USE OF LADLE INJECTION TREATMENT AT A MINI STEEL PLANT

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During the last ten years ladle injection treatments have been developed at Ovako Oy-Ab. Part of this development has been carried out in co-operation with other Scandinavian steel works but in many technical and metallurgical problems we have found special applications of our own. At the present time ladle injection is utilized both on billet continuous casting and conventional ingot casting route. The benefits of injection treatments on the process side are improved deoxidation and desulphurization as well as better castability and surface quality. In addition to these effects that have resulted in better yield in the process, the ladle injection has many advantages on the properties of the final products. Inclusion cleanness and the control of the inclusion type results in better formability and improved machinability. A strict control of the analysis attained by ladle treatment means e.g. a very narrow Jominy band.

INTRODUCTION

Ovako Oy-Ab - a Finnish private steelmaking company and one of the largest in Scandinavia - consists of three groups: Basic Steel Group, Steel Wire Group and Steel Products Group. The Basic Steel Group comprises Imatra Steel Works and Koverhar Iron and Steel Works with a total capacity of about 700 000 tonnes crude steel a year. Of that figure Koverhar Iron and Steel Works produces 450 000 tonnes based on imported ore and about three fourths of its billet products are rolled in the other rolling mills of Ovako, Figure 1.

Imatra Steel Works which is using both domestic and imported scrap is making and rolling bar and wire products. A vital part are the high grade special steels for many applications; wire rods, bolt manufacturing, automobile industry, for instance.

Steelmaking in Imatra - on which this report is based - is a scrap-based process with two electric arc furnaces of 40 and 60 tonnes. The amount of production via ingot casting is at the moment higher than that via continuous casting route but towards the end of 1981 this relation will be averse as a result of succeeded development work to convert more and more high grade steels to the continuous casting route /1..4/.

The continuous casting machine itself is a 16 years old Concast S-type machine with three strands. Optional billet sizes are ∅ 100 mm and ∅ 125 mm. T-type shrouding with nitrogen is used between moulds and tundish and aluminium wire is fed into the mould if necessary. A funnel tile is used to drive the ladle stream under the steel level in the tundish to avoid splashes. On the ingot casting only one ingot size of 3.6 tonnes is used, and all casts are made by bottom pouring. The ladles are equipped with sliding gates and refractory material is high alumina at present, but we are changing it to dolomite for decreasing refractory costs and for better stability against lining reduction in ladle treatments.

This development work is very important as we are at Imatra Steel Works concentrating on the manufacture of special steel grades with high demands such as good surface quality, good cold or hot formability, good response to heat treatment and precise control of final physical and mechanical properties.

