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Influence of Steel Cleanliness by Ladle Furnace Processes

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Non-metallic inclusions in steel can be treated by ladle metallurgy processes. Main ladle metallurgy processes that influence composition, morphology and quantity of non-metallic inclusions in steel are: deep deoxidation by Al wire injection; desulphuration by refining slag; alloying to final chemical composition; modification of alumina inclusions by additions of CaSi and/or CaO; elimination of non-metallic inclusions. Employing methods for determination of composition, morphology and quantity of non-metallic inclusions, formation of alumina inclusions during deep deoxidation of steel melt by Al wire injection, modification of alumina inclusions by Ca based additions were investigated. It is shown that elimination of non-metallic inclusions is a result of steel melt bath agitation by Ar gas bubbling. Composition and structure of slag from ladle metallurgy treatment are provided.

Keywords: ladle furnace, non-metallic inclusions, Ar gas bubbling, ladle furnace slag.

1. INTRODUCTION

World of steel in present is governed by two main factors. The first one is the growing amount of produced steel in world. The second one is never ending pressure on increase of produced steel quality. New and demanding applications of steel are connected with better mechanical properties of steel, with new methods of surface preparation and treatment, etc [1]. One of important factors forming the quality of steel is its cleanliness [2 – 4].

Concept of steel cleanliness is subdivided into two categories: chemical cleanliness and metallurgical cleanliness. Chemical cleanliness deals with the steel composition, with contents of tramping (harmful) and trace elements in steel. Its importance is growing with growing use of steel and iron scrap in steelmaking charge. Metallurgical cleanliness deals with presence of non-metallic particles in steel matrix that can negatively influence both next processes of steel forming and treatment and steel products properties.

Ladle metallurgy processes are oriented besides chemical and temperature homogenization, deep deoxidation, exact alloying also to decrease of non-metallic inclusions contents in steel to very low levels. The processes in ladle can be complemented by processes in tundish of continuous casting with the same aim of high metallurgical cleanliness. An interesting discussion among metallurgical specialists continues concerning the limits of metallurgical cleanliness. In other words: can be total absence of non-metallic inclusions harmful to steel properties?

The present paper deals with influence of steel cleanliness in ladle furnace, the second member in sequence electric arc furnace – ladle furnace – continuous caster. Influence of steel melt agitation, modification of inclusions and steel melt light agitation (light inert gas bubbling) on elimination of non-metallic inclusions from the steel melt is studied. As the steel matrix can contain exogeneous inclusions of ladle furnace slag, the composition and structure of ladle furnace slag is also studied.

2. STEEL MELT TREATMENT IN LADLE FURNACE

Described electric arc furnace (EAF) is used only for preparation of steel melt from solid scrap charge. Oxidation and dephosphorization processes take place in the furnace. All subsequent processes take place in the ladle, either during tapping of steel from EAF, or in the ladle metallurgy stand, where proper temperature is kept with the help of electric arc. Capacity of both EAF and ladle furnace (LF) is 60 tons of steel [5].

Primary deoxidation by Al and primary alloying by FeMn and FeSi is done in the ladle during steel tapping. By the end of tapping refining slag is formed by additions of lime and special material on alumina base (min. 82 % wt of alumina).

Ladle metallurgy processes are applied in following sequence:

– deep deoxidation by Al wire injection;
– desulphurization by refining slag;
– alloying to final chemical composition;
– modification of alumina inclusions – additions of CaSi and/or CaO in filled profiles;
– elimination (floating up) of non-metallic inclusions.

Temperature and chemical homogenization, steel melt agitation is reached by argon gas bubbling through porous plug positioned at the ladle bottom. Three different regimes of Ar gas bubbling, listed in Table 1, are applied.

Table 1. Regimes of Ar gas bubbling

	Ar quantity, $l \cdot min^{-1}$	Time of bubbling, min
Deoxidation, desulphurization	300	20 – 25
Chemical homogenization	120 – 130	10 – 20
Light bubbling	25	8

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Table 2. Chemical composition of studied grades of steel, % wt.

	C	Mn	Si	P	S	Al	Ca	O	N
Grade A	0.17	1.20	0.25	0.010	0.012	0.025	0.0025	0.0045	0.0070
Grade B	0.08	0.44	0.23	0.010	0.012	0.030	0.0030	0.0040	0.0075

3. DEVELOPMENT OF NON-METALLIC INCLUSIONS COMPOSITION AND MORPHOLOGY

Two different grades of steel melts were sampled during their treatment in the ladle furnace. Steel samples were taken in following parts of the process:

– after Al wire application (A);
– before CaSi profile application (B);
– after CaSi profile application (C);
– from tundish (D).

