CONCEPTS OF ENGINEERED REFRACTORY AGGREGATES AND SOME PRACTICES IN CASTABLES

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ABSTRACT

Refractories are increasingly becoming sophisticated with carefully designed compositions and microstructures, for which refractories engineering is of a great necessity. Most past efforts in this aspect were focused on matrix portion. Today, attention has turned to the necessity to engineer aggregates too, as they constitute dominant part in most of refractory products. Concepts of aggregates engineering were put forwarded and possible engineered structures by purposely designed and controlled shape, surface feature, chemical and phase compositions and their distribution as well as microstructure inside and on aggregate surface were suggested. Some newly developed engineered aggregates including spherical bauxite grog, mullite based hollow balls, forsterite based porous spherical aggregates and micro-pored sintered alumina and their adoptions in light weight and dense castables were introduced. Advantages and benefits from using them can be highlighted by higher strength, increased flowability, reduced thermal conductivity, enhanced thermal shock resistance and improved size processing effectiveness, compared with conventional counterparts.

KEY WORDS: Aggregate engineering, Spherical aggregate, Castable

INTRODUCTION

Refractories are nowadays not just of fired mineral ores, nor their simple mixtures, but more and more sophisticated products with carefully designed compositions and deliberately “built” microstructures, for which refractories engineering is of a great necessity. Most past efforts in refractories engineering were focused on the matrix portion. Today, attention has turned to the necessity to engineer aggregates too. Because aggregates constitute a dominant part in most, if not all, of refractories, engineering of aggregates should bring new breakthroughs in refractories technologies.

Aggregates engineering refers to a working system, including design, customization, properties testing, performance evaluation in refractory products and adoption of them for desired purposes. Design and customization of engineered aggregates are implemented by specially designed and controlled shape, surface features, chemical and phase compositions and their distribution as well as microstructures inside and on the aggregate surface.

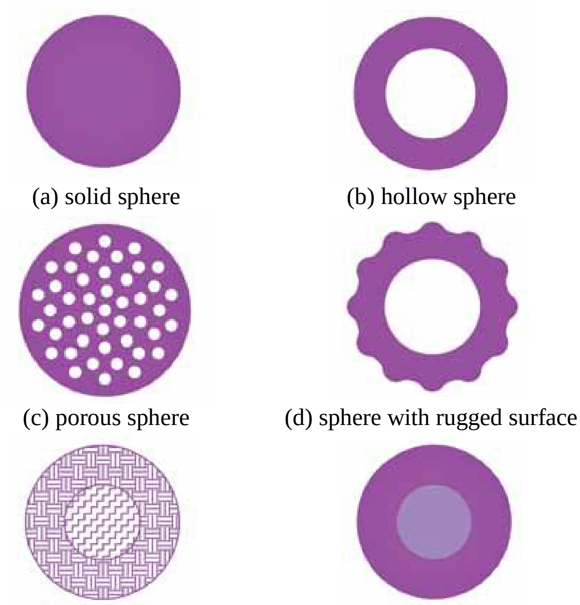
In this paper, concepts of aggregates engineering were put forwarded and possible engineered structures were suggested. Some newly developed engineered aggregates and their uses in light weight and dense castables were introduced to prove expected advantages and benefits brought by adopting them.

CONCEPTS OF AGGREGATES ENGINEERING

R & D have led to many improvements in the matrix constitution of refractories, especially monolithics. To fully optimize refractories design, aggregates, as dominant part in most of refractory products, must be improved too. Conventional crushed aggregates are irregular in shape and many with sharp vertices, resulting in some negative effects. By engineering aggregates, it is possible to optimize refractories designs for multiple improvements in terms of flowability, pumpability, higher thermal shock resistance, reduced wear, better thermal insulation, etc [1, 2].

Several engineered structures for refractory aggregates have been proposed[2], with spherical aggregates as the main direction of efforts, which are schematically illustrated by Fig. 1. It is believed that using spherical aggregates can bring about following benefits.

- Reducing water demand and minimizing dilatancy to facilitate flowing and pumping
- Improving filling and bonding between aggregate and matrix
- Reducing wear of mixing and installation facilities
- Reducing fluctuation in particle size distribution
- Improving size processing effectiveness and reducing some waste during crushing
- Enabling near-impermeable structures, either heavy duty or lightweight



(a) solid sphere (b) hollow sphere
(c) porous sphere (d) sphere with rugged surface
(e) core–shell sphere with different texture between core and shell (f) core– shell sphere with different chemical composition between core and shell

Fig. 1: Schematic illustrations of proposed spherical refractory aggregates

Other features and advantages that new engineered aggregates may bring about were predicted and discussed in references [2, 3]. Some practices of using newly developed engineered aggregates in castables are introduced below.

