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Thermodynamic evaluation of SiC oxidation in Al_2O_3–$MgAl_2O_4$–SiC–C refractory castables

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Abstract

The literature suggests that $MgAl_2O_4$ can accelerate SiC oxidation in Al_2O_3–$MgAl_2O_4$–SiC–C refractory castables. Thus, in this work thermodynamic calculations have been carried out using FactSage® software in order to explore, search for and understand the role of $MgAl_2O_4$ on the SiC oxidation. According to the thermodynamic predictions, at 1500 °C and under a reducing atmosphere, there is no evidence that spinel might directly affect SiC oxidation. The increase of SiC content in an Al_2O_3–SiC–C (AL) castable composition was mainly related to the reaction between mullite and carbon. On the other hand, the SiC generation in the Al_2O_3–$MgAl_2O_4$–SiC–C (SP) composition was a result of the reaction involving liquid SiO_2 and carbon from the refractory. Therefore, the lower SiC content in the SP castable resulted from the refractory's phase transformations. It was also suggested that the samples thermally treated 15 times at 1500 °C did not reach the equilibrium condition, which explains the differences between experimental and thermodynamic results.

Keywords: Oxidation; Carbon containing refractories; Thermodynamic calculations; FactSage®

1. Introduction

Al_2O_3–SiC–C and Al_2O_3–$MgAl_2O_4$–SiC–C refractory castables are mainly used in main blast furnace troughs due to their superior thermal shock and corrosion resistance, when in contact with liquid slags and metals [1,2]. The main trough is usually designed with a zone lining, which implies that the composition of the refractories in the slag line and metal line could be distinct. Al_2O_3–SiC–C castables usually contain a high amount of SiC (15–20 wt%) in order to improve their corrosion and thermal shock resistance. However, the high oxidation of SiC by FeO is the main cause of refractory wearing when they are applied to the metal zone. Thus, one alternative to reduce this effect consists of adding MgO or $MgAl_2O_4$ as a component of trough castables, which could provide a higher FeO corrosion resistance [3–6]. Al_2O_3–$MgAl_2O_4$–SiC–C castables show a lower wear rate during their working time because FeO can be incorporated as a solid solution in the spinel phase.

On the other hand, a drawback for the $MgAl_2O_4$ addition is its possible influence on the silicon carbide oxidation [1,3,4,7]. According to the literature, a few reactions could be used to explain how spinel accelerates SiC oxidation. Kageyama et al. [1] estimate that the oxidation mechanism can be described as follows:

(1) Active SiC oxidation under a reducing atmosphere:

$$C(s) + 1/2O_2(g) \rightarrow CO(g) \quad (1)$$

$$SiC(s) + CO(g) \rightarrow SiO(g) + 2C(s) \quad (2)$$

$$SiO(g) + CO(g) \rightarrow SiO_2(s) + C(s) \quad (3)$$

(2) Mg(g) release from the spinel grains in a reducing atmosphere.

$$MgO \cdot Al_2O_3(s) \rightarrow Mg(g) + 1/2O_2(g) + Al_2O_3(s) \quad (4)$$

(3) Acceleration of SiC oxidation.

(a) The oxygen released (Eq. (4)) will induce CO(g) generation and, consequently, SiC oxidation.

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(b) $SiO(g)$ can also react with oxygen and increase the $SiO_2(l)$ amount.

$$SiO(g) + 1/2O_2(g) \rightarrow SiO_2(l) \quad (5)$$

Furthermore, Iida et al. [4] suggested that the partial pressure of $SiO(g)$ from SiC and $Mg(g)$ from spinel (presented in the reacting environment) could affect the oxidation rate of the trough castable. The hypothesis discussed by these quoted authors is described as follows [4]: (1) $Mg(g)$ generates liquid in the refractory pores by reacting with the matrix of the solid (liquid phase comprised by MgO–CaO–Al_2O_3–SiO_2). (2) SiO_2 has some solubility in the liquid so $SiO(g)$ can also be dissolved in the liquid phase. (3) The consumption of $SiO(g)$ lowers its partial pressure and to keep the equilibrium of the system more SiC is oxidized (Eq. (2)).

Other studies also stated that after the formation of a SiO_2 film on the SiC grains, the O_2 diffusion rate in this region is the determining step of further oxidation [3,7,8]. In the case of refractories containing spinel, MgO migrates into the SiO_2 and the diffusion rate of O_2 increases, resulting in the advance of SiC oxidation.

