INFLUENCE OF DRY TUNDISH WORKING LINING AND COLD START OF CASTING ON STEEL CLEANLINESS

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Abstract
Current global trends in the development of new materials and technologies, as well as the increasing demands for performance and lifetime of individual production units in steel casting brought several key innovative features, including the method of preparing tundish working lining and conditions for its direct utilization in the casting process. Since the worldwide introduction of dry tundish lining and cold start casting concept, there were several Research projects related to this technology from the refractory point of view, however, only limited findings were presented about its influence on liquid steel and overall casting process. Besides the initial measurements and evaluation of hydrogen pickup during casting of the first and second heat on tundish, this research work was focused on investigation of influence of mentioned technology on cleanliness of tin steel grades, especially the presence of spinel type inclusions ($\text{Al}_2\text{O}_3 \times \text{MgO}$) and its direct comparison with regularly used wet tundish working lining practice.

Keywords: continuous casting, tundish lining, cold start casting, steel cleanliness

1 Introduction
In general, today there are two basic modern concepts of preparing tundish working linings – regular wet spraying (or gunning), in which the mixture for tundish lining is mixed before the actual application with water in a specified ratio and dry mixtures, in which the material is poured directly between the wall of permanent tundish lining and inserted form in particular thickness. The essential difference between the mixtures used in these two technological processes, in addition to MgO content, is their actual application to different steel grades in different production plants. [1, 2].

A dry filling technology was for the first time worldwide applied in 1986. The main goal of introduction of this technology was replacement of present regular wet tundish operational lining by dry lining without time-consuming drying process. A complete elimination of water application by preparation of wet lining mixture is a large advantage, especially when applied in winter period.

The main advantages of this new technology introduction can be summarized as follows [3, 4, 5]:

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• No necessity to add water during tundish lining preparation
• Energy saving through shorter preheating time
• Constant thickness of operational lining, defined by form dimensions
• Easier dumping of residual steel and operational lining after casting completion
• Possible cold start casting without previous high-temperature intensive preheating
• Decrease of work force and time demands for tundish preparation to casting
• Expected possible improvement of steel quality

In addition, the dry mixtures from different suppliers differ in type of binder used, mainly organic based, and also in the way of application. An important role in terms of final density of poured mixture and minimization of potential steel infiltration into the lining pores during casting itself plays material vibration (compaction) when pouring into the form [6]. Nevertheless, the fundamental difference in the use of these dry mixtures rests in the possibility of eliminating the intense heating of the tundish before actual steel casting. This process is known as cold-start. In this case, the material of dry mixture after pouring into the form requires only drying phase, but other ceramic materials of tundish (stopper rods, inner tundish nozzles and submerge entry nozzles) are even despite mentioned cold start of working linings heated before casting through special sleeves (chimneys). The following Fig. 1 characterizes this difference in the way of heating of the tundish before casting compared to standard wet spraying (i.e. with intensive heating of the lining itself), and the difference in the energy intensity for both characterized processes.

![Fig. 1](image)

**Fig. 1** The way and energy intensity of tundish intense heating with dry mixture (left) and regular wet spraying (right)

Since 2009, preliminary plant trials of mentioned technology were conducted also within U. S. Steel Košice, s.r.o. in following two alternatives:

1.1 **Hot hardening (so called hot set)**

For the purpose of primary bond creation, filled lining needs to be heated. With this alternative, cold or hot start casting could be applied. Prepared material is filled without mixing and without additives between a permanent tundish lining and a mold (or form). An increase in temperature to 350°C starts chemical reaction of hardening. The tundish lining is after moulding prepared for cold or hot start of casting. In case of hot start casting, total tundish volume is preheated to temperature approximately 1100°C and in case of cold start casting, only special tundish refractories (stoppers, SEN’s) are
preheated about 90 minutes before casting start. For this purpose of uniform preheating, special chimneys manufactured from fibrous materials are applied.

1.2 Cold hardening (so called cold set)
Primary bond in the tundish lining is created after chemical bond initiation. With this alternative, cold or hot start casting could be applied. Prepared material is after admixing of chemical bond initiator filled between permanent tundish lining and a mold. After lapse of time necessary for setting the mold is taken out and lining is prepared for casting. By analogy with previous hot set, a cold or hot start casting could be applied. Specific application of both above mentioned alternatives depends on particular production conditions and actual situation. Generally, the cold set is advantageous from the energy standpoint due to significantly lower natural gas consumption. In addition, this technology allows very fast tundish preparation and utilization, especially in case of unwanted production events or casting terminations. From this perspective, this cold start casting is widely utilized, however, there are still some limitations to use this technology during casting of special, qualitatively most demanding steel grades.

