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## INTERACTION BETWEEN NON-METALLIC INCLUSION AND SLAG

The non-metallic inclusions are assimilated by slag in the tundish and CCS crystallizer during the refining process. The following slag-phase elements participate in this process:

- converter slag, which entered the ladle upon pouring,
- slag-forming mixtures in the form of synthetic slags or mould powders purposefully introduced to the ladle,
- steel deoxidation products, which nucleate then flow out and are assimilated by slag,
- elements of worn out refractory lining of ladles and ceramic casing as well as the products of secondary steel oxidation, a result of contact of open metal surface with atmosphere or oxidizing slag.

The assimilation of non-metallic particles by slag is determined by such parameters as: viscosity of slag, density of non-metallic inclusion and of slag, interfacial tension: non-metallic inclusion/slag $\sigma_{IS}$, non-metallic inclusion/steel $\sigma_{IM}$, steel-slag $\sigma_{MS}$.

A system of forces is acting on a particle: gravity force and capillary force, which are oriented downward, also buoyancy, taking the opposite direction and viscous drag force.

**buoyancy force** $F_W = \frac{4}{3} \cdot \pi \cdot R^3 \cdot (\Delta_b \cdot \rho_S - \rho_W) \cdot g$ $F_b = \frac{4}{3} \cdot \pi \cdot R^3 \cdot (\Delta_b \cdot \rho_s - \rho_i) \cdot g$

$$F_B = \frac{4}{3} \cdot \pi \cdot R^3 \cdot (\Delta_b \cdot \rho_s - \rho_i) \cdot g$$

$$\Delta_b = \frac{1}{4} \cdot \left(\frac{\rho_M}{\rho_S} - 1\right) \cdot \left(\frac{Z}{R}\right)^3 - \frac{4}{3} \cdot \left(\frac{\rho_M}{\rho_S} - 1\right) \cdot \left(\frac{Z}{R}\right)^2 + \frac{\rho_M}{\rho_S}$$

$\Delta_b = \frac{1}{4} \cdot \left(\frac{\rho_M}{\rho_S} - 1\right) \cdot \left(\frac{Z}{R}\right)^3 - \frac{4}{3} \cdot \left(\frac{\rho_M}{\rho_S} - 1\right)\left(\frac{Z}{R}\right)^2 + \frac{\rho_M}{\rho_S}$ **capillary force** $F_\sigma = (-2 \cdot \pi \cdot R + 2 \cdot \pi \cdot Z) \cdot \sigma_{MS} + 2 \cdot \pi \cdot R \cdot \sigma_{WS} - 2 \cdot \pi \cdot R \cdot \sigma_{WM}$

$$F_\sigma = (-2 \cdot \pi \cdot R + 2 \cdot \pi \cdot Z) \cdot \sigma_{MS} + 2 \cdot \pi \cdot R \cdot \sigma_{IS} - 2 \cdot \pi \cdot R \cdot \sigma_{IM}$$

**viscous drag force** $F_{VIS} = 6 \cdot \pi \cdot R \cdot \eta_S \cdot B \cdot \frac{dZ}{dT}$ $F_{VIS} = 6 \cdot \pi \cdot R \cdot \eta_S \cdot B \cdot \frac{dZ}{dT}$

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As a result of operation of these forces the particle remains in the lowest layer of slag, where it can be dissolved partly or completely, or it may be moved back to metal and entrained by the steel flow. A necessary condition for an inclusion to penetrate slag is appropriate energy resulting from the outflow velocity.

The results of calculations of the capillary force acting on a non-metallic particle in the vicinity of the liquid steel-slag interface and the inclusion's position are presented in figs. 1 (r = 10 μm). The simulations were made for various values of surface energy on the liquid steel and slag contact, at a constant energy of the inclusion-slag and inclusion-liquid steel interfacial tension $\sigma_{IM}$ = 1.5 N/m, slag–inclusion interfacial tension σIS = 0.1 N/m, and 3 various values of surface energy on the liquid steel and slag contact: variant 1: $\sigma_{MS}$ = 0.8 N/m, variant 2: $\sigma_{MS}$ = 0.6 N/m, and variant 3: $\sigma_{MS}$ = 1.0 N/m.

