INVESTIGATION OF NON-METALLIC INCLUSIONS IN LIQUID STEEL AND SQUARE BILLETS OF CARBON STEELS

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Abstract

The article presents research results performed to determine the size and shape of non-metallic inclusions, on different steel production stages, for steel grades intended for long products. The tests were carried out under industrial conditions during normal production cycle, while casting of carbon steel groups. Samples were taken from liquid steel (“lollypop” probes) and from billet (as a disc shape with 20 mm thickness). The size and shape of inclusions was determined by quantitative analysis, according to a specific scheme.

Keywords: Continuous casting, billet, non-metallic inclusions

1. INTRODUCTION

Nowadays, the concept of pure steel is characterized by the product not only with strictly controlled concentrations of harmful and undesirable elements, but also control of non-dissolved components in steel, which may cause structural defects in finished products. Particularly important is the separation of so-called non-metallic inclusions, which are formed during the refining of liquid steel. Non-metallic inclusions are formed as products of deoxidation and desulphurisation of steel, during solidification, as a result of a decrease in the solubility of alloy components and as a result of contamination of a metal bath with particles of a refractory lining or slag. Non-metallic inclusions adversely affect, among others, plasticity, deformability, brittleness or fatigue strength of steel [1-3]. Therefore, it is important to conduct research, including model studies, aimed at understanding the behavior of non-metallic inclusions during refining and casting of liquid steel.

Non-metallic inclusions are removed from steel at several stages of its production, mainly during secondary steelmaking treatment, where the largest amount of inclusions are removed, but also during the flow of steel through the intermediate tundish or finally in the mould of the continuous steel casting machine. Although the basic premise for the widespread use of secondary steel treatment is to accelerate the course of production processes, the optimization of steel processing from the point of view of its "metallurgical purity" has become another important task. The basic and commonly used secondary treatment is blowing in liquid steel with inert gases. Thanks to the use of purging, not only the temperature and chemical composition can be homogenised, but also the oxide and sulfide content of non-metallic inclusions can be reduced; in addition, the beneficial effect of refining was found to reduce the number of inclusions in the liquid metal. There is also the possibility of removing non-metallic inclusions in the tundish and mould which was confirmed by the results of model studies presented in numerous works [4-6].

To investigate the non-metallic inclusions removal process, first size and shape of inclusions occurring in the investigated steel grades has to be study. The main aim of presented results was to determine the geometric parameters (size and shape) of non-metallic inclusions. The probes were taken at various stages of steel production (secondary metallurgy station, tundish and billet). The gained information are extremely important to carry out further investigations (numerical simulations of non-metallic inclusions removal process).

2. METHODOLOGY OF INDUSTRIAL INVESTIGATIONS

The work is a part of a larger study on secondary metallurgy and continuous casting of high carbon steel intended for wire rods. In order to supplement and refine the input parameters for mathematical models intended for numerical modeling of processes, appropriate industrial research was carried out. In this case, it concerned the determination of the size and shape of inclusions occurring in the investigated steel grades.

Industrial research was carried out in the steelworks of one of the national steelworks. Carbon steel grades C45 and C60 were tested. In order to determine the initial parameters for modeling, first attempts were made to investigate the determination of the size of non-metallic inclusions and their morphology. Sampling took place during the normal production cycle, from the same heat. The samples were taken:

- in the ladle furnace;
- from a device for continuous steel casting (samples taken from a tundish);
- from continuous ingots.

Three tests were carried out at the ladle furnace after delivery of the steel ladle to the position of the Ladle Furnace station (LF) and 3 tests before transferring the steel ladle to the continuous steel casting station (end of the melt). In total, six samples were taken from the ladle furnace. Then, the samples were taken from the tundish while casting steel from the same steel ladle. The first tests were taken after pouring about 30 t of liquid metal and the next ones were collected after pouring about 120 t. Samples from the finished product were taken for the appropriate veins (principle of symmetry). The samples taken were intended not only for micro studies, but also for determining changes in the chemical composition of liquid metal during the technological process.

The main purpose of this research was to determine morphology, to identify chemical composition and to measure geometric parameters of non-metallic inclusions. The main research was carried out with the INSPECT F scanning microscope. The tests were carried out at various stages of steel production. First, tests were carried out from liquid steel from the ladle furnace at the beginning of the steel working process. Subsequently, samples taken from the ladle furnace, tundish and samples taken from finished cast steel (billets) were tested. The research material was cut out and analyzed from the middle of the so-called lollipop sample taken from the ladle furnace and a tundish ladle. In the case of tests of non-metallic inclusions in the finished product, a map of the analyzed areas was determined. The order of the areas to be analyzed in the first and subsequent stages of the research was also determined. The areas subjected to microscopic analysis are shown in **Figure 1**. In the case of templets, tests were performed for areas 1,3,5,7 and 9. The identification of the chemical composition of non-metallic inclusions was made with the help of Energy Dispersive X-ray Spectroscopy (EDS). Commercial software was used to analyze the number and structure of non-metallic inclusions. The analysis was carried out on the photographs recorded by the scanning microscope. To describe the structural parameters, the following parameters were used: particle area [μm^2], equivalent diameter [μm] and classic shape factor. The shape index was determined on the basis of Feret's diameters.

