sufficient trials for a good statistical analysis, trials may take too long (rolling mill and galvanising furnaces) or are too risky (blast furnace and coke ovens). In such a case it becomes important to understand how thewear might be caused and that relevant test can beperformed to optimise the chance of success and minimize the risks.

The refractory lining of the galvanising line DVL1 in IJmuiden was not performing well and the refractory lining was under suspicion of contributing from time to time to soiling of the steel strip. Within this kind of furnaces two types of linings are normally used, insulating bricks or ceramic fibres. In Tata Steel IJmuiden it is not allowed to use ceramic fibre materials because of possible health risks and the used insulating bricks lining was not performing. A proven alternative lining was not on the market, so to find an alternative solution, many factors had to be considered besides the life and cleanliness of the steel strip, like heating up and cooling down time of the lining during maintenance, fast cooling with nitrogen during an unexpected production stop, investments costs and energy losses. For the technical evaluation as well as for the heating and cooling characteristics evaluation a thermal mechanical model (FEM) was used [11]. A lot of cracks developed during the life in the insulating bricks. Standard modelling doesn't explain the appearance of such type of cracks in the lining. For understanding how the crack were formed a special modeling technique was used by varying randomly,within the spread in material properties, the Young'smodulus of the bricks in the lining, resulting in thedamage distribution as is shown in fig 11. The typical vertical cracks in the model are a good representation of the cracks found in the real situation.

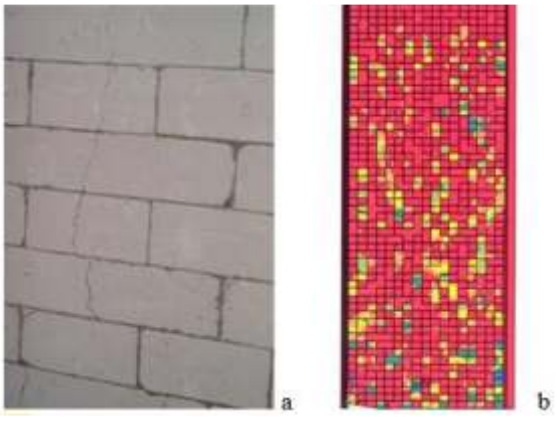


Fig 11: Damage predicted by the model (b) and observed during autopsy (a). In (b) the damage is presented in form of plastic strain distribution – elements.

Besides predicting refractory cracking /failure, computer modelling of refractories can also be used for energy savings and logistical optimisations. The hot metal loses a lot of energy during the transportation in the torpedo car between the blast furnace and the steel plant. These heat losses present a problem for the environment and represent a significant amount of money. One could optimise the situation by building in every torpedo car thermocouples and try to steer on that. This is very time consuming, costly and not very efficient. For the torpedo cars in IJmuiden a thermal model has been developed [12]. This model takes into account the logistics of the torpedo car (fig 12). To have a reliable model, it has been validated withthermocouple measurements. For this you need onlyone torpedo car, but several thermocouples for sufficient reliable data. The model can be further validated with thermal images from the outside, however in case of a torpedo car the weather conditions have a significant effect of the readings.

In case of blast furnaces and Coke ovens it is hardly possible to build in test panels for trials. Modelling is therefore a useful tool, but for a good model aminimum knowledge about the wear mechanism is indispensable. However to take a sample out and to analyse the wear mechanism in case of a blast furnace this can be done only once every 10-15 years and in case of a coke oven every 40 years. This is insufficient for developments.

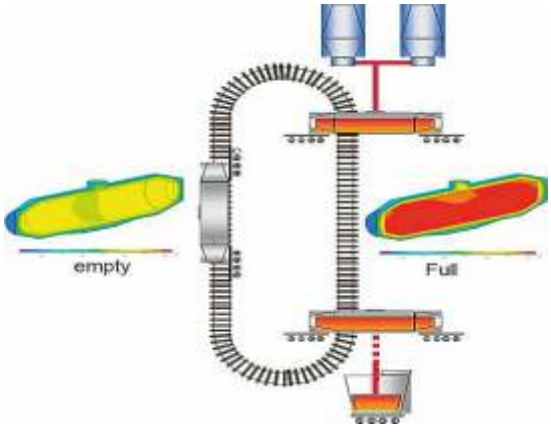
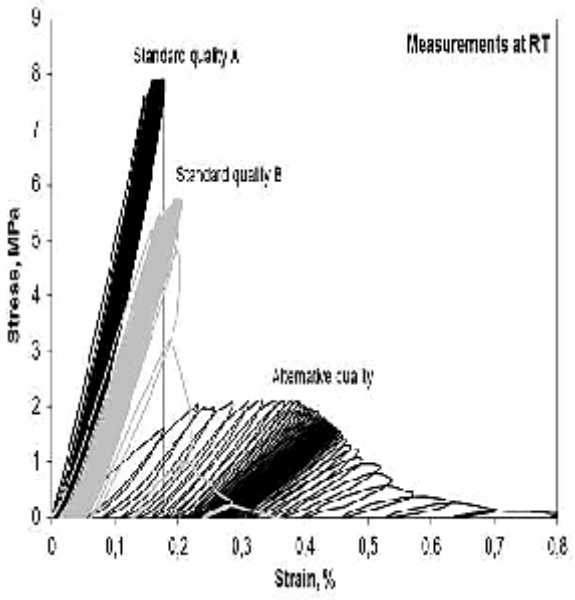


