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The Process of Oxide Non-Metallic Inclusion Dissolution in Slag

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The process of nonmetallic inclusions (Al_2O_3, $MgO{\cdot}Al_2O_3$ and MgO) dissolution in synthetic slags of system CaO-Al_2O_3-SiO_2 as well as in the industrial slag at 1550 °C is investigated in present research. Investigations are carried out using high-temperature confocal laser scanning microscope.

Keywords: NON-METALLIC INCLUSION, SLAG, DISSOLUTION, DISSOLUTION RATE, HIGH-TEMPERATURE CONFOCAL LASER MICROSCOPE

Introduction

Non-metallic inclusions lead to significant deterioration of qaulity and mechanical properties of finished steel products [1]. Inclusions from products of deoxidation, reduction, steel and slag interaction and from fragments of refractories can appear during out-of-furnace treatment [2]. Appeared non-metallic inclusions should be moved to the interface metal-slag and transformed into slag phase in which they will dissolve in order to improve cleanness of steel. Except for hydrodynamic flows in the molten steel, such properties of phase boundary line metal-slag as wetting quality [3] affect the transition of non-metallic inclusions into slag. The process of nonmetallic particle dissolution in molten slag can be investigated using high-temperature confocal laser scanning microscope (CLSM) [4-7].

The purpose of present research is to investigate the dissolution process of nonmetallic particles Al_2O_3, $MgO{\cdot}Al_2O_3$ and MgO in two synthetic three-phase slag systems: CaO-Al_2O_3-SiO_2 and in the industrial slag by means of CLSM. Additionally, effect of Al_2O_3 content in slag on dissolution rate and mass transfer was investigated.

Methodology

Heat chamber of high-temperature confocal laser scanning microscope (CLSM) is shown in **Figure 1**.

Grinded particles Al_2O_3, MgO and $MgO{\cdot}Al_2O_3$ with size 250-350 microns were applied in the investigation. Synthetic slags were composed of $CaCO_3$, SiO_2 and Al_2O_3, remelted, cooled and grinded. Further, their chemical composition was analyzed with the use of roentgenofluorescence spectrometer (RFA). Industrial slag was taken from the intermediate ladle. Chemical composition of slag is presented in **Table 1** and **Figure 2**. The basic capacity (CaO/SiO_2) was 1 in synthetic slag and 1.3 in the industrial.

Before investigation slag samples (0.09 grams) were melted in the platinum crucible and soaked for 5 minutes at 1550 °C for the purpose of homogenization. Then slag was cooled, a nonmetallic particle was placed on slag surface (**Figure 1b**), slag together with the particle was heated up to 1550 °C. Slag was melted down during the heating process and the particle was sinking to crucible bottom. The time of reaching the bottom was the start point of smelting process. Change of particle area in time was measured from recorded video by means of "analysSIS5.0®" program. Then we calculated the equivalent radius R of the particle and ratio between remained volume of the particle and its area.

Results and Discussion

Behavior of particles during dissolution

The chemical composition of slag affects the process of nonmetallic particle dissolution. The particle can dissolve uniformly on the whole surface or pointwise only in some points of the surface. As a result, dissolution process can progress with smooth or rough surface that has a further effect on dissolution rate. During dissolution Al_2O_3 has a smooth surface, while $MgO{\cdot}Al_2O_3$ forms a rough one. Both types of particles dissolve in the observed slag systems in a diffusion way without any chemical reactions. And rates of particle radius decrease and density of mass flow are constant during the whole dissolution process, and volume change of particle weight changes linearly in time. Change of dimensionless equivalent radius of Al_2O_3 particle in synthetic slag is presented in **Figure 3** as an example.

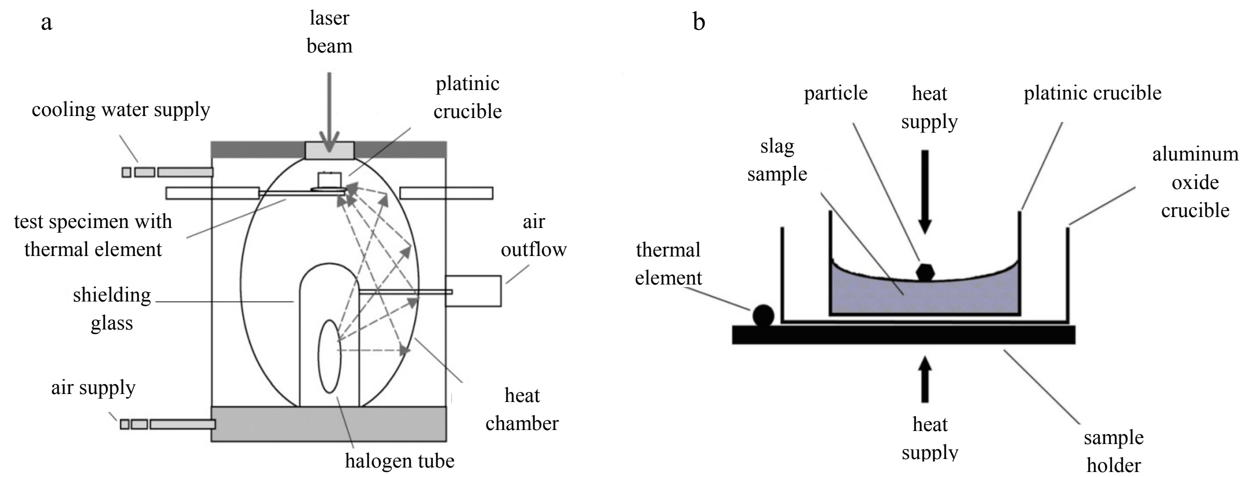

Figure 1. Heat chamber (*a*) and arrangement of investigated systems in this chamber (*b*)