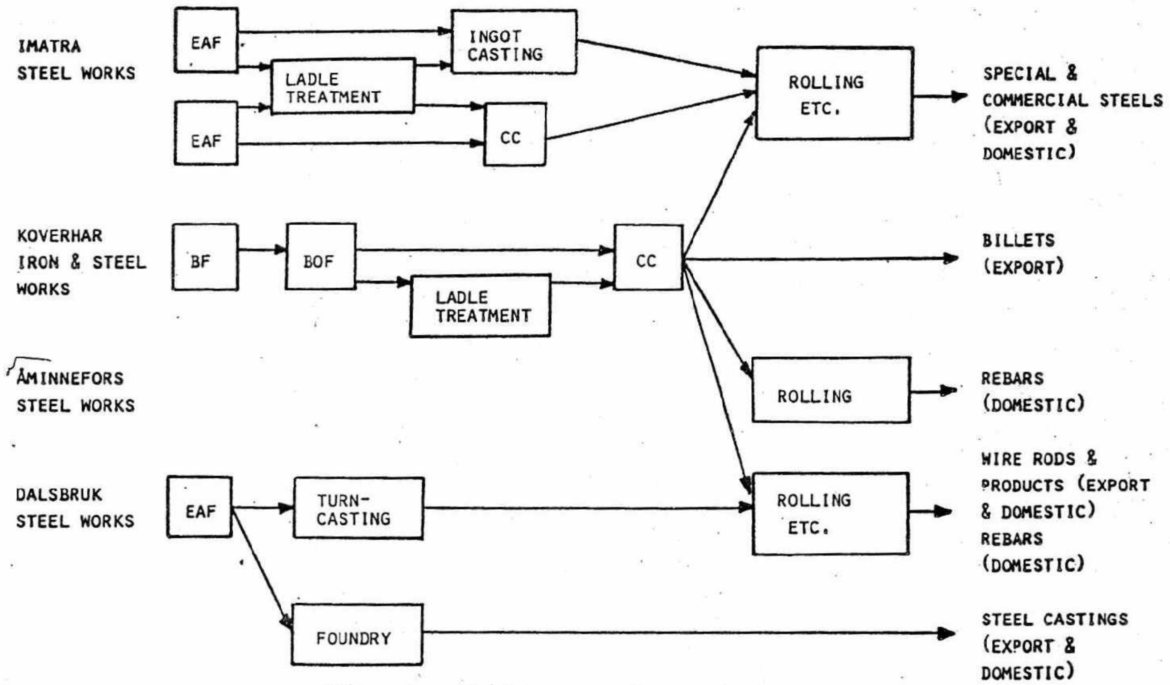

Fig. 1. Ovako process routes.

Table I. Development of Injection Metallurgy at Ovako.

1968..69	Injection of Ca-alloys in the arc furnace → deoxidation
1970..71	Ladle injection trials
1970	Application for a patent
1972..77	Development of ladle injection technique in co-operation with Jernkontoret research committees
1974	Ladle injection trials in Imatra
1976	A pilot-type injection equipment to Imatra
1977/78	Ladle injection trials in Koverhar
1979	Ladle treatment stations for injection, gas rinsing and analysis adjustment to both Imatra and Koverhar.

This development into high grade oriented product mix has required quite an extensive process development. The ladle injection treatment forms today a vital part of this development in order to fulfil the growing demands of the customers and to increase the high grade steel production through continuous casting route.

DEVELOPMENT OF LADLE METALLURGY AT OVAKO

The first steps of injection metallurgy were taken at the end of 1960's, when injection trials of Ca-alloys were performed in the electric arc furnace (Table II). Very efficient deoxidation was obtained but the effect was to a large extent lost in the subsequent process. Thereafter the concept of ladle injection was developed. Tests were made but due to an insufficient technique the development was retarded. Since 1972/73 the development of the injection technique has been made in co-operation with Jernkontoret, which is a research organization of different Scandinavian steel works.

At the end of 1976 a pilot-type injection equipment was installed. This pilot station has been both in research and production use until the end of 1979 when a proper production scale station for powder injections and analysis adjustments was commissioned, figure 2.

At the same time when injection technique has been developed in Imatra, also the interests of Koverhar basic oxygen steel plant have been taken into consideration. So it was nearly at the same time when the ladle treatment station started its operation in Koverhar, too.

Table II. The Effect of Al-Content and The Amount of CaSi Injected On the Resulting Inclusions Type.

Al_{sol} wt-%	CaSi kg/t	Inclusion type
< 0.005	< 1	Al_2O_3-CaO-SiO_2-MnO complex oxide, with MnS. The oxide and sulphide very easily deformed. Melting limits ~1400..1500°C, Area 1.
< 0.005	> 1	Ca_2SiO_4-complex oxide with small amounts of Al_2O_3. Also CaS areas. Undeformable inclusion with melting limits 1900..2100°C, Area 2.
~ 0.010	< 1	Al_2O_3-CaO-SiO_2-complex oxide, the inner part is mainly Al_2O_3 and the peel is (Mn,Ca)S. The oxide part undeformable with melting limits 1600..2000°C. The sulphide peel deformable, Area 3.
> 0.010	> 1	Al_2O_3-CaO-SiO_2 complex oxide, silica content < 5 5%. Usually CaS-areas. Undeformable inclusions. Melting limits of the oxide part 1350..1600°C, area 4.

