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NON-METALLIC INCLUSIONS CONTROLING AT THE LADLE FURNACE (LF) STATION

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The article contains the results of research performed on the determination of the quantity and morphology of non-metallic inclusions identified at the secondary metallurgy process during the cold-swelling steel production. Continuous improvement of steel quality standards, which today is primarily associated with the amount of inclusions contained in the steel product, enforces actions taken to remove the largest possible number of inclusions from steel and/or by their modification at the final stage of secondary metallurgy processing. Therefore, research was undertaken at the ladle furnace industrial stand, and the steel samples were subjected to metallographic testing. It was shown that the number and/or the size of inclusions identified in the samples taken at the beginning and end of the process decreased, and in addition they were modified.

Keywords: secondary metallurgy, steelmaking, ladle furnace, metallographic testing, non-metallic inclusions

INTRODUCTION

The constant improvement of steel quality standards, which is currently defined primarily by the amount of non-metallic inclusions contained in steel, forces steel producers to try to remove as many inclusions as possible from steel at each production stages. The largest amount can be removed at the stage of secondary metallurgy, and in addition to their removal, they are also modified at the final stage of secondary metallurgy. Also the actions are taken to limit their introduction into liquid metal [1-3].

Non-metallic inclusions contained in steel cause defects in both the semi-finished and finished steel products, which may lead to damage to the products during plastic forming processes or later during the use of the finished product. Complete removal of inclusions is not possible, because of a continuous process of their formation as a result of nucleation and the growth of products of subsequent chemical reactions as a result of operations carried out at the ladle furnace station (mainly deoxidation and alloying). In addition, their source is the constantly wearing refractory lining of metallurgical aggregates. Moreover, some of them are the result of decreasing, along with decreasing temperature of the metal bath, solubility of a given component in steel. That is why it is important to constantly strive to reduce the amount of inclusions in steel and to control them at every stage of production.

Due to the difficulties that arise when conducting research in industrial conditions, often research on the removal of non-metallic inclusions from liquid steel are carried out using numerical and physical modelling (on water models) [4-7]. Tests are carried out both in the steel ladle as well as in the tundish and mould. The first treatments of refining inclusions from a steel bath are carried out at a secondary furnace treatment station, usually in a ladle furnace [8-10]. Due to the nature of this process, the largest number of inclusions is removed. This is because the intensive blowing of argon baths significantly accelerates the process of transporting inclusions rising along with gas bubbles to the slag covering the metal surface.

The article presents the results of tests carried out during the normal production cycle of steels for cold upsetting. The research concerned in particular the determination of the amount and morphology of non-metallic inclusions identified during the secondary metallurgy process. Therefore, research was undertaken at the ladle furnace industrial stand, and the samples taken were subjected to farther metallographic testing.

PLANT INVESTIGATION OF NON-METALLIC INCLUSIONS REMOVAL AND MODIFICATION

The presented article attempts to control the content of non-metallic inclusions during its processing at the ladle furnace (LF) station. The LF station scheme and sampling location are given in Figure 1. Samples were taken at the initial stage of the process and just before the ladle left for the continuous steel casting station. The tests were carried out during the production of steel grades from the group with increased plasticity for cold deformation. An example of the composition is given in Table 1. Sampling took place during the normal production cycle.

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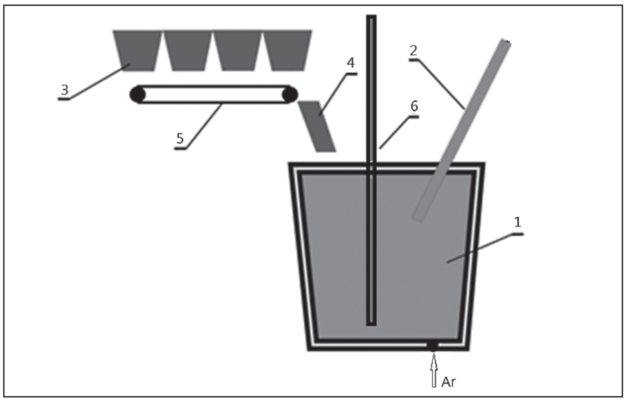


Figure 1 Ladle furnace (LF) station scheme and sampling location: 1 – ladle, 2 – automatic temperature measuring and metal & slag sampling, 3 – ferroalloy reservoirs, 4 – charge chute, 5 – automatic scales, 6 – Ar lance.

During the experiment at the LF stand, samples were taken at the beginning of the smelting and from the finished stage, when the liquid metal was waiting for the transportation to the casting station. At a later stage, the tests were subject to metallographic analyses, during which a quantitative analysis of the identified inclusions was carried out. The amount and size of the identified inclusions and the shape factor were determined. In addition, inclusions were identified by EDS microanalysis.