As quoted before, some hypotheses are presented in the scientific literature, but all studies are only based on experimental results and there is no general agreement among them. Thus, this work aims to carry out some thermodynamic calculations using the FactSage® software in order to further explore, search for and understand the $MgAl_2O_4$ role in the SiC oxidation.

2. Thermodynamic calculations

These calculations are based on the minimization of free energy of the system, making it possible to find out the nature of the solid, liquid and gaseous phases, as well as their chemical composition and reaction rate at the thermodynamic equilibrium [9–11]. Simulations have been carried out using FactSage® (version 6.0), a fully integrated database and software jointly developed between Thermfact/CRCT (Montreal) and GTT-Technologies (Aachen). It consists of a series of modules that access, manipulate thermodynamic databases and perform various calculations.

The databases used in this study are: Fact53 (gas species, solid and liquid compound thermodynamic database) and FToxid (compounds and solutions for oxide databases). The equilibrium phases were predicted using the ‘‘Equilibrium’’ module, considering the following as possible phases: gas, slag or liquid and various solid solutions (including spinel, mullite, etc.).

The compositions used in this work were based on the refractories studied by Kageyama et al. [1] (see Table 1). Other castable formulations were also evaluated [3–5], but the obtained results followed the same trends observed in the investigation presented as follows.

Firstly, the oxidation behavior of SiC and C contained in the castable compositions were evaluated at 1500 °C (isothermal condition) and as a function of the $CO(g)$ content. After that, the phase evolution of the AL and SP castables was explored in the 1100–1600 °C temperature range, in the presence of distinct $CO(g)$ amounts. Additionally, the resulting amount of SiC, SiO_2 and C based on the calculations and the experimental testing were compared.

Table 1
Castable compositions evaluated in the thermodynamic simulations (wt%) [1].

Materials	AL	SP
$MgAl_2O_4$	–	65
Al_2O_3	81	16
SiC	15	15
C	2	2
CaO	2	2

2.1. *SiC oxidation behavior in the presence of CO(g)*

Some papers present experimental investigations of the role of $MgAl_2O_4$ on the SiC oxidation under a reducing atmosphere at 1400 °C and 1500 °C [1,3,4,7]. Therefore, the chemical phase evolution of the AL and SP castables at 1500 °C and under a reducing atmosphere were evaluated using the thermodynamic calculations. It was considered that 0.1 moles of CO for each 100 moles of solid material was sufficient to provide a reducing atmosphere [12]. However, in order to check which condition fits the experimental tests, the effect of the $CO(g)$ content in the calculations was investigated and the amount of gas phase added to the system ranged from $\langle A \rangle = 1$ g to 10 g (which is equivalent to 0.04–0.4 moles of $CO(g)$).

Fig. 1a shows the phase evolution for the AL castable at 1500 °C as a function of $CO(g)$ content. In this case, when a small amount of CO is in the reacting environment (about 1 g or 0.04 moles), Al_2O_3, CA_6 ($CaAl_{12}O_{19}$), SiC, C and liquid (comprised by CaO, SiO_2 and Al_2O_3) are present in the thermodynamic equilibrium. According to Eqs. (2) and (3), the reactions between SiC and CO induce the silicon carbide consumption and carbon deposition as the oxidation progresses (see Fig. 1).

When a higher amount of $CO(g)$ is added to the system, $CaAl_{12}O_{19}$ is decomposed and a liquid phase is formed. This liquid might also be consumed according to the following equation:

$$CaO(s,l) + 2SiO_2(s,l) + Al_2O_3(s) \rightarrow CaAl_2Si_2O_8(s,l)\ (\text{anorthite}) \quad (6)$$

Moreover, the mullite generation ($Al_6Si_2O_{13}$ – Eq. (7)) only occurs when the oxidation of SiC by $CO(g)$ is increased.

$$2SiO_2(s,l) + 3Al_2O_3(s) \rightarrow Al_6Si_2O_{13}(s) \quad (7)$$

On the other hand, Fig. 1b shows the results for the composition containing pre-formed $MgAl_2O_4$. When $\langle A \rangle = 1$ g, phases CA_2 ($CaAl_4O_7$), $MgAl_2O_4$, SiC, C and liquid are present in the thermodynamic equilibrium. Depending on the $CO(g)$ content in the environment, some transformations might be carried out, such as: SiC oxidation, carbon deposition, CA_2 dissolution into the liquid phase and an increase in the liquid