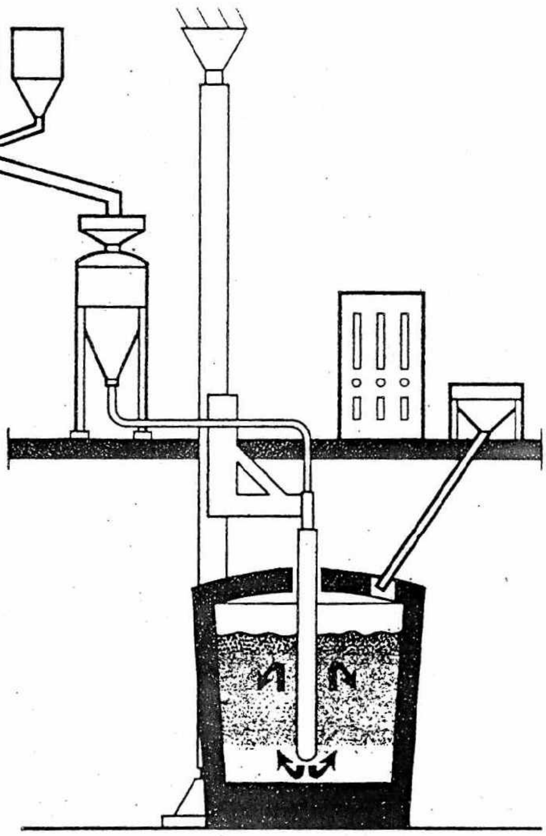

Fig. 2. Injection station.

Today ladle treatment is a routine practice, which is utilized in Imatra both on billet continuous casting and ingot casting routes. In addition to those advantages of ladle treatment mentioned earlier, is the fact that it has made it possible to simplify and shorten the steelmaking practice in the arc furnace. Thus, long reduction periods or new slag methods because of deoxidation and desulphurization have been given up. On the other hand, the prevention of furnace slag to flow into the ladle during tapping has become more important for ladle treated heats.

RESULTS AND DISCUSSIONS

The ladle injection treatments have been developed and practised for some years. The metallurgical results have been fairly good. Unfortunately, there are some limiting factors which have prevented from taking the full advantage of this unit. The relatively small ladle sizes (40 and 60 tonnes) cause quite high temperature losses during treatments. Also reoxidation owing to the partially open teeming streams and refractory materials have caused that altra low total oxygen contents could not have been guaranteed in the final products. Although we are putting much stress on the prevention of reoxidation in the near future, many good results can be reported of the use of ladle treatments without perfect shrouding systems and basic refractories.

Modification of Inclusions and Desulphurization

It is well known that calcium - like the other alkaline earth elements - reacts very easily with sulphur and oxygen. The good desulphurizing ability of calcium has been assumed to result from the fact that calcium can react directly with sulphur to form sulphide in the liquid steel:

$$|Ca| + |S| \rightarrow CaS$$

On the other hand, from the thermodynamic standpoint calcium reacts with oxygen far easier than with sulphur:

$$|Ca| + |O| \rightarrow CaO$$

This means that if we want to take the full advantage of the desulphurizing power of calcium, the steel must be well deoxidized.

Calcium is also a better reducing agent than the classical deoxidants, e.g. aluminium. Thus, it can reduce the existing inclusions remaining in the steel. If calcium is injected sufficiently, the alumina clusters are transformed into globular aluminates. On the contrary, we have indications in the practice that if the sulphur content is high, calcium reacts with sulphur before acting on the alumina inclusions.

Because the reliable analyzing of calcium content in steel is very difficult, we have preferred to use a parameter of CaSi kg per tonne steel instead of the analyzed calcium content in our studies. Quite a lot of research has been done in the field of inclusions modification by calcium silicon injection in Ovako.

The composition of inclusions has been analyzed by microprobe X-ray scans. A typical inclusion in aluminium-killed steel is shown in figure 3. The modification mechanism of inclusions by calcium treatment is schematically presented in figure 4. The alumina inclusions are converted to calcium aluminates which form the cores of the resulting oxysulphides. The peel is calcium sulphide when sulphur content is low or calcium-manganese sulphide when sulphur content is higher. Even with low sulphur contents some sulphur is bound to angular type III manganese sulphides, but this type is not harmful for the quality of billets or rolled products.

