IMPACT OF INTERSTITIAL ALUMINIUM CONTENT ON OCCURRENCE OF NON-METALLIC INCLUSIONS IN STEEL

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Abstract

This paper details the study of interstitial aluminium impact on non-metallic inclusion occurrence on the basis of individual samples examination taken during steel production and processing. The aim was to identify and describe the relation between the content of interstitial aluminium in metal volume and the concentration of non-metallic inclusions on Al_xO_y basis occurring in steel. The identification of the non-metallic inclusions occurring in liquid steel was within this study implemented by the (AES) method based on the atom emission spectrometry evaluating the presence of the respective elements in the metal volume. This method works on a principle of emitted light from the existing source with a high voltage spark. The results of this study indicate a correlation between the interstitial aluminium content and concentrations of non-metallic inclusions on the Al_xO_y basis.

Keywords: steel cleanliness, secondary metallurgy, continuous casting, inclusions in steel

1 Introduction

It is necessary to ensure and maintain a high purity of produced steel especially for those types designed for a specific application. Regulation of the non-metallic inclusion content, amount and distribution has an essential impact on the steel purity [1]. Development of packaging materials significantly relates to thin electrolytically tinned sheets, which are nearly irreplaceable in some branches of the packaging sector. They are mainly used in the food industry [2-5] thanks to their slim thickness, wide range of mechanical properties, high corrosion resistance and of course their harmlessness to health. The ability to regulate, respectively to control the concentration, morphology and composition of the non-metallic inclusions [6,7] represents one of the most important factors to the improvement of steel purity, respectively the quality improvement of steel products. It is important to study the increased concentration distribution of the non-metallic inclusions due to its impact on steel product quality in the form of the resulting defects [8, 9]. The priority is to decrease the number of defects inside the steel ingot that results from the non-metallic inclusions present in steel [10]. The non-metallic inclusions present in metal are of different origins, e.g. from deoxidation, refractory materials, slag entrainment, casting powders and entrainment of the clogged parts of the submerged entry nozzle into the metal volume [11-16]. According to professional literature, during the continuous casting of steel on the casting equipment, casting with stable speeds is preferred. Generally, changes of speed in the casting process in production are inevitable [17]. A negative impact on the non-metallic inclusions to

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steel purity depends on their concentrations, content, types and shapes. It is recommended to avoid big and angular non-metallic inclusions [14-16]. The impact of the non-metallic inclusions on commercial properties of steel materials is partially caused by the refinery process and steel casting. In the secondary refinery process, the tundish plays a significant role in the continuous steel casting [21-23]. Elimination of the non-metallic inclusions is one of the secondary refinery functions in the steel production process. This process is based on the non-metallic inclusions washout principle into the slag volume [24, 25]. Elimination of the non-metallic inclusions is based on the liquid metal bubbling principle by inert gas in the bubbling and rinsing process [26-28].

2 Experimental Materials

Within this study samples were taken from the individual phases of the production and processing of steel packaging quality. During the samples analysis there were assessed the concentrations of non-metallic inclusions on the Al_xO_y basis and respective contents of interstitial aluminium, i.e. aluminium bound in the form of non-metallic inclusions. Two sets of samples were analysed; the first set of evaluated analyses (**Table 1, 2**) identifies the behaviour of the assessed melting parameters in the production process between the basic oxygen converter (OC) through the stirring station (SM) up to the caster machine (CC). At the first set eight samples were taken from the same heat at various phases of the steel production and processing. The second set comprised of ten heats, where from each heat two samples were taken – one from the tundish and one from the mold for the caster machine (**Table 3**). In table (**Table 1**) there are the individual samples assigned to the different stages of the steel production and processing as they were taken. The first column (**Table 1-3**) means: „T/V“ heat number (T)/number of the sample (V). In tables (**Table 2-3**) there are individual columns with marks from left to right, except for the already mentioned first column „Al_{INS} [%]“ identifying the interstitial aluminium content in percentage. „Al_xO_y [ppm]” describes the concentrations of identified non-metallic inclusions on aluminium and oxygen basis; the non-metallic inclusions on the basis of the other elements reached minimum concentrations which were at the limit of identification in relation to equipment sensitivity. Each analysed sample was assessed in three so called tracks (S_1, S_2, S_3), consequently the data ($S_{\varnothing}$) represents the evaluated average of the three analysed tracks. In the assessment of the analysed samples (**Table 2, 3**) there are highlighted values of Al_xO_y concentrations (>10ppm), and values of interstitial aluminium (0.003 and more). This highlighting enables us better identification of Al_xO_y concentrations and Al_{INS} contents, which may lead to defects, resp. degradation of steel metallographic purity.

