On Refractories' High Performance and High Cost-Effectiveness

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The terms of "high performance" and "high cost-effectiveness" for refractories are so familiar. However, to answer questions like what the real meaning of high performance is, how to represent it, what the evaluation criterion is and how to realize high performance and meanwhile high cost-effectiveness seems to be not that easy without thinking in depth. For decent refractories, from original intention of design to production process, installation and on site service, each link is closely related to performance and cost, and in pursuit of, as much as possible, high performance and low cost. How to investigate subjectively high performance and how to feasibly realize low costs for refractories are worth further consideration and implementation by R&D workers and managers.

1 Introduction

Performance-to-cost ratio can be used to represent a relationship balanced between input and output for a certain process. As-high-as-possible cost effectiveness is what people run after and it is directly related to the profit and market acceptance of a product. From this concern, cost effectiveness is an important criterion to evaluate a specific technology or production process as well service results of refractories.

Considering the present background of economic downturn, overcapacities and serious challenges encountered by the refractories industry and the major end users in China, to seek out a high-performance oriented design concept which can be cost-effectively and feasibly accessed is undoubtedly of practical meaningfulness. Based on authors' cognitions and some carried out or ongoing work involved, approaches to high performance with cost effectiveness are put forward and discussed.

2 Implication of high performance and high cost-effectiveness

It needs to be emphasized that high performance is concerned from the point of view of the behaviour during application, not equal to high property. Performance means any recognized accomplishment, of a process or manner assessing the functioning or operating behaviour. For a certain material which is superior in one or more properties or indexes it will not necessarily be referred as high performance, unless a remarkably improved application result has been proven and confirmed by field test, attributed indeed to the property improvement.

In practical research and application work, property and performance are often confused and misunderstood. Some tend to represent high performance by high property, which is however not true.

Criteria of high performance can hardly be simple and single, but actually relate to multiple factors (e.g. key property, application result, market acceptance, performance-to-cost ratio, etc). High performance in fact implies high reliability, high durability, high efficiency and high feasibility.

It is necessary to point out that with regard to high performance of a refractory, it is unnecessarily and impossibly to cover all or many properties.

What matters is actually to make a breakthrough in key properties or those, which are directly and closely related to service performance. The key is to clarify key properties for a good design and production of any refractories.

Cost effectiveness is generally represented by a ratio of performance to cost (performance/cost – P/C), showing the cost paid for the most concerned performance. As P/C ratio is a kind of proportionality, there is certain applicable range, which should not be treated at will. High cost effectiveness can be achieved by means of performance enhancement, cost reduction or a positive

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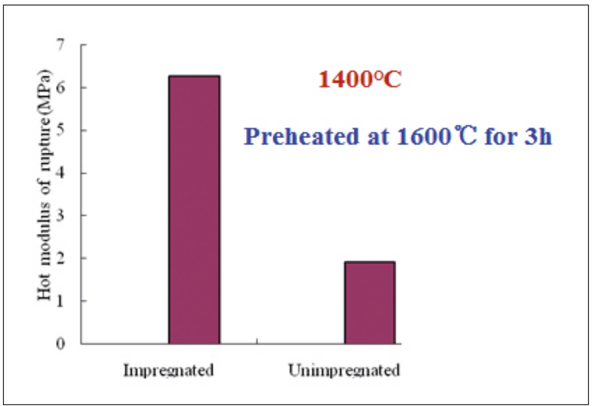


Fig. 1 Effect of impregnation with a magnesium sulphate solution on HMOR of an Al_2O_3 based castable

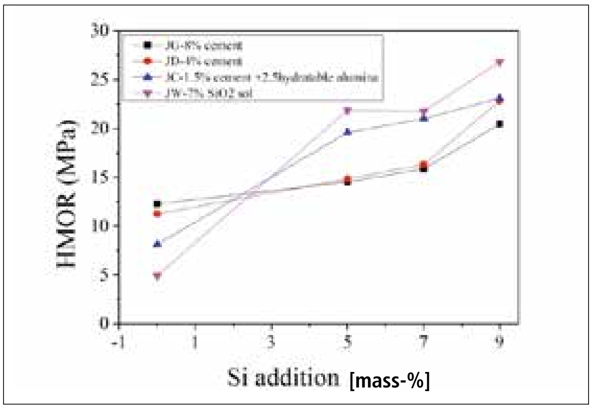


Fig. 2 HMOR of high alumina castables incorporated with Si powder after nitridation (4 binding systems: high level of cement, low cement, ultra low cement and non-cement; pre-treatment: nitridation at 1450 °C for 9 h; test: 1300 °C, 0,5 h, carbon embedded)

effect brought about by changing both. It is not difficult to show that high cost effectiveness can be fulfilled via the following:

- greatly enhancing the performance at edged up costs
- enhancing the performance at original costs
- equivalent performance at lower costs and
- enhancing performance at reduced costs.

Without doubt, those ideas and approaches enabling performance enhancement at unchanged or even decreased costs are worth more attention and practice.

3 Approaches to high performance and high cost effectiveness

The interrelationship of a composition, microstructure, property, service performance and their optimisation are the purpose and target of R&D work on materials. Property changes of a material result from its composition and microstructure. From this point of view, the ways to improve the composition and microstructure of a material deserve also to be the ways to achieve high performance. If regardless of costs, high performance may probably always be fulfilled. The real challenge, however, is to realize high performance at also high cost effectiveness. Attention should be paid on the following parameters.

3.1 Nanometer technology

For a certain component with grain sizes down to submicron or even nanometer scale, qualitative change may occur in its own nature and interaction with the surrounding components, resulting in changes to properties or enabling certain outstanding features. Benefits for refractories from the nanometer effect are mainly high dispersity and high reactivity brought by nanosized materials, whereas problems in terms of poor dispersion, high costs, unavailability, etc. are still awaiting effective solutions. Costs of many nanosized powders that can be applied in refractories so far remain to be intolerable by most refractory products. This led to the situation that sufficient lab research is done, while insufficient industrial application for nanometer technology is available. Out of this concern, new approaches need urgently to be explored to realize the positive nanometer effect on refractories using more feasible technologies at lower costs.