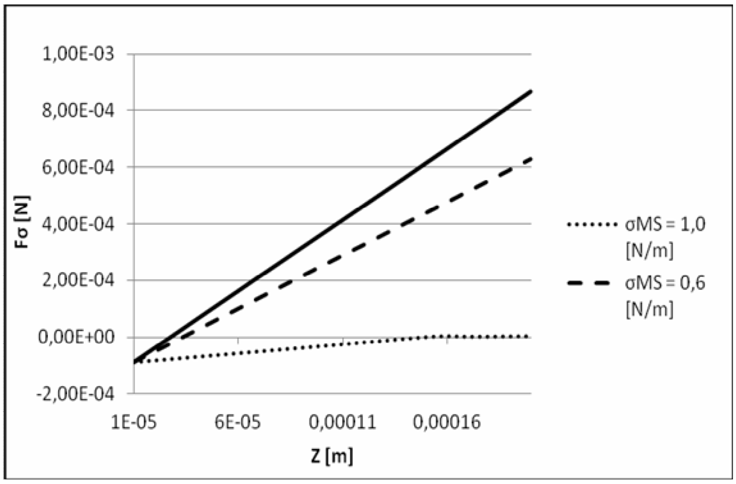


Fig. 1. Calculated capillary force Fσ acting on inclusion particle of radius r = 0.00001 [m] in the vicinity of interfaces for surface energy: $\sigma_{MS}$ = 1.0 [N/m], $\sigma_{MS}$ = 0.8 [N/m] and $\sigma_{MS}$ = 0.6 [N/m] against coordinate Z.

The aggregation of particles in bigger groups enhances the process of their removal from steel, thus increasing the metallurgical purity and quality of ready products. The main forces acting on the non-metallic particle, i.e. capillary force and buoyancy depend on the position and size of the particle. The value of the capillary force acting on the particle increases as the inclusion approaches the interface; the change of steel-slag surface energy does not change this trend. The analysis of calculation results of capillary force acting on a particle in the vicinity of the steel-slag interface at changing surface energy values between inclusion and slag show that capillary force depends on the interfacial tension between inclusion and slag only to a small degree.

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**References**

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## INTERACTION BETWEEN NON-METALLIC AND SOLIDIFICATION FRONT

The process of steel solidification in the CCS crystallizer is accompanied by a number of phenomena relating to the formation of non-metallic phase, as well as the mechanism of its interaction with the existing precipitations and the advancing crystallization front. In the solidification process the non-metallic inclusions may be absorbed or repelled by the moving front. As a result a specific distribution of non-metallic inclusions is obtained in the solidified ingot, and their distribution is a consequence of these processes. The interaction of a non-metallic inclusion with the solidification front was analyzed for alumina, for different values of the particle radius. The simulation was performed with the use of own computer program. Each time a balance of forces acting on a particle in its specific position was calculated. On this basis the change of position of alumina particle in relation to the front was defined for a specific radius and original location of the particle with respect to the front.

Physically this phenomenon describes a system of forces acting on a particle and from which we have a velocity vector. In a situation corresponding to the conditions of COS crystallizer, the following system of forces acts on a particle:

– force of gravity: $F_g = \frac{4}{3} \cdot \pi \cdot r^3 (\rho_m - \rho_{cz}) \cdot g$

– viscous resistance force $F_d = 6 \cdot \pi \cdot \mu \cdot r \cdot V_p \cdot \theta$

Coefficient $\theta$ depends on the direction of the particle and its distance from the front $\mathbf{h}$ :for particles distant from the front: $\theta = 1$, for particles approaching the front: $\theta = \frac{\mathbf{r}}{\mathbf{h}}$, for particles moving parallel to the front: $\theta = \ln\left(\frac{\mathbf{r}}{\mathbf{h}}\right)$

– Saffman force: $F_S = 6.46 \cdot \mu \cdot r^2 \cdot V_{cz} \cdot \sqrt{\frac{S}{\nu}}$