3 Results and Discussion

Table 1 Sample taking phase

T/V	Sample taking phase
$T_{01/1}$	after blowing (OC)
$T_{01/2}$	after tapping (OC)
$T_{01/3}$	after addition of Al (SM)
$T_{01/4}$	3 min. of bubbling (SM)
$T_{01/5}$	6 min. of bubbling (SM)
$T_{01/6}$	9 min. of bubbling (SM)
$T_{01/7}$	12 min. of bubbling (SM)
$T_{01/8}$	mold (CC)

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Table 2 Heat T_{01} analysis

T/V	Al_{INS} [%]	Al_xO_y [ppm]			
		S_1	S_2	S_3	$S_{\varnothing}$
$T_{01/1}$	0.003	14	19	44	26
$T_{01/2}$	0.004	30	12	12	18
$T_{01/3}$	0.002	02	07	03	04
$T_{01/4}$	0.001	03	13	10	09
$T_{01/5}$	0.001	04	01	01	02
$T_{01/6}$	0.001	01	05	01	03
$T_{01/7}$	0.002	02	06	02	03
$T_{01/8}$	0.001	02	07	01	03

Table 3 Analysed heat during CC

T/V	Al_{INS} [%]	Al_xO_y [ppm]			
		S_1	S_2	S_3	$S_{\varnothing}$
$T_{02/1}$	0.002	22	01	01	08
$T_{02/2}$	0.002	04	09	05	06
$T_{03/1}$	0.002	02	11	16	10
$T_{03/2}$	0.001	03	01	01	02
$T_{04/1}$	0.002	01	07	00	03
$T_{04/2}$	0.001	01	05	03	03
$T_{05/1}$	0.001	02	03	06	04
$T_{05/2}$	0.002	14	04	04	07
$T_{06/1}$	0.003	08	13	07	09
$T_{06/2}$	0.002	04	06	05	05
$T_{07/1}$	0.002	20	12	02	11
$T_{07/2}$	0.002	04	02	05	04
$T_{08/1}$	0.002	02	06	00	03
$T_{08/2}$	0.002	00	07	03	03
$T_{09/1}$	0.002	08	11	06	08
$T_{09/2}$	0.002	06	04	09	06
$T_{10/1}$	0.001	00	01	01	01
$T_{10/2}$	0.001	01	00	01	01
$T_{11/1}$	0.003	14	24	02	13
$T_{11/2}$	0.001	03	04	04	04

Graphic dependence between the identified Al_xO_y concentrations and analysed values of Al_{INS} during the production and heat processing (T_{01}) (**Table 1**, **2**, **Fig. 1**) in the first set indicates some connection.

Results of the analysis related to the samples taken in the second set (**Table 3**) indicate non-metallic inclusions presence (INC>10ppm) on the Al_xO_y basis in seven cases (heats). Graphic scheme (**Fig. 2**) divides the second set heats into two groups, heats with the presence of non-metallic inclusions smaller than ten ppm (INC<10ppm), and the heats with the presence of non-metallic inclusions bigger than ten ppm (INC>10ppm). Followingly, the heats with the presence of non-metallic inclusions bigger than ten ppm are divided according to the sample taking place Graphic analysis (**Fig. 3**) evaluates the dependency of interstitial aluminium contents on the

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corresponding average concentrations of identified non-metallic inclusions from both analysed sets.

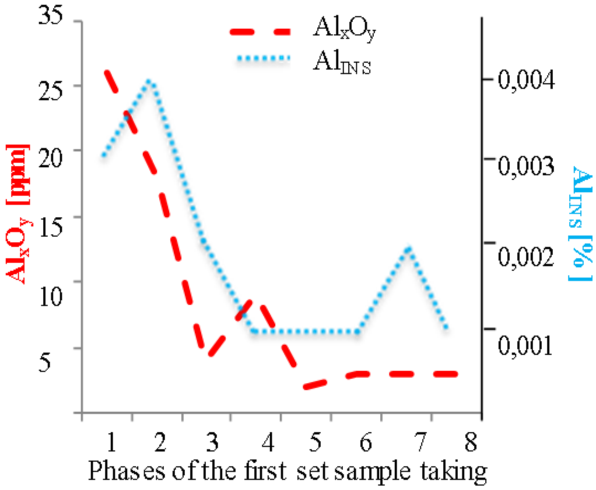

Fig. 1 Assessment of the first set

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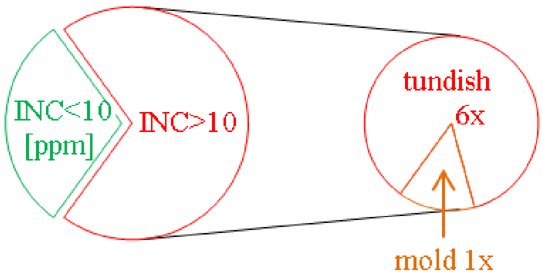

