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THE CURRENT STATUS OF TUNDISH COVERING SLAGS IN A SLAB CASTER PLANT

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Tundish metallurgy development, which has been focused on steel cleanliness improvement in last few years, affected also tundish slag systems. Molten slags are the most suitable for both absorbing and refining functions of tundish cover slags, while a system of extremely low density does satisfy their isolating functions in the best way. Hence it is obvious, that it is not possible to assure the main functions using one sort of tundish covering slags. In addition, traditional acid slags, are being replaced with basic covering slags, or combination of both types. In this work, we have tried to investigate the operation of tundish covering slag under the condition of slab continuous casting. A genesis of covering slag from applied cover powders its refining functions have been investigated, as well as the changes of covering slag chemical composition during one tundish casting sequence.

Key words: *slab continuous casting, tundish metallurgy, tundish covering slags, slag mode, slag refining ability*

Današnje stanje međulonca s pokrivnim troskama u ljevaonici slabova. Razvoj metalurgije međulonca koji se usmjerio na unapređivanje čistoće čelika tijekom zadnjih nekoliko godina odrazio se i na vrste troske u međuloncu. Rastaljena troska je najpogodnija kako za funkcije apsorbiranja tako i za funkcije rafiniranja pokrovne troske međulonca sve dok sistem krajnje male gustoće zadovoljava na najbolji način njene izolacione funkcije. Iz toga je jasno, da nije moguće osigurati glavne funkcije uporabom samo jedne vrste pokrovnih troski međulonca. Osim toga, tradicionalne kisele troske zamjenjuju se bazičnim pokrovnim troskama, ili se koristi kombinacija obadva tipa. U ovom članku se nastojalo istražiti rad pokrovne troske međulonca u uvjetima kontinuiranog lijevanja slabova. Istraživano je kako se uporaba pokrovne troske razvijala iz uporabe pokrovnih prahova te njene funkcije rafiniranja kao i promjene njenog kemijskog sastava tijekom jednog ciklusa lijevanja međulonca.

Ključne riječi: *kontinuirano lijevanje slabova, metalurgija međulonca, pokrovne troske u međuloncu, vrste troske, rafiniranje troske*

INTRODUCTION

Tundish is an important metallurgical device, whose main functions are creation and regulation of steel amounts when continually casting the steel. Steel cleanliness may be significantly degraded and the contents of several components, as are N, O, H, Si, C, may be increased if the tundish design is inappropriate, the burning is unsuitable, the casting flow protection is insufficient or applied cover slags are of poor quality. On the other hand, tundish allows us to [1]:

- modify the inclusions,
- improve the steel cleanliness by flow regulation,
- improve the steel cleanliness by applying the argon through the tundish bottom,
- improve the steel cleanliness by ceramic filters application,
- raise and keep the casting temperature in an optimum range by using the inductive or laser burner,
- prevent the slag penetration from tundish into the mold by using an appropriate slag separators.

TUNDISH COVERING SLAGS

Character of tundish processes primarily depends on physical and chemical features of cover slags and their availability under the operational conditions.

The samples of dust and molten slag, taken from the tundish usually show structure and composition differences, starting with the thickness of both dust and slag with prevalent structural pattern. The slag is composed of three layers:

- the top layer which is softly cemented, thickness about 20 - 30 mm,

J. Kijac, P. Kováč, E. Steranka, Faculty of Metallurgy, Technical University of Košice, Košice, Slovakia, V. Masek, P. Marek, U. S. Steel Košice, Košice, Slovakia

- stable middle layer, which is softly plastic of thermo-isolation importance,
- the lower layer, which is the most interesting in terms of metallurgy, floating on the steel surface; both composition and thickness of this layer is significantly being changed during casting.

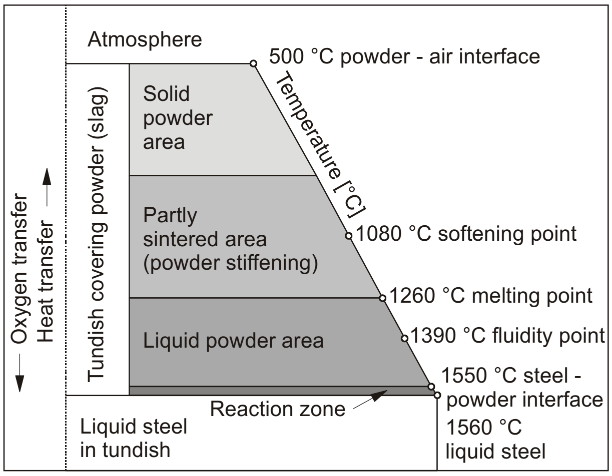

Figure 1. **Describes possible zones on the steel surface in case of covering powder application**
Slika 1. **Opis mogućih zona na površini čelika pri primjeni pokrovnog praha**

The most important refining ability of covering slag is its good absorption ability toward the floating contaminations [2]. Operational experiments confirmed, that 70 % of coontaminations in continuous cast products could be removed by using appropriate tundish metallurgy techniques. The processes of oxide inclusions coagulation and assimilation impact the inside cleanliness of steel product in a large extent.

