THE INFLUENCE OF SLAG ON DEGRADATION OF TUNDISH WORKING LINING

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Received: 09.09.2013
Accepted: 18.04.2014

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Abstract
This paper is focused on the influence of the slag formed by covering and refining powders on lifetime, respectively on the wearing of the working lining of tundish. The experimental part deals with the influences of used covering and refining powders on the working. Besides the influence of covering and refining powders is also considered the influence of the ladle well filler and slag from the ladle. The wear of the lining is evaluated using the change in dimensions of working lining in the range of slag mark on particular tundishes. Based on chemical composition of the slag and thermodynamics are modeled chemical reactions causing corrosion of the refractory material. The experimental part contains also comparison of measured chemical composition of the slag during the sequence with material balance.

Keywords: continuous casting, corrosion, refractory lining, slag, refining and covering powders

1 Introduction

In present 92.8% of world steel production is casted on continuous casting machine. Therefore great emphasis is given to maximalize effectivity of this process. The key phase of continuous casting is tundish so that's why major attention is given to it. The lifetime of tundish working lining is affected especially by tundish slag, which consists of covering and refining powders [1]. This slag also contains other, unwanted components as ladle well filler and slag from ladle, while its amount is difficult to estimate, when the material balance should be calculated.
In solving issues related to technology, which affects the degradation of the tundish working linings are most important the results of experimental tests. These more or less extensive data sets are characterized with a precision observed phenomenon, eg. some physical or chemical parameter [2, 3]. The aim of this experiment was to examine influence of covering and refining powders on the degradation of the tundish lining in the operating conditions [4, 5, 6].
Effect of the covering and refining powder on degradation of tundish working lining based on MgO was observed on two tundishes. Two types of covering powders and one type of refining powder were used during the experiment. The system of analyses was as follows:

- Measuring the dimensions of tundish at the area of the slag line at specified points before pre-heating,
- Taking samples of slag from the tundish during sequence at periodical intervals,
- Measuring the dimensions of the tundish at the area of the slag line at specified points after casting

DOI 10.12776/ams.v20i3.357 p-ISSN 1335-1532
e-ISSN 1338-1156

- Taking samples of refractory lining from the slag line,
- Analysis of slag chemical composition,
- Analysis of samples taken from tundish refractory lining.

The processing of analysis:

- Modelling of interactions in the examined system consists of the slag, steel, refractory lining and atmosphere
- Comparison of the slag chemical composition and material balance
- The description of influence of individual slag components on refractory lining corrosion
- Evaluation and comparison of the impact of the investigated powders on tundish working lining corrosion

Based on thermodynamics can be expected some reaction processes between the slag components and tundish refractory lining [7]. These reactions may take place between the slag components, while their product subsequently reacts with components of the lining through the interphase interface between the slag and lining. It may be an ongoing reaction inside the refractory elements between slag and lining components, assuming that the slag phase to get through the pores inside the refractory material.

2 Methodology of experiment

2.1. Working lining of tundish

During the experiment it was used monolithic working lining JEMATUN H3, based on MgO. The thickness of this lining was 50 mm to 100 mm. Chemical composition of the lining is following: MgO- 84%; Fe_2O_3- 7,5%; CaO- 3%; SiO_2- 2,5% a Al_2O_3- 0,4%. This lining has the chemical bond and its operation temperature is 1680°C. Granulometry of gunning material is 0-1 mm.

2.2. Used covering and refining powders

During the experiment was evaluated the influence of refining powder Refraflux 4248S in combination with a cover powder Intratherm-Calcinex Nera, or KP 1/S on tundish lining degradation. The composition of the covering and refining powders and ladle well filler Tesand IPC 8020 is in **Table 1**.

Table 1 The composition of the covering and refining powders and ladle well filler Tesand IPC 8020

	SiO_2 [%]	Al_2O_3 [%]	CaO [%]	MgO [%]	Fe_2O_3 [%]	C [%]	TiO_2 [%]	Cr_2O_3 [%]
Intratherm Calcinex Nera	92,6	3,2	-	0,1	0,089	3,2	0,007	0,089
Refraflux 4248S	4	42	48	1	2	-	2	-
KP 1/S	39	12	6	9	6	25	-	-
IPC Tesand 8020	83	-	-	-	-	1	-	13

2.3. Determination of dimensional changes of tundish lining in the slag line area

Dimensions of new lining were measured in five reference points. View the reference measurement point and place of sampling lining is shown in **Fig. 1**. Dimensions of the lining were re-measured after the sequence at the same points. These were the points at the first and

DOI 10.12776/ams.v20i3.357 p-ISSN 1335-1532
e-ISSN 1338-1156

fourth tundish well, in the middle of the tundish, in the inlet and also were measured thickness of baffle.

