IMPROVEMENT OF TITANIUM YIELD IN HIGH C AND Si KILLED STEELS INJECTING WIRE HIGHLY COMPACTED FERROTITANIUM

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Abstract

Titanium is an alloying element used to refine grain size in steel and improve its physical and mechanical properties. In some stainless steels it is used to increase the resistance to corrosion by the precipitation of titanium carbides or carbonitrides. Its alloying performance is highly variable and depends largely on the stage of the secondary metallurgy process when it is added. Furthermore, the addition method (wire injection or direct addition) has a remarkable influence in secondary refining. This paper describes the tests performed in vacuum degasser (VD), with a highly compacted and encapsulated Ferrotitanium wire (FeTi HC). The yield of titanium in steel increased from 52% to 89%. Moreover, the consumption of the highly compacted Ferrotitanium was optimized.

Introduction

Several methods are employed to add titanium to liquid steel, being one of the most important the injection of Ferrotitanium powder highly compacted and encapsulated in wire. Due to the high reactivity of titanium with some elements such as oxygen, carbon, nitrogen and sulfur, its performance is highly variable and dependent of the moment of addition during the refining process. This behavior may lead in some cases to desirable properties, but in others, it may reduce the yield [1]. At 1600 °C titanium has a great affinity for oxygen, which is why it is used sometimes as a powerful deoxidizer in steel. However, this practice can be very expensive for the steelmaker so it is preferred to use aluminum for de-oxidation purposes. Once the liquid steel has been completely de-oxidized, the performance of titanium should be maximized. The main influence of titanium on steel quality is associated with the formation of carbides, nitrides and carbonitrides [2]. These intermetallic compounds precipitate at the austenitic grain boundaries and prevent their growth during subsequent heat treatments. The most common titanium alloy for powder injection purposes is the Ferrotitanium eutectic (68-70% Ti) which has the lowest melting point (1085 °C) as presented in the equilibrium diagram shown in Figure 1.
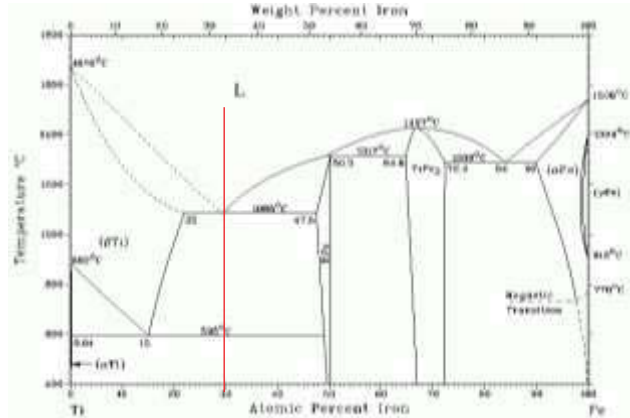
Figure 1. Fe-Ti equilibrium diagram [1].

Due to its higher density and lower melting temperature, Ferrotitanium is dissolved faster in the liquid steel, obtaining better recoveries in most of the cases. The wire injection technology was developed in the 1980s (Conventional Cored Wire, CCW) aiming to optimize the penetration of Ferrotitanium into liquid metal, which would prevent oxidation losses [3]. However, this technology may bring some disadvantages, e.g. unstable performance. This problem may be related to an inadequate wire filling generated by a low powder compaction. Also a lack of penetration produced due to an improper injection speed may have an important effect in the yield unsteadiness.This paper describes a project developed at Compañia Siderurgica de Huachipato (CAP Acero) aiming to improve the titanium yield by using a highly compacted and encapsulated Ferrotitanium wire with a thicker wall thickness. This technology allowed a higher penetration into the liquid steel aided by a higher compaction of Ferrotitanium powder. In this way it was possible to obtain a maximum dissolution in the bottom of the ladle giving as result an increment in the titanium yield. The tests were performed in a vacuum degasser where the de-oxidation of the liquid steel is guaranteed.

Background

Huachipato Steel Company is an integrated steelworks that produces billets and bars made of carbon steel and alloy steels for the construction industry. It is located in the community of Talcahuano near the city of Concepción, Chile. Its steel making route is: Basic oxygen furnace (BOF) – Ladle Furnace (LF) - Vacuum degasser (VD) - Continuous casting of billets or bars (CC), see Figure 2. The average weight of the heats is 105 ton.

