DEVELOPMENT CONCEPTION OF OPTIMAL SELECTION OF REFRACTORIES FOR CASTING STEEL WITH LONG SERIES ON CCM

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Abstract
One of the important indexes for exploitation CCM is index of quantity condition product from 1 ton liquid steel. This index can be considerably improved during casting 16-20 hours from one tundish.

By the way for casting long sequence it is necessary to provide harmony between all around refractory systems of tundish [1]. During experimental investigations it was determined that high quality stoppers and submerged nozzles can provide necessity duration of casting without additional actions. In this case most important point is maximal lifetime of submerged nozzles. But lifetime of submerged nozzles is connected with both some special conditions of casting and manufacture quality.

This paper reports studies of main conditions, which can influence on the lifetime stoppers and submerged nozzles. As a result of these studies it has proved possible to improve casting time from one tundish till 12-15 heats.

1. MAIN WORKING CONDITIONS OF REFRACTORIES IN TUNDISH
Process continuous casting of steel is using some special refractory units and materials. These units and special materials are necessary for providing long contact with liquid steel without serious damages. Generally biggest erosion refractories in tundish can arise in next structure elements:
- refractory lining of inner surface of tundish;
- individual section of stoppers;
- individual section of submerged nozzles and nozzles.

1.1. Tundish refractory lining
Tundish refractory lining has contact with steel during all period of casting. In this time steel has motion in the melt bath. This motion of steel (at first fall steel jet that coming from ladle) is promote for forming direction flows, which can improve erosion refractories for some zones of tundish. During experience investigations it was showed that biggest erosion of refractories lining are observe in the zone of slag line and in the zone where fall steel jet has direct contact with refractories.

In the case of continuous casting with long sequences speed of erosion refractory lining in zone of contact between refractories and covering powder is increase. It can be connect with dynamics of development situation in the tundish from every next ladle. Firstly nearly finish casting from every ladle some quantity of ladle slag downfall to the tundish. Of course this processes are changing chemical composition of covering slag in tundish and further development reactions between covering slag and refractories lining. Especially it is visible for the MgO gunning layer, which are using as like working lining in tundish very often. Therefore for the continuous casting process with long sequences it is necessary to increase thickness of working lining in slag zone an accordance with time of casting and to suppress aggressive possibilities of slag which will form during casting big quantity steel ladles.

In touching of erosion refractory lining in the place of contact with downfall steel jet that this effect is needing of special protect measures. For instance it can be measures for increasing of thickness refractory lining or using special impact blocks with high anti-erosion
features or application special ladle shrouds tubes which can change hydrodynamic motion downfall jet in steel bath of tundish.

1.2. Stoppers

Refractory ceramic stoppers are an integral part of the modern continuous casting process. They provide not only safe working CCM, directing and dosing the steel flow from tundish to mold but also increasing complex flow control and providing argon injection into steel jet. It is ensure that quality of casting product wills not detriment.

Damages to tundish stoppers have been mainly caused by the following items (Fig.1 a):

Fig.1. Schematic drawing of typical damages to tundish stopper (a) and submerged nozzle (b).

1) Slag line erosion, which occurs during casting process and development in dependence with chemical composition of covering slag.
2) Erosion of sector stopper’s head, which has, evokes by steel flow around head, chemical reactions between refractory components and some components in steel (for example, calcium) and physical impact with surface of tundish nozzle.
3) Neck cracking in the zone of nut binding caused by insufficient mechanical strength of refractory material of stopper and resistance to thermal stress.
4) Vertical cracking which occurs during casting process by thermal shock in steel bars of mechanism for motion stopper.
5) High mechanical stress, arising from manipulation mechanism and vibration effects during casting.
6) Spoiling at the refractory material because of oxidation and oxygen injection.
The developments of technology continuous casting steel are give possibility to cast steel from one tundish more as 20-24 hours. In this case tundish stoppers must guarantee a work during whole casting period. Accordingly construction of stopper (geometry configuration, chemical composition and technology for manufacture) must to take into consideration main damages which can happened during casting with long series.

