A NEW METHOD FOR DETERMINING CHEMICAL COMPOSITION OF REFINING SLAG IN THE LADLE FURNACE

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ABSTRACT

The objective of ladle metallurgy processes is to provide steel with specified final chemical composition, temperature and required inclusions cleanliness for the steel application. A ladle furnace operations strongly depend on refining ability of slag. The final result of ladle furnace operations also depends on liquid steel initial composition, alloys addition and refining slag composition. The last mentioned factor should be obtained during dynamic system analysing. A new concept of modeling the changes of metal and slag chemical composition has been elaborated. The determination of refining slag components were obtained base on equilibrium states analyse in heterogeneous system. The results of the model have been verified using an industrial database.

INTRODUCTION

A ladle furnace is a unit, that meets both essential logistic functions and the metallurgical ones. The ability to keep metal in a ladle and to control its temperature makes it possible to synchronize the work of a continuous caster (CC). The ladle furnace functions, that result from the production process organization, are controlled by the upper level of the steel mill management system. However it is another issue to realize the metallurgical functions of the ladle furnace. The appropriate work of the furnace needs the full information about the metal and the ladle slag.

Steel Refining in Ladle Furnace

The construction of a modern ladle furnace enables it to record all the most essential process parameters and enables it to construct and verify a complex model. It applies especially to the following information:

- Weight and chemical composition of the slag getting into the ladle during tapping
- Weight of metal after tapping from the furnace
- Metal temperature
- Metal chemical composition
- Oxygen activity in metal and slag before the refining process startup
- Weight of the ladle additions put into the ladle during tapping and their chemical composition
- Weight of the additions put into metal at the ladle furnace post and their chemical composition
- Intensity and time of argon injection into steel
- Oxygen activity after argon injection
- Metal chemical composition after argon injection
- Bath temperature after argon injection
- Slag chemical composition.

The aim of the conducted examination was to construct the static and dynamic model for the process realized in the ladle furnace. It was the thermodynamic model that gave the basis for the static model, enabling it to use all the above mentioned process parameters. The thermodynamic model calculations were done upon the data incorporated in the thermodynamic base FACT53 of the software FactSage v. 5.5. [5]

The dynamic model of the ladle furnace process was realized upon the hybrid model. It uses the mixing model based on the tank model theory, as well as it uses the process kinetics at the metal-slag boundary.

The key role for the prognosis correctness of the mentioned models is the knowledge about the slag state in the ladle furnace. The correct assessment of its weight and chemical composition is the key problem. Additionally, the ladle furnace slag in the preliminary process phase is not homogenous and this fact is troublesome to be included even in the phase of the conceptual model construction. Some solutions are provided by the metering probes, that enable it to determine the FeO content in slag. The solution, despite of still not being ideal, makes the right direction for development of the ladle furnace process model. It cannot be assumed for the ultimate solution, that the calculation will be done upon the tested preliminary slag composition. The time necessary to analyse the slag chemical composition is too long, to carry out the calculation in the industrial practice upon this information. [1] It is rather the slag weight and chemical composition assessment, upon the knowledge of the additions put into the ladle completed with the FeO activity measurement, that seems to be the right solution.

Anyway, it is reasonable at the model verification phase, to take slag samples before the argon injection process startup. It makes it possible to assess prognosis correctness of slag forming and the final result of bath refining.

Static Model of Ladle Furnace Process

The concept of the static model of the ladle furnace assumes, that the state close to the metal-slag equilibrium is being achieved at the refining final phase. It is the chemical composition and the weight of the formed ladle slag that have the decisive impact on the set equilibrium state. The process time has no role in the solution proposed by the static model and therefore the validity period of the static model is limited only to the process final stage.

Examinations for verifying the static model consisted of two stages. The first one incorporated the model verification in the industrial environment regarding the prognosis correctness of the metal bath chemical composition. The second one incorporated virtual experiments aimed at assessing the impact of the selected parameters on the final result of the steel refining.

The first stage of examination required constructing the model and incorporated trials to find the equilibrium state having the configuration of the known number of phases and components. The equilibrium state is defined as the state, for which, while considering all the possible reactions taking place in the configuration, the minimum value of the free enthalpy ΔG has been found. The calculations are done with the software FactSage v.5.5 [5], having the access to the required thermodynamic data. The verification of the proposed model was carried out in the 140-tonne ladle.