Chemical composition of the samples was determined by a spectrometer analyzer – quantometer. Non-metallic inclusions were observed on metallographic surfaces under metallographic optic microscope. Composition of some of them was determined by energy dispersive electron microanalysis. Quantity of non-metallic inclusions was determined by method of point counting in metallographic optic microscope. Typical chemical analysis of both studied grades of steel is in Table 2. Composition, morphology and quantity of non- metallic inclusions were studied on steel samples, taken during ladle treatment of six steel heats, four of them of the grade A, two of the grade B. Change of oxidic inclusions contents during ladle treatment is in Fig. 1 [6].

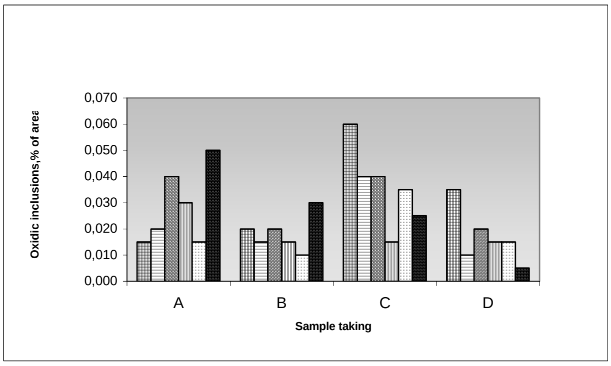

Fig. 1. Change of oxidic inclusions contents during the ladle treatment

After Al wire application (A) inclusions of alumina were formed by reaction of aluminium with oxygen, dissolved in steel melt. The alumina particles were in form of either individual particles (Fig. 2), or in clusters of very small particles. They remained solid in the melt because of their melting temperature. Agitation of steel bath by Ar gas bubbling supported elimination of many alumina particles to slag, as clearly demostrated in the Figure 1 (step B).

Addition of CaSi profile (C) changed the composition and morphology of alumina inclusions, that remained in the melt. By reaction of calcium with alumina the inclusions of calcium aluminates were formed (see Fig. 3). Because of their low melting temperature they were liquid in the steel melt with resulting globular shape. Incomplete reaction resulted in calcium aluminates inclusions that contained not reacted alumina inside particle. Because of shape such inclusions easily floated up from the melt, as demonstrated in the Figure 1 (D).

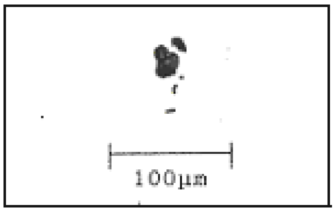

Fig. 2. Alumina inclusion in steel sample

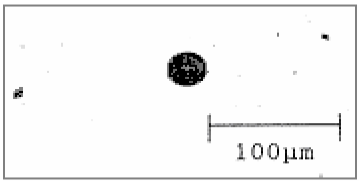

Fig. 3. Inclusion of calcium aluminate in steel sample

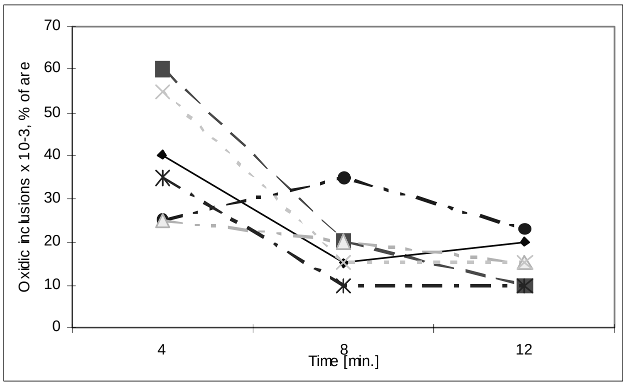

Fig. 4. Change of oxidic inclusions contents during Ar gas light bubbling

Sulphidic inclusions at the beginning of the treatment were in a form of small globular or oval particles of MnS I or (Fe,Mn)S I. After modification of oxidic inclusions by calcium inclusions of CaS were also formed. They occurred mostly as tiny rims of calcium aluminates. Their quantitative characterization was impossible.

4. ELIMINATION OF NON-METALLIC INCLUSIONS BY Ar GAS LIGHT BUBBLING

As can be seen from the Fig. 1, most of calcium aluminates inclusions were eliminated in the final step of ladle treatment, when steel bath was agitated by Ar gas light bubbling (25 l of Ar per minute). Next, research of influence of Ar gas light bubbling time on elimination rate of non-metallic inclusions from the steel melt was performed [7]. Six steel heats of grade A were studied. All of them were ladle treated by the same sequence, the last step was 12 minutes of Ar gas light bubbling. The steel samples were taken after 4th, 8th, and 12th minutes of Ar gas light bubbling. Amount of oxidic inclusions was determined by method of point counting in metallographic optic microscope.