3.1.1 Sol-gel and precursor approaches

Problems of difficult dispersion and high costs are known and can hardly be tackled by direct introduction of nano-powders. However sol-gel or precursor approaches are more workable and feasible. Particle size of effective components in sol or precursor solution can reach nano-scale, and can be easily employed and dispersed.

There is no lack of successful practices in this aspect, e.g. silica sol-gel or alumina sol-gel bonded castables or bricks. Silica sol-gel has been adopted as binder and also SiO_2 source for in situ formed mullite bonding and some solid state gel powders have also been used in specific components. Such sol and gel materials can exist in a refractory matrix in nanoscale size and take part in reactions in it. This is favourable for optimisation of microstructures and performance enhancement of refractory products.

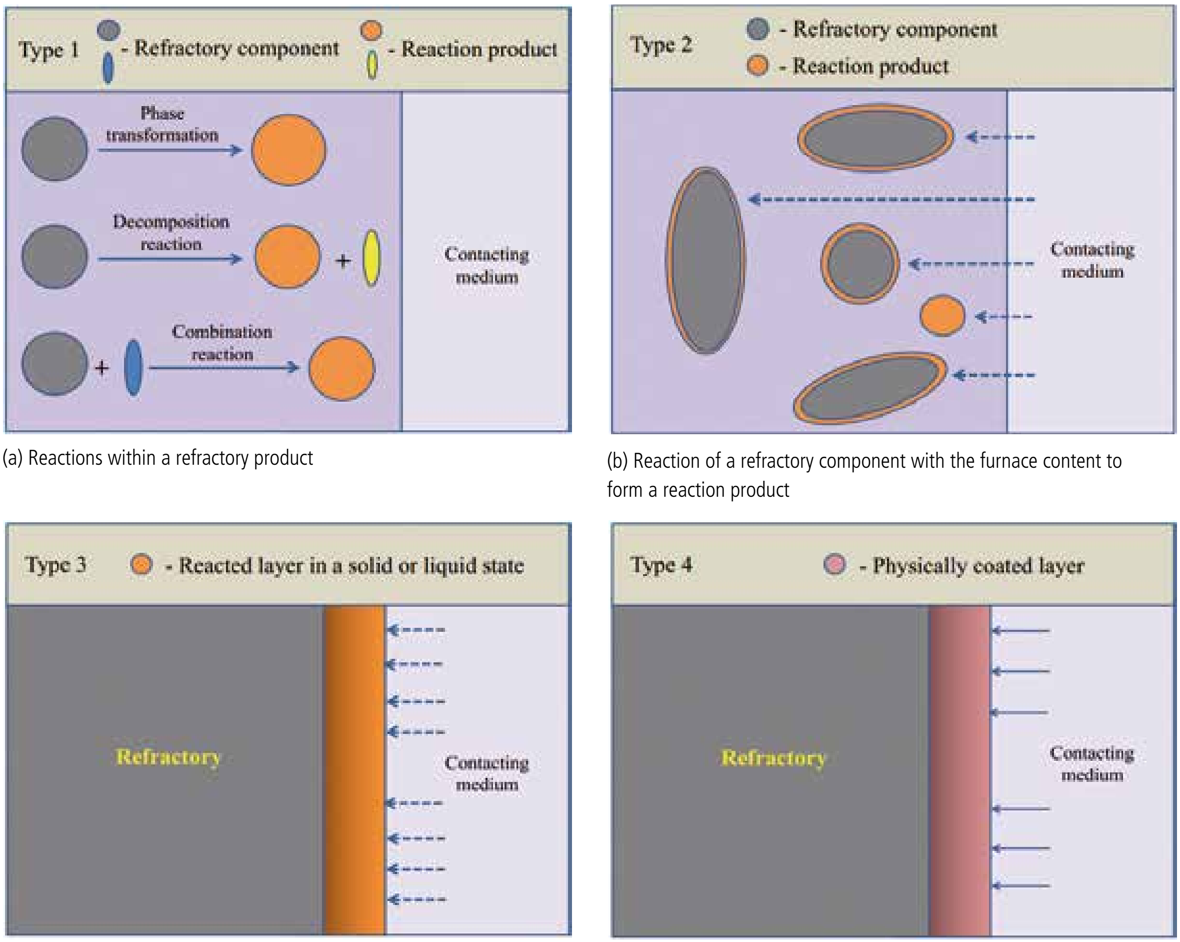
Suitable solutions, besides being used as a binder, can be applied for impregnation to improve properties of refractories. For example, it has be reported [1] that being impregnated in magnesium sulphate solution, HMOR of Al_2O_3 based castable specimen can be remarkably improved (Fig. 1). Such performance improvement is attributed to the nanometer effect of a MgO component derived from the solution.

3.1.2 Gaseous phase approach

With addition of certain substances in refractories, which can react with a gaseous component, in situ formed bonding phases may help to improve mechanical and thermal properties.

Gaseous phases in atomic scaled dimension and their exceptional penetration is beneficial to eliminate unavoidable pore defects in refractories. By introducing beneficial components in the form of gaseous phase, favourable microstructures and bonding phases can be in-situ formed under controlled conditions. This is a way for obtaining the nano-effect with good cost-effectiveness.

The nanometer effect by a gaseous phase is usually associated with the addition of metallic substances. Bi Zhenyong et al. [2, 3] investigated the effect of silicon introduction into bauxite based high alumina castables using different binder systems.



