PAPER • OPEN ACCESS

Root cause analysis of metallurgical defects in continuous cast steel slabs at ISD DUNAFERR Zrt.

To cite this article: K Wizner and A Kvári 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **903** 012043

View the article online for updates and enhancements.

Root cause analysis of metallurgical defects in continuous cast steel slabs at ISD DUNAFERR Zrt.

K Wizner[1] and A Kővári[2]

[1] Technology department senior associate, ISD Dunaferr Zrt. Dunaújváros, Hungary
[2] University of Dunaújváros, Dunaújváros, Hungary

E-mail: wizner.krisztian@isd-dunaferr.hu

Abstract. As market demands tighten, ISD Dunaferr Zrt. is placing increasing emphasis on improving the quality of its products. Line Scanner equipment used in rolling mills can identify most surface defects, but the majority of metallurgical faults are located beneath the surface (e.g. inclusions, cavity, gas bubbles, etc.). There is no standardized device for detecting them, only ultrasonic and microscopic testing is possible. In addition, it should be noted that some of the defects detected on the surface (e.g. surface cracks) can only be determined by microscopic testing, whether they are metallurgical or due to the parameters of the rolling process.
Several pilot programs have been implemented to explore the causes. In this theme, the most significant pilot programs, as well as the evaluation of their results will be presented.

1. Introduction

As part of the continuous product development in ISD Dunaferr Zrt, several pilot programs are implemented. These programs are basically divided into three groups: testing of new raw materials, product development / test production, quality development / problem exploration. Due to the numerous technological steps, both metallurgical and rolling phases are often involved in the experiments. This study primarily presents the metallurgical aspects of experimental programs in the context of recent quality improvement and problem-solving programs.

2. Examining the causes of surface defects attributable to casting powders

The casting powder used in continuous casting performs many tasks [1]. It seals the steel surface from the environment's oxygen, provides lubrication and better heat flow between the strand and the mould surface. There is extensive literature dealing with the choice of the right powder, but due to the complex function of the powder and the different conditions in each plant, it is selected through field tests even today. Incorrect choice increases the amount and severity of surface defects originated from the mould. In the worst case, it can even cause outbreak of the strand.

Metallographic examinations of the samples of defective parts of rolled products have confirmed the metallurgical origin of defects by measurements and images, most likely due to casting powders, which were marked on the slab surface maps.

The macroscopic nature of the ruptures differs from the nature of the line defects, but in most cases penetrated oxide and decarburization around the ruptures are visible. All this suggests that the errors are originated from the slab. In some cases, mechanical damage to the slab cannot be excluded, which could have caused the surface defect.

Scanning electron microscopy in the vicinity of the defects revealed the presence of alkaline oxide elements in several cases, confirming that the origin of the defect is casting powder.

During the period under investigation Dunaferr had two casting powder for regular use (S1, PG) and two for test production (SR, AX).

Table 1 Used casting powders in Dunaferr

Casting powder code	Steel type	Usage	Investigated heat pcs	Downgraded (t)	Production (t)	Downgraded (%)
S1	Alloyed	Regular	200	1,745	3782,345	0,05%
PG	Non-alloyed	Regular	200	0	3748,22	0,00%
SR	Alloyed	Test	27	52,185	521,124	10,01%
AX	Non-alloyed	Test	42	192,336	917,323	20,97%

In the case of the casting powder used for the two non-alloyed steels (PG, AX), it is clear that the ratio of downgrading is much higher for the heats cast with the AX trial casting powder than those with the PG casting powder.