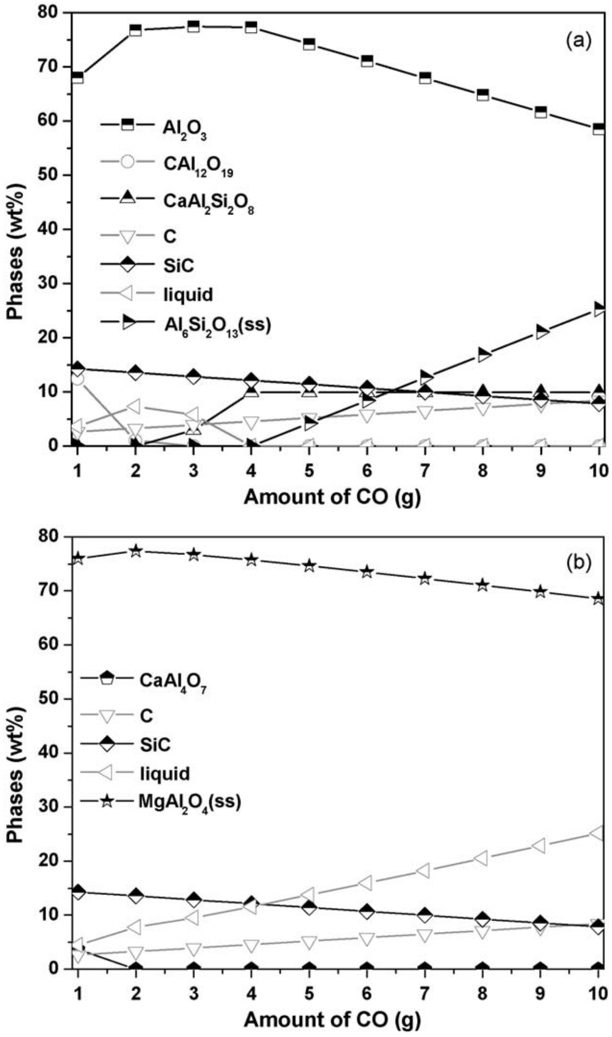

Fig. 1. Phase evolution of the castables (a) AL and (b) SP at 1500 °C as a function of the CO(g).

content. The partial dissolution of the MgO and Al_2O_3 from spinel and of the SiO_2 generated from SiC oxidation are the main causes for the liquid phase content increase. Additionally, the 16 wt% of alumina initially added to the SP composition is partially incorporated into the $MgAl_2O_4$ solid solution, which explains why the spinel amount is higher than the original 65 wt%.

Comparing the results shown in Fig. 1, the same values of SiC and C were obtained for both tested materials. Therefore, it can be concluded that the addition of $MgAl_2O_4$ to the SP castable does not seem to affect the silicon carbide oxidation. For the evaluated conditions, there was no evidence that reaction (4) and Mg(g) formation occurred due to the lower values of the gas phase activity in this system (gas activity < 1). Thus, according to the thermodynamic results, the mechanisms proposed by Kageyama et al. [1] are not applied in this case.

At this point, the results of the thermodynamic predictions did not confirm the influence of Mg(g) on the SiC oxidation at 1500 °C. Therefore, the next step of the investigation was to evaluate the chemical phase changes for the AL and SP castables in the 1100–1600 °C temperature range and in the presence of distinct CO(g) contents (Figs. 2 and 3). The aim of this evaluation was to observe whether some of the transformations in the castable compositions might consume or generate SiC at high temperatures.

The addition of 2 g (0.08 moles), 4 g (0.16 moles), 7 g (0.28 moles) or 10 g (0.4 moles) of CO to the environment and its influence on the phase evolution of the castables was investigated. The thermodynamic predictions were further compared with the experimental results of some castable samples, which were previously thermally treated 15 times at 1500 °C with a dwelling time of 3 h at this maximum temperature [1]. During the experimental tests, AL and SP refractories were fired inside a sealed box, where the samples were embedded in coke, to assure that CO would be present and to avoid the castable's oxidation by O_2.

The amount of CO(g) available in the reducing atmosphere and the temperature act directly in the phase transformations of the castables, as can be seen in the following discussions and in Figs. 2 and 3.

2.1.1. *Reducing atmosphere containing 2 g (0.08 moles) of CO(g)*

When only 0.08 moles of CO are added, the predicted phases in the equilibrium for the composition containing a high Al_2O_3 content (AL), at 1100 °C, are: Al_2O_3, CA_6 ($CaAl_{12}O_{19}$), anorthite ($CaAl_2Si_2O_8$), SiC and C (Fig. 2a). The amount of SiO_2 was estimated using Eq. (8) and considering that all gases of the environment would be involved in this reaction.

$$SiC(s) + 2CO(g) \rightarrow SiO_2(l) + 3C(s) \tag{8}$$

About 2.1 wt% of SiO_2 will be available to react and form anorthite at 1100 °C. From the original 15 wt% of SiC, 1.4 wt% reacted with CO, leaving 13.6 wt% (see Fig. 2a). Furthermore, the resulting carbon amount based on Eq. (8), as well as the 2 wt% initially present in the AL composition makes a total of 3.3 wt% of C. The increase in carbon content was also observed in the experimental results for samples treated at 1500 °C under a reducing atmosphere, i.e., changing from 2 wt% to 3 wt% in the AL castable [1].

