



A study of comparison different $\text{Al}_2\text{O}_3\text{-ZrO}_2\text{-C}$ slide gate plates for the casting Al killed steel

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Continuous casting refractories are the most important materials that provide critical flow control components in steel making process. Ladle slide plates, named in this group, are subjected to sudden thermal shock, physical erosion of molten hot metal and slag. Therefore, the slide gate plate must have good resistance to both thermal shock and corrosion [1]. Generally, alumina based plates are used for Al-killed steel casting processing, however these plates are subjected to huge corrosion during alloy casting which contains higher amount of Mn, Cr or Ca (Ca >15-30ppm) [2]. In order to overcome this major concern ZrO_2 additives have been started to be used. Its well-known that, addition of Ca is the best way to avoid Al clogging problems in Al killed steels. However, the Ca content in $\text{Al}_2\text{O}_3\text{-ZrO}_2\text{-C}$ (AZC) slide plates results in increased corrosion. Hence, it is necessary to determine the most suitable ZrO_2 percentage content in the sliding plate for the continuity of the process and the reliability of continuous casting.

The present paper deals with corrosion and diameter expansion comparison results of three different content of ZrO_2 slide plates that used in 250-ton ladles in medium carbon Al-killed steel production. In the comparison studies, LF (Ladle Furnace) output analyzes, temperature of liquid steel ($T_{s\text{-liq-s}}$), casting speeds, total casting times values and operating factors such as full open or semi open operation of the mechanism were taken into considered.

The test results provide information about which zircon ratio is suitable for a reliable casting process and the maximum number of castings that can be achieved.

Keywords: $\text{Al}_2\text{O}_3\text{-ZrO}_2\text{-C}$; Slide gate plates; Casting

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1. Introduction

In the production of clean steel, as in many refractory products, continuous casting refractories are asked to meet the expectation have long-life, economical and safe flow control. Ladle slide plates which are the one of the continuous casting refractories, are materials that provide controlled steel flow from the ladle to the tundish. Therefore, the temperature strength properties of the refractories used for ladle slide plates should be given more importance since they are in first contact with hot liquid steel [1].

Together with the advancing technology, different steel qualities and increased capacity, the ladle slide plate contents have started to vary due to its great impact on

steelmaking cost. Operating conditions (capacity, time, cost) in terms of refractory requirements for ladle slide plates are listed as follows:

- High thermal shock resistance
- Erosion resistance to metal slag
- Low coefficient of thermal expansion
- High thermal conductivity
- Good crushing strength
- Abrasion resistance [2]

In general, the refractory raw materials used in the sliding plate are high Al_2O_3 and MgO based materials. The addition of carbon brings in high thermal conductivity, low coefficient of thermal expansion and non-wettable properties to $\text{Al}_2\text{O}_3\text{-C}$. Additionally, it also has some advantages such as high resistance to thermal spalling, to

abrasion, to erosion and corrosion. It minimizes the contact between the slag and refractory [3]. However, as with all refractory materials, some factors affect corrosion in continuous casting plates. There have been many studies investigating the corrosion of carbon-bonded Al_2O_3 materials in continuous castings [4, 5].

Some studies conducted for corrosion related cracks in plates, laboratory and operational trials have been carried out by focusing on tabular alumina ratio [6].

Furthermore, the problem of Al clogging in Al-killed steel production is a common problem which affects not only the slide plates but also the tundish continuous casting refractories and causes the casting to stop. The addition of Ca to the steel is effective way for preventing Al clogging problems in Al killed steels because Ca reacts with alumina inclusions and forms low melting point calcium aluminates, which do not form precipitated layers [7]. In general, Ca treatment range is between 15-30 ppm in Al-killed steel production. However, it is known that the corrosion of Al_2O_3 -ZrO₂-C (AZC) slide gate plates increases when they are used for the casting of Ca-added steel [8].

Therefore, ZrO₂, which has high corrosion and erosion resistance, has started to be used. Some studies focus the subject of "ceramic / steel / slag local corrosion attack" has been investigated with different ZrO₂ forms and different grain sizes [9].