1.3. Submerged nozzle

Ceramic submerged nozzles are an integral part of the modern continuous casting process also. They provide directing steel flow from tundish to mold and shielding steel from the process of secondary oxidation. The bottom part of submerged nozzle is immersed into melt bath of mould. The most significant source of instability in the mould and primary cause of conditions likely to lead surface defects has been found to be design of the submerged nozzle. By the way a change configuration of inner part submerged nozzle during casting process can modify flows of steel in liquid core. Of course after big changes in configuration submerged nozzles process of casting steel can be stop or submerged nozzle will be change on new one. But in any cases we will lose some quantity steel for the scrap. Therefore for achievement continuous casting process with long sequences it is necessary to aspire improve lifetime of submerged nozzles.

In the present time the isostatic alumina-graphite submerged nozzles is widely used continuous casting of molten steel. Exploitation features of these submerged nozzles have some differences in dependence with chemical composition of refractory material, duration of casting and method of killed oxygen (Al-killed or vacuum-killed).

Damages to submerged nozzles in Al-killed steels have been mainly caused by the following items (Fig. 1 b):

1. Slag line erosion, which occurs during casting process and affects by the characteristic casting powder and surface flow in mold. Normally the erosion is bigger in high speed casting and electro-magnetic stirring conditions in the mold. It is known that higher fluorine content and lower basity of casting powder speed up the erosion in slag line.
2. Vertical cracking which occurs during the initial stage of casting due insufficient of preliminary preheating of submerged nozzles (thermal stress).
3. Spoiling at the working surface which has contact with bottom part of nozzle (oxidation and oxygen injection).
4. Clogging effect of inner hole of submerged nozzles by particles of Al₂O₃, slag’s drops and solidified steel clusters. Alumina-clogging is a phenomena of alumina build up in submerged nozzle.

All aforesaid items have most significance if duration of continuous casting period will be improving. Meanwhile our experience had shown that biggest problem for improvement exploitation period of submerged nozzles is problem they’re clogging for Al-killed and high Al steels.

2. EXPERIMENT

2.1. Total measures for improvement lifetime stoppers and submerged nozzles

Stoppers and submerged nozzles for continuous casting are generally composed of alumina-graphite material with graphite content of approximately 20-30% by weight. Biggest part of these articles have actual contact with molten steel and some parts with molten tundish or mold slag. It is known that various correlation chemical components in refractory material provide significant changes mechanical strength and corrosion resistance.

Corrosion resistance and mechanical strength of alumina-graphite materials were examined by the high frequency induction furnace with using 40 kg molten steel and 2,5-3,5
kg slag. Three kinds of steel (low carbon Al-killed, middle carbon Al-killed and high magnesium Al-killed) and few kinds of slag were used in this tests. Hot face of tested samples were investigate by visual control and hot tested samples were destroy by special press (static and dynamic loading).

2.2. Water model for investigation flows motion from tundish to mould

The most cost effective way to achieve optimizing flows motion nearly head of stopper, in the inner of submerged nozzle and in the bath of molten steel in the mould is build water model for this system.

Few types of water model were tested during present investigation: full size water model with scale 1:1, diminished water model with scale 1:2 and diminished-planed water model with scale 1:2. All types of water models were builds from transparent plastic glass. As shown our investigation there is most easy and effective to use diminished-planed water model with distance between inner surfaces of plastic glasses 10-20 mm. This model is give next advantages: decreasing water volume and improvement quality of picture flow motion without essential distortion hydrodynamic effects. For selection working parameters of casting Raynold’s and Froud’s criterions of hydrodynamic similarity flow had be using in present water model.

The final water model layout consists of diminished-planed tundish with nozzle and adjustable stopper to control the flow, bolted to the tundish submerged nozzle and mould. It is possible to change stopper, nozzle, and submerged nozzle and mold dimension. Moreover for investigation argon injection on steel flow motion in submerged nozzle and mould it was foresee a system for gas injection into stopper and submerged nozzle for water model.

The water is circulated using a submersible pump placed in the tank used to store the water when the model is not use. A gate valve and flow meter are used to set the water flow rate into the tundish, commensurate with the casting speed to be modeled. Another gate valve is used to restrict a flow of water back to tank and thus set the meniscus height in model.