(a) Reactions within a refractory product

(b) Reaction of a refractory component with the furnace content to form a reaction product

(c) Interface reaction to form a protective layer

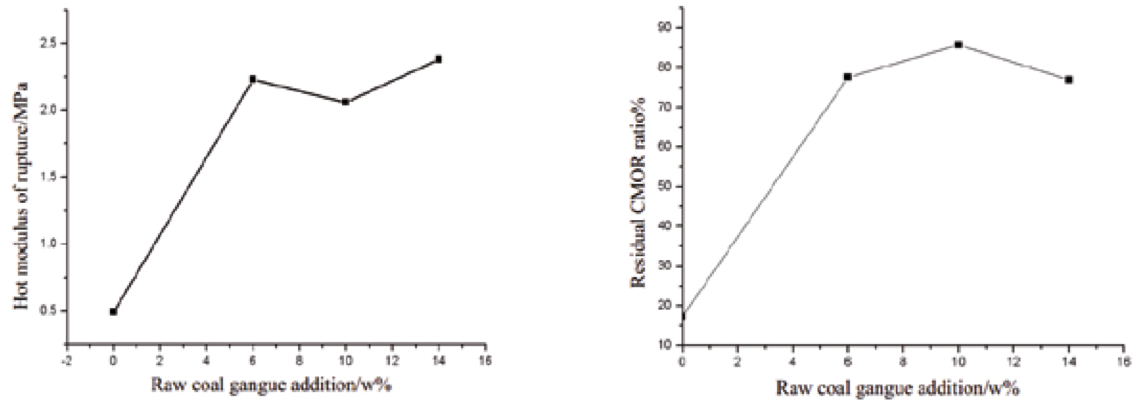
(d) Surface adhesion to form a protective layer

Fig. 3 Four types of in situ refractory

After nitridation by heating in nitrogen atmosphere at certain temperatures, the HMOR of the castables can be remarkably enhanced – more significantly for ultra low cement and cement-free binding systems, as shown in Fig. 2.
With respect to high safety and durability of some products when subjected to a long service period and tensile stresses at high temperatures – like anchors prepared by pre-casting of castables – such a high hot strength is meaningful and very necessary. This is a good example to convince that key performance can be significantly enhanced at relative low cost. Using a similar approach the enhancement of HMOR can also be achieved in SiC-based castables [4], alumina-based castables [5], etc.

3.2 In situ effect

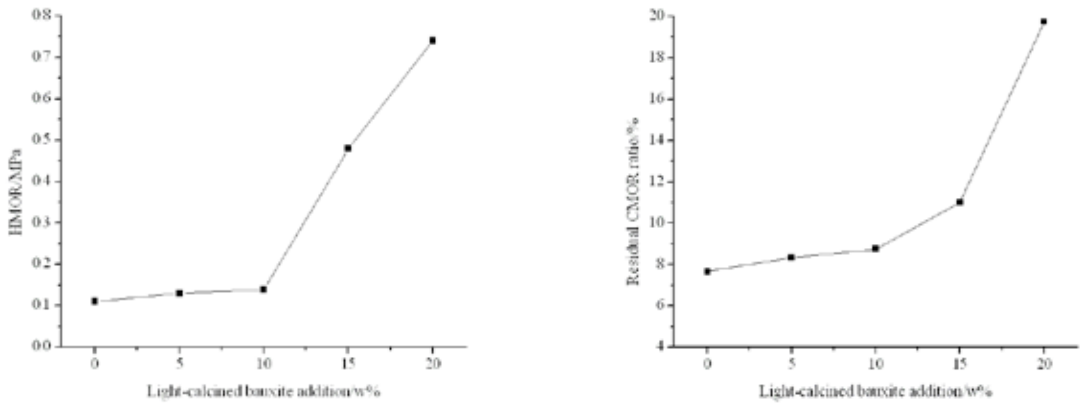
The concept of in situ refractory was firstly put forwarded by W. E. Lee and R. E. Moore [6, 7], defined as "the in use product(s) of reaction within a refractory system or between the refractory and furnace contents leading to improved refractory behaviour". Two key points of in situ refractory are worth to be highlighted, i.e., in use refractory product(s), implying the reaction occurs during the service, and improved refractory behaviour, implying the reaction and the reaction product are beneficial. In situ refractory can be divided into four types, as schematically shown in Fig. 3.
Broadly speaking, many have been in accordance with the concept of in situ refractory: e.g. monolithics, unburned or lightly burned refractory products, coating of cement clinkers on cement kiln linings, slag splash on steel converters, water cooling stave for BF, and so on. It is underlined by in situ refractory to make beneficial reactions happen during service, which inspires some approaches to high performance by taking advantage of the in situ effect, usually at lower costs compared to some sophisticated ways. Good examples are here the direct use of some natural raw minerals and lightly calcined minerals as partial raw materials in some refractories.
Systematic research work has been carried out on the application of kaolin, raw bauxite, semi-raw kaolin and bauxite in aluminosilicate castables [8–10]. In LC Al_2O_3–SiO_2 castables the addition of powders and small grains of raw bauxite, coal gangue, mild-calcined bauxite and coal gangue respectively leads to improved properties and microstructures featured by in situ formed mullite which serves as an enforced bonding phase to enhance HMOR.
Other benefits have also been found in terms of microcracks or gaps after their decomposition, higher reactivity compared to their dead burned counterparts and slightly reduced bulk density, which



