Tabular Alumina for High Purity Corundum Brick

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ABSTRACT

High purity corundum brick with Al_2O_3 content above 99% is studied based on tabular alumina and white fused alumina (WFA) as single aggregate and the combination of both. In comparison with Tabular alumina, WFA aggregate has relatively higher SiO_2 content of above 0.10% and shows fluctuation on soda content. WFA also has a high open porosity of 8.8%, which very often exists in the form of single large pore or in the form of agglomeration of pores rather than the small closed and evenly distributed pores in tabular alumina. Bricks with different ratio of tabular alumina and WFA have been tested for firing shrinkage, bulk density and apparent porosity, cold and hot strength, thermal shock resistance, and abrasion resistance. Also slag tests with a coal gasifier slag and an oil cracking slag have been conducted. The results from this evaluation conclude that tabular alumina brick outperforms WFA bricks and importantly gives more balanced performance.

INTRODUCTION

High purity corundum brick is widely used as refractory lining for oil cracking unit, coal gasifier, carbon black furnaces, black liquor gasification and other industrial furnaces. This is attributable to the outstanding performance of corundum brick on chemical corrosion resistance, mechanical abrasion resistance and thermomechanical properties like high temperature strength, refractoriness under load and creep resistance, even in environments with corrosive gas or liquid and with high pressure.

Synthetic alumina based aggregates like white fused alumina and tabular alumina are the two main aggregates available for high purity corundum brick. They are selected due to low impurity content (e.g. SiO_2), high bulk density and thermomechanical properties, which enables corundum bricks that meet the requirements on thermal, chemical and structural attacks [1] which gasifiers and other furnaces apply in operation.

The different processes for WFA and tabular alumina production (fusion vs. sinter) certainly create differences between the aggregate, which also have an impact on the properties and performance of the corundum brick. Tabular alumina is well received and extensively used in the refractories for steelmaking such as slide gate plate, Al_2O_3-MgO-C brick, castables and pre-cast shapes. However, for a long period of time, WFA is very commonly used as the aggregate for high purity corundum brick to non-steel applications like gasifier and other industrial furnaces. It is often claimed that WFA aggregate has higher bulk density which consequently increases the density of fired brick and the corrosion resistance which could enhance the overall performance. However these perceptions should be investigated by an extensive evaluation.

This work is designed to evaluate in a comprehensive way the differences on performance of tabular alumina and white fused alumina in respect to aggregate itself and brick properties in order to understand these differences and provide appropriate application guideline for high purity corundum brick.

EXPERIMENTAL

1. Raw material

Almatis global tabular alumina product T60/64 and a common commercial Chinese WFA grade are selected as the aggregate and fine. In the matrix, Almatis' calcined alumina CT800FG is also used. Sulphite pulp liquor is used as temporary binder for corundum brick making.

2. Brick formulation

Five recipes are used in this evaluation. As per the tabular alumina content in aggregate, the formula is named as T100, T75, T50, T25 and T0 and the numbers stand for tabular alumina content in respective brick. Table 1 gives the details with bold highlighted for tabular alumina.

Table 1 Brick formulation

	T100	**T75**	**T50**	**T25**	**T0**
Aggregate, %, (**Tabular** or WFA)					
1-3mm	**42**	**19.5**+22.5	42	42	40
0.5-1mm	**15**	**15**	**12**+3	15	15
0-0.5mm	**10**	**10**	**10**	10	10
Fine, %, (**Tab -325 mesh** or WFA -240 mesh)	**23**	**23**	**23**	**23**	25
Calcined alumina CT800FG, %	10	10	10	10	10
Sulphite pulp liquor, %	+3	+3	+3	+3	+3
Amount of **Tab**, %	**100**	**75**	**50**	**25**	**0**

3. Brick Making and Test Specimen Preparation

Raw materials are well mixed with binder in a high speed mixer. After aging for eight hours, the wet mixes are pressed by a frictional press of 6300kN into Chinese standard brick with dimension of 230mmx115mmx65mm. After drying, the bricks are fired in high temperature liquid petrol gas kiln at 1750°C for 8 hours.

Specimens for each test are prepared from fired bricks and tested according to Chinese national standard except abrasion resistance test, which is measured according to ASTM C704. Thermal shock resistance is conducted by water quenching method per Chinese national standard at temperature of 1300°C to room temperature. Creep resistance is tested at 1500°C and under the load of 0.2MPa for 25 hours.

