UDC/UDK 669.041:669.14
Professional article/Strokovni članek

ISSN 1580-2949
MTAEC9, 41(4)185(2007)

INVESTIGATION OF THE INFLUENCE OF THE MELT SLAG REGIME IN A LADLE FURNACE ON THE CLEANLINESS OF THE STEEL

RAZISKAVA VPLIVA REŽIMA ŽLINDRE V PONOVČNI PEČI NA ČISTOST JEKLA

Zdeněk Adolf, Ivo Husar, Petr Suchánek

VŠB-Technical University of Ostrava, Department of Metallurgy, 17. listopadu 15/2172, Ostrava-Poruba, 708 33, Czech Republic
zdenek.adolf@vsb.cz

Prejem rokopisa – received: 2006-10-16; sprejem za objavo – accepted for publication: 2007-01-15

An experimental investigation of the influence of the ladle slag's chemical composition, the ladle slag's mass and the furnace slag's mass (during the tapping flow in the ladle) on the sulphur content in steel was carried out. The parameters of the slag and the steel were obtained in operational conditions of oxygen LD converter melts and from the subsequent ladle furnace LF processing.

Key words: ladle furnace, steel processing, effect of slag composition, refining effect

Eksperimentalna raziskava vpliva kemične sestave, količine (pri izlivu jekla v ponovco) na vsebnost žvepla v jeklu. Parametri jekla in žlindre so določeni pri izdelavi jekla v kisikovem konvertorju in obdelavi taline v ponovčni peči.

Ključne besede: ponovčna peč, procesiranje jekla, sestava žlindre, rafinacijski učinek

1 INTRODUCTION

Steel refined in a ladle furnace should have the following characteristics prior to casting:

- a chemical composition within the prescribed interval of alloying-element content and limited amounts of impurities,
- the required metallographic purity in terms of composition, magnitude, number and density of inclusions,
- the required casting temperature, depending on the steel's liquidus temperature.

In order to achieve these parameters the steelmaker usually has at his or her disposal a reheating ladle furnace, aluminium wire and a cored wire feeder, the mixing of steel with argon blowing or with induction stirring and an oxygen activity measurement system.

The slag is the most important factor for ensuring the quality of molten steel in the ladle. Ladle slag is formed from the products of de-oxidation of the steel, the added mixtures and from the corrosion products of the ladle lining, particularly at the slag line. Admixtures added intentionally to the slag ensure the required chemical composition of the slag, its fluidity and its ability to refine steel, i.e., for the absorption of inclusions and unwanted elements from the steel. The admixtures consist mostly of lime, fluorspar, calcium carbide and fireclay. Also, synthetic slags usually containing Al_2O_3, CaO, MgO, SiO_2, and a minimum of iron oxides, MnO and sulphur are used more and more often. Slags are often prepared from waste materials, either by simple mixing or by sintering, while the most expensive slags of the highest quality are manufactured by re-melting the input raw materials. These slags are usually used as a replacement for fluorspar and for the preservation of the required fluidity and for obtaining a sufficient refining effect in the ladle.

In this article the slag regime in a ladle furnace during steel refining, partly under fluorspar and partly under alumina slags, is compared. The slag regime of heats was evaluated with respect to the type and mass of the additions to the ladle, the ladle slag mass, the mass of converter slag overflowed to the ladle, the mass of corroded ladle lining and the slag desulphurisation capacity.

2 CHARACTERISTICS OF THE HEATS

The investigated steel I (intended for rail production) has an increased content of carbon (0.70–0.76 %), manganese (0.85–0.85 %) and silicon (0.30–0.40 %), controlled amounts of sulphur (0.01–0.02 %) and limited amounts of aluminium (0.003 %). It is, therefore, produced according to a technology without the use of aluminium and the deoxidation of steel in the ladle with coke, FeSi and MnSi. At the same time, during the tapping from the LD converter slag-forming materials are added to the ladle, e.g., lime (1200 kg), fluorspar (300 kg) and fireclay (150 kg), or lime, fluorspar and synthetic slag CCA with high contents of Al_2O_3 (see **Table 1**).

Table 1: Chemical composition of the synthetic slag CCA
Tabela 1: Kemična sestava sintetične žlindre CCA

w/%	Al_2O_3	CaO	MgO	SiO_2	S	Granularity
average	55.05	26.60	6.56	3.21	0.0295	5–50 mm
min	53.60	26.10	6.21	3.21	0.0290	
max	56.50	27.10	6.91	3.21	0.0300	

The refining of the rail steel was compared to that of the structural steel II with 0.18–0.20 % C, 0.41–0.51 % Mn, 0.20–0.30 % Si, with limited sulphur content (0.020 %) and a specified aluminium content (0.015–0.030 %). During tapping to the ladle this steel is deoxidised by aluminium and alloyed with FeMn and FeSi. At the same time, lime (1200 kg) and fluorspar (200 kg), or lime (900 kg) and synthetic slag CCA (700 kg), replacing the fluorspar, are added to the ladle.