In order to attain the full advantage of calcium treatment the steel must be well deoxidized, if possible with aluminium. Although calcium treatment modifies inclusions of Si-Mn-deoxidized steels from manganese-silicate to calcium-aluminium-silicates with very low manganese content, a far better desulphurization and deoxidation with improved inclusions control and cleanness can be obtained if the steel is pre-deoxidized with aluminium. In figure 5 the typical areas of inclusion composition obtained by different deoxidation and injection practice are described (see also Table II).

In most cases area 4 is the most desirable. To some extent some researchers have been interested in anorthite type inclusion composition (area 1) as far as machinability is concerned. Anyway, the higher is the aluminium content in the steel, the less silica is in the inclusions. This means normally better deoxidation and improved cleanness for the steel.

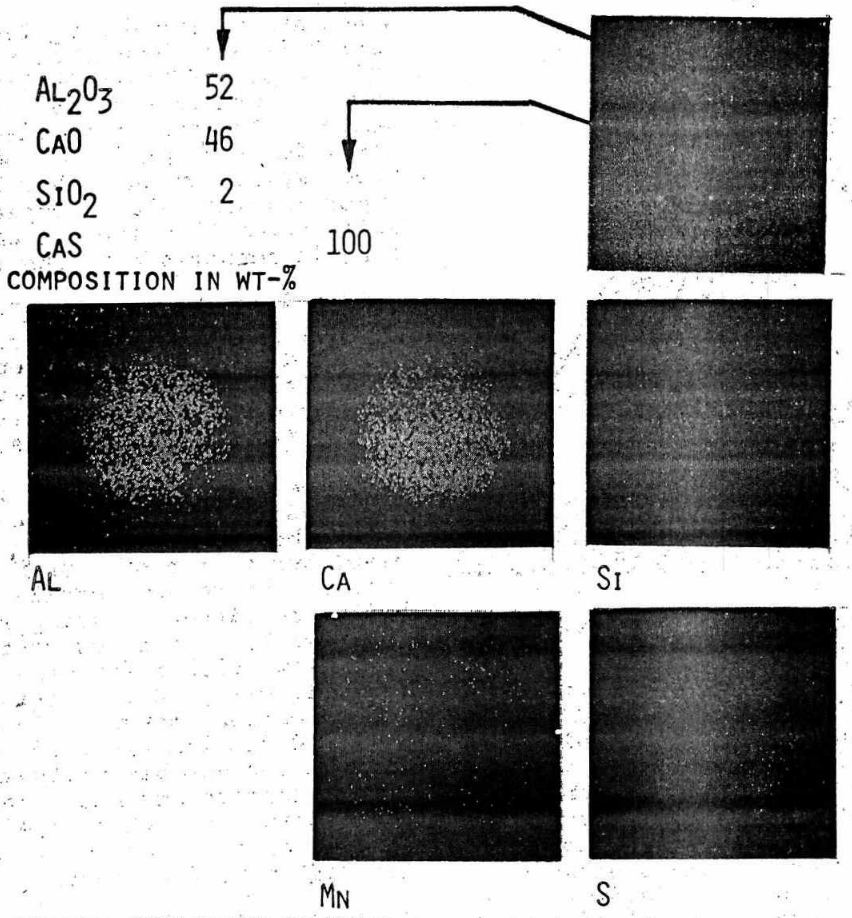

Fig. 3 TYPICAL INCLUSION IN CA-TREATED AL-KILLED STEEL

C = ,38 %, AL_{SOL} = ,028 %, CA = ,0065 %, S = ,005 %