Slag resistance of bricks is tested in a rotary kiln lined with the bricks to be tested. Two different types of slag are used for these tests. Their chemical composition is shown in table 2. The test is conducted at 1550-1600°C and lasts for 18 hours. Fresh slag is added into the kiln every 30 minutes to maintain the corrosiveness of slag during the duration of test.

Table 2 Chemical composition of slag for corrosion test

Wt.%	Coal gasifier slag	Oil cracking slag
SiO_2	40.8	24.5
Al_2O_3	23.6	31.5
Fe_2O_3	5.1	1.0
TiO_2	1.1	2.0
CaO	20.9	39.0
MgO	3.8	0.5
K_2O+Na_2O	1.1	/
NiO	/	2.0
V_2O_5	/	1.1

RESULTS AND DISCUSSIONS

1. Chemical composition and physical properties of tabular alumina and WFA

Chemical composition as shown in table 3 demonstrates that WFA has higher SiO_2 content of 0.1% when compared to tabular alumina. Soda content of WFA is 0.35% on average, but some fluctuation of soda level has been observed even between samples form the same batch. Tabular alumina has high stability in respect of chemical composition.

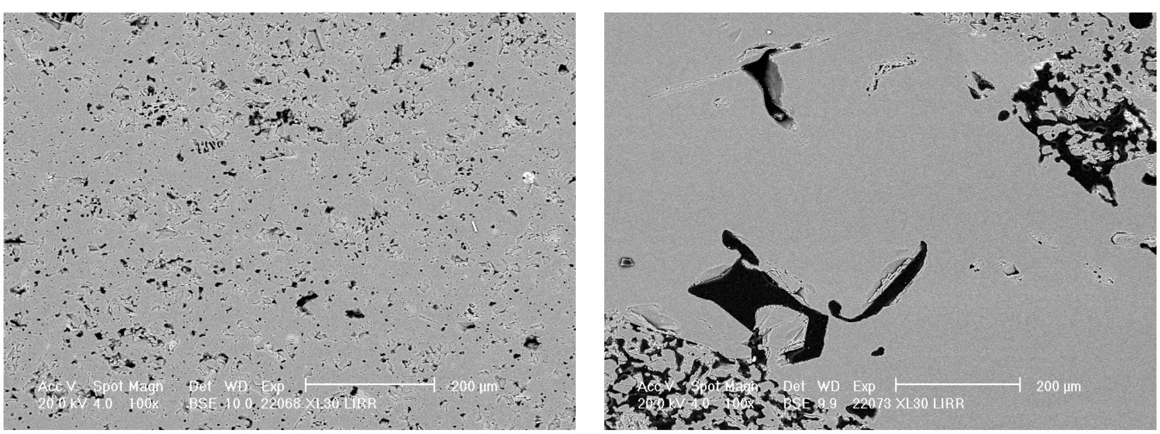
WFA has slightly lower bulk density and obviously higher open porosity of 8.8%, which is visually detectable as shown in figure 1. Tabular alumina has no visual open pores and low open porosity of 2.9% only. Microstructure per Microscope as shown by figure 2 reveals that tabular alumina has only small pores, either closed or interfacial, in the size of below 10μm and these pore are evenly distributed into whole structure. For WFA, the pores are larger which can be in the scale of mm and very often the pores are in the form of agglomeration.

Table 3 Chemical composition and physical properties of tabular alumina and WFA

	Tabular alumina	WFA
Al_2O_3, %	99.5	99.36
Na_2O, %	0.35	0.35
SiO_2, %	0.04	0.10
Fe (magnetic), %	0.002	/
Apparent porosity, %	2.9	8.8
BSG, g/cm^3	3.56	3.51

Tabular alumina WFA

Figure 1 Visual appearance of tabular alumina and white fused alumina (WFA)



Tabular alumina WFA

Figure 2 Microstructure of tabular alumina and WFA

2. Bulk density, apparent porosity and shrinkage of bricks after firing

After fired at 1750°C, pure tabular alumina brick shows lowest apparent porosity of 13.8% and also highest bulk density up to 3.26g/cm^3 as indicated in Figure 3. The more the tabular alumina contains in brick, the lower the apparent porosity and the higher the bulk density. Pure WFA brick gives highest apparent porosity and lowest bulk density, which is contradictory to normal perception. In consideration together with high shrinkage of tabular alumina brick, it is believed that the better thermal reactivity of tabular alumina is beneficial to the densification on sinter [2], which might enabled pure tabular alumina based brick to be fully sintered under relatively lower temperature for cost-effective production.

