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VALUES OF THE SOLUTAL MARANGONI NUMBER IN VERY DILUTE Fe-C-O SOLUTIONS AT 1873K

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ABSTRACT

Low carbon, aluminum killed steels are well represented by the adequate part of the Fe-C-O system, where are available useful experimental data, regarding the surface tension and viscosity. The reference dynamic characteristic scale, of about 1-2μm at which local chemical inhomogeneities where experimentally observed in some particular conditions is possible to be extended at around 10μm and even more, according to basic relations .A characteristic concentration of 0.0001%mass oxygen was taken into account at 1873K. At oxygen contents up to 0.0020%mass and at low contents of carbon(0.05-0.15%mass), the values of the Marangoni solutal number (Ma_s) always were found to be higher than the critical values($Ma_s^c = 50$*) especially due to the reduction of the viscosity with the oxygen content. When the dynamic characteristic length is 6μm, Ma_s=379 and the parameter* ε *=6.58, permitting the development of hybrid convection roll cells. Even at such high dilutions, in Fe-C-O solutions at 1873K, the convection due to the solutal effect is present.At a concentration of 0.0017%massO(soluble) takes place a change of the relations between viscosities and between the value of Marangoni numbers.It is sugegested that the finally induced dynamics in liquid steels are responsible for some decreasing of the steel cleaness.*

KEYWORDS: surface tension, characteristic length scale, viscosity, Marangoni number

1.Introduction

Advanced refining and controlled solidification, in normal and low gravity conditions lead to materials of higher purity and controlled structure. In systems with specific reactions, affecting the surface tension and viscosity, like in low carbon, aluminium killed steels, the evaluations of aspects regarding the local dynamics of layers at mico and nanoscale could contribute to the quality increasing.Fe-C-O system, at low dilutions is closed to this class of steels grades. Traditionally, only sensible higher contents of soluble oxygen are considered to exert an influence on the surface tension of the steels, also on the interfacial tension. In real conditions, liquid steels are processes for different purposes, including for advanced refining, in an advanced state of deoxidization, when soluble oxygen content is of order of several ppm. In this paper are analised the values of the Marangoni numbers at very low dilutions of oxygen in the system Fe-C-O. The oxygen content must be understood as being totaly in solution.

2. Local effects of surface tension variations

The qantitative aspects of local convection in the limit layer (100-10μm), usualy are annalysed under many simplified premises. It is generally accepted that the thermal Marangoni effect in liquid steels is small when compares with the solutal and electrical Marangoni effects[2].

In ref. [1] it is suggested that interfacial chemical reactions induce Marangoni and natural convection at slag- metal interface, leading to interfacial waves, due to Kelvin-Helmholtz instability, causing the waves to become instable and lead to emulsification of slag in steel and of steel in slag, affecting the quality of steels at high aluminum and/or titanium contents.

In ref. [2], at the interface, it was found that solutocapillarity contributed only with 15% to the maximum interfacial depression. Aspects of the interface dynamics argue that at higher initial rates of interface reactions, the interfacial area becomes even higher due to the droplet emulsification [1][2]. A length scale of inhomogeneity of 1-2μm was established based on the presence of pockets of fluid of the same dimensions [2], with different oxygen contents, moving about within the bulk Protuberances of the near the interface, during the early stages of the involved reaction [1]. same size were observed on the droplet surface [2].These dimensions of the local instability are more realistic compared to those reported in the ref. [1].In principle, it is mentioned [1] that both thermal and chemical variations at interface give rice to Marangoni flow along the interface and since the viscosity of metal and of slag largely differs, the velocity of the motion of each phase, parallel to the interface, will be different.

A reference scale length in the systems of liquids(density ρ_l) in equilibrium with their vapors(density ρ_g) is the capillary length expressed in forms given by rel. (1)[3] or rel (2)[4]:

$$l_c=\sqrt{\gamma/g\rho} \qquad (1)$$

$$l_c^2=2\gamma/g(\rho_l-\rho_g) \qquad (2)$$

Rel.(1) dictates the curvature of the interface far away from the contact line with a solid substrate[3], rel.(2) governs the propagation of the capillary waves[4].The variation of the length scale, as effects of the local variations of the surface tension γ could be considered as a dynamic characteristic length scale(l_c’) , having similar forms:

$$l_c^{'}=\sqrt{\Delta\gamma/g\rho}\ ,\ \Delta\gamma(c)=\gamma(c_1)-\gamma(c_2) \qquad (3)$$

$$l_c^{'}=\sqrt{\frac{\partial\gamma(c)}{\partial c}c_0/g\rho} \qquad (4)$$

The solutal Marangoni number(Ma_S) is given in the following forms:

$$Ma_S=\left(-\frac{\partial\gamma}{\partial c}\right)c_0L/\mu D \qquad (5)$$

The term between brackets is the coefficient of dependence of the surface tension (γ) upon concentration (*c*) of the surface active element, the sign (-) being taken when to avoid negative values of the Ma number; c_0- is a characteristic concentration; *L*- is a characteristic length, m; μ- dynamic viscosity, Ns/m^2; *D*- diffusivity of the surface active element , m^2/s.