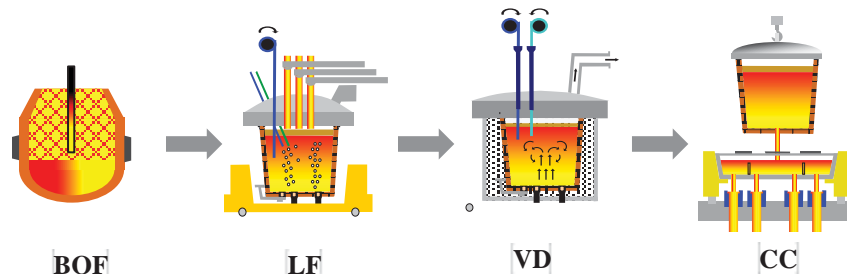**BOF**   **LF**   **VD**   **CC**

Figure 2. Steelmaking route at Compañía Siderúrgica de Huachipato, CAP Chile.

Ferrotitanium conventional (FeTi CCW).

In CAP Steel, some high carbon steels for applications in the mining industry are injected with FeTi wire. The role of titanium in these kind of steels is very important to achieve the toughness and wear resistance requirements. The normal FeTi treatment is carried out with conventional cored wire. In this presentation, FeTi powder is encapsulated in a steel sheath which is lately closed by drawing process. This process generates a fold that is 4 times the thickness of the sheath which serves for preventing the ferroalloy escaping from the wire [4]. Figure 3 shows the cross-section of a conventional wire. The filling rate of the wire used is 370 g/m (eutectic of 68-70% Ti) with a diameter of 13 mm and a wall thickness of 0.4 to 0.6 mm.

Figure 3. Cross-sectional schematic of FeTi CCW.

The FeTi CCW injection process was performed in the VD tank after the high vacuum treatment of the steel. The injection speed was set at 120 m/min. The yield of titanium obtained for the 874 heats under study was 52% average with a standard deviation of 12.9%. Depending on the steel grade, the Ti% objective ranged from 0.008 to 0.026. For steels with higher Ti% requirement, FeTi CCW consumption increased, but the yield was lowered. In Figure 4 can be observed that 97% of the heats analyzed had Ti targets higher than 0.020%, obtaining yields under 55% and consumption rates greater than 0.20 kg Ti / ton.
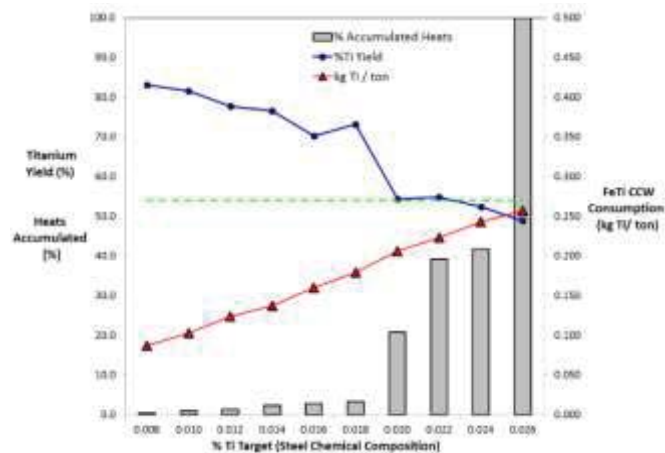

Figure 4. Ti yield reduction and consumption vs. %Ti target.

In general terms, these low Ti yields with the FeTi CCW are associated with its lower wall thickness and its higher injection rate in liquid steel. Sarbendu et al. [5] developed a mathematical model to estimate the melting time of conventional wire steel sheet and to evaluate its impact on the yield of the injected ferroalloy. According to these estimations, if the FeTi

CCW is injected at 120 m/min (2 m/s) the maximum depth reached by the wire into the liquid bath will be 2.4 m (Figure 5). This is due to the fact that for higher injection rates, the wall thickness of the first layer of solidified steel, produced by the effect of the super-cooling around the sheet, will have a lower wall thickness thus reducing the melting time of the wire and then reaching fewer depths (Figure 6). On the other hand, if the wire is injected at low speed, this first skin or shell will grow while slowing the melting of the wire, allowing to reach greater depths in the liquid bath. For 105 ton heats, the steel column height is 3.1 m, releasing the FeTi powder at 0.7 m from the bottom of the ladle. This may lead to Titanium leftover since the FeTi powder that does is not dissolved in the steel reacts with the slag.
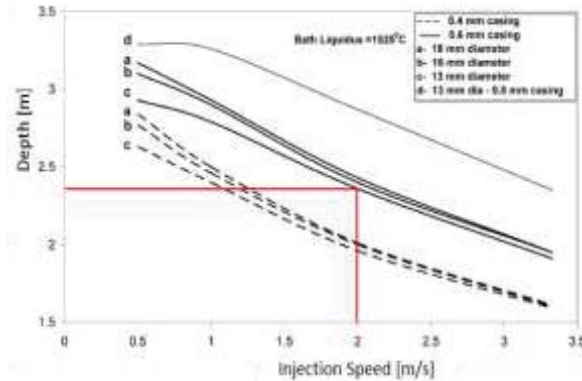

