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REFINING STEELS PRODUCED IN ELECTRIC ARC FURNACE

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Characteristics and properties of cast and forged steel products are put in danger when they have in their composition elements that cause a quality decrease. In order to reduce the content of accompanying elements that may affect product proprieties, several methods of refining the molten metal have been developed, such as: degassing and removal of non-metallic inclusions in vacuum, inert gas bubbling, magnetic stirring and others.

Research of the methods applied in steel refining and efficiency in reducing unwanted elements P, S, H, O and N aim to demonstrate the need for steel refining to increase product quality.

Keywords: steel refining, inclusions, vacuum degassing.

1. Introduction

Among the accompanying elements negative impact on steel quality, most often found in high concentrations are: phosphorus - causes cold steel brittleness, sulfur – high temperature brittleness and H, O and N gases causes during solidification porosities and cracks.

Inclusion sources are from raw and auxiliary materials used in steel making (contamination with P and S), refractory lining of metallurgical aggregates (oxides as MgO, ZrO, Al_2O_3) and surrounding atmosphere (gas absorption H, O and N from the atmosphere).

This paper presents efficient methods used to refine 37 heats (71T/heat), grade S34MnV (see table 1), vacuum casted into ingots by direct MSD-Ar method[4]. The cast ingots are for crank throw and main journal manufacturing used to assemble crankshafts for the marine industry (see Fig. 1).

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Fig. 1 - Crankshafts

To obtain an improvement in steel quality by removing unwanted elements from the liquid metal bath and to increase the purity on different secondary treatment units a number of methods are presented (see Fig. 2) by the transition from EAF refining (Electric Arc Furnace) to the secondary treatment facilities **LF** (**L**adle - **F**urnace), **LF - VD** (**L**adle **F**urnace - **V**acuum **D**egassing) and **VAD** (**V**acuum **A**rc **D**egassing).

Steel refining methods presented in this paper use conventional dephosphorization, steel oxidation using oxygen gas in EAF, deoxidation by diffusion and precipitation, desulphurisation and degassing by injecting an inert gas (Ar) also vacuum exposure.

2. Influence of gaseous components in quality steels

Dephosphorization occurs at low temperature (near steel melting point), high content of oxygen in the metal bath and high slag fluidity. Following the expressions:

$$2[Fe_2P] + 5[FeO] = [P_2O_5] + 9[Fe] \quad (1)$$

$$[P_2O_5] + (CaO) = (CaO \bullet P_2O_5) \quad (2)$$

Metal bath oxidation follows in first phase (intense boiling) a significant decrease in gas content (H and N) and continues the dephosphorization[1]. At this stage the inclusions from the metal bath pass in the slag, thus being eliminated thru flotation.

Deoxidation of the metal bath represents decreasing the oxygen content remained after the oxidation step (boiling), by linking it with elements that have higher affinity than that of iron. The process is achieved by diffusion and precipitation reactions as:

diffusion,

$$3Ccoal + (CaO) = (CaC_2) + \{CO\} \quad (3)$$

$$3(FeO) + (CaC_2) = (CaO) + 3[Fe] + 2\{CO\} \quad (4)$$

precipitation,

$$[FeO] + [D] = (DO) + [Fe] \quad (5)$$

$[D]$ - deoxidizing element

(DO) - resulting oxide.

Desulphurization is based on the use of elements with higher affinity to sulfur than iron, such as Mn, Ca, Ba, Mg and Lanthanide. Resulting sulphides are not soluble in steel and are absorbed by the slag. Desulphurization using manganese is favored by low temperatures and high Mn content, sulfur removal with calcium is performed at high temperatures. Following the expressions:

$$[FeS] + [Mn] = (MnS) + [Fe] \quad (6)$$

$$[MnS] + (CaO) = (CaS) + (MnO) \quad (7)$$

$$[FeS] + (CaO) = (CaS) + (FeO) \quad (8)$$

Injection of inert gases in steel has influence over deoxidation, desulphurization and degasing of the metal bath because the chemical reactions taking place are accelerated by a mix of the chemical composition and temperature[2].

Vacuum treatment of liquid steel can be summarized in the following directions:

- Protection of the molten metal from the action of the gas phase;
- Shift the balance of chemical reactions taking place with the formation of a gaseous component;
- Moving the equilibrium of the phase processes;
- Degassing the molten metal.

