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IRMA JOURNAL **-** A Publication of:
INDIAN REFRACTORY MAKERS ASSOCIATION
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MESSAGE FROM THE CHAIRMAN

Dear Colleagues,

In the first meeting of newly elected Board of Directors, the responsibility of leading IRMA came onto me. It gives me a sense of profound humility for being chosen by my fellow colleagues in the Board to lead this prestigious body. The seedling planted in 1958 has now grown to be a formidable tree due to careful nurture of so many industry leaders, technocrats, scientists etc. A metaphor attributed to Bernard of Chartres from the 12th century was made famous by Sir Isaac Newton in 1675 when he said: "If I have seen further it is by standing on the shoulders of giants." We as a new Board are standing on the shoulders of giants many of whom have left us. The work that was put in by them and the sacrifices that were made, allow us to now be able to stand solid, look further to have a clear picture of where we have come from and where we are going.

It is now up to the newly elected Board to carry their good works further, to etch out a better future for Indian refractory industry. I truly believe that there exists within the Board a cohesive unity and willingness to truly do what is in the best interests for IRMA and its members in particular and the refractory industry in general. We share the same excitement about the bright prospects of Indian economy as well as our industry. Make no mistake, we have lots of work to do and goals to achieve but we are excited and eager to start working towards that future!

IRMA is a membership-based organisation. We do not sell a product. Our business revolves around people and relationships. Relationships with our members, relationships with all our stakeholders and relationships between us and the different levels of governance structures. I am confident this relationship niche will continue to bloom further in the coming days and I have always felt honoured and thrilled to be your colleagues. Let us get the very best for Indian refractory industry.

Ish Garg
Chairman

ASSOCIATION ACTIVITIES

New IRMA Chairman & Deputy Chairman

Mr Ish Garg (Calderys India Refractories Ltd.) has become IRMA Chairman for the period 2022-24. Mr Sameer Nagpal (Dalmia Bharat Refractories Ltd) has become the Deputy Chairman of IRMA for the same period.

IRMA Annual General Meeting

The 9th IRMA AGM was held on 30th September 2022 on Zoom Platform under the chairmanship of Mr Parmod Sagar. The Chairman thanked the members for attending the AGM. He briefly discussed the present market conditions and said that the operational and fiscal discipline observed by the refractory makers during the pandemic have helped them overcome the crisis period. The Vote of Thanks was proposed by Deputy Chairman Mr Ish Garg. All the normal business transactions were carried out as per the rules and regulations of the Association

IRMA Board of Directors Meeting

The first meeting of the newly elected IRMA Board of Members was held on Zoom platform under the chairmanship of Mr Parmod Sagar. The issues discussed were election of Chairman and Deputy Chairman of the Association, co-option of Additional Directors and Permanent Invitees, IREFCON 22 etc.

Paper on Glass & Refractories

The Energy Research Institute (TERI) in association with Bureau of Energy Efficiency (BEE) has prepared a sectoral roadmap for energy saving in refractory and glass MSME clusters. IRMA had provided technical and logistic support to the researchers during the study period. The report has been released and is available with TERI.

COMPOSITION OF IRMA BOARD OF DIRECTORS (2022-24)

Chairman	**Representing Company**
Ish Garg	Calderys India Refractories Ltd.
Deputy Chaiman	
Sameer Nagpal	Dalmia Bharat Ltd
Directors	
V.G.Rajendran	Carborundum Universal Ltd.
Kamal Sarda	IFGL Refractories Ltd.
Arvind Gugalia	Mahakoshal Refractories Pvt. Ltd.
Aditya Agarwalla	Maithan Ceramic Ltd
Prahlad Rai Agarwalla	National Refractories
V.Udaya Sankar	Refratechnik India Pvt Ltd
Parmod Sagar	RHI Magnesita India Ltd.
Ashok Kumar Agarwal	Sarvesh Refractories Pvt Ltd
Sunanda Sengupta	TRL Krosaki Refractories Ltd
Subrata Roy	Vesuvius India Ltd
Alternate Director	
Ranjan dey	Carborundum Universal Ltd.
Manoj Rakhecha	IFGL Refractories Ltd.
Mayank Gugalia	Mahakoshal Refractories Pvt. Ltd.
Vishal Agarwalla	Maithan Ceramic Ltd
Arasu Shanmugam	Dalmia Bharat Refractories Ltd
Tusharkumar G. Dholaria	Nobel Refractories

A.k.Chattopadhyay	National Refractories
Ujjal Sengupta	Refratechnik India Pvt Ltd
RVS Rudraraju	RHI Magnesita India Ltd.
Kushal Agarwal	Sarvesh Refractories Pvt Ltd
Krishnendu Kumar	TRL Krosaki Refractories Ltd
Nitin Jain	Vesuvius India Ltd
Additional Director	
Ghanshyambhai Govindram Dholaria	Noble Refractories
Gangadharan Manari	Totale Global Pvt. Ltd.
Ashish Jain	Vishva Vishal Refractory Ltd
Permanent Invitee	
Sharad Agarwal	Associated Ceramic Ltd

IN THE NEWS

India Steel Output

India's crude steel output rose by 2.56 per cent to 30.06 million tonne (MT) during the July-September period of the ongoing financial year. As per research firm SteelMint, the top six steel makers -- SAIL, Tata Steel, JSW Steel, JSPL, AMNS India and RINL -- produced 18.29 MT steel, the rest 11.77 MT came in from the secondary sector.

The country had produced 29.31 MT of steel during the same quarter in the preceding 2021-22 financial year, according the data shared by SteelMint.

Rashtriya Ispat Nigam Ltd

RINL achieved earnings before interest, taxes, depreciation and amortisation (EBITDA) of Rs 3,469 crore, marking a growth of 148 per cent over the previous year. The 5.77 tonne hot metal production was the highest for any single unit of a public sector steel plant in the country.

JSW Cement

JSW Cement on Tuesday will invest more than Rs 3,200 crore to set up two greenfield cement manufacturing facilities having a total manufacturing capacity of 5 million tonnes per annum in central India. The proposed investment will be for an integrated cement plant with 2.5 MTPA (Million Tonnes Per Annum) clinker capacity, 2.5 MTPA grinding capacity, 15 MW Waste Heat Recovery System, a modern residential colony in Madhya Pradesh and a 2.5 MTPA grinding unit in Uttar Pradesh.

Birla Corporation

MP Birla Group firm Birla Corporation plans to increase its cement production capacity by 50 per cent to 30 million tonnes per annum by 2030, the company said in its latest annual report. The company, which has commissioned a greenfield unit at Mukutban, Maharashtra with an investment of Rs 2,744 crore, has plans to set up some new units and expand the production capacity of the existing units.

AMNS India

AMNS India, an Indian joint venture between ArcelorMittal and Nippon Steel, is investing $5 billion to expand steel production capacity at its Hazira plant in Gujarat.

The move is aimed at meeting the growing demand for steel in India and increasing market share. AMNS India will build two blast furnaces and other facilities, which are scheduled to be operational by mid-2026. It is planned that after the expansion, the volume of steel production at the Hazira plant will reach approximately 15 million tons per year.

Nalco

National Aluminium Company Ltd has registered the highest-ever sales of Rs 14,181 crore and a record profit of Rs 2,952 crore in the 2021-22 financial year (FY'22). The Odisha-based public sector undertaking has also reported record production of aluminium cast metal of 4,60,000 tonne, achieving 100 percent capacity utilisation of its plant for the first time since inception .