For fixing of results investigation video and photography cameras were applied.

3. RESULTS

3.1. Erosion rates of alumina-graphite refractories

Cross sections of specimens after erosion tests with molten steel and slag in induction furnace are investigated. All the specimens showed significant erosion especially around slag-metal interface zone, and most slight erosion for steel bath zone.

The rate of erosion refractory for middle carbon Al-killed steel had minimal index-value. Moreover higher fluorine content (more then 5-6%) and lower basity (less then 1,0-1,1) are improved erosion rate on 20-25% or more. Erosion rate has increase during long contact with slag. These phenomena are noted after 5-7 hours stay specimen in steel and slag.

Three refractory compositions with different content carbon and Al2O3 were tested. It was determine that content of carbon can to change erosion rate on 10-15%. Moreover higher erosion stable is correspond with some decrease of mechanical strength of material. Therefore for any refractory articles we can select some optimal point for erosion rate and mechanical strength of material.

For the low carbon Al-killed steel rate of erosion in slag zone has same index-value likely for middle carbon Al-killed steel. But rate of erosion for refractory material, which contacted with steel, had improved in 2-4 times in the connection with duration of contact time.

For the high magnesium Al-killed steel rate of erosion in slag zone has been improve in 2-4 times. It is mention especially that rate of erosion refractory material which contacted with molten steel has been same likely for middle carbon Al-killed steel.
By the way it is necessary to note that intensity of flow motion in the bath of molten steel have influence on the rate of erosion. For instance in our trials with induction furnace that intensity of forced mixing has change rate of erosion on 20-30%. But this flow motion and dynamic of mixing steel can not be comparable with flow motion during continuous casting.

### 3.2. Flow motion between tundish and mould

Schematically process of flow motion in the inner of submerged nozzle and their interaction with surrounding gas is shown on the Fig.2. Generally flow motion are characterize by compact jet configuration, which decreasing section of jet from tundish nozzle to bottom of submerged nozzle (Fig.2a). If process of flow motion has normal development that walls of submerged nozzle and surface of jet have not constant contact during casting. Therefore normal development of flow motion in the inner of submerged nozzle are exclude intensity precipitation of corund (\(\text{Al}_2\text{O}_3\)) inclusions on the inner surface of submerged nozzle.

![](image)

But for the practice of continuous casting with system “nozzle-submerged nozzle” is observing the phenomena of suck air cross joint chink, which takes place between bottom surface of nozzle and head part of submerged nozzle. Effect sucking air into the submerged nozzle provided formation of air-water mixture zone on the external surface of jet, which has movement from tundish to mould (Fig.2b). The formation of this zone causes splashes of water in the inner of submerged nozzle that improved possibilities for contact flow liquid and walls of submerged nozzle.

For the process injection inert gas cross stopper (Fig.2c) flow of liquid are characterize by compact jet configuration (classic form). Injection gas is placed in the central part of jet. Of course inert gas gives protection from secondary oxidation by oxygen of air because it is
decreasing effect of suck air cross joint chink, which takes place between bottom surface of nozzle and head part of submerged nozzle. Meanwhile for the molten steel bubbles of gas will improve volume in 3-4 times because of warm up effect. It will stabilize process of movement jet in the inner of submerged nozzle.

Big influence for the flow motion can exert location of stopper relatively of nozzle’s saddle (Fig.3). Visible deformation of jet configuration had note in the case if displacement of axis stopper relatively axis nozzle was more likely 25-30% from radius of nozzle hole (Fig.3b). This deformation of jet provides a changer of flow trajectory to the any wall of inner surface at submerged nozzle. As result liquid has slide along submerged nozzle during whole casting process. It causes good condition for precipitation of corund (Al₂O₃) inclusions, slag drops and solidify metal on the inner surface of submerged nozzle. Moreover deformation of jet can develop with erosion head of stopper and nozzle’s saddle during continuous casting.

Fig.3. Schematic drawing to explanation of mechanism deformation of jet and its sliding along surface of submerged nozzle (water model).

