

Al₂O₃-SiO₂ Nano-Bonded Castables Containing a Boron-Based Sintering Additive



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A suitable alternative to reducing the starting sintering temperature of ceramic compositions is based on using small contents of mineralizing compounds that may speed up the reaction rate and/or induce the generation of a transient liquid phase in the resulting microstructure. This work addresses the evaluation of the thermomechanical behaviour (up to 1000 °C) of three vibratable refractory castables, mainly comprising tabular alumina, mullite or fused-silica aggregates and containing a boron-based mineralizing agent and colloidal silica as a binder. Hot modulus of rupture, in situ hot elastic modulus and XRD measurements were carried out in order to characterize the samples' behaviour. Additionally, a complementary analysis based on equilibrium phase diagrams of Al₂O₃-SiO₂, Al₂O₃-B₂O₃ and Al₂O₃-SiO₂-B₂O₃ systems was also performed to explain the interaction of the selected boron-based compound with the different raw materials. The attained results indicated that the selected mineralizing additive led to the generation of a liquid phase at intermediate temperatures (>400 °C), which interacts with the castables' components, resulting in different reaction products. The Al₂O₃/SiO₂ ratio in the formulations' matrix fraction affected these phase transformations. Despite the presence of a liquid phase in the castable structure, the SiO₂-rich compositions did not reduce their mechanical strength at 1000 °C, which is associated with the fact that silica may be incorporated by the liquid, changing its properties (i.e., increasing the liquid viscosity). The designed refractories are suitable options to be used in petrochemical and aluminium production processes.

Introduction

Boron-based additives can be added to refractory systems in order to speed up the in situ reaction between MgO and Al₂O₃, resulting in spinel (MgAl₂O₄) generation at lower temperatures. Due to this important feature, such compounds are also classified as mineralizers, as their incorporation (in reduced amounts) into ceramic compositions can also induce the formation and/or crystallization of other phases at high temperatures [1].

Mineralizers usually act: (i) speeding up the reaction rate in a system, (ii) changing the viscosity and surface tension of the formed liquids (affecting the growth rate and morphology of crystalline compounds), and (iii) reducing the temperature for the generation of a certain phase and also increasing its stability. However, using such additives needs to be optimised especially

in refractory products in order to avoid high amounts of liquid phases at high temperature that may affect their refractoriness [1, 2].

Boron-containing compounds (i.e., B₄C, borosilicates, etc.) are used as antioxidants in MgO-C refractories, as they induce the formation of B₂O₃ and 3MgO·B₂O₃ during the first heating treatment of these compositions. At high temperatures, these latter phases are found as liquids and they act closing the pores and/or coating the carbon surface (halting its oxidation) [3, 4]. Besides that, recent studies have shown that simultaneously adding colloidal binders and a boron-based compound to refractory castables is a suitable route for designing high performance materials for the aluminium and petrochemical industries [5–7]. As reported by Braulio et al. [5], this improved behaviour was based on the gen-

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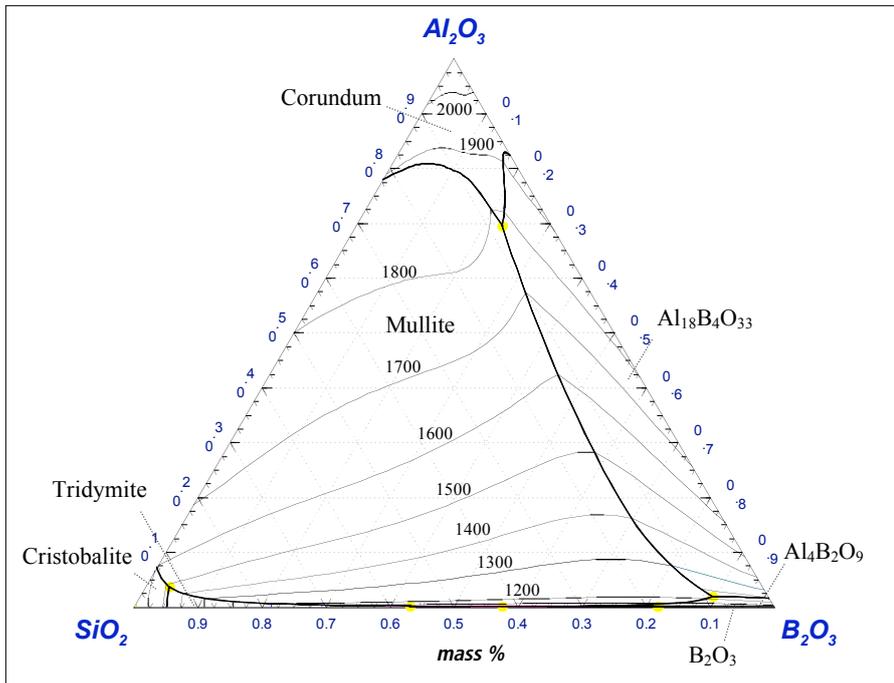


Fig. 1 Liquidus projection of the $\text{Al}_2\text{O}_3\text{-SiO}_2\text{-B}_2\text{O}_3$ system [9]

Tab. 1 Invariant reactions of the $\text{Al}_2\text{O}_3\text{-B}_2\text{O}_3\text{-SiO}_2$ system [9]

Temperature [°C]	Invariant Reactions	Composition (Al_2O_3 / B_2O_3 / SiO_2) [mass-%]
1770	$\text{Al}_2\text{O}_3 + \text{L} \rightarrow \text{Al}_{18}\text{B}_4\text{O}_{33} + \text{mullite}$	69,38 / 22,96 / 7,65
1128	$\text{Al}_{18}\text{B}_4\text{O}_{33} + \text{L} \rightarrow \text{Al}_4\text{B}_2\text{O}_9 + \text{mullite}$	1,84 / 89,6 / 8,57
810	$\text{mullite} + \text{L} \rightarrow \text{Al}_4\text{B}_2\text{O}_9 + \text{SiO}_2$	0,12 / 66,33 / 33,55
438	$\text{L} \rightarrow \text{Al}_4\text{B}_2\text{O}_9 + \text{SiO}_2 + \text{B}_2\text{O}_3$	$0,32 \times 10^{-3}$ / 92,99 / 7,00

eration of a transient liquid in the resulting microstructure, which did not damage the hot mechanical properties of the castables and induced faster sintering and densification of the samples at lower temperatures (800–1200 °C).

