

## Influence of Steel Cleanliness by Ladle Furnace Processes

Ľubomír MIHOK\*, Katarína SEILEROVÁ, Mária FROHLICHOVÁ

Faculty of Metallurgy, Technical University in Košice, Letná 9, 042 00 Košice, Slovakia

Received 28 May 2005; accepted 01 September 2005

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·min <sup>-1</sup>	Time of bubbling, min
Deoxidation, desulphurization	300	20 – 25
Chemical homogenization	120 – 130	10 – 20
Light bubbling	25	8

\*Corresponding author. Tel.: +421-55-6023151; fax.: +421-55-6022751.  
E-mail address: lubomir.mihok@tuke.sk (Ľ. Mihok)



samples were taken after 4<sup>th</sup>, 8<sup>th</sup>, and 12<sup>th</sup> 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<sub>2</sub> 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<sub>3</sub> contents is connected to elimination of calcium aluminates with sulphidic rims to slag.

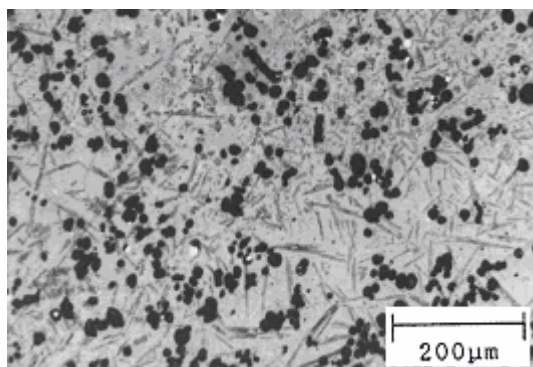


Fig. 5. Partially crystallized structure of slag with remnants of non reacted lime

Table 3. Chemical composition of slag samples, % wt

Sample	CaO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	MgO	MnO	FeO	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>
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

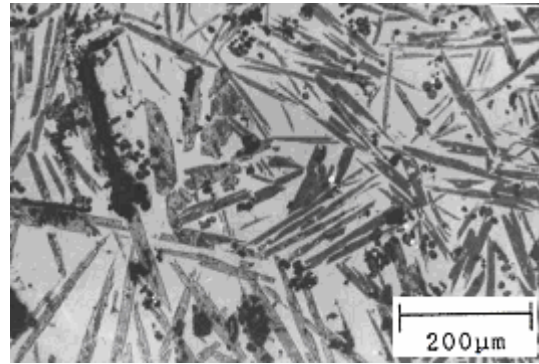


Fig. 6. Particles of tricalcium silicates and dicalcium silicates in glassy matrix

X-ray diffraction structural analysis revealed three structural components in all four samples:  $\beta$ -2CaO · SiO<sub>2</sub>; 3CaO · SiO<sub>2</sub>; 3CaO · Al<sub>2</sub>O<sub>3</sub>. 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.

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.

#### REFERENCES

1. **Oeters, F.** Metallurgy of Steelmaking. Sutter and Partner, Essen, 1994.
2. **Zhang, L., Thomas, B. G.** State of the Art in Evaluation and Control of Steel Cleanliness *ISIJ International* 43 (3) 2003: pp. 271 – 291.
3. **Mitura, K., Landová, S.** Non – Metallic Inclusions in Steel and their Influence on Steel Properties. SNTL Prague, 1986.
4. **Pělucha, P., Trávníček, R., Pěluchová, M., Prnka, T.** Ensuring of High Cleanliness of Continuously Cast Steel by Ladle Furnace Treatment *Metalex Ostrava* 1991: pp. 190 – 205.
5. **Mihok, E., Seilerová, K., Baricová, D.** Recycling of Steelmaking Slag from Electric Arc Furnace *Archiwum Odlewnictwa* 4 (13) 2004: pp. 165 – 170.
6. **Seilerová, K., Mihok, E., Domovec, M., Balco, K.** Influence of Steel Cleanliness in Ladle Furnace *Acta Metallurgica Slovaca* 10 (2) 2004: pp. 102 – 110.
7. **Seilerová, K., Mihok, E., Domovec, M., Balco, K.** Influence of Churning in Ladle Furnace on Steel Cleanliness *Acta Metallurgica Slovaca* 10 (1) 2004: pp. 36 – 41.

DOI: 10.5755/j02.ms.26543