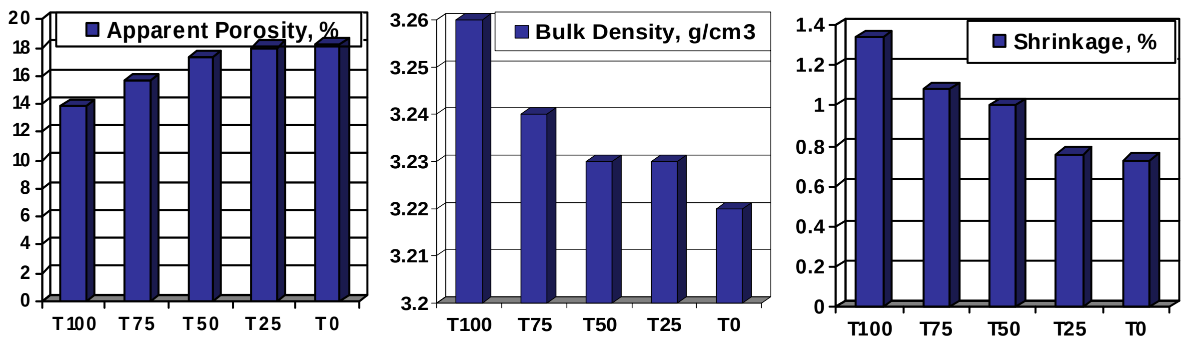
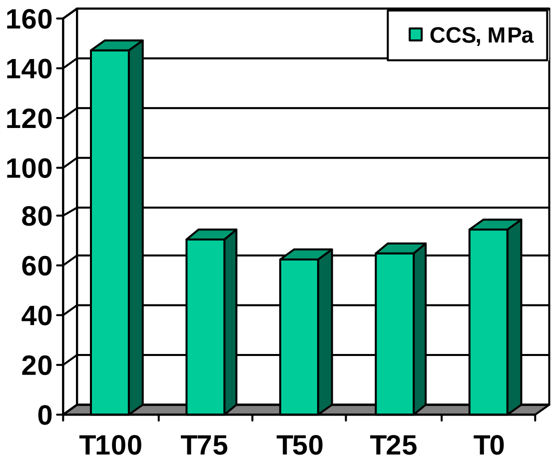


Figure 3 Apparent porosity, bulk density and shrinkage of fired corundum bricks

3. Thermo-mechanical properties

Cold crushing strength (CCS) and cold (CMoR) as well as hot modulus of rupture (HMoR) at 1400°C of fired corundum bricks are shown in figure 4 and 5. Pure tabular alumina brick has outstanding CCS of 147MPa, which doubles the strength of pure WFA based brick. Also for CMoR and HMoR, the strength of tabular brick is higher. The lowest strength of pure WFA based brick is not only related to WFA aggregate itself but also related to the ceramic bonding of brick after firing. As indicated in Figure 6, there are interfacial gaps between aggregate and matrix in WFA brick, which contribute to the lower fired strength.



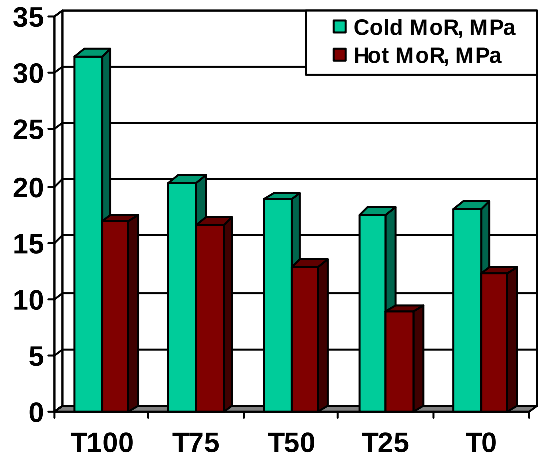


Figure 4 Cold crushing strength of bricks

Figure 5 Cold and hot MoR of bricks

Results from abrasion resistance test are shown in Figure 7. It shows that pure tabular alumina brick performs best with only 4.4cm^3 on material loss, which is only half of pure WFA brick. Better ceramic bonding and naturally-born toughness of tabular alumina encourages this outstanding performance. The co-use of tabular alumina and WFA as coarse aggregates is not in favour of better abrasion resistance.