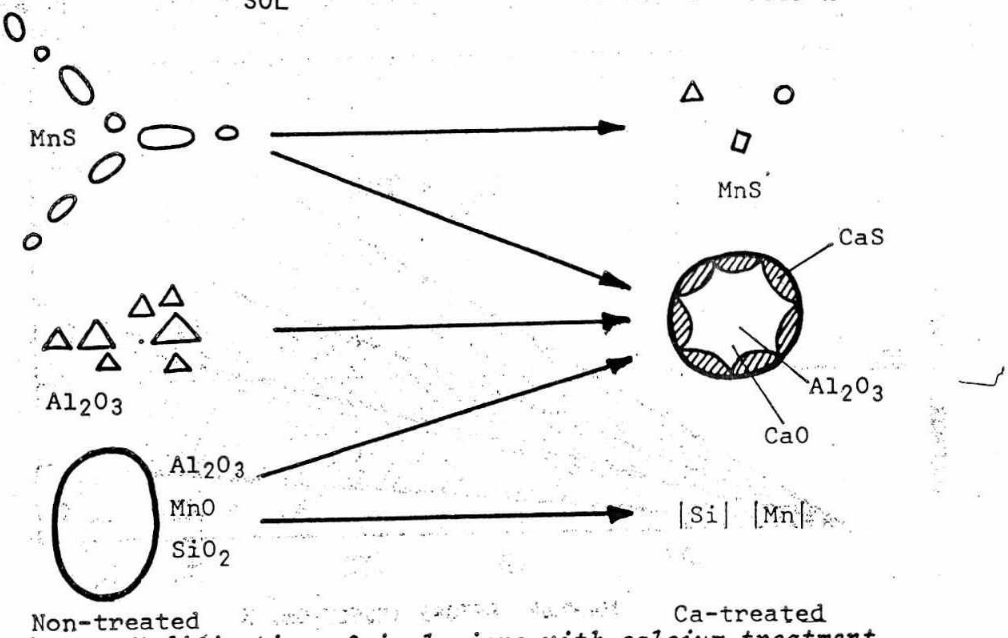

Fig. 4. Modification of inclusions with calcium treatment (schematic presentation).

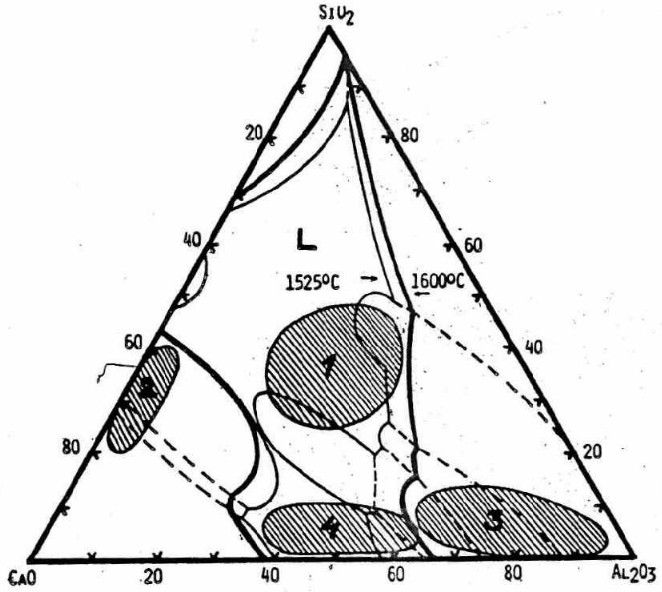

Fig. 5. Inclusion compositions after injection treatment.

Remembering that by calcium treatment we can easily get rid of and prevent the formation of solid aluminium clusters, castability is normally improved. On the other hand, a prolonged calcium treatment with low aluminium levels can result in inclusion composition in area 2, where nozzle blockages occur probably due to solid Ca_2SiO_4 particles. With strict control of aluminium content and amounts of calcium injected it is possible to get quite close to the eutectic composition of the inclusions. This means that the inclusions are molten during teeming and castability is essentially improved. This result has been utilized especially in our continuous billet casting route where it has been possible to increase aluminium content from 0.004 wt-% up to 0.004 wt-%. On the other hand, on the ingot casting calcium injected casts allow about 20°C lower teeming temperature in comparison to the untreated casts.