Nevertheless, it is still necessary to better explore and understand the phase transformations associated to using borates and borosilicates in refractory systems, considering that B_2O_3 volatilization is expected to take place at high temperatures (>1200 °C). In this context, the $\text{Al}_2\text{O}_3\text{-B}_2\text{O}_3\text{-SiO}_2$ ternary phase equilibrium diagram (Fig. 1) is of fundamental importance from the industrial and technological point of view. Mullite and $\text{Al}_4\text{B}_2\text{O}_9$ can be easily formed by adding minor contents of Al_2O_3 to $\text{B}_2\text{O}_3\text{-SiO}_2$ compositions. Furthermore, mullite solid solution should be the main primary phase for mixtures presenting more than 15 mass-% of silica, whereas $\text{Al}_{18}\text{B}_4\text{O}_{33}$ is expected to be found in ternary compositions

containing a small SiO_2 content (<15 mass-%). Another important aspect is that B_2O_3 may be incorporated into the mullite structure at high temperatures [8]. Tab. 1 shows the four main invariant reactions of the $\text{Al}_2\text{O}_3\text{-B}_2\text{O}_3\text{-SiO}_2$ system [9]. Depending on the selected compositions, refractories with distinct thermomechanical performance should be attained. Aiming to identify the main phase transformations and the interaction of a boron-based compound with different raw materials, this paper evaluates the thermomechanical behaviour (up to 1000 °C) of vibratable castables comprising tabular alumina, mullite or fused silica as aggregates. The selected binding agents consisted of colloidal silica suspensions.

Materials and techniques

Tabular alumina, mullite or fused silica-based refractory castables were designed according to the Alfred particle packing

model ($q = 0,26\text{--}0,24$) [1]. The high alumina and mullite-containing systems comprised 85,5 mass-% of tabular alumina ($d < 6$ mm, Almatiss/DE) or mullite aggregates ($d < 6,73$ mm, CE Minerals/US), respectively. 2 mass-% of Al powder ($d < 45$ μm, Alcoa/BR) and 0,5 mass-% of boron-based compound ($d < 45$ μm, $\text{B}_2\text{O}_3 \sim 53,38$ %, under patent application) were added to these compositions. On the other hand, the silica-based mixture contained 70 mass-% of fused SiO_2 ($d < 4,75$ mm, CE Minerals/US) and 16 mass-% of tabular alumina ($d < 0,2$ mm, Almatiss/DE). In this latter case, according to preliminary tests, 1 mass-% of each sintering additive (Al powder or boron-based compound) was required to improve the densification behaviour of the castable samples.

All compositions were prepared with 10 mass-% of reactive alumina (CL370C, Almatiss/DE) and 2 mass-% of silica fume (MS971D, Elkem/NO). A colloidal silica suspension with 40 mass-% of concentration (Bindzil 1440, Eka Chemicals/SW) was selected as the main binder source for the high-alumina and silica-based castables. In order to attain mixtures with vibratable flowability of roughly 60 %, 7 mass-% and 8,7 mass-% of the colloidal silica suspension was used to prepare the Al_2O_3 and SiO_2 -containing compositions, respectively. Moreover, a higher concentrated colloidal silica suspension (50 mass-% of solids, Bindzil 50/80, Eka Chemicals/SW) was added to the mullite-based castable (13 mass-%).

The refractories were processed in a rheometer especially developed for refractory castable mixing [10]. After that, the mixtures were cast in metallic moulds and the attained prismatic samples (150 mm × 25 mm × 25 mm) were cured at 50 °C for 24 h (without humid control) and dried at 110 °C for another 24 h. Hot modulus of rupture (HMOR) measurements were carried out at 400, 600, 815 and 1000 °C respectively (using samples pre-fired for 5 h at the same testing temperature) in HBTS 422 equipment (3-point bending test, Netzsch/DE) based on ASTM C583-8.

Elastic modulus (E) changes of the castables with temperature were evaluated in order to identify the sintering effect of Al and the boron-based compound. These measure-

ments were carried out in the range between 30–1000 °C (heating and cooling cycles, with a heating rate = 2 °C/min) using the bar resonance technique (ASTM C 1198-91) [11]. After the first thermal treatment up to 1000 °C of the previously dried (110 °C/24 h) castable samples, a second heating and cooling cycle was also performed in order to evaluate whether further changes could still take place and affect the castables' stiffness.

Due to its higher reactivity and aiming to identify the phase transformations in the matrix fraction (particle size <100 µm) of the designed compositions, XRD analyses of the matrix samples fired at 600, 815 and 1000 °C for 5 h were carried out. After firing the materials at the selected temperatures, they were ground below 42 µm. The obtained powders were placed in sample holders and evaluated using Bruker equipment (D8 Focus, CuK_α radiation [$\lambda = 1,5406 \text{ \AA}$] and a nickel filter, using 40 mA, 40 mV and a scanning step of 0,021°).

Results and discussion

Fig. 2 shows the elastic modulus changes with temperature for the designed castables. According to the attained results, after their first heating, all evaluated systems presented a significant E increase above 700 °C, reaching values around 60 GPa (alumina), 55 GPa (mullite) and 35 GPa (silica) at 1000 °C. This behaviour is associated to the generation of a liquid phase (B₂O₃) that speeds up the samples' sintering, favouring a faster densification of the refractories [5, 6].

On the other hand, during the cooling step, the alumina-containing composition (Fig. 2 a) showed a continuous increase of the sample's stiffness (up to 80 GPa), whereas the mullite one kept the E results close to 60 GPa. Moreover, the silica-based castables presented an elastic modulus drop below 500 °C (Fig. 2 c), indicating that the original raw materials, as well as the generated phases during this first thermal treatment were not well accommodated in the resulting microstructure. Consequently, the presence of cracks and flaws induced the decrease of the samples' stiffness due to the thermal expansion mismatch among the components contained in the silica-based material.

