CALCIUM METALLURGY FOR SLAB AND BILLET CASTING AT HOOGOVENS IJMUIDEN

by

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ABSTRACT

For the production of constructional steels with improved mechanical properties in through-thickness direction, Hoogovens has been developing a practice for calcium treatment of steel since 1983. The injection of Ca-cored wire first took place in the MgO-lined 60 tons tundish of slab caster 21 in BOS No.2: the steel ladles had acid linings at that time.
From 1986 onwards, the injection of Ca-cored wire in BOS No.2 has been carried out at the stirring station into 315 tons ladles with a sillimanite lining (60% Al_2O_3). CaSi-, Ca-mix- and CaFe-cored wire are used for treatment of constructional, line pipe and HSLA steels, aiming at a Ca/S-value in the slab of 0.4. The observed effect of calcium treatment is a pronounced decrease in Al_2O_3-clusters and MnS type II inclusions, resulting in $\geq$ 60% reduction of area. The inclusion modification by calcium also gives higher impact values in the Charpy V test. For Al-killed steel grades, clogging is observed when Ca in the mould is < 20 ppm. A special practice was established to enhance the recovery of Ca-mix and CaFe wire to counteract clogging.
In 1988 two 6-strand billet casters came on stream in BOS No.1. To promote the castability through either submerged or ϕ 15 mm metering nozzles, all Al(Si)-killed steel grades are treated with Ca-cored wire at one of the two stirring stations. With a velocity of 180 m/min, the ϕ 13 mm CaSi-, Ca-mix-, or CaFe-cored wire is injected through a hood with argon shielding into 100 tons dolomitic lined ladles. The recovery of calcium at the end of ladle treatment is 25% for CaSi wire, 9% for Ca-mix wire and 13% for CaFe-cored wire, with a consumption of 0.2, 0.7 and 0.5 kg/ton, respectively. To prevent pinholes in rimming substitutes grades, precise control of the free oxygen level is necessary. For free oxygen levels below 50 ppm, deoxydation with aluminium is followed by fine adjustment with Ca-cored wire to limit the formation of Al_2O_3-inclusions. A low content of FeO and MnO in the ladle slag under 2%, is a prerequisite for a successful calcium treatment. In BOS No.1 the amount of slag carry-over from the converter is limited by special measures to an average weight of 600 kg. To condition and kill the slag, Al shot and $CaO/Al_2O_3/CaF_2$ flux are added during and after tapping.

1. INTRODUCTION

Hoogovens IJmuiden, a member of 'Hoogovens Groep', is a major, integrated steelworks with a production of around five million ton of steel per year. The company produces semi-finished products, reinforcing bars, heavy plate, hot and cold rolled coil and sheet, packaging and galvanized steel. To implement its plans for changing from ingot casting to continuous casting of slab and billets, Hoogovens has installed in BOS No.2 its first two-strand slab caster, CC21, in 1980 and a second one in 1986. Two 'Concast' billet casters in BOS No.1 made their first heats in March and June 1988.
Hoogovens has been active in the slab and billet market for many years now. With the gradual change to continuously cast slabs and billets, Hoogovens is ready for future supplies of high grade slabs and billets to its customers.
Hoogovens supplies slabs (and its hot and cold rolled coils and sheets from the own rolling mills) and billets to many mills in Western Europe and North America, but also to many countries in Asia, Africa and Central and South America. The ideal geographical location with direct access to the sea via its own harbour facilities in the Port of IJmuiden and all the major motor- and waterways of Europe, contribute to short 'in transit' times.

Both steelplants have been developing Ca-treatments to improve the castability and mechanical properties of their steel. Because both steelplants produce totally different kind of steel grades, the Ca-treatments are different. BOS No.2, with slab casters, developed a Ca-treatment to improve the mechanical properties in through-thickness direction, while BOS No.1, with billet casters, developed a Ca-treatment mainly for castability reasons.
Therefore both steelplants and their Ca-treatments will be discussed separately, starting with BOS No.2 and followed by BOS No.1.

2. CALCIUM TREATMENT IN BOS NO.2 (slab casting)

2.1 Steelmaking facilities

BOS No.2 at Hoogovens IJmuiden, which dates from 1968, has been drastically modernized and enlarged over the past 13 years. The steelplant is equipped with three 315 tons converters. Introduction of converter 23 with OG and waste-gas analysis system, later provided with a sublance and OG gas recovery, opened the period of modernization. In 1980 the first two-strand slab caster, CC21, and a ladle trim station started operation. In 1984 an RH-OB installation, the first one in Europe, came on stream. In august 1986 the second slab caster, CC22, made its first heat. A second ladle metallurgy station provided with argon stirring and multiple wire-injection facilities was put into operation at the same date. This stirring station has the availability of three wire injection machines, which can inject wires at the same time in the bottom stirred ladle. One injection machine is used for Al wire (ϕ 12 or 15 mm). The other two injection machines are each provided with Ca-cored wire of ϕ 13 mm from a so-called 'flipperstand'. Each flipperstand can contain two coils. This double coil set-up is necessary to prevent interruptions during injection. A schematic drawing of this stirring station is shown in Figure 2.1. The

Ca-treatment always starts 30 minutes before the ladle opens above the tundish. Injection speed is set to 210 m/min.

Other alloy additions are carried out by the alloy addition system of the RH-OB installation which is situated close to the stirring station 22. For a schematic drawing of the BOS No.2 lay-out, see Figure 2.2. [1].

2.2 Production of 'Sulphide Shape Controlled' steel

Until 1986 a part of the Sulphide Shape Controlled steel was still produced by adding "Ce-Mischmetall" into the ingot mould during teeming.
Due to the turnover to continuous casting, the steelmaking process for Sulphide Shape Control had to change dramatically. Since 1983 tests with Ca-cored wire were carried out in the tundish (see Figure 2.3). Because the ladles were acid lined and only the tundish had a basic MgO-lining, this was the only possible place. In 1986 the Ca-injection was moved to the new stirring station 22. In that time all acid lined ladles were replaced by high-alumina lined ladles.
Although the metallurgical results of tundish injection were good, the change-over was justified by the troubles caused by calcium injection into the tundish: smoke, mixing problems (different Ca-levels for strand 1 and 2), slag build-up and so on.

