Development of a gas-tight slide gate to reduce re-oxidation during steel casting

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Summary

Due to increasing demands on steel products every steel manufacturer works on several measures to reduce the risk of re-oxidation during steel making. One important point to give answer on the key question of an ingot caster is the air pick-up of the slide gate and the gap between slide gate and trumpet of the runner channel of an ingot casting system. A lot of improvements have been tested and installed in the past, e. g. injection of argon between refractory plates and the outlet of the slide gate valve into the ingot. Sometimes discontinuous operating conditions are one reason that previous approaches of slide gates do not lead to the desired constant quality improvement of ingots for forgings every time. Recent developments and practical tests with a gas-tight slide gate valve in combination with shrouding between the gate and the casting system have been carried out. The paper gives an overview of the development work to create a gas-tight version of a 3-plate system and compare the new system with existing slide gates solutions. Furthermore handling experience at steel plant of BGH Edelstahl Siegen GmbH will be summed up as well as the results on steel product quality and assessment of situation of the operating costs of the developed system.

Key Words

Re-oxidation, gas-tight slide gate, ingot casting, quality improvement

Introduction

Capability of special steel products is strong related to cleanliness of steel. Minimization of the content of non-metallic inclusions is the main target of premium supplier of special steels products by improving the steel melting technologies. Depending on the origin of non-metallic inclusions, different measures are necessary to ensure a sufficient cleanliness level with a highest reliability from heat to heat.

BGH Edelstahl Siegen GmbH is located in Siegen (Germany) and produces a wide range of special alloyed and stainless steel products. The material portfolio includes structural steels, stainless steels, heat resistant alloys as well as nickel based alloys. Figure 1 show the production process which cover the whole processing line from scrap to machined forgings.

The steel is produced by melting scrap down in a 60 ton electric arc furnace followed by the secondary metallurgy treatment with AOD process, ladle furnace treatment and vacuum degassing. After the refining steps the steel will be casted by ingot casting process, the smallest ingot is a 2 ton ingot, the biggest a 50 to ingot. Most of the production will be 100 per cent checked by ultrasonic inspection with modern, automatic ultrasonic equipment, in some cases with strong acceptance criteria in the subsurface area up to 0.8 mm FBH.

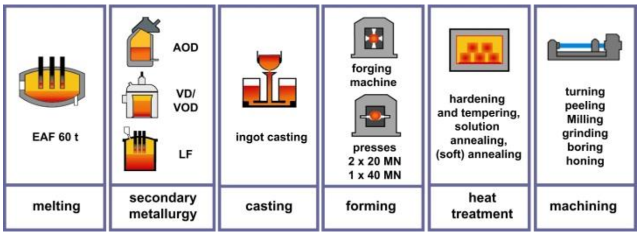

Figure 1: Production process of BGH Edelstahl Siegen GmbH

Figure 2 shows test results of steel bars forged from 50 tons ingots (same steel grade, six different heats). As an example for connecting metallurgical parameter with ultrasonic test result the aluminum content in the final analysis has been given /1/.

heat	ingot size	ingot location of bar	amount of subsurface UT indications [FBH]				diameter in mm	content of aluminium after VD in %
			0,8 - < 1,0 mm	1,0 - < 1,5 mm	1,5 - < 2,0 mm	≥ 2,0 mm		
A	KP 50.0	bottom	0	0	0	0	723,6	0,023
		top	0	0	0	0	773,5	
B	KP 50.0	bottom	0	0	0	0	656,3	0,030
		top	0	0	0	0	656,3	
C	KP 50.0	bottom	23	1	0	0	742,3	0,042
		top	12	2	0	0	741,7	
D	KP 50.0	bottom	30	12	0	0	527,7	0,034
		mid	3	3	0	0	528,1	
		mid	2	0	0	0	528,1	
		top	0	0	0	0	528,3	
E	KP 50.0	bottom	13	1	0	0	786,0	0,031
		top	4	0	0	0	762,1	
F	KP 50.0	bottom	3	4	0	0	530,7	0,034
		mid	11	4	0	0	530,7	
		top	6	3	0	0	656,9	