A sufficient calcium treatment with combination of increased aluminium content and low sulphur content in steel essentially improves the surface quality of continuous casting billets and the total yield in the process.

The desulphurization in our CaSi-injected casts is presented in figure 6. It can be seen that at the average a desulphurization of over 50 per cent can be obtained by conventionally deoxidized billet continuous casting steel (Al< 0.004 wt-%), but to guarantee a sufficient low sulphur for many products (e.g. < 0.015 wt-%) it is necessary to raise the aluminium content. In addition to the good desulphurization, higher aluminimum content also reflects on the inclusion cleanness and guarantees the fine grain structure, which are the main prerequisites for continuous cast billets for high demand purposes.

Inclusion Cleanness

Gas stirring in the ladles has also been practised in Imatra for several years. The main purpose is to homogenize

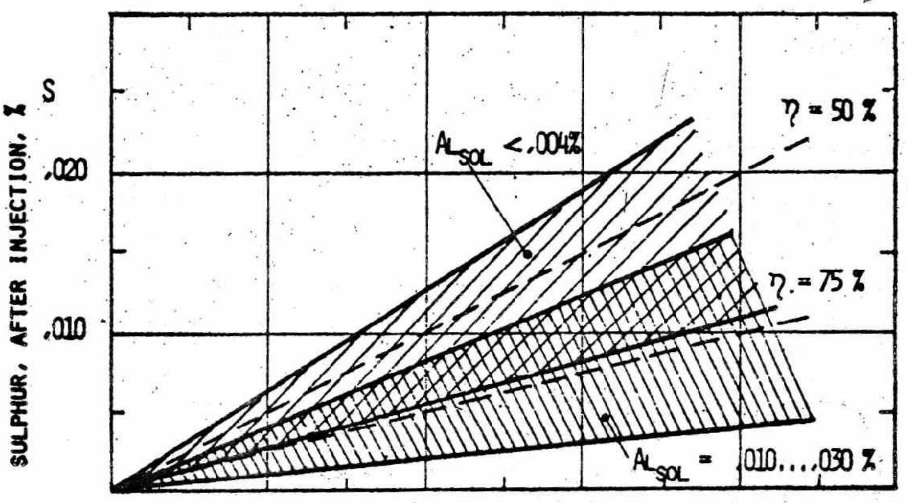

Fig. 6. Influence of Al-deoxidation on desulphurization.

the ladle analysis and temperature for casting. It has also been noted that the amount of oxide inclusions can be reduced providing that the deoxidation and slag prevention from the furnace is under control. After the gas rinsing treatment there still exist some oxide inclusions, but quite many of the alumina clusters found in the final product are supposed to form by reoxidation. The amount and size of this kind of inclusions is not normally harmful in aluminium-killed steels unless aluminium content remains very low (<0.010 wt-%), when the amount of inclusions can drastically increase.

As earlier mentioned, CaSi-treatment of aluminium-killed steels leads to calcium-aluminate types of inclusions surrounded by sulphide peel. According to our results the total inclusion cleanness is fairly improved in CaSi-treated steels but there still remain some single globular oxysulphides which tempt to grow bigger than the conventional micro-inclusions, up to 30 microns. The absence of alumina in calcium-treated steel is assumed to be due to that calcium gives a protection to aluminium against reoxidation, which might be one of the reasons to growing of the calcium-aluminates.

On the other hand, these inclusions are undeformable and because of the lack of conventional manganese sulphide and alumina cluster rows the anisotrophy caused by inclusions in the deformed product decreases essentially. In fact this type of inclusion is often favourable for many special properties, e.g. machinability, as will be discussed later. For some products, however, as e.g. wire materials, the well deformable type inclusions as silicate are wanted. In these cases the use of calcium injection must be considered very carefully.

For this type of steels or for steels with high inclusion cleanness requirements the injection of lime based powder might be a good solution. At least the same desulphurization efficiency than with CaSi-treatment can be obtained. On the other hand, the micro inclusion cleanness has been better in comparison to the CaSi-injected casts. The remaining inclusions have been very finely scattered but no modification of inclusions can be reported.