2.3 Calcium injection practice per steel grade

In principle the calcium treated steel qualities can be divided into two groups:

1) qualities with an aim of Si of 0.250% and
2) qualities with a Si-maximum of 0.030%.

Both groups contain Nb and/or V and have a maximum nitrogen level of 50 ppm.

2.3.1 Steels with an aim of Si of 0.250%

The tapping temperature is derived from the desired tundish temperature. At the start of the stirring process the temperature should be 65 ^{o}C above the tundish temperature. Other temperature influencing factors are:

- transport time from BOF to stirring station,
- first or next cast in a sequence,
- holding time of the ladle,
- casting time.

To avoid nitrogen pick-up during the process, the turndown carbon should be as high as possible and argon bottom stirring is applied during the converter process.
The bulk of the alloying elements is added during tapping (Mn, Si, V and Nb). The pick-up of Nb and Mn from the slag during Ca-injection on the stirring station is well-known and accounted for.
If calcium is to be added successfully, slag-free tapping is essential.

For this purpose a slag ball is placed into the converter during tapping. To lower the oxygen content of the slag in the ladle, 500 kg of CaO is added and the heat is stirred during tapping. Another 4 minutes of stirring, directly after tapping, before transport to the stirring station is applied.

The stirring process at the stirring station can be divided into two steps. In the first step one starts with one minute of stirring to homogenize the heat before measuring the temperature. Using the sample taken at the fourth minute of stirring after tapping, fine adjustment of the heat is made during the following minutes of stirring.
The second step starts 30 minutes before opening the ladle. The beginning of this step is used for the final temperature and chemical composition adjustment, then CaSi-cored wire is injected. The amount added is determined by the S-level. The aim is a Ca/S ratio in the slab of 0.4. Injection time takes about 10 minutes. To enhance mixing and minimize nitrogen pick-up, the heat is stirred very gently. After the injection the stirring is stopped immediately and a final sample is taken.

Table 2.1 shows some typical calcium consumption values and recovery yields, together with nitrogen data. The average nitrogen level in the case of aluminium deoxydation during tapping is above 50 ppm in the tundish, which means that a lot of heats had to be downgraded. Therefore the Al-deoxydation was moved to the stirring station, resulting in an average nitrogen content in the tundish of 45 ppm.

2.3.2 HSLA-steels with a Si-maximum of 0.030%

In general HSLA-steel grades are treated in the same way as described in chapter 2.3.1. The tapping temperature is somewhat higher because Ca-injection takes more time.
Injection is carried out with Ca-mix-cored wire. This wire has a much lower recovery yield than the CaSi-cored wire. To keep the injection time within limits and to increase the yield, the wire is fed into the ladle with two machines for the first five minutes, followed by ten minutes feeding by one machine.
Data for consumption, recovery and nitrogen levels are presented in Table 2.2.

As a consequence of the calcium treatment, sometimes problems with clogging were met during casting. It turned out that the calcium level in the mould had to be over 20 ppm, presumably to avoid formation of the complex $CaO.6Al_2O_3$ inclusion. Some data are summarized in Table 2.3.

2.4 Results in the final product

The main purpose of the calcium treatment is Sulphide Shape Control to improve the mechanical properties in the through-thickness direction.
Table 2.4 shows the effect of Ca-injection into the tundish (practice before mid-1986). Two heats are compared: one without Ca-treatment and one with CaSi wire injection. The obtained Ca-level is 35 - 40 ppm. The ψ_z-value (reduction of area) increases from 50% to 63 - 73% (depending on plate thickness). The $q_{//}$-value, a Hoogovens' measure for stringers in

plate, decreases from 18 --> 4. Microscopic inspection of slab samples are in agreement with these results: Al_2O_3-clusters disappear and the number of MnS-inclusions type III and in particular of type II has been drastically reduced. Microprobe analysis revealed that in case of Ca-treatment, the angular sulphide type III also contains CaS, CaO and Al_2O_3 (oxysulphides). These kind of inclusions hardly elongate during rolling.
Table 2.5 and 2.6 present the reduction of area and Charpy V values for plates from continuously cast heats which were treated with calcium in the ladle. Reference data are given for plates without Sulphide Shape Control and for those with Ce-treatment. The last group has been ingot cast.

3. CALCIUM TREATMENT IN BOS NO.1 (billet casting)

3.1. Steelmaking facilities

BOS No.1 is equipped with three 100 ton converters. This heat size is very suitable for producing billets: large enough to achieve economical operating costs, yet able to meet market demands for smaller quantities.
All hot metal is desulphurized by soda ash addition into the ladle. If the required sulphur level cannot be met by adding soda ash only, Mg-cored wire is injected [2].
The 100 ton converters are equipped with bottom stirring systems which result in a better yield, improved nitrogen control, a lower oxygen level and the ability to produce steel with a carbon content as low as 0.020%.
Due to the construction of two 6-strand continuous billet casters, the facilities for secondary steelmaking had to be extended. There are two identical stirring stations located over the ladle transfer tracks. The steel is argon stirred, either by a porous plug or by lance. Temperature and oxygen activity are measured and samples are taken. The composition can be adjusted by adding FeMn, FeSi, etc. The temperature can be lowered to the required value by adding coolant scrap. During the process the steel ladle is covered with a special hood with argon shrouding. Injection of four different wires with one injection machine is possible. Al wire for precise deoxydation and alloying, C-cored wire for adjusting the carbon content of the steel, Ca- and CaSi-cored wire for deoxydation and to improve the castability of Al- and Al/Si-killed steels and S-cored wire for resulphurized steels to improve the machinability of the steel.

3.2. Product mix

Hoogovens produces billets in steel grades equivalent to those produced via the traditional ingot method. Gradual change-over from ingot to continuously cast steel will improve quality, cost efficiency and responds to market demands [3]. The start-up of the machines was in the first half of 1988. The aim of 50% ingot / 50% continuously cast billets was established at the end of 1988. The aim is a 100% continuous casting practice at the end of 1989.