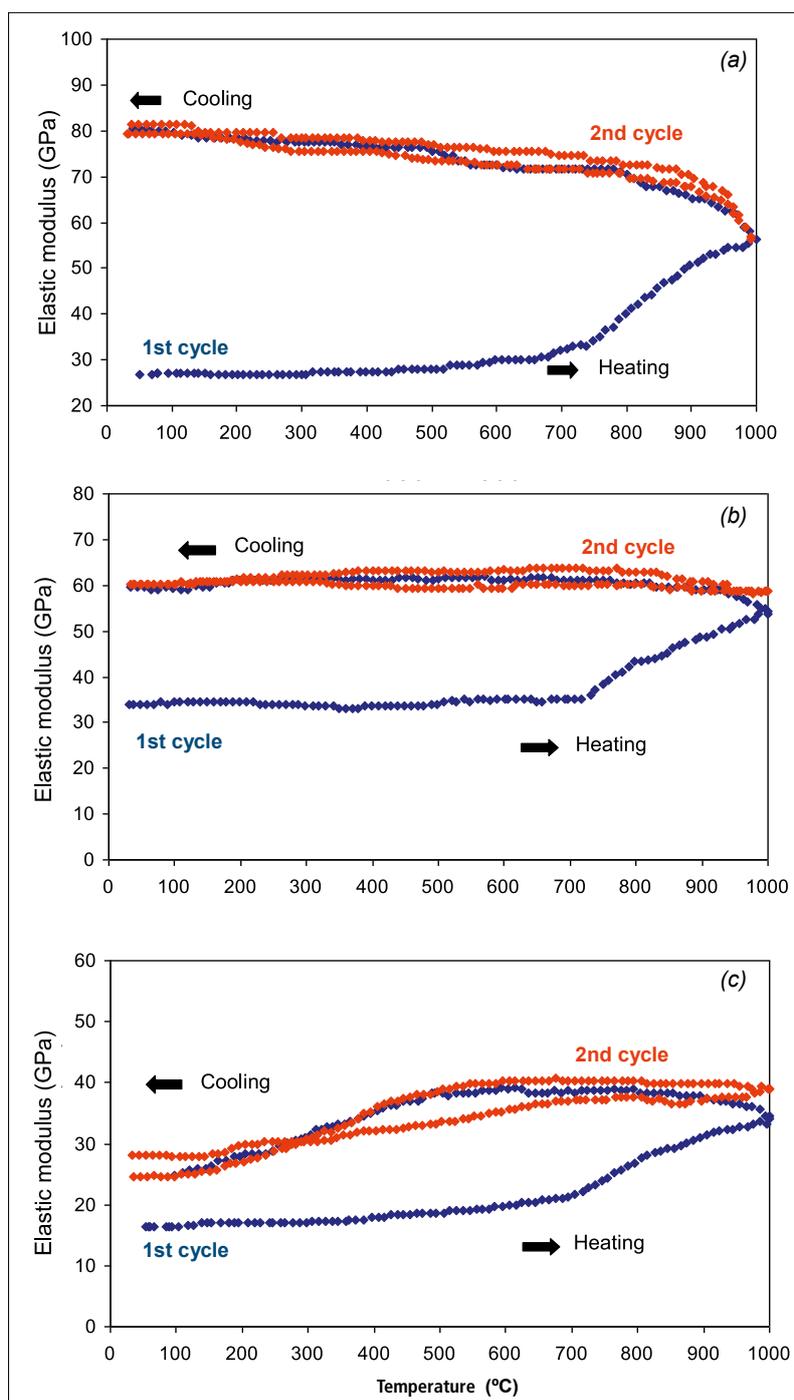


Fig. 2 a–c Elastic modulus changes with temperature for: (a) alumina, (b) mullite, and (c) silica-based castables (before the first thermal cycle, all samples were previously cured at 50 °C for 24 h, and dried at 110 °C for another 24 h)

A further E decrease detected during the second heating cycle of the Al₂O₃-containing sample (Fig. 2 a) highlighted that a liquid phase was still present in this system at high temperatures (>800 °C), resulting in the softening of the castable structure. This effect was not observed for the other evaluated compositions (mullite and

silica-containing materials). Furthermore, it is important to point out that the main transformations that took place in the first thermal treatment of the refractories were permanent, as the E values achieved during the second heating and cooling of the samples were kept at the same level as the ones reached at the end of the 1st test. The only

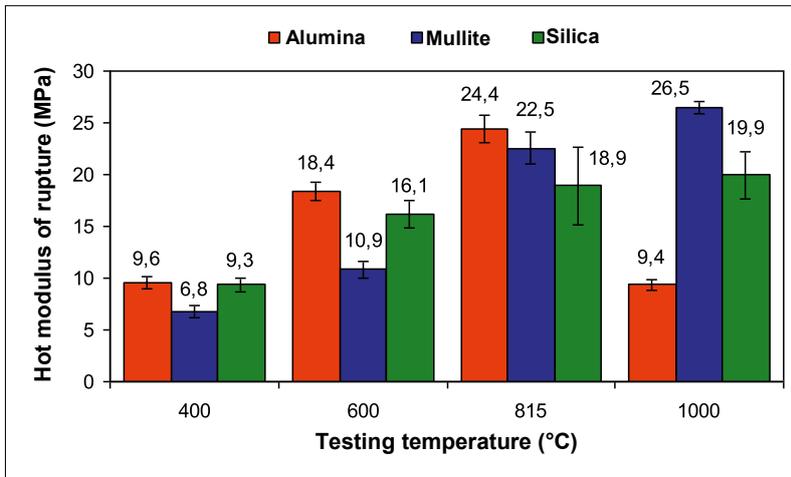


Fig. 3 Hot modulus of rupture of the nano-bonded refractory castables

Tab. 2 Estimated chemical composition of the castables' matrix

Oxides [mass-%]	Designed Castables		
	Alumina	Mullite	Silica
Al ₂ O ₃	68,20	58,81	37,04
SiO ₂	25,18	37,51	53,70
B ₂ O ₃	6,62	3,68	9,25

exception was the silica-based castable, as due to the initial raw materials used in this formulation (70 mass-% of coarse fused silica aggregates and 16 mass-% of tabular

alumina) and the different thermal expansion behaviour of these components, crack formation was still observed and corroborated by the continuous elastic modulus