During steel refining because of the different reactions gas compounds are formed and by using vacuum an advanced removal of impurities is achieved. Such phenomena are found in processes of degassing, deoxidation and decarburization[3].

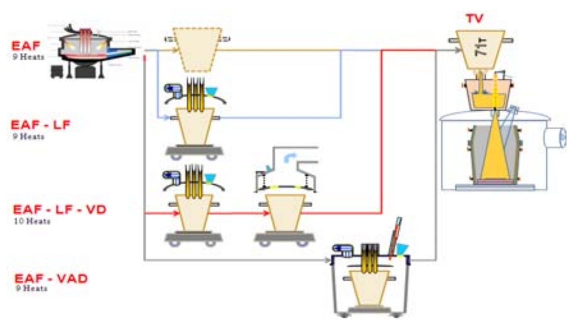


Fig. 2 - Flow diagram of melting and refining of steels.

Table 1

Chemical Composition of S34MnV

El.	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Al
Min. %	0. 38	0.2	1	-	-	-	-	-	-	0.06	
Max. %	0. 41	0.3	1. 25	0. 012	0. 005	0.25	0.4	0.25	0.15	0.08	0.01

3. Experimental Program

Starting from the steel making installation (EAF) steel refining (37 heats) is made in four ways using raw and auxiliary materials.

The working method and the time needed to melt and refine the heats are in Fig. 3. For steel refining, all the steps were mentioned to reduce the negative influence on product quality.

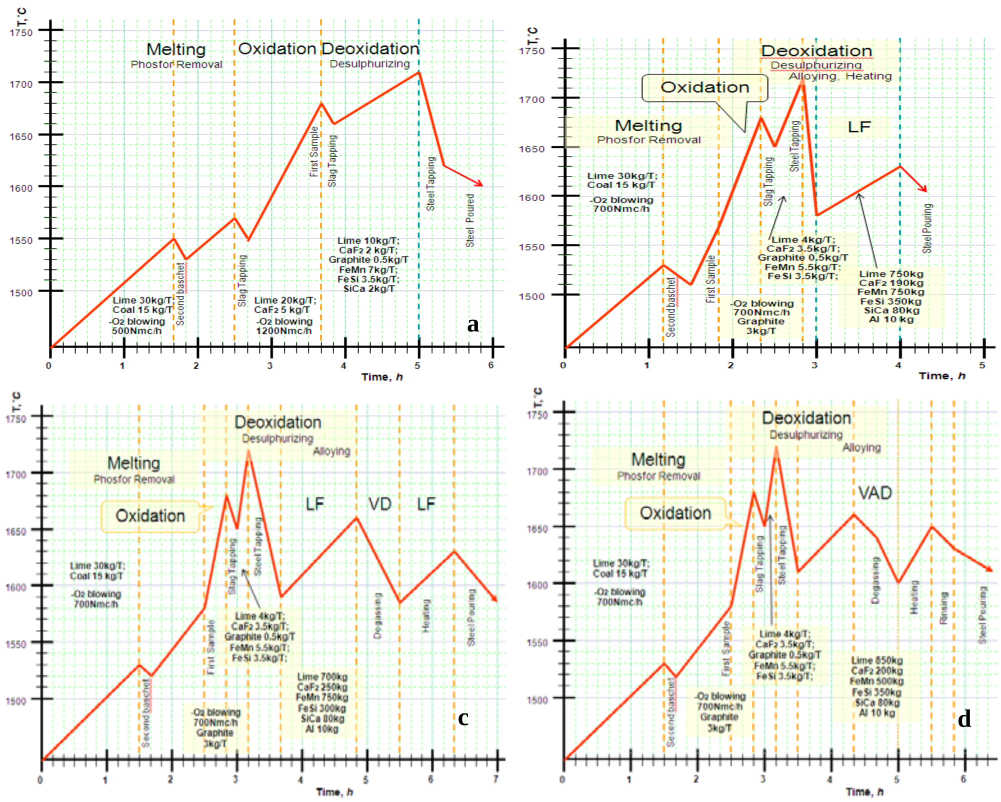


Fig. 3. Operation mode on installation: a – EAF; b – EAF-LF; c – EAF-LF-VD; d – EAF-VAD.