Figure 5. Maximum depth reached by FeTi CCW at 120 m/min (2 m/s).

Some efforts were made to improve the performance of Titanium; however, tests with different speeds induced mechanical drawbacks such as wire breaks. These problems, not only cause delays in the process, but also increase the risk of heats out of chemical specification. Figure 6 shows a normal distribution of the Titanium yields obtained in the 874 heats analyzed according to the final Ti content in the steel. It can be observed that 5% of the heats analyzed had less than 0.0080% Ti, i.e. they were out of specification and their average yield was 34%. Furthermore 92% of the analyzed heats were within the chemical specification (between 0.008% - 0.018% Ti). For such heats the Ti yield observed ranged from 39% to 67%. Moreover, only 3% of the treated heats had yields greater than 76%, with Ti content above 0.018%. Considering these low yields, arose the need of finding a FeTi wire alternative with a higher wall thickness that could increase the titanium yield aided by a better dissolution of the powder at the bottom of the ladle.

Development

Highly Compacted Ferrotitanium (FeTi HC).

In order to delay the wire melting, a new FeTi wire (68-70% Ti) with a higher wall thickness (1.2 mm) was developed. Such wire has a diameter of 14 mm and also increased mechanical properties. The improvement in the strength of the steel sheath allows an injection with more rigidity which favors higher depth penetration even at lower injection speeds. Additionally, the risk of wire breaks is highly reduced compared against FeTi CCW. Another of the most outstanding features of this new wire generation is the sealing of the steel sheath, which is done with high frequency (HF) welding process.
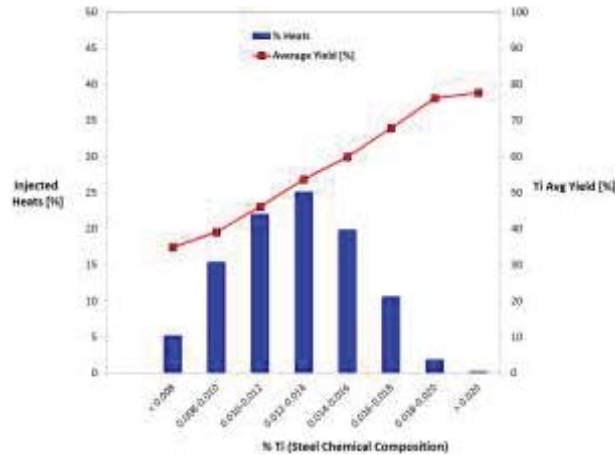
Figure 6. Normal distribution of average yield (FeTi CCW).

This welded seal eliminates the traditional "hook" of closure characteristic of the conventional wires, promoting an improved protection against the oxidation and degradation of the ferroalloy. In this way, a better quality of the powder at the injection time is obtained. Finally, high compaction of the FeTi powder (98%) enables to obtain a homogeneous filling of 410 g/m throughout the wire coil. This high compaction have a quite important positive impact in the repeatability of Ti% supplied and therefore a low standard deviation in wire performance. Figure 7 shows a cross-sectional schematic of the highly compacted FeTi wire FeTi HC.
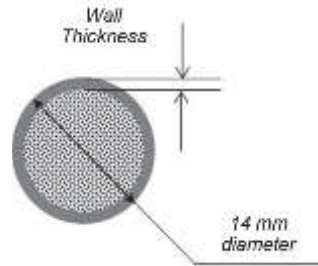

Figure 7. Cross-sectional schematic of the highly compacted FeTi wire.