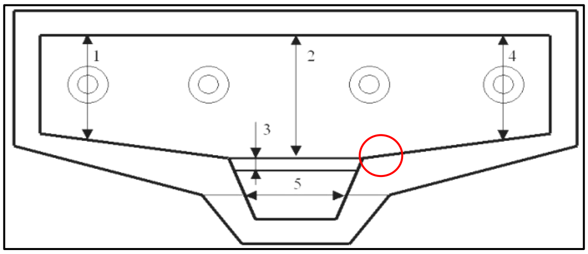

Fig.1 Reference measurement points and location of sampling lining

During the casting with tundishes No.11 and No.8 was taken four samples of slag. According to the level of melt of used powders always the first sample was taken after opening the fourth ladle. Additional samples were taken after the opening of the eighth, twelfth and fourteenth ladle. Samples were taken always above the first tundish well.

3 Discussion

3.1 Evaluation of the individual refining and covering powders on refractory lining loss of thickness

The measured values of tundish refractory lining thickness loss are in the **Tables 2** and **3**.

Table 2 Dimensions changes in the tundish No.11 in the slag line area

Reference point	Berore pre-heat [mm]	After casting [mm]	Dimension change [mm]
1	495	500	-5
2	910	Baffle broken	-
3	100	Baffle broken	-
4	505	515	-10
5	655	725	-70

Table 3 Dimensions changes in the tundish No.8 in the slag line area

Reference point	Berore pre-heat [mm]	After casting [mm]	Dimension change [mm]
1	485	510	-25
2	870	Baffle broken	-
3	95	Baffle broken	-
4	490	515	-25
5	670	790	-120

After casting it was not possible to measure their size in the middle part, or to determine the thickness of baffle, as has always been broken, as illustrated by **Fig. 2**.

Duration of casting, the number of casted heats and the average basicity of slag in the tundish are shown in **Table 4**. Based on measured values it can be seen that the use of covering powder KP 1 / S (tundish No. 8) occurred from 2.5 to 5 times greater loss of thickness of the lining above tundish well and nearly two-times decrease in the inlet of the tundish as using covering powder Intratherm-Calcinex Nera (tundish No.11). The higher lining wear in tundish No. 8

DOI 10.12776/ams.v20i3.357 p-ISSN 1335-1532
e-ISSN 1338-1156

occurred despite the fact that the basicity of slag was higher than in tundish No.11. This could be due to a longer time of casting about 47 minutes, but also by different chemical composition and viscosity of slag then in tundish No.11.

Fig.2 New and broken baffle

Table 4 Casting time, slag basicity and amount of casted heats

Tundish No.	8	11
Duration of casting	16h:17min	15h:30min
Basicity	0.72	0.47
Casted heats	14 (770t)	14 (770t)

3.2 Evaluation of changes in chemical composition of the slag during the casting

Analysis of the slag samples composition from tundish No. 11 and No. 8, are listed in **Tables 5** and **6**. The material balance of materials entering into the slag during the sequence should also cover the ladle well filler and the slag from EAF, which is also heavily involved as the total remains slag basicity, as well as its chemical composition. Expression of ladle well filler quantity is calculated from the consumption on 1ton of steel, which means that each casting ladle volume of 55 tons of steel brings about 20.52 kg of ladle well filler with the chemical composition given in Table 1. It is complicated to express slag quantity which passes from ladle into the tundish and it depends on the human factor due to used technology of slag detection. The changes in slag chemical composition can negatively affect steel cleanness [8, 9].