For improving corrosion resistance and hot strength, ZrO₂ is added to Al_2O_3 -C refractories. In order to obtain different properties, like to improve toughness and mechanical strength, different additives are added, like silica and micro silica, in combination [10]. Similarly, in an another comparison study with a standard Al_2O_3 -C plate and ZrO₂ plate, it was evaluated that steel samples inclusive CA6 aggregate (which formed due to Ca treatment) penetrated into the standard Al_2O_3 -C slide plate matrix. It was also found that ZrO₂ containing plate was 30% better in terms of corrosion resistance. However, a comparison with a sample containing only 20 ppm Ca content and 13% ZrO₂ does not give an idea about the optimum ZrO₂ ratio [7].

In another study related to the subject, the interaction of Al_2O_3 -ZrO₂-C and Ca was investigated in the samples of three different slide plates. However, calcium interaction was studied only under laboratory conditions. As mentioned in the study, the effects of process parameters such as Ca ppm, casting speed, oxygen opening should also be taken into consideration [11], which will be the case in this study.

In this study, corrosion and bore diameter changes of sliding plates containing ZrO₂ in different ratios were observed. The maximum number of castings was determined with these refractories. All experiments and observations were performed under controlled casting conditions and in real-time production conditions

2. Operational Procedure

a. Properties of Materials

Deciding on the type of plate refractory depends on the characteristics of alloying materials in the steel, residual impurities, ladle capacity and even the tundish filling speed and cast speed. Hence, a good understanding of the process and knowing the reasons for the degradation of the plate gives the necessary information for process improvement. In some cases, producers aim to choose to maximize the amount of steel produced per each cast. Therefore, the establishment of an automatic sliding gate control system aided by slag detection sensors is preferred by the manufactures. Figure 1 shows the slide gates plate's



refractories mounted in the slide gate mechanism as a pair and Figure 2 shows the general refractory layout.

Figure 1. Slide gate refractory mounting

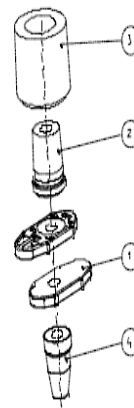


Figure 2. General Refractory Layout (1: Side gate plates, 2: Inner nozzle, 3: Ladle well block, 4: Outer nozzle-exchangeable)

Most of the refractory requirements for slide plates, which are mentioned above, are satisfied by Al_2O_3 -C refractories. The presence of carbon gives them good resistance to abrasion, corrosion and thermal spalling. Carbon has non-wettability property, which prevents the infiltration of metal and slag to the system. In addition, carbon will improve the thermal shock resistance of the material. Al_2O_3 -C refractories are having good flexural and compressive strength at high temperature, which prevents erosion by molten steel and slag. Apart from these properties, Al_2O_3 -C has high thermal conductivity and low coefficient of thermal expansion resulting in high resistance to thermal spalling. Good affordability assisted by above mentioned properties

make $\text{Al}_2\text{O}_3\text{-C}$ a potential candidate flow control refractories in Iron and steel industries [2].

The technical characteristics of the three samples (coded as A, B, C) with different ZrO_2 ratios used in the study are given in Table 1.

Apparent porosity and density test results obtained according to ASTM C 20-00. Leco SC-144 DR Carbon / Sulfur Analyzer was used for carbon analyzes and Thermo ICAP 7400 ICP-OES was used for oxide analysis. The materials of all the examples are carbon impregnated. Samples A and B are carbon bonded and sample C is ceramic bonded refractories. Carbon bond is most conventional bonding system with proper firing; ceramic bond - most stable bonding system with solid state sintering at high temperature. In the chemical analyzes, the analysis of these regions called inserts were taken separately and only the ZrO_2 ratio was examined. As shown in the table, the ZrO_2 ratios of samples A and B are relatively close to each other; in general, it is known that the ratios of ZrO_2 in the sliding plates used on the market are such.

Table 1. Side plate refractories chemical & physical analysis results

Sample Name	Code	ΣC (%)	$\Sigma \text{Al}_2\text{O}_3$ (%)	ΣZrO_2 (Insert zone) (%)	SiO_2 (%)	A.P (%)	Bulk density (g/cm ³)
Ladle Slide Gate	A	7,4	80,1	8,50	11,00	6,82	3,14
Ladle Slide Gate	B	7,0	80,5	5,00	10,00	4,00	3,20
Ladle Slide Gate	C	7,0	99,5	95,80	0,20	3,00	3,13

The plate diameters used in the experiments were selected by calculating 70 mm according to casting parameters. The area shown in bold in Figure 3 is the portion forming the plate casting zone (insert). Figure 4 shows the mounting process of slide plates.