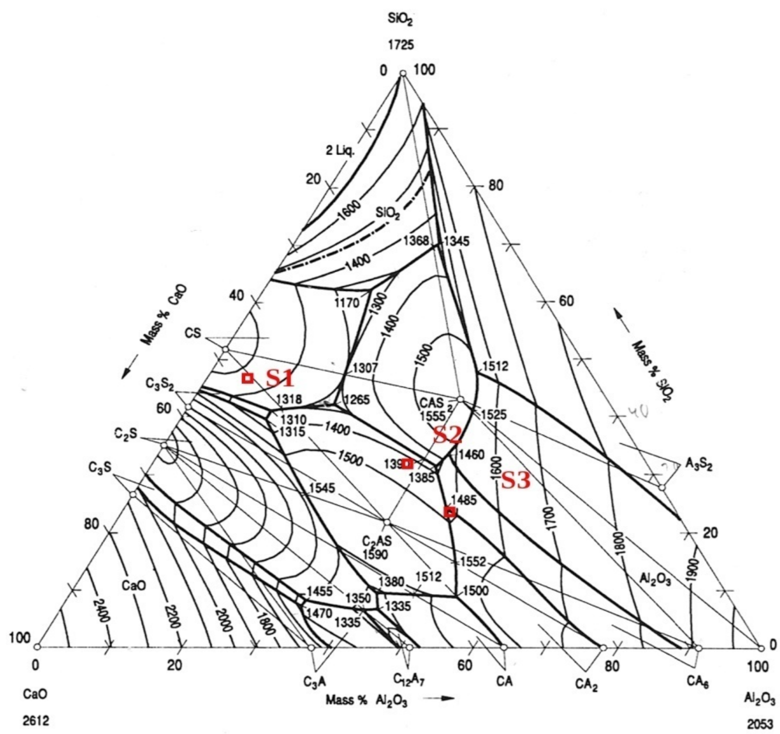

Figure 2. Phase diagram of slag system CaO-Al_2O_3-SiO_2 [8]

The process of MgO dissolution in slag S2 can be divided in three periods (**Figure 4**). In the first period, particles dissolve in a diffusion way. This period lasts approximately 20 seconds. A dense spinel layer $MgO \cdot Al_2O_3$ is formed around particles due to chemical interaction of dissolved MgO with slag in the end of this period. This layer slows down further dissolution. Particles are dissolved in the area surrounded by $MgO \cdot Al_2O_3$. By the certain moment (it is 290 seconds in the given example which is 90 % of total dissolution time) the particle is completely dissolved in its inner shell. Spinel dense layer is dissolved in the same period because of dynamic equilibrium between spinel phase dissolved in slag and dense layer. The second period is finished with complete dissolution of spinel layer. The third period is related to particle structure destruction on small parts which are distributed in the slag and dissolve very fast. The similar phenomenon of MgO dissolution has been already described in work [7].

Intensity of dissolution

Average intensity of dissolution is the relation of initial radius R_0 to time of dissolution τ. Obtained values of dissolution intensity are presented in **Table 2**. Increase of aluminum oxide content by 30 % in slag S_2 as compared to S_1 leads to decrease of intensity of Al_2O_3 dissolution from 2.14 to 0.47 mkm/s. Further increase of aluminum oxide content by 10 % in the industrial slag even more slows down the dissolution process. Intensity of $MgO \cdot Al_2O_3$ dissolution decreases with increase of aluminum oxide content in slag. Increase of Al_2O_3 content by 40 % in slag S_3 as compared to S_1 reduces intensity of dissolution in 7 times. Dissolution intensity drops as well as Al_2O_3 content grows at dissolution of MgO particles.

Table 1. Composition of investigated slag

Slag	Mass content of oxides, %								Type
	CaO	SiO_2	Al_2O_3	Cr_2O_3	Fe_2O_3	MgO	MnO	TiO_2	
S1	48.0	46.7	5.3	-	-	-	-	-	synthetic
S2	32.6	31.7	35.7	-	-	-	-	-	synthetic
S3	26.1	19.8	46.9	0.2	0.5	2.6	0.9	2.1	industrial

Table 2. Initial radius of particles and average intensity of dissolution in slags S1, S2, S3

Slag	Al_2O_3		$MgO \cdot Al_2O_3$		MgO	
	R_0 [mkm]	R_0/τ [mkm/s]	R_0 [mkm]	R_0/τ [mkm/s]	R_0 [mkm]	R_0/τ [mkm/s]
S1	195	2.14	170	2.50	157	1.54
S2	169	0.59	178	1.62	170	0.54
S3	148	0.47	169	0.36	157	-