These processes are closely connected with quality and quantity of covering slags as well as with the way of their

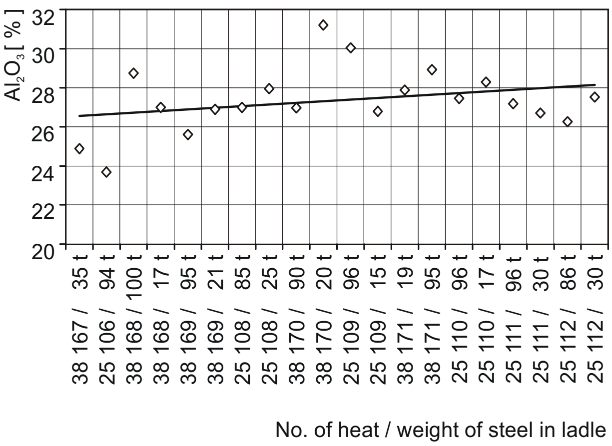

Figure 2. **Al_2O_3 contents change in covering slag during the monitored sequence**
Slika 2. **Promjene količine Al_2O_3 u pokrovnoj troski tijekom promatranog ciklusa**

application on the steel surface. Under the conditions of nowadays technology and a possibility of slag absorption ability recovery in the tundish, the situation occurs, that around 4th - 5th heat the slag is being saturated by Al_2O_3 inclusions. Subsequent refining in next casts in the sequence is pretty problematic, the inclusions are not enough fixed in the slag and proceed into the mold and get into the final product. The solution of this complicated problem depends mainly on:

- chemical composition of applied synthetic components,
- physical features of created covering slag,
- slag thickness changing,
- the quantity of ladle slag which gets into the tundish,
- molten flow in the tundish [4].

EXPERIMENT AND USED EXPERIMENTAL METHODOLOGY

The effect of covering slags quality impact on the tundish assimilation ability of slab continuous casting has been investigated in our study. In Table 1., chemical composition [5, 6] of applied covering slags in continuous casting devices in U. S. Steel Košice, s.r.o. is reviewed. Investigated cast sequence started with new tundish first dose of 42 kg covering slag MOLD 29 and 15 kg of isolation fill. In order to recover the slag features, one package of covering slag and isolation medium were added at each new heat. Samples of molten covering slag were taken from 50 tons tundish when casting package grades.

Table 1. **Chemical composition of tundish covering slags**
Tablica 1. **Kemijski sastav pokrovne troske međulonca**

Components		MOLD 29	TOPEX ISO-T
SiO_2	[%]	31 - 35	39
CaO	[%]	36 - 41	2.73
MgO	[%]	5 - 7	1.41
Al_2O_3	[%]	4 - 6	19.9
MnO	[%]	0.46 - 0.96	max 0.5
Fe_2O_3	[%]	0.30 - 0.50	5.69
Na_2O	[%]	0.10 - 0.50	5.56
K_2O	[%]	0.35 - 0.65	3.03
F	[%]	2.5 - 3.5	-
C_{total}	[%]	6.14 - 9.27	20.3
C_{free}	[%]	6 - 9	19.4
H_2O	[%]	max 0.75	-

The slag samples were taken from the ladle containing the steel of weight of about 100 and 20 tons; when using covering slag TOPEX ISO-T only 100 tons. The samples were taken in the protective tube area. The slags were cast at the metal board and immediately solidified.