Fig. 4 presents influence of Ar gas light bubbling time on amount of oxidic inclusions remaining in the steel melt. It is clear from the Figure, satisfactory purification of the steel melt from oxidic (and also from sulphidic) inclusions is reached after 8 minutes of Ar gas light bubbling. It is obvious that this fact is valid only for conditions of the studied process, but such study can result in important savings of costs and time of ladle treatment.

5. DEVELOPMENTS OF SLAG STRUCTURE DURING LADLE TREATMENT

Slag samples were taken during ladle treatment of three heats of grade B. The slag samples were taken in following points:

- before Al wire application;
- after Al wire application;
- before CaSi profile application;
- after CaSi profile application.

The slag samples were divided into three parts. The first one was used for wet chemical analysis. On the second part metallographic surface was prepared and typical structural components were characterized by observation under metallographic optic microscope. The third part was used for X-ray diffraction structural analysis. Chemical analysis of slag samples taken from one of studied heats is in Table 3. From the data in the Table 3 it follows that the contents of CaO and SiO_2 increased as a result of Ca and Si bearing materials additions. Decrease of MnO and FeO contents is related to reverse reduction of these oxides. Increase of SO_3 contents is connected to elimination of calcium aluminates with sulphidic rims to slag.

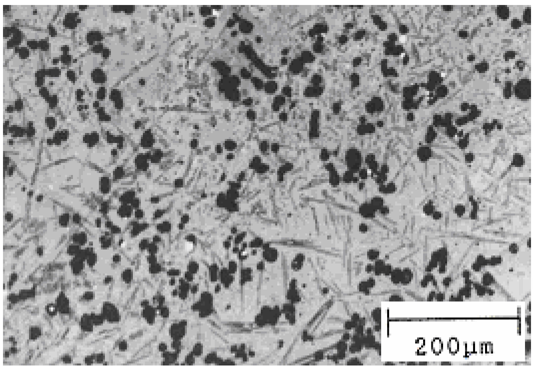

Fig. 5. Partially crystallized structure of slag with remnants of non reacted lime

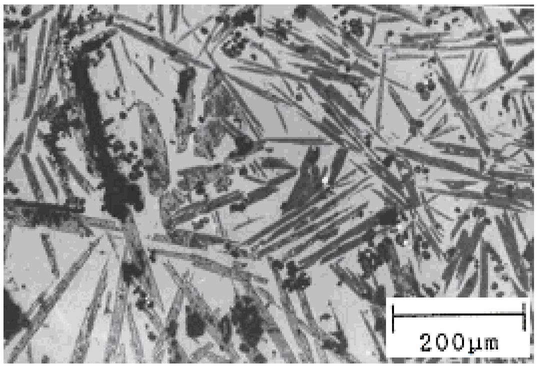

Fig. 6. Particles of tricalcium silicates and dicalcium silicates in glassy matrix

X-ray diffraction structural analysis revealed three structural components in all four samples: β-$2CaO \cdot SiO_2$; $3CaO \cdot SiO_2$; $3CaO \cdot Al_2O_3$. Most of ladle furnace slag mass was formed by glassy matrix. Its background overlapped parts of diffraction lines, recognition of other structural components were problematic. Fig. 5 shows partly crystallized slag structure with many remnants of non reacted lime, Fig. 6 shows tricalcium silicates (needles) and dicalcium silicates in glassy matrix of ladle furnace slag.

In some cases exogeneous inclusions of slag can be found in steel castings. To trace their origin, it is important to know also the structure and composition of ladle furnace slag.

6. CONCLUSIONS

The paper presents study of metallurgical cleanliness of steel treated by methods of ladle metallurgy. The results are as follow:

1. Injection of Al wire into steel melt in the ladle resulted also in creation of alumina inclusions, products of reaction between aluminium and oxygen, dissolved in the steel melt. Vigorous agitation of melt by Ar gas bubbling supported floating up of inclusions to surface covered by slag.
2. Addition of CaSi in profiles modified alumina inclusions to globular calcium aluminates that easily eliminated to slag. The process of floating was helped by Ar gas light bubbling.
3. Modified globular calcium aluminates were covered by rim of CaS. By this way elimination of calcium aluminates inclusions positively influenced desulphuration of steel melt.

Table 3. Chemical composition of slag samples, % wt

Sample	CaO	Al_2O_3	SiO_2	MgO	MnO	FeO	P_2O_5	SO_3
A	56.09	25.59	3.91	6.51	0.79	6.81	0.098	0.50
B	56.55	26.95	6.14	7.93	0.84	3.54	0.039	0.61
C	57.23	24.37	6.55	7.14	0.26	3.24	0.011	1.23
D	59.65	23.06	6.41	6.65	0.21	2.62	0.011	1.24

4. Influence of Ar gas light bubbling time on elimination rate of calcium aluminates was also studied. 8 minutes of Ar gas light bubbling was considered as satisfactory.
5. Composition and structure of ladle furnace slag was also determined.

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