Based on the flame-scarfing inspection of the slab, the following defects were found on the surface (Table 2):

Table 2 Average surface defects on slabs

Surface	Casting powder	Inspected (pcs)	Left side			Central curve			Right side		
			Gas bubble (pcs)	Starch crack (pcs)	Longitudinal crack (pcs)	Gas bubble (pcs)	Starch crack (pcs)	Longitudinal crack (pcs)	Gas bubble (pcs)	Starch crack (pcs)	Longitudinal crack (pcs)
A	S1	8	1,25	1,38	0,00	2,88	0,00	0,00	3,25	3,13	**0,25**
	PG	16	0,88	0,44	0,06	0,63	0,19	0,00	0,81	0,75	**0,31**
	SR	2	**9,50**	**24,00**	0,00	0,00	**6,00**	0,00	0,00	**12,00**	0,00
	AX	19	0,42	2,89	0,05	0,16	**4,32**	0,11	0,37	3,37	0,00
B	S1	10	1,20	2,00	0,00	0,20	0,90	0,00	2,20	**7,00**	0,00
	PG	18	0,61	0,17	0,00	0,33	0,17	**0,17**	0,44	2,00	**0,22**
	SR	3	**7,00**	0,67	0,00	1,33	**4,00**	0,00	0,00	4,00	0,00
	AX	20	0,75	1,60	**0,25**	0,30	**5,95**	0,05	1,75	**9,75**	0,00

*__Bold__ indicates extremely high values

Both sides of the slab have not been inspected in all cases, so this is the reason of difference between the pieces tested on „A" and „B" sides.

2.1. Result of inspection
From the data, it is clear that slabs cast with AX and SR have the most metallurgical defects (typically starch cracking).

Although the surface inspection was carried out much less times with slabs cast with SR and AX casting powder, the results are consistent/in line with the statistics of downgradement.

The samples taken from 2 coils of tested heats confirmed that most of the surface defects were already present in the pushing furnace, where they opened, and were later rolled in. Other surface defects could be attributed to scale rolling-in or mechanical damage.

3. Inspection of casting powders

In the light of the results described in the previous section, the purpose of the pilot program is to develop an assay system that allows for the detection of inadequate texture / composition of casting powders. This system makes possible to eliminate errors due to the consistency / composition of the casting powder. Our study is primarily focused on the crystal structure, chemical and granulometric composition of the casting powders used.

In practice, incoming casting powders are randomly inspected by visual inspection. The casting powder delivered to the plant is sampled in every 25 tonnes. These samples are subject to sieve analysis. Casting powders are subject to chemical analysis only at random. Based on the examinations carried out so far, the majority of the supplied casting powders complied with the data on the certificate. The most typical deviation from the certificate was the granulometric composition (too high powder fraction). Based on the examinations so far, the composition can be considered as permanent and conforms to the certificate. The mineralogical composition study (X-ray diffraction) of casting powders has not been done yet at Dunaferr.

The investigation of casting powders, as already used in the literature [2, 3] and in the operating metallurgical plants, involved the observation of the parameters forming the essential properties of the casting powders.

During the experiment, the samples were taken from 158 different big-bags. Out of a total of 56 pcs of PG, 47 pcs of S1, 3 pcs of AX and 1 pc of SR casting powder, due to the low number of samples, measurement data of AX and SR casting powders were not used.

3.1. Physical and chemical homogeneity test

To qualify casting powders, it was important to investigate whether granulometric segregation or chemical composition [4, 5] changes occurred within big-bags. Samples were taken from the bottom emptied big-bags for testing at the beginning of use and approx. 90% of usage.

3.1.1. Granulometric homogeneity test

The statistical (t-test) results of the comparison of the first and second sample series of big-bags are shown in Table 3. Based on the results it can be stated that the granulometric composition of the samples can be considered to be the same, thus the examined powders are not segregated for different size fractions during filling, transport or storage.