Fig 12: Thermal logistical model to predict heat losses as function of time and vessel filling [12].

Wear of the refractories in the blast furnace can have many different causes. Investigations during an intermediate repair of the blast furnace 7 in IJmuiden in 2010 showed that besides carbon bursting, hotmetal penetration in the refractories contributed to the wear of the hearth below the tapholes [13]. Normally porosity measurements and pore size distribution are used for selecting materials best fit against hot metal penetration. The relation between the data measured with these tests and the phenomena found in the blast furnace hearth is not always in line with each other. To understand whyand also for selecting purposes, a hot metal penetration test under pressure has been developed. This test shows significant differencesbetween different qualities (fig 13).Some qualities penetrate already with over pressures of 1 bar, others don't show any penetration even after an over pressure of 2.5 bar.

Fig 13: Hot metal penetration test. Left: material penetrated under 1 bar over pressure. Right: material after testing under 2.5 bar over pressure.

Comparable with the blast furnaces, in coke oven batteries trials are difficult. The IJmuiden coke plant no.2 is already more than 45 years old. A few walls are replace every year [14]. Because coke oven walls last more than 40 years it is not possible to do small trials in the installation to choose the right material. To repair/replace the walls one can use similar technology (silica bricks) as originally built, however it has a long buildingtime and long heat-up time which will reduce the production volume. New refractory technologies/materials are available that overcome these problems, however how to judge the possible performance? Silica bricks in a coke oven wall show in the first 10 till 20 years hardly any major wear/problems. After this period slowly the number of areas with cracks and broken material is increasing. Standard refractory testing doesn't predict this behaviour nor give indications for improvement. Based on this is impossible to select between the old technology with silica bricks or the new technology of fused silica blocks. The developed mechanical strain controlled fatigue tests allow direct correlation of the loads and the materials response in the stressstrain coordinates. At the same time it allows monitoring the material degradation during repetitive loading cycles(fig 14[15]).



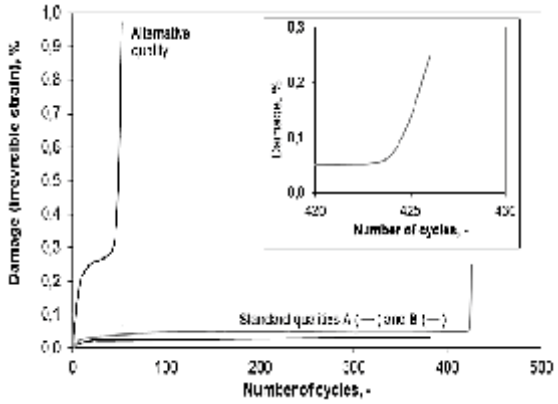


Fig 14: Stress-strain curves of cyclic fatigue tests of different silica materials fort he Coke oven. Top: minimal strain per cyclevs cycle number Bottom: Amplitude = 70% of thestrain at failure.

Benchmarking

Despite the fact that no steel plant is the same, one of the most and efficient ways for improvements is benchmarking. A good benchmark is more than comparing lining constructions, production figures and steel qualities produced.

	time ladle out of service	availability	safety	wear rates	energy savings	capacity utilisation	utilisation of the ladles
A	++	0	++	++	0	-	0
B	+	-	+	+++	++	+++	+++
C	0	+	0	+	++	+++	+
D	+++	0	0	0	+	-	++
E	-	+	++	++	0	-	++
F	-	++	+++	+	++	-	-
G	+++	++	++	0	++	0	0
H	0	+++	+++	+++	+++	-	+
J	+	-	+++	+++	+	++	0
K	+++	+	0	+	0	++	++
I	+++	++	0	0	0	+	0

Fig 15: Steel ladle benchmark between different steel plants (A-I), compared for different requirements.