The average chemical composition of ladle slags based on lime and fluorspar prior to the exit from the LF stand is given in **Table 2**.

Alumina slags were formed during the making of steel I for rails with synthetic slag CCA (700 kg) with 800 kg of lime (variant A), or with 600 kg of lime (variant B), and during the making of structural steel II with the synthetic slag CCA (700 kg) with 900 kg of lime. **Table 3** gives their average chemical compositions.

The average content of FeO in the fluorspar slags was 0.55 %, and in the alumina slags it was 2.0 %. If we compare both types of slags, then fluorspar slags have approximately 8 % to 11 % more CaO, higher basicity and a significantly higher content of CaF_2, which is added to the ladle during tapping in the form of fluorspar. On the other hand, alumina slags have higher contents of Al_2O_3 (by 9 % to 13 %) and MgO (by 1.5 % to 3.5 %). The synthetic slag CCA is, apart from converter slag and lime, also a source of MgO and Al_2O_3.

3 RESULTS AND DISCUSSION

The mass of the slag in the ladle was calculated from the balance of CaF_2 (Steel I - fluorspar slags) and from the balance of Al_2O_3 (Steel I and II - alumina slags). The mass of converter slag that overflowed into the ladle was calculated from the balance of CaO, and the extent of the wear of the ladle from the balance of MgO in the ladle slag. These data are for fluorspar slags and for two variants of alumina slags (rail steel I or structural steel II) summarised in **Table 4**.

The data in **Table 4** shows that ladle slags differ primarily in terms of their mass. Steel I fluorspar slags are formed, apart from SiO_2, from deoxidising silicon, lime, fluorspar and fireclay. The sum of the masses of these three components in the charge was approximately 1720 kg. The converter slag that overflowed into the ladle during the tapping affects the mass and the

Table 2: Chemical composition of the fluorspar slags (CaF_2)
Tabela 2: Kemična sestava fluoridnih (CaF_2) žlinder

w/%	CaO	SiO_2	Al_2O_3	MgO	CaF_2	S	Basicity
Steel I - rails							
average	52.9	23.5	4.2	4.9	13.29	0.64	2.25
min	50.9	21.9	3.5	4.5	11.74	0.42	2.12
max	55.2	25.2	5.1	5.7	14.48	0.75	2.52
Steel II - structural							
average	56.41	19.34	12.94	7.02	4.22	0.41	2.92
min	50.30	17.40	10.90	5.30	2.84	0.28	2.52
max	59.80	21.70	14.60	14.00	6.11	0.66	3.23

Table 3: Chemical compositions of alumina slags (CCA)
Tabela 3: Kemična sestava aluminatnih žlinder (CCA)

w/%	CaO	SiO_2	Al_2O_3	MgO	CaF_2	S	Basicity
Steel I - rails							
Variant A							
average	45.2	22.3	15.4	8.11	1.0	0.23	2.02
min	45.0	20.9	15.0	7.88	0.6	0.19	1.93
max	45.5	23.6	15.7	8.50	1.8	0.20	2.15
Variant B							
average	44.7	20.1	17.9	8.5	0.9	0.23	2.22
min	44.0	18.9	17.4	7.7	0.2	0.14	2.13
max	45.3	21.3	18.3	9.3	1.5	0.31	2.44
Steel II - structural							
average	45.23	17.89	22.05	8.51	0.10	0.20	2.53
min	41.10	15.50	18.00	6.80	0.00	0.13	2.12
max	48.30	21.10	25.30	11.00	0.27	0.31	2.95

Table 4: Parameters of ladle slags
Tabela 4: Parametri ponovčne žlindre

m/kg	LS	CS	MgO lining
Steel I - rails			
Fluorspar slags			
average	2411	325	71.5
min	2319	291	52.6
max	2508	380	82.9
Alumina slags – variant A			
average	2569	564	99.1
min	2519	431	93.4
max	2637	745	111.0
Alumina slags – variant B			
average	2210	590	69.0
min	2161	521	64.9
max	2273	719	75.6
Steel II – structural			
Fluorspar slags			
average	3374	1495	88.4
min	2632	153	57.3
max	4092	2800	99.8
Alumina slags			
average	3650	1693	86.9
min	2743	323	59.3
max	4645	3308	101.0

Note:
mass LS = mass of ladle slag, *m*/kg
mass CS = mass of converter slag that overflowed into the ladle, *m*/kg
MgO lining = wear of ladle lining, *m*/kg

chemical composition of the ladle slag. The mass of the slag in the heats with fluorspar slag was approximately 250 kg lower than the average for heats with alumina slag, for which a slightly lower overall mass of ladle slag was used. Alumina slags are formed of lime and synthetic slag CCA with an average mass of 1510 kg in variant A, and 1310 kg in variant B (again, apart from the SiO_2 from the deoxidising silicon).