On the other hand, SiC and C values (predicted by the thermodynamic calculations) were constant up to 1600 °C in the evaluated condition and Eq. (8) is the only reaction that consumes SiC and generates C, over the temperature range of 1100 °C and 1600 °C. Moreover, 4.9 wt% of anorthite (Eq. (6)) and 11.9 wt% of CA_6 (Eq. (9)) are expected to be formed at 1100–1400 °C (Fig. 2a).

$$CaO + 6Al_2O_3 \rightarrow CaO \cdot 6Al_2O_3 \tag{9}$$

After all these reactions, the alumina content in the AL composition is reduced from 81 wt% to 68 wt%, following reactions (6) and (9).

However, at temperatures higher than 1400 °C, some phase changes such as anorthite and CA_6 decomposition lead to the liquid phase generation. This liquid is comprised by CaO, SiO_2 and Al_2O_3 and a total amount of 8.7 wt% is formed at 1600 °C (Fig. 2a). SiC and C contents are kept constant and no gas formation is observed when only 0.08 moles of CO(g) are

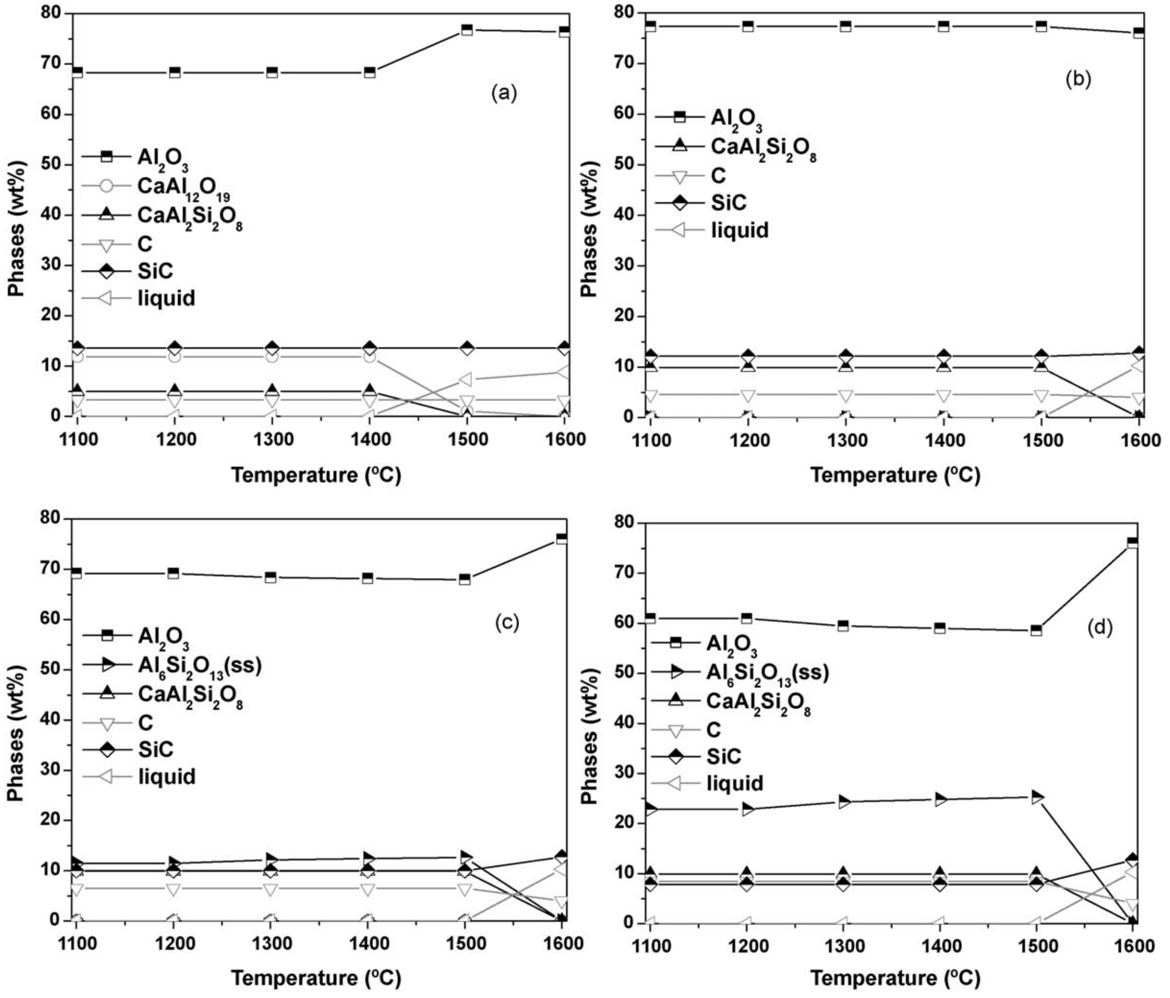

Fig. 2. AL castable phase evolution as a function of temperature under reducing atmosphere: (a) 2 g or 0.08 moles, (b) 4 g or 0.16 moles, (c) 7 g or 0.28 moles and (d) 10 g or 0.4 moles of CO(g).

added to the firing environment of the AL castable samples at the temperature range of 1100 °C to 1600 °C.

The presence of a small amount of melilite (which is a solid solution between guelenite ($2CaO{\cdot}Al_2O_3{\cdot}SiO_2$) and akermanite ($2CaO{\cdot}MgO{\cdot}SiO_2$)) at 1300 °C, is the main difference between the AL (Fig. 2a) and SP (Fig. 3a) results. The same SiO_2, anorthite and CA_6 contents quoted before in the analysis of the AL castable results are attained again for the SP composition between 1100 °C and 1200 °C (according to reactions (6), (8) and (9)). The liquid phase is detected