Table 5 Slag composition during casting in the tundish No.11

Ladle(batch)	**Fe sum. [%]**	**MnO [%]**	**SiO_2 [%]**	**CaO [%]**	**MgO [%]**	**Al_2O_3 [%]**	**Cr_2O_3 [%]**	**Basicity [-]**
4	0.91	10.3	42.1	16.2	7.1	16.3	0.26	0.399
8	1.04	8.62	40.1	19.3	8.52	17	0.13	0.487
12	0.94	3.9	61.3	16.6	7.14	9.98	0.06	0.333
14	0.6	3.58	35.9	24.4	11.9	17.6	0.07	0.679

Table 6 Slag composition during casting in the tundish No.8

Ladle(batch)	**Fe sum. [%]**	**MnO [%]**	**SiO_2 [%]**	**CaO [%]**	**MgO [%]**	**Al_2O_3 [%]**	**Cr_2O_3 [%]**	**Basicity [-]**
4	2.56	1.76	31.7	16.2	9.08	28	0.24	0.4234506
8	0.26	1.34	29.8	30.3	11.1	22.4	0.03	0.7931034
12	0.32	1.07	30.5	26.9	12.4	21.5	0.06	0.7557692
14	0.28	0.9	30.7	27.5	15.5	17.5	0.22	0.8921162

DOI 10.12776/ams.v20i3.357 p-ISSN 1335-1532
e-ISSN 1338-1156

3.3 Description of interactions in the slag – refractory lining system

Selected expected chemical reactions using the software HSC 5.1 are listed in **Table 7**. In the tundish, in which covering powder KP1/S was used, it is possible due to its carbon content to assume that the consequent reduction of Fe_2O_3 in the lining by carbon from the slag. It is also expected formation of tricalcium silicate by reaction of CaO with SiO_2 in the slag as well as in the lining. Reaction of MgO from lining with Al_2O_3 and SiO_2 from the slag is also possible and product will be cordierite. It can also happen to create monticellite $CaO.MgO.SiO_2$ as low-melting compounds causing washing-off MgO grains from lining and its subsequent decline in thickness. Another low-melting compound, resulting from the reaction between MgO from lining and CaO and SiO_2 from the slag is akermanite, the principle of corrosion lining of this product will be similar to the monticellite. On the reaction interface slag - lining it is also possible to assume the presence of forsterite $2MgO.\ SiO_2$ [10, 11].

Table 7 Assumed interactions between slag and refractory lining components

Oxide from lining	Slag component	Product of reaction	ΔGT °1500°C [kJ.mol-1]	Melting point [°C]	Product
Fe_2O_3	C	Fe, C	-432.75	1538	ferrum
CaO	SiO_2	Ca_3SiO_5	-185.93	-	tricalcium silicate
MgO	CaO, SiO_2	Ca3Mg(SiO_4)2	-160.86	-	merwinite
MgO	Al_2O_3, SiO_2	Al4Mg2Si5O18	-142.15	-	cordierite
MgO	CaO, SiO_2	$2CaO.MgO.2SiO_2$	-136.53	1454	akermanite
MgO	CaO, SiO_2	$CaO.MgO.SiO_2$	-121.78	1503	monticellite
MgO	SiO_2	$2MgO.SiO_2$	-41	1890	forsterite

3.4 Evaluation of working lining samples

Visual comparison of samples of working lining is shown in **Fig. 3**. Reaction surface samples can be divided into three zones according to the effects of exposure. For both samples it is seen higher wear in the area of slag line. Due to the low strength of the sample from tundish No.8 part that was exposed to the steel failed. For sample from tundish No.8 rounded slag line radius is greater than in samples from tundish No.11. For both samples, the whole volume of the samples is in addition to the pores and cracks with length from 3 mm to the full width of the sample. Through this cracks in some cases the molten slag penetrated to the permanent lining.

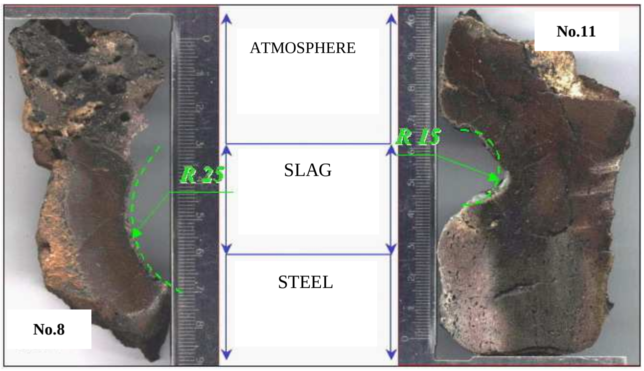

Fig.3 Visual comparsion of samples of working lining

DOI 10.12776/ams.v20i3.357 p-ISSN 1335-1532
e-ISSN 1338-1156

In the case of sample from the tundish No. 8 a radius of slag line is 25 mm and in sample from tundish No. 11 it is about 15 mm. A significant difference in the size of the radius of curvature can be caused both by a significant change tundish level, but also by different chemical and physical properties of molten slag.