The chemical compositions of dry working linings from various suppliers tested in U. S. Steel Košice, s.r.o. are characterized by the following Table 1. In addition, Fig. 2 shows an example of such lined tundish and special sleeve (chimney) intended for preheating of pouring systems, SEN, tundish inner nozzle and stopper rod before casting start.

| Table 1 Chemical composition of dry working linings tested in USSK conditions |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Supplier | MgO [%] | CaO [%] | Al₂O₃ [%] | SiO₂ [%] | Fe₂O₃ [%] |
| A | 59,0 | 2,5 | 2,0 | 27,0 | 7,0 |
| B | 86,0 | 7,0 | - | 3,5 | 3,0 |
| C | 83,0 | 9,0 | - | 4,0 | 3,1 |
| D | 85,0-90,0 | 1,0-3,0 | 0,0-2,0 | 3,0-5,0 | 0,0-2,0 |
| E | 82,0-87,0 | 1,0-2,5 | 1,0-1,9 | 7,5-9,5 | 2,0-2,8 |
| F | 82,0 | 2,5 | 0,3 | 6,5 | 7,8 |

Fig. 2 Example of tundish with applied dry working lining prepared for casting (left) and special sleeve (chimney) intended for preheating of pouring systems.

2 Material and experimental methods
From the metallurgical point of view, the first phase of testing these materials addressed the issue of hydrogen content pickup, which causes potential problems during steel casting, particularly in relation with breakout risk. In this context, it was necessary to implement several real measurements of hydrogen pickup in operation during casting of the first and second heat on tundish with different dry mixtures from
multiple vendors for better mapping of possible restrictions in their application given the cast steel grades. Therefore, the hydrogen content in steel was measured on selected heats after completion of heat processing at Stirring Station and subsequently the hydrogen content was measured during their casting in the tundish using the movable Hydris\textsuperscript{®}-Lab analyser from Heraeus Company.

To study the inclusions in the steelmaking process and final products, techniques are being developed to rapidly identify inclusions in steel \cite{7,8}. Understanding the origin of inclusions and developing practices to control their composition and content in liquid steel are key point for optimization of production processes and parameters \cite{9,10}. The inclusion analysis technique used in this work was based on a computer-controlled scanning electron microscope known as the Automated Steel Cleanliness Assessment Tool (ASCAT). This unique equipment owned and used within the U. S. Steel Corporation can determine the size and composition of hundreds of inclusions in less than 30 minutes \cite{11}.

The process of analysis and identification of each inclusion on ASCAT consist of four steps: 1) Inclusion detected and sized, 2) Spectrum is analyzed – percentage of each element is determinate, 3) Spectrum data processed through special modules and rules, 4) Inclusion classification is assigned.

This process is depicted in following Fig. 3, along with typical example of complex spinel inclusions \cite{12}, analyzed and investigated in this research work considering the chemical concept of the material used for preparation of tested and compared tundish working linings.

![Fig. 3 Process of inclusion analysis and identification on ASCAT (left) and microscopic example of investigated spinel inclusions (right)](image)

To verify the influence of dry mixtures of tundish working linings with cold start on the cleanliness, the steel samples were taken from two sequences of casting of the same selected steel grades. During the first test the tundish working lining was prepared using regular, normally used wet gunning with intensive heating of tundish before start of casting, and in the second case the tundish working lining was prepared using dry mixture from the selected vendor, with applied cold start.

In both cases, each heat was sampled from the mold (regular lollypop sampling), and subsequently the cleanliness results were mapped and compared based on ASCAT analyses. Two main steel cleanliness criteria were investigated and evaluated - the average number and the area fraction of both represented categories of spinels (\(\text{Al}_2\text{O}_3 \times \text{MgO}\) based inclusions), i.e. below and above 10 \(\mu\text{m}\) in the analyzed samples.

3 Results and Discussion
As mentioned above, since there were only limited worldwide research findings related to influence of this technology on liquid steel and overall casting process, besides the initial measurements and evaluation of hydrogen pickup during casting, this research work was
especially focused on investigation of influence of mentioned technology on steel cleanliness and its direct comparison with regularly used wet tundish working lining practice.

3.1 Hydrogen pickup

According to latest worldwide research findings, a typical hydrogen pickup during casting of especially the first heat on tundish using dry mixtures is shown in Fig. 4. These literature sources indicated, that average increase ranges around 0.8 - 1.4ppm [6,13].

![Fig. 4 Trend of hydrogen pickup when casting first heat on tundish with using dry mixtures of working lining](image)

Continuously evaluated results of direct operation measurements confirmed the trend in the figure above, when the real hydrogen pickup in the first heat ranged from 1 - 1.9 ppm and in the second heat it was 0.7 - 1.2 ppm. These measured hydrogen pickups limit the possibility of using these dry mixtures particularly for special demanding steel grades intended for electrotechnical industry, on which there was previously confirmed strong dependence between maximum permitted hydrogen content in steel and frequency of breakout during casting.

3.2 Steel Cleanliness Analyses

Based on approved suggestion, this study was conducted during casting of selected tin steel grades and according to chemical composition of implemented tundish working linings, especially presence of spinel type inclusions (Al$_2$O$_3$ x MgO) was investigated.

Generally speaking, very dilute content of Magnesium may be observed in steel in practice, since this element enter to the process usually only as impurity of ferroalloys or refractory [14, 15].

However, in specific practice conditions, even a very small amount of this element can affect formation of complex oxide inclusions [16] and promotes the possible clogging issues in continuous casting nozzles [17].

Effect of spinels on castability of low carbon steel grades was previously relatively widely discussed, but the common denominator in most cases was only a general statement, that with higher occurrence of these types of inclusions in steel, there were observed problems with clogging of well nozzles during casting. However, the latest available research findings in this field confirm, that with regular contents of these inclusions in steels, this trend of poor castability was not demonstrated [18].

Based on conducted