ANALYSIS OF THE SLAG AND METAL INFLUENCE ON THE LIFE OF ELECTRIC ARC FURNACE HEARTH REFRACTORY LINING

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ANALÝZA VPLYVU TROSKY A KOVU NA ŽIVOTNOSŤ VÝMUROVKY NISTEJE ELEKTRICKEJ OBLÚKOVEJ PECE

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Abstract

MgO-based refractory linings for electric arc furnace (in further EAF) hearth are most preferred worldwide. Potential for elimination and knowledge of causes, mechanisms of refractory wear coupled with continuous correction of plant parameters is needed in order to prolong refractory life. Wear process can be significantly modified by changes in technology. The most critical location in the EAF hearth is a slag line. Slag compatibility (i.e. dual saturation of slag both with CaO and MgO) with refractory lining using dolomitic lime, MgO- briquettes or refractory wastes is an effort of slag management. Slag foaming is very beneficial against wear. Governing of FeO content in the slag is a critical aspect of both slag foaming and refractory wear point of view.

This study deals about analysis of slag and metal composition influence on the EAF hearth refractory lining wear level based on the statistical evaluation of plant data. Influence of specific slag (CaO, MgO, FeO, Al_2O_3, SiO_2, basicity) and metal (C, Mn) constituents on the extent of EAF hearth lining wear was analysed at selected number of 24 campaigns. Average values of slag composition of mentioned campaigns together with wear data were plotted to the pseudoternary diagram which expresses the relation between basic, acidic oxides and oxides with oxidation potential. Results were affected by scattering factor of used EAF shop statistical data reinforced with human factor (manual slag and metal sampling, non-ideal method of wear extent measurement), factor of oxygen lance use just before sampling in the same location as well as contribution of other various (except of slag and metal) non-constant factors acted in some campaigns.

Key words: wear, refractory lining, steelmaking, electric arc furnace, oxidic slag, metal

Abstrakt

Vo svete sa vo výraznej väčšine preferuje murovanie nisteje elektrických oblúkových pecí (EAF) materiálmi na báze MgO. Predlžovanie životnosti výmurovky EAF si vyžaduje poznanie príčin, mechanizmov opotrebenia a ich možnej eliminácie v relácii s kontinuálnou korekciou prevádzkových parametrov. Zmenami v technológii sa môže výrazne zmeniť proces

opotrebenia. Najkritickejším miestom nisteje EAF je trosková čiara. Pri riadení troskového režimu je snaha dosiahnuť chemickú kompatibilitu trosky (t.j. nasýtenie trosky MgO a CaO) a výmurovky používaním dolomitického vápna, MgO-brikiet prípadne recyklovaných žiaruvzdorných materiálov. Veľmi pozitívne na opotrebenie vplýva technológia napeňovania trosiek. Riadenie obsahu FeO v troske je kritickým momentom ako z pohľadu napeňovania tak aj z pohľadu opotrebenia.

Táto práca pojednáva o analýze vplyvu zloženia kovu a trosky na mieru opotrebenia výmurovky nisteje elektricke oblúkovej pece (EAF) na základe štatistického zhodnotenia prevádzkových ukazovateľov. Graficky sa analyzoval účinok jednotlivých zložiek trosky (CaO, MgO, FeO, SiO_2, Al_2O_3, bazicita) a kovu (C, Mn) na mieru opotrebenia nisteje EAF u vybraných 24 kampaní. Pre lepšiu ilustráciu boli priemerné zloženia trosiek kampaní v spojení s hodnotami opotrebenia zakreslené do pseudoternárneho diagramu vyjadrujúceho vzťah zásaditých, kyslých oxidov a oxidov s oxidačných potenciálom. Vo výsledkoch sa prejavil skresľujúci faktor použitia štatistických prevádzkových údajov znásobený ľudským faktorom (ručný odber vzoriek kovu aj trosky, nedokonalá metóda merania opotrebenia), používaním kyslíkovej trysky tesne pred odberom vzorky v mieste odberu ako aj prispením rôznych ďalších (mimo kovu a trosky) viac alebo menej v danej kampani prejavených nekonštantných negatívnych faktorov.