The following steel grades for long products are produced at Hoogovens:

* Commercial Si-killed steel grades, including the requirement for Hoogovens' Rebar Mill. Commercial Si-killed steel qualities are available

for reinforcing and commercial wire applications and they also include applications for profiles.
* Rimming substitutes. Rimming substitutes are an important part of the product range, with suitable grades available for various applications, e.g. wire rod for welding material, plating and fine wire drawing.
* Carbon, carbon-manganese and low-alloy qualities, coarse and fine grained. A wide range of steel grades for various final applications is produced:
- welding material, CO_2 welding grades, low-alloy welding grades;
- steel grades for construction, case hardening and quench-tempering;
- steel for general wire applications, for bright wire or bar and for cables;
- spring steels;
- steel for forged and cold headed fasteners.

Alloyed steel composition is limited to the following maxima:

0.750% C; 2.000% Mn; 1.500% Cr; 2.000% Ni and 0.040% S.

The possible installation of a ladle furnace in the near future might change these maxima.
Present as-cast cross-sections are: 100, 115, 120, 125, 130, 140 and 200 mm square. The maximum billet length is 18 m. The minimum machine cutting length is 3.5 m. Billets are bundled.

3.3 Slag carry-over and conditioning

In Table 3.1 an overview is given of the steel grades which are calcium treated in the ladle and for what purpose. The used ladles have a dolomitic lining. Only for Si-killed commercial grades without calcium treatment a bauxite lined ladle is used.
A prerequisite for a successful calcium treatment is a ladle slag with a low oxygen potential. The total amount of FeO and MnO should be below 2%. Figure 3.1 presents the typical FeO + MnO content of the converter slag of low carbon steel. When no special precautions are taken, the FeO + MnO content of the ladle slag is as shown in Figure 3.2.
Trials to condition the ladle slag started before commissioning of the billet casters. These trials included artificial slag addition during tapping and slag killing by aluminium shot. A summary of the established practice is given in Table 3.2.
With this practice good results are obtained, see Figure 3.3. This figure presents data from present continuously cast Al-killed and rimming substitute heats; ladle slags before injection of Ca.
Conditioning of the slag is only possible when the slag carry-over from the converter is limited and constant. For this purpose a slag-free tapping practice has been developed:

- Preparation of the taphole (e.g. by gunning), to assure a tapping time above 5 minutes. The influence of tapping time on the amount of slag carry-over is well-known.
- Put old rags into the taphole before tapping to prevent slag to come out when tilting the converter into the tapping position.
- Slag detection by means of the Electro Magnetic Level Indication device (EMLI).
- Pneumatic slag stopper on the taphole, activated by hand on the EMLI-signal.

- Contra tapping.

At first this practice was performed without EMLI-system and without the pneumatic stopper. In 1986 the EMLI-device was installed followed by a pneumatic slag stopper in 1987. The effect of these devices is shown in Figure 3.4a, b and c: a) without EMLI and without stopper, b) with EMLI and without stopper and c) with both EMLI and stopper. The tapping time of all heats is longer than 5 minutes and turndown carbon is below 0.2%.
The slag carry-over is measured by means of the so-called dip-pin method. By this method the slag thickness is measured with an accuracy of 0.75 cm (= 150 kg). A correction is made for remaining slag from the preceding heat and slag formed by the tapping additions.
As shown, an average amount of carry-over slag of 600 kg is reached. The probability to restrict the weight of carry-over slag to ≤ 1000 kg is 90%.

3.4 Calcium injection practice per steel grade

3.4.1 Al-killed steel

For Al-killed, calcium treated steel grades, a ladle slag with less than 2% FeO + MnO is a precondition. With the practice described in 3.3, this condition can be met. The success of this practice is checked by means of a slag thickness measurement; no slag sample is taken.
Failure of the system (over 1000 kg slag carry-over) results in a switch of the heat to another grade.
The bulk of the required additions are made during tapping.
After 10 minutes from end of tapping, the steel and the slag are fully mixed by vigorous stirring (0.25 Nm^3/hr.ton) to establish a perfect equilibrium.
After this mixing a sample is taken and the composition is adjusted by injection of wires and additions of Fe-alloys.
When the right chemical composition is reached, gentle stirring (0.05 Nm^3/hr.ton) is required for at least 4 minutes. This is necessary to obtain a reproducible total oxygen content of less than 60 ppm. If a ladle deslagging device and a ladle furnace will be installed in the near future, it is anticipated that the total oxygen content will decrease.
The Ca-aim after calcium treatment is 60 ppm. However, the treatment is considered satisfactory when a level ≥ 42 ppm Ca is reached. These aim and minimum values are thought to be the right ones to obtain a liquid calciumaluminate inclusion which is liquid at casting temperatures. Actually, the CaO/Al_2O_3-ratio should be approximately 1 according to the phase diagram of Al_2O_3 and CaO (Figure 3.5). An overshoot of calcium is preferable to withstand the open casting which occurs when the tundish is filled up. A low sulphur content of less than 0.012% prevents the formation of CaS, which is also a clogging inclusion.
The aim Ca-content should therefore meet the following requirement:

Ca-total/O-total = 1, with a minimum of 0.7

The Ca-aim is reached by injecting both CaSi- and CaFe-cored wire. CaFe-cored wire proved to have a higher and more reproducible recovery yield than Ca-mix wire. This is the reason why the change-over from Ca-mix wire (recovery 9%) to CaFe-cored wire was made. Depending on the actual Si and Si-maximum, CaSi- and CaFe-cored wire are injected in a certain amount

and certain ratio. During injection a very gentle stirring is applied ($\leq$ 0.05 Nm^3/hr.ton). The injection speed of 180 m/min allows the calcium to be released near the bottom of the ladle. Typical recovery yields and average consumption values of additions are summarized in Table 3.3.
The argon shrouding of the cover and the gentle stirring practice limits the total pick-up of nitrogen during Ca-treatment to about 8 ppm (see Figure 3.6).
With a submerged casting system and in cross-sections $\geq \phi$ 115 mm, Al-killed steels are now frequently cast in sequences of 2 heats. Trials with metering nozzles have not been done yet, but are planned for the near future in the squares smaller than 115 mm.
With the exception of some heats with stream shrouding problems between ladle and tundish, no clogging has occurred during sequences of two. The inclusions found in the billet are globular and are composed of alumina and calciumoxide (see Figure 3.7).
The present state and expectations for the future sequence sizes are summarized in Table 3.4.