Industrial Testing in Vacuum Degasser

First Stage

This work with FeTi-HC comprehended, at the first stage, 13 heats of high C steel with a chemical specification of 0.9% C and 0.0080 to 0.0180% Ti. The injection tests were carried out in Vacuum Degasser Tank # 1 (VD #1). The average weight of treated heat was 105.7 ton of steel. In order to define a first approximation of the rate of injection of FeTi HC, the model proposed by Sarbendu [5] was considered. The temperature of the liquid steel in these high C steels just before injecting FeTi HC ranged from 1500 to 1510 °C. According to these conditions of lower temperature, a time for the fusion of the sheath of 2 s was assumed. The injected speed was set at 1.5 m/s (90 m/min) to reach the bottom of the ladle. Figure 8 shows the evolution of the yield and consumption of Titanium in steel with FeTi HC in the 13 heats treated. It is observed a slight increment of the Ti yield as the tests progressed. Moreover, the current %Ti

was always higher than the objective. Such excellent stability allowed to reduce the length of FeTi HC wire injected ensuring the compliance of chemical composition. Table I presents the results obtained in this first stage with FeTi HC in VD #1. The length of FeTi HC injected was reduced from 65 m to 43 m and the average yield was 92%.

Second Stage

The second stage of this project covered 262 heats, 95% of these were treated in the VD station. A reference yield value of 90% was considered to calculate the meters of wire to be injected. The injection rate was set the same 90 m/min. Table II shows the Ti yield results obtained at each treatment station. Although the average yield was lower than for stage I, the results were within the same scatter band and highly above the yields obtained with FeTi CCW. Furthermore, the average wire consumption in this second phase were lower (17.1 and 17.8 kg per heat) compared with those obtained for the first 13 heats (22.4 kg). In general terms better yield results are obtained in VD stations. This is an effect of the better de-oxidation conditions of the steel prior to the injection of FeTi HC compared against LF. On the other hand, another factor that may have influenced this lower Ti yield in LF is the type of treated steel.
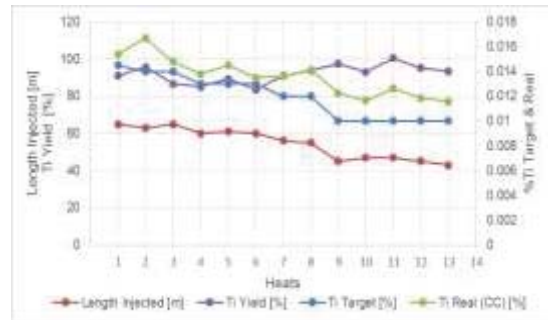

Figure 8. Ti yield & consumption evolution during first stage.

Figure 9 shows the variation of yield and consumption of Ti in the treated heats at each station (LF, VD #1 & VD #2) and each different steel grade considering the two %Ti target. It is observed that better yield and lower consumptions were obtained in heats with %Ti target lower (0.01 %). For steel grades A, B & D, only one level of %Ti target was selected (0.01%). For these steel grades the consumption of FeTi was optimized up to 0.160 kg/ton. Steel grades B & D treated in VD showed very good yield results (88 & 90%). Such values are a consequence of the better de-oxidation obtained in VD stations. Furthermore, for A steel grade treated in the LF, its de-oxidation conditions were not so favorable, thus a lower yield was achieved, i.e. 84% with the same consumption of 0.160 kg/ton. Additionally, for steel grades F & G, a yield reduction was observed with %Ti target 0.012%. In order to reach such % Ti objective, it was required to inject a higher quantity of Ti (0.190 kg/ton). Such heats, although treated in VD, showed yields in the range of 74 – 85%, with an average of 0.0103%Ti. The excess of Ti injected may have returned to the metal-slag interphase since an important quantity of FeTi HC reacts close to the slag resulting in its oxidation while reducing the Ti yield. Such effect is aided by an increase in the time required to melt the sheath due to its higher wall thickness. A clear example of the increment of Ti yield with lower consumption is observed in steel grade E, whose heats were treated in the VD with %Ti target, 0.010% & 0.012 %.

Table I. First stage results in VD #1

Heat	Steel Grade	Liquid Steel [ton]	% Ti Target	FeTi - HC Length Injected [m]	FeTi - HC [kg]	Ti [kg]	% Ti Real	% Ti Yield
1	C	110.0	0.0145	65	26.6	18.6	0.0154	91.0
2	C	103.5	0.0140	63	25.8	18.0	0.0167	95.8
3	C	109.0	0.0140	65	26.6	18.6	0.0148	86.7
4	C	106.0	0.0130	60	24.5	17.2	0.0138	85.2
5	C	107.5	0.0130	61	24.9	17.5	0.0145	89.3
6	C	106.5	0.0130	60	24.5	17.2	0.0135	83.7
7	E	107.3	0.0120	56	22.9	16.0	0.0136	91.0
8	E	104.5	0.0120	55	22.5	15.7	0.0142	93.9
9	E	102.4	0.0100	45	18.4	12.9	0.0123	97.4
10	E	107.4	0.0100	47	19.2	13.5	0.0117	93.1
11	E	107.0	0.0100	47	19.2	13.5	0.0126	100.5
12	E	103.4	0.0100	45	18.4	12.9	0.0119	95.1
13	E	99.4	0.0100	43	17.6	12.3	0.0116	93.5
AVERAGE		105.7	0.0120	55	22.4	15.7	0.0136	92.0