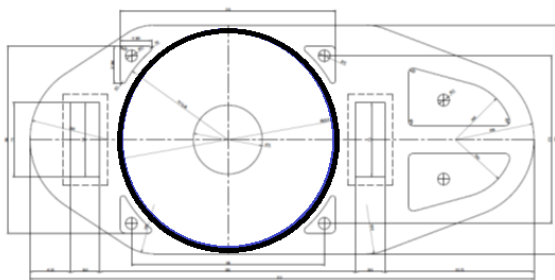


Figure 3: Plate Casting Region (Insert zone)

b. Operational Conditions (Experimental Methods)

A total of 9 plates were tested in three different quality plates such as A.1, A.2, A.3. In order to better observation of the condition of the plates and to ensure casting safety, testing slide plates was used in only one of the ladles.

Another situation subject to observation is the mechanical stress that occurs due to the fully open or semi-closed mode of the mechanism during casting. Depending on the filling speed of the tundish or in cases where the casting speed needs to be reduced, the mechanism is operated at semi-closed. This naturally leads to an increase in ferrostatic pressure on the insert surface. Examinations after casting, the results were obtained according to the measurements (number of casting and diameter change) taken from slider plates due to it was subjected to friction movements and more mechanical stress.

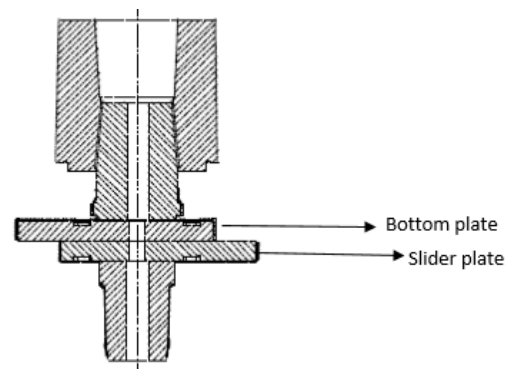


Figure 4. Mounting process of slide plates

In Figure 5 shows some plates coming out of casting.

The casting data and mechanism operating conditions of 9 plates of 3 grades are given in Table 2.

3. Result and Discussion:

By examining the working conditions of the plates coming out of the casting, the diameter changes and the number of castings taken are given in the Table 3.

By examining the results, plates with high ZrO_2 (C coded tests) even high Ca ratios in steel (23 ppm-46 ppm), diameter expansion is within acceptable limits in case of opening with O_2 and semi-closed operation. Additionally, by examining the surface structure of the plate, macro cracking or steel/slag penetration was not observed. The casting conditions in the A coded test products is also acceptable and provide safe casting conditions with 3 mm bore diameter change and castings two times. No steel leakage was observed between the plate. In the B coded product, especially after high Ca treatment and during casting, it was observed that due to the semi-closed working condition, the steel was leaked between the plate and a serious corrosion occurred in the surface area. It is concluded that the 5% ZrO_2 ratio is not sufficient for the insert region (high Ca ratio), and semi-closed operating conditions.

As shown in Figure 6, there is no extreme differences between casting speeds. Although the casting time of B and C samples are close, it appears that C sample receives significantly more castings.

		MECHANISM CONDITION			LF OUTPUT ANALYSIS						VD	CCM		
Slider (Moveable) Plate Quality	Code	Ladle Capacity	Mechanism Opening (Start Casting)	Mechanism Status (During Casting)	C	Si	Mn	S	Ca	Al	Process Time	T _{ladle}	V _{avr}	Total Casting Time
		Ton			%	%	%	%	%	%	(min)	(°C)	(m/min)	(min)
A	A.1	250	Normal	Full open	0,0507	0,0187	0,4159	0,0038	0,0024	0,0305	30	1588	3,7	59
	A.2		Normal	Full open	0,0455	0,0153	0,3776	0,0091	0,0033	0,0284	30	1590	3,7-4,0	57
	A.3		Normal	Full open	0,0382	0,0341	0,4989	0,0015	0,002	0,0302	30	1583	4,0	58
B	B.1	250	Normal	Full open	0,0623	0,0279	0,5116	0,0023	0,0031	0,0224	30	1595	4	58
	B.2		Normal	Semi-closed	0,0549	0,0289	0,5162	0,0022	0,004	0,025	30	1605	3,6	62
	B.3		O ₂	Full open	0,0456	0,0361	0,3806	0,0005	0,0024	0,0138	30	1582	4,1	60
C	C.1	250	Normal	Semi-closed	0,0551	0,0382	0,5549	0,0043	0,0046	0,0324	30	1588	3,9	61
	C.2		O ₂	Full open	0,0438	0,0304	0,5029	0,0023	0,0026	0,0279	30	1587	4	57
	C.3		Normal	Semi-closed	0,0415	0,0212	0,4637	0,0045	0,0022	0,0324	30	1587	3,7	63