The correctness criterium of the model prognosis was defined as the calculation accuracy for the final content of the additions, that were added at the time of refining. The basic data necessary to carry out the calculations is presented in Table 1. The assessment of the prognosis correctness of the proposed model is presented on Figures 1 and 2, that present the calculation results for the main components in the tested groups of metals

Table 1: Specification of the testing heats used for static model verification. (T1- temperature before refining, T2- temperature after refining)

	No	Mass, Mg	T1, K	Chemical composition before refining, %						Main addition during refining, kg			
				C	Mn	Si	S	Al	O	CaSi	FeSi	MnSi	Al
GROUP I	1	139.2	1829	0.15	0.69	0.18	.064	.003	.00340	22.2	80	30	35
	2	136.8	1847	0.14	0.66	0.13	.066	.003	.00419	22.1	140	60	30
	3	139.2	1850	0.15	0.66	0.14	.073	.003	.00440	22.1	150	30	30
	4	134.4	1860	0.13	0.52	0.09	.080	.002	.00623	22	160	-	110
	5	139.2	1867	0.12	0.54	0.12	.073	.004	.00533	22.1	80	30	65
	6	136.8	1834	0.13	0.54	0.14	.076	.004	.00375	22.1	-	80	60
	7	141.6	1840	0.15	0.69	0.22	.045	.005	.00274	22.1	-	-	-
GROUP II	8	140.5	1796	0.05	0.38	0.12	.049	.003	.00112	22	-	30	10
	9	130.3	1884	0.03	0.34	0.08	.059	.003	.00775	19.8	130	20	20
	10	141.5	1872	0.04	0.36	0.09	.053	.004	.00597	19.8	100	20	40
	11	140.5	1867	0.04	0.36	0.11	.052	.005	.00606	18	60	40	33
	12	137.4	1858	0.04	0.35	0.11	.056	.003	.00551	18	70	130	40
	13	138.4	1813	0.04	0.31	0.09	.051	.003	.00426	18	70	130	40
	14	142.5	1840	0.04	0.36	0.10	.055	.002	.00553	7	-	260	30

	No	Mass, Mg	T2, K	Chemical composition before refining, %					
				C	Mn	Si	S	Al	O
GROUP I	1	139.2	1866	0.21	0.75	0.21	.035	.004	.00176
	2	136.8	1861	0.20	0.76	0.21	.030	.005	.00165
	3	139.2	1858	0.18	0.75	0.19	.034	.005	.00084
	4	134.4	18741	0.17	0.64	0.14	.026	.005	.00086
	5	139.2	1875	0.17	0.65	0.16	.031	.005	.00082
	6	136.8	1878	0.18	0.66	0.16	.043	.005	.00194
	7	141.6	1865	0.20	0.75	0.22	.015	.005	.0017
GROUP II	8	140.5	1863	0.06	0.41	0.12	.030	.003	.00187
	9	130.3	1868	0.06	0.41	0.12	.018	.004	-
	10	141.5	1869	0.06	0.4	0.11	.014	.005	.00257
	11	140.5	1873	0.06	0.41	0.13	.014	.005	-
	12	137.4	1872	0.06	0.41	0.12	.018	.00421	.00121
	13	138.4	1867	0.06	0.41	0.12	.018	.004218	.00218
	14	142.5	1867	0.09	0.78	0.11	.025	.0040204	.00204

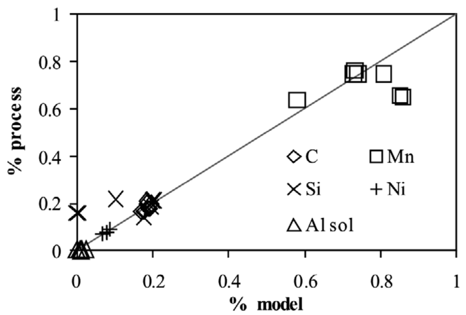

Figure 1: Prognosis findings of the model calculations for the metallic phase of the No. 1 group of heats

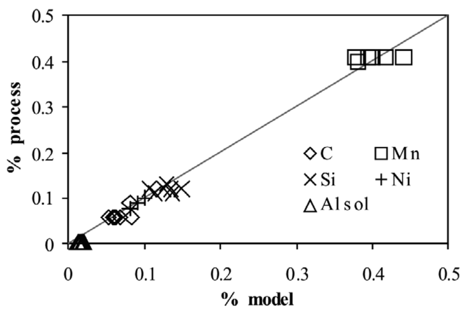

Figure 2: Prognosis findings of the model calculations for the metallic phase of the No. 2 group of heats

It can be concluded upon the findings, that the static model prognosis accuracy is satisfying. Both Mn and Si show the highest accuracy of the model prognosis for the considered steel additions in both groups. The addition criterium for the static model assessment is the final calculation correctness of the refining slag chemical composition within its main components CaO, SiO_2, Al_2O_3. Figure 3 specify the model calculations and the actual data referring to the slag main components.

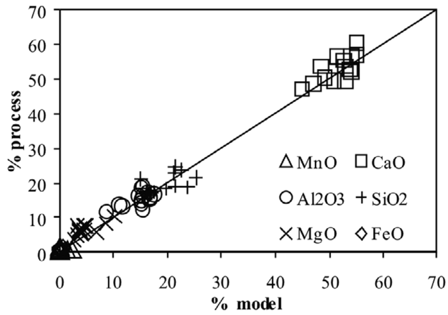

Figure 3: Prognosis findings of the model calculations for the slag phase total for group 1 & 2

Basing on the verified static model of the ladle furnace process, the impact of the ferrous oxides content in slag on the refining result has been examined. It was the yield level of the introduced alloy additions that was used as the criterium. The calculations were carried out assuming the FeO in slag percentage changing in the range from 0 to 7%. The calculations referring to aluminum are presented in Figure 4, to silicon on Figure 5 and to manganese on Figure 6.