PRACTICES OF USING ENGINEERED AGGREGATES IN CASTABLES

●Spherical bauxite grog

In a bauxite based LC castable, spherical bauxite grog (made by powder agglomeration and then sintering) is used to uniformly replace traditional irregular bauxite aggregates in sizes of 8-5mm, 5-3mm, 3-1mm and 1-0mm and properties of the castables were compared.

Fig. 2 compares the outlook of the two aggregates with equivalent grade, Al_2O_3 ~68% for irregular vs. ~65% for spherical, SiO_2 ~27% vs. ~29%; BD 2.80 g/cm^3 vs. 2.75 g/cm^3.

(a) Spherical

(b) Irregular shape

Fig. 2: Bauxite grog aggregates with different shape

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The following has been achieved: 1) Adding spherical aggregates leads to significantly improved flowability and reduced water demand, see Fig. 3; 2) Compactness of the castable can be enhanced, as evidenced by reduced apparent porosity shown in Fig. 4; and 3) Cold crushing strength of the castable increases with the addition of the spherical aggregate, see Fig. 5.

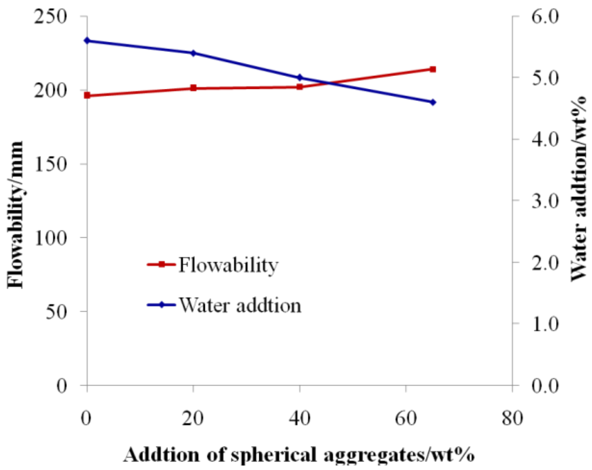

Fig. 3: Influence of spherical bauxite aggregate addition on vibration flow-value of the castables

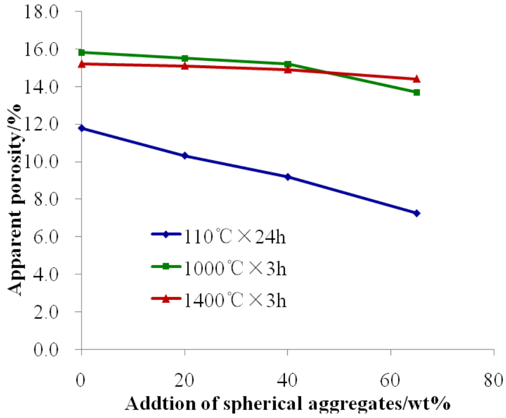

Fig. 4: Influence of spherical bauxite aggregate addition on apparent porosity of the castables

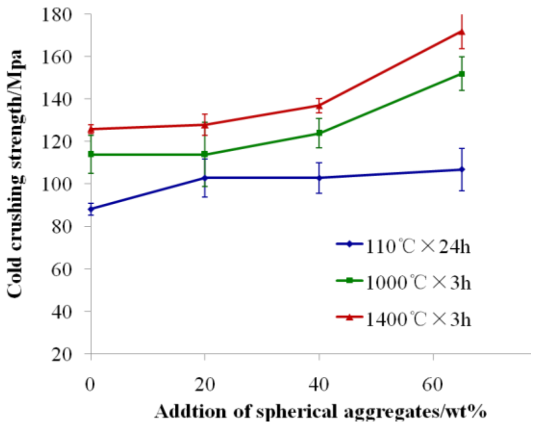

Fig. 5: Influence of spherical bauxite aggregate addition on CCS of the castables

●Mullite based hollow balls

Mullite based hollow balls with properties shown in Tab. 1 and outlook shown in Fig. 6 have been used in lightweight (LW) castables.

Tab. 1: Properties of mullite based hollow balls

Al_2O_3	55 - 60 %
K_2O+Na_2O	≤1.0%
Packing density	0.68 - 0.76 g/cm^3
Refractoriness	≥1770℃
Cylinder compressive strength	2.2 - 2.8 MPa
Diametre	3 - 8mm
Shell thickness	0.5 - 3 mm

Fig. 6: Mullite based hollow balls sized 3-5mm

For LW castables using hollow ball aggregates, as shown in Fig. 7, water addition can be reduced to a great extent, because the added water does not enter into the aggregates, which is in favor of high strength and good volumetric stability. Cold strength and volumetric stability of the LW castable with a BD around 1.8g/cm^3, can be significantly improved by appropriate addition of andalusite. The maximum CCS of the castable after heating at 1400℃ can reach as high as 70MPa[4].