China Refractory Raw Materials Index

According to Refwin, the China Refractory Raw Materials Price Index in March 2022 was 211.21, a month-on-month decrease of 0.62% and a year-on-year increase of 17.9%.

OVERSEAS NEWS

RHI Magnesita

RHI Magnesita is heading a European Union Horizon project called ReSoURCE. The project seeks to develop a sensor-based refractory waste sorting and powder handling system. It involves academic partners in Austria, Germany, Ireland, Norway and the UK. The European Health and Digital Executive Agency (HADEA) supplied Euro6m in funding for the study, while the UK government supplied Euro1m. Global refractory waste generation is currently 28Mt/yr.

Oman Chromite

Oman Chromite Company produced 25,900 tonnes of chromite ore in the first half of 2022, a significant increase over the corresponding output of 9,349 tonnes a year earlier. After tax, the firm earned a profit or RO 653K, representing an increase of 245 per cent compared to RO 266K a year earlier. The uptick in profits was aided by the company's ability to reduce costs, among other factors.

Tata Steel Netherlands

Italy-based plantmaker Danieli has announced that it will supply Energiron® DRI (direct reduced iron) plants, which is the technology developed jointly by Italy-based Tenova and Danieli, to Tata Steel Netherlands, a subsidiary of Indian steelmaker Tata Steel.

The Energiron® DRI plants will be used for the transition of Tata Steel Netherlands' IJmuiden steel mill from the current blast furnace technology to green hydrogen-based steel production. All Energiron® DRI plants can start using hydrogen as reduction gas without equipment modifications.

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

Imerys

Imerys will be expanding its production capacity, Research & Development and sustainability efforts at its manufacturing plant in Visakhapatnam, Andhra Pradesh.

The ₹350-crore Visakhapatnam plant currently has a capacity to produce 30,000 tonne of calcium aluminate binder for use in the Indian refractory and construction industries.

"Imerys plans to expand capacity to 50,000 tonnes by 2030, to serve rising demand from the domestic steel and cement sectors, which continue to add capacity across the country. This makes the Vizag facility, the single largest site and investment in India for Imerys' refractory, and construction businesses," the company said in a release.

ECONOMY AT A GLANCE

- The Indian economy is poised to shrug off the modest tapering of growth momentum in the first quarter of 2022-23. Aggregate demand is firm and poised to expand further as the festival season sets in. Domestic financial conditions remain supportive of growth impulses. Inflation remains elevated and above the tolerance level, underscoring the need for monetary policy to keep second order effects contained and inflation expectations firmly anchored.
- The Indian economy expanded 13.5% year-on-year in the second quarter of 2022, the most in a year but less than market forecasts of 15.2%.
- Gross value added increased faster for agriculture, forestry & fishing (4.5% vs 2.2% in Q2 2021); electricity, gas, water supply & other utility services (14.7% vs 13.8%); financial, real estate & professional services (9.2% vs 2.3%) and public administration, defence & other services (26.3% vs 6.2%). On the other hand, a slowdown was seen for mining & quarrying (6.5% vs 18%); manufacturing (4.8% vs 49%); construction (16.8% vs 71.3%) and trade, hotels, transport, communication & services related to broadcasting (25.7% vs 34.3%).
- On the expenditure side, household consumption accelerated (25.9% vs 14.4% in Q2 2021) and government expenditure rebounded (1.3% vs -4.8%). Meanwhile, gross fixed capital formation slowed (20.1% vs 62.5%) and net foreign demand contributed negatively to growth, as exports rose 14.7% while imports advanced at a faster 37.2%.
- Going forward, the dynamics playing out between divergent forces – demand picking up; some softening in input price pressures in recent months and continuing global uncertainties – could determine the impact on headline inflation.

TECHNICAL SECTION

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

Rinus Siebring, Tata Steel Europe, Centre of Expertise Refractories

Refractories expertise is seen as a core competence at Tata Steel Europe. 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 Europe 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. 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 [1]. Within the Centre of Expertise Refractories, which is part of the Ceramics Research Centre of Tata Steel Europe, 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 with the needs of a steel producer like Tata Steel Europe.

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

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. Tata Steel Europe in IJmuiden (=TSIJ) produces around 7 mln tons of steel. The requirements on the refractories for IJmuiden 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 & thermal-mechanical 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). Especially in avoiding 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 are carcinogenic, mutagenic or toxic to reproduction) or can 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 information on the safety data sheets (SDS) differs between the different suppliers. To get in control TSIJ made a special questionnaire. 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.) and also steel producing benefits to consider (energy saving, capacity optimisation, etc.). These cost and benefits can be significant higher than the direct refractory costs [2]. Fig.2 shows besides the direct costs of refractories many other cost and possible benefits to consider.

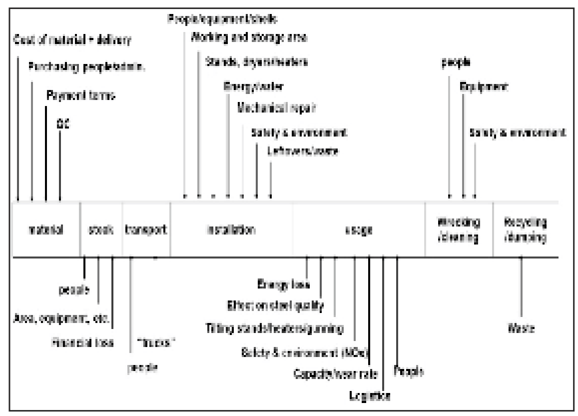

Fig.2: Different steps in the life cycle of steel ladle refractories and related costs/benefits [2]

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 Tata Steel Europe developed for the steel ladle an economical model [2].

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 significant refractory 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 [1].

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 [1].

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 characteristics can 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/control system is in place at Tata Steel in IJmuiden with product definitions, test certificates and QC control [3].

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 [1]. 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 Tata Steel Europehas started to use for the steel ladle “advanced analysis (AA)” to find relations between process and refractory wear [4]. 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.

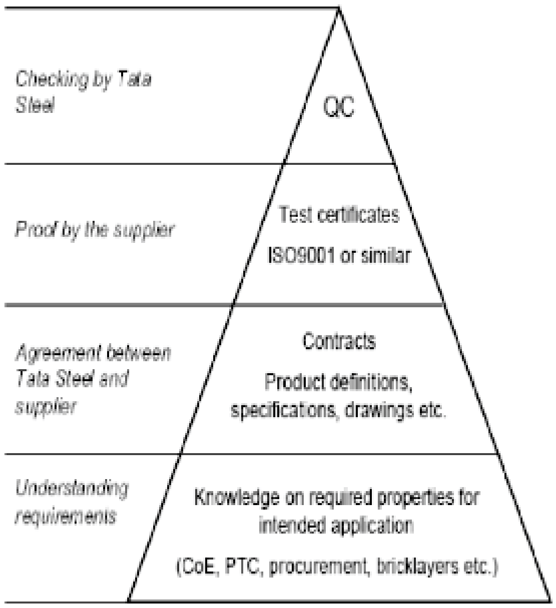

Fig.5: Refractory quality management / control system in place at Tata Steel IJmuiden [3]

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.