Table 2. **Slag chemical composition change in tundish when using MOLD 29**
Tablica 2. **Promjena kemijskog sastava troske u međuloncu pri uporabi MOLD 29**

No. of heat / weight of steel in ladle	Fe_{total} [%]	SiO_2 [%]	CaO [%]	MgO [%]	Al_2O_3 [%]	H_2O [%]	P_2O_5 [%]
38 167 / 35 t	2.46	33.3	23	5.82	24.88	6.48	0.029
25 106 / 94 t	2.9	33.07	23.07	5.81	23.68	4.89	0.069
38 168 / 100 t	1.9	25.57	25.89	6.93	28.75	7.33	0.036
38 168 / 17 t	2.57	26.45	24.93	6.65	27	6.05	0.057
38 169 / 95 t	2.23	32.72	22.47	5.97	25.61	6.06	0.028
38 169 / 21 t	2.23	30.4	25	5.9	26.9	6.18	0.052
25 108 / 85 t	3.46	27.9	25.16	6.08	27	5.65	0.036
25 108 / 25 t	3.3	28.48	9.96	7	27.96	4.42	0.062
38 170 / 90 t	3.01	30.69	22.01	5.45	26.97	4.81	0.019
38 170 / 20 t	2.57	33.35	23	5.52	31.21	4.55	0.058
25 109 / 96 t	2.12	27.62	24	6.4	30.05	4.46	0.074
25 109 / 15 t	2.68	30.98	23.89	5.66	26.79	5.71	0.047
38 171 / 19 t	2.9	31.8	20.86	5.57	27.88	4.52	0.041
38 171 / 95 t	2.57	33.35	21.27	5.5	28.93	4.88	0.053
25 110 / 96 t	2.79	31.06	20.8	5.78	27.45	5.02	0.039
25 110 / 17 t	3.13	32.96	9.75	5.31	28.29	4.82	0.022
25 111 / 96 t	3.24	31.87	8	4.85	27.19	4.47	0.038
25 111 / 30 t	3.29	30.54	20.58	5.6	26.71	5.32	0.063
25 112 / 86 t	2.9	32.1	8.44	5.25	26.26	4.82	0.041
25 112 / 30 t	4.8	30.99	8.67	4.72	27.52	3.9	0.043

RESULTS

The results of chemical analysis of corresponding samples are reviewed in Table 2. and 3. The trends of both aluminum and total iron oxide contents changes are showed in Figure 2. and 3. The changes of metal aluminum in the steel, that correspondent to slag features changes are presented in Figure 4.

Table 3. **TOPEX ISO-T covering slag samples chemical composition**
Tablica 3. **Kemijski sastav uzorka pokrovne troske TOPEX ISO-T**

No. of heat	Fe_{total} [%]	SiO_2 [%]	CaO [%]	MgO [%]	Al_2O_3 [%]	MnO [%]	P_2O_5 [%]
25 640	1.67	32.46	25.58	6.34	26.11	3.00	0.005
38 709	2.23	31.04	25.42	5.22	27.66	3.51	0.006
25 641	1.79	26.89	29.89	5.63	29.12	2.91	0.006
38 710	2.79	26.85	27.21	5.23	27.48	3.73	0.008

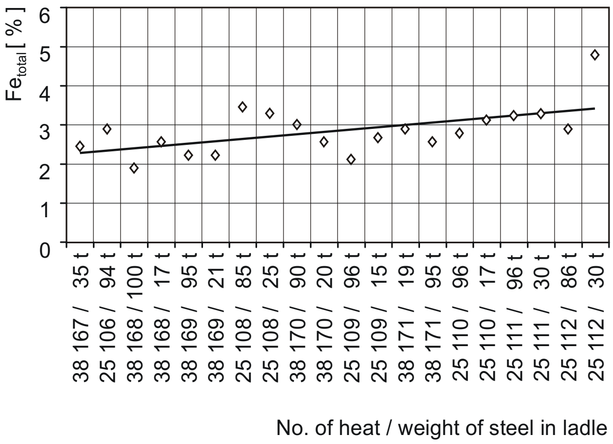

Figure 3. **Fe_{total} contents change in covering slag during the monitored sequence**
Slika 3. **Promjena količine Fe_{total} u pokrovnoj troski tijekom promatranog ciklusa**

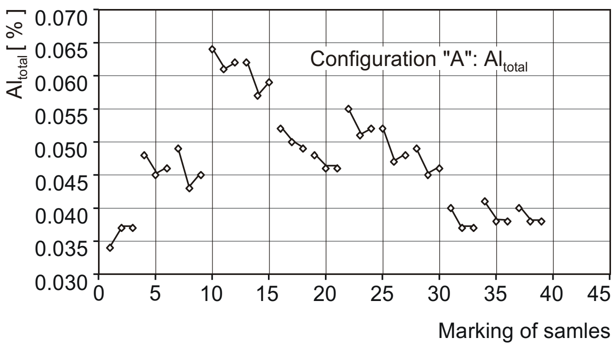

Figure 4. **Measured values of total aluminum contents**
Slika 4. **Izmjerene vrijednosti ukupne količine aluminija**

DISCUSSION

Covering slag Mold 29.0

***Fe**total - (slag samples)*

From the measured results we have learned that Fe_{total} content increases in dependence on the number of heats. Content of Fe_{total} fluctuated in the interval from 1.9 to 4.8 wt. %. Total content of Fe_{total} has increased in comparison with the value of Fe_2O_3 given by the producer of covering slag. This increase is probably caused by the penetration of ladle slag into the tundish, which happens always during the cast of the last steel from the ladle.