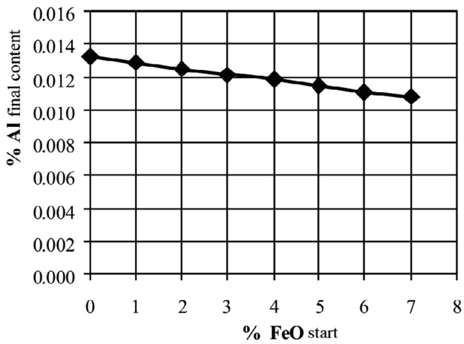

Figure 4: Al final content in the bath in relation to FeO in slag content

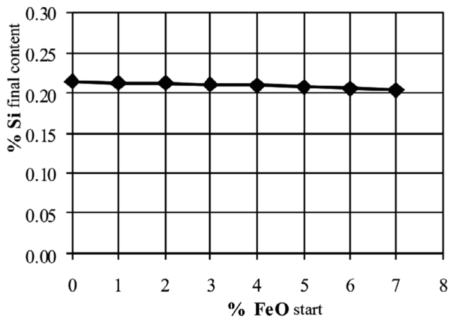

Figure 5: Si final content in the bath in relation to FeO in slag content

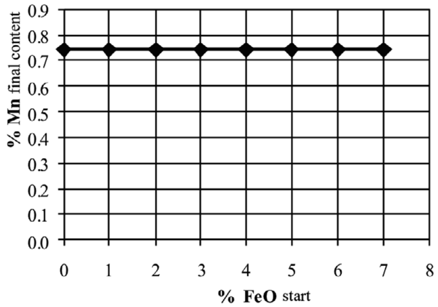

Figure 6: Mn final content in the bath in relation to FeO in slag content

As it was expected, the content increase of FeO in slag reduces the yield of the inserted alloy additions in every considered case and leads to increase of the nonmetallic inclusions in steel. In fact FeO content in slag phase has greater influence because of oxygen transport from atmosphere to metal bath. This is not taken under consideration in static model.

Dynamic Model of Ladle Furnace Process

The time period of the ladle furnace process together with continuous bath stirring with neutral gas cause, that the close to equilibrium state is achieved at the end of the process. Referring to the ladle furnace, there is no urgent need to create the dynamic model. On the other hand, in non-typical situations, e.g. while dozing additions at the end of the refining process, it is really needed to be able to access diversification of the bath chemical composition. Calculations were carried out on a hybrid model, which assumptions were presented in [2, 4].

The hybrid model is based upon the stirring model, the so called *tank model* that incorporates the thermodynamic model for reaction equilibrium simulation at the metal-slag boundary. In case of the ladle furnace, the ladle volume subdividing into tanks is presented on Figure 7 [4].

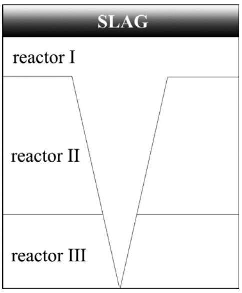

Figure 7: Ladle volume subdividing into tanks in hybrid model

The Figure 8 presents simulation finding for average $[Al]_{total}$ content in relation to the time for heat No. 1 in Table 1. The Al content change takes into account the increase caused by inserting aluminum addition to the ladle. Simultaneously, it has to be stressed, that achieving the final Al content, that is consistent with analysis done after the process finishing, did require the time being taken into account. Basing on the presented model, it is possible to simulate the other metal bath components.

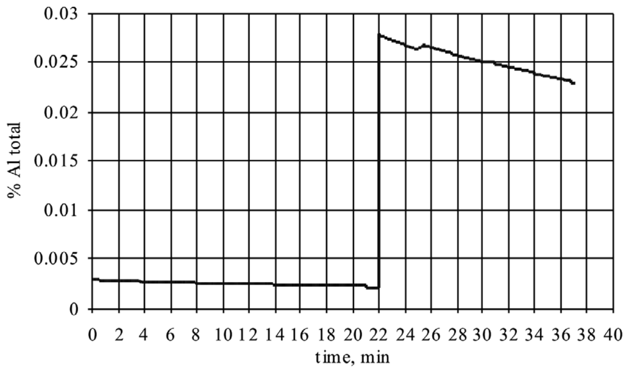

Figure 8: Change of Al content in metal bath during ladle furnace refining

CONCLUSIONS

- The ladle furnace is a unit, for which it is purposeful to create a static model in order to determine precisely the weight of the alloy additions.
- When the thermodynamic model, that uses the market available thermodynamic data bases, is applied in calculations, it makes it possible to determine the equilibrium state in very complicated metal-slag configurations.
- Complementing the static model with the dynamic one enables it to monitor the dynamics in change of metal and slag chemical compositions, and consequently to prepare better the metal bath for a continuous caster.

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