Table 3 Two-sample t-test results (t critical two-tailed)

Casting powder			Granulometric size fraction (mm)					
			>1,0	**1,0-0,5**	**0,5-0,25**	**0,25-0,125**	**0,125-0,063**	**<0,063**
PG	t value		-0,343	-1,509	1,335	-0,714	-0,483	1,294
	variance	Equal	1,981	1,981	1,981	1,981	1,981	1,981
		Non-equal	1,986	1,993	1,983	1,981	1,982	1,982
S1	t value		0,313	0,227	-0,712	0,175	1,260	1,027
	variance	Equal	1,986	1,986	1,986	1,986	1,986	1,986
		Non-equal	1,986	1,986	1,988	1,988	1,990	1,988

3.1.2. Chemical homogeneity test
Based on the samples taken from the first 9 big-bags, similarly to the granulometric analysis, it was found that the samples did not show significant chemical differences, so from a chemical point of view the contents of the big-bags can be considered homogeneous.

3.2. Characteristic granulometric distribution of casting powders
Based on the results of the t-test, it is possible to determine the typical granulometric composition for the types of cast powder tested.

Based on the granulometric composition (Table 4) for both casting powders, the powder fraction (<0.063 mm) can be considered to be about 1%.

The average amount of the fraction below 0.125 mm for each casting powder does not exceed 10%.

Table 4 Characteristic granulometric composition of casting powder samples (w%)

Casting powder	Sample	Granulometric size fraction (mm)					
		>1,0	1,0-0,5	0,5-0,25	0,25-0,125	0,125-0,063	<0,063%
PG	1	0,00%	3,96%	62,88%	25,83%	6,44%	0,89%
	2	0,01%	3,37%	63,86%	26,35%	5,65%	0,76%
S1	1	0,01%	4,70%	65,22%	23,66%	5,59%	0,82%
	2	0,01%	9,77%	68,83%	17,87%	2,35%	1,17%

For both PG and S1 casting powders, there was a case where the granulometric fraction was significantly different from the above. For S1, the proportion of powder fraction on one occasion (<0.063 mm) was 80%. For both casting powders, it is observed in some cases that the fraction above 0.5 mm greatly increases. These phenomena can cause changes in the properties of the slag formed from the casting powder (especially higher dust content) which later can cause the appearance of surface defects on the slabs.

3.3. Chemical composition inspection
Casting powder samples were analyzed by different measurement methods according to the variety of components.

The C content of the casting powder significantly influences the rate of its melting [6], so it initially seemed appropriate to measure the organic, inorganic C content separately and the total C content.

Based on 31 big-bag samples, it was observed (~50% PG, ~50% S1 casting powder) that the C content of PG casting powder was significantly derived from organic carbon, while S1 casting powder contained higher levels of inorganic carbon. Based on the analyzes performed using the LECO RC-412 instrument, the total carbon content of both casting powders was considered to be constant.

In the remaining samples, only the total carbon content was measured with a simpler solution – using Horiba EMIA-320V instrument.

Based on the measurement results, it was observed that the **results of the two measuring instruments showed ~ 1% difference. Due to this difference, a consultation has been initiated between the supplier and Dunaferr's laboratory to harmonize the test methods (measuring instruments, methods, measuring points, etc.).**

Based on the normalized standard deviation of casting powder components (Fig. 1), it is observed that the standard deviation of the components [7] (C, Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, Fe_2O_3) having a significant effect on the casting powder quality is low. For MnO and F^-, the value of the normalized standard deviation is slightly higher, which is due to the low values of the concentration and the inaccuracy of measurement.

