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TREND AND APPLICATION OF MODERN METHODS IN INGOT CASTING

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SUMMARY
Casting is a final metallurgical operation in steel metallurgy. After the melting in primary furnace (BOF,EAF), steel is tapped in steel ladle, treated on secondary furnace (ladle furnace) and finally sent for ingot casting. After cooling, casting products (ingots) are treated in forge plant or rolling mill. The final result of ingot casting is to make simple geometrical shapes aimed for further plastic deformation. The modern approach for ingot casting implicates an application of secondary metallurgy, steel degassing and casting. For this concept application it is necessary to have appropriate devices and equipment and to lead the process as per exact technological instructions. In this elaborate the modern concept of ingot casting with main characteristic is given, but focus will be on the equipment and devices necessary for casting technology.
Keywords: ingots, casting ladle, mould, casting pit

1. INTRODUCTION
Casting is a final metallurgical operation in steel metallurgy. After the melting in primary furnace (BOF, EAF), steel is tapped in steel ladle, treated on secondary furnace (ladle furnace) and finally sent for ingot casting. After cooling, casting products (ingots) are treated in forge plant or rolling mill. Steel after casting need to have minimum deegre of segregation, good surface quality and required chemistry [3].
During steel casting a numerous reaction happening (metal with refractory, suraonding atmosphere, with slag), temperature drop (metal cooling) and solidification (liqued to solid) etc. All this reaction having influence on ingot quality. Mixing of casting powder because of high turbulence of metal in mould and refractory material causing reducing of mechanical properties of steel (e.g. strenght). However, that all is difficult to be noticed before ingot use starts (reduction of machining capability, poor strength on fatigue, breaks at drawing and so forth). Because of all this mentioned it is neccessery to know all details regarding casting, also it is neccessery to have proper equipment and trained personal for proces managament. In this presentation basic problems during ingot casting and modern approach and application of new methods and technology are given.

2. STEEL VACUUMING AND DEGASSING
The first steel casting phase is vacuuming and degassing. Vacuuming is one of the oldest and cheapest secondary metallurgy treatments. It is rather simple. After steel is poured from converter to ladle, it is placed in a hermetically closed vacuum chamber connected to vacuum pumps. Vacuum makes melted gasses leave the heat. This treatment is suitable for production of low carbon steel, high hard steel, micro-alloyed steel, stainless steel etc. The heat in a pot is additionally mixed with Argon that goes through porous plug. After certain under pressure is obtained, the steel boils and degassing starts [1].
Inter - surface slag/heat in pot takes part in a vacuum treatment during degassing as well. Vacuum (if no stirring) acts only in an upper active heat layer. Active layer depth is around 1,2m when non-killed steel is treated and 0,6m when killed steel is treated [2]. Deeper layers are vacuumed only by Argon

stirring. The vacuuming plant consists of the pot and vacuum chamber. In practice it is possible to move either ladle or vacuum cover. Movable vacuum cover is better because of easier maintenance and refractory lining, figure 1.

High fire resistant 80% Al_2O_3 is used as a protection for heat spilling over cover. Argon stirring with porous plug is shown in Figure 1. It is common that Argon is introduced through plug on the floor. Non- killed heat is poured into basic lined pot in which all metallurgical operations are accomplished. After the pot is lowered into vacuum chamber the flexible Argon line is connected and is opened only after the pot is closed. Heat degassing is increased by pressure dropping. Antioxidants, slag-forming substances or Ferro-alloys are added later. When the needed pressure is obtained, the degassing is completed. Pot vacuuming is more often used for deep drawn steel. Hydrogen is decreased from 0,0007 to 0,0001 mass% in 10 minutes. Gases H, N and O in molten steel are relatively easy melted to balanced condition.

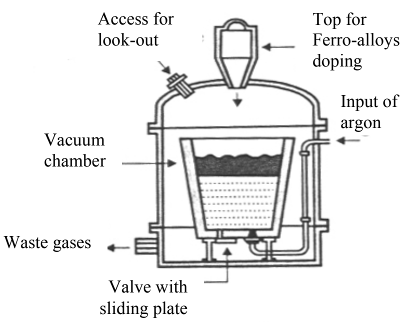

Figure 1. Vacuum tank

Contact with surrounding atmosphere should be avoided so not to have increased gas melting during blowing and pouring from converter.