Table 1 **Chemical composition of investigated steel grade / mas. %**

	C	Mn	Si	S	Cr	Ni	Mo
Min.	0,27	0,80	-	-	0,17	-	-
Max.	0,32	1,10	0,10	0,025	0,23	0,15	0,05

The lollipop samples were cut in the middle part, and then a smaller part was taken from the side of the catted-out piece of sample, which was incorporated and analysed (Figure 2). On the sample, on which the metallographic specimen was made, 15 measurements were carried out to average the value, with magnification of 1 000 times and a measuring field of 0,086 mm^2.

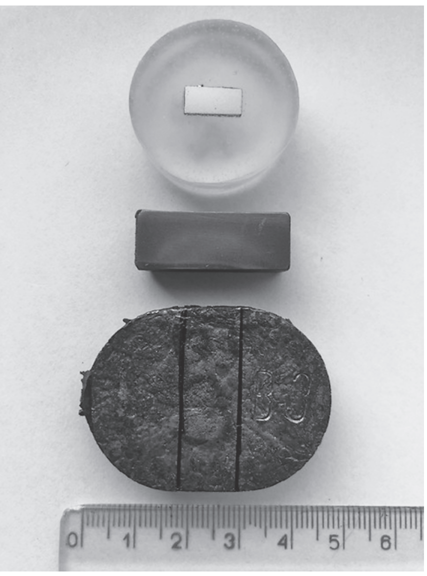


Figure 2 Preparation of the sample for metallography investigations.

As a representative value of inclusion size the equivalent diameter was used, which is calculated as the diameter of a circle with the same area as the inclusion. The second representative value of inclusion morphology is the shape ratio, which is defined by the ratio of the maximum dimension to the minimum dimension of the inclusion.

RESULTS AND DISCUSSION

Samples taken during the tests were subjected to quantitative and qualitative analysis. Quantitative analysis was aimed at determining the average (identified on a specific sample surface) amount of inclusions in samples taken at the beginning and end of the process. It was assumed to compare the number of inclusions identified in the central region of lollipop samples taken as representative of the entire sample. Tables 2 and 3 present the results obtained from two industrial tests.

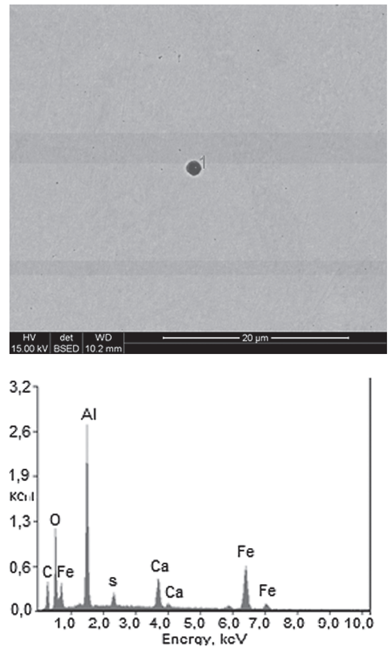
Table 2 **Number of inclusions identified in industrial trials (measurement No. 1)**

Equivalent diameter distribution / µm		Inclusions number	
		start	end
0,00	1,00	194	28
1,00	2,00	47	36
2,00	3,00	10	18
3,00	4,00	4	0
4,00	5,00	0	0
5,00	6,00	0	0
Sum:		255	82
Shape ratio:		0,95	0,99

Table 3 **Number of inclusions identified in industrial trials (measurement No. 2)**

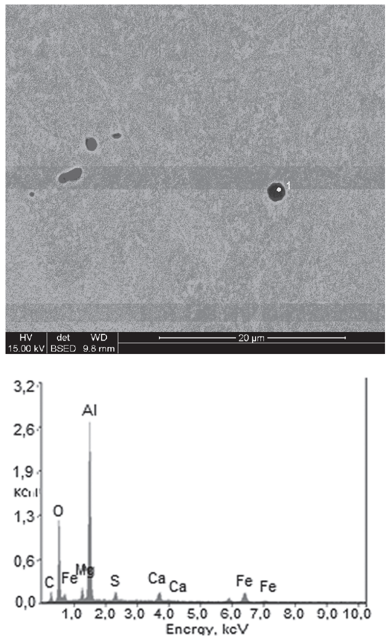
Equivalent diameter distribution / µm		Inclusions number	
		start	end
0,00	1,00	37	64
1,00	2,00	25	32
2,00	3,00	15	7
3,00	4,00	5	0
4,00	5,00	2	0
5,00	6,00	1	0
Sum:		85	103
Shape ratio:		0,91	0,93

