Measures to Improve Oxide Cleanness in Continuous Casting

Prof. Dr.-Ing. Klaus Wünnenberg
Steel Consulting
Straubinger Straße 38a
47249 Duisburg, Germany
Phone : (0049) 203 706304
e-mail: klaus.wuennenberg@vodafone.de

Dr.-Ing. Jürgen Cappel
RHI AG
Wienerbergstrasse 11
1011 Vienna, Austria
Phone: (0043) 50213 6673
e-mail: juergen.cappel@rhi-ag.com

Key words : Clean Steel, Oxide Cleanness, Macro Inclusions, Castability, Deoxidation, Reoxidation, Slag carry over, Refractory material, Tundish, Mold, Rinsing, Shrouding systems, Continuous Casting

ABSTRACT

Oxide cleanness today is one of the most important items of high quality steel. What is "Clean Steel"? Micro- and macro inclusions. Formation by deoxidation and reoxidation. Refractory material. Measuring systems. Shrouding systems. Support of floatation of inclusions in tundish and mold using furniture for optimal flow pattern. Rinsing with inert gas. Distribution of inclusions in the cast strand. Influence of the design of the casting machine.

INTRODUCTION

Steels of high performance call for excellent oxide cleanness. Customers therefore steadily increase the demand for low levels of inclusions. This is especially true for autobody sheet, machining steel for hydraulics and motor components because of surface conditions and of high tensile steels for linepipe or off-shore equipment to reduce the sensitivity against HIC.

Steelworks all over the world rendered great efforts to improve technologies in secondary metallurgy and in continuous casting. The melting units like EAF and BOF are only of marginal influence on steel cleanness. The main aims are to minimise the inclusion content in the liquid steel, to promote the separation of particles and to avoid reoxidation by ambient air, slags and refractory materials.

1. SOURCES OF INCLUSIONS

Oxide particles are formed in the process line by deoxidation, reoxidation and reactions with the refractory material of the various containers like ladle, tundish and shroud. Beyond that, casting powder can be emulsified at the meniscus of the mould. During the processes most of the large particles are seperated from the liquid steel by floatation, some remain in the liquid steel. The main three types of inclusions can be identified by their chemical components. Alumina is a deoxidation or reoxidation product, spinel with certain contents of magnesia is originated from reactions of solved aluminium with the refractory lining, especially under vacuum treatment **[1]**. Typical elements in casting powder are alkalines like sodium and potassium.

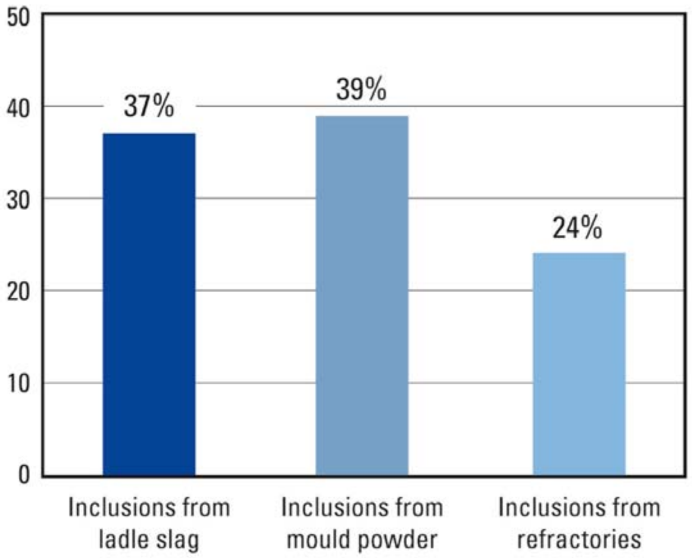


Figure 1: Origin of detrimental inclusions

Fig. 1 shows a bar diagram of different types of inclusions in aluminium killed line pipe steels. Roughly spoken, the cast steel contains one third of each type. Such, the deoxidation practice should allow good separation conditions, shrouding systems have to be controlled perfectly to avoid reoxidation and high resistant refractory materials be used to reduce wear. The steel flow in the mould should avoid casting powder to be emulsified **[2]**.

1. WHAT IS CLEAN STEEL?

The concentration of undesirable components is in the order of ppm. The total of such impurities is limited to 100 ppm. These low concentrations of total oxygen, sulfur, phosphorus and nitrogen are the result of metallurgical extraction reactions in BOF, ladle treatment and vacuum process. They have to be maintained during continuous casting.

Nevertheless steel products contain impurities which locally do harm to sensitive applications. When talking about cleanness of steel, oxide inclusions are the main point of discussion. The majority of oxide particles formed in the process line are able to separate from the liquid steel in ladle, tundish and mould. They are dissolved in the slag.