1. Introduction - Theoretical review

Magnesia or magnesia-carbon bricks (monolithic linings at the top zones of the furnace) are usually applied within the sidewalls and bottoms of electric arc furnace (in further EAF) hearths as a refractory lining in the EAF steelmaking (fig.1). Refractory materials used for periodic replacement and repair of EAF hearth lining represent valuable financial investment associated also with several hours of downtime and production losses. It´s well known that refractory wear rate in EAF has the largest extent in comparison to all of the other steelmaking aggregates [1]. It´s necessary to think about the EAF lining lifetime prolongation in order to reach the maximal economical effect. This aim is associated with elimination of negative factors damaging the lining such as permanent high temperature influence (1500-1700°C), mechanical-abrasive stresses at low and elevated temperatures, chemical interactions with slag and metal (mainly FeO, SiO_2 content), thermal shocks, erosion, direct impact of electric arc, use of gaseous oxygen and others [2,3,4,5,6,7,8,9,10,11]. The changes in EAF technology could modify the wear process significantly.

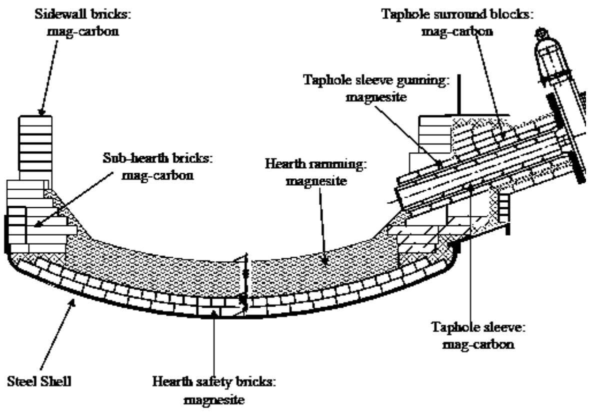

Fig.1 Refractory lining of sidewalls and bottom of EAF hearth, [16]

Ideally, the EAF refractory wear would be uniform, but various aggressive factors could be more or less emphasized at different EAF locations. This was the reason why a concept of lining zonation (layers of miscellaneous materials with various thickness in different zones of lining i.e. slag line, sidewalls, hearth bottom) has become traditionally used within most of EAFs. The most critical location in the EAF hearth lining is a slag line at which MgO-C materials with various carbon and antioxidants additions are used (advantages: high strength, high refractoriness, low porosity, good resistance against erosion, mechanical, abrasive wear and low wettability by slags). Water cooled panels or staves are commonly installed in the upper sidewalls areas at modern EAFs. Necessity of EAF refractory lining thermal conditions control (by using thermovision, cooling water temperature measurement, etc.) is essential for enormous wear or accidental situation prevention. The most important negative factors could be identified on the base of spent brick laboratory examinations or plant characteristics study [2,6,7,8,12,13].

The aggressive acidic slag (mainly consisting of olivine and wustite phases [10]) is formed in the EAF at the beginnings of the heat. This slag must be transformed as soon as possible (by an addition of dolomitic lime, MgO-briquettes, recycled refractories) to the slag of required quality. Since lining represents a magnesium oxide (from a chemical point of view) and calcium oxide is necessity for refining reactions effectiveness, it´s important to create a slag which has sufficient content of mentioned oxides. The best case are the slags dually saturated both with CaO and MgO which satisfy not only the refractory wear decreasing and refining effectivity requirements, but also contribute to better slag foaming parameters. Estimation of required fluxes addition amount is greatly complicated because of interrelationships within solubility of specific slag compounds. Slag saturation with magnesia plays the key role from the refractory-slag compatibility point of view. Solubility of MgO in the ternary CaO-FeO-SiO_2 system is illustrated in the fig.2. Some EAF shops operates with insufficiently MgO-saturated slags, so low refractory life (dissolution of lining to slag), high gunning mixes consumption, bad slag foaming quality are the consequences of this fact. Another common problem is a large content of iron oxide in the slag, which increases the total slag mass, decreases metal yield and at last destructs the lining (reaction between carbon of magnesia-carbon brick and iron oxide). Big importance should be also assigned to chemical interaction between MgO (of refractory lining) and aggressive acidic oxides - particularly silica or Al_2O_3, TiO_2, P_2O_5 (generally at the beginnings of the heat) [2,3,4,5,14].