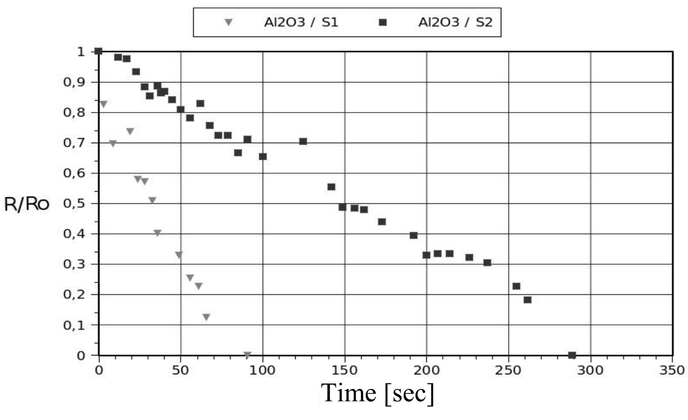

Figure 3. Change of dimensionless equivalent radius of Al_2O_3 particles in synthetic slags, R_0 – initial radius

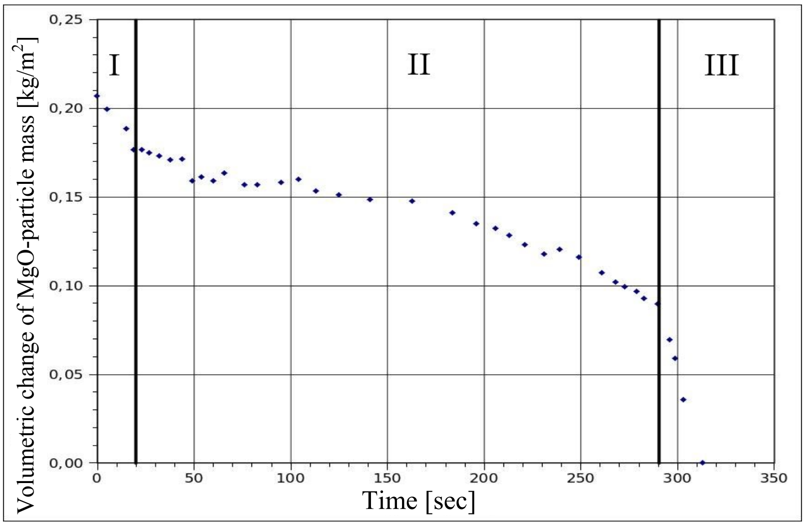

Figure 4. Volumetric change of MgO-particle weight during dissolution in slag S2

Density of mass flow

The density of mass flow at dissolution in slag is particle mass variation per unit time. The density of mass flow of Al_2O_3 - and $MgO·Al_2O_3$ particles during the whole dissolution process is presented in **Table 3**.

The density of mass flow at dissolution of Al_2O_3 in slag S_1 is 2.7 g/m² and only 0.52 g/m² in slag S_3 with higher concentration of Al_2O_3. Points corresponding to chemical composition of slag S_1 and S_3 at 1550 °C are in the field of isotherms with lower and higher melting temperatures on the structural diagram (**Figure 2**), which is the cause of reduction of mass flow density in the second case. The density of mass flow at dissolution of $MgO·Al_2O_3$ also depends on Al_2O_3 content in slag.

Density of mass flow at MgO dissolution in slag S_2 changes in absolutely different way (**Figure 4**). Dissolution of MgO particle begins with density of mass flow equal to 1.4 g/m²·s. By the start of second period of dissolution it drops to 0.21 g/m²·s because of dense spinel layer on the surface. Spinel layer is dissolved after complete dissolution of MgO particles.

As a result, density of mass flow is 4.0 g/m²·s in the third period.

Table 3. Density of mass flow during dissolution

	Density of mass flow [g/m²·s]		
Slag	Al_2O_3 (ρ = 3.8 g/cm³)	$MgO·Al_2O_3$ (ρ = 3.4 g/cm³)	MgO (ρ = 3.4 g/cm³)
S1	2.66	2.02	1.06
S2	0.67	1.51	0.21 – 4.0
S3	0.52	0.30	-

Conclusions

The process of non-metallic inclusion dissolution in slag depends on chemical composition of inclusion and slag. The increase of Al_2O_3 content in slag reduces intensity of dissolution and density of mass flow. It is determined that Al_2O_3 and $MgO·Al_2O_3$ are dissolved in a diffusion way at the constant rate.

Dense spinel layer is formed at MgO dissolution which slows down the process of total dissolution.

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Процесс растворения оксидных неметаллических включений в шлаке

Хагеманн Р., Петцольд Л., Шеллер П.Р.

В данной работе представлены исследования процесса расстворения неметаллических частиц (Al_2O_3, $MgO·Al_2O_3$ и MgO) в синтетических шлаках системы $CaO-Al_2O_3-SiO_2$, а также в промышленном шлаке при температуре 1550 °C. Исследования проводились в высокотемпературном конфокальном лазерном сканирующем микроскопе.