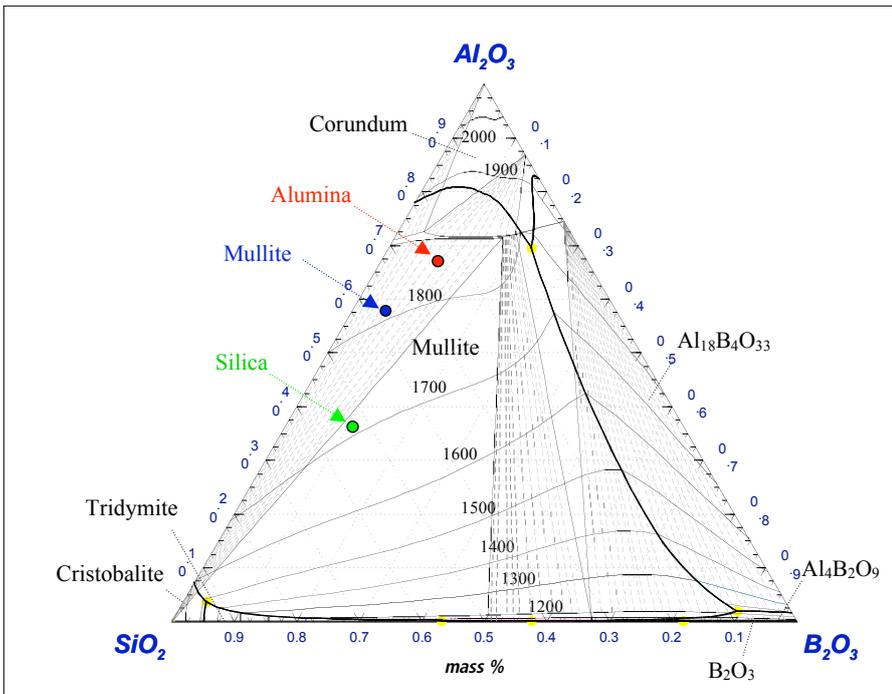


Fig. 4 Superposition of the Al₂O₃-B₂O₃-SiO₂ isothermal section at 815 °C and liquidus projection diagrams [9] (the highlighted points indicate the position of the matrix composition of the designed castables)

decrease during the 2nd cooling step of this refractory.

The sintering effect derived from adding Al powder and a boron-based compound to the designed formulations can also be supported by the hot modulus of rupture (HMOR) measurements. As highlighted in Fig. 3, the alumina-based composition showed a marked increase of its mechanical strength from 400 °C up to 815 °C. Moreover, the same trend observed in the E measurements was also attained in the HMOR values for this castable, as the mechanical strength decreased at 1000 °C due to the liquid phase generation in the samples' microstructure at this testing condition. This distinct behaviour (compared to the other evaluated systems) indicated that, depending on the blend of alumina, silica and boron oxide, it might result in the formation of compounds with low melting temperatures, affecting the overall refractoriness and thermomechanical properties of such compositions.

Considering the Al₂O₃-B₂O₃-SiO₂ equilibrium phase diagram and the chemical composition of the castables' matrix (Tab. 2, as this is the most reactive fraction of the formulations), additional analyses were carried out in order to explain the phase transformations responsible for the main changes in the refractories' performance. Fig. 4 indicates that mullite(ss) and silica should be the phases present in the matrix fraction of the alumina and mullite-based compositions at 815 °C, whereas for the silica-one, mullite, silica and liquid should be found.

Comparing the diagrams shown in Fig. 4–5 (the latter represents the Al₂O₃-SiO₂-10 mass-% B₂O₃ system), the phases generated in the evaluated castables at higher temperatures (>815 °C) can be identified. Due to the similar transformations observed for the mullite and alumina-based matrix compositions, the following discussions will be mainly focused on the alumina and silica-containing materials.

Mullite, silica and liquid should be found in the silica-based castable from 800 °C up to 1200 °C according to the thermodynamic equilibrium condition. Above 1200 °C, all silica can be dissolved, resulting only in mullite and liquid (Fig. 5). On the other hand, the alumina-containing material may be comprised by mullite and silica in the 800–1000 °C range, but the liquid

presence is only predicted to be found at temperatures higher than 1000 °C. Based on these data, the liquid crystallization path can be described from the point where the liquid phase reaches the line that delimitates the mullite and silica fields (Fig. 5).

Fig. 6 presents the $\text{Al}_2\text{O}_3\text{-B}_2\text{O}_3\text{-SiO}_2$ liquidus projection diagram in combination with the isothermal section at 1000 °C for the same system in order to point out the lines that delimitate the mullite(ss) field. The liquid phase of the silica-based matrix intercepts the line between the SiO_2 and mullite fields at approximately 1200 °C, according to the triangle (solid red line) associated with the silica-mullite-liquid equilibrium. Nevertheless, with the temperature decrease, the liquid composition will follow the changes indicated by the red dotted line located at the bottom of the diagram shown in Fig. 6, resulting in silica and/or mullite precipitation until it reaches the point associated to the invariant reaction that takes place at 810 °C (Tab. 1). When the liquid phase presents the chemical composition and temperature (810 °C) highlighted by the blue circle in Fig. 6, $\text{Al}_4\text{B}_2\text{O}_9$ and SiO_2 should be generated. Another important aspect is related to the mullite solid solution, as due to the non-stoichiometry of this compound, when the new compatibility triangle is drawn (dashed line) comprising the final composition of the liquid phase (at the invariant reaction point), a shift of the triangle vertex is observed (compared to the one with the solid line). This change indicates that a high content of B_2O_3 might be incorporated into the mullite(ss) structure in this latter condition.

Regarding the alumina-based matrix composition (Fig. 7), the mullite-silica-liquid compatibility triangle (red solid line) was drawn from the isothermal curve at 1100 °C, which intercepts the line between the mullite and silica fields. This triangle will be shifted (red dashed line) with the temperature decrease, inducing the precipitation of mullite and silica down to 1000 °C. At this condition, the liquid cooling step will not progress according to the invariant reaction described before, because the point that represents its initial composition (Fig. 7) will not be inside the new compatibility triangle. Thus, all remaining liquid should give rise to mullite crystals. Consequently, from 1000 °C down to 800 °C,