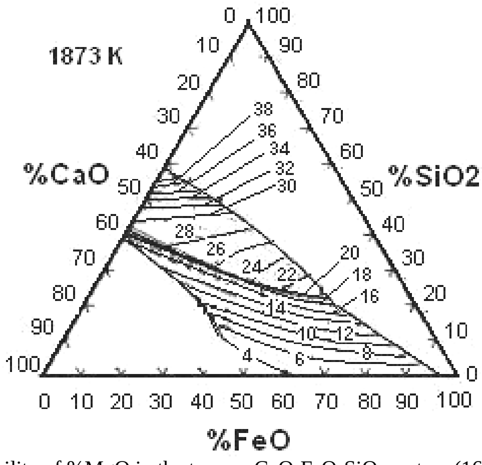

Fig.2 Solubility of %MgO in the ternary CaO-FeO-SiO_2 system (1600°C), [11]

Gradual growth of an oxygen and potential gradual decline of other elements content (according to their affinity to oxygen) occurs in the metal during the heat in the EAF. The content of Si, Al, Ti, P levels in the EAF charge is important for refractory wear extent since high amount of these elements in the charge means high percentage of sum (SiO_2 + Al_2O_3 + TiO_2 + P_2O_5) in the slag, lower basicity and more aggressive influence on the lining (longer tap-to-tap time in the case of phosphorus too). Carbon and manganese levels play important role in the wear process. If their content in the metal falls beneath a certain critical value, then a superoxidation of the metal and violent increase of FeO in the slag will be a consequence. Metal non-saturated with carbon dissolves the carbon originated from the MgO-C refractory [2,3,14].

The wear process uses to be the most intensive in the slag line area, because of different slag and metal viscosity. Corrosion mechanism of magnesia-carbon bricks by slag (metal) in the EAF slag line location is based on the solubility and chemical interaction between slag-metal-refractory material (reaction with slag oxides, oxygen of metal) together with slag penetration into the pores and mechanical (erosive) destruction of lining surface (depending on the slag viscosity, wettability angle, interfacial tension between slag-metal-refractory). Dissolution of MgO in the slag is a limiting step of the whole wear process [14,15].

The slag foaming phenomenon has been one of the most discussed issues in the EAF studies during last decade. Maybe the greatest benefit of foaming technology is a remarkable refractory wear decline, campaign duration prolongation [3,6,7] and decrease of gunning mixes consumption (more then twice [10]). There was achieved more then triple increase of EAF sidewalls lifetime after the foaming slag practice implementation in Fletcher Industries (Pacific Steel, New Zealand) EAF shop [16]. The principle of mentioned excellent success originates in the fact that during slag foaming in the EAF a significant wear mechanism change takes place as follows: Refractory corrosion by foamy slag is inhibited owing to presence of CO gas bubbles large quantity (lower reaction surface between slag-refractory), also arc is covered so arc radiation (and resulting damage of lining) is reduced [10].

2. Experimental – statistical analysis of the plant data

The influence of the most important constituents of slag (CaO, MgO, FeO, SiO_2, Al_2O_3) and metal (C, Mn) phases on the EAF hearth lining lifetime was graphically analysed based on the statistical plant data (slag, metal compositions, wear levels of selected number of 24 campaigns). Data were arranged in the table according to increasing value of the wear level (Tab.1). Boundary point between low and high wear was established as 0,1 cm per heat, so the data were divided into 2 groups of 12 light and 12 dark marked campaigns.

The average values of specific slag oxides (metal elements) were used in each campaign. Slag and metal samples were taken manually by operator using a long steel spoon from the slag door area approximately in the same time (7-12 minutes before tapping) at the temperature of approx. 1550-1560 °C and at 0,06-0,08% carbon content in the steel. There exists a big probability of discrepancy between acquired sample data and real heat data owing to non-automatic (manual) sampling even also at relatively negligible differences in the depth, location or time of sampling [12]. Oxygen lance was used just in the time before sampling (oxygen blowing in the sampling area in order to simplify the sampling – potential negative effect for the slag, metal composition data). The section of refractory lining under the sill level (behind the slag door area) was the critical wear level location for most of the campaigns (owing to oxygen lance using and the vicinity of one of three oxygen-fuel burners). Another important feature was that there wasn´t reached MgO-saturation level in the slags at almost all of the analysed campaigns (for these slag it´s around ~ 6-8% MgO [4]).

Hearth refractory wear level measurement (MgO-C bricks with 15% carbon content) was conducted by calculating of differences between new and spent refractory bricks relating it to number of heats (acquired data in cm per heat).