(a) HMOR at 1400 °C

(b) Residual CMOR ratio after 1 circle of 1100 °C-water quenching

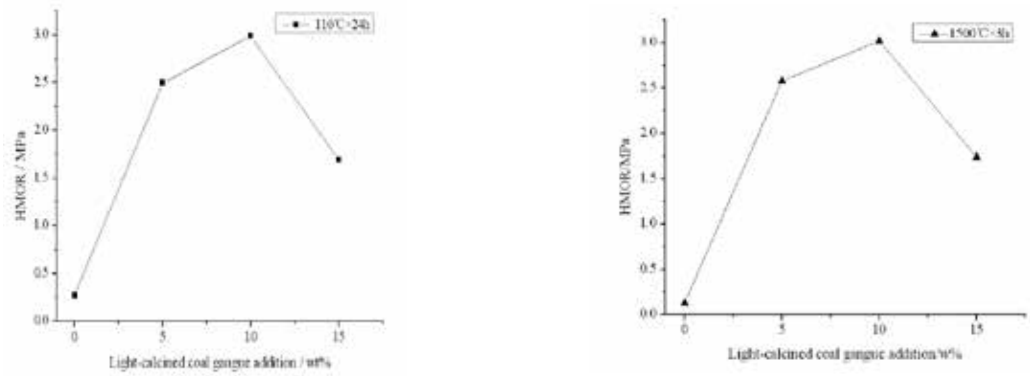
Fig. 4 Effects of adding coal gangue (up to 14 mass-%) in LC Al_2O_3–SiO_2 castables



(a) HMOR at 1400 °C

(b) Residual CMOR ratio after 1 circle of 1100 °C-water quenching

Fig. 5 Effects of adding mild-calcined bauxite (up to 20 mass-%) in LC Al_2O_3–SiO_2 castables



(a) Tested by using the specimens after drying at 110 °C

(b) Tested by using the specimens pre-fired at 1500 °C for 3 h

Fig. 6 HMOR at 1400 °C of the Al_2O_3–SiO_2 castables with mild-calcined coal gangue (up to 15 mass-%), using specimens with and without pre-firing respectively

consequently contributes to the improved resistances to drying-out explosion, thermal shock and reduced thermal conductivity, as presented in Fig. 4–6.

Similar positive effects may also be obtained by playing with in situ formed bonding phases in terms of spinel (MA), calcium hexaluminate (CA_6), forsterite (M_2S), etc. in suitable castables. It can be said that most refractory castables in use are featured by gradients inside. Introducing raw or semi-raw minerals, which may enrich such beneficial in situ and gradient effect, is appropriate.

3.3 Engineering of raw materials and pores

The American Engineers' Council for Professional Development has defined engineering as "the creative application of scientific principles to design or develop structures, machines, apparatus, manufacturing processes or works utilizing them single or in combination. Or to construct or operate the same with full cognizance of their design. Or to forecast their behaviour under specific operating conditions respecting an intended function, economics of operation, safety and properties".
Nowadays, the term engineering also refers to meticulous design, elaboration and optimisation, like microstructure engineering.Raw materials are the important basis of a product. The adoption of engineered raw materials is necessary for refractory products to achieve certain features and performance improvement. The concept of refractory raw materials engineering has recently been put forwarded, having received wide attention in the refractories community.
Some publications have described and discussed this concept and introduced latest achievements in R&D and application [11–13].

3.3.1 Engineering aggregates

Aggregates are the main part of a refractory product. Aggregates engineering refers to a working system, including design, customisation, properties testing, performance evaluation in refractory products and adoption of them for desired purposes. Design and customisation of engineered aggregates are implemented by specially designed and controlled shapes, surface features, chemical and phase compositions and their distribution in microstructures inside and on the aggregate surface. There are several possibilities for engineered refractory aggregate, as schematically shown in Fig. 7 [13].
Through such combinations of shape, structure and material systems as shown above together with the optimisation in the bonding state and reactivity between matrix and aggregate, a big variety of engineering aggregates can be derived to offer more options for high performance of refractories. Good examples are already available, e.g., spherical aggregates, lightweight and dense spherical aggregates are commercially available and the refractory castables using them have been put into use.
Fig. 8 shows mullite based hollow ball aggregates with Al_2O_3 content of 55 ~ 60 %, K_2O + Na_2O less than 1 % and a packing density of 0,68 ~ 0,76 g/cm^3. Lightweight castables using such hollow balls as aggregates have shown good flowability, high strength and high refractoriness with service temperatures up to 1450 °C. They can even replace conventionally used materials for working linings of some atmospheric fur-