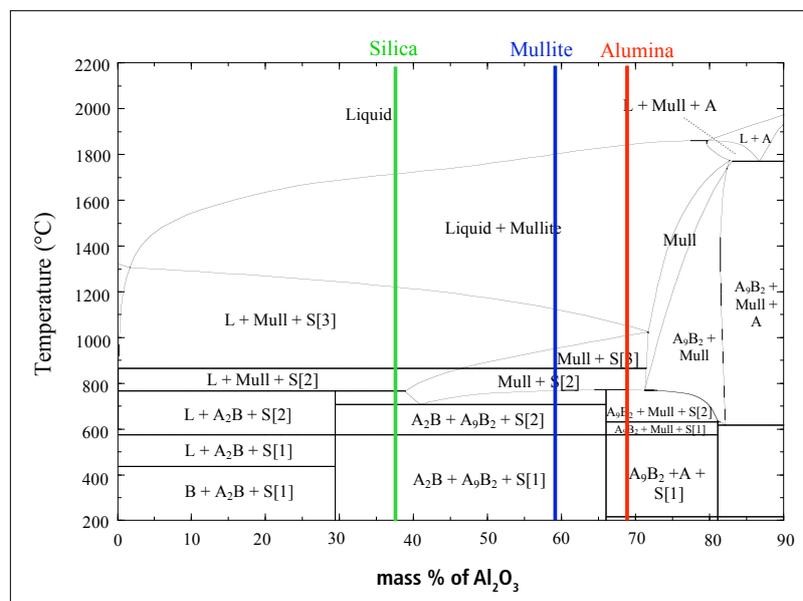


Fig. 5 Phase diagram of the $\text{Al}_2\text{O}_3\text{-SiO}_2\text{-10 mass-% B}_2\text{O}_3$ system [9]

mullite and silica should be the main components in equilibrium.

Based on the evaluation of the crystallization path of the liquid phase contained in the castables' matrix, the $\text{Al}_2\text{O}_3/\text{SiO}_2$ ratio of these compositions will not only affect the reaction steps but also the liquid features as, depending on the selected temperature, different silica contents should be dissolved into the liquid of each system up

to 1200 °C. However, the discussion presented above only takes into consideration the thermodynamic aspects without paying attention to the kinetic of these transformations. For instance, most likely mullite generation should not be observed by just heating the alumina-based castable samples at 1000 °C and keeping them for 5 h at this temperature, as such a short thermal treatment will not allow all the reactions to take

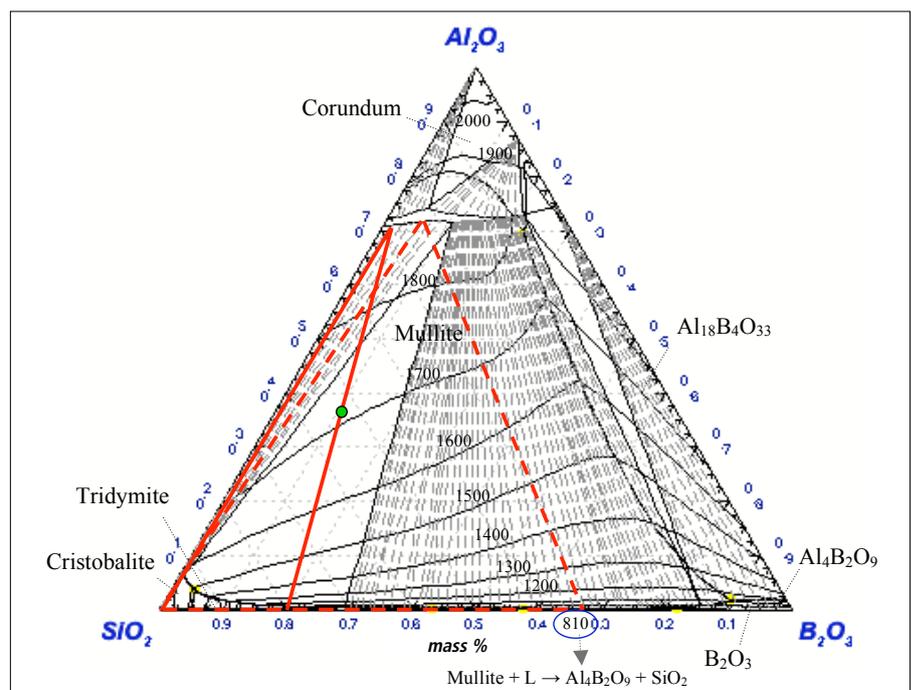


Fig. 6 Superposition of the $\text{Al}_2\text{O}_3\text{-B}_2\text{O}_3\text{-SiO}_2$ isothermal section at 1000 °C and liquidus projection diagrams [9] (the red solid and dashed lines point out the crystallization path of the liquid contained in the silica-based castable's matrix)

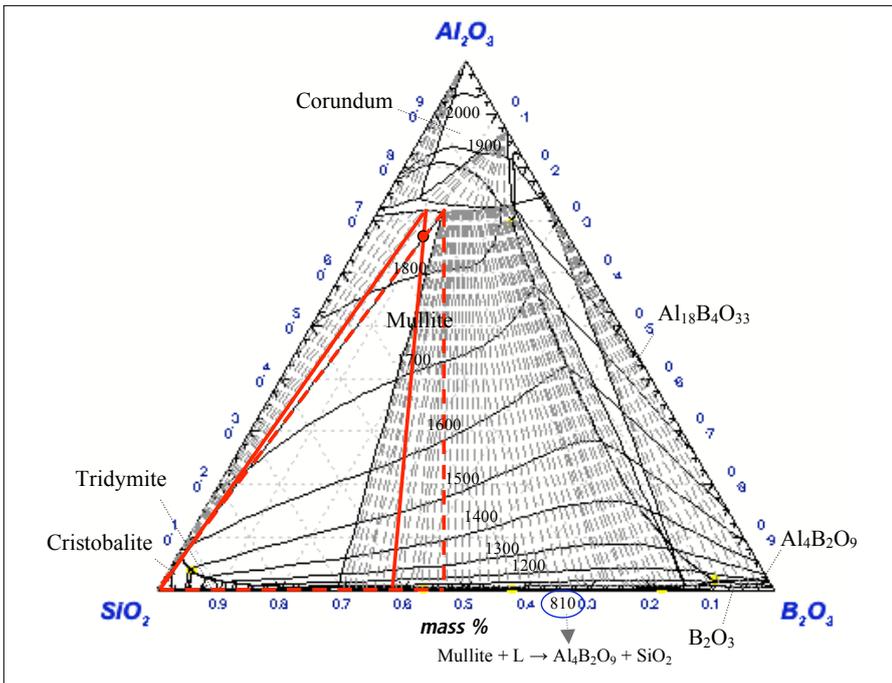


Fig. 7 Superposition of the $\text{Al}_2\text{O}_3\text{-B}_2\text{O}_3\text{-SiO}_2$ isothermal section at $1000\text{ }^\circ\text{C}$, and liquidus projection diagrams [9] (The red solid and dashed lines points out the crystallization path of the liquid contained in the alumina-based castable's matrix)

place and reach the equilibrium condition predicted by the phase diagrams. Hence, a more suitable analysis consists of focusing on the castables' behaviour at intermediate temperatures ($>450\text{ }^\circ\text{C}$), when $\text{B}_2\text{O}_3(\text{l})$ (derived from the used sintering additive) will interact with the matrix components of these materials.