Results from Dunaferr's laboratory show that the tested elements do not show a high degree of standard deviation.
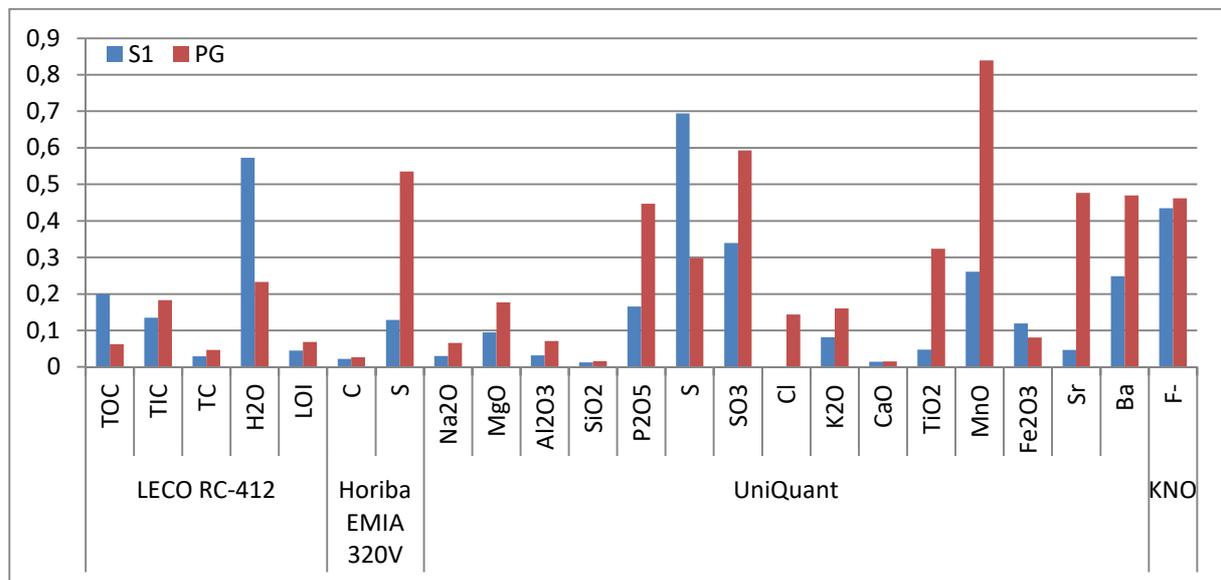
Figure 1 Normalized standard deviation values for the tested components

3.4. Measurement of casting powder slag thickness

According to the literature [8], the thickness of the slag formed from the casting powder is in relation with the conditions of the casting equipment and varies within narrow limits.

According to the data measured on the casting machine, the typical slag thickness for both casting powders (PG, S1) is ~ 9.2 ± 0.8 mm. Under operating conditions the measured values can be considered constant and no correlation can be found with the chemical or granulometric composition of the casting powder.

3.5. Changes in physical and chemical properties over time (from manufacture to use)

S1 casting powders were used after an average of 158 days, and PG casting powders were used after an average of 66 days.

Assuming homogeneous physical and chemical composition at the time of casting powder production and the fact that both casting powders were homogeneous within the big-bag at the time of sampling, it can be concluded that the elapsed time does not significantly influence the granulometric or chemical composition of the casting powder. However, it should be noted that casting powders contain compounds in a complex form (similar to hot metal and steel slags) and these compositions may change over time while the chemical composition of the casting powder remains unchanged.

Due to the homogeneity of the granulometric and chemical composition and the consistency of the molten casting powder, **no significant crystal structure differences can be expected between the various types of powder and therefore X-ray diffraction examination of the crystal structure was not justified**.

3.6. Result of the investigation

The investigation was based on 185 casting powder samples from big-bags supplied by 4 different manufacturers. Due to the low number of samples (4 pcs), casting powders from two manufacturers were excluded from the evaluation. Based on the results, it can be stated that the granulometric and chemical composition of the casting powders were homogeneous by manufacturer. The slag thickness was constant for both casting powders. In the light of the results, no X-ray diffraction crystal structure test was performed. The two casting powders are not comparable because PG is primarily used for non-alloyed steels, while S1 is used for alloyed steels. However, the results of the experiments provide a good basis for testing further new casting powders.

4. Exploration of metallurgical surface defects on continuous casted slabs

The aim of the investigation is to explore the effect of „constant" conditions, which do not change during casting, but may affect the surface texture of the strand. During the casting, the „non-constant" effects (change in casting speed, interventions in either the ladle or the tundish, mould level fluctuations, etc.) are not dealt with in detail in this investigation.