The oxide particles remaining in the steel are very small and have diameters of a few microns. This micro-cleanness is defined by the total oxygen content in the liquid steel. It must be supposed that these micro-inclusions are not harmful even for steel products of high performance. Even so, the micro-cleanness is of great importance because it is the basis for macro-inclusions which can be formed by agglomeration and coagulation in turbulent flow areas.

The causes of defects in the steel products are usually macro-inclusions which must be avoided in the steelmaking process. A low level of inclusions is one of the criteria of Clean Steel but is not the only one. “Clean Steel” is focussed on the steel product and it’s special application **[3]**. In these terms, the necessary cleanness may be quite different for exposed parts of auto bodies, bearing steels, high tensile applications of offshore equipment and linepipe business or cold drawn wire. It should be recognised that these requirements become more severe as the applied product thickness is reduced.

In this context location and deformability of inclusions play an important role. Inclusion engineering in the secondary metallurgy is a very popular measure to control the deformability of inclusions. The location of inclusions in the cast strand can be influenced by machine design, casting speed and flow control in the mould, for instance.

Macro-inclusions in the cast strand are responsible for defects in the final product. In contrast to this, mico-inclusions below 40 microns usually are not harmful. They are integrated into the cast structure and not the reason of cracks or sinks for hydrogen. Therefore macro-cleanness is of great importance, mico-cleanness is more or less negligible. In the case, that mico-inclusions would do harm to the product, all steelworks would have to be shut down.

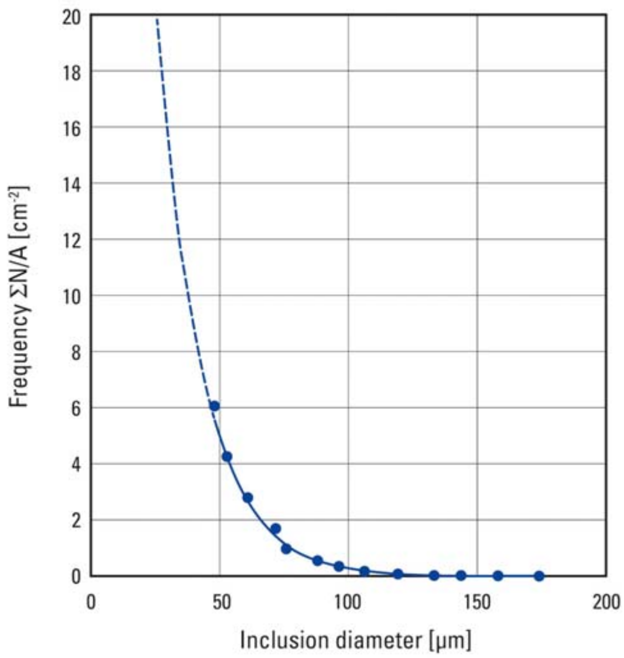


Figure 2: Cumulative frequency of inclusion diameter

Macro-inclusions are rare in the cast product. **Fig. 2** shows the cumulative frequency distribution as a function of inclusion diameter. The number increases steeply with decreasing size. “Clean Steel is Harder to Measure Than Produce” **[4]**.

2. QUANTITATIVE MEASUREMENT OF OXIDE CLEANNESS

Macro-inclusions of more than 50 µm are difficult to be detected. Therefore it is necessary to develop inspection systems using large samples. This is the only possibility to find the “needle in a haystack”.

Fig. 3 shows the preparation of heavy samples. Using the MIDAS system **[5]** (**M**annesmann **I**nclusion **D**etection by **A**nalysing **S**urfboards), large samples of 130 mm length are taken in casting direction and marked with a saw cut at

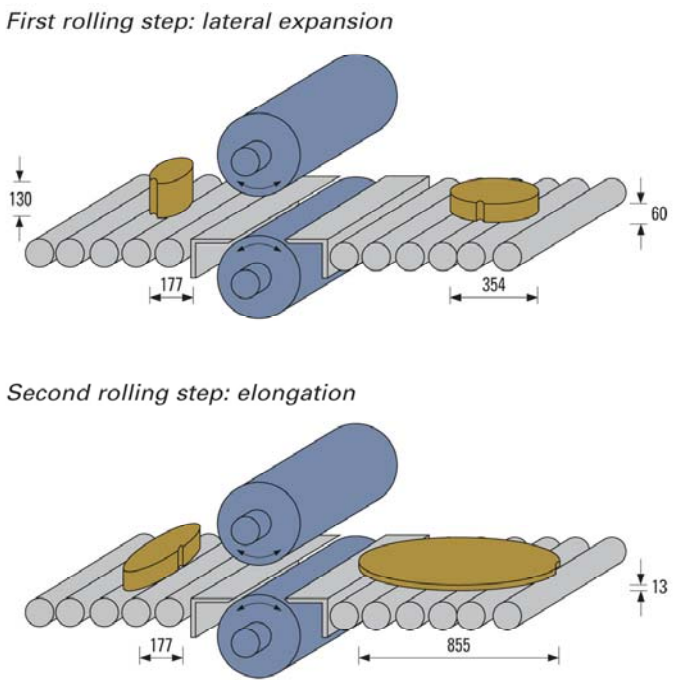


Figure 3: Preparation of heavy samples for US testing (MIDAS)

the outer radius. In a small rolling mill they are spread 2-fold and expanded 5-fold in the direction of machine radius. With this rolling method the oxide particles are condensed and the inclusion band conserved at the upper side of the surfboard. This part is ultrasonically tested and the detected inclusions counted. This quantitave method is used for cleanness investigations and quality control of extremely sensitive steel grades. **Fig. 4** shows the result of US-testing of the upper part of a surfboard with the sections A-B-C-D.