As pointed out in the $\text{SiO}_2\text{-B}_2\text{O}_3$ phase diagram [12] (Fig. 8 a), B_2O_{30} will become saturated in SiO_2 after incorporating more than 50 mass-% of this oxide

in the $800\text{--}1000\text{ }^\circ\text{C}$ range. Conversely, for the $\text{Al}_2\text{O}_3\text{-B}_2\text{O}_3$ system [13] (Fig. 8 b), the initial contact of this liquid phase with alumina should result in a fast saturation of the former, inducing the further precipitation of $2\text{Al}_2\text{O}_3\cdot\text{B}_2\text{O}_3$ (A_2B) below $1000\text{ }^\circ\text{C}$ and $9\text{Al}_2\text{O}_3\cdot 2\text{B}_2\text{O}_3$ (A_9B_2) between $1000\text{--}1400\text{ }^\circ\text{C}$ for compositions containing more than 2,5 mass-% of alumina. This latter aluminium borate is a more interesting compound due to its higher refractoriness. However, A_2B should be preferentially gen-

erated below $1000\text{ }^\circ\text{C}$ (as the temperatures evaluated in this paper). It is expected that the decomposition of this borate (due to a peritectic reaction, Fig. 8 b) should lead to liquid formation at $1000\text{ }^\circ\text{C}$, affecting the hot mechanical strength of the designed castables containing B_2O_3 .

Fig. 9 presents further analysis considering the isothermal section of the $\text{Al}_2\text{O}_3\text{-B}_2\text{O}_3\text{-SiO}_2$ phase diagram. Aiming to illustrate the reaction products after the interaction of the B_2O_{30} with castable matrices presenting different $\text{Al}_2\text{O}_3/\text{SiO}_2$ ratio, a composition with 90 mass-% of B_2O_3 (points highlighted in Fig. 9) and matrices with 70 mass-% (tie-line in red) and 30 mass-% (tie-line in blue) of Al_2O_3 were selected. For both cases, the selected mixtures are located in the $\text{A}_2\text{B} + \text{liquid}$ field.

The total content of the aluminium borate in the alumina-rich composition is around 3,65 % higher than that for the alumina matrix (30 mass-%). Besides that, the amount of SiO_2 dissolved into the liquid phase at $1000\text{ }^\circ\text{C}$ is 5,95 mass-% and 2,52 mass-% for the materials presenting 30 mass-% or 70 mass-% of Al_2O_3 , respectively. Consequently, compositions containing a higher $\text{Al}_2\text{O}_3/\text{SiO}_2$ ratio are more susceptible to the negative effect of the A_2B decomposition and the generated liquid phase should present lower viscosity due to its reduced silica content. This explains the elastic modulus and HMOR decrease observed at $1000\text{ }^\circ\text{C}$ for the prepared alumina-based castable (Fig. 2 a and Fig. 3). Fig. 9 indicates that liquid formation is also expected to take place at $1000\text{ }^\circ\text{C}$ for the

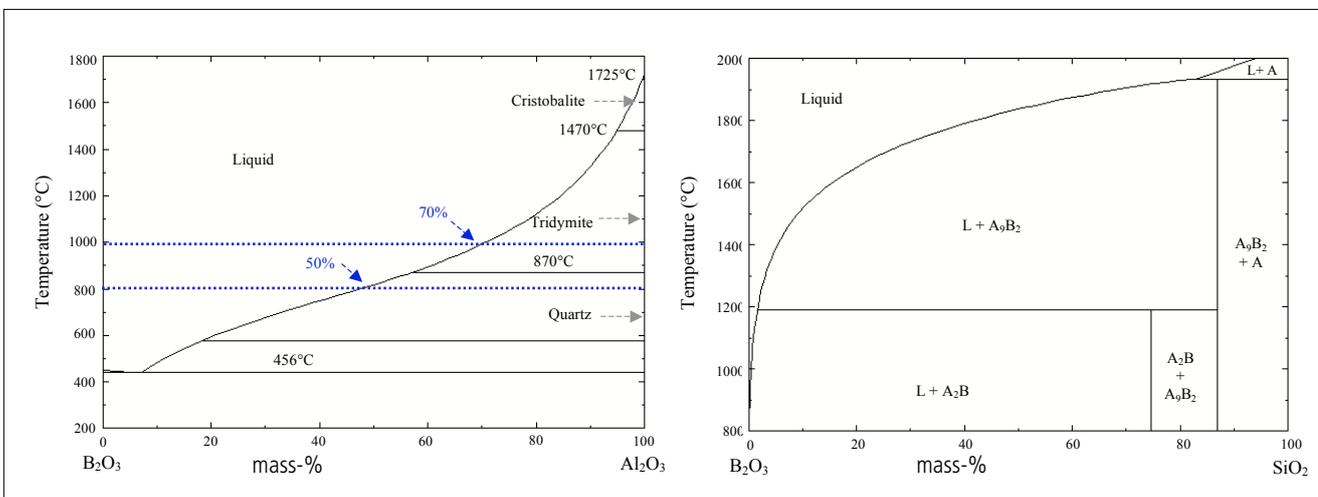


Fig. 8 a-b (a) $\text{Al}_2\text{O}_3\text{-SiO}_2$ [12], and (b) $\text{Al}_2\text{O}_3\text{-B}_2\text{O}_3$ [13] phase diagrams