Figure 2: Connection of process parameter and test result is the basis for continuous improvement /1/

To fulfill such criteria BGH Edelstahl Siegen GmbH improves metallurgical processes by optimization all process steps in the steel plant. Process optimization is mainly focused on the reduction of non-metallic inclusions, which can arise from several sources such as deoxidation, re-oxidation and chemical reactions /2/. The following approaches could help minimize inclusions:

- Preventing the formation of oxide inclusions during melting
- Elimination agglomeration microscopic inclusions
- Prevention of entry of contaminants by refractories
- Avoidance of entering casting flux into the melt
- Preventing carry-over slag during casting
- Protecting steel melt against re-oxidation.

In the field of exogenous inclusions of the shield of the pouring stream is of particular importance because it is in a close contact with the ambient air. Especially in the area between sliding gate and trumpet of the casting system a very turbulent jet is formed. Accordingly large is the area available for diffusion of oxygen. Argon shielding of the pouring stream reduces the oxygen intake significantly.

Sliding gate valve

From the beginning – almost 50 years ago – a sliding gate valve consists mainly of 2 refractory plates which ensure the shut-off and the regulation of the stream. One, the upper plate, is fixed and the hole of the plate is in line with the channel inside the ladle respectively the inner nozzle. The lower plate (sliding plate) together with the outlet (collector nozzle) is pressed by means of springs against the upper plate. An external drive system – usually a hydraulic cylinder - pushes the lower plate into the desired position: open, closed or in a regulating position, figure 3.

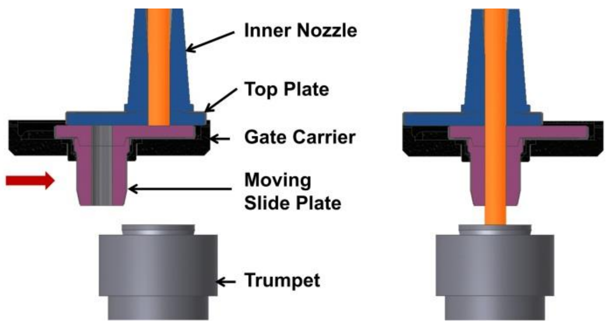

Figure 3: Schematic drawing of a sliding gate valve with two refractory plates

This system is generally sufficient for continuous casting. For the teeming of ingots, the standard sliding gate system with two plates has some disadvantages:

- When the ladle is put above the trumpet of the runner channel, the outlet is displaced from the open position. The operator has to bear this in mind when he positions the ladle.

- If throttling of the flow of steel becomes necessary the outlet is again not fully in line with the central teeming axis. Therefore the steel flow can be in contact with the trumpet.

These disadvantages were eliminated with the 3-plate valve, figure 4. In this sliding gate valve the upper and the lower plates are fixed and the closing and regulating is done with a third plate between them. Due to this arrangement, the positioning of the ladle at the teeming station becomes easier and during throttling there is no movement of the outlet.

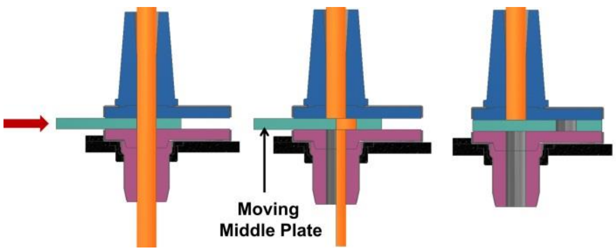

Figure 4: Schematic drawing of a sliding gate valve with three refractory plates

Pouring stream protection

In studies on the origin of nonmetallic inclusions was found that around 60 per cent of the inclusions were formed with a size greater than 20 microns by re-oxidation. During casting, there are three main sources of oxygen necessary for re-oxidation:

- Burning out of the nozzle of the ladle
- Contact of steel bath surface with ambient air
- Contact of pouring stream with ambient air /3/.

The steel bath surface in the mold is exposed to the ambient air during bottom-poured casting only very briefly, because reaching the casting power the steel bath is covered with a layer of slag. The pouring stream has Reynolds numbers in the range of 10^5, so it is highly turbulent. It is therefore to be assumed that the main part of the oxygen transfer takes place in the pouring stream. Re-oxidation is therefore already reduced considerably if the pouring stream is alone shielded from the ambient air.