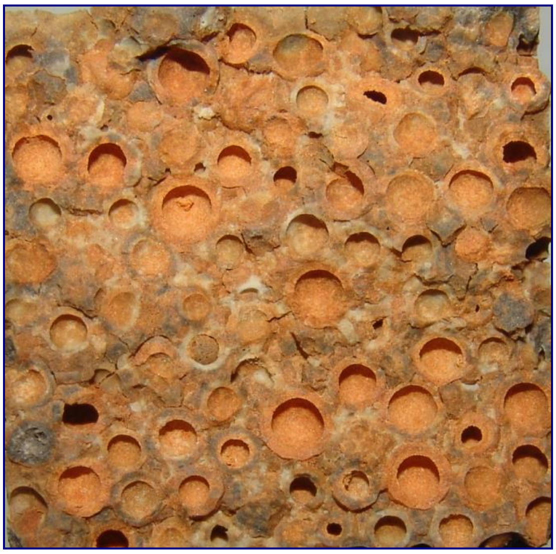

Fig. 7: Section of the LW castable using mullite based hollow balls as aggregate

●Forsterite based porous spheres

High temperature properties of naturally occurred olive ore are unsatisfactory, due to high ferric oxide content, which is not conducive to tough working conditions. Considering the resources of magnesia and silica with relatively high purity is rather rich and relatively cheap, it is promising to develop semi-basic LW castables using synthesized high purity forsterite as aggregates. Synthesized porous forsterite balls with MgO 58-60%, SiO_2 38-40% and BD about 1.4g/cm^3 has thus been developed by using magnesite, silica fines as starting materials. The conversion ratio of M_2S is as high as 95% after firing at appropriate high temperature, as confirmed by XRD shown in Fig. 8.

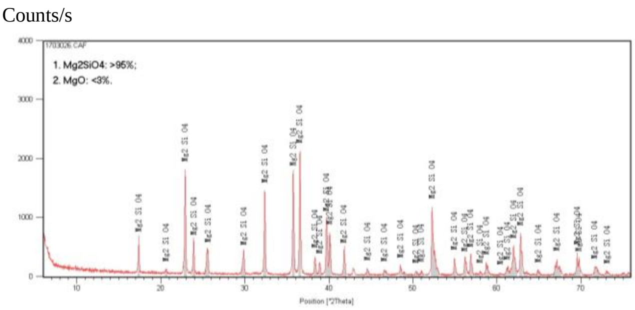

Fig. 8: XRD pattern of the synthesized forsterite.

Fig. 9 shows the appearance of the forsterite balls and Fig. 10 presents their porous structure observed by SEM.

Reduced water demand and improved strength by replacing the crushed irregular forsterite aggregates with an identical BD with the ball shaped counterparts in $MgO-SiO_2$ castables using $MgO-SiO_2-H_2O$ binding have been achieved.

Fig. 9: Synthesized porous forsterite balls with sizes 2-5mm

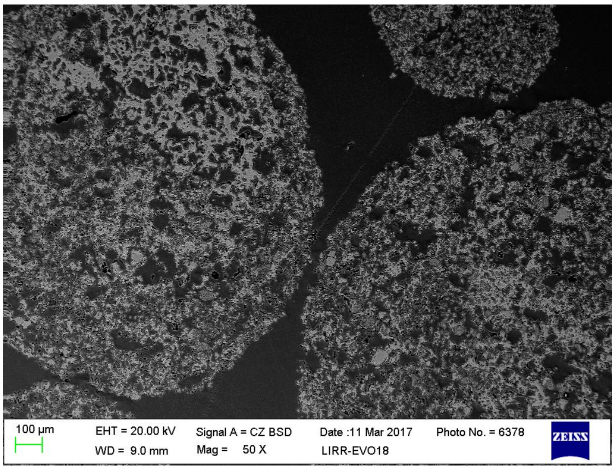

Fig. 10: Section of the porous forsterite balls by SEM observation

●Micro-pored sintered alumina

Making refractory linings slightly lighter by using appropriately micro-pored sintered materials is meaningful in reducing heat loss, releasing structural stress and improving thermal shock resistance, while maintaining other important properties satisfactory. Such a kind of material structure is contributive to achieving higher durability while lower material consumption and heat loss. More details to this connection can be found in [5, 6].

With an innovative special technology, micro-pored sintered alumina (MSA) has been developed, featured by reduced BD and significantly increased closed pores with diameters in micron or sub-microns, leading to reduced thermal conductivity, while other properties remain equivalent, compared to conventional sintered alumina.