at a lower temperature (1300 °C) and a total of 8.9 wt% of liquid is expected to be formed at 1600 °C with the following composition: 2 wt% CaO, 0.5 wt% MgO, 2.1 wt% SiO_2 and 4.3 wt% Al_2O_3. Moreover, the $MgAl_2O_4$ content increase (changing from the original 65 wt% to 76 wt% at 1600 °C) is related to the alumina incorporation into the spinel solid solution.

The same amounts of SiC (13.6 wt%) and C (3.3 wt%) were observed for the AL and SP thermodynamic calculations in the 1100–1600 °C temperature range. These results confirm that the SiC content was only affected by its reaction with CO(g) (Eq. (8)), which is the gas phase initially added to the system. Thus, the alumina–magnesia spinel did not play a role in the SiC oxidation when 0.08 moles of CO(g) are present in the environment. This result is not compatible with the chemical composition of the samples obtained in the experimental tests, which was 3 wt% and 4.3 wt% of C and 9.5 wt% and 8 wt% of SiC for Al and SP castables, respectively [1].

Therefore, aiming to evaluate whether the experimental results and thermodynamic predictions differences are due to the reducing atmosphere, further calculations involving higher amounts of CO(g) were performed as follows.

2.1.2. Reducing atmosphere containing 4 g (0.16 moles) of CO(g)

The addition of 0.16 moles of CO(g) increases the SiC oxidation of the Al and SP castables and 4.3 wt% of SiO_2 and 2.6 wt% of C can be generated at 1100 °C. After this reaction, 12.1 wt% of SiC remains in the castable composition and all CaO reacts with alumina and silica forming anorthite (Eq. (6)) at this temperature, as shown in Figs. 2b and 3b.

Anorthite decomposition and liquid formation will only occur above 1500 °C and the SiO_2 and C interaction might also