As compared with gas-rising treatment with top slag both treatments result in inclusion cleanness but the same result can be attained by slag powder injection in a much shorter treatment time. That is very essential fact when operating with small ladle sizes.

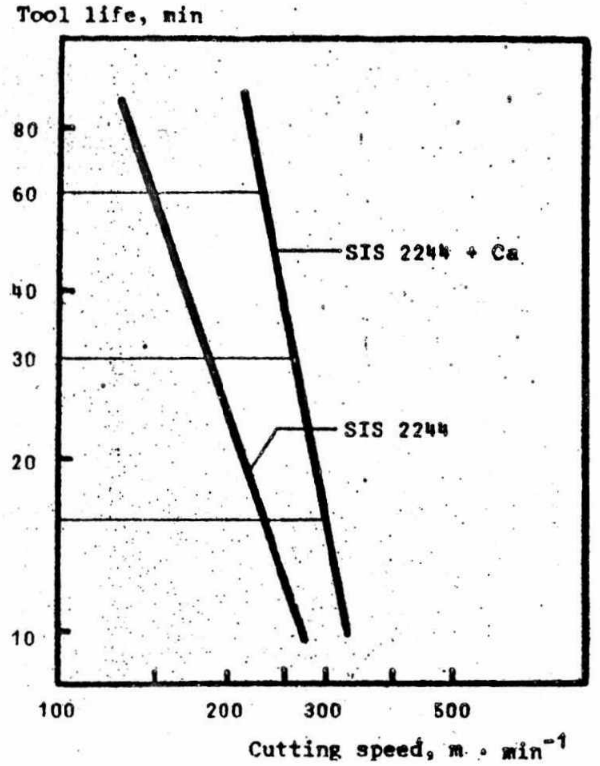

Fig.7. Effect of Ca-treatment on hard metal tool machinability.

Effects on Product Properties

An important application of calcium treatment is the improvement of machinability of hardening and tempering as well as case hardening steels. The calcium treatment has a very strong effect especially on hard metal tool machinability as can be seen from figure 7. In the calcium-treated steel the modified oxysulphides form an oxide layer on the tool resulting to longer tool life and possibility to use higher cutting speed. Better surface quality of the product to be machined is obtained, too.

Because of the resulting absence of anisotropy the calcium treatment is a very popular way to improve many mechanical properties on the transverse direction when making steel plates. Yet in the area of steel bar and wire products better transverse ductility of our boron steel flat is presented.

Normally calcium treatment improves the cold-formability but the real advan-

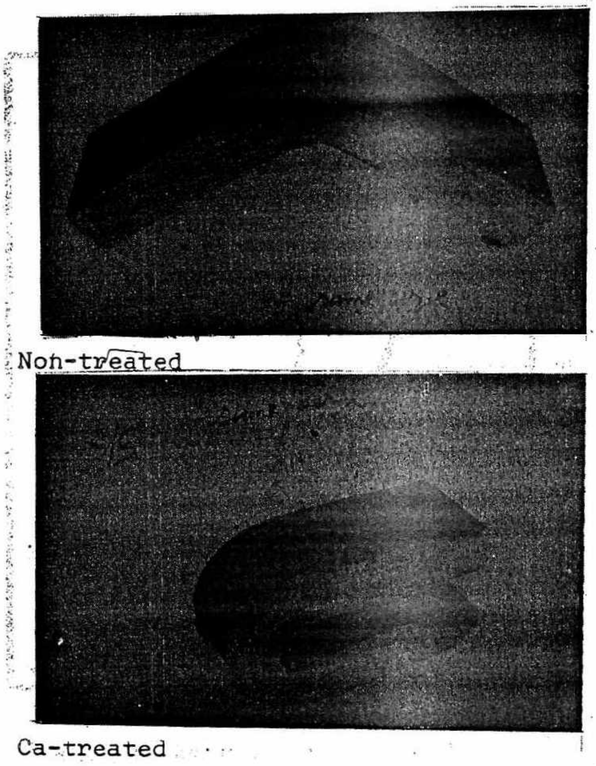

Fig. 8. Effect of Ca-treatment on transverse ductility. Boron steel BM 212, R_M = 550 N/mm^2, 165 HB.

tage is greatly affected by the direction of the stresses which exist during deformation. On the other hand, if the formation process is very complicated with high reductions, a very good micro slag cleanness is usually required. In this kind of cases the casts with slag powder injection have given promising results.