3.4.2 Al/Si-killed steels

The practice for Al/Si-killed steel grades is equal to the one applied for Al-killed steel. The aim Ca-content is also determined by:

Ca-total/O-total = 1 , with a minimum of 0.7

However, the total oxygen content turned out to be maximum 45 ppm for the low carbon Al/Si-killed steels. This kind of steel can be totally treated with CaSi-cored wire; average consumption value and recovery yield as shown in Table 3.3.
The nitrogen pick-up is limited to 4 ppm on average (see Figure 3.8).
The aim Ca-content in the ladle is based on some overshoot to 'survive' the filling up of the tundish and the incomplete shroud of the stream between ladle and tundish at the start of a sequence. This effect is made visible by the evolution of the nitrogen content during casting. Examples of this 'open casting' effect and the stabilization after some minutes are shown in Figure 3.9.
As for Al-killed steel, the calcium treatment is performed at a sulphur level $\leq$ 0.012%. However, some grades have to be resulphurized. This is done by means of S-cored wire with a yield of 75%, whereby no stirring is applied!
Actually, a sequence of 4 heats can be cast through the submerged casting system without clogging (only wear of the sliding-gate plates is observed). So far only sequences of 2 have been cast with the metering nozzles; no clogging was observed.
The expectations are that also larger sequences will be possible through metering nozzles in the near future (Table 3.4).
The calcium treatment results in liquid calciumaluminates during casting. This is confirmed by the shape of inclusions detected in samples from as-cast billets: they are globular as shown in Figure 3.10.

3.4.3 Rimming substitutes

For rimming substitute steel grades Ca-treatment is used for exact control of the free oxygen level. To minimize the amount of Al_2O_3 in the final product, the use of aluminium is restricted.
During tapping some aluminium is added and during ladle treatment Al wire is used to obtain free oxygen levels of about 50-60 ppm.
Although one of the casters is equipped with rotary MEMS (Mould ElectroMagnetic Stirring) facilities, it is necessary for some rimming substitute grades to establish a free oxygen level below 50 ppm to prevent pinhole formation. To fulfil this requirement, fine deoxydation is carried out by injection of CaSi- or CaFe-cored wire, the cored wire type depending on the Si-content. For the average consumption values, see Table 3.3.
The filling up of the tundish results in an oxygen pick-up of 20 ppm. When the shrouding of the ladle to tundish stream is perfect, the oxygen level will drop very rapidly to the one which was established in the ladle (comparable to the nitrogen evolution as shown in Figure 3.9).
Sequences of 4 heats through metering nozzles and with bellow shrouding of the stream between tundish and mould are performed on a regular base, normally without any pinhole formation.
The present and future sequence size can be found in Table 3.4.

4. CONCLUSIONS

BOS No.2:

Better mechanical properties are obtained by calcium treatment of constructional and HSLA steels. Two different Ca-treatments are developed for (HSLA) steel with an aim of Si of 0.250% and a Si-maximum of 0.030%, respectively.
To prevent an Al-killed and Ca-treated heat from clogging, a minimum calcium level of 20 ppm in the mould is necessary.

BOS No.1:

The developed slag-free tapping practice together with the established practice for conditioning the slag, fulfil the prerequisite for low-oxygen slags for calcium treatment.
Calcium treatment for steel grades containing aluminium (both Al/Si- and Al-killed) is sufficient to prevent the heat from clogging during casting.
Sequences of 4 heats are to be expected without any clogging problems.
Calcium treatment for rimming substitute grades makes it possible to establish a very low free oxygen content of the steel, thus preventing pinhole formation during solidification.

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Table 2.1: Ca-addition and recovery yield together with nitrcgen data; (HSLA) steel with Si-aim of 0.250% Si

deoxidation during tapping	number of heats	type of Ca-cored wire	amount of Ca (kg/ton)	recovery in ladle (%)	delta [N] ladle treat-ment (ppm)	[N] in tundish (ppm)
Al + SiMn	22	CaSi	0.46	19	14	56
SiMn	56	CaSi	0.44	16	15	45

Table 2.2: Ca-addition and recovery yield together with nitrogen data; HSLA steel with Si-maximum of 0.030% Si

deoxidation during tapping	number of heats	type of Ca-cored wire	amount of Ca (kg/ton)	recovery in ladle (%)	delta [N] ladle treat-ment (ppm)	[N] in tundish (ppm)
Al	18	Ca-mix	1.09	4	14	43
Al	2	CaFe	0.93	8	24	57

Table 2.3: Clogging tendency of HSLA steel with a Si-maximum of 0.030%

clogging tendency	number of heats	type of Ca-cored wire	amount of Ca (kg/ton)	**Calcium in mould (ppm)**	delta [N] ladle treat-ment (ppm)	[N] in tundish (ppm)
yes	7	Ca-mix	1.13	**16**	10	44
no	11	Ca-mix	1.07	**22**	17	43

Table 2.4: Ca-treatment of Al/Si constructional steel in the tundish; metallurgical effects

item	treated with Ca	reference heat
injection data	CaSi-cored wire ϕ 9 mm, 30 gr Ca/m V_i = 100 m/min	-----
S	0.007 %	0.007%
Ca - level	35 - 40 ppm	-----
recovery of Ca	8.5 %	-----
Al_2O_3-clusters in slab	0	0.8/cm^2
MnS type II in segregation zone of slab	0.9/cm^2	39.5/cm^2
same for 'MnS' type III	14.5/cm^2	25.4/cm^2
ψ_z - value in plate	63% (15 mm) 73% (40 mm)	50% (25 mm)
$q_{//}$ in plate (10 - 40 mm)	4	18

Table 2.5: Plate results of percentage of reduction of area; constructional steel