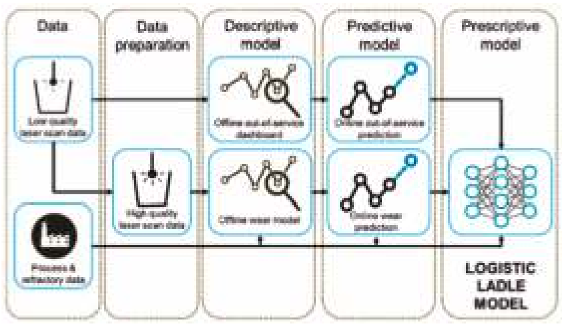

Fig.6: Steps to realize the logistic ladle model at Tata Steel IJmuiden [4]

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 [1], 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 Tata Steel IJmuiden has a 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 [5].

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).

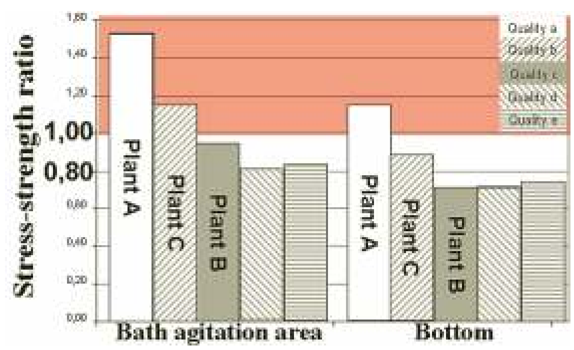

Fig 7: Stress-strength ratio of 5 different material (different suppliers) at 3 different steel plants around the bath agitation and bottom area.

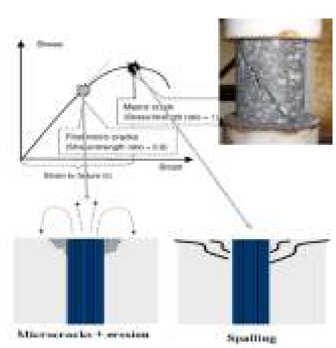

Fig 8: Material characteristics linked to the wear around the bath agitation

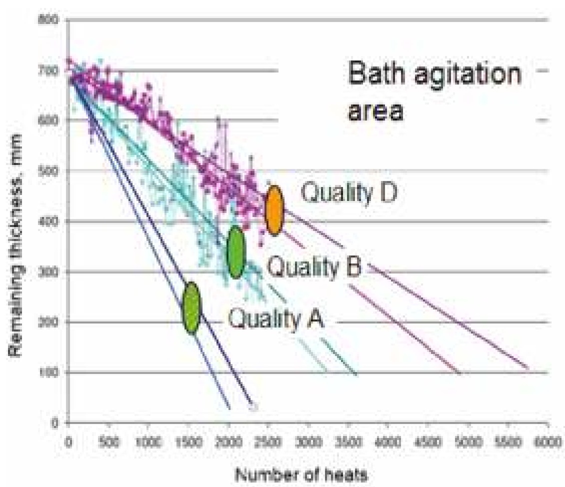

Fig 9: Rest thickness measurements of different qualities used around the bath agitation

With the above knowledge of the important required refractory characteristics a development trajectory was set up with different suppliers. Because of the in-house 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 [6]. 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 at a particular temperature has a direct correlation with the impact property of the material at that temperature. Other relations (also for the flexibility) were much more weaker. This helps again for selecting improved materials for this area without doing a lot of trials in the converterthat might have a negative effect on the availability.

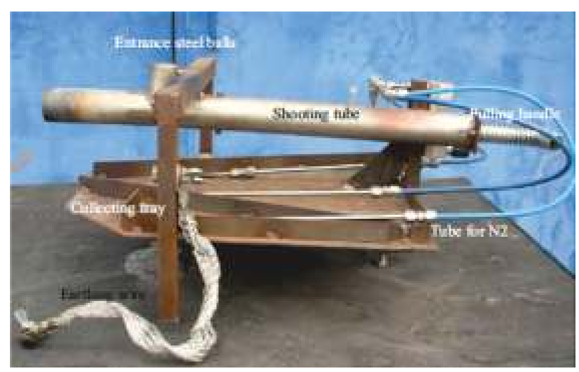

Fig 10: High temperature impact test shooter.

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 the wear might be caused and that relevant test can be performed 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 [7]. 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 modelling technique was used by varying randomly, within the spread in material properties, the Young's modulus of the bricks in the lining, resulting in the damage 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.

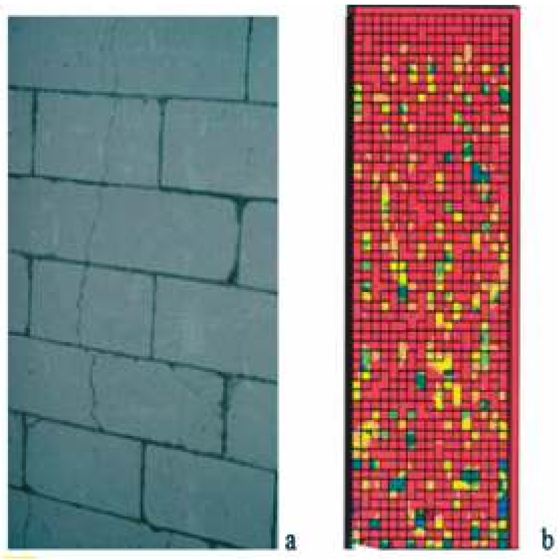

Fig 11: Damage predicted by the model (b) and observed during autopsy (a). In (b) the damage is presented in form of plastic strain distribution – elements.

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 [8]. This model takes into account the logistics of the torpedo car (fig 12). To have a reliable model, it has been validated with thermocouple measurements. For this you need only one 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 there adings.

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 a minimum 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.

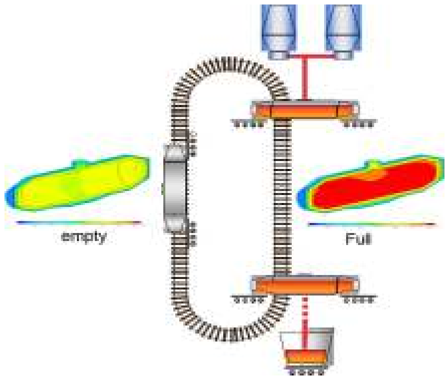

Fig 12: Thermal logistical model to predict heat losses as function of time and vessel filling [8].

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, hot metal penetration in the refractories contributed to the wear of the hearth below the tapholes [9]. 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 why and also for selecting purposes, a hot metal penetration test under pressure has been developed. This test shows significant differences between 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 [10]. 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 judgethe 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 stress-strain coordinates. At the same time it allows monitoring the material degradation during repetitive loading cycles(fig 14[11]).