Significant decrease of N and H content is possible with treatment that includes intense inert gas stirrring. H is relatively easy removed from steel, but Nitrogen removal is harder (possible only with longer keeping of steel in vacuum chamber). Heat treatment in pot for N removal should be done under the protective slag layer. If gas pressure above heat is decreased by vacuuming or Argon stirring, partial pressure drops and H content with it.Not only partial pressure influences degassing, but other elements too. Cr reduces N activity, while C makes it bigger.

That is why N is hard to remove from heat with higher Cr content (stainless steel heat). Nitrogen removal is better if S and O content is very low. It is explained by so called surface S and O activity. Not only nucleation, but mass transfer within Argon bubble influences degassing. Spontaneous homogenous nucleation of bubble or heterogeneous nucleation on inter-surface metal/refractory material takes place within heat. H removal is mostly accomplished by diffusion within existing bubble (blowing with pure inert gas) and by diffusion from heat to space above the heat. H removal speed is controlled by the mass transfer in molten steel:

$$l_n \frac{[\%H]_f}{[\%H]_i} = K_H \cdot t \qquad ... (1)$$

Where: $[\%H]_i$ - H content in heat before vacuuming, $[\%H]_f$ - H content in heat after vacuuming, K_H - H degassing speed total constant. Numerous mathematical models for H removal from heat are developed, but final H content in steel widely depends on pressure in pot during Argon stirring, figure 2.

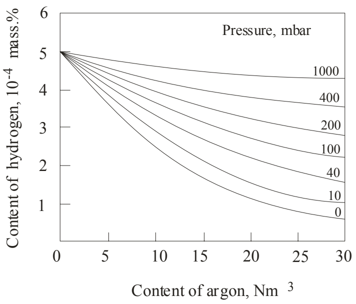

Figure 2. Influence of pressure in VD tank on hydrogen content

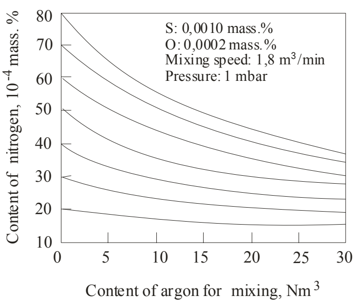

Figure 3. Nitrogen removing from molten steel

Nitrogen can be removed from molten steel during vacuum treatment considering heat is totally killed and S content is low. N removal speed in reference to different initial N content in heat is shown in figure 3. The data is referred to killed steel with 0,0002 mass% of O_2 and 0,0010 mass% of S and pot pressure of 1 mbar. Under these conditions around 50% of N is removed from heat in 15 minutes.
Therefore, for implementation of vacuum treatment it is necessary to install appropriate equipment which can realize mentioned technology, i.e. vacuum facility shall be installed.

3. INGOT CASTING
Aim of classical steel casting (ingot casting) is to get geometrical simplest shapes in permanent vertical moulds. Solidified steel is semi product and it is named ingot. Ingots are intended to go on plastic processing (rolling, forging). Incot casting of steel can be done from top and casting from bottom, figure 4.

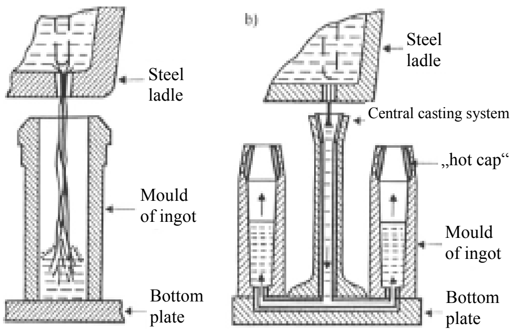

Figure 4. Ingot castin
a) from top b) from bottom

Ingot casting from top is known as direct casting from steel ladle into moulds which is placed directly down below steel ladle. Usage is for productions ingot and slabs under 300 tones. Disadvantage this mode of casting can be that surface of casted ingot can be coarse because of steel splashing and unbalanced solidification on mould sides. On ingot casting from bottom few moulds are filling with liquid steel in same time. On begining steel cast in to central casting hole which is conected with moulds across refractory pipes in bottom part. Steel level slowly go up and filling mould with steel (bottom pouring) and that provides better surfaces of ingots. Generally on bottom board is placed few moulds.