3.5 Comparison of the materials balance with the obtained chemical composition of the slag

Comparing the obtained and calculated values can be seen significant differences with all components, which is also reflected in difference of basicity. Graphic representation of this comparison is shown in **Figs 4** and **5**. All rated slag is siliceous, but there is a significant difference in Al_2O_3, CaO and MgO content. An important factor influencing the observed differences could be a slag from ladle, which always get at the end of each batch in various amounts into the tundish.

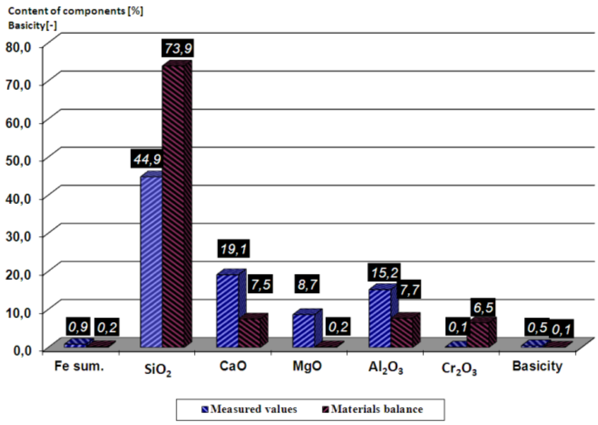

Fig.4 Comparison of the materials balance with the measured values of the chemical composition of the slag in tundish No.11

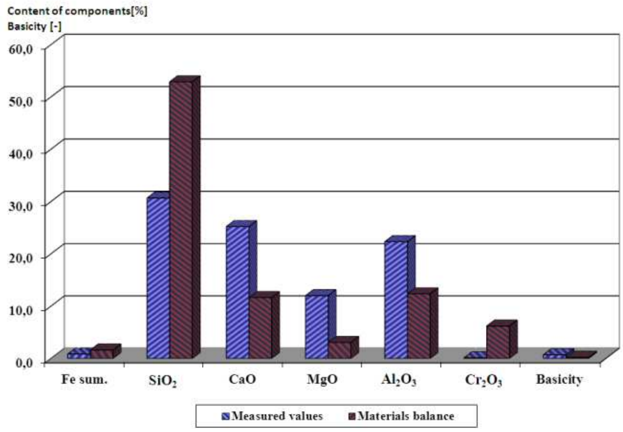

Fig.5 Comparison of the materials balance with the measured values of the chemical composition of the slag in tundish No.8

DOI 10.12776/ams.v20i3.357 p-ISSN 1335-1532
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3.6 Effect of the ladle well filler and slag from ladle on the wear of the tundish lining

Used ladle well filler is acidic in nature, because it is based on SiO_2. Its chemical composition is given in **Table 1**. After opening each ladle, tundish slag receives about 20.5 kg of ladle well filler. Approximately 287 kg of ladle well filler gets into tundish slag during the 14 heats sequence. Materials balance is shown in **Tables 8** and **9**. The amount of slag from ladle, which gets always at the end of casting each batch into the tundish slag, is difficult to quantify given the used method of detection. Representative chemical composition of the slag from ladle cannot be expressed because it depends on previous steel treatment. Generally, the slag brings particular components such as SiO_2, CaO, MgO, Al_2O_3, as well as Cr_2O_3. The set-up of the tundish inlet and the baffle makes the assumption that the concentration of components brought by ladle well filler and slag from the ladle, will be higher at the inlet of the tundish than in other areas of the tundish which are separated by a baffle [12, 13, 14, 15]. It is assumed that a significantly higher wear in the slag line area at the tundish inlet, which was five to ten times higher than in the other areas, was mainly due to the ladle well filler and slag from ladle.