	% reduction of area (ψ_z-value) (plate thickness 20 to 50 mm)		
	mean value of 3 specimen	scatter 5%	scatter 95%
Si/Al-killed steel without Sulphide Shape Control	25	10	45
Si/Al-killed steel Ce-treated	40	15	60
Si/Al-killed steel Ca-treated	60	50	70

Table 2.6: Charpy V plate results from the impact tests

	testing temperature				
	- 60°C	- 40°C	- 20°C	0°C	+ 20°C
	energy transverse (J/cm^2)	(J/cm^2)	(J/cm^2)	(J/cm^2)	(J/cm^2)
Si/Al-killed steel without Sulphide Shape Control	25	38	50	75	100
Si/Al-killed steel Ce-treated	50	75	100	130	138
Si/Al-killed steel Ca-treated	113	150	200	250	263
HSLA Si/Al-killed steel without Sulphide Shape Control		30	40	50	
HSLA Si/Al-killed steel Ca-treated		60	90	110	

Table 3.1: Calcium treatment per steel grade

steel grade	calcium treatment	aim
Al-killed	yes	anti-clogging
Rimming Substitute	yes	oxygen control
Al/Si-killed	yes	anti-clogging
Si-killed quality	no	--
Si-killed commercial	no	--

Table 3.2: Slag conditioning per steel grade

steel grade	artificial slag composition CaO (%)	CaF_2 (%)	Al_2O_3 (%)	others (%)	amount (kg/t)	aluminium shot
Al-killed low C	80	20	--	--	10.0	yes
Al-killed	65	14	14	7	5.0	no
Rimming Substitute	80	20	--	--	10.0	yes
Al/Si-killed	65	14	14	7	7.5	no
Si-killed quality	65	14	14	7	5.0	no
Si-killed commercial	--	--	--	--	--	no

Table 3.3: Ca-addition and recovery yield

steel grade	type of Ca wire	amount (kg/t)	recovery (%)
Al-killed	CaSi + CaFe	0.13 + 0.33	23 13
	CaFe	0.50	13
	Ca-mix	0.70	9
Al/Si-killed	CaSi	0.20	25
Rimming Substitute	CaSi	0.10	
	CaFe	0.10	

Table 3.4: Present and future average sequence size

steel grade	casting system	present sequence size	future sequence size
Al-killed	submerged	2	up to 4
Rimming Substitute	bellow	4	5
Al/Si-killed	submerged/bellow	2	up to 5
Si-killed commercial	open	7	7
Si-killed quality	bellow	5	5

The open and bellow casting systems are in combination with metering nozzles of ϕ 14 or ϕ 15 mm.

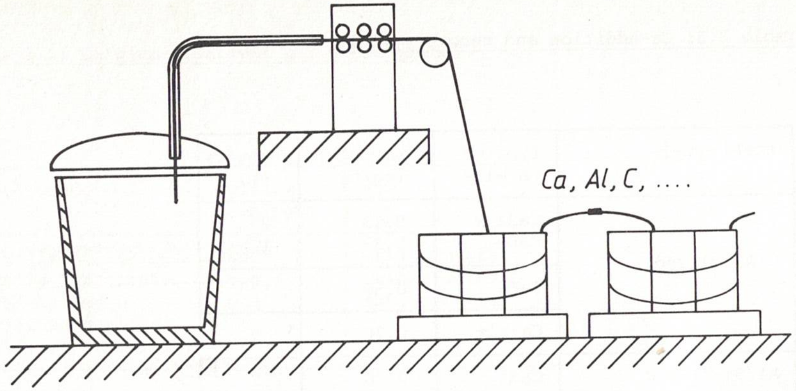

Fig. 2.1 : Schematic drawing of BOS No.2 stirring station 22 with 'flipperstand' for (cored) wire injection