4.DISCUSSION

4.1. The improvement construction and lifetime of tundish stopper

We conclude that there is a not big influence of the Al₂O₃-C composition material of stopper on the erosion resistance and mechanical strength of refractory. For the continuous casting of steel with long series it is not enough for providing normal casting during whole period. Besides body of stopper has standing not only thermal and erosion loading but also dynamical mechanical oscillations and blows. It is meaning that most important sectors of stopper are necessary to intensify. For instance we can recommend next measures:

- improvement of diameter stopper on 20-30% in the top sector of stopper (zone of mechanical bolting with metallic bar and zone of slag erosion);
- improvement of mechanical strength for refractory in the head of stopper (most content of Al₂O₃ or using composition on the basic MgO).
4.2. The optimization of submerged nozzle construction

Lifetime of submerged nozzle limits of long continuous casting sequence. It was shown that as minimum two factors can result for destruction of submerged nozzle (Al-killed steels): erosion refractory in slag line, clogging of inner hole by particles of $Al_2O_3$, slag’s drops and solidified steel clusters.

Most of qualitative results of submerged nozzle wear are in line with known facts: $ZrO_2$ resists in slag line well to the nozzle wear [2]. Normally $ZrO_2$ resist can be lift up lifetime of submerged nozzle in 2-3 times. Therefore lifetime of submerged nozzle in slag line can compile 7-9 heats in connection with fluorine content in casting powder and content manganese in steel.

From another side lifetime of submerged nozzle has result with clogging phenomena for Al-killed steels. It was determined that clogging process can closed submerged nozzle after 2,5-4 heats in dependence from content of $Al$ and degree of secondary oxygen steel. Alumina clogging suppression effects are improved by special anti clogging coats [3,4]. In this case lifetime of submerged nozzle can lift up on 30-50%. Some more additional improvement of lifetime can provide application of argon injection into steel jet cross stopper. But all this actions provide for improvement lifetime of submerged nozzle (clogging phenomena) in 1,5-2,0 times. Besides it is necessary remember that lifetime of submerged nozzle can be decrease in the case if conditions for flow motion will not positive enough (for instance placed stopper head relativity of nozzle).

We conclude that for casting $Al$-killed steels lifetime of submerged nozzles has limits with bath reasons erosion in slag zone and clogging. It is possible to cast from one submerged nozzle enough limited quantity of steel. Accordingly after few heats (4-6 or little more) it is necessary to stop casting or change submerged nozzle on new one.

Therefore for organization continuous casting with long sequence (10-12 heats or more from one tundish) it is necessary to use system “nozzle-submerged nozzle” with possibility to change submerged nozzles time to time. In this case the phenomena of suck air cross joint chink between nozzle and submerged nozzle must be to take into consideration. On the practice we can recommend protection with argon rink or tube wool [5,6].

5. CONCLUSIONS

We have studied the behavior of tundish system refractories during long sequence continuous casting and peculiarity steel flow motion between tundish and mould. From the results of these studies we have made following conclusions:
1. Intermediate tundish lining can be performed on the basis MgO gunning material, which can guarantee casting time on the level 10-12 heats or more.
2. Improvement of lifetime of stoppers can be achieve by selection of optimal configuration and diverse composition of alumina-carbon material for different zones of stoppers in accordance with erosion effects.
3. Clogging effect in submerged nozzles causes by precipitation particles of $Al_2O_3$, slag’s drops and solidified steel clusters. It has big result with character flow motion in the inner of submerged nozzle.
4. It is shown that for Al-killed steel really lifetime of submerged nozzles is not enough for continuous casting with long sequence. Therefore it would rather to use system “nozzle-submerged nozzle” with possibility to change submerged nozzles time to time. For this system we can recommend to use argon injection cross stopper and argon protection joint chink between nozzle and submerged nozzle. It will improve alumina clogging suppression effects in 1,5-2,0 times.
Further studies will be devoted to optimizing costs for system refractories in tundish, covering insulting slag in tundish, casting powder in mould and ea. with objective of securing continuos improvements.

LITERATURE