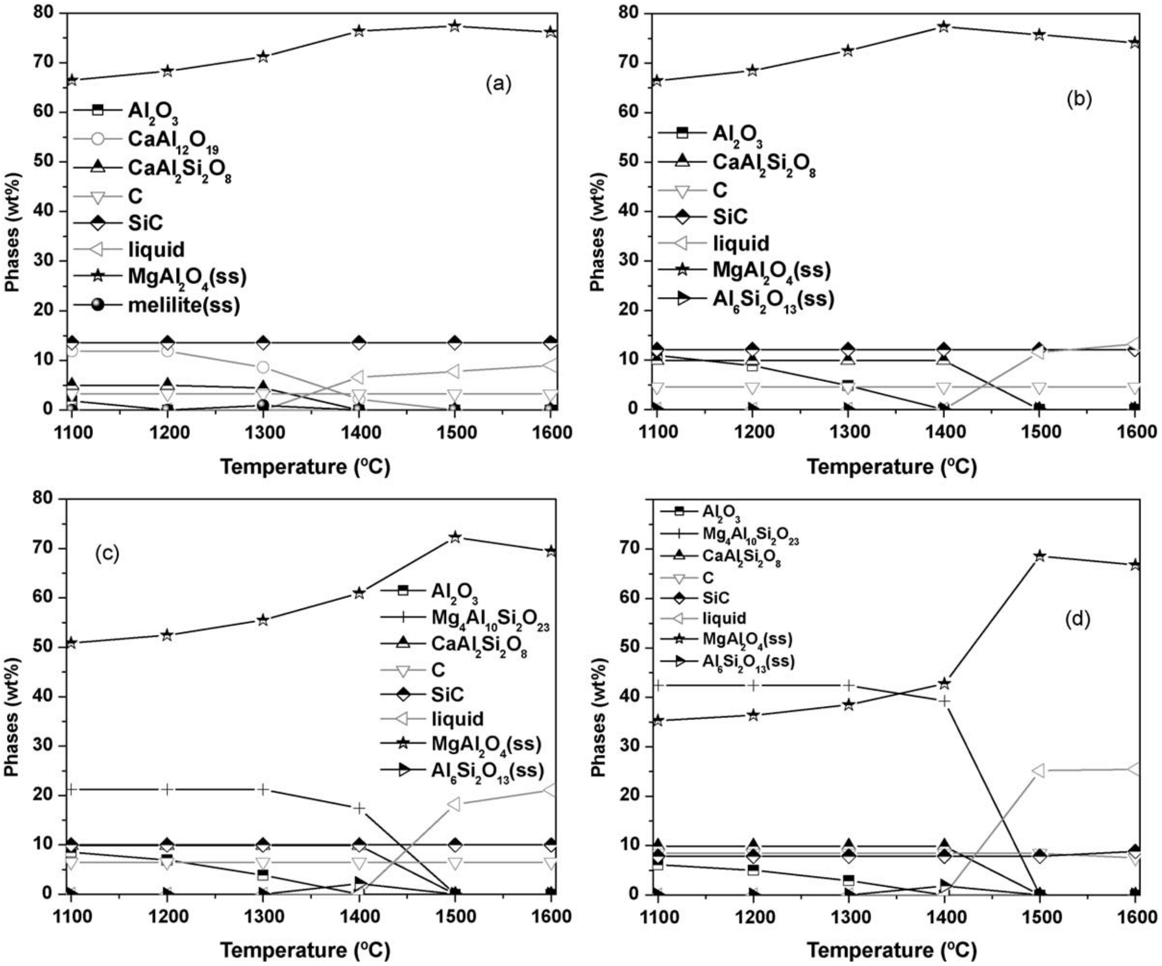

Fig. 3. SP castable phase evolution as a function of the temperature under reducing atmosphere: (a) 2 g or 0.08 moles, (b) 4 g or 0.16 moles, (c) 7 g or 0.28 moles and (d) 10 g or 0.4 moles of CO(g).

increase the SiC amount at the maximum temperature evaluated −1600 °C, according to Eq. (10).

$$SiO_2 + 3C \rightarrow SiC + 2CO \qquad (10)$$

Therefore, the SiC and C final values in the AL castable composition, are 12.7 wt% and 4 wt%, respectively, at 1600 °C (see Fig. 2b).

The presence of $MgAl_2O_4$ can cause some changes in the SP castable results. As quoted before for Eqs. (6) and (8), approximately 9.9 wt% of anorthite and 4.3 wt% of SiO_2 are obtained at 1100 °C. The spinel chemical composition is modified due to the incorporation of Al_2O_3 into this solid solution, as the temperature is increased (Fig. 3b). Anorthite decomposition is carried out above 1400 °C and the spinel phase partially induces the increase of the liquid up to 1600 °C. Although the Al castable presented a small increase of SiC at high temperatures, the amount of SiC and C did not change between 1500 °C and 1600 °C, for the SP composition. Thus, a small difference in SiC and C contents in both studied materials was detected at the maximum temperature evaluated. AL and SP castables showed similar values of SiC and C at 1500 °C based on the thermodynamic analyses, but these results are not compatible with the experimental tests.

2.1.3. Reducing atmosphere containing 7 g (0.28 moles) of CO(g)

When exposed to a reducing atmosphere with 0.28 moles of CO(g), the AL castable faced the same transformations described before. The main difference was the higher amount of mullite formed at 1100 °C due to the 7.5 wt% of SiO_2 generated from the SiC oxidation by CO(g). Thus, 4.3 wt% of SiO_2 is expected to be consumed to produce anorthite (Eq. (6)) and the remaining 3.2 wt% can also react with Al_2O_3 forming 11.4 wt% of mullite (Eq. (7)).