The investigation examined the sectional enrichments of 7 slabs of 5 heats, parallel to the surface of the flame cutting, in the distance of 100 mm. On the surface, 7x75-90, in total 525-630 analyzes were performed, of which 2x75-90 were as close as possible to the wide side. The sample was divided into 6 sections for ease of handling, which were further subdivided for more precise determination of the test points (Figure 2). In each „square", 3 measurements were taken in the center line parallel to the wide side. In the „squares" near the wide side, further analysis was carried out as close to the wide side as possible. Figure 3 shows a section of an examined slab divided into units.
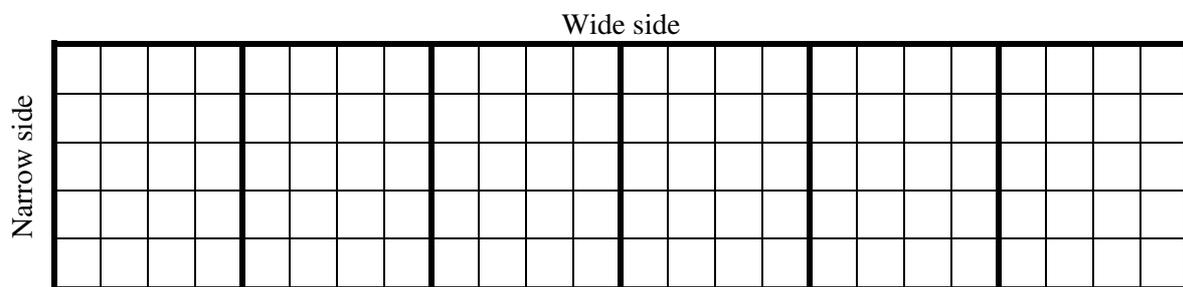

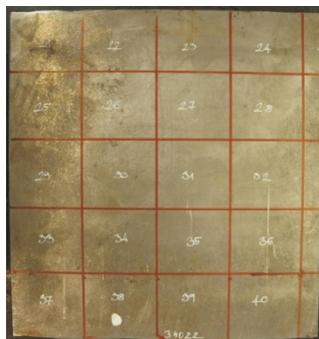**Figure 2** Division of the examined section into units of measurement
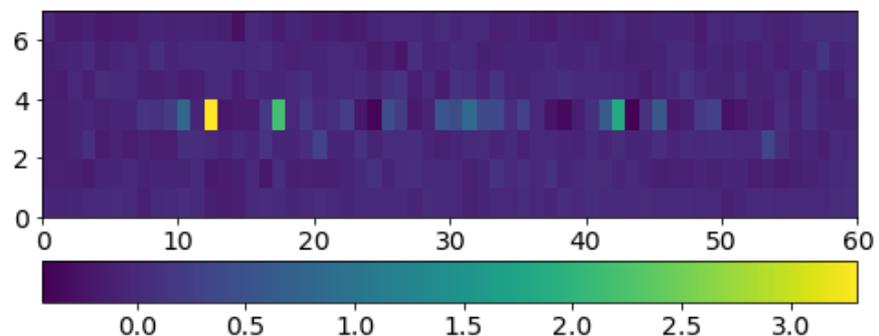

Figure 3 1/6th part of the examined surface

Figure 4 Deviation from average concentration

Based on the examination of the results, the cross-sectional composition of the slabs is similar in all cases (Fig. 4), regardless of the different production conditions. Both the spectroscopic chemical analyzes and the Baumann sulfur imprints made during the experiment clearly support the midline enrichment and the presence of stronger enrichment centers at the midline from the narrow edges, but no significant enrichment was observed near the surface of the slabs.

These results indicate that apart from the midline enrichment, the cross-section of the slabs can be considered homogeneous. Because of the chemical homogeneity, it is likely that downgrading is not attributable to the chemical composition / homogeneity of the cast slab.