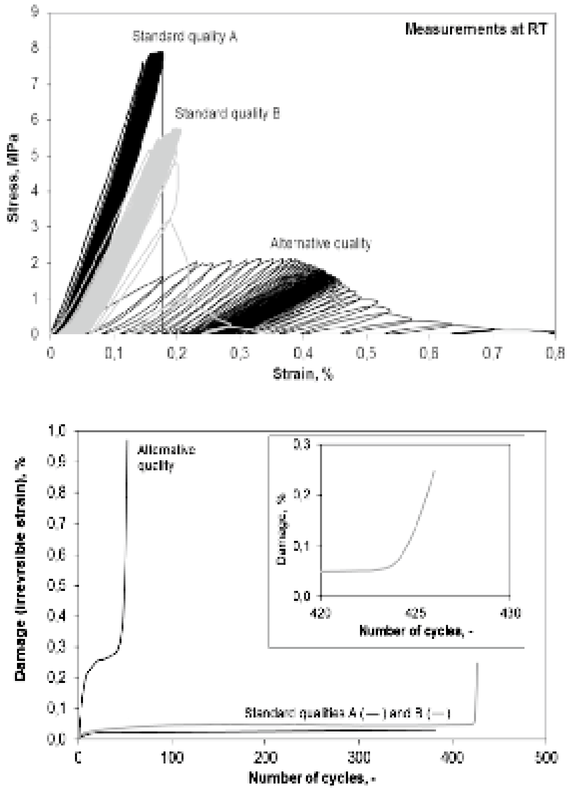

Fig 14: Stress-strain curves of cyclic fatigue tests of different silica materials fort he Coke oven. Top: minimal strain per cycle vs cycle number Bottom: Amplitude = 70% of the strain at failure.

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	av ailability	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 [12]. 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 knowledge of the refractory suppliers about the composition and the characteristics of the refractories and with the scientific knowledge of research institutes and universities. For this Tata Steel Europe is active within FIRE (Federation for International Refractory Research and Education), ATHOR (European training network dedicated to Advanced THermomechnical multiscale mOdelling of Refractory linings) and participates in university investigations together with raw materials suppliers. The cooperation with universities focusses on development of new tools (e.g. [13]), 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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TECHNICAL SECTION

PERSONAL PERSPECTIVES FOR REFRACTORY TECHNOLOGY AND SCIENCE

Masakazu Iida, Shinagawa Refractories Co., Ltd.

Abstract

This article describes the history, current topics and future forecast of the refractory industry, focusing on technology and science, which rely on each other closely. The difference between technology and science is considered for each topics, that is, the purpose of technological research is optimization according to individually-different requirements while that of scientific research is generalization according to mathematics. For further improvement in the refractory industry and academia, it is essential to see things as they are without preconceptions.

Prologue

Over the centuries, refractory materials have been developed in association with development of high temperature industries such as steel making, cement making, non-ferrous metal making, glass making, waste incineration, etc. During that period, uncountable refractory technological innovations have improved the high temperature industry and refractory industry itself.

Similar to the other industries, a scientific approach considerably accelerated technical development. Science indicates directions for technological research. Science unifies various phenomena in the industry to a simple theory, resulting in further improvement of applied technologies. On the other hand, technology provides new aspects for science. New technology enables new experiments, detailed observations, rapid data treatment, instant communications among researchers, etc.

This article describes personal perspectives on refractory material R&D from the view point of technology and science by citing historical topics and the author's research. Then, future trends in refractory R&D will be forecast taking recent situation into account.

Prior to the discussion, let's take a short look at technology and science.

Technology and Science

While the concept of "technology" and "science" is similar, strictly speaking, they are different. As is summarized in **Table 1**, the elements of these two concepts are oriented in opposite directions.

Basically, technology is a practical matter that improves industries and social activities. Contrarily, science is idealistic knowledge that explores and unveils the secrets of nature. Thus, the position and purpose of technological research and scientific research are different.

Table 1 Comparisons between technology and science concepts

Technology	(Pure) Science
Practice	Nature
Needs, Wants	Curiosity
Material, Tool, Device	Theory, Equation, Law
Industry	Academy
Basing on Science	Using technology

Figure 1 shows the position and relationship between these two types of research. Theoretically, nothing but researcher's curiosity limits scientific research. Hence, the purpose of scientific research is to generalize natural phenomena and show the ultimate truth in a mathematical manner. On the other hand, many factors limit technological research. The limiting conditions vary among organizations, societies, geography, time, and so on. Thus, the purpose of technological research is to provide optimal solutions taking individually different limitations into account. Unlike scientific research, there can be many solutions for one issue.

Achievements in scientific research are strong tools for promoting technological research as everyone can imagine. Scientific research may create

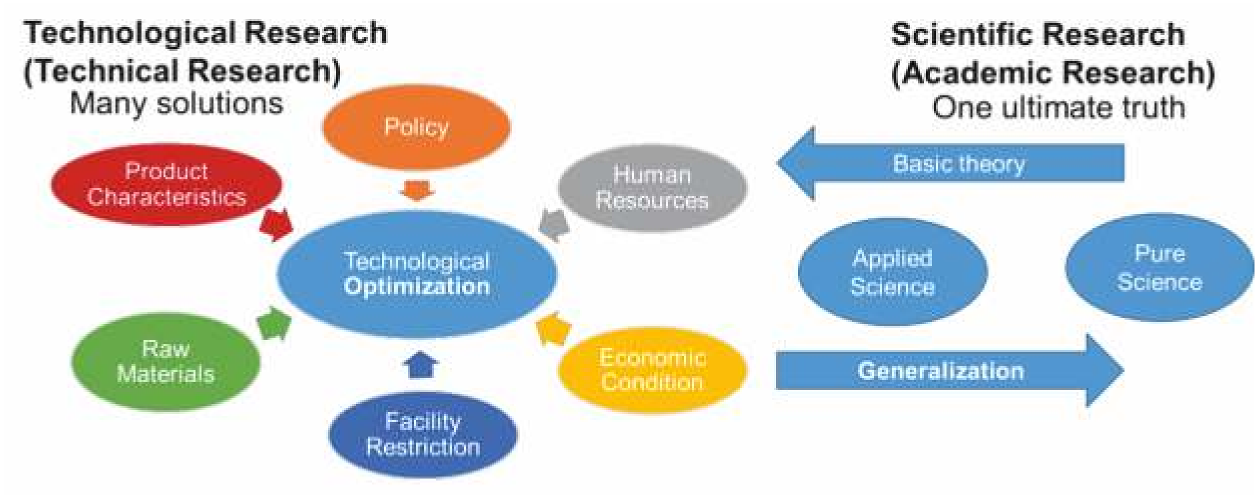

Fig. 1 Position and relationship of technical research and academic research.

a new theory from the results obtained from technological research. Therefore, a new scientific field is likely to be created by generalizing industrial phenomena. As discussed above, technology and science closely rely on one another. Practically, money often limits the scientific research so sometimes industry assists researchers financially.

Therefore, the field of applied science is broadening. It is on the intermediate position between technology and pure science.

In the next section, historical refractory topics will be shown in terms of technology and science.

History of Refractories

Origin of Refractories

Since refractories are ceramic materials, their origin is pottery earthenware, invented in the Stone Age. The first refractory was specific pottery designed for high temperature applications such as bronze casting and earthenware firing. While it is natural to assume that stones and sand were used for cooking, they weren't artificially designed materials.

From an industrial point of view, refractories should be the materials that are intentionally arranged for high temperature applications.

The raw material of pottery is clay. A wellkneaded clay-water mixture is shaped and dried under sun light followed by firing. In ancient days, technological developments of refractories were considered to be the exploration and discovering of good clay and creation of suitable shapes for

individual applications.

Development of Modern Refractories

Over the millennium, clay was considered to be the main material for refractories. But that situation changed in early 19th century. **Figure 2** summarizes the major inventions in the steel and refractory industries1,2). Obviously, rapid growth of technology in both industries occurred in the 20th century. This is attributable to applications of scientific approaches such as thermodynamics, phase rule, theory of mass transfer, etc.3). In the next section, two well-known topics of modern refractory inventions will be described briefly, those are, silica brick and tar-bonded dolomite brick for the Thomas converter. Those topics are cited from K. Sugita1).