Table II

Argon pressure used for refining steel

	Period / Instalation	Transport	Sampling	Heating	Mixing	Degassing	Pressure, [Bar]
Debit	LF	10	5	10	50	-	12
Ar,	LF-VD	10	5	10	50	>50	12
Nl/min	VAD	10	5	10	50	>50	8

Both during transport and secondary treatment period, the molten metal is stirred by injecting Ar gas through the porous plug thus obtaining chemical composition and temperature uniformity and the flotation of non-metallic inclusions.

Research on each plant working method is based on combined use of refining methods, as follows:

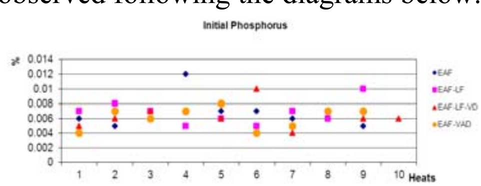
- EAF - steel refining is made by reactions between existing and added elements through oxidation and deoxidation processes;
- LF - refining is similar to EAF refining except the continuously injection of Ar gas through the porous plug located on treatment ladle's bottom;
- LF-VD it's similar with LF treatment but during this process the liquid metal is degassed in vacuum;
- VAD - steel refining using this method is made in low pressure (vacuum) the entire process time (slag making, heating, alloying and advanced degassing).

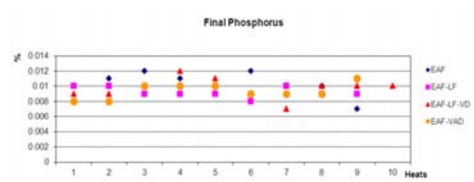
In order to compare results obtained from our research we have considered similar furnace loads and also the used auxiliary raw materials must be part of the same batch.

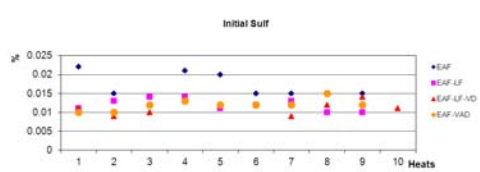
Molten metal can be contaminated during the process of refining its quality by harmful elements. Of these, a very important harmful effect is produced by gas from the metallurgical aggregates atmosphere also from raw and auxiliary materials, fuels, etc.

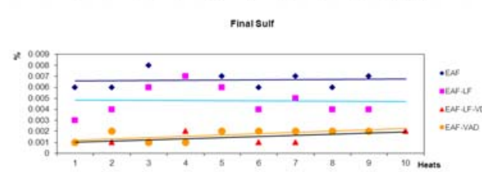
Nitrogen comes in steel through scrap, deoxidation, alloying elements and from furnace atmosphere as a result of dissociation occurring in the electric arcs and among the materials added to form slag, lime is the main carrier of hydrogen. Being hygroscopic, in contact with the atmosphere containing moisture it hydrates very quickly.

Efficiency of each equipment using the methods described above can be observed following the diagrams below.