An industrially produced MSA with BD of 3.42 g/cm^3 was used to equally replace a conventional sintered alumina with BD of 3.55 g/cm^3 as aggregates with top size 10mm in an Al_2O_3-spinel castable, up to 60% at an interval of 12%, coded as QA0, QA1 up to QA5, and properties were compared. Slightly reduced BD while almost unchanged AP is achieved by using MSA. No negative influence from MSA on CMOR and CCS is found, instead they are even enhanced after firing at 1550℃. MSA addition showed little negative effect on slag resistance by crucible test, as compared in Fig. 11. Using MSA as aggregates in the castables leads to significantly improved thermal shock resistance, see Fig. 12.

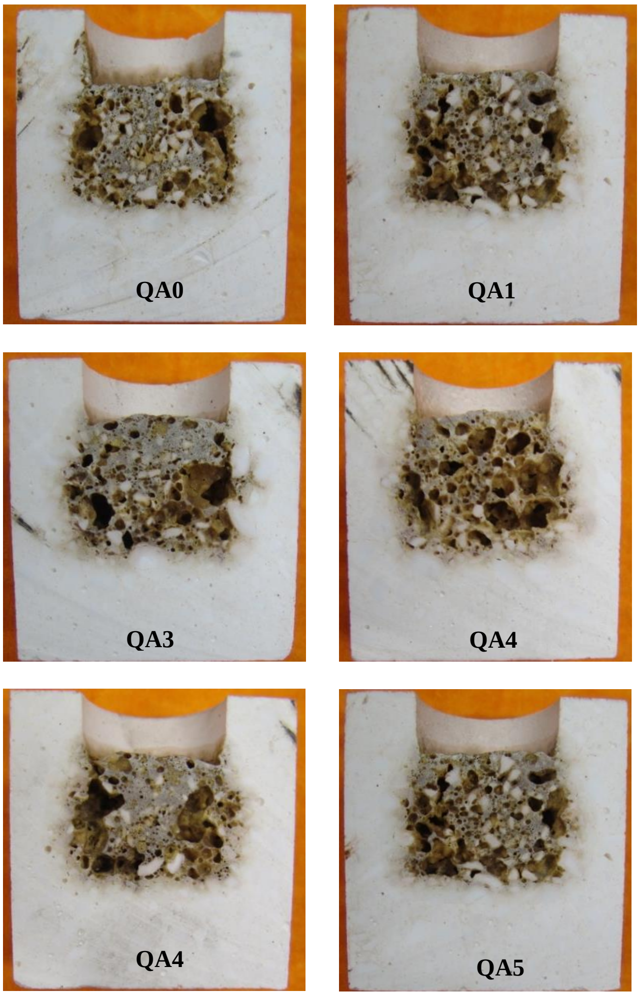

Fig. 11: Slag resistance comparison by crucible slag test at 1550 ℃ for 3h, using an in-plant steelmaking slag

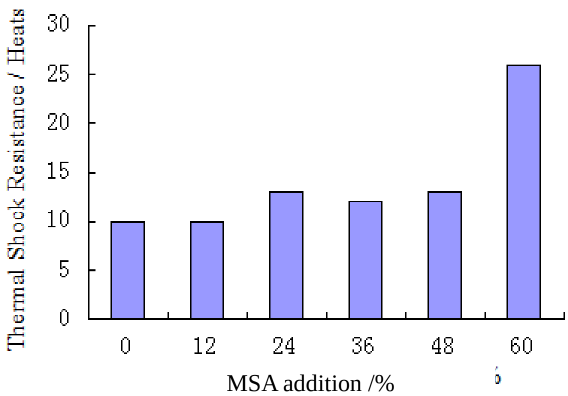

Fig. 12: Thermal shock resistance vs. MSA addition, by 1100 ℃ to water quenching test

For dense refractories, aggregates have traditionally been required to be as dense as possible, no matter sintered or fused. For high strength and abrasion resistance purposes, it is with no doubt necessary. However, the strength of a refractory product does not depend only on the aggregate, but more on the bonding between aggregate and matrix, the former being, in many cases, over-capable in strength, in particular where there is no direct contact with molten iron or steel or strong abrasion by furnace media and atmosphere. The above presented results from this work support this viewpoint.

CONCLUDING REMARKS

Engineered aggregates in terms of specific shape, composition and microstructure have potentials to improve properties and enable features of refractories. Compared to irregular aggregates, spherical aggregates impart castables with better flowability and other improved properties. Spherical aggregates can easily be made light-weighted, either hollow or micro-porous, and can facilitate making high performance lightweight castables. Dense aggregates with slightly reduced BD or increased porosity, featured by micro-pore and closed pore microstructure, are recently developed and applied in castables with positive results. This is promising to implement the concept of lower consumption by making refractories properly lighter. R & D and application of engineered aggregates will offer new approaches to the optimization in properties and performance/cost effectiveness.

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