A special application of utilizing also the inclusion cleanness and the low sulphur content attained by slag injection is the automatic welding process. One of Ovako's units is manufacturing chains and for the present the slag powder injected casts have given the best welding joint with fine and clean grain structure and high strength.

One thing that is also worth mentioning is the opportunity to adjust the analysis with small amounts of ferro alloy additions during injection or gas rinsing in the ladle. It is clear that this practice requires a reliable and quickly analyzable sample from the ladle, on which the additions are based. The amounts of alloy additions must be limited as unpredictable temperature losses are not desired. One of the applications of this technique is, for example, the improved control of hardenability. On several special steel grades we have succeeded in narrowing the Jominy-band to half of its breadth, fig. 9.

In general, the properties of final products must be thoroughly considered when choosing the treatment practice.

CONCLUSIONS

The uses of ladle injection treatment at Ovako can be summarised as follows:

- A desulphurization degree of 70 wt-% is attained.

- The castability of aluminium deoxidized steels is improved on the in-

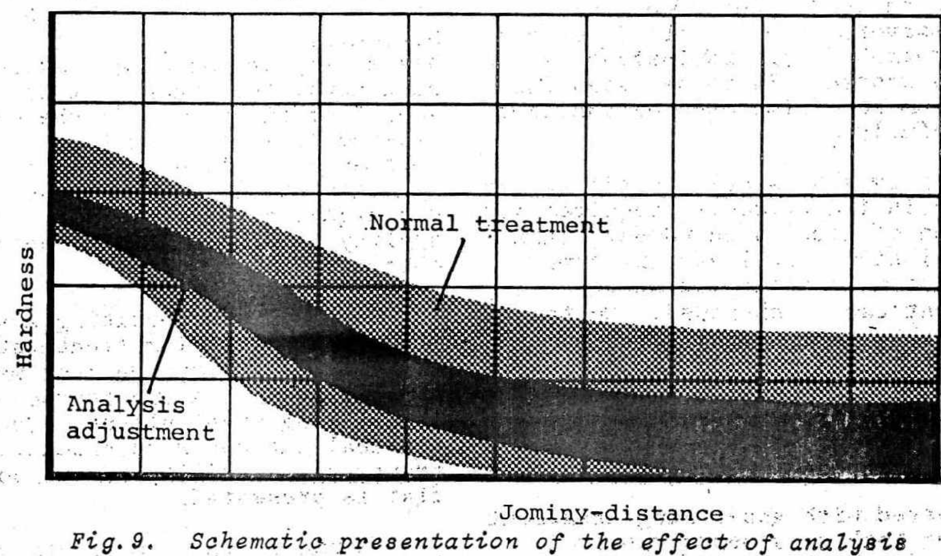

Fig. 9. Schematic presentation of the effect of analysis adjustment practice on the Jominy-band.

got casting route and especially on the continuous casting route.

- It has been possible to cast steels up to 0.040 wt-% aluminium through billet continuous casting.

- The improved deoxidation and effective desulphurization has resulted in good surface and internal quality and minimizing of segregation cracking caused by manganese sulphides thus resulting in the decreasing need for billet conditioning.

- Ladle treatments have made it possible to shorten and simplify the refining time in the arc furnace.

- The machinability of hardening and tempering as well as case hardening steels has strongly improved by CaSi-treatment.

- Casts treated with lime based powders have managed very well on manufacturing processes where the inclusion cleanness of the material plays a significant role.

- Small scatter of many product properties can be assured by strict control and adjustment of the analysis during treatment.

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