When non-metallic inclusions are responsible for, either directly or indirectly, lower fabrication capability or in-service properties or requirements, then the steel is not clean but when there is no such effect, then the steel can be considered to be clean, irrespective of the number, type, size or distribution of non-metallic inclusions **[6]**.

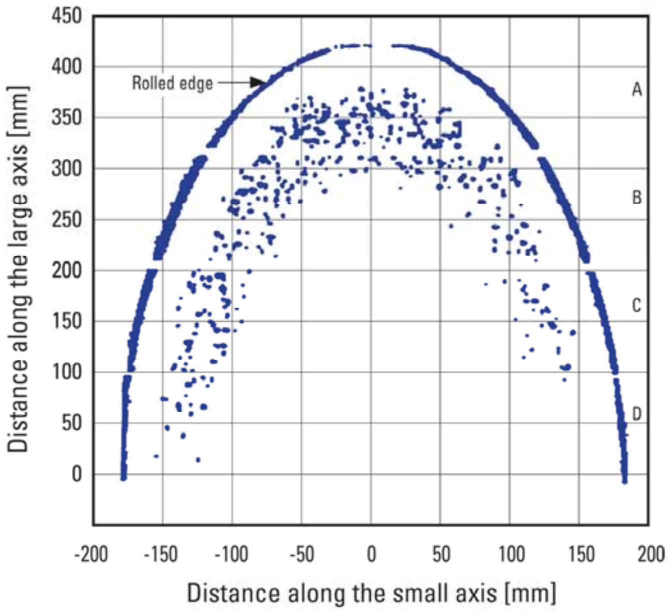


Figure 4: Distribution of inclusions in the surfboard (MIDAS)

But does the customer know what he needs to tell the steel producer what he has to guarantee? Anyway the quality control systems are not up-to-date for an overall inspection. Spotwise inspection is only partly representative. In conclusion, it has to be stated that oxide cleanness does not allow a general definition, but that it has to be related to the special application of the steel.

3. SIZE OF DETRIMENTAL INCLUSIONS

Customers present products with defects for rejection. Inclusions are always macroscopic. Taking an example, **Fig. 5** shows such a defect caused by a macro-inclusion in a sensible motor component.

This inclusion in the final product has a length of several 100 microns. EDX investigations show a heterogeneous structure with Al, Ca and Mg. This inclusion contained spinal from refractory reaction and calcium-aluminate from ladle treatment.

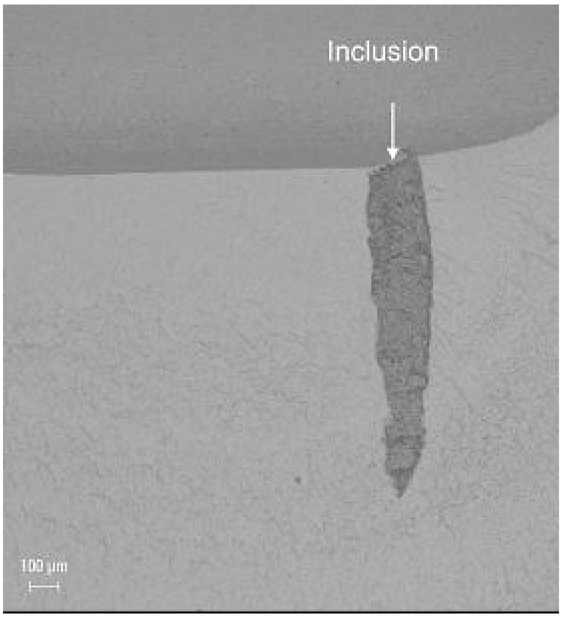


Figure 5: Macro-inclusion of spinal and calcium-aluminate in a high strength motor component

An interesting example of inclusion behaviour is shown in **Fig. 6**. In a linepipe steel X 65 large inclusions of more than 50 microns (a) were found in the inclusion band and inclusions of less than 10 microns (b) were distributed over a large thickness area in the slab which could not be detected by ultra-sonic testing of a surfboard **[7].**