The increasing trend of this content is caused by permanent distribution of Fe oxides into the tundish during the penetration of ladle slag contaminated by a certain portion of basic oxygen converter slag, which contains on average 20 - 25% Fe_{total}. The carry out of ladle slag into a tundish is caused by insufficient indication technique, while a tundish operator indicates drag slag only visually.

Al_2O_3 *- (slag samples)*

The refining capacity of slag is best described by the change of content of Al_2O_3 in a covering slag. If the content of Al_2O_3 in a covering slag increases, it means that non-metallic inclusions are floated from steel and are absorbed into a covering slag. Content of Al_2O_3 in a covering slag increases up to the seventh heat in depending on the number of heats. During the cast of further heats the content of Al_2O_3 in slag was at a fixed value or decreased. We can make a conclusion that covering slag fulfilled absorbing functions only during the first seven heats, so until the time of its saturation of Al_2O_3 and then in the second part of the sequence it had only an isolating function.

With the fluctuations of the content of Al_2O_3 are also connected the changes of the content of Al_{total} & Al_{metal} in the samples of steel taken from tundish and mold.

Al_{total} *- (steel samples)*

Only during the first heat we can state the increase in 30 ppm, which corresponds with 8.82% from the measured value of Al_{total} in the surroundings of a ladle shroud tube.

This increase can be explained by heterogeneous process during the start of a new tundish. At the third heat there was the highest decrease of an Al_{total} in the sequence in 60 ppm in a tundish. This decrease indicates peak of absorbing abilities of a covering slag. During the 5th and the 9th heats the decrease of Al_{total} was about 50 ppm, which correspond with the increase of Al_2O_3 in covering slag at the 5th heat in 4,5% and at the 9th heat in 4%.

The conclusion is that there is probably a correlation between the content of Al_2O_3 from the covering slag and the decrease of the content of Al_{total} in steel, that is:

At the maximum of absorbing ability of covering slag we can assume the correlation between the decrease of Al_{total} about 10ppm and at the same time the increase of Al_2O_3 in 1%.

Covering slag TOPEX ISO-T

At the sampling of covering slag TOPEX ISO-T we were able to obtain only 4 samples because the layer of slag, which was created during the 4th heat was very thin and it couldn't be taken by a ladle.

The sample formation of this layer of covering slag can be justified by a higher content of C in a covering slag, which is a regulator speed of melting covering slag. A thin layer of slag (TOPEX ISO-T) does not have such absorbing capacity than a thicker layer (MOLD 29.0) and that is why, from the point of absorption of non-metallic inclusions on the basis of aluminates, Mold 29.0 is more effective.

We cannot assess the influence of TOPEX ISO-T on the refining of cast steel during its whole sequence on the basis of chemical analysis because we could not take more samples during testing of refining effectivity of TOPEX ISO-T (14 heats).

From values presented in Table 3. we can conclude that taken samples are similar to ladle slag composition.

CONCLUSION

As it is obvious from presented documentation, the quality of applied covering fills impacts the development of tundish processes. The higher basicity of MOLD 29, or higher contents of alkaline components in molten slag along with the interaction of metal bath cause more effective refining when compare to TOPEX ISO-T. At the same time, lower contents of aluminum oxide in initial fill material allows us to balance a significantly higher efficiency of first slag in comparison with the slag which originates from TOPEX. Different contents of iron oxides in the initial fill are another considerable factor that impacts the production quality. Another important factor, probably the most important, is the speed of molten slag creation on the steel surface. Liquid layer of slag when using MOLD was created already at the second heat, while in case of using TOPEX at the fourth heat.

Although the slag from MOLD 29 shows significantly higher level of assimilation ability compared to the slag created from TOPEX ISO-T, it is obvious, that both slags are being saturated with aluminum oxide already after several cast heats, and therefore they are performing only isolation functions. During next casts, partial additions of initial material cause the slag activation, indeed, but it is probably insufficient. A higher efficiency might be reached through continuous removal of utilized slag and forming a new one.

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