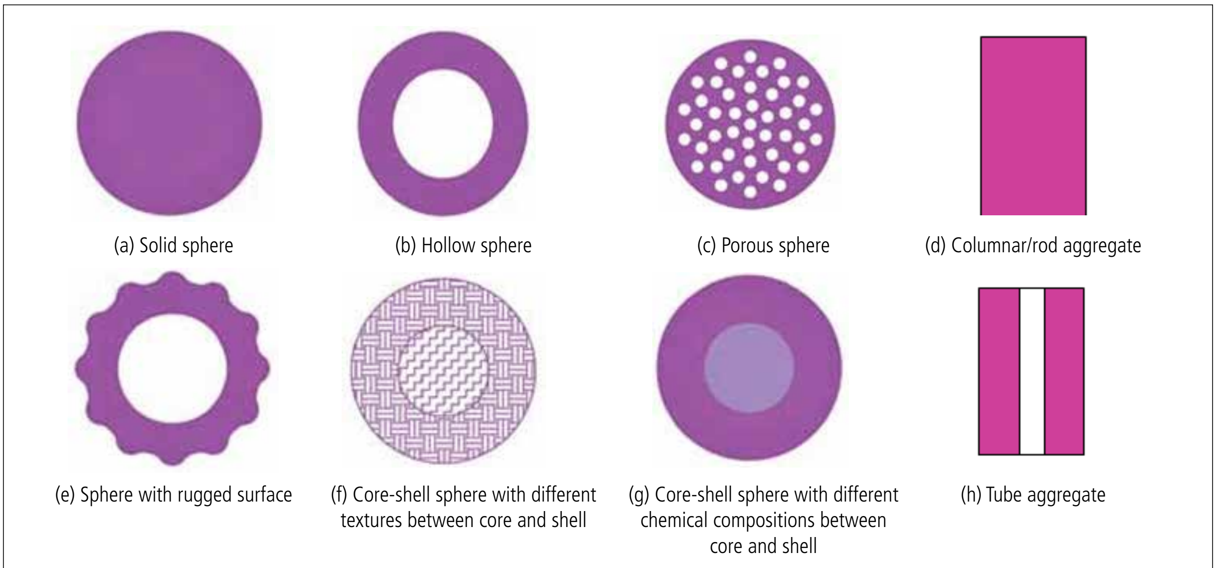


Fig. 7 Possibilities for engineering aggregates

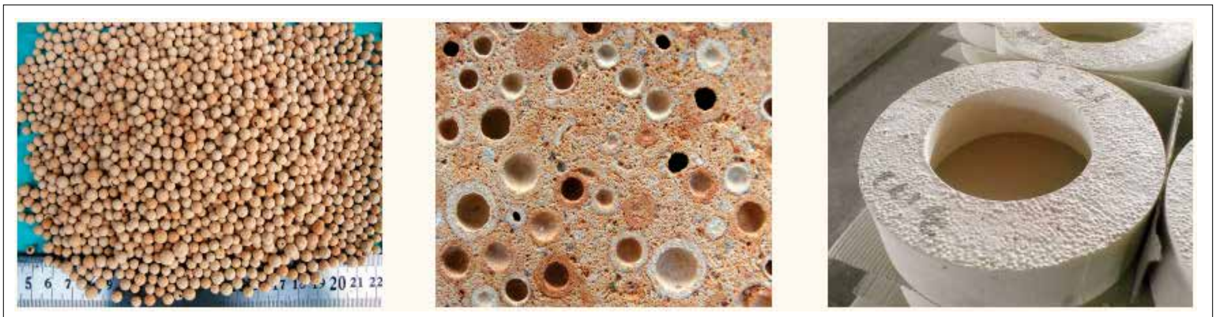


Fig. 8 Mullite-based hollow balls and their application in castables and pre-cast shapes

Tab. 1 **A comparison of spherical bauxite and conventionally crushed bauxite**

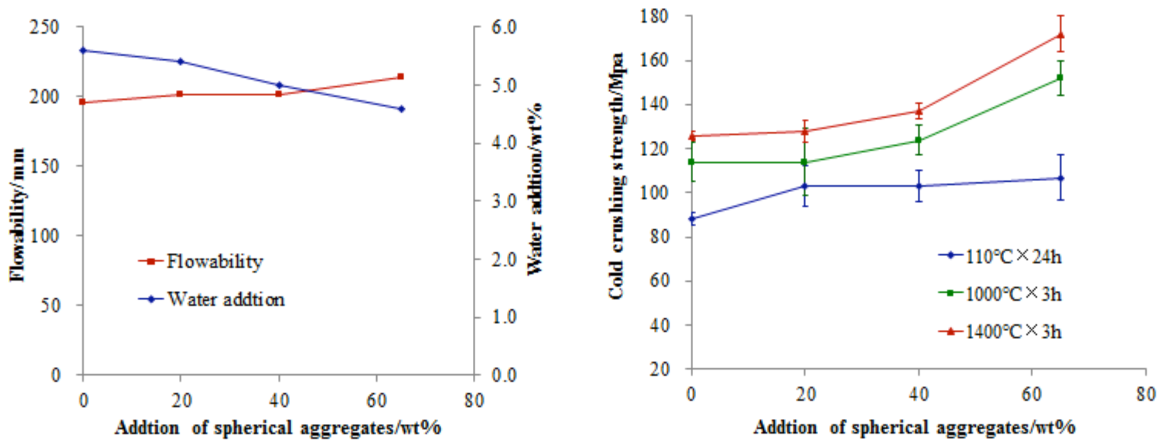
Aggregate Type	Al_2O_3 [mass-%]	SiO_2 [mass-%]	Bulk Density [g/cm³]	Water Absorption [%]	Appearance
Spherical	64,77	28,09	2,78	2,5	
Irregular shaped after crushing	67,64	27,29	2,80	1,5	

naces. Successful applications of such high performance lightweight castables can be found for water cooled skid and post lining of reheating furnace, wall linings, pre-cast burners of heating furnace, roofs of metallic magnesium reduction furnaces and so on.

In an attempt to replace traditional aggregates with dense spherical aggregates, research work has been undertaken by High Temperature Materials Institute of Henan University of Science and Technology. Bauxite based spherical aggregates with properties shown in Tab. 1, were added in Al_2O_3–SiO_2 castables to replace traditional bauxite aggregates. As expected, reduced water demand, improved flowability and cold crushing strength enhancement have been achieved, as shown in Fig. 9. Further investigations on its effect on thermal shock resistance, hot strength, etc. are on going.

Recently, a so-called stress dissipative aggregate has been developed which can reduce stress concentration by causing the stress to deflect or buffer in the transmission direction when incorporated in alumina based shaped and unshaped refractories.

As expected, thermal shock resistance of alumina-spinel castables has be improved by introducing such stress dissipative aggregates with diameters around 0,1 mm, consisting of agglomerated alumina ultrafines, as shown in Fig. 10. They, when added in the castable, are not well sintered even after heated at 1600 °C for 3 h, so a large number of existed internal grain boundaries can play a role of flexibility. Some microring gaps, emerging between ball shaped pow-



(a) Flowability and water addition

(b) Cold crushing strength

Fig. 9 **Properties comparison of Al_2O_3–SiO_2 castables using spherical bauxite to replace conventional bauxite aggregates**