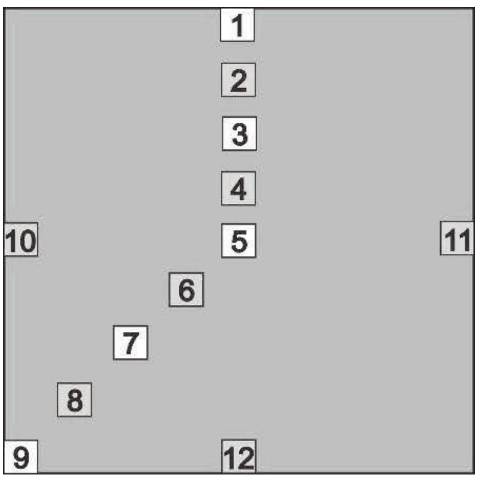

Figure 1 Areas analyzed in samples from the finished product

3. TEST RESULTS

Identification of chemical composition of inclusions and measurements of their geometrical parameters was carried out. **Figure 2** shows an example of a scanning microscope image on which non-metallic inclusions are identified. **Table 1** presents an example of chemical microanalysis for the analyzed inclusions shown in **Figure 2**. The analyzes were performed comprehensively for individual melts in the sequence. **Tables 2** and **3** present the results of the quantitative assessment of the structure of non-metallic inclusions in the sample taken from the tundish and the finished product for the given smelting, respectively.

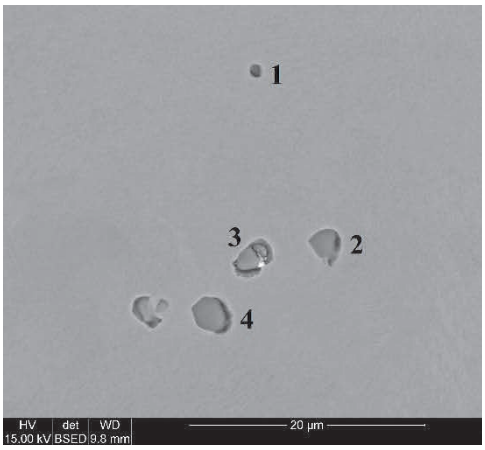

Figure 2 Image of non-metallic inclusions in the analyzed sample taken from the ladle furnace, area 2000x

Table 1 An exemplary chemical composition from the surface of a sample taken from a ladle furnace (wt. %)

No.	C	O	Al	S	Ca	Mn	Fe
1	0.9	-	1.06	16.29	7.10	18.64	56.01
2	-	-	-	32.4	-	47.49	18.13
3	1.11	4.79	0.56	34.95	-	3.11	85.39
4	-	-	-	34.99	-	53.76	11.25

Table 2 Sample analysis of non-metallic inclusions in a sample taken from a tundish

	surface area (μm^2)	equivalent diameter (μm)	shape factor (-)
average	4.01	1.87	0.93
standard deviation	5.13	1.28	0.14
minimum	0.14	0.42	0.44
maximum	19.66	5.00	1.00
share of the area (%)	0.23		-
the number of inclusions	56	-	-

Table 3 Sample analysis of non-metallic inclusions in a sample taken from a finished product

	surface area (μm^2)	equivalent diameter (μm)	shape factor (-)
average	3.13	1.84	0.99
standard deviation	2.74	0.77	0.06
minimum	0.46	0.77	0.59
maximum	14.18	4.25	1.00
share of the area (%)	0.06	-	-
the number of inclusions	46	-	-

4. CONCLUSION

Studies on the identification of the chemical composition of non-metallic inclusions were carried out and measurements of their geometrical parameters were made. Samples for testing were collected during the normal production cycle. Based on the conducted chemical composition tests of identified inclusions, the presence of mainly composed manganese sulphides and calcium-modified sulphides was found. After analyzing the amount and structure of inclusions, it was found that in samples taken from the so-called "lollipops" (samples from LF and tundish), the share of the area (in %) of inclusions for all analyzed probes range from 0.07 to 0.44% (0.23 for given in article example probe). While in the case of samples taken from the templets, the value of the share of the area (in %) range from 0.06 to 0.35% (0.06 for given in article example probe). The diameters of analyzed non-metallic inclusions range from 1 to 19 µm. According to the shape of detected inclusions, in case of the classic shape index, for most of the inclusions its value is close to one, so it can be assumed that the majority of analyzed non-metallic inclusions has a globular shape. The information obtained from industrial research is extremely important to carry out further numerical simulations.

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