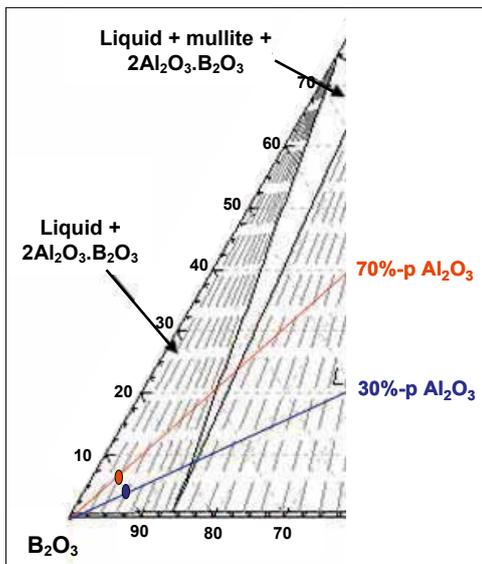


Fig. 9 Isothermal section at 1000 °C of the $\text{Al}_2\text{O}_3\text{-B}_2\text{O}_3\text{-SiO}_2$ system, highlighting the composition presenting 90 mass-% of B_2O_3 and 10 mass-% of matrix for different $\text{Al}_2\text{O}_3/\text{SiO}_2$ ratios

other evaluated systems (mullite and silica) but, as no significant change in the hot modulus of rupture values was detected at this temperature, it is assumed that this phase did not affect this property to a greater extent. Therefore, the performance of the evaluated refractory systems containing a boron-based compound is associated to the features of the resulting liquid phase, which directly depends on the $\text{Al}_2\text{O}_3/\text{SiO}_2$ ratio of the ceramic matrix.

Fig. 10 presents the X-ray diffraction results for the alumina, mullite and silica-based castable samples fired at 600 °C, 815 °C and 1000 °C for 5 h. The main identified phases were alumina, mullite and silica. For the materials fired at high temperatures, this latter component was also associated with the silica fume and colloidal SiO_2 (binder) crystallization. Aluminium was still detected in the samples fired at 600 °C for 5 h, but a decrease of their related peak intensity and Si generation with the temperature increase (up to 1000 °C) were detected in all the evaluated compositions. These results indicate that an oxi-reduction reaction [14] (eq. 1) took place in the castables' matrix.

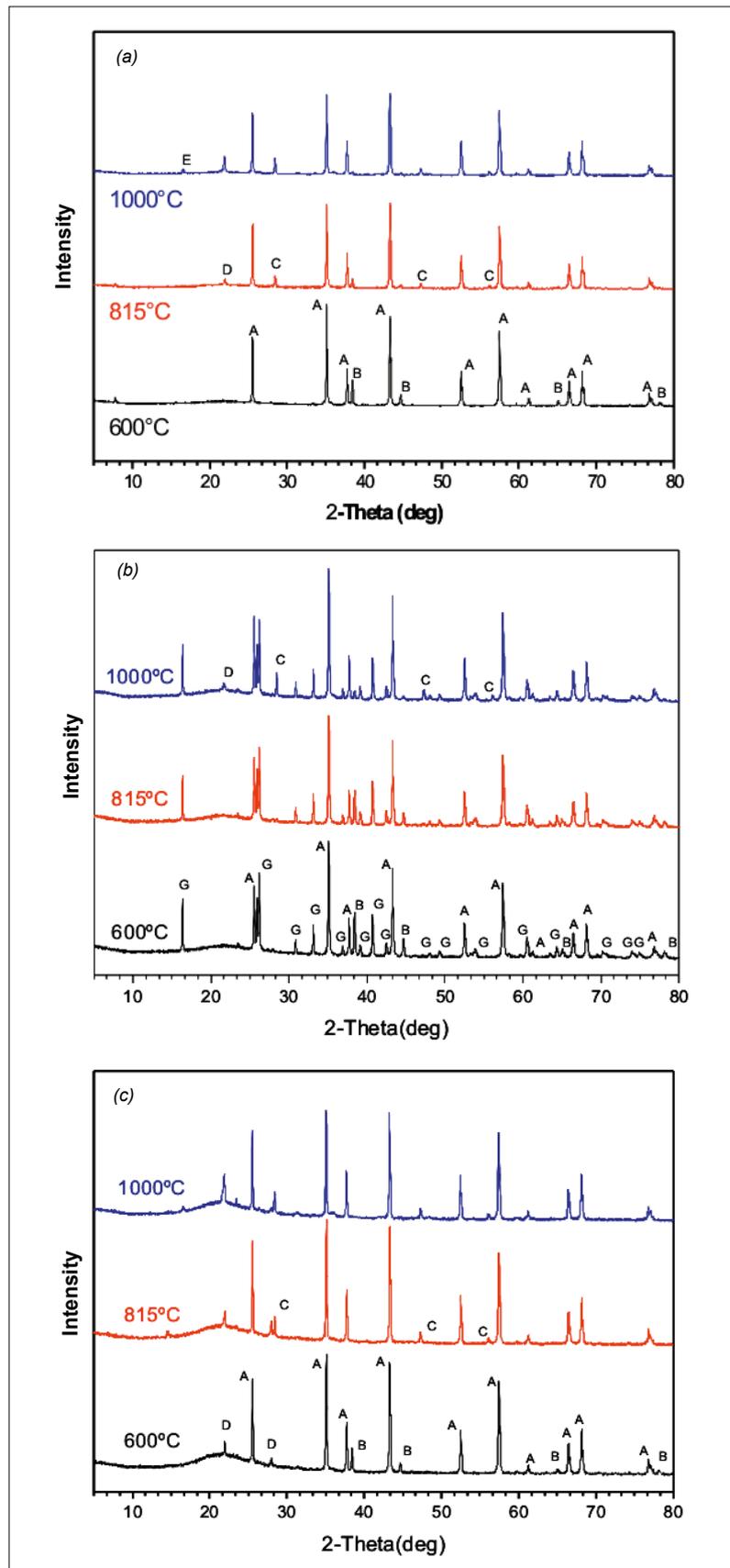
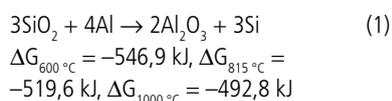


Fig. 10 a-c XRD profiles: (a) alumina, (b) mullite, and (c) silica-based castables fired at different temperatures; A = Al_2O_3 , B = Al, C = Si, D = SiO_2 , G = mullite, and E = $\text{Al}_4\text{B}_2\text{O}_9$