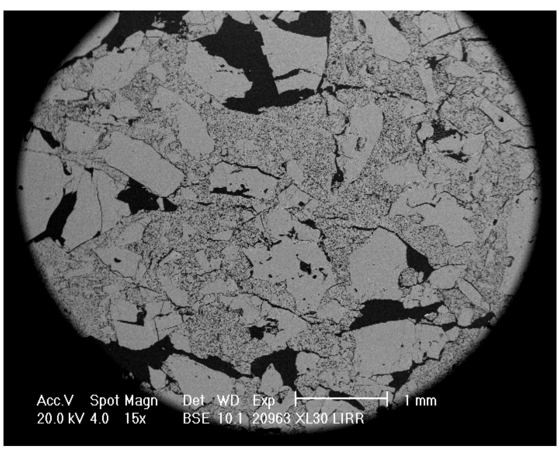


Figure 6 Microstructure of pure WFA brick showing interfacial gaps between WFA grains and matrix

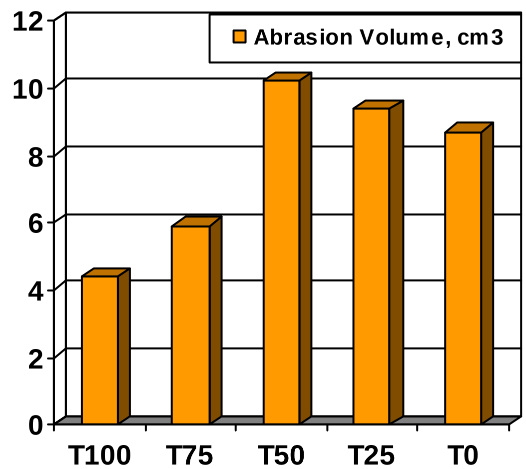


Figure 7 Abrasion resistance of bricks (ASTM C704)

As shown in figure 8, tabular alumina containing bricks show better results from 5 heats up to 7 heats. Such performance is generally considered as acceptable under such harsh test condition. The co-use of tabular alumina and WFA could benefit thermal shock resistance, possibly due to expansion miss-match between tabular alumina and WFA aggregates. However, this method is so severe that it is not perceived as an ideal way to verify the difference between similar bricks.

The creep behaviour of the bricks at 1500°C after 10, 15, 20 and 25 hours is shown in figure 9. The results demonstrate that pure tabular alumina and pure WFA bricks perform better than the bricks composed of tabular alumina and WFA. Here, blends of the aggregates do not improve the brick behaviour, which is opposite to the thermal shock resistance. Different expansion of tabular alumina and WFA aggregates may contribute to the slightly higher deformation under load.

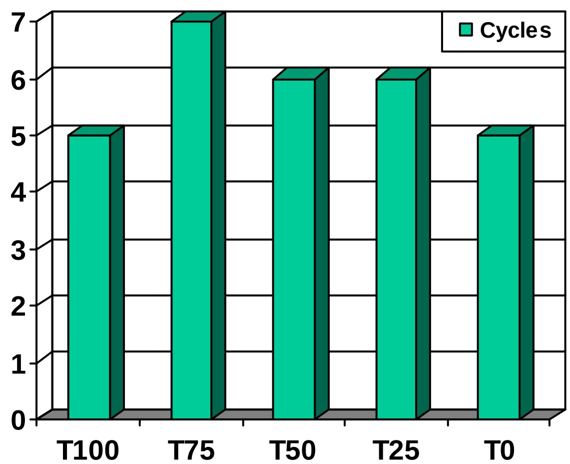


Figure 8 Thermal shock resistance of bricks (1300°C – water quenching)