Table 2. The casting data and mechanism operating conditions



Figure 5: After Casting (a: B.2 Slide Plate, b: B.1 slide plate, c: C.2 slide plate)

Table 3. Diameter changes and average number of cast

Slider (Moveable) Plate Quality	Code	Bore Diameter (Before Casting)	Bore Diameter (After Casting)	Plate Service Life	Average Diameter Differences	Average Plate Life
		mm	mm	Cast	mm	Cast
A	A.1	70	73	2	3	2
	A.2	70	74	2		
	A.3	70	72	2		
B	B.1	70	78	2	8	1,67
	B.2	70	81	1		
	B.3	70	75	2		
C	C.1	70	76	4	2,67	4
	C.2	70	71	3		
	C.3	70	72	4		

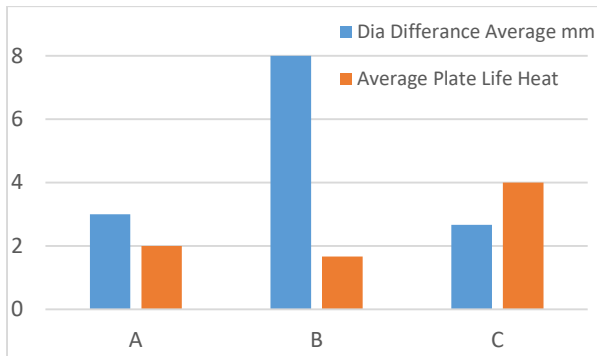


Figure 6. Comparison between diameter differences and plate service life

Diameter difference after Ca treatment is shown in Figure 7. As can be seen from the Figure 7, the A and C test materials seem to be acceptable as mentioned above. It can be said that even 5% ZrO_2 ratio is insufficient in the penetration of calcium aluminate due to Ca which is sometimes used in the upper limits under variable operating conditions. 5% ZrO_2 ratio can only be accepted as lower limit for operating conditions.

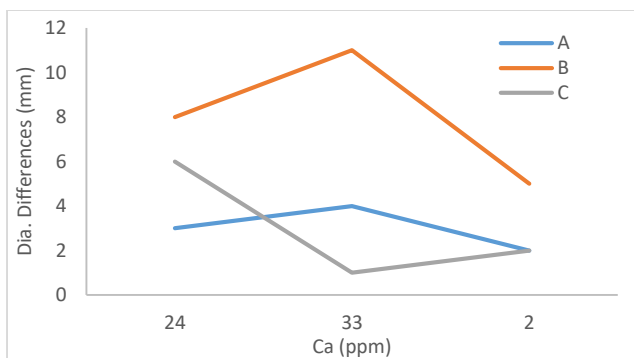


Figure 7. Correlation between Ca treatment ratio and Diameter Differences

Figure 8 shows the correlation between CCM parameters and plate life. As it can be observed from the Figure 8 that C type refractory test material show the best results compared to the others based on the casting time, V_{avr} , and average plate life values.

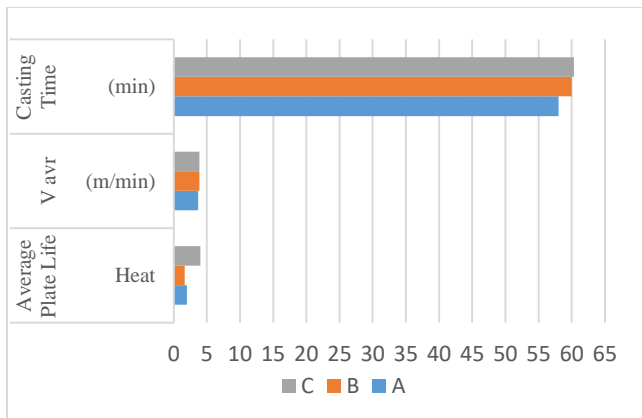


Figure 8. Correlation between CCM parameters and plate life

The plate consumption calculation is performed for 250 tons crude steel (1 ladle) based on the average number of castings taken. It is observed that C and A plates are more suitable because of lower consumption rate than B (Table 4).

