INVESTIGATION OF MOLD FLUXES PROPERTIES USED IN THE CONTINUOUS CASTING OF STEELS

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ABSTRACT

Mold fluxes or mold powders are synthetic slags used to cover the liquid pool surface during the continuous casting of steel. The main task of mold fluxes is the creation of a lubricant film between steel strand and the refrigerated mold. After melting, in contact with the molten steel, the mold powder forms a slag which changes its chemical composition as function of time. These changes occur at the slag / metal interface, and have also implications on the friction force between solidified shell and the copper mold. The study of these frictional forces is important for two reasons: (i) to prevent sticker breakouts (B.O.) and (ii) to improve ingot surface quality, which is affected mainly by frictional forces. Alumina absorption by mold flux slags causes an important effect on frictional forces, since the mineralogical constitution of slags depends on it. The results of the present paper suggest that computational thermodynamics can be used to predict the chemical interactions of mold fluxes in contact with liquid steel. Thus, the best possible conditions during the continuous casting of steel products in terms of product quality and production stability can be identified.

INTRODUCTION

Mold fluxes or mold powders are synthetic slags used to cover the liquid pool surface during the continuous casting of steel. The main task of mold fluxes is the formation of a lubricant film between steel strand and the refrigerated mold. After melting, in contact with the molten steel, the mold powder forms a slag which changes its chemical composition as function of time. Because of these changes some slag properties are altered, *e. g.* viscosity. These chemical transformations, which occur at the liquid slag / liquid metal interface, have also implications on the friction force between solidified shell and the copper mold [1].

The study of these frictional forces is important for two reasons: (i) the prevention of sticker breakouts (B.O.) and (ii) the improvement of ingot surface quality, which is affected mainly by frictional forces. As the majority of surface defects on cast products originate in the mold due to bad lubrication conditions, it is of prime importance to limit as much as possible the friction level. For *on spot* mould monitoring systems, there are relations among friction level and the three main types of surface defects: inclusions, longitudinal and transverse cracks. Although the B.O. prevention remains an important problem and can be even epidemic on some casters, the major priority in terms of caster economics is the surface quality. Statistics over a large number of casters have indeed shown that in general the annual cost for surface inspection and repair can be as high as five times the annual cost due to B.O. incident [2].

Frictional forces were measured at plant [3] and it was concluded that alumina absorption by mold flux slags had an important effect on the frictional forces, since the mineralogical constitution of the analyzed plant slags was a function of their alumina content.

Some works have been devised searching for ways to assess the frictional forces between the solidified shell and the copper mold during continuous casting of steel. There are various tests to simulate these frictional forces; on this context the chemical interactions between liquid slag (mold powder) and liquid steel are of great importance [1].

The kinetics of the chemical interactions exerts a strong influence on the magnitude of the interfacial tension acting between liquid steel and liquid slag during mass transfer. Under conditions of intense mass transfer, the interfacial tension will often decrease to very low values, and will remain at this general level until the system approaches its chemical equilibrium, at which point the interfacial tension will gradually increase and ultimately attain an essentially constant (or equilibrium) value [4]. Interfacial energies in actual industrial systems vary greatly with the exact slag chemistry that is found in the mold of the continuous caster and also as a function of time [5].

The objective of the present work is to evaluate the chemical interactions between a proprietary mold flux in contact with a TRIP steel, with the help of the computational thermodynamics, using the *FactSage* software tool. The influence of the chemical interactions on the interfacial tension would be further studied in a future work.

METHODOLOGY

The software employed in the present work is *FactSage* version 5.5. It contains the module *Equilib*, which is the Gibbs energy minimization workhorse of *FactSage* [6]. It calculates the concentrations of chemical species at the state of thermodynamic equilibrium from elements or compounds selected as input. The following databases were used in the present work:

- *FToxid solution database* (FToxid53Soln.sda): contains oxide solutions evaluated and optimized by the FACT group; one of these is the molten slag phase, which contains the system CaO-SiO_2-Al_2O_3-FeO-Fe_2O_3, where all available data for binary, ternary and quaternary sub-systems have been fully optimized. Other systems such as slags containing Mn e F are not optimized in a complete way. The molten slag phase is represented accordingly to the modified quasichemical model.

- *FACT53* (FS53Base.cdb): contains data for over 4500 compounds (pure substances) from standard compilations as well as most of the data for those compounds which have been evaluated and optimized to be thermodynamically consistent with the FACT FToxid solution database.
- *FSstel* (FSSTEL53BASE.CDB): this database is intended to provide a sound basis for calculations covering a wide range of steelmaking processes. The phase *Fe-LIQUID* was used in the present work.

RESULTS AND DISCUSSION

Thermodynamic simulations were done considering the composition of the proprietary mold flux Accutherm Al4D, from Stollberg, in contact with a TRIP steel.