The number of identified inclusions is of particular importance for the quality of the steel semi-product and at the end the final product. During the treatment of liquid metal at the ladle furnace, as a result of deoxidation of liquid steel and its alloying, large amounts of various types of non-metallic inclusions (simple or complex) are formed, which should then be removed from it. One should noticed that not always, the total number of inclusions will decrease during the process. Although, even the total number of inclusions is higher, important



Element	wt, %	at, %
C K	18,34	36,68
O K	15,77	23,68
AlK	20,85	18,56
S K	01,86	01,40
CaK	06,60	03,95
FeK	36,59	15,74

Figure 3 Representative example of the identified inclusion at the beginning phase of the process (experiment 1)



Element	wt, %	at, %
C K	13,77	24,28
O K	28,05	37,15
MgK	02,31	02,01
AlK	34,75	27,29
S K	02,49	01,65
CaK	03,77	01,99
FeK	14,86	05,64

Figure 4 Representative example of the identified inclusion at the beginning phase of the process (experiment 2)

is the size of inclusions – eg. in measurement no. 2 (Table 3) there are more inclusions in probe but their size has been decreased. At the end of the ladle process the size of all inclusions identified in the probe was less than 3 μm.

Moreover, not only the number and size of inclusions are important. Their shape factor is also important. The closer the spherical inclusion, the better. The measurements clearly show that the shape factor is closer to one for the inclusions identified in the samples taken at the end of the secondary furnace process. In the first measurement, this ratio increased from 0,95 to 0,99, and in the second measurement from 0,91 to 0,93 (slightly, but there was an increase).

The purpose of qualitative analysis (Figures 3-5) was to determine the chemical composition of captured non-metallic inclusions and to determine whether they are modified during the secondary metallurgy process.

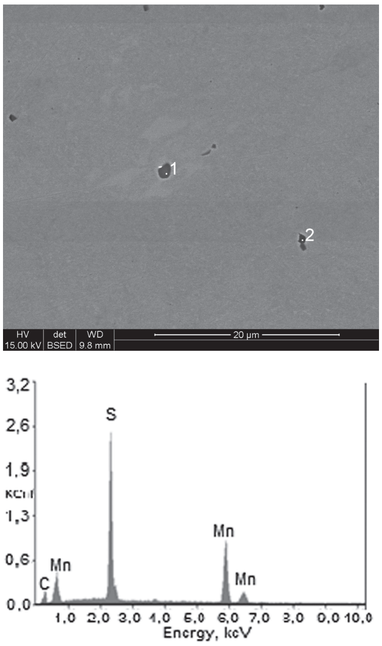
In the final phase, the presence of complex manganese sulphides and calcium-modified sulphides was found. This is unequivocal evidence of the modification of iron sulphides previously present in the steel and of carrying into the slag particularly undesirable oxide inclusions in steel, mainly Al_2O_3.

SUMMARY

Based on the conducted research, it was found that in samples taken from the lollipop probes, the surface share of inclusions ranged from 0,07 to 0,44 %. The microanalysis of the chemical composition of inclusions, present in the tested samples, showed that they were mostly inclusions of complex manganese sulphides, calcium-modified sulphides, aluminium oxides and calcium oxides.

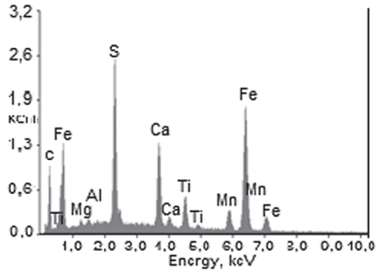
It was shown that the number of inclusions identified in the samples taken at the beginning and end of the process was reduced, and even if not at total number – the size of inclusions was decreased. In addition the inclusions were modified during the process.

As shown, non-metallic inclusions number not always can be decreased during secondary metallurgy operation. Because of that, it is even more important to modify the inclusions to get less harmful inclusions for farther plastic forming processes.



Element	wt, %	at, %
C K	19,45	46,77
S K	29,04	26,16
MnK	51,50	27,07

a) point 1



Element	wt, %	at, %
C K	20,98	51,44
MgK	00,39	00,48
AlK	00,37	00,40
S K	10,67	09,80
CaK	08,46	06,22
TiK	04,82	02,96
MnK	06,66	03,57
FeK	47,65	25,13

b) point 2

Figure 5 Representative example of the identified inclusions at the ending phase of the process (experiment 2)

Acknowledgements

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Note: The responsible for English language BJO s.c., Poland