Table 1 Arrangement of selected campaigns parameters according to increasing wear level

refr.wear (cm/tav)	CaO+ MgO (%)	FeO+ MnO (%)	Al2O3+SiO2 +TiO2+P2O5 (%)	MgO (%)	FeO (%)	SiO2 (%)
0.060	27.7	53.0	20.3	6.2	44.2	12.4
0.063	30.3	47.9	20.1	3.4	39.2	12.2
0.068	35.5	40.7	22.8	2.4	32.5	12.5
0.073	28.2	50.6	22.2	5.2	42.3	13.4
0.075	37.2	38.6	23.8	2.7	30.4	14.5
0.076	30.7	49.1	20.2	4.5	40.6	12.5
0.076	35.1	41.2	22.6	3.1	32.5	13.6
0.076	40.2	35.6	24.3	2.7	27.5	15.0
0.086	38.6	37.2	23.1	2.2	29.4	13.8
0.086	36.0	39.3	23.0	1.9	31.0	12.9
0.089	33.6	41.6	23.6	2.2	33.2	13.5
0.095	35.2	39.8	24.1	2.0	31.2	13.7
0.103	27.4	53.0	18.8	3.4	44.6	11.2
0.106	26.6	54.6	16.8	2.9	46.4	9.8
0.107	33.0	45.0	20.1	3.2	36.6	12.1
0.109	25.5	54.9	18.7	3.9	46.1	10.6
0.111	30.8	47.6	19.1	2.3	39.4	11.1
0.113	24.8	58.4	16.4	4.3	50.6	9.7
0.117	26.7	54.2	18.1	3.0	46.0	11.0
0.119	32.0	46.8	20.5	4.4	38.7	11.4
0.130	25.6	55.6	18.3	2.9	47.2	11.0
0.130	30.1	50.6	15.9	2.4	43.2	9.2
0.132	25.2	57.8	16.0	2.8	49.3	9.2
0.133	26.0	54.1	18.2	2.7	46.0	10.8

3. Discussion of the results

3.1 Refractory wear as a function of slag composition

The data were plotted (for better imagination) to the section of the pseudoternary diagram (fig.3), which represents interrelationships of basic, acidic oxides and ones with oxidation potential. Every campaign was marked with number indicating the wear level (growing number means higher wear). Three different areas (A,B,C) can be seen in this diagram – there´s an A-region of low wears with concentration of 8 dark points (No. 3,5,6,7,9,10,11,12) in the left. There´s a cluster of 4 light and 4 dark points (No. 1,2,4,8 and No. 15,17,20,21) – it´s transient B-region in the middle and in the right side is presented a dense group of 8 light points (C-region) indicating high wear area (No. 13,14,16,18,19,22,23,24). The highest basic oxides content (in average 36,4% CaO+MgO), the lowest FeO content (in average 31,0%) and relatively higher amount of acidic oxides (in average 23,4%) are typical for A-region, whereas inversely the lowest CaO+MgO (in average 19,7%), the highest FeO content (in average 47%) and relatively lower amount of acidic oxides (17,7%) can be noted for C-region. The middle B-region consists of 3 campaigns with considerably very low wear levels (No.1,2,4). It´s interesting that the best campaign (No.1) is already in the boundary with the C-region of high wears (slags close to campaign No.13). Probably owing to influence of the highest MgO-levels in the slag (6,2%) of all of the analysed slags there wasn´t suffered of high wear level within campaign No.1 even the slags were nearly the same (except of MgO) to ones of campaign No.13. This fact can also be interpreted at campaign No.4 (the second highest MgO content – 5,2%) or in the case of campaigns No.8 and No.17 (both close to each other in B-region), which were differed only in the MgO levels (%MgO in campaign No.8 is almost the twice like that of No.17).