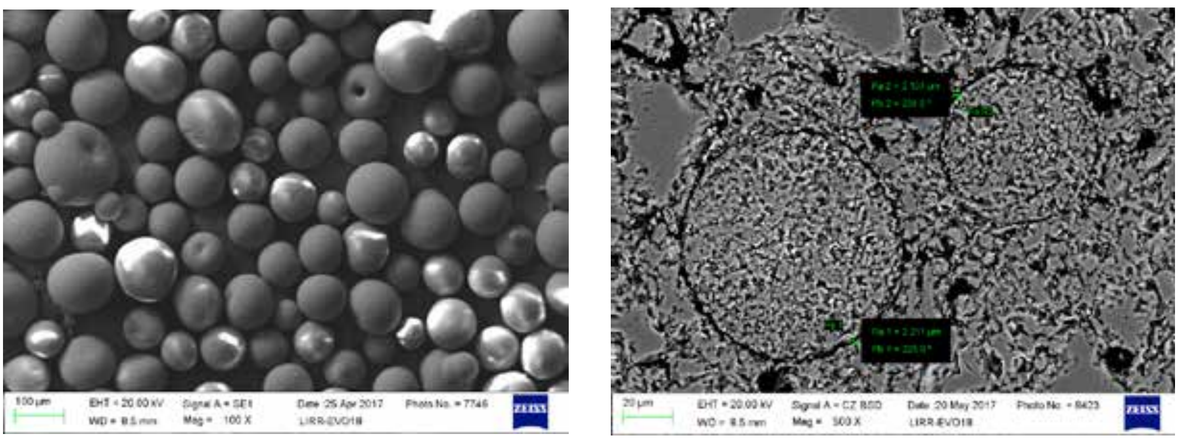
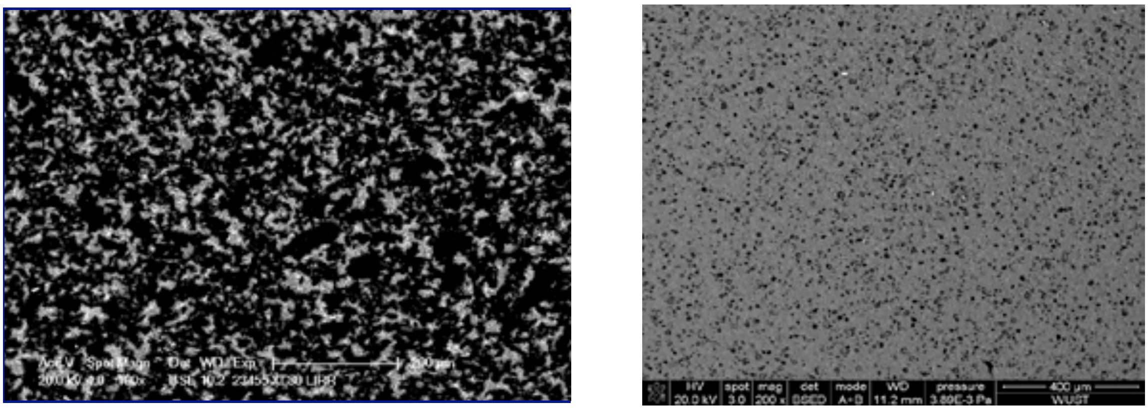
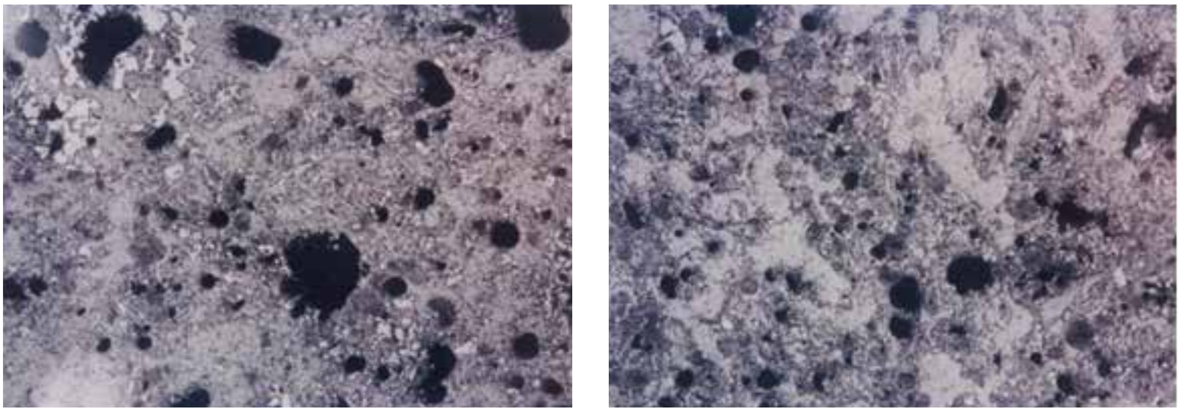


Fig. 10 **Stress dissipative aggregates of alumina micrograins, as-received and in the castable**



(a) Micropored porous mullite, BD 1,2 g/cm³; av. pore size ~3 µm (b) Micropored sintered alumina, BD 3,3 g/cm³; av. pore size ~1 µm

Fig. 11 Micropored porous and dense aggregates



(a) Original MgO–C brick (b) Pore modified MgO–C brick

Fig. 12 Microstructure comparison between the MgO–C bricks with and without using pore-modifying additive

der aggregates and the matrix after heating at high temperatures, can be in favour of dissipating the stress inside the material, leading to improved thermal shock resistance.