Fig. 2 INC from the second set

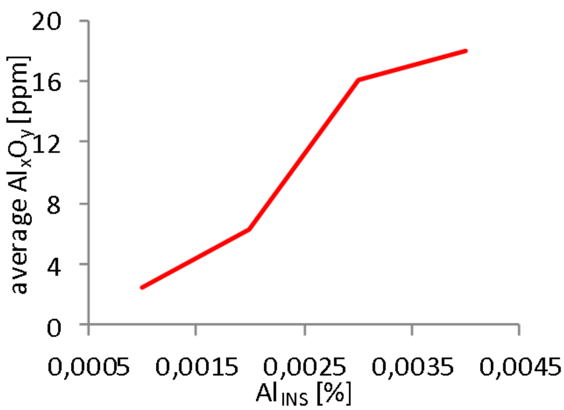

Fig. 3 INC and Al_{INS} dependency in the analysed sets

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Graphical outcome of the first set (**Table 2**) is transformed into continuances (**Fig. 1**) that show – at the beginning of the analysed process, respectively at the tapping of steel from the oxygen converter – standardly higher concentrations of the non-metallic inclusions on the Al_xO_y basis, and the higher values of interstitial aluminium which decrease after tapping. In the next stages of the analysed process (SM) (**Fig. 1**), analysed Al_xO_y concentrations and interstitial aluminium values indicate a significant decrease. In the caster machine, in this case there are no significant fluctuations and the courses in both cases indicate minimum Al_xO_y concentrations and minimum interstitial aluminium contents. Analysed concentration occurrences of non-metallic inclusions and the interstitial aluminium analyses from the first set (**Table 2**) during the heat processing (T_{01}) show a similar trend in the courses evaluated (**Fig. 1**). In this case, a higher concentration of interstitial aluminium contents is related to the increased concentration of the non-metallic inclusions on the Al_xO_y basis.

In the second set of samples ten heats were analysed (**Table 3**, **Fig. 2**), where seven showed the presence of non-metallic inclusions of higher concentrations (>10ppm). Out of these seven cases, one exceeding presence of the non-metallic inclusions was identified in the sample taken from the mold. In six cases, the identified presence of non-metallic inclusions was from the tundish. Classification of the identified non-metallic inclusions (INC) according to the concentration and the sample taking place (**Fig. 2**) shows a significant predominance of INC>10ppm in the tundish. This fact does not necessarily indicate non-metallic inclusions that may be coming out in the following processing phases in the form of surface defects. Turbulent flow of liquid metal was a supposed reason of higher concentrations of non-metallic inclusions in the tundish closely under the surface (**Table 3**, **Fig. 2**). This sample points to a possible washout and capturing of non-metallic inclusions in the slag volume. In the second set (**Table 3**) three groups of interstitial aluminium values (0.001; 0.002; 0.003) were analysed. With the increasing content of interstitial aluminium, an increase in concentrations of non-metallic inclusions on the Al_xO_y basis were registered, and an increased percentage of INC>10ppm presence in the analysed heats, which reached 100% at the value of Al_{INS} 0.003%. From this reason the value Al_{INS} (0.003%) can be called critical with regards to the presence of non-metallic inclusions of higher concentrations (>10ppm). The evaluated graphical dependency from the analysed sets (**Fig. 3**) describes the correlation between the Al_xO_y concentrations and the Al_{INS} values, as with increasing value of Al_{INS} also a higher average concentration of non-metallic inclusions on the Al_xO_y basis was registered. In this case, the critical value of Al_{INS} (0.003) has been proved in relation to the concentration of identified non-metallic inclusions.

4 Conclusions

The analysis of the interstitial aluminium content within this study showed its correlation with the concentration of non-metallic inclusions on the Al_xO_y basis. Both sets of the analysed samples proved the increased concentrations of non-metallic inclusions in the places, where the increased content of interstitial aluminium was identified. The analysed samples of the first set transformed into continuances showed a similar trend in the concentrations of non-metallic inclusions and the interstitial aluminium contents during steel processing from the oxygen converter through the stirring station up to the caster machine; despite the fact, that in comparison to the first set the second set of samples was taken explicitly from the caster machine. The results correspond in principle to identifying the correlation between the concentrations of non-metallic inclusion on an aluminium basis and the interstitial aluminium contents. Although the occurrence of non-metallic inclusions in higher concentrations has been

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identified, and higher values of interstitial aluminium in different phases of the steel production process, on the other side it is necessary to highlight the fact that proved high steel purity in the samples taken from the mold – as the final phase of the production process and liquid steel processing – showed minimum values of interstitial aluminium and minimum concentrations of non-metallic inclusions on the Al_xO_y basis.

In the future, it is necessary to pay more attention to identifying interstitial aluminium in the production process due to the elimination of occurrence of higher concentrations of non-metallic inclusions, which will lead to an increase steel cleanliness.

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