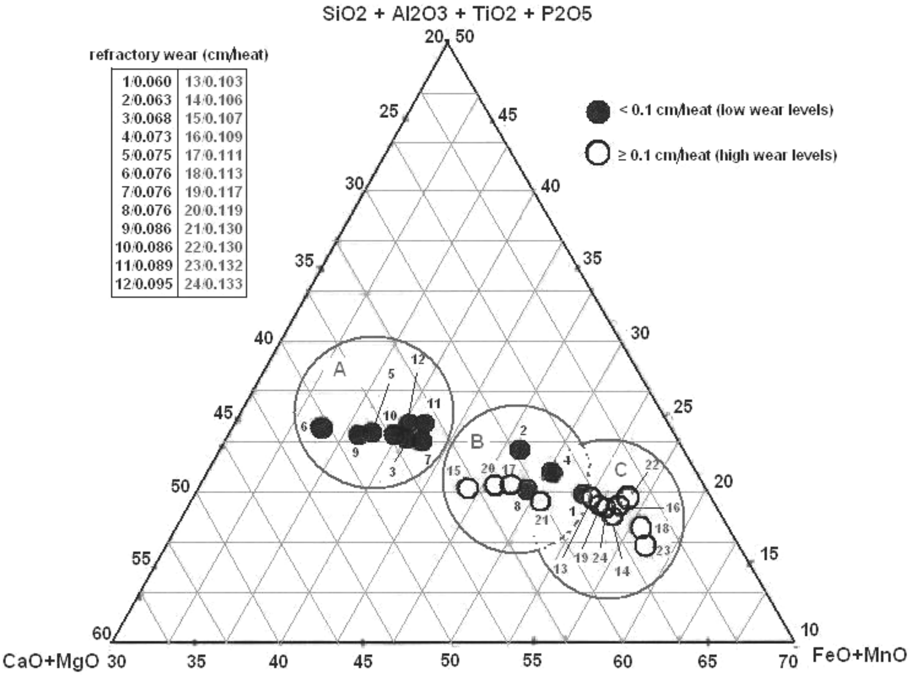

Fig.3 Pseudoternary diagram (CaO+MgO)-(FeO+MnO)-(SiO_2+Al_2O_3+TiO_2+P_2O_5) with marked wear levels

It was expected that statistical analysis of wear and CaO, MgO content would prove a positive effect of these compounds on the refractory lining (since lining is based on magnesium oxide). Graphical relationships of wear versus basic oxides content confirmed this statement (increase in CaO or MgO content showed decrease of wear), but owing to big degree of scatter in both cases (correlation coefficient lower then 0,2) these graphs are not presented in this study.

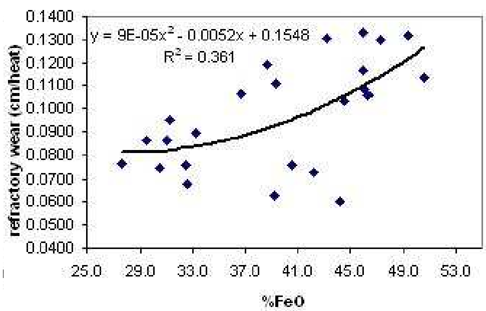

Fig.4 Refractory wear related to FeO content

Fig.4 demonstrates dependence of wear and FeO content in the slag. It´s clear that rising iron oxide content has very detrimental influence on the refractory wear. EAF technology must be therefore managed in a way of enormous FeO growth prevention. Correlation coefficient R^2 = 0,361 is a good value. MnO levels were in tight intervals (in average 4,4-5,8%). Its relation to wear was found positive but R^2 value was low so it´s not presented here.

Graphical dependence of wear and acidic oxides is shown in fig.5

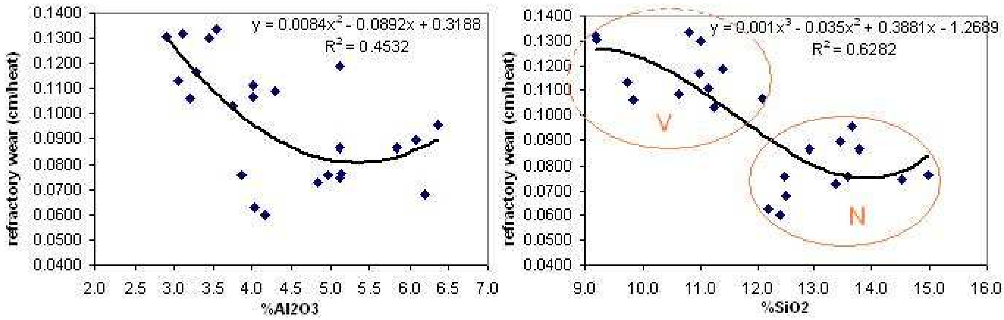

Fig.5 Refractory wear related to alumina and silica content

As can be seen in the left figure (fig.5) the highest wears were concentrated at low alumina levels (3% Al_2O_3) while the lowest ones fell in the area of 4 -5% Al_2O_3 (bigger scatter). The noticeable is content around 5% - wear is increasing with alumina content growth (as shown in curve with very good correlation coefficient). The relationship of wear and silica content demonstrated a strange distribution of campaigns into 2 groups: All of the „light“ (i.e. high wears – marked with letter V) campaigns were concentrated in the region characterized by 9-12% contents of SiO_2 whereas residual „dark“ (i.e. low wears – marked with letter N) campaigns were accumulated in the 12-15% SiO_2 content region. A degree of polynomial regression curve was increased from 2 to 3 within this graph. It rose R^2 value (from 0,59 to 0,63) and curve showed growing wear above 14% of silica content in the slag.