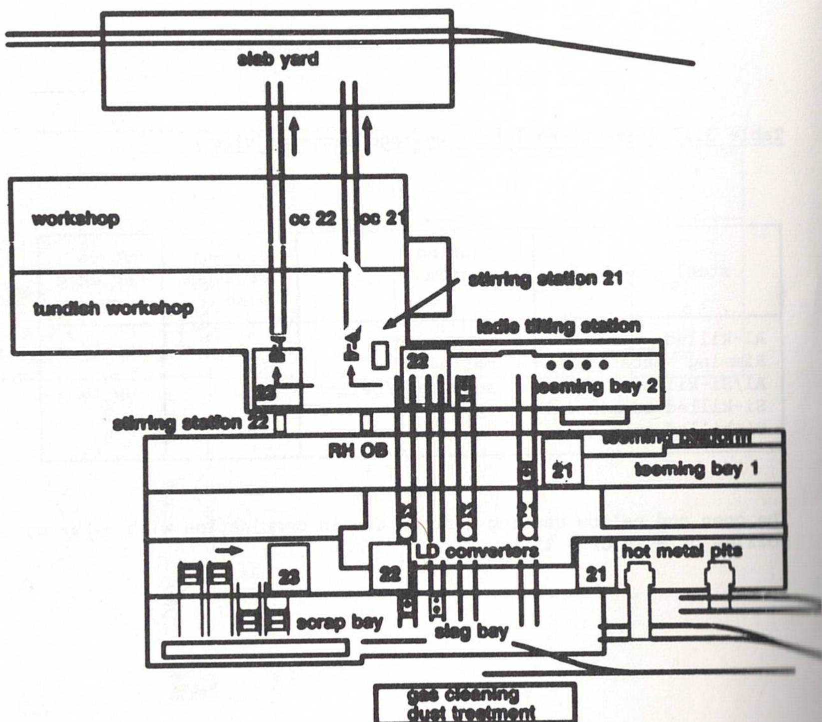

Fig. 2.2 : Lay-out of BOS No.2 after implementation of CC 22 (situation 1988

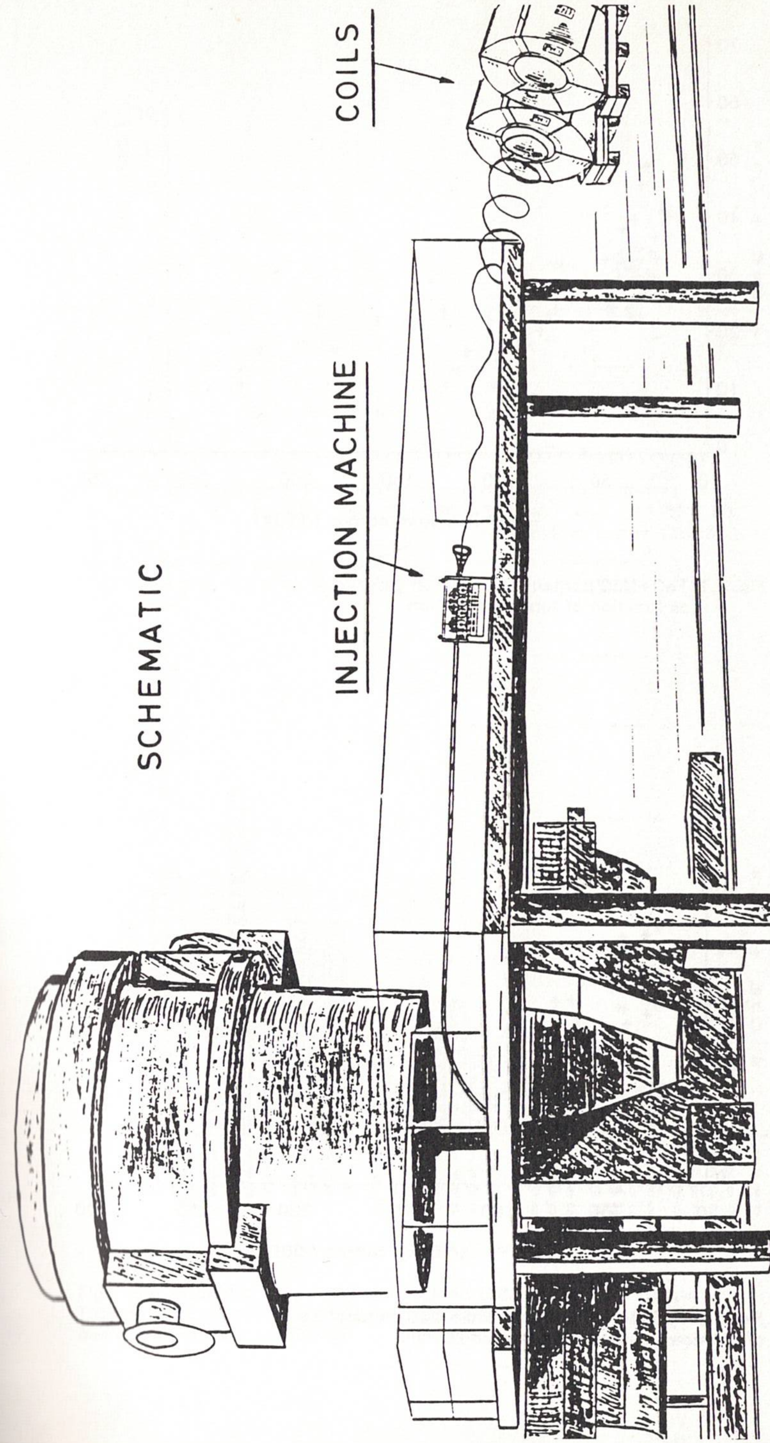

Fig. 2.3 :
INJECTION OF CORED WIRE INTO THE TUNDISH FOR SULPHIDE SHAPE CONTROL

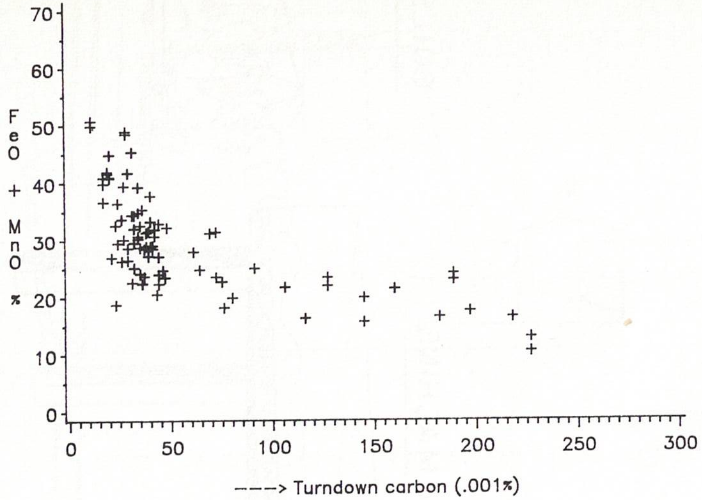

Fig. 3.1: FeO+MnO content of converter slag as function of turndown carbon

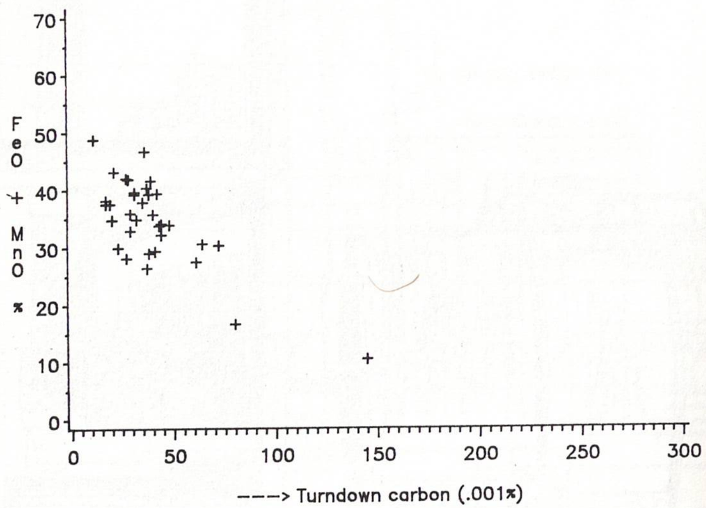

Fig. 3.2: FeO+MnO content of ladle slag as function of turndown carbon. No slag conditioning