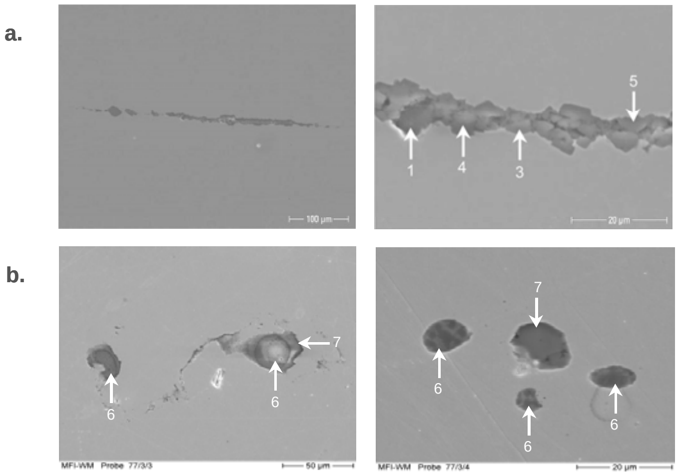


Figure 6: Large inclusions (a) of Ca- aluminate and small inclusions (b) of Ca-sulfide

The coarse inclusions come from deoxidation and ladle treatment in the tank degasser, the small inclusions are originated by the calcium wire feeding after vacuum treatment. The small inclusions of calcium-aluminate and calcium-sulfide were unable to float up to the solidification front of the inner radius of the caster. They were not harmful for the product.

4. DEOXIDATION AND MEASURES TO REDUCE REOXIDATION

The converter process has only marginal influence on oxide cleanness of the final product. The addition of aluminium reduces the widely spread oxygen content at the end of blow almost entirely. The alumina formed agglomerates in the turbulent flow of the tapping stream and the bottom gas of the ladle into coarse particles, which dissolve in the slag. Tapping temperature, contents of oxygen in the steel and iron content in the slag should be stable and reproducible.

The steel properly operated in the ladle has a very low content of inclusions, which should be withhold during the following processes. For this, shrouds or casting boxes are used. **Fig. 7** shows a long shroud which is connected to the ladle nozzle and sealed with argon gas. This device asks for a good free opening rate of the ladles and enough space for the manipulator. The short distance to the bottom of the tundish allows tundish slag to be added shortly after start of casting.

Fig. 8, as an example, shows total oxygen and nitrogen contents in the tundish equipped with a casting box as a function of casting time. At the start of casting, the shrouding system is not yet closed and therefore, high levels of oxygen and nitrogen pick-up occur. Complete shrouding in the argon pressure box is

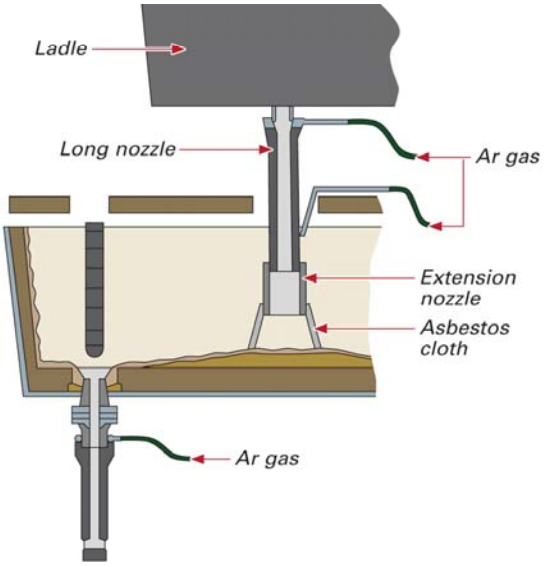


Figure 7: Shrouding system between ladle and tundish with a long nozzle

achieved only when the ladle is lowered into casting position, the steel in the tundish has risen up to the shroud box weirs and powder has been added.

Lowering the total oxygen and nitrogen contents to their lowest achievable levels in a time of 20 to 30 min depends on the weight of steel in the tundish and casting rate **[8]**.

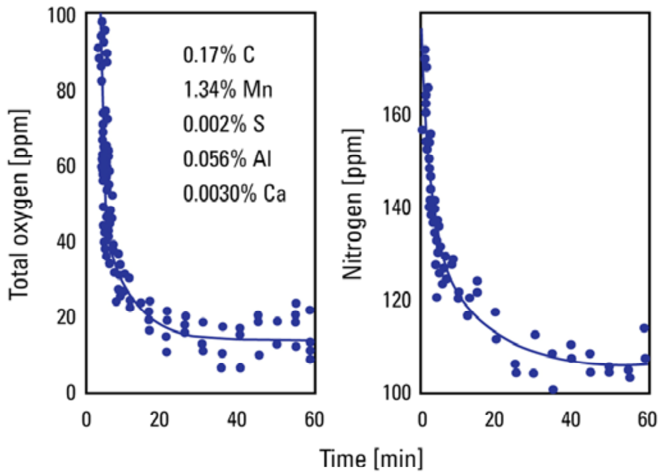


Figure 8: Pick up of oxygen and nitrogen after opening of the ladle

Reoxidation can be reduced by closing the shrouding system as soon as possible after the start of casting. The use of a slag carry-over detection system (AMEPA) makes it possible to keep the ladle shrouded until it has been nearly completely drained with the result that reoxidation is kept at a minimum.