But there is little evidence from which minimum argon flow re-oxidation is reliably prevented. Further, there is potential for improvement in terms of maximum efficiency of the flooding of the mold and funnel with which the desired effect can be achieved easily.

Figure 5 shows some tested concepts to protect the pouring stream against re-oxidation. In two concepts argon is used to protect the pouring stream. Another concept is to close the gap between slide gate and trumpet of runner system by a refractory solution /4/.

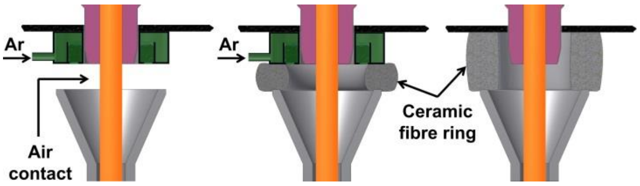

Figure 5: Concepts to protect the pouring stream during ingot casting (schematic) /4/

Actual a combination of ceramic of refractory fibre ring and argon shrouding is actual state of the art in the most steel making shops, figure 6.

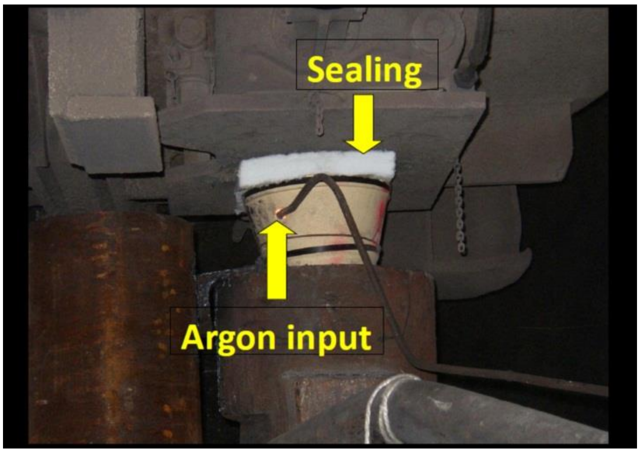

Figure 6: Pouring stream protection during ingot casting /5/

Gas tight sliding gate valve

While the problems as described above where solved, there was still the risk of air pick up in the sliding gate valve and consequently the risk of re-oxidation of steel. It is obvious that the handling with this risk is essential for high quality steel-producers.

In consequence a gas-tight three plate sliding gate valve was developed. By means of seals this mechanism is capsuled.

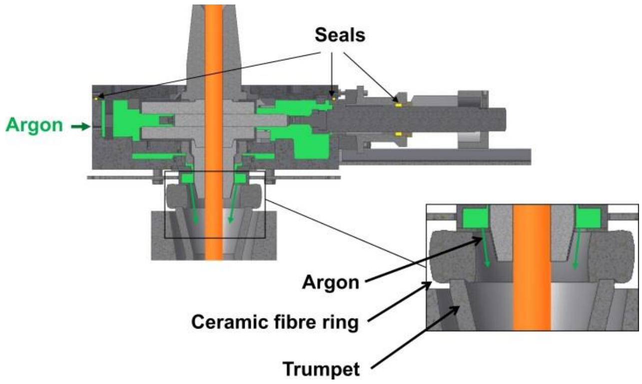

Figure 7: Schematic drawing of the new developed gas-tight sliding gate

The sealing avoids or minimizes the aspiration of air into the mechanism. This mechanism allows injecting argon (or another gas) into the mechanism in order to create an inert atmosphere inside the housing. The injection of gas into a mechanism, directly or through grooves in the plates, is state of the art. Now, with the mechanism shown in figure 7, this gas can be used as well to protect the stream coming out of the mechanism. The new FT3 160GT is shown in figure 8.