Table II. Second stage results

Station	Qty of Heats Injected	% Heats	FeTi - HC [kg]	FeTi - HC [kg/ton]	% Ti	% Yield	St. Dev.
VD #1	194	74.0	17.1	0.165	0.0102	88.6	10.0
VD #2	56	21.4	17.8	0.173	0.0103	86.9	12.0
LF	12	4.6	17.3	0.167	0.0100	84.1	8.5

For this steel grade with a Ti selected was 0.012%, the yields reached levels of 85 & 80% in VD #1 & #2 with a consumption of 0.019 kg/ton Ti. With a lower %Ti target (0.010 %), the consumption was reduced up to 0.0160 kg/ton, having an important yield increase reaching, above 90% both VD tanks. According to Sarbendu's estimations [5], for the FeTi HC wire with the largest wall thickness (1.2 mm), injected at a lower velocity (90 m/min), its first "skin" of solidified steel was thicker (Figure 10), delaying the melting of the original wire sheath allowing to reach greater depths in the ladle. In the case of FeTi CCW, this skin layer did not have sufficient time to grow since the wire is injected at a faster rate (150 m/min) and therefore melts earlier during injection, thus reaching lower depths in the ladle.

Conclusions

The yield of Ti in the Si killed high-carbon steels increased from 52% to 88%, by injecting a highly compacted Ferrotitanium powder wire encapsulated in a thick sheet. The FeTi HC injection process was optimized by reducing the wire consumption from 0.190 kg FeTi / ton to 0.160 kg FeTi / ton, to obtain 0.0100% Ti in the steel. The yield of Titanium with this optimization reached values between 90 and 100%. The Ti yield in the steel grades A, B, D, E, F

and G were evaluated. From the FeTi HC injection tests performed on the LF, it was also concluded that the de-oxidation and degassing conditions of the steel affect the yield of FeTi HC, since the best yields (above 90%) were obtained in VD #1 & VD #2, where the lowest oxygen levels are achieved, while in the LF station the average yield was 84%. The combination of a higher wall thickness in the wire (1.2 mm) and the low injection velocity (90 m/min) enabled a better penetration of FeTi HC in the liquid metal, maximizing Ti dissolution in steel and increasing the yield of the wire.
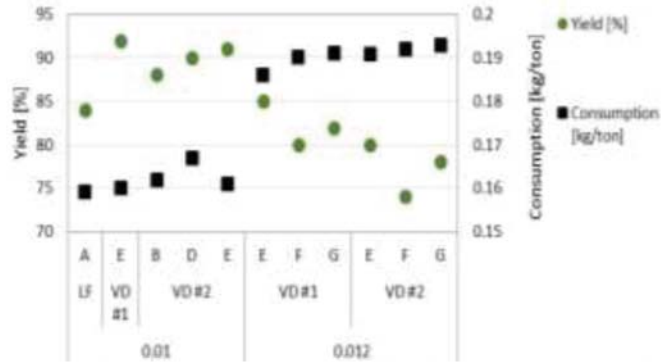

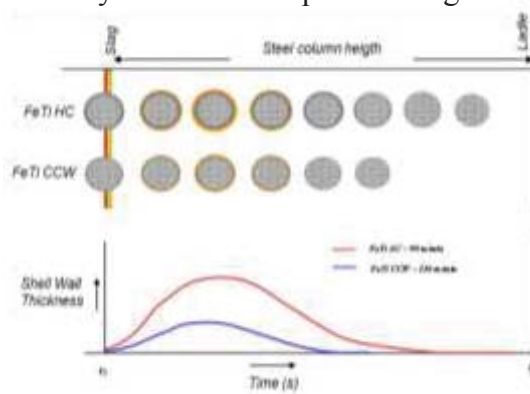
Figure 9. Ti yield & consumption during second stage.

Figure 10. Diagram of solidification profile and growing of the steel shell formed around FeTi CCW and FeTi HC injected at different speeds.

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