For steel II the fluorspar slags are formed, apart from SiO_2 and Al_2O_3, from deoxidising silicon and aluminium, of lime and fluorspar with a total mass of 1400 kg; for alumina slags fluorspar is replaced with the slag CCA and the new mass of lime and slag CCA is 1600 kg.

The wear of the lining is expressed as the mass of MgO released from the ladle wear into the slag. The smallest lining wear for steel I was observed in the variant B, while the greatest wear was observed for the variant A of alumina slag. This is apparently related to the considerable differences in the total mass of slag in the ladle. The fluorspar slag shows – contrary to expectations – on average a low wear of lining; however, with a large scatter of values of approximately 30 kg of MgO.

The mass of converter slag overflowed into the ladle was, for the structural steel, three to five times greater then for the steel I. The share of converter slag in approximately 35 % of the total slag mass in the ladle is the source of the relatively high content of MgO in the ladle slag. The wear of the lining is practically the same for both types of ladle slags, and it is more influenced by the slag's mass then by the slag's chemical composition.

The parameters of the steel II desulphurisation with fluorspar and alumina slags are given in **Table 5**.

Table 5: Parameters of steel II desulphurisation by fluorspar and alumina slags
Tabela 5: Parametri razžveplanja jekla II s fluoridno in z aluminatno žlindro

	c'_s	$w\ [S]_{BOF}/\%$	$w\ [S]_{LF}/\%$	$\eta/\%$	Ls
Fluorspar slag					
average	0.009945	0.026	0.011	68.769	40.24
min	0.006744	0.016	0.006	47.619	15.56
max	0.015171	0.043	0.018	80.000	55.00
Alumina slag					
average	0.002481	0.030	0.019	36.131	11.42
min	0.001426	0.018	0.011	20.000	4.48
max	0.003582	0.038	0.029	52.778	20.71

Note:
c'_s= sulphide capacity of slag, [1]
$[S]_{BOF}$ = sulphur content in steel during tapping from the converter, *w*/%
$[S]_{LF}$ = sulphur content in steel after treatment in the ladle furnace, *w*/%
η = rate of steel desulphurisation after treatment in the ladle furnace, %
Ls = distributing coefficient of sulphur (S_{slag} /S_{steel}), [1]

It can be concluded from Table 5 that fluorspar slags have a greater desulphurisation effect than alumina slags (see η, Ls), due to their higher basicity and their higher value of sulphide capacity given by the CaO content, which is on average higher by 10 %.

It was observed that fluorspar slags had a greater fluidity than alumina slags. This means that a small content of CaF_2 (up to 5 %) in the fluorspar slag increases the fluidity of this slag in a wide range of chemical compositions, especially of the CaO content. In contrast to this, the liquidity of the alumina slags can only approach that of the fluorspar slags in a relatively narrow range of content of the more active oxides (CaO, Al_2O_3, SiO_2, MgO). It is necessary to increase the CaO content to at least 50 %, the Al_2O_3 content to 25–30 %, and preserve the SiO_2 content at the level of 15–20 % and the MgO content at the level of 7 % in order to increase the sulphide capacity of the alumina slag to the level of the fluorspar slag.

4 CONCLUSION

The slag regime of heats during the making of rail steel I with a limited content of aluminium, increased amounts of C, Mn and Si and with controlled amounts of sulphur and structural steel II deoxidised by aluminium with a limited sulphur content are compared. The original fluorspar slag with low amounts of Al_2O_3 was substituted with an alumina slag in which the fluorspar was replaced by synthetic slag CCA.

The following conclusions from the comparison of both slag regimes of these heats (based on 200-tonne heats) are proposed:

a) Alumina slags formed by lime, synthetic slag CCA and the products of steel deoxidisation have a lower desulphurisation capacity then the fluorspar slags due to their lower CaO content.

b) The main advantage of fluorspar slags is in their great desulphurisation effect over a wide range of slag chemical compositions, even for a low CaF_2 content.

c) The liquidity of alumina slags is limited to a narrow range of CaO, Al_2O_3, SiO_2 and MgO content.

d) The mass of ladle slags is markedly affected by the volume of furnace slag overflowed into the ladle that has to be minimised.

e) The wear of the lining depends on the mass of the ladle slag. The effect of the slag's chemical composition is of minor importance.

This investigation was carried out in the frame of Grant project Reg. No. 106/04/0029 with the financial support of the Grant Agency of the Czech Republic and the project EUREKA Reg. No. OE214, with the financial support of the Ministry of Education, Youth and Sports of the Czech Republic.