Table 8 Materials balance of slag composition in the tundish No.8 at the end of casting

	Weight [kg]	[%]
IPC Tesand	**287**	**0,478**
KP 1/S	192	0,319
Refraflux	122	0,203

Table 9 Materials balance of slag composition in the tundish No.11 at the end of casting

	Weight [kg]	[%]
IPC Tesand	287	0,499
Intratherm Calcinex Nera	198	0,344
Refraflux	90	0,157

4 Conclusions

From the results of the given experiment, it is possible to define a number of factors to each other after works on corrosion tundish working lining in the slag line. This is particularly the influence of refining and covering powders, but also the effect of ladle well filler and slag from ladle. The components of all these elements together contribute to the formation of tundish slag, and thus its impact on the life of tundish lining. Based on the measurements and analyses is less corrosive effect on the lining showed used covering powder Intratherm Calcinex Nera together with refining powder Refraflux 4248 S. Overall, higher working lining wear was found using the covering powder KP 1 / S together with refining powder Refraflux 4248 S. In essentially, the tundish working lining wear was involved by using of the ladle well filler and slag from a ladle in particular of wear in the area of tundish inlet. As the nearly 50% of weight of tundish slag consists of ladle well filler at the end of 14 heats sequence, it can be assumed its negative impact on slag refining properties. The next solution of possibilities of the slag mode in the tundish will need to consider alternatives to reduce the amount of ladle well filler to get out of the ladle into the tundish, or to optimize the composition of the well filler to reduce its aggression against the lining. By optimized slag mode we can improve economy of steel continuous casting. It is also possible to decrease quantity of wastes produced in this process.

DOI 10.12776/ams.v20i3.357 p-ISSN 1335-1532
e-ISSN 1338-1156

References

[1] G. Connor: *Chemically bonded Tundish Lining Systems and associated near Tundish Refractories*, Vesuvius-Foseco Limited, Staffordshire, 2009
[2] R. Tonhajzer, M. Puškár, M. Kopas, E. Faltinová, P. Čopan: Applied Mechanics and Materials, Vol. 611, 2014, p. 304-310, DOI: 10.4028/www.scientific.net/AMM.611.304
[3] K. Michalek, K. Gryc, Z. Hudzieczek, J. Morávka, J. Pieprzyca: Hutnik, Vol. 77, 2010, No. 2, p. 43-47
[4] B. Buľko, J. Kijac, P. Demeter, J. Demeter: Acta Metallurgica Slovaca, Vol. 17, 2011, No. 1, p. 51-57
[5] P. Bigoš et al.: *Computational and experimental methods for improving performance and service life of drives and construction of selected transport equipment*, First edition, Košice: TU – 2010, p. 215 (in Slovak)
[6] V. Rusňáková, J. Kijac, G. Rusňák: Acta Metallurgica Slovaca, Vol. 13, 2007, No. 3, p. 345-352
[7] M. Frohlichová, M. Tatič: *Refractory materials for the continuous casting steel*, In.: Hutní keramika – Ostrava: Tanger, 2009, p. 60-67
[8] N. Bessho, H. Yamasaki, T. Fuj, T. Nozak, S. Hiwasa: ISIJ International, Vol. 32, 1992, No.1, p. 157-163, DOI: 10.2355/isijinternational.32.157
[9] H. Tanaka, R. Nishihara, I. Kitagawa, R. Tsujino: ISIJ International. Vol. 33, 1993, No. 12, p. 1238-1243, DOI: 10.2355/isijinternational.33.1238
[10] J. Schindlerová, L. Válek, J. Haščin: *The Parameters Which Influence the Lifetime of Refractory Materials for Continuous Casting of Steel*, Theory and Practice of Steelmaking, Rožnov pod Radhoštem, 2005, p. 186-191
[11] A. McLean: *Paths of Progress in an Age of Change*, I&SM, Austria, 1998, p. 55-61
[12] K. Gryc et al.: Materiali in Tehnologije, Vol. 46, 2012, No. 4, p. 403-406
[13] B. Smetana et al.: Hutnické listy, Vol. 64, 2011, No. 3, p. 67-71
[14] K. Gryc et al: Hutnické listy, Vol. 64, 2011, No. 2, p. 65-71
[15] J. Siwka: ISIJ International, Vol. 48, 2008, No. 4, p. 385-394, DOI: 10.2355/isijinternational.48.385

Acknowledgements

This research work was performed under the grant project No.1/ 0783 / 11 and was financially supported by VEGA MŠ SR a SAV.