5. WATER MODEL EXPERIMENTS TO IMPROVE FLOATATION

A water model of scale 1:1 was used to generally study the flow pattern and the possibilities to improve the separation of inclusions from the liquid steel in the tundish. The idea was to have the flow steams close to the meniscus and elongate retention time.

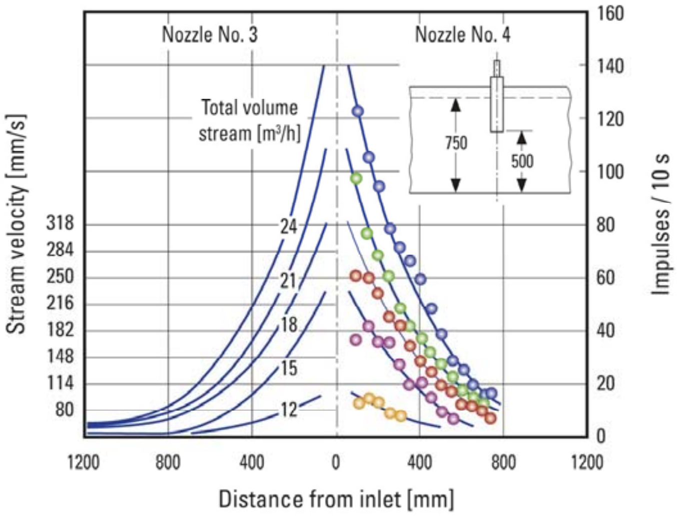


Figure 9: Velocity and distribution of flow in a water model of scale 1 : 1

In **Fig. 9** the stream velocity increases with the flow rate. The flow distribution is symmetrical to both sides of the tundish and the velocity decreases steeply from the outlet into the direction of the side walls. If dams or weirs should be installed, they must be positioned close to the ladle stream **[9]**.

Fig. 10 shows an example. In the upper diagram without furniture (a) the steel moves along the bottom of the tundish and flows back along the meniscus. At the inner strands short circuits with little retention time could result in dirty strands whereas the outer strands should be cleaner. In the lower diagram (b) dams lead the stream to the meniscus, the flow directon is diverted. The retention time increases all before at the inner strands.

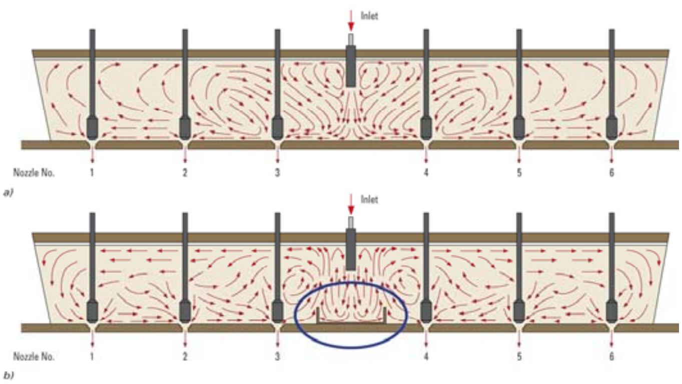


Figure 10: Water model tundish without (a) and with (b) furniture (turbulence breaker)

6. PLANT TRIALS

Using the MIDAS system reproducible results of the inclusion content could be measured. It was of great interest to proof whether or not the oxide cleanness of the strands could be influenced by the steel flow. For this, the tundish was equipped with different furniture and the effect on the cleanness investigated on parellel strands under constant conditions. **[10, 11].** At first, a straight tundish without any special flow control was used as a basis.

Fig. 11 shows the MIDAS results for the inner strands No. 3 and No. 4 and the outer strands No. 1 , No.2, No. 5 and No 6. The submerged nozzles used had diameters of 40 mm or 22 mm.

The cleanness results are, as expected, better on the outer strands than on the inner strands. Comparing the number of inclusions on the outer strands the smaller SEN 22 shows much better results than the larger SEN 40.