Frequently are used modified forms of Ma_s as $\Delta c=c_s-c_b$, between surface (c_s) and bulk (c_b) concentrations, also for *L* could be considered one of proposed forms in rel. (3) or (4)

3. Results

Following data for Fe-C-O system containing up to 0.0020% mass O and up to 0.15%mass C, were used:

1.Surface tension dependence upon mass percentage content of oxygen, at T=1873K[5]; according to experimental data from[6], up to carbon contents of 0.5%mass, there is not an influence on surface tension :

$$\gamma=1.903-0.28\ln(1+170[\%O] \qquad N/m \qquad (6)$$

2.Kinematic viscosity(ν) dependences upon mass percentage content of oxygen , are obtained from base relation established in [7], in 10^{-7} m^2/s:

-at C=0.05%mass

$$\nu=9.453-2072.527[\%O]-31107.5[\%O]^2-1.42x10^7[\%O]^3 \qquad (7)$$

-at C=0.10%mass

$$\nu=8.632-1473.113[\%O]-94290[\%O]^2-1.42x10^7[\%O]^3 \qquad (8)$$

-at C=0.15% mass

$$\nu=7.881-955.269[\%O]-149227.5[\%O]^2-1.42x10^7[\%O]^3 \qquad (9)$$

Dynamic viscosities are computed using the relation;

$$\mu=\nu.\rho \qquad Ns/m^2 \qquad (10)$$

3. At 1873K, diffusivity of oxygen in iron is D_O=11.7x$10^{-9}$$m^2$/s and density of liquid iron is taken ρ= 7038Kg/m^3 [8].

The value of the characteristic length scale taken into account is 1μm in normal gravity, being of the same magnitude with the experimentally found inhomogeneity domain extend (1-2μm)[2].

The characteristic concentration (Δc =)c_0= =0.0001%mass oxygen.

In fig.1 are presented corresponding values of the Ma_S, resulting values Ma_s>Ma_s^c(=50) on all range of considered contents of oxygen.

As an example, at values of $l_c^{'}$=6μm and c_0=0.0001%O mass, in an alloy containing 0.05%C and 0.0005%O, when Navier and Biot numbers are zero, the parameter describing the distance from the threshold of the instability , ε [8] is:

$$\varepsilon=(Ma_s-Ma_s^c)/Ma_s^c=(379-50)/50=6.58 \qquad (11)$$

At values ε >6.3 convection rolls, hybrid cells are formed[9].

In fig.1 at a value of about 0.0017% mass oxygen a the relations between the viscosities of Fe-C-O predicted based on the relations(7)-(9) change and because of this situation, also the relations between the viscosities.

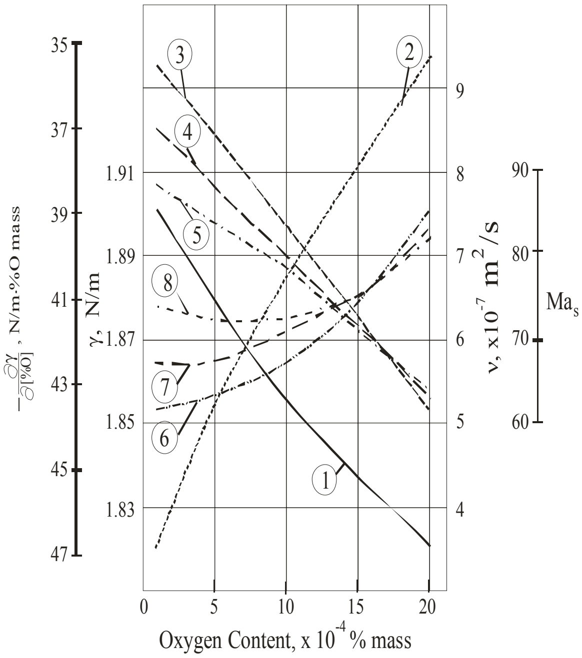

Fig. 1. *Values of Marangoni numbers in Fe-C-O system at low contents of solutes and the evolution of some related quantities, at 1873K, in normal condition of gravity. 1- surface tension* γ *; 2-concentration coefficient of the surface tension,* $\partial\gamma / \partial[\%O]$ *;3,4,5-kinematic viscosity* ν *at 0.05%C, 0.10%C, 0.15%C, respectively; 6,7,8- Marangoni solutal numbers at 0.05%C, 0.10%C, 0.15%C, respectively.*

4. Conclusions

In dilute Fe-C-O systems, at 1873K, corresponding to some classes of steel grades, even small variations of solutes are able to promote a local pattern of flow due to the Marangoni effect.

Values of $Ma_s > Ma_s^c (=50)$ are obtained for local characteristic concentrations or variations of 0.0001%mass O, when C=0.05-0.15%mass, at microscale corresponding to an experimentally determined inhomogeneity of 1μm.

Increasing of the oxigen content leads to increasing of Ma_s values, due to their effect in decreasing the viscosity and in a lower decreasing of the absolute values of concentration coefficient of the surface tension. At higher values of the involved parameters variations, higher values of Ma_s are obtained.

A value of the soluble oxygen content of 0.0017% mass appeared as being a particular point where the relations between viscosities and the values of the Marangoni numbers change and on this account it would be possible that the quality in some industrial steel grades to be affected.

Based on the aspects mentioned in this paper it could be better explained some unexplained cases when some indicators of quality in steel, like cleaness in non-metallic inclusions decrease in the final stage of processing in liquid state.

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