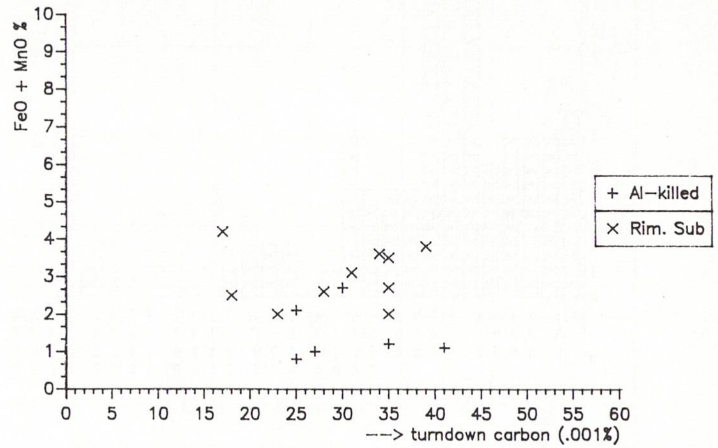

Fig. 3.3: FeO + MnO content of ladle slag.
Conditioned slag with artificial slag and Al shot

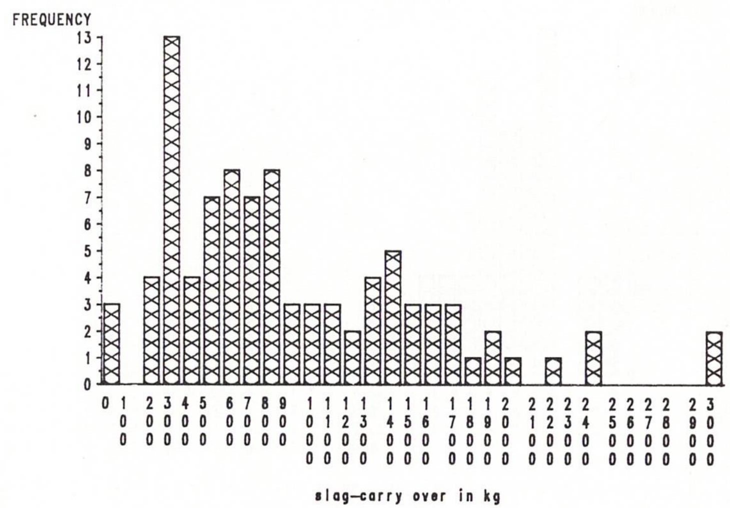

Fig. 3.4a: Amount of slag carry-over without EMLI and without stopper
Tapping time > 5 minutes, turndown carbon < .200%
average carry-over = 1000 kg

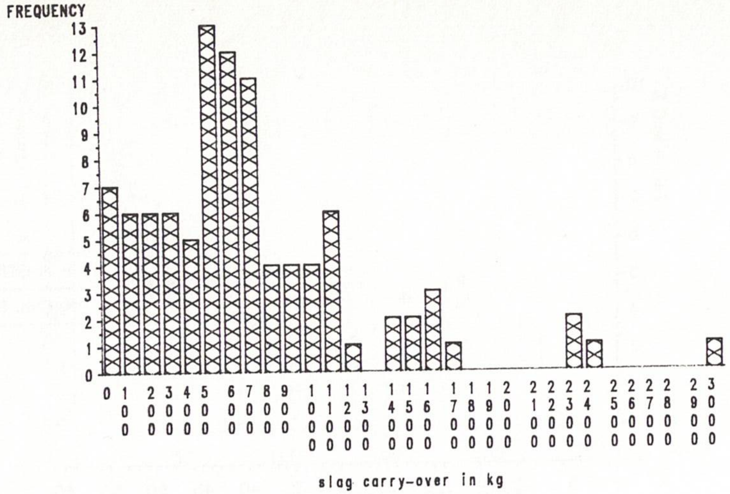

Fig. 3.4b: Amount of slag carry-over with EMLI and without stopper
Tapping time > 5 minutes, turndown carbon < .200%
average carry-over = 700 kg

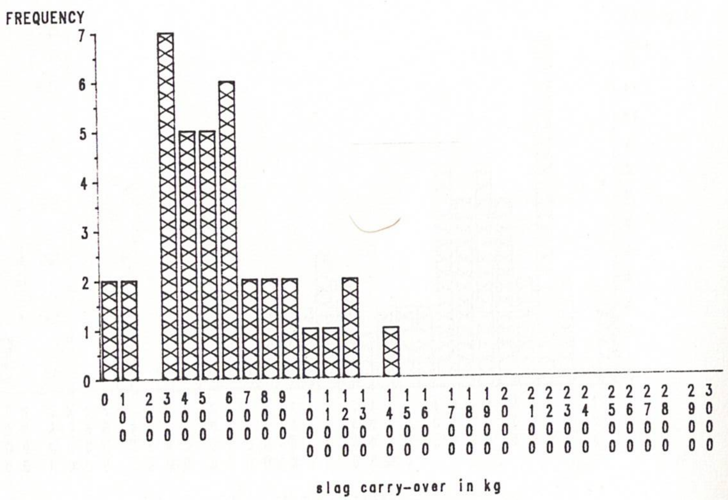

Fig. 3.4c: Amount of slag carry-over with EMLI and with stopper
Tapping time > 5 minutes, turndown carbon < .200%
average carry-over = 600 kg