In the reheating furnace, the surface of the slabs is oxidized and removed as scale before rolling. Copper dissolved in the iron matrix does not oxidize and can therefore be enriched on the surface of the slabs in the course of heating. The effect of the furnace goes beyond the present study.

Slight surface enrichment of trace elements in steel may also cause surface defects [9]. Based on the analysis of trace elements, it showed similar results as other alloys. Unfortunately, for several

elements (Sb, Sn) the accuracy of the spectroscopic measuring equipment was not sufficient to examine the distribution of the elements. Based on the results of the investigated elements (Cu, As) it can be seen (Fig. 5, Fig. 6) that, like other elements, their distribution is almost completely homogeneous.
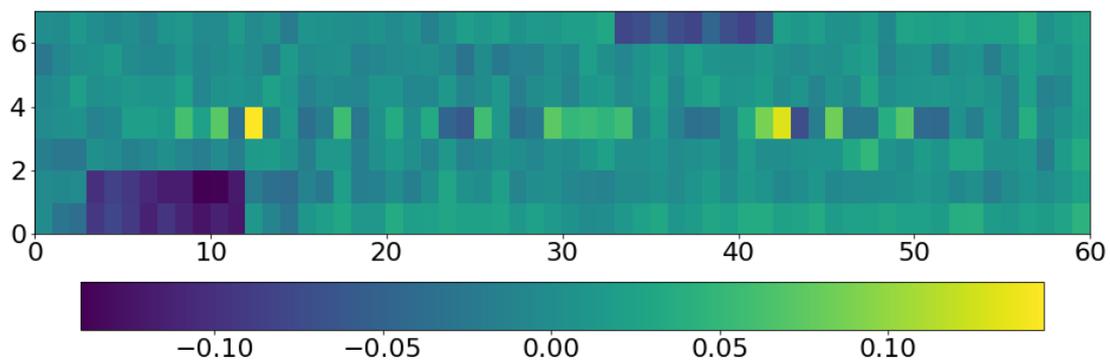

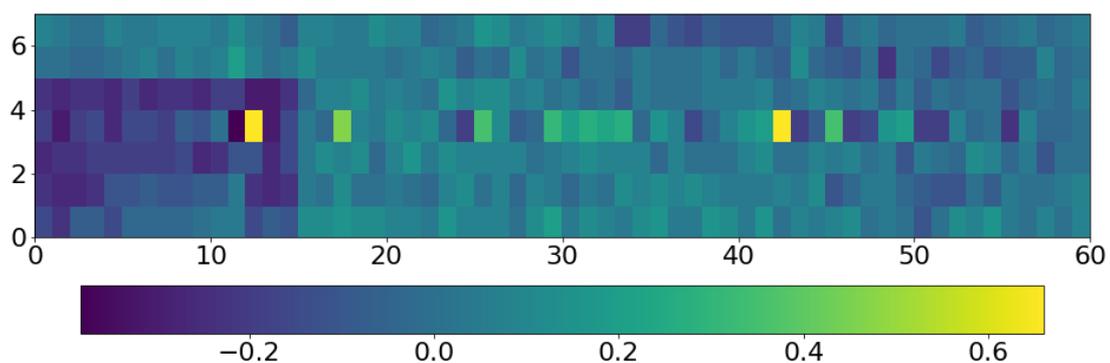**Figure 5** Deviation from average concentration (Cu)

Figure 6 Deviation from average concentration (As)

According to the literature, the surface quality of steel can be greatly influenced by the concentration of some trace elements near the surface. In the case of surface defects, copper is the most important element. Copper enrichment is primarily responsible for the formation of surface scales and surface cracks, and above a certain temperature it forms a liquid phase which causes surface cracks. This liquid phase occurs when the concentration of copper in the austenite exceeds the solubility limit [10]. Copper precipitation typically occurs during reheating. Some elements affect the solubility of austenite in copper, thereby counteracting or enhancing the effect of copper on surface quality. The copper solubility of austenite is improved by its nickel content. The 2:1 Ni:Cu ratio completely eliminates the copper surface defect. Even with a 1:1 ratio, surface cracking can be prevented, but this depends on the reheating temperature.