Silica Brick

The first silica brick was invented in 1820 and industrial production started from 1856. This is the first non-clay based high purity brick. Although Quartz is an abundant high purity mineral and a natural resource, it was difficult to use for refractory bricks as the main component due to cracking during firing caused by eccentric thermal expansion as well as insufficient strength. In order to solve the problem, addition of small amount of lime and accurate control of firing temperature were found to be effective. As a result, a brick with high refractoriness and excellent creep resistance was invented, even though the cause of eccentric expansion during firing and influence of lime were still unclear at that time.

Many decades later, science clarified how these phenomena occur. The eccentric thermal expansion is attributed to the crystal

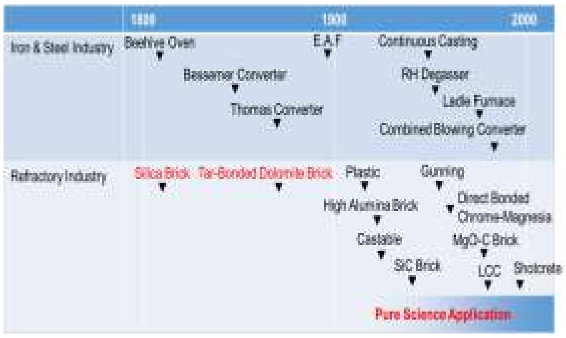

Fig. 2 Major inventions in iron & steel industry and refractory industry 1, 2).

polymorphism of SiO_2. As is well-known, the crystal shape of Quartz changes to Trydimite and Cristobalite in accordance with temperature rise under normal pressure. Since it is accompanied by considerable volume change, eccentric thermal expansion occurs. While Trydimite is the ultimate stable mineral phase in firing/service temperature, Cristobalite is formed priorly with a rapid reaction rate. Thus, Quartz, which is the starting crystal, changes to Cristobalite instantly, then turns to Trydimite during firing and commercial applications gradually.

Lime particles, which are surrounded by Quartz, form calcium silicate melt at high temperature. It acts as the matrix of Trydimite formation. As a result of SiO_2 dissolution in the melt from Cristobalite, the SiO_2 concentration reaches saturation followed by precipitation of Trydimite around the Cristobalite particles, resulting in unsaturation that allows further dissolution of Cristobalite. This dissolution and precipitation mechanism strengthens bonding among particles so that cracking during firing was eliminated and excellent creep resistance was achieved4).

Tar-bonded Dolomite Brick

Tar-boned dolomite brick, which is the key technology of the Thomas converter, was invented in 1879. It is an interesting material in terms of the application design of the basic materials, carbon and organic binder. The fundamentals of MgO-C brick were involved in it. The famous story of the invention of the Thomas converter is described below.

It was already known that excessive amounts of carbon make pig-iron brittle. In 1856, British engineer Henry Bessemer invented the bottom air injection process that removes carbon in pig-iron quickly. The equipment was called a Bessemer converter. It was a powerful tool to produce steel from pig-iron. When low phosphate ore was used as raw material of pig-iron, excellent steel could be obtained since it contains only a small fraction of phosphate, which is the undesirable element in terms of steel quality. Hence, low phosphate ore was explored intensively. Although it was known that lime addition and agitation removes phosphate effectively, instant brick corrosion inhibited this dephosphorization treatment. Silica brick was applied to the Bessemer converter.

In the early days, science predicted that applying basic brick for dephosphorization treatment would be effective in improving corrosion resistance. Hence, MgO brick or other basic bricks were tried. However, the results seemed to be insufficient. British metallurgist Sidney Thomas carried out a lot of laboratory experiments intensively and finally invented tar-bonded dolomite brick. It showed great success for reduction in brick corrosion and the equipment was called the Thomas converter. It enabled the use of high phosphate ore, which is abundant in nature, as raw material.

In these examples, science first provided principals to solve the problems and engineer's efforts materialized them in an industrial manner. They optimized the process and materials and got solutions.

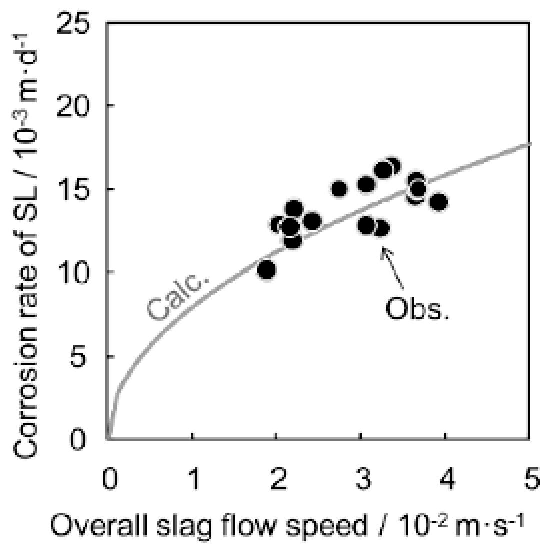

Fig. 3 Comparison in BF trough corrosion rate between observed data and calculation5,6).

Recent Research Conducted by the Authors

For many years, the author of this article was in charge of blast furnace (BF) cast house refractoryR&D such as taphole clay and trough materials. Inthis section, two topics will be cited from the author'sresearch.

Corrosion Variation of BF Trough

In 2008, due to the world economic crisis, steel production decreased considerably like other industrial sectors. Thus, BF productivity decreased until it was close to its lower limit. At that time, a manager who was responsible for trough maintenance tweeted the following;

"Although the BF trough service life was extended, pig-iron through-put didn't reach the same level of high productivity".

It shows that the corrosion rate is not proportional to time or through-put. According to the author's hypothesis that the corrosion rate of BF trough is explainable by the theory of mass transfer and variation in the corrosion rate being attributable to slag flow speed variation, numerical analysis was carried out5,6).

The corrosion rate was calculated with someassumptions according to the combined application of Fick's 1st law and Paulhousen's equation. As shown in **Fig. 3**, calculation results agreed well with observation. Based on theory and sensing technology, corrosion rate prediction became possible, allowing accurate trough repair scheduling.

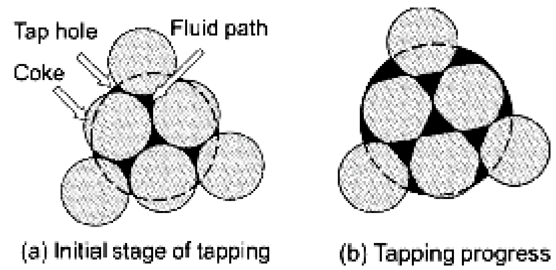

Fig. 4 BF taphole and coke packing configuration during tapping7).

In this case, careful application of a sophisticated science system clarified the influence of operating conditions on refractory wear. The trough maintenance manager's frank tweet, without preconceptions, triggered the research.

Tapping Time Fluctuation

As is well-known, the tapping time of BFfrequently fluctuates. A BF operation manager asked the author a question as follows;

"Long tapping time can be achieved during the high hearth bottom temperature period. Is sintering of taphole clay promoted?"

Another manager asked as follows; "Tapping time tends to decrease when FeO content in slag is high. Is taphole wear susceptible to FeO?"