Fig. 12 shows plant results with a baffle or a slit weir in the 6-strand tundish **[12]** The stream of the liquid steel should be directed to the side walls along the steel level. This increase of retention

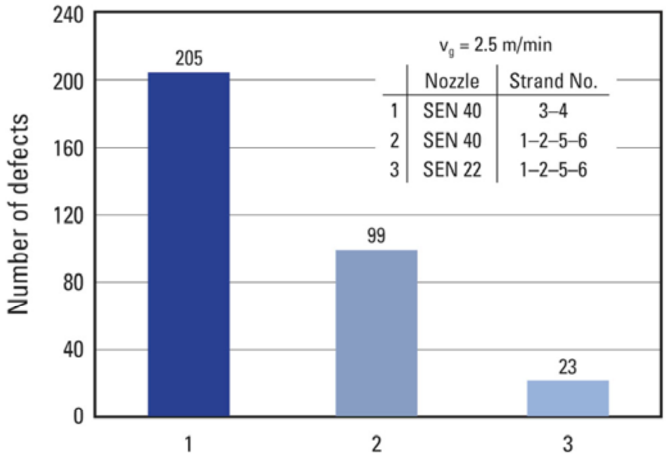
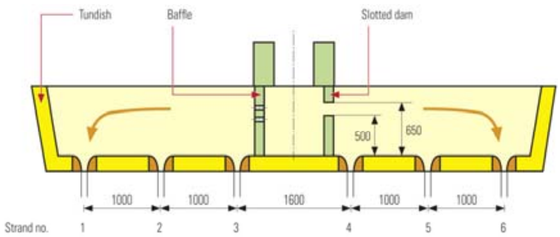


Figure 11: Defects in inner and outer strands using different types of submerged nozzles

time improves the separation of inclusions. At an overall lower level the inner strands have better results than the outer strands.



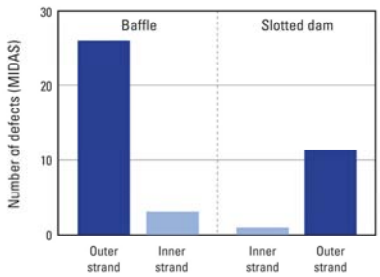


Figure 12: Inclusions in outer and inner strands using baffle or slit weir

The evaluation of many cast heats gives the proof that the number of inclusions decreases 5-fold when using the narrow submerged nozzle, **Fig. 13**.

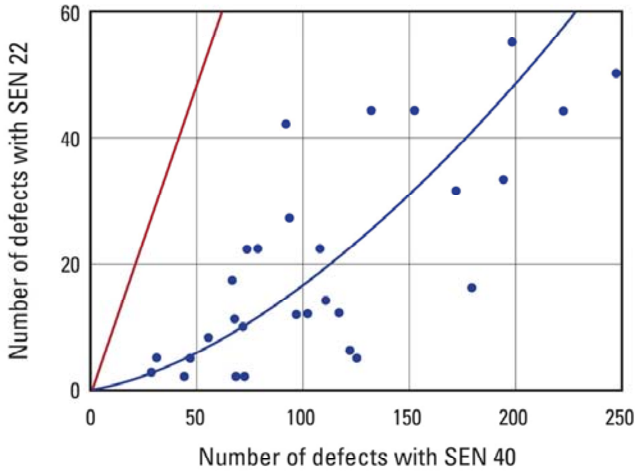
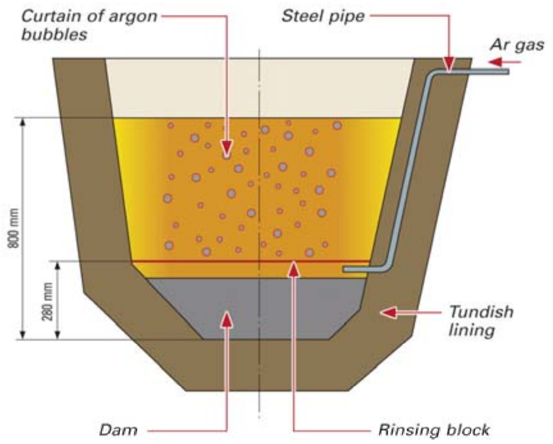


Figure 13: Number of defects using submerged nozzles with 22 and 40 mm

Argon rinsing is a well known measure to improve the floatation of inclusions in the ladle. The options of this technique should be investigated in the casting machine. **Fig. 14** shows the layout with a rinsing block on the floor of the tundish. The pipe for argon is protected by the refractory side wall and connected with the porous rinsing block.



. Figure 14: Tundish with argon rinsing block

An argon curtain develops in front of strand No.4. The results in **Fig. 15** show the good reproducibility of sequencial samples. The improvement of argon rinsing is evident and it is even more effective with decreasing casting speed **[13]**.