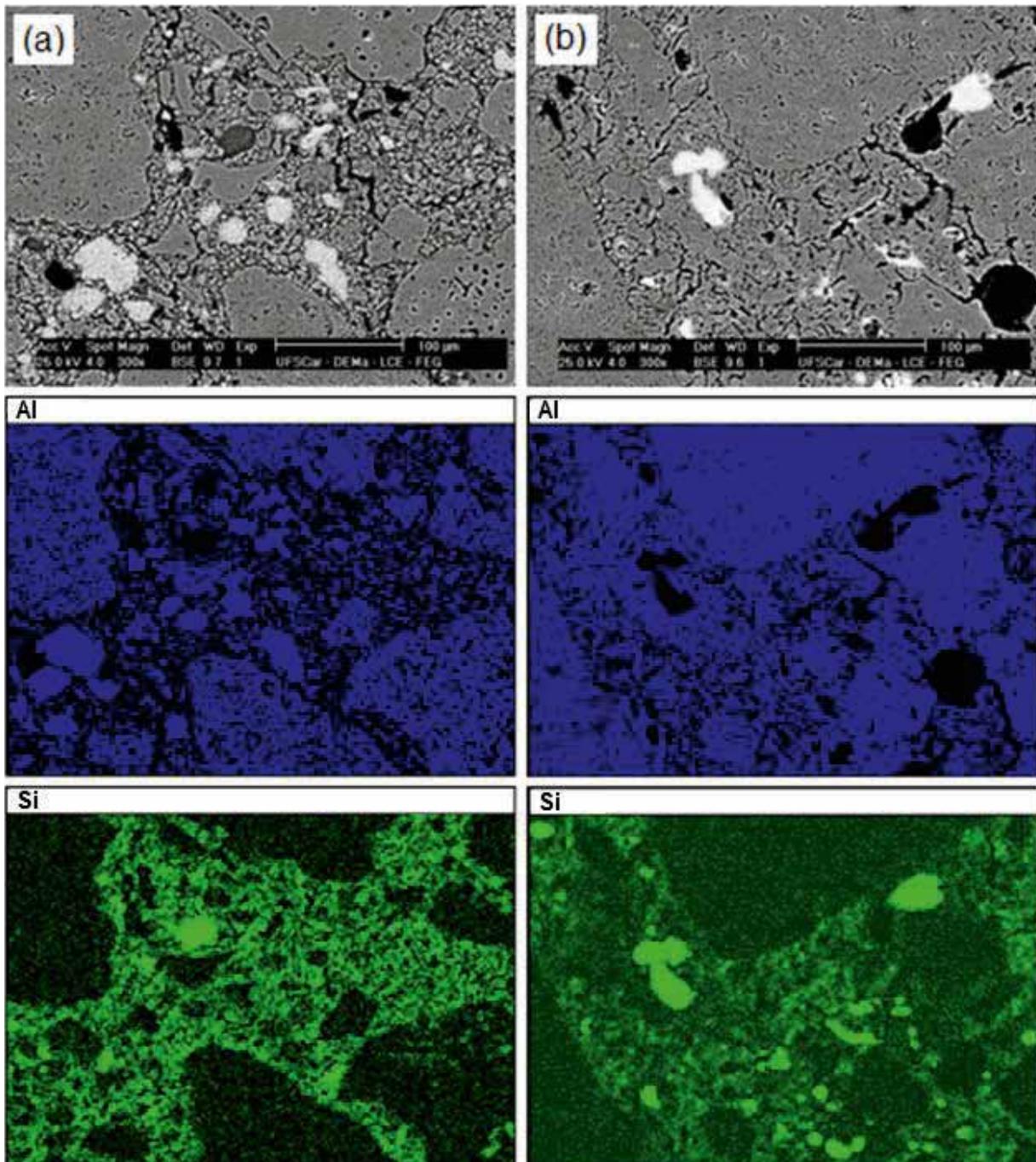


Fig. 11 a–b SEM images and EDS mapping of Al and Si for a high-alumina colloidal silica-bonded castable after firing at: (a) 815 °C, and (b) 1000 °C for 5 h [6]

SEM images and EDS mapping analysis (carried out in a previous study by the authors [6]) of Al and Si elements contained in high-alumina colloidal silica-bonded castable samples also pointed out that the transformation indicated in eq. 1 was observed after firing this sort of refractory at 1000 °C for 5 h (Fig. 11).

According to the reaction products of eq. 1, Al_2O_3 formation should have a positive ef-

fect on the refractories' properties, improving their densification and mechanical resistance [6, 15]. Thus, the sintering additives evaluated in this paper acted at different temperatures (boron-based compound induced liquid generation above 400 °C and Al reacted with fine silica above 600 °C) and by distinct mechanisms.

The A_2B phase was only identified in the high-alumina refractory fired at 1000 °C

for 5 h. This result is in agreement with the previous analysis of the phase equilibrium diagrams of the $\text{Al}_2\text{O}_3\text{--B}_2\text{O}_3\text{--SiO}_2$ and $\text{Al}_2\text{O}_3\text{--B}_2\text{O}_3$ systems, which pointed out the generation of this compound in compositions presenting high alumina content. According to the in situ hot elastic modulus measurements, the sintering effect and benefits (inducing higher mechanical strength and faster densification) of adding

a boron-based compound to the evaluated refractories are very clear. Furthermore, the present work highlighted that the amount of the Al_2O_3 and SiO_2 contained in the formulation matrix should directly affect the role of this sintering additive.

Final remarks

According to the attained results, a marked elastic modulus increase was observed for the nano-bonded Al_2O_3 - SiO_2 castables up to 1000 °C mainly due to the sintering effect induced by the boron-based compound used in this work. Based on the analysis of the Al_2O_3 - SiO_2 - B_2O_3 phase diagram, the action of this additive is related to the generation of a liquid phase at intermediate temperatures (>400 °C) that interacts with the castables' components, resulting in the formation of different reaction products. The $\text{Al}_2\text{O}_3/\text{SiO}_2$ ratio in the formulations' matrix fraction affects these phase transformations, as alumina-rich compositions induce the generation of $2\text{Al}_2\text{O}_3$ - B_2O_3 during the first heating of the castables. Nevertheless, according to the peritectic reaction predicted to take place in the Al_2O_3 - B_2O_3 system at 1000 °C, the decomposition of this aluminium borate should increase the liquid phase content at this temperature, resulting in the decrease of the hot modulus of rupture of the alumina-based samples. Despite the presence of a liquid phase in the castable structure, the SiO_2 -rich compositions did not reduce their mechanical strength at

1000 °C, which is associated to the fact that silica may be incorporated by the liquid, changing its properties (i.e., increasing the liquid viscosity). Considering the thermomechanical performance presented by the designed compositions, these refractories are suitable options to be used in the petrochemical and aluminium production processes.

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