It is common sense that variations in the above factors are too small to influence taphole clay corrosion. Thus, a new taphole flow resistance model was proposed7,8). If we could observe the taphole directly from the front, liquid discharge through gaps among coke particles would be observable (**Fig. 4 (a)**). In accordance with tapping progress, gaps extend with coke dissolution (**Fig. 4 (b)**), resulting in reduced flow resistance. Therefore, the drainage rate would be limited by taphole diameter enlargement as well as gap extension among coke particles.

This configuration was modeled as shown in **Fig. 5**. Pressure drop in the taphole tube and coke-filled part were calculated by Darcy-Weisbach equation and Kozeny-Carman equation, respectively. The calculation coefficients were quoted from literature7,8).

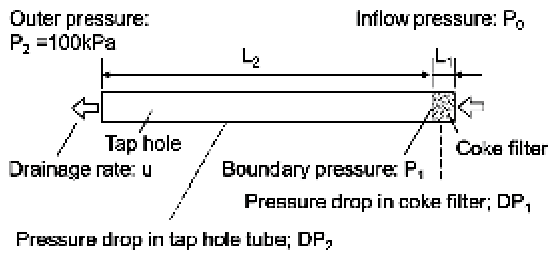

Fig. 5 BF taphole pressure drop model[7]).

Figure 6 shows the influence of the FeO content in the slag on tapping time. Calculations were carried out for two different cases where the C unsaturation degree in the pig-iron differed. Hereafter, the FeO in the slag and the C in the pig-iron will be expressed as (FeO) and [C], respectively. For every calculation, the taphole diameter enlargement rate was assumed to be constant. Hence, it is reasonable to assume that variation in the coke dissolution rate due to variations in (FeO) and [C] may possibly cause the tapping time fluctuation.

With respect to the hearth bottom temperature, its correlation with [C] was discussed as follows. It was revealed that variations in the hearth bottom temperature are induced by the formation and elimination of a low permeability zone on the BF hearth. Takeda et., al9). assumed sudden formation and elimination of a low permeability zone in order to explain the variations in hearth bottom temperature. When a low permeability zone covers the hearth, liquid flow in the furnace hearth is suppressed. Therefore, the heat transfer coefficient decreases, resulting in bottom pig-iron solidification and reduction in hearth bottom temperature. On the contrary, sudden elimination of a low permeability zone promotes liquid flow that causes solidified iron to melt as well as bottom temperature to increase.

During the low hearth bottom temperature period, the transportation time of the produced pig-iron is short due to shallow bath, so that, the dissolution amount of C is small. On the other hand, a long transportation time and mixing with solidified iron are expected for the high hearth bottom temperature period, resulting in high [C]. The correlation between [C] and hearth bottom temperature is widely accepted7).

In this case, honest questions coming from

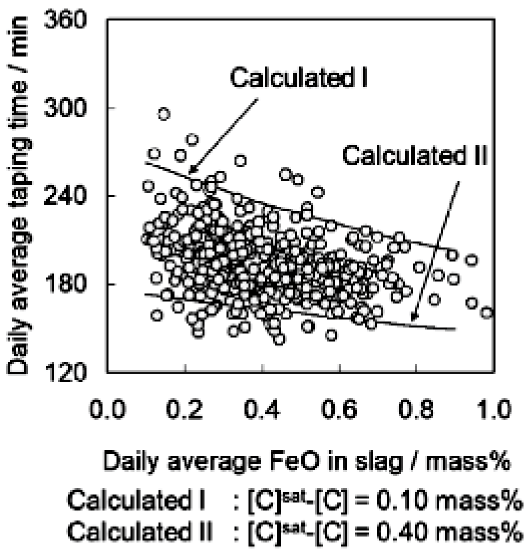

Fig. 6 Influences of (FeO) and [C] on tapping time[7]).

scientific considerations of two BF operation managers gave the new idea for a drainage rate regulation system. Although their opinions weren't proper due to lack of knowledge of refractory wear, their scientific attitudes that viewed practical data as it is without preconceptions should be appreciated.

Recent Trend from UNITECR 2019

Table 2 provides the sessions and numbers of articles issued in the proceedings of UNITECR 2019 , which was held in Yokohama, Japan from October 13 to 16, 2019. It was hosted by the Technical Association of Refractories Japan (TARJ). 859 participants were gathered from 37 countries.

Obviously, the major part of the presentations was occupied by refractories for steel industry. In the articles, refractories for secondary metallurgy and continuous casting seem to get much attention. One reason is that no session for monolithic refractory was arranged in UNITECR 2019. Accordingly, topics for steel ladle castables, tundish castables, and repair materials for these facilities were presented in the session.

Another reason is considered to be the result of the growing demand for high cleanliness high grade steel. Steel is now under severe competition with other materials such as non-ferrous alloys, carbon composite, ceramics, and so on. Thus, improvement of its characteristics is an urgent issue. Therefore, development of various kinds of steel treatments is being carried out intensively. An uncountable amount of refractory optimization efforts are thought to be going on in these technological fields. The second and fourth largest sessions were "Testing" and "Basic Science", respectively. The theme of UNITECR 2019 was; "Refractories for the Future: Collaboration among Customers, Manufactures and Academia in Pursuit of Further High-Temperature Technology". Along with the theme, many basic knowledge was presented from the academia. Adding articles of the session titled "Collaboration among Customers, Manufactures and Academia", to the fore mentioned two categories, the sum of all these categories was 22.2 %.

Table 2 Session titles and articles included in UNIRTECR 2019 Proceeding:

Session Title	Number	%
Basic Science	17	7.1
Testing	25	10.5
Refractories for Iron and Steel Making - Coke Ovens and Blast Furnace	15	6.3
Refractories for Iron and Steel Making - Hot Metal Transport	6	2.5
Refractories for Iron and Steel Making - BOF	8	3.3
Refractories for Iron and Steel Making - Ladle and Secondary Refining	32	13.4
Refractories for Iron and Steel Making - Continuous Casting	23	9.6
Refractories for Glass and Cement Production	9	3.8
Refractories for Non-ferrous Metal Industry	8	3.3
Refractories for Petrochemical Industry	4	1.7
Refractories for Waste Incineration and Others	9	3.8
Industrial Refractories Applications	7	2.9
New Development	11	4.6
Refractory Engineering Systems and Design	12	5.0
High Temperature Engineering Ceramics	6	2.5
Energy Saving and Insulation	16	6.7
Environmental Sustainability and Recycling	3	1.3
Advances in Manufacturing, Installation and Equipment	2	0.8
Raw Materials	15	6.3
Collaboration among Customers, Manufactures and Academia	11	4.6

Among them, articles that described DEM simulation of refractory fracture were attractive10-12). DEM, which stands for Discrete Element Method, is a computer calculation method that simulates particle movement. In the iron making field, the coke flow in the BF has been simulated by DEM successfully13-16).

In the ceramics field, particle flow during molding can be simulated by DEM. As mentioned above, DEM describes the movement of individual particles in a particle-packed structure.

Traditionally, refractory deformation has been simulated by FEM (Finite Element Method). In principal, since the method assumes a continuous body, initiation and propagation of cracks that divide a continuous structure, are impossible to be treated.

Contrarily, DEM calculates interaction among discontinuously-contacted particles according to a suitably-assumed force acting among the particles.

The articles show very interesting results so that extension of DEM analysis on a refractory fracture is predictable.