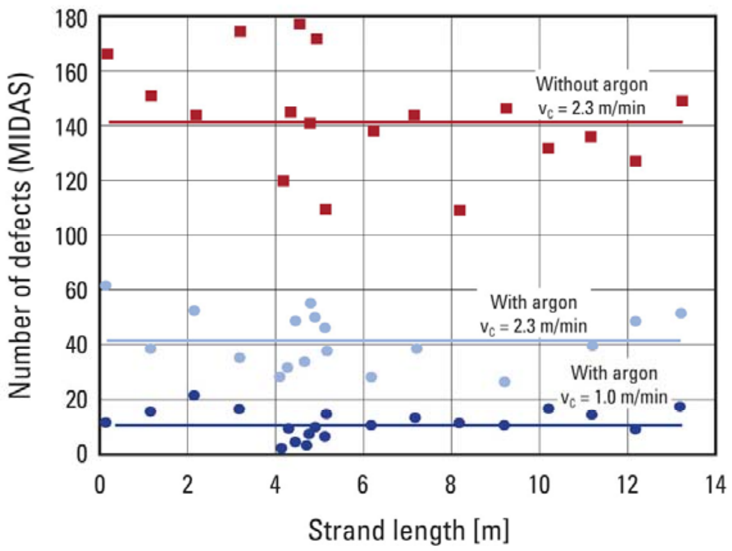


Figure 15: Influence of argon rinsing and casting speed on the number of inclusions

7. FLOW PATTERN IN THE MOULD

The distribution of inclusions in the strand is closely linked to the flow of steel coming from the submerged nozzle. Clogging at the stopper seat and at the outlet channels of the SEN promote uneven flow distribution. A special development has been made to avoid back stream at the bore for argon addition to the nozzle seat.

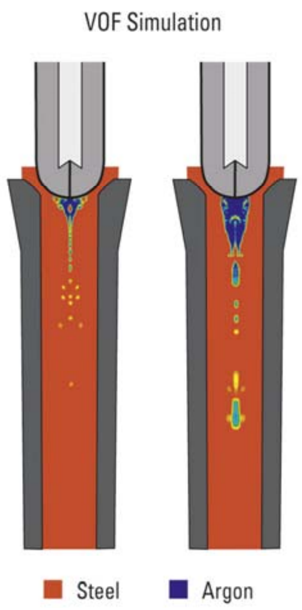


Figure 16: Modified stoppers to avoid back flow on the tip

In **Fig. 16** the conventional nozzle at the left side and the improved one at the right side are shown. The recently developed nozzle has a reducing piece in the height of the meniscus to avoid strong heating of the wall and expansion of the gas. Thus, the flow of argon gas remains even and keeps the tip of the nozzle free of depositions

Fig. 17 shows the asymmetric flow of steel in the mould. This results in an uneven distribution of inclusions in the strand.

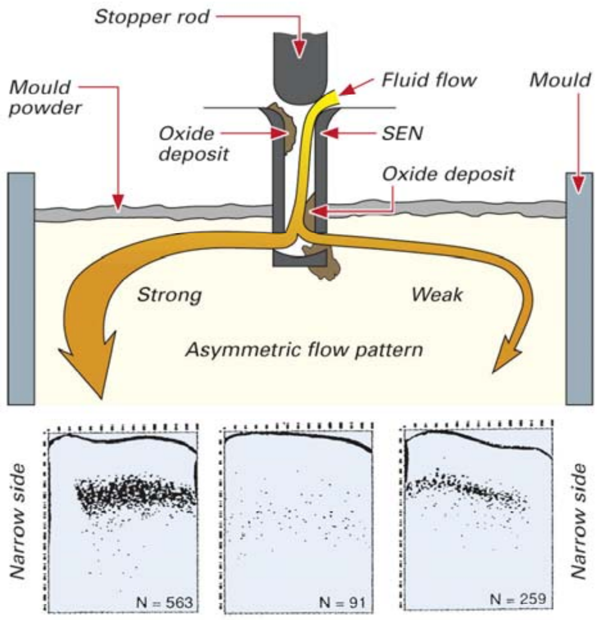


Figure 17: Influence of depositions on flow of steel and distribution of inclusions

In the lower diagram many more inclusions are detected at the left side with high than on the right side with low stream volume. Much steel transports many more inclusions to the narrow faces of the slab than small volumes.

8. POSITION OF THE INCLUSION BAND

For many applications the inclusion band should not be too close to the strand surface. When rolling thin gauges for cans or exposed parts of auto bodies, the oxide particles might come to the surface and make difficulties to painting.

The position of the inclusion band was measured for different casting machines. Surfboards were taken from circular arc slab casters with 5 m and 12 m radii and from a vertical-bending caster with a vertical section of 2,8 m and 9 m radius. The distance from the slab surface was measured for the upper and lower limitations of the inclusion band. The values must be divided by 4.8 for the slab, which corresponds to the elongation of the rolled slab samples.

Fig 18 shows the evaluation for all steel grades from strip to large diameter line pipe, for all strand widths from 950 to 2070 mm and all casting speeds **[13]**. These influences are responsible for part of the scatter. The inclusion band moves from the outside to the inside with increasing machine radius.