Numerous (simple or complex) basicity formulas can be found in literature and publications [3,10,17, and others]. Complex basicity expressing ratio of basic oxides sum versus acidic oxides sum plus FeO was used in this study. MnO was added to basic oxides. Effect of TiO_2 was considered as negligible since its content didn´t exceed 0,5%. FeO doesn´t represent an acidic compound itself but owing to negative effect on the lining it can´t be associated with CaO and MgO in this case. Graphical result of wear vs. basicity relationship is presented in the fig.6. It´s clear that increasing basicity decreases refractory wear.

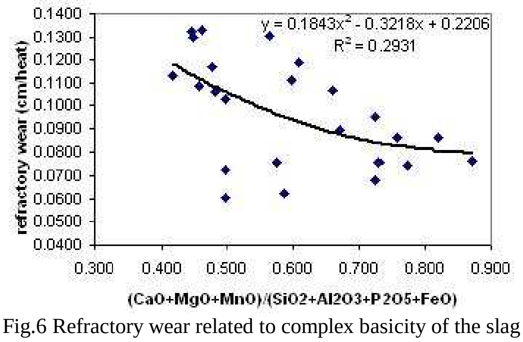

Fig.6 Refractory wear related to complex basicity of the slag

3.2 Refractory wear as a function of metal composition

Fig.7 graphically illustrates potential influence of the most important elements of the metal (C, Mn) that changes during the heat on the EAF hearth refractory wear. Relationship of phosphorus content and wear was removed owing to very low R^2.

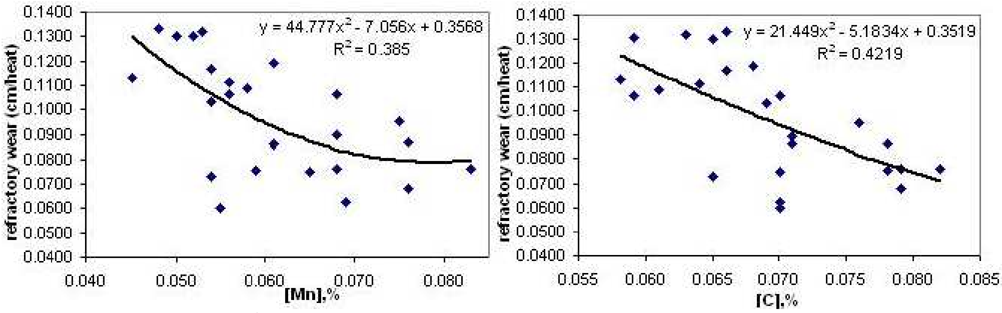

Fig.7 Refractory wear related to carbon and manganese content in the metal

When the carbon and manganese content in the metal decreases (and related oxygen content increases) then the wear process is emphasized as a consequence of oxygen growth in the metal and iron oxide growth in the slag. Correlation factors are satisfying in both cases.

4. Conclusion

This study was dedicated to the analysis of the influence of slag and metal composition on the EAF hearth refractory wear using statistical plant data (24 selected campaigns). The most critical area for refractory lining (based on magnesium oxide) damaging is located in the slag line as a consequence of slag-metal-refractory interaction. Both graphical relationships as well as illustration of analysed campaigns in the pseudoternary diagram proved increase in wear with decrease of basic oxides content, basicity, carbon and manganese content (it means growing oxygen content) in the metal and with increase of FeO (the most aggressive effect). Graphs representing relationships of wear versus silica, alumina contents showed a minimum extremes (5% Al_2O_3 or 14 %SiO_2) on its regression curves and higher wear levels at lower contents of these oxides in both cases. It´s needed to underline a negative effect of manual slag and metal sampling, non-ideal refractory wear level measurement method and negative influence of oxygen lance (or vicinity of oxy-fuel burner) on the scatter of results.

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