In steel, Sn and Sb significantly reduce the copper solubility in austenite (up to a third by Sn).

4.1. Result of the investigation

A cross-sectional chemical study of the slabs shows that apart from the midline enrichment, the slabs are considered to be homogeneous. Because of the chemical homogeneity, it is likely that downgrading is not attributable to the chemical composition / homogeneity of the cast slab. However, the slab to be rolled may be subject to heat effects in the reheating furnace which can cause enrichment in the surface layers of the slab.

Primary downgrading cannot be unambiguously paralleled with the parameters examined due to the small number of samples (7 pcs slabs).

5. Summary

Implementing and evaluating pilot programs based on factory measurements is an integral part of Dunaferr's continuous quality and product development. The experiments described above provide only insight into the numerous experimental programs to reduce defects of metallurgical origin.

Studies have shown that a large proportion of the surface defects on the slab are of casting powder origin. Most of the surface defects were already present in the pushing furnace and, when opened, were later rolled in. The remainders were due to scale rolled in or mechanical damage.

For two experimental casting powders (AX, SR), an increased amount of downgraded products was clearly detectable.

Chemical and granulometric analysis of the tested casting powders can be considered as homogeneous. Due to the homogeneity and the same casting powder slag thickness, the crystal structure composition is assumed to be homogeneous in the casting powders under investigation.

Operationally used PG and S1 casting powders are not comparable because PG is primarily used for non-alloyed steels and S1 casting powders for alloy steels. However, the results of the experiments provide a good basis for testing further new casting powders.

A cross-sectional chemical study of the slabs shows that apart from the midline enrichment, the slabs are considered to be homogeneous. Because of the chemical homogeneity, it is likely that downgrading is not attributable for the chemical composition / homogeneity of the cast slab. However, the rolled slab may be subjected to heat effects in the reheating furnace which can cause enrichment in the surface layers of the slab.

Primary downgrading cannot be unambiguously paralleled with the parameters examined due to the small number of samples (7 pcs of slabs).

References

[1]   Mazumder B 1999 A Process for Developing Continuous Casting Mould-Powder for Steel Industries *Journal of Scientific & Industrial Research* **58** pp 773-780

[2]   Reeb P and Schmitz H-U and Scher I 2015 Complexity of reception inspection for casting powders at Dillinger Steel Works *Cetas-Conference* Düsseldorf

[3]   Lis T and Kania H and Nowacki K. 2012 The impact of the chemical composition of continuous casting moulds on their physical properties *Journal of achievements in materials and manufacturing engineering* **55**(2) pp 345-348

[4]   Benavidez E. et al 2012 Influence of different oxides on the viscosity of fluorine-free mold fluxes *Procedia Materials Science* **1** pp 389-396

[5]   Benavidez E et al 2015 Microstructural characteristics of mold fluxes associated to their termal behavior *Procedia Materials Science* **8** pp 218-227

[6]   Wei E et al 2006 Effect of carbon properties on melting behavior of mold fluxes for continuous casting of steels *Journal of Iron and Steel Research International* **13**(2) pp 22-26

[7]   Görnerup M et al 2004 Mould fluxes in continuous casting of steel–characterization and performance tuning. *Proc. VII International Conference on Molten Slags Fluxes and Salts, African Institute of Mining and Metallurgy* pp 745-752

[8]   Pradhan N et al 1999 Prediction of slag pool thickness in continuous casting mould *ISIJ international* **39**(8) pp 804-808

[9]   Herman J C and Leroy V 1996 Influence of residual elements on steel processing and mechanical properties *Iron & steelmaker* **23**(12) pp 35-43

[10]   Leroy V et al 1995 Effects of tramp elements in flat and long products *European Commission technical steel research*