Casting from bottom have certain adventages (low speed of filling moulds, in same time casting into few moulds, passible monitoring of level of steel in moulds, longer life of ladle nozle on steel ladle). Inner sides of mould are slightly conical (1-4%) because of that it is easier to strip ingots from moulds or moulds from ingots. Moulds can be with extending on bottom or on top, and can be with bottom and without bottom. In first case ingot strip from mould which stay in place, but in second case moulds strip from ingots which stay on bottom platte. After striping temeprature of ingots are about 700 and 950 °C or higher depending of steel grade or time which ingot stay into mould. Mould cooling have to be done slowly. Where is posible, moulds shold be on braced girder with air blowing. Cooling which is to fast (for example with water) increasing stresess, step up incipients or even cracks. Mould life do not depend only from mould design then from holding time whih ingot stay in mould (longer time cuased preheatin mould sides, increasing grain size and overmuch strss in mould sides). 50 tons ingots for forge stay in moulds until 15 hours.
Life of mould considerbly is decreasing with suddenly temperature flashs during the cooling. Depending of steel grade which is casting the best results are with cooling of moulds on air. Rapidly cooling of moulds with water is adversely for moulds life. Optimal temperature of moulds before casting liquid steel is 50-100^{0}C. With higher temperatures skin layer of solid ingot stay more in time in contact with mould which cused wear-out of mould. If is mould to cold it is possible condensation of humidity (from air) on cold surfaces, which go to the bad for steel quality. Mutualy mould position (on bottom plate) should to make possible their natural keel cooling from all sides. Mould life is 50-150 castings. Consumption of mouls because of cracks is 1,5-2,5% of steel ingot mass. Ratio betwen high and diameter of mould considerably influence on quality of internally structure of ingot (3-3,5 for carbon steel, and 2,3-3,3 for alloy steel). On shorter ingots gas extracting is facilitated. Longer or higher ingots are wanted for increasing of mills capacity. Ussualy in use are quadratic, tetragonal, annular and corrugated cross-sections of ingots. During solidification top of ingot is shrinking making shricage cavity which is not advisable for further use. Top of ingot is posible to adjust with usig „hot cap“ adding exotermic casting powder, coke or using special equipment for heating of top surface of

liquid steel in mould. In that case we get shricage cavity from solidification only top zone (which is removing in further usage). For implementation ingot castin operation, it is necesary to have steel ladle, ladle car, moulds wit casting equipment , and casting pit with moulds.

4. TECHNICAL & TECHNOLOGICAL CARACTERISTICS OF INGOT CASTING FACILITY

To achieve technological proces for ingot casting, and also introduction of modern way of ingot casting in ArcelorMittal Zenica was instaled production line with following equipment: facility for vacuum degasing, VD tank with cover, car for transfer VD tank cover, Ladle transfer and casting, bridge crane, mold for ingot casting with auxiliaries, casting pit, stand for mold preparation, bench for mold preheating, air mail and main control room with devices for controls and measurements. Unlike previous ingot casting cocncepts in this case steel is casted to molds from casting ladle are placed on car, while molds and auxiliary are placed in casting pit bellow a car. This improvement provide more flexibility during production.

Main parameters of facilities are: annual production 50.000 tons, weight of ingots from 15 tons up to 40 tons, weight of hot metal in ladle 110 tons, dimension of halls 48x24x24,5m. Planned underpressure in vacuum tank is about 200 mbars. Vacum degasing tank was made from boiler steel sheet and welded construction. Internal diameter of tank is 5.950mm and height 5.790mm.

Inner side of vacuum tank is lined with refractory material. Ladle transfer car is used for transport of steel ladle and also for casting of steel from ladle to the mold. Dimension of ladle transfer car is 9,9x5,1x1,5m, and speed of car movement is 0–30m/min. Maximal stroke of car motion is 30m. Molds for ingot casting are with different capacities from 15 tons up to 40 tons. The molds with auxiliary are placed in casting pit. Moreover in halls is instaled bridge crane for ingots striping and transport of ingots to next phase of processing.

5. CONCLUSION

According to the analyses given in chapters above following conclusions regarding modern method in ingot casting are:

- Casting into ingots is complex metallurgical opeartion.It can be divided into two operations: vacuuming and degassation in first phase and ingot casting,
- With vacuuming and degassation it is possible reduce hydrogen and nitrogen content in molten steel. Reduction of hydrogen content from 0,0007 na 0,0001 mass % can be done in ten minutes time. Current figures are given in diagrams, figure 2 and 3.
- Casting into ingots have been done till today with crane holding the ladle with liqued steel. This practice had a lot of problems. In this presentation is described how to cast from ladle into ingots placed on casting car.
- To realise casting described in text above it was neccessery to install required equipment for that opeartion. Technical and technological characteristic installed equipment are given in chapter 4.
- Probablly this method in ingot casting will be more and more in metallurgical practice.
- Installed equipment enable more flexibillity in metallurgical operation.

6. REFERENCES

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