3.3.2 Engineering of pore structures

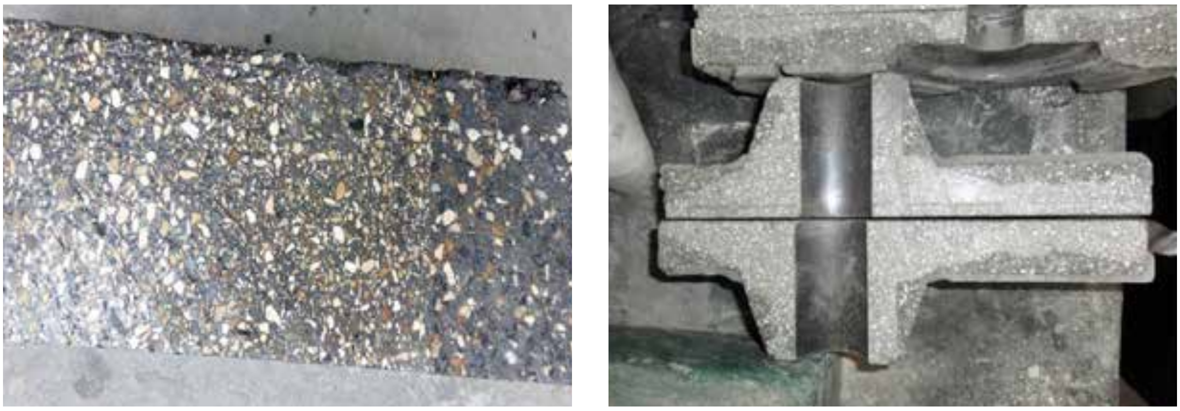
From a structure point of view, a refractory consists of not only solids in terms of aggregates and powders, but also pores with different size and shape. In some sense, gaseous phase can also serve as a raw material for refractories, perhaps the cheapest one. Pore engineering by optimising porosity, pore size and shape and their distribution in a refractory deserves to be an effective way leading to high performance and high cost-effectiveness.

Realistic examples include the application of micropored aggregates, porous mullite aggregates featured by micro-pores, micropored sintered alumina, etc. [14]. Fig. 11 exhibits the microstructure of two types of micropored aggregates. They can be assigned to the afore-introduced porous type of engineered aggregates. By using such aggregates, it is possible to reduce thermal conductivity on the one hand, and on the other hand, the differences in surface morphology, chemical reactivity and the bonding ability with the matrix of the micropored aggregates, compared to conventional aggregates, may offer new possibilities for performance improvement and optimisation.

In addition to using micropored aggregates, it is also worth to undertake efforts to make a micropored matrix by using precursors, which can be decomposed or burned out. As known, micronized hollow powders with sizes in microns have been developed, breaking the normal understanding on the scale of traditional hollow spheres. Exciting and encouraging results may be obtained by using such hollow micro-powders in castables and insulating coating materials.

Moreover, introducing suitable surfactant additives in refractories to improve the pore size distribution can be another way to achieve high performance. It was tried using an organic based pore-size modifying agent made by an Italian company in a MgO–C brick. The portion of big pores in the brick has been reduced without changing its manufacturing parameters, leading to enhanced HMOR and thermal shock resistance. Meanwhile it has been shown that it is also beneficial to reducing thermal conductivity at high temperatures. The microstructure comparison is shown in Fig. 12 at a same magnification.

Such pore modifying additives have also been applied successfully in alumina-spinel



(a) Hot metal ladle brick (b) A sliding plate system

Fig. 13 Physical combinations for cost reduction

castables to modify their flow behaviour, reduce bleeding, improve hot strength and thermal shock resistance.

3.4 Combination/assemblage effect

Unlike ceramic and glass materials, which are homogeneous, most refractories are heterogeneous, composed of two or more matters to give a full play of the each part and avoid certain weaknesses. Looking for a better combination or assemblage of matters is another way to achieve high performance for refractories. In practical uses to fit specific working condition, refractories usually are serviced as a system consisting of multiple materials with their different roles, rather than a single product. This reality makes it possible to achieve high cost-effectiveness of an entire system by optimising duty-combination of the applicable refractories.

3.4.1 Chemical combination

From the view point of the coexistence of phase balance, although a refractory is, in most cases, a heterogeneous multiple phase material. This does not mean that the more, the better – usually 2 or 3 phases. A too high multiple phase approach leads to a reduced thermodynamic stability of the whole system and consequently the designated system may likely be out of control of the expected performance.

According to the role and proportion of each phase, there are usually two types. A binary system consisting of a main crystalline phase and a binding phase, or a multiple complex system consisting of a main crystalline phase, a secondary crystalline phase and a binding phase. In each case the character of the binding phase is the key factor affecting the service performance of the product. Therefore binding systems with high purification, good stabilization and high performance have been attracted endeavours for high performance of refractories, in particular those approaches to a better binding phase at lower cost.

Typical examples are oxide–non-oxide composited refractories. The non-oxides in such a system are not recommended to be introduced by pre-synthesized materials. This is costly on the one hand, and on the other, no bonding role is played. In comparison, enhanced bonding by non-oxide phases like SiC, Si_3N_4, Si_2N_2O, SiAlON, Al_4C_3, AlN etc. can be obtained by incorporation of metallic materials such as Si, Al, Zn, Mg etc., to react with carbonaceous and other reaction components like Al_2O_3 and SiO_2, in controlled atmosphere (e.g. reducing or nitrogen atmosphere).

This conforms also to the aforementioned in situ refractory concept. More possibilities in this aspect are worth of being explored along this line of thought. For instance, Zhang Mengmeng et al. [15] prepared ZrO_2-non-oxide powders through carbothermal reduction and nitridation technology, using zircon and carbon as starting materials. It was found beneficial to improve thermal shock resistance and oxidation resistance when added in a sliding plate mix in Al_2O_3–C system.

3.4.2 Physical combination

Duty combination of different materials, as a simple and effective approach to high cost-effectiveness for a refractory system, deserves to be well explored and practiced. Some physical combination practices have already been carried out for the purpose of cost reduction.

As shown in Fig. 13, lower grade materials can be used for back lining or some less critical areas, considering a gradient situation in the refractories in use, which can be referred to as simple combination system. Physical combination of different materials can be applied in many shaped and unshaped refractories, such as unfired sliding plates in an Al_2O_3–(ZrO_2)–C system, MgO–C, MgO–Al_2O_3–C and Al_2O_3–MgO–C bricks for working linings of steel ladles, Al_2O_3–SiC–C bricks for hot metal ladles and torpedo cars, Al_2O_3–SiO_2–SiC and basic bricks for cement kilns, and pre-cast shapes for roofs, side walls, anchors, burners, etc. for various industrial furnaces.