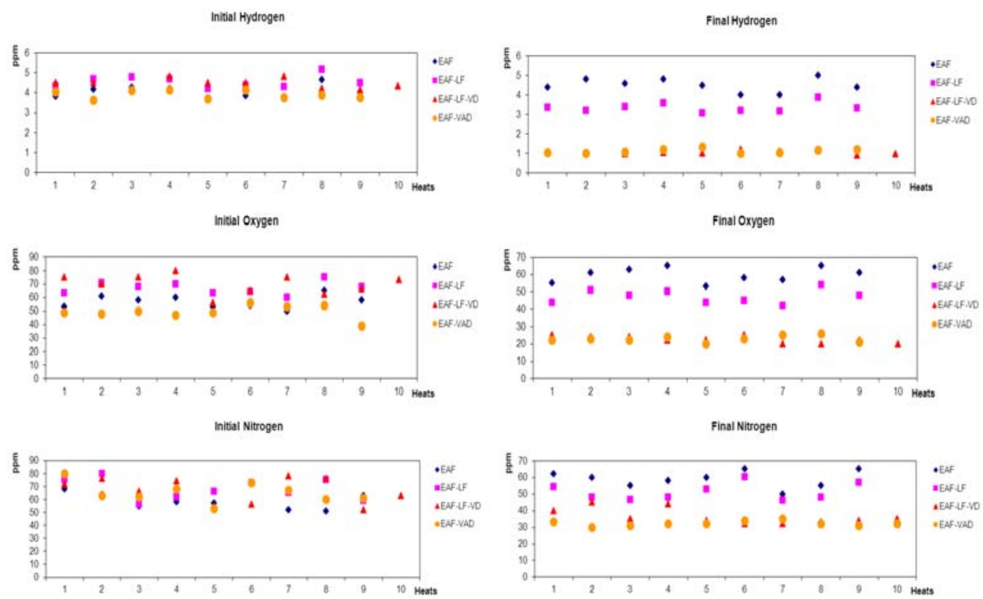


Fig.4.The undesirable elements content in molten steel: before refining – after refining.

From the diagrams analysis it can be observed that steel refining outside the melting furnace combining different refining methods bring far higher returns than refining the furnace (see fig. 5).

Because of the addition of alloying elements phosphorus content in molten steel increases regardless of the applied refining method. Reducing phosphorus can be done only on EAF during melting and oxidation, so it is necessary to reduce the phosphorus content during melting in the EAF.

$$\eta = \frac{[Ei]-[Ef]}{[Ef]} x100 \qquad (9)$$

where,

η - efficiency,

[Ei] - initial Element,

[Ef] final Element.

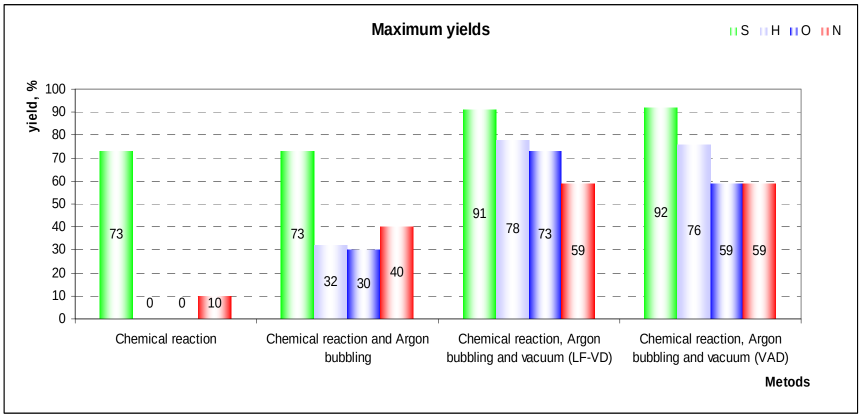


Fig.5. The efficiency of different refining methods

Desulphurization takes place in much better condition when the metal bath is agitated by an inert gas homogenizing the chemical composition, temperature and increasing the contact area between slag and steel (η> 70%). Maximum efficiency is obtained by combining the presented refining methods (η> 90%).

The EAF tap-to-tap time must be as small as possible due to the absorption of gases from the surrounding atmosphere during the tapping of steel from the furnace (see fig.6). You can see significant increases in hydrogen (4 ... 22%) and oxygen (0 ... 14%) content.

Refining steel by injecting inert gas would successfully lower the gas content, this is directly proportional to the injected gas flow rate, stirring time and temperature of the metal bath.

Steel vacuum treatment is the most effective method of refining because of both desulphurization and degassing results. The method is strictly dependent on the vacuum created (as low as possible), metal bath temperature, gas flow and the amount of slag[3].

Fig. 6. EAF tapping in ladle

4. Conclusions

1. EAF steel refining method is of great interest to obtain a good quality, especially in terms of reduced phosphorus content. Achieving optimum desulphurisation (to fit the conditions imposed by the technology) by this method requires increased process time (low productivity) and high energy and materials consumption, which casts doubt on the product market competitiveness.

2. Argon stirring outside furnace makes an outstanding contribution to the steel quality. It homogenizes the chemical composition and temperature and also increasing the reactions taking place (desulphurization, deoxidation, etc.). Much better results compared with the EAF refining can be observed.

3. Secondary treatment in a facility with vacuum degassing of the liquid steel proved absolutely necessary. Decreased atmosphere pressure significantly increased the speed of the reactions taking place in the metal bath. It can be easily observed, following research conducted in this paper, that the results obtained using a combination of methods shows that this method of refining is very useful.

Acknowledgment

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R E F E R E N C E S

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