Understanding why choices are made (based on the needs of a steel plant), problems encountered and results achieved are the real added value of a benchmarking. Benchmarking doesn't deliver direct solutions but it increases the knowledge that is the basis for every steel plantto optimise their own situation. Beside this it also can help facing problems that arise from legislation on HSE and can give directions to suppliers on what kind of developments are the most urgent. A good example is the results out of a benchmark coordinated by TSIJ of 2014. Figure 15 shows the final comparison of results out of a questionnaire sent to different steel plants [16]. It shows very clear the differences and different philosophies and it also explains right away why no steel plant has the same refractory solutions. It shows where plants are stronger or weaker compared to other plants. Adapting refractories in order to improve at certain points result in weakening at other points. Understanding choices and solutions from others will give directions for developments and improvements.

Cooperation with refractory institutes and universities

TSIJ is a steel producer and steel can't be produced without refractories. Investing time to improve refractories is beneficial to optimise steel production.It is however impossible and too expensive to do all the developments alone. One of the most important aspects is thereforeto combine the knowledge about wear of refractories of IJmuiden with the knowledgeof the refractory suppliers about the composition and the characteristics of the refractories and with the scientific knowledge of research institutes and universities. For this TSIJis active within FIRE (Federation for International Refractory Research and Education), ATHOR (European training network dedicated to Advanced THermomechnical multiscale mOdelling of Refractory linings), CESAREF (Concerted European action on Sustainable Applications of REFratories) and participates in university investigations together with raw materials suppliers. The cooperation with universities focusses on development of new tools (e.g. [17]), that we can use to better understand the wear of

refractories in our installations and to facilitate the option for students to get some practical experience. Cooperation with suppliers focuses on exchange of the information on wear of the refractories in such a way that they can develop solutions for us that solve our problems.

Final remarks

A large set of tools leading to higher and more economical refractory performances, have been developed over the last decades at the Ceramics Research Centre in IJmuiden. With current and upcoming challenges like coke oven wall replacements, blast furnace reline, new walking beam furnace, further steel ladle improvements and a new slab casting machine there are still a lot of Value in Use optimisations to solve and all the different kind of disciplines are required.To develop all these tools and the tools that still have to be developed knowledgeable people are an essential part in improving the refractory performance at Tata Steel Europe.

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STATISTICS

EXPORT OF REFRACTORY ITEMS	2019-20		2020-21		2021-22	
	m.t.	Rs. Lakhs	m.t.	Rs. Lakhs	m.t.	Rs. Lakhs
FIRE CLAY BRICKS & SHAPES	38.32	8291.99	48.6	6447.6	245.91	9050.12
HIGH ALUMINA BRICKS & SHAPES	117.58	92537.61	195.98	100840.55	11764.88	92974.41
SILICA BRICKS & SHAPES	21.11	7948.84	14.35	4319.98	30.72	2048.78
BASIC BRICKS & SHAPES	38.86	20859.68	27	13098.51	262.08	21633.15
MONOLITHICS/CASTABLES	170.42	40809.87	151.88	34718.77	204.23	47298.63
SPECIAL PRODUCTS	15.67	38065.42	19.82	53246.5	159.71	69456.58
CERAMIC FIBRES ETC	6.77	8086	12.33	11629.15	106.76	16005.34
OTHERS	15.53	26550.02	12.67	19905.69	89.62	19361.52
TOTAL	424.25	243149.43	482.63	244206.75	12863.9	277828.53

IMPORT OF REFRACTORY ITEMS	2019-20		2020-21		2021-22	
	m.t.	Rs. Lakhs	m.t.	Rs. Lakhs	m.t.	Rs. Lakhs
FIRE CLAY BRICKS & SHAPES	21.21	4641.02	50.8	1750.78	2.14	1161.32
HIGH ALUMINA BRICKS & SHAPES	189.42	43227.73	31.5	37768.07	1374.45	54204.16
SILICA BRICKS & SHAPES	40.17	11866.4	13.59	6389.28	604.55	6494.78
BASIC BRICKS & SHAPES	199.48	120436.98	181.67	97508.88	12277.49	140586.69
MONOLITHICS/CASTABLES	176.15	85409.36	159.45	76381.31	208.59	108711.3
SPECIAL PRODUCTS	3.6	6787.93	8.63	1849.69	1.84	3150.55
CERAMIC FIBRES & OTHERS	10.51	23638.69	71.98	22604.34	334.44	31625.55
OTHERS	49.92	38488.7	63.97	28535.07	844.59	28808.78
TOTAL	690.46	334496.81	581.59	272787.42	15648.09	374743.13

(Updated from figure published in June 2022 issue of IRMA Journal)
Source: Ministry of Commerce - Government of India.