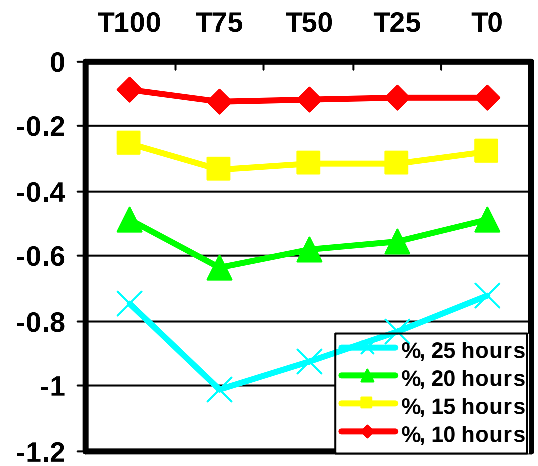
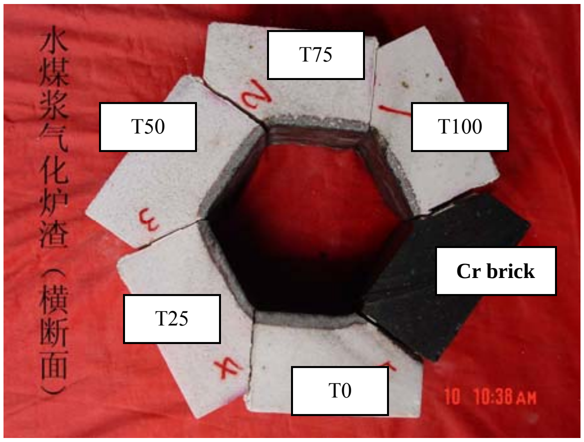


Figure 9 Creep resistance of bricks at 1500°C

4. Slag resistance

Figure 10 shows the bricks after corrosion test against coal gasifier slag. It clearly demonstrates that slag penetration in this test is more severe than erosion. Pure tabular alumina brick has the lowest penetration and WFA brick has the highest, as illustrated in figure 11. With the increase of tabular alumina in the bricks, slag penetration resistance is improved accordingly. Lower apparent porosity and higher density and better ceramic bonding of tabular containing bricks is in favour of slag penetration resistance. High Cr_2O_3 brick in this test shows less erosion and less penetration as well.



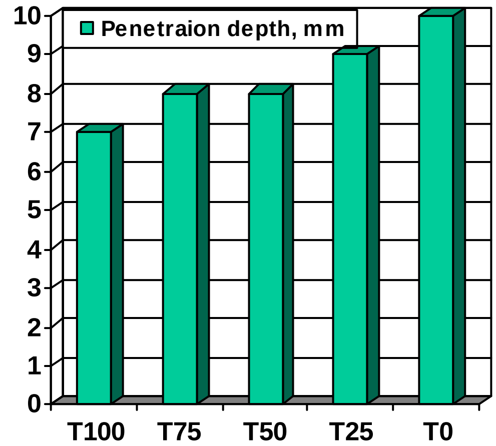
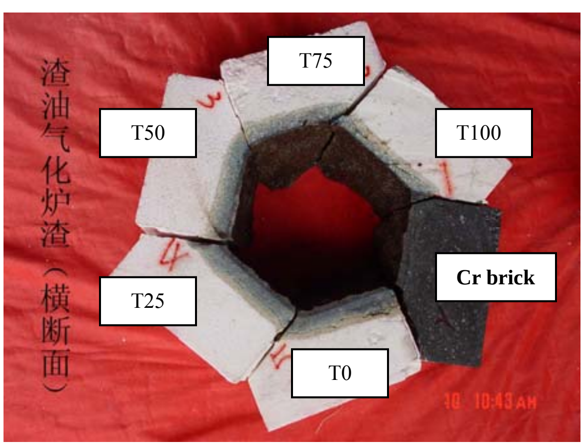