Table 4. Consumption ratio of slide plate refractories

Quality	Average Plate Life	Consumption (for 250 t crude steel)
	Cast	kg/t
A	2	0,0200
B	1,67	0,0240
C	4	0,0150

4. Conclusion

In this study, corrosion resistance of the different ZrO_2 content slide gate plates used in production under real-time process conditions were investigated. Slide gate plates refractories are corroded related to too many factors such as raw materials used in manufacture, casting speed, opening with O_2 , steel grade, mechanism working conditions. Experiments were evaluated by considering variables such as LF output analysis, casting rate, casting times, mechanism working conditions and Ca processing rates.

Experiments clearly show that the minimum ZrO_2 ratio to be used in cases where high Ca treatment is required is 5%, depending on operating conditions. However, high Ca ratio should not be considered as the only factor. The mechanism of semi-closed working conditions and the slide plate opening procedure with O_2 are other factors affecting the corrosion of the material. According to these results, if the Ca treatment range is kept between 15-30 ppm and suitable CCM conditions are available, it is possible to continue casting with a class A plate. However, since it is known that slider (moving) plates are subjected to more mechanical stress, it is recommended that class B plates be used only as fixed (bottom) plates. Type C plates are suitable for both casting safety and the desired controlled flow when working with high Ca ratio applications or under difficult conditions (new casting trials, first casting trials, etc. or where CCM parameters change when high casting quantities are targeted).

In continuous casting, it is important to ensure controlled flow, but it is always necessary to examine refractory applications in terms of cost.

The consumption calculation is performed for 250 tons crude steel (1 ladle) based on the average number of castings taken. It is observed that C and A plates are more suitable because of lower consumption rate than B.

References:

- [1] A. Paul, Effect of bonding phases on the properties of Al₂O₃. Roll no: 212CR2439, Department of Ceramic Engineering, National Institute of Technology, Rourkela (2014)
- [2] S.K. Patra, Effect of specially formulated graphite on the thermo-mechanical properties of Al₂O₃-C slide gate plate refractory, Department of Ceramic Engineering, National Institute of Technology, Rourkela (2014)
- [3] H. Fan, Y. Li, S. Sang, Microstructures and mechanical properties of Al₂O₃-C refractories with silicon additive using different carbon sources, *Materials Science and Engineering A* 528 (2011) 3177–3185
- [4] A. Cooper, W. Kingery, *Corrosion of Refractories by Liquid Slags and Glasses*. ed. W. Kingery, MIT, (1959), pp.85-91
- [5] B. Benedetti, G. Burlando, Corrosion resistance of resin bonded magnesia carbon refractories. *British Ceram.Trans. J.*, (1989), 88, 55-57
- [6] S. Ganguli, S. Satpathy, A. K. Samanta, P. B. Panda, Design of high performing chemically bonded slide gate plates for casting of alloy steel and mild steel, TRL Krosaki Refractories Limited, Belpahar-768, 218, Odisha (2015)
- [7] Y. Kato, T. Ikemoto, K. Goto, Investigation of the corrosion mechanism of Al₂O₃-ZrO₂-C slide gate plates for the casting of Ca-added steel, I.Nippon Steel & Sumitomo Metal Corporation, Futtsu, Japan (2017)
- [8] J. Pascual, C. Bauer, M. Wiesel, Wear mechanism in slide gate plates during casting Ca-treatment steel, 54th International Colloquium on refractories, (2011), 100.
- [9] C.G. Aneziris et al., Corrosion mechanisms of low porosity ZrO₂ based materials during near net shape steel casting, *Journal of the European Ceramic Society* 20, (2000), 159-168.
- [10] H. Fan, Y. Li, Y. Huang, S. Sang, Y. Li, L. Zhao, Microstructures and mechanical properties of Al₂O₃-ZrO₂-C refractories using silicon, microsilica or their combination as additive, *Materials Science and Engineering A* 54, (2012), 148–154.
- [11] M. Labadie, M.L. Dignani, S. Camelli, Interaction between Calcium and Al₂O₃-ZrO₂-C Slide Gate Plate, Brazilian Metallurgical, Materials and Mining Association (2012)