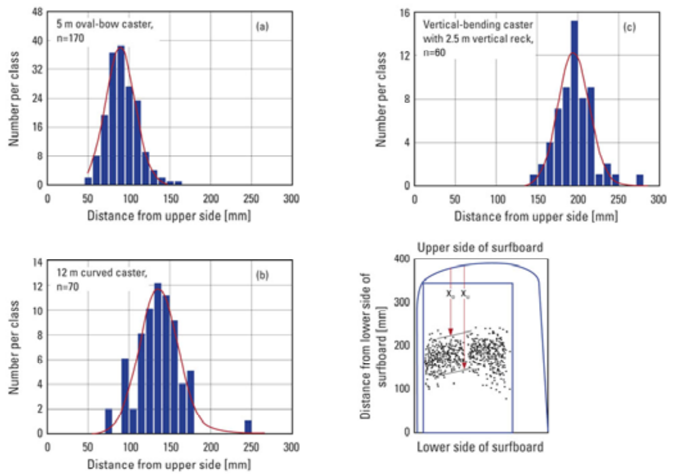


Figure 18: Influence of the caster design on the position of the inclusion band in the surfboards

9. CONCLUSIONS

Oxide cleanness is one of the most important items of quality steel. Macro-inclusions of more than 50 microns form defects in the product. They are originated by deoxidation, reoxidation, reactions with refractory material and emulsified casting powder.

Macro-inclusions are rare and difficult to detect. Special rolling strategies of large samples and ultra-sonic inspection help to find “the needle in the haystack”.

Reoxidation is minimized using reliable shrouding systems. Remaining inclusions in the steel must be separated by optimal flow of the steel in the tundish. Water model experiments are prone to develop suitable ideas, which can be proved in plant trials. Argon rinsing helps to float out inclusions from the steel in the tundish.

A special shroud design avoids clogging at the stopper seat and improves the flow pattern in the mould.

The position of the inclusion band can be influenced by the machine radius and the length of the vertical part.

10. REFERENCES

1. W. Löscher, W. Fix, Proceedings Internat. Symp. Phys. Chem. Iron Steelmaking, Toronto, Canada, 1982, IV, pp. 20–25K.
2. Wünnenberg, Proceedings of 2008 International Symposium on Clean Steel, Anshan Iron and Steel Group Corporation, The Chinese Society for Metals, September 17 – 19, 2008, Anshan China, pp. 10–17
3. “State of the Art and Process Technology in Clean Steelmaking”: IISI Study on Clean Steel, IISI Committee on Technology (TECHCO), Editorial Board: Prof. Dr.-Ing. Klaus Wuennenberg, Dr. Stuart Millmann, Michèle Nadif, Christian Marique, Morihiro Sumida, Dr.-Ing. Hans-Joern Weddige. There, further extensive International References on Oxide Cleanness of Steel.
4. Iron & steelmaker 16 June 1989, I&SM-5
5. H. Jacobi, J. Bäthmann, J. Gronsfeld, Stahl und Eisen 108,Vol. 20, 1988, pp. 646–658
6. S. Millman, „Clean steel – Basic features and operating practices”, p. 39, in: K. Wünnenberg, S. Millman, M. Nadif, C. Marique, M. Sumida,H.-J. Weddige, IISI Study on Clean Steel, International Iron and Steel Institute, 2004, Bruxelles
7. J. Cappel, R. Flender, R. Höffken, G. Kemper, K. Wünnenberg, “ Centre Segregation, soft reduction and oxide cleanness for large diameter line pipe with highgest demands on HIC”, Proceedings 1st Chinese-German Seminar on Fundamentals of Iron and Steelmaking, Beijing, China, October 18-19, 2004, also: steel research 76 (2005) Vol. 8, pp. 588-594
8. K. Wünnenberg, H. Jacobi, H.-J. Ehrenberg, J. Glaser, H.-E. Wiemer, Operational measures to improve oxide purity in round strads. In: Proceedings Conference on Continuous Casting of Steel in Developing Countries, 14-18 September 1993, Beijing, China: The Chinese Society for Metals, pp. 253-260
9. K. Wünnenberg, H. Förster, Stahl und Eisen 104 (1984) V0l. 13/13, pp. 581-585
10. H. Jacobi, H-J. Ehrenberg, K. Wünnenberg, Stahl und Eisen 118 (1998) Vol. 11, pp. 87-95 H. Jacobi, K. Wünnenberg, Ironmaking and Steelmaking 2003 Vol. 30 No. 2, pp. 130-141
11. H. Jacobi, K. Wünnenberg, Ironmaking and Steelmaking 2003 Vol. 30 No. 2, pp. 130-141
12. H. Jacobi, H. Nilsson, H.-J. Ehrenberg, K. Wünnenberg,, Process Technological and Metallurgical Measures to Improve the Oxide Cleanness of CC Strands and Their Evaluation by the MIDAS Method.In METEC Congress 1994, 2nd European Continuous Casting Conference,Düsseldorf, 20-22 June 1994, Proceedings, Vol. 1, pp 46-54.
13. B. Hoh, H. Jacobi, H.-E. Wiemer, K. Wünnenberg, Stahl und Eisen 109, No. 2, 1989, pp 69-76