Figure 10 Bricks after coal gasifier slag test

Figure 11 Penetration depth of coal gasifier slag into bricks

In the corrosion test against oil cracking slag, both slag erosion and penetration are severe as shown in figure 12. Among all the bricks, tabular alumina brick has lowest erosion and penetration and increasing tabular alumina content improves the erosion resistance in bricks with aggregate blends as indicated by figure 13. After corrosion test, gehlenite ($Ca_2Al_2SiO_7$), CA_2 ($CaO \cdot 2Al_2O_3$), minor $CaO \cdot V_2O_5$ and glassy phase enriched with NiO and V_2O_5 are observed in the slag and transition zone as shown in figure 14. V_2O_5 and NiO encourage the formation of low temperature melting phase which obviously escalates the slag erosion. In order to determine the slag penetration, SiO_2 content from brick surface towards inside is measured by EDXA in SEM. The results as shown in figure 15 indicate that slag penetration into tabular alumina bricks T100 and T75 stops already in the distance of 12mm from brick surface while pure WFA brick still has a high SiO_2 content even in the depth of 15mm. Tabular alumina improves not only slag erosion but also slag penetration resistance. High Cr_2O_3 brick also has high erosion and penetration resistance against oil cracking slag, which is even slightly better compared to corundum bricks. Pure tabular alumina brick is the most comparable to high Cr_2O_3 brick with regards to slag corrosion resistance and may replace high Cr_2O_3 brick for an environmental-friendly approach [3].



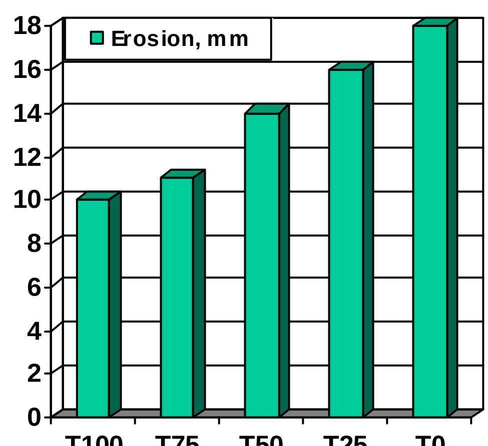


Figure 12 Bricks after oil cracking slag test

Figure 13 Erosion of bricks after oil cracking slag test

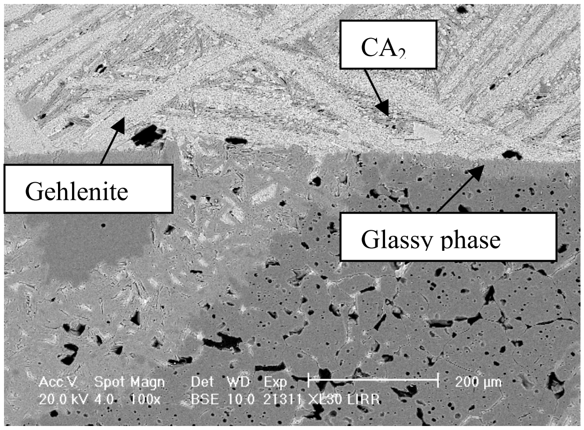


Figure 14 Microstructure of brick T50 after oil cracking slag test

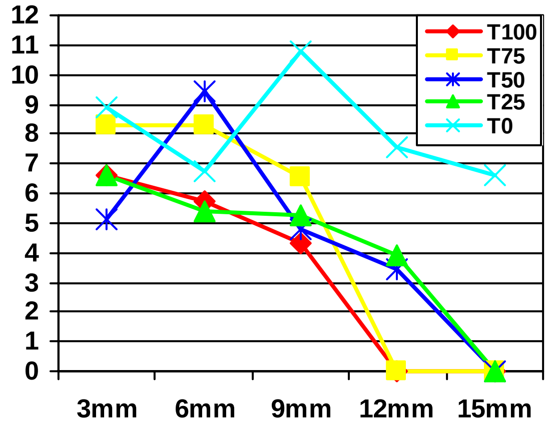


Figure 15 SiO_2 content in bricks at different distance from surface

SUMMARY

Comprehensive study on tabular alumina and WFA for high purity corundum bricks has demonstrated that tabular alumina can generally improve the performance of the bricks and provides more balanced performance which is summarised as follows:

- Tabular alumina containing bricks show higher sintering reactivity during brick production, which results in improved densification;
- Tabular alumina containing bricks have higher bulk density and lower apparent porosity;
- Tabular alumina brick has outstanding cold crushing strength and cold modulus of rupture and also highest hot modulus of rupture at 1500°C;
- Tabular alumina brick has highest abrasion resistance;
- Tabular alumina containing bricks outperform pure WFA based brick on corrosion and infiltration resistance against slag from coal gasifier and oil cracking unit;
- The co-use of tabular alumina and WFA as aggregates can improve thermal shock resistance of corundum bricks;
- Pure tabular alumina and WFA bricks perform better on creep resistance compared to blends of the aggregates.

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