Refractory Technology in the Future

Industry 4.0

"Industry 4.0" and "SDGs (sustainable development goals)" are key words for the future just as they are in other industrial sectors. With respect to "Industry 4.0", revolutions in IT technology will accelerate the on-going development of refractory technology from many aspects. A highly advanced networking system utilizing cloud enables immediate transmission of a huge amount of information. Io Tassembled devices and wearable devices allows the sending of data without keyboard typing. These data are analyzed by AI quickly.

It improves refractory consumption forecasts at on site locations, resulting in accurate inventory management. In addition, immediate feedback of changes in furnace operating conditions becomes possible. Well-organized production control becomes possible on refractory manufacturing sites.

Frequent production schedule modifications according to order information updates will become

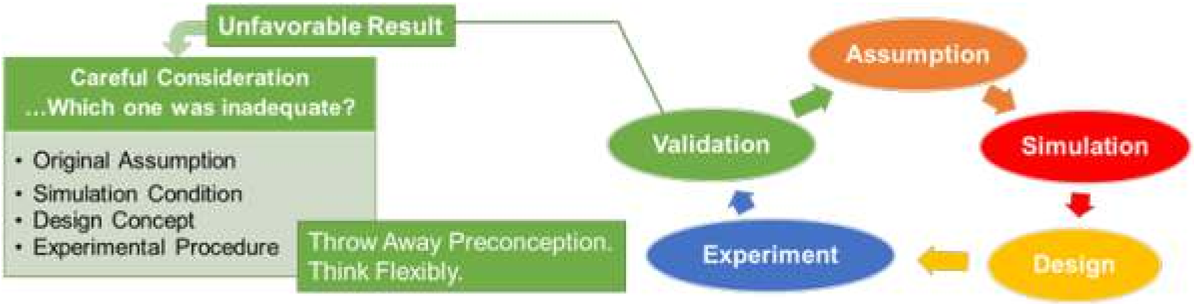

Fig. 7 R&D cycle

possible. Failures in manufacturing equipment are informed directly from sensors and optimal repair methods and options of production schedule modification are proposed. Therefore, quick response with minimum stock of products will be achievable.

These systems must be developed by human. In order to utilize technologies according to the "Industry 4.0", establishment of basic knowledge and technology by human beings is essential. Since AI is the protocol that judges things according to learning, creating the right learning method is crucial.

SDGs

In 2015, United Nations adopted SDGs (sustainable development goals) as international targets from 2016 to 2030. It includes 17 items as; (1) No Poverty, (2) Zero Hunger, (3) Good Health and Well-Being, (4) Quality Education, (5) Gender Equity, (6) Clean Water and Sanitation, (7) Affordable and Clean Energy, (8) Descent Work and Economic Growth, (9) Industry, Innovation and Infrastructure, (10) Reduced Inequalities, (11) Sustainable Cities and Communities, (12) Responsible Consumption and Production, (13) Climate Action, (14) Life bellow Water, (15) Life on Land, (16) Peace, Justice and Strong Institutions, and (17) Partnership for the Goals.

While SDGs will be led by politics, industryshould also be responsible for it. From the technological point of view, reduction of environmental load is a challenging target.

Implementation of on-going trials such as extending service life, promoting recycling, improving thermal insulation, excluding harmful components, etc. will be the certain way to reach target. Doing so will provide innovative ideas for the future.

Polarization

Looking towards the future, current polarization, i.e., commoditization and specialization, will progress further. In order to produce generalized products, cheap refractory materials will be supplied from all over the world. Normalization and systemization are the key words from the view point of commoditization.

On the other hand, highly advanced special materials are produced through specific high temperature processes that require special refractory technology. For this, optimization and customization according to mutual trust will become more and more important. High quality solutions will be provided by experts from all over the world.

R & D

Obviously, R&D focuses on the specialization side. SDGs will influence on operation policies, so that a variety of furnace operating conditions will broaden. Hence, requirements for refractory material optimization are expected to increase. For the sake of optimization, information according to on-site specialist becomes more significant. In that case,communication technology according to industry 4.0 will be a powerful tool.

From the scientific point of view, basic research will be expected to be activated according to the industrial demand as mentioned in section 4. Many researchers will be challenged by the new research toestablish theories that describe complex phenomena caused by refractory materials that possess in homogeneous texture.

Especially, applications of computer simulationare expected to expand. FEM for thermal stress **Fig. 7 R & D cycle.** analysis and CFD (Computational Fluid Dynamism)for molten steel flow simulation have traditionally been used in the refractory industry. In addition, DEM is one of the promising candidates as described in section 4. Moreover, Lattice-Boltzmann method is employed to describe refractory corrosion17-20). PhaseField method reproduces evolution of dendriteduring steel solidification successfully 21-23).

Applications of these methods allows the simulationof mass transfer and chemical reaction in fluid.

Accordingly, research that involves simulation in its cycle (**Fig. 7**) will increase. This is appreciated since simulation requires quantitative mathematical thinking that improves the engineer's ability considerably. Basing on new ideas, an assumption will be established followed by simulation.

According to simulation results, experiments will be carried out to validate the assumption. In many cases, experimental results may be unfavorable, particularly for basic research. In those cases, it is important to consider which step, i.e. assumption, simulation, design, experiment, was inadequate. In the process, it is important to see the result. Careful consideration without preconception is necessary.

Epilogue

In this article, the author provided personal perspectives on technology and science through

discussions on refractory technology. Historically, an honest scientific attitude and continuous challenge broke through the problems. The author believes that it is also essential for creating the future.