After these transformations, 69 wt% of alumina still remains in the AL castable at 1100 °C (Fig. 2c). The mullite phase is not a stoichiometric compound and alumina might be incorporated into solid solution at high temperatures [13]. The results obtained in the FactSage® considers that 12.6 wt% of mullite is available in the AL castable composition at 1500 °C. This increase in the mullite amount (changing from 11.4 wt% to 12.6 wt%) is associated to the extra alumina content solubilized into this solid solution at this temperature. There is no other transformation in the AL castable composition in the 1100–1500 °C temperature range, as can be seen in Fig. 2c. Nevertheless, anorthite and mullite decompositions induce the increase of Al_2O_3, SiC and liquid phases above 1500 °C. In fact, the reaction between mullite and carbon from the refractory material leads to the formation of Al_2O_3, SiC and CO (Eq. (11)) [14].

$$3Al_2O_3{\cdot}2SiO_2(ss) + 6C \rightarrow 3Al_2O_3 + 2SiC + 4CO \qquad (11)$$

As a result, 2.4 wt% of SiC is generated and a total of 12.7 wt% of this carbide is found in the castable composition at 1600 °C. The amount of CO(g) generated in Eq. (11) is 3.3 g, which is equivalent to 0.14 moles of gas. According to the thermodynamic calculations, this gas phase mainly consists of CO (pCO = 0.991 atm), SiO ($pSiO = 8.07 \times 10^{-3}$ atm) and CO_2 ($pCO_2 = 4.97 \times 10^{-5}$ atm).

Castable SP, which contains spinel in its composition, presents a high content of saphirine ($4MgO{\cdot}5Al_2O_3{\cdot}2SiO_2$) derived from the reaction between spinel, alumina and silica at 1100 °C (Fig. 3c). After the anorthite formation, the remaining SiO_2 of the castable is consumed on the saphirine formation (Eq. (12)).

$$4(MgO \cdot Al_2O_3) + 2SiO_2 + Al_2O_3 \rightarrow 4MgO \cdot 5Al_2O_3{\cdot}2SiO_2 \qquad (12)$$

The incorporation of alumina into the spinel solid solution (about 5.8 wt% in the 1100–1300 °C temperature range) displaces the equilibrium to the $MgAl_2O_4$(ss)–mullite–saphirine compatibility triangle and induces mullite formation at 1400 °C (Eq. (13) and Fig. 3c).

$$4MgO \cdot 5Al_2O_3{\cdot}2SiO_2 + 2Al_2O_3 \rightarrow 4(MgO \cdot Al_2O_3) + 3Al_2O_3{\cdot}2SiO_2 \qquad (13)$$

The spinel and liquid amount increases due to the anorthite, mullite and saphirine decomposition between 1400 °C and 1500 °C. Furthermore, no changes to the SiC and C contents were detected between 1100 °C and 1600 °C (Fig. 3c) in the SP castable composition and the SiC content derived from its initial oxidation by CO(g).

2.1.4. *Reducing atmosphere containing 10 g or 0.40 moles of CO(g)*

In this case, the high amount of mullite and saphirine formed after the SiC oxidation was the main change in the studied castables at 1100 °C. SiC content did not change in the range from 1100 °C to 1500 °C and above this temperature, SiC generation and C consumption mechanisms for each castable composition are distinct. As quoted before, the increase of SiC content in the AL castable composition is carried out by the reaction between mullite and carbon (Eq. (11)). On the other hand, the SP castable does not present mullite in its composition above 1500 °C and the SiC generation is only related to the reaction involving liquid SiO_2 and carbon from the refractory (Eq. (10)). At 1600 °C, about 4.1 wt% of SiO_2 is required to form SiC in the spinel containing castable.