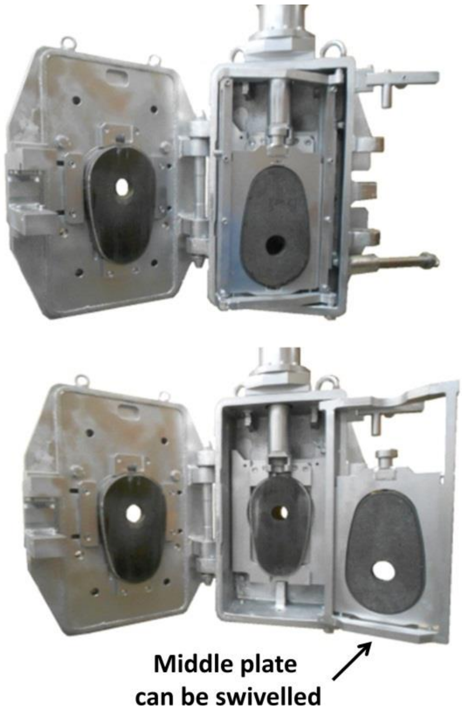

Figure 8: New developed FT3 160GT slide gate

Operational experience

BGH Edelstahl Siegen GmbH starts plant tests with the developed gas-tight slide gate in October 2013. Based on positive handling tests in the steel plant, in addition three gas-tight slide gates have been installed since August 2014. It is clear, that the refractory costs are higher in comparison to the costs using a slide gate with two plates, figure 9.

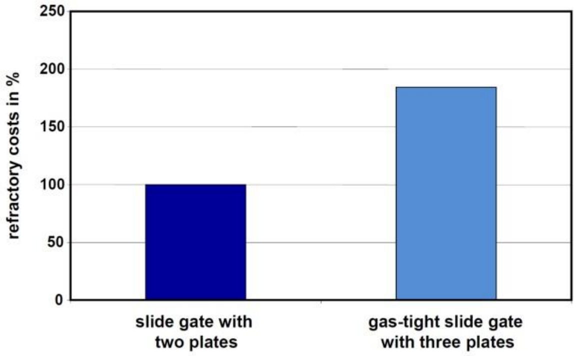

Figure 9: Refractory costs of a gas-tight slide gate with three plates in comparison to a slide gate with two plates

An advantage of the gas-tight slide gate is a simple practical handling of the pouring stream protection. Figure 10 shows a ladle during casting ingots. Actual the refractory material of the inner nozzle and the plates will be optimized to reduce the operation costs. BGH Edelstahl Siegen GmbH has planned the complete exchange of the slide gate system to the gas-tight slide gate with three plates.

Figure 10: Casting operation at BGH Edelstahl Siegen GmbH

Impact on steel quality

For forgings and forged steel bars ultrasonic testing is an important tool for quality assurance. BGH Edelstahl Siegen GmbH has defined test criteria, so that a comparative evaluation of the tested products is possible. Figure 11 shows that the internal scrap due to subsurface non-metallic inclusions by approx. 50 per cent was reduced. The assessment contains results of the complete steel production in 2014.

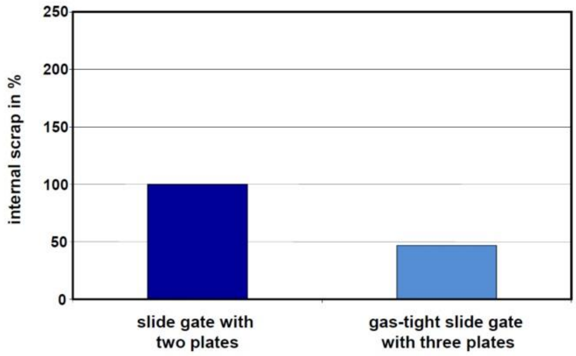

Figure 11: Influence of the slide gate system on the internal scrap (subsurface non-metallic inclusion, detected by ultrasonic testing)

Conclusion

The lessons learned from the gas-tight slide gate with three refractory plates show a visible improvement in the prevention of re-oxidation during casting. The failures due to subsurface macro inclusions could be reduced; the additional refractory costs and the effort for maintenance of this slide gate type can be compensated by the benefit given by process improvement. In addition, the gas-tight slide gate supports the development of special alloyed and stainless steel products with the highest requirements on the mechanical-technological properties and degree of purity, which is to ensure by ultrasonic examination with sensitive threshold for registration and classification.

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