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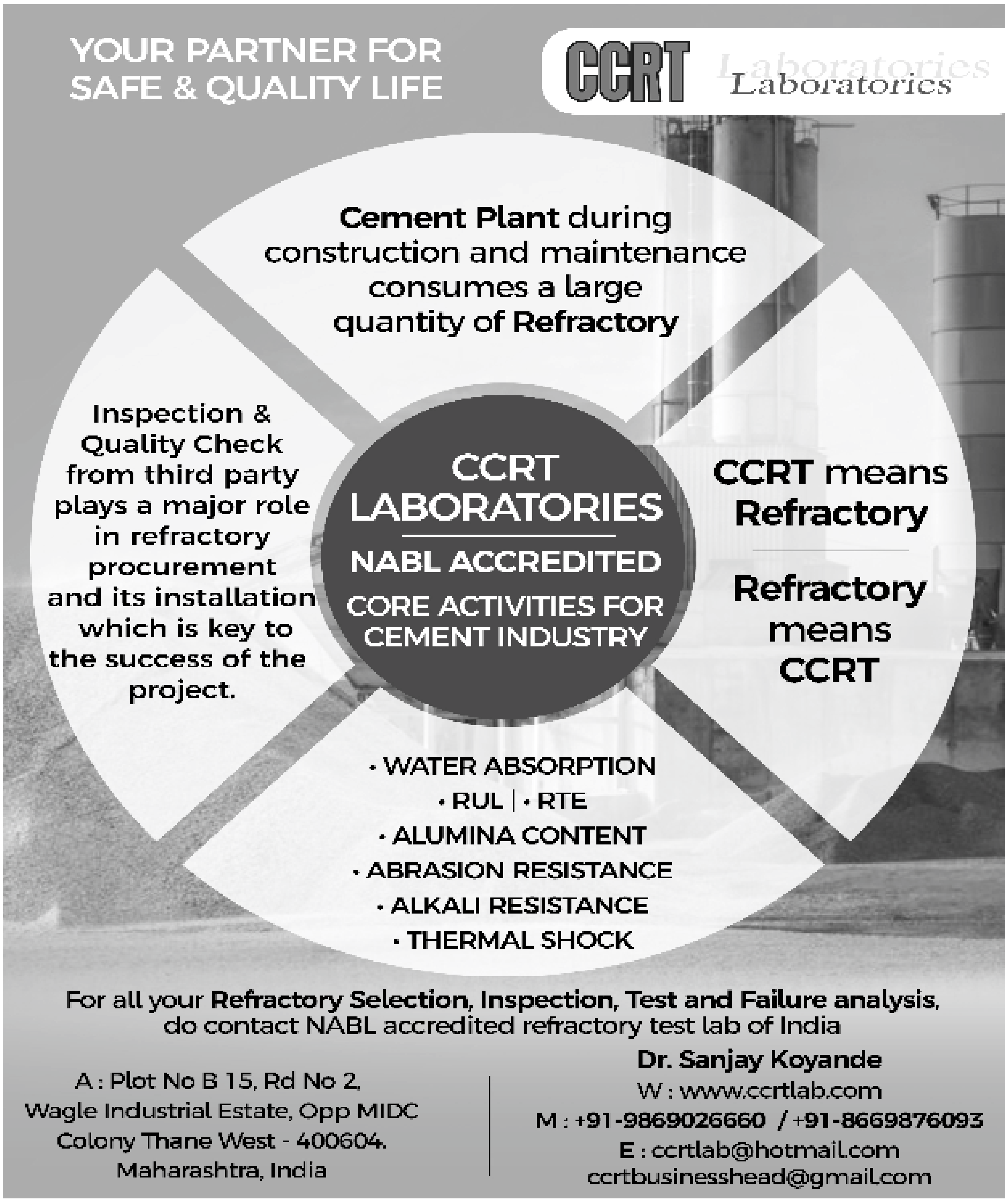
STATISTICS

Import Data of Basic Raw Materials

		2021-22	
HSN Code	**IMPORT OF REFRACTORY RAW MATERIALS**	**QTY(Mt)**	**(Rs.Lakhs)**
25199010	Fused Magnesia (Natural)	42.30673	26,144.42
25199020	Dead-Burnt (Sintered) Magnesia	170.74403	53,405.75
25199030	Magnesum Calcined NES or included	44.23128	9,407.44
25199040	Magnesium Oxide	67.33297	20,674.69
25199090	Other Magnesium W/N pure	49.39248	18,255.77

(Source: IRMA)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procurement
and its installation
which is key to
the success of the
project.
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CEMENT INDUSTRY
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Refractory
Refractory
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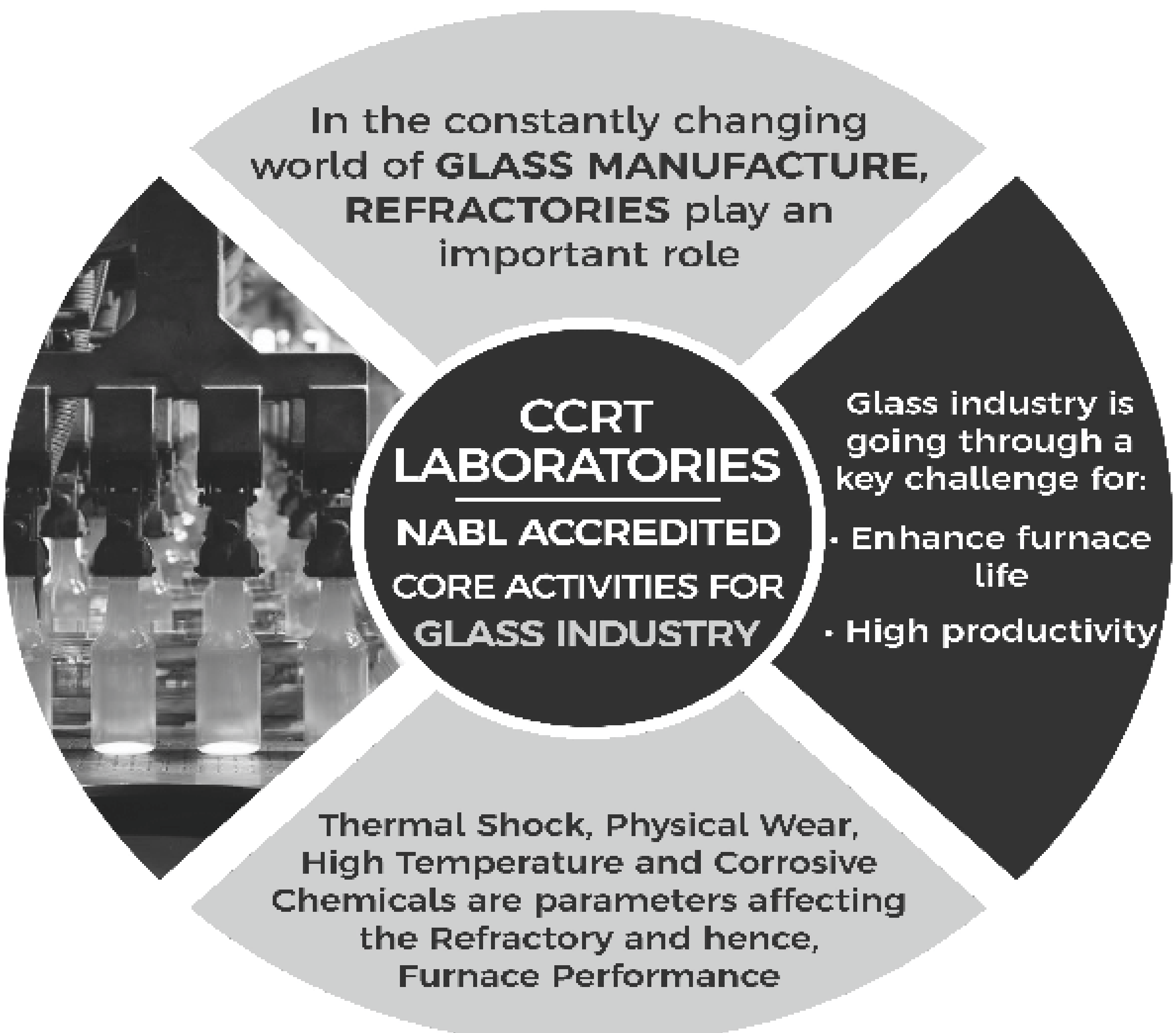
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- MONOLITHICS - 1500 METRIC TONS /MONTH
- PRECAST PREFIRED SHAPES: 100 METRIC TONS /MONTH

BRICKS

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- ➢ HIGH ALUMINA BRICKS
- ➢ MULLITE BRICKS
- ➢ ZIRMUL BRICKS
- ➢ SILLIMINITE BRICKS
- ➢ INSULATING(HFI/HFK/PORROSYNTH) BRICKS
- ➢ MAGNESITE/MAGCHROME/CHROME MAG BRICKS

MONOLITHICS:

A) CASTABLES:

- ➢CONVENTIONAL
- ➢LOW CEMENT
- ➢ULTRA LOW CEMENT
- ➢INSULATING

B) PRECAST: BLOCKS & SLABS UPTO 1000 Kgs

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