According to Eq. (10) and the thermodynamic predictions, the SiC content increases from 7.8 wt% to 8.8 wt% (Fig. 3d) and 3.8 wt% of CO is equivalent to 0.16 moles of gas (pCO = 0.992 atm, $pSiO = 6.73 \times 10^{-3}$ atm, $pMg = 7.26 \times 10^{-4}$ atm and $pCO_2 = 4.98 \times 10^{-5}$ atm). At 1600 °C, the castable SP presents a lower gas phase and SiC formation than the AL one, but the presence of Mg(g) indicates that spinel decomposition (Eq. (4)) and/or the reaction between MgO(l) and C(s) (Eq. (14)) might occur.

$$MgO(s) + C(s) \leftrightarrow Mg(g) + CO(g) \qquad (14)$$

It is believed that role of Mg(g) on the SiC oxidation at high temperatures is negligible, due to the low amount of this phase in the equilibrium condition. The SiC content in the AL and SP castables (as a function of temperature and up to 1500 °C) are very similar (Figs. 2 and 3), but the reaction between mullite and carbon is the main cause for the increase in the SiC content (from 7.8 wt% to 12.7 wt%) in the composition without spinel. Moreover, the SiO_2 content as a liquid in the AL and SP castable at 1600 °C, are: 3.4 wt% and 6.7 wt%, respectively. Therefore, the lower SiC content in the SP castable results from the refractory's transformations and reactions involving SiO_2 and C. There was no evidence that the spinel sped up SiC oxidation and based on the calculations carried out using the FactSage® software, the spinel addition to Al_2O_3–SiC–C castables did not affect SiC oxidation.

Table 2
Summary and comparison between experimental and thermodynamic results.

Castable's component			SiC (wt%)		SiO_2 (wt%)		C (wt%)	
Compositions			AL	SP	AL	SP	AL	SP
Experimental values [1]	1500 °C		9.5	8	4.5	7.5	3	4.3
Temperature (1500 °C)								
Thermodynamic results		0.08 moles CO(g)	13.6	13.6	2.1	2.1	3.3	3.3
		0.16 moles CO(g)	12.1	12.1	0	4.3	4.6	4.6
		0.28 moles CO(g)	10.0	10.0	0	7.5	6.5	6.5
		0.40 moles CO(g)	7.8	7.8	0	10.7	8.4	8.4
Temperature (1600 °C)								
Thermodynamic results		0.08 moles CO(g)	13.6	13.6	2.1	2.1	3.3	3.3
		0.16 moles CO(g)	12.7	12.1	3.3	4.3	4.0	4.6
		0.28 moles CO(g)	12.7	10.0	3.3	7.5	4.0	6.5
		0.40 moles CO(g)	12.7	8.8	3.3	9.2	4.0	7.5

3. Comparison between the experimental results and thermodynamic calculations

Although the experimental results showed that the AL and SP samples have different SiC and C contents after thermal treatment at 1500 °C, in the thermodynamic equilibrium these values are similar, even when distinct CO(g) contents are presented in the environment. Table 2 shows a summary of the experimental and thermodynamic results. According to the thermodynamic predictions, SiC and C values in the AL and SP castables will only be distinct above 1500 °C, due to the reactions involving mullite (Eq. (11)) and SiO_2 (Eq. (10)) with the carbon from the refractory.

Nevertheless, it is believed that the equilibrium condition was not attained in the tests performed by Kageyama et al. [1], due to the remaining 4.5 wt% of SiO_2 in the AL castable sample. This fact indicates that the reaction between Al_2O_3 and SiO_2 to form mullite was not completed and silica was still present in the refractory.

Spinel addition did not accelerate SiC oxidation under the thermodynamic equilibrium condition at 1500 °C. Most likely, the higher liquid phase amount generated in the SP castable composition, at high temperatures, may affect its working performance over time.

The amount of CO(g) added to the reacting system induces SiC oxidation at temperatures higher than 1100 °C. Moreover, in the same conditions and in the thermodynamic equilibrium, AL and SP castables must present the same values as SiC and C at 1500 °C.

4. Concluding remarks

Although, the SiC content in the Al_2O_3–$MgAl_2O_4$–SiC–C (SP) castable samples fired at 1500 °C and in a reducing atmosphere was lower than the Al_2O_3–SiC–C (AL) ones, the same trend was not observed in the thermodynamic predictions conducted using the FactSage® software. According to the calculations, the amount of SiC, SiO_2 and C might change due to some transformations at temperatures higher than 1500 °C.

Mullite formation and its presence in the castable composition at high temperatures induces the SiC generation due to the mullite reaction with the carbon in the AL castable samples. On the other hand, the addition of spinel to the SP castable allows saphirine's formation and in the temperature range of 1300–1500 °C, only a small amount of mullite might be formed in the refractory castable. At temperatures higher than 1500 °C, the reaction involving SiO_2 from the liquid phase and C from the solid, increases the SiC amount. In addition, spinel addition might also help forming a high amount of liquid phase, which could affect the refractory performance. Thus, according to the thermodynamic predictions, the lower SiC amount is not associated to the spinel addition, but to the reaction transformations of the AL and SP castables.

Acknowledgments

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