Although such an approach is believed to be helpful in the cost-effectiveness improvement, its acceptance remains presently to be limited, as end users tend to have some concerns.

Since recent years, physically assembled refractories have been developed rapidly due to their improved performance-to-cost effectiveness. More attentions have been paid to achieving higher P/C effectiveness by increasing the performance value of a targeted refractories system through physical assemblage, instead of just reducing the cost. Physical assemblage is not just simply for cost reduction, but increasingly turns into duty assemblage, and is even expected to provide effective solutions to some technical problems (e.g. reducing heat loss of

Fig. 14 Multi-layer assembled bricks for rotary cement kilns

refractory lining). The acceptance by end users is therefore bound to be increased.

Fig. 14 shows multi-layer assembled bricks with reduced thermal conductivity for rotary cement kilns. They have been carefully designed and prepared – the dark colour part serving for hot side, while the light colour part for the permanent layer. The two parts are physically assembled together, using a saw tooth biting on the interface for good a stability of the combination. Fibre modules can also be assembled by embedding partially in the permanent layer, which can avoid otherwise big pressure on the fibre module during service, while reduce thermal conductivity of the whole lining. Such functional assembled refractories should certainly have a higher added value for its high technology level and fine work.

Another representative example of duty assemblage is the inner design of rotary kiln for iron ore sintering, as shown in Fig. 15. The entire cylinder is installed by a combination of pre-cast shapes and on-site cast castables with a column of intervals. Radial-wise, the pre-cast shapes are manufactured with a combination of lightweight castables as outer layer and dense castables as working layer.

For the on-site casting space, lightweight castables and dense castables are accordingly cast respectively. This rationally designed whole lining system has led to satisfactory service performance. In addition to a good thermal insulation effect, such systems have achieved an extended service life, compared to full brick linings.

All in all, physical assembled refractories have big potentials to be explored and exploited in terms of technology and economic benefit, although careful control of the preparation and installation is required. Gradient feature exists in the use of refractories in most cases, physical assembling of refractories may fit the conditions in different zones better and reach a good balance in service performance. The challenge is to make efforts to work out a high performance programme with competitive cost-effectiveness, taking into consideration such unbalanced dynamic conditions.

3.5 Reuse of used refractories

Like the combination/assemblage concept, reuse of recycled refractories is also an effective way to obtain good cost effectiveness, with the target of less, equal or even better service performance, while significantly reducing the costs. By so far, the recycling of used refractories has been centred on consuming type refractories and some high-end refractories. Under the circumstances of low profit or even deficit for many refractory enterprises, more attention is paid to the application of renewable materials, truly embodying the principle of making the best use of everything.

Are there technical ways to explore to reduce the costs while improving the performance in recycling the used refractories? The answer is yes. Whether good performance can be obtained by adding appropriate amount of recycled refractories is determined by the processing and properties control. On the basis of good classification, sorting, impurity removal and processing, the following technical supports are needed to achieve high performance when using recycled materials:

- purifying technique;
- stability control of the used refractories;
- interface control during the processing of the used refractories;
- rigidity-flexibility control.

Taking a ladle lining for example, the service life of side wall bricks produced by using dominantly renewable refractories can reach more than 150 heats, equivalent to the counterparts using only fresh raw materials. Benefit to thermal shock resistance of magnesia-carbon brick for slag line can be obtained by adding appropriate amount of recycled magnesia-carbon bricks.

3.6 Application of scientific methods

Besides the technical approaches mentioned above, application of scientific

Fig. 15 Physical assemblage of rotary kiln lining for iron ore sintering

methods or means can also provide more efficient, accurate and effective ways to optimise the performance of refractories. The following are worth to be mentioned.

3.6.1 Effective simulation tests

In research work it is often difficult to determine which property or parameter is the most critical or the most relevant to service performance. If more pertinent tests to simulate real working conditions can be worked and carried out, property optimisation will have benefits.

3.6.2 Application of big data

During the whole process from design, raw material preparation, production and in-plant application of refractories, a lot of data or information corresponding to each link can be collected. Such data or information, no matter positive or negative, is accumulated along with every production activity. In many cases, they serve only as a reference to products' quality control without further sorting and analysing in-depth. Therefore, some valuable information is not explored and utilized, which may otherwise be helpful to quickly determine the dominating factor(s) and timely adjusted parameter(s) by scientific analysis on the existing data, when the service behaviour of a product fluctuates.

3.6.3 Application of computer-aided simulation

Just like a person may have good or bad temper, refractories seem also to have certain temper. Those being prone to spalling or fracturing can be regarded as the one having a bad temper, while those with relatively mild temper can refer to the refractories with less possibility of collapse during service. The stress distribution state inside a refractory is believed to correspond to such sentimental description.

There is no lack of such experience in real life, i.e., service behaviours and lives of refractory products for the same application may have a big difference, nevertheless their composition and properties are quite identical, like magnesia-carbon bricks, ladle purging plugs, sliding plates, functional refractories for CC of steel, etc. The normal routine tested properties in a lab seem hardly to be able to reflect differences in service performance.

By means of computer aid simulation, the adaptability of refractories' properties and their lining structure to specific working conditions may be well correlated by simulating temperature fields and stress status in related refractories. In his way key factors may likely be clarified.

4 Concluding remarks

High performance of refractories must gear to practical situations and requirements with as much as possible high performance-to-cost ratio. The approaches to improved properties and service performances under the premise of possibly low cost are worthy of more efforts.

Such approaches as nanotechnology, in situ effect, raw material and pore engineering, combination/assemblage effect, reuse of recycled materials and so on deserve to be actively tried and practiced, considering they possess good theoretical feasibility and technological basis to achieve high performance and high cost-effectiveness.

Attaching more importance to learning from and adopting useful ideas and approaches of other disciplines and actively practicing the above mentioned approaches are believed to bring about more vitality to R&D, manufacture and application of modern refractories.

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