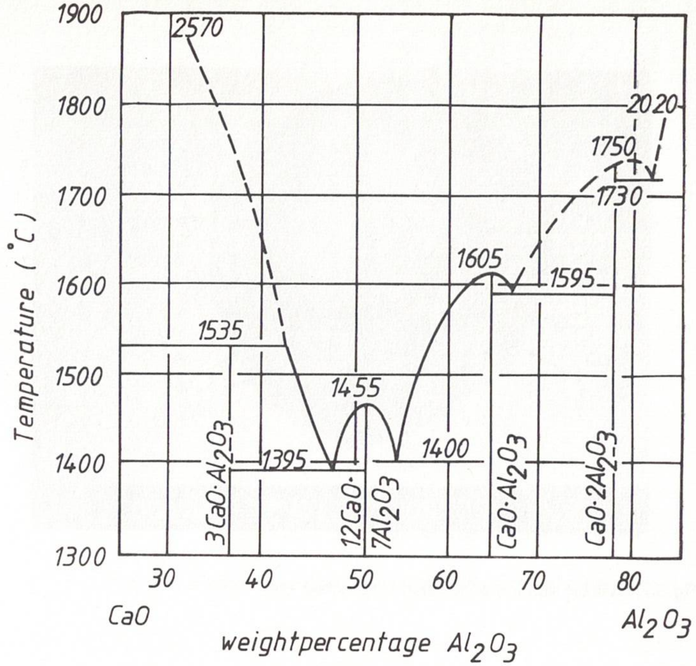

fig. 3.5: phase diagram $CaO - Al_2O_3$

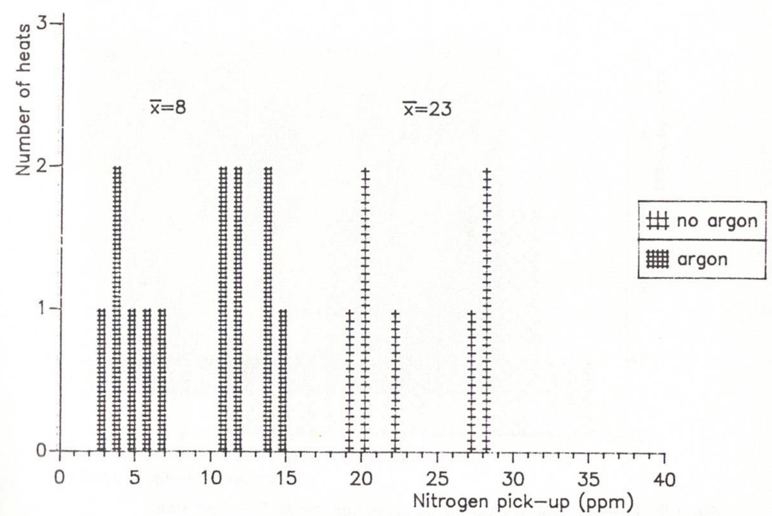

Fig 3.6: Nitrogen pick-up during Ca-injection for Al-killed steels.

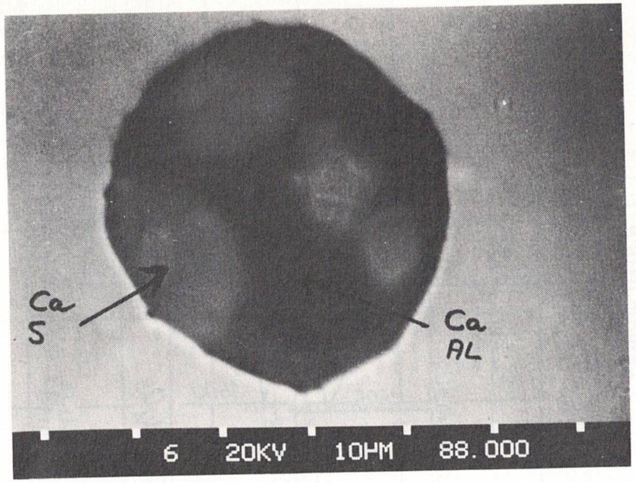

Fig 3.7: Calciumaluminate inclusion in Al–killed steel

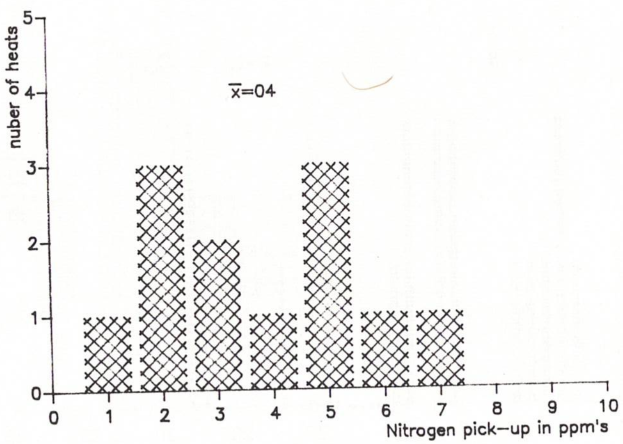

Fig 3.8: Nitrogen pick–up during Ca–injection for Al/Si–killed steel.
With argon shrouding.

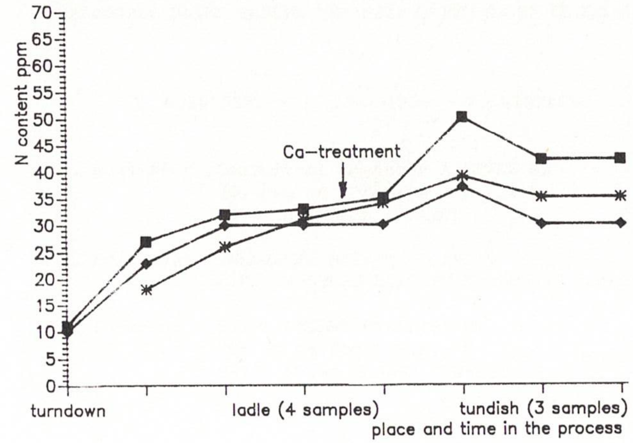

Fig. 3.9: Nitrogen evolution of 3 heats of Al/Si–killed steel.

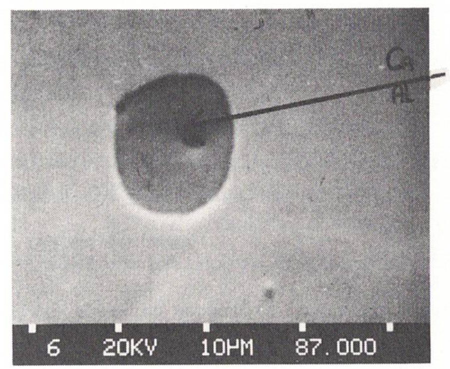

Fig 3.10: Calciumaluminate inclusion in Al/Si–killed steel