Several thermodynamic equilibria were calculated for a fixed amount (100 grams) of the mold flux and increasing amount of the TRIP steel. The slag composition as *oxides*, as a function of steel amount, can be seen at Figure 1. All the calculations were done at 1530ºC. The zero value for steel mass means the original composition of the mold flux. No oxygen was added to the system, i. e. the simulations were done under severely reducing conditions. This consideration makes sense since the carbon content of the mold fluxes creates a reducing atmosphere on the top of the steel pool.

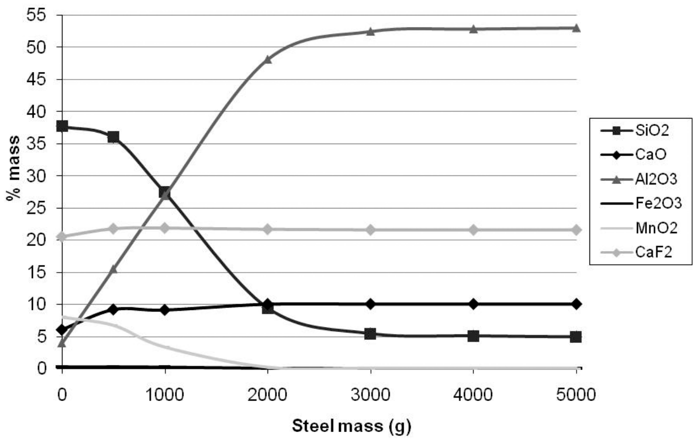

Figure 1: Variation in liquid slag chemical composition calculated with FactSage software at 1530ºC

Results from an experimental analysis done to assess the kinetic behavior of reactions between the same mold powder Accutherm Al4D and the TRIP steel used in the aforementioned simulation are shown in the literature [1], Figure 2. The experiments – at laboratory scale – were done in the temperature range of 1525-1535ºC. Samples were taken at time intervals starting from the point where the mold flux was put in contact with the molten steel (time zero). The evolution of the slag composition as a function of time was evaluated through chemical analysis. The great increase in alumina content of the slag – with the simultaneously diminishing amount of silica – can be clearly seen.

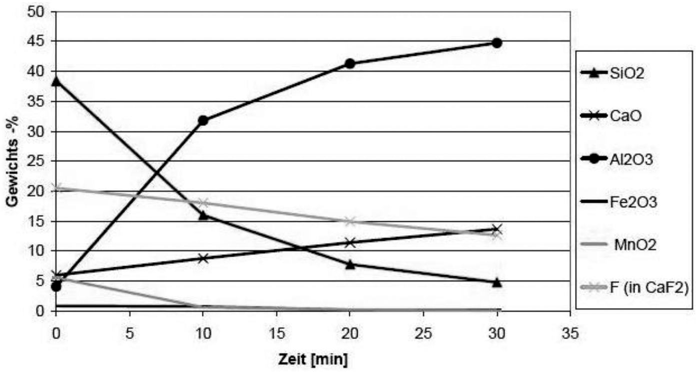

Figure 2: Variation in liquid slag chemical composition with time (experimental work) [1]

From a comparison of the theoretical with the experimental results, a good correspondence is found. This is actually an astonishing conclusion, since results shown in Figure 1 are from a thermodynamic (timeless) analysis, while Figure 2 displays experimental results, directly coupled with the velocity of reactions (rate phenomena). Thus, they are of an absolutely different nature.

The following Figure 3 is a compilation of data from Figures 1 and 2. Figure 3(a) contains the results of the aforementioned experimental work [1] and Figure 3(b) displays the seven points showed at Figure 1 (calculated by *FactSage*).

Given a certain allowance, these results suggest that computational thermodynamics can be used to evaluate the chemical interactions between mold flux and steel as a function of time.

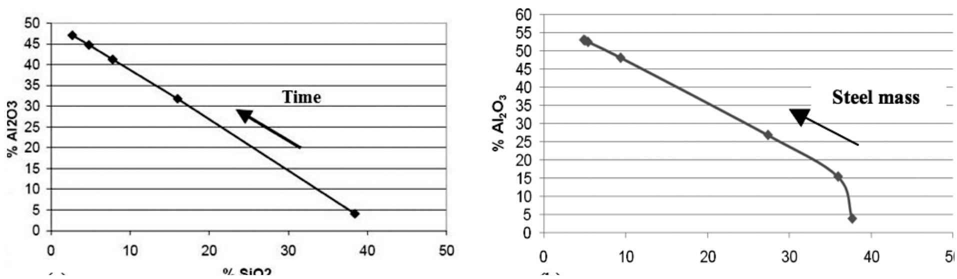

Figure 3: $\%Al_2O_3$ versus $\% SiO_2$ content: (a) results of an experimental work [1]; (b) results from a thermodynamic determination (present work)

Frictional forces were measured on plant [3] and it was concluded that alumina content of mold flux slag had a significative effect. In this context, the mineralogical constitution of the plant slags was very important. These researchers found some interesting relations between the frictional force at the mould and the chemical composition of the slag. These relations are showed at Figures 4, 5 and 6.

Figure 4 shows the friction force as a function of $\%Al_2O_3$ content for mold fluxes *A* (left) and *C* (right) during continuous casting of slabs (aluminum-killed steel). For the mold flux A a drastic decrease of the friction force when $\%Al_2O_3$ content of slag reaches 11% Al_2O_3 can be seen. This behavior is not verified for the mold flux *C*. The casting speed was in the range of 0,9-1.0 m/min.

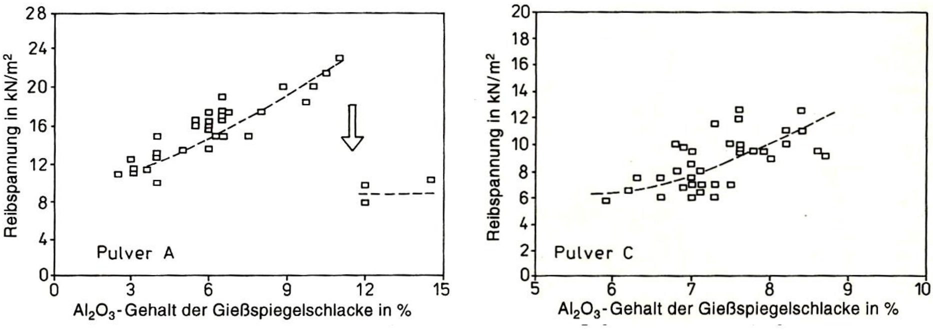

Figure 4: Friction force per unit area as a function of %Al_2O_3 [3]

Figure 5 shows main solid mineral phases coleted *on spot*, related to the mold fluxes *A* and *C* as a function of %Na_2O and %Al_2O_3. The solid phase cuspidine was ignored in this diagram, since it is always present.

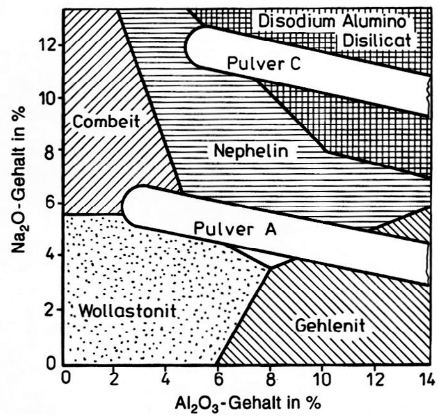

Figure 5: Solid mineral phases as function of %Na_2O and %Al_2O_3 content [3]

Figure 6 shows the relation among friction force, viscosity of meniscus slag and %Al_2O_3 of the slag, during continuous casting of slabs (for a aluminium-killed steel).

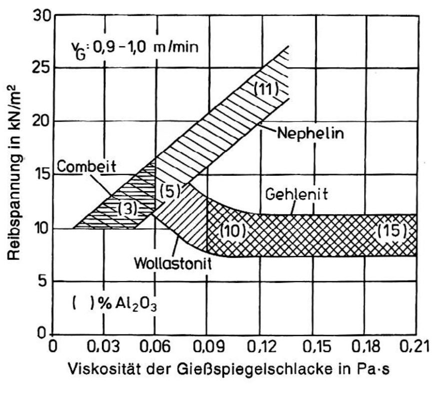

Figure 6: Friction force per unit area as a function of meniscus slag viscosity and %Al_2O_3 of the slag [3]

When comparing Figures 4, 5 and 6, it can be seen that the sudden decay of the friction force for mold flux *A* around 11% Al_2O_3 (Figure 4 – left) is related to the mineral phase transformation nepheline - gehlenite (Figure 5) and to the measured friction force, which does not increase with slag viscosity values higher than ~ 0,14 (Figure 6).

It is important to notice that in the gap between mold and strand the global friction force is not only given by viscosity and thickness of the liquid slag layer, but also by the nature and proportion of the different mineralogical phases which can exist in the mold fluxes after solidification [3]. There are different mineralogical phases, whose proportion varies depending on the crystallization characteristics of the mold flux. Then, to obtain the best possible conditions during continuous casting in terms of product quality and production stability, the effect of the different mineral phases which can exist in mold fluxes must be considered.

Sticker breakouts are caused by the interruption of the liquid slag flow into the mould/strand gap resulting from a blockage in the meniscus region. If such a blockage were to occur, it might be expected that the chemical and mineralogical composition of the slag film would have been altered; *e. g.* if the blocking agglomerate was alumina, the liquid slag layer that flows around this blockage would be richer in alumina; the slag from the shell side closer to the sticking point would be expected to be richer in alumina. Then, the conclusion was that sticker breakouts frequently occur when the casting conditions favor the formation of alumina. Because of this, it is recomended that steps should be taken, in both plant operation and design, in order to minimize steel contact with the atmosphere and the consequent oxidation of the steel [7].

CONCLUSIONS

The chemical interactions between a proprietary mold flux in contact with a TRIP steel were evaluated, with the help of the computational thermodynamics, using the *FactSage* software tool. The results and discussions of the present paper suggest that computational thermodynamics can be used to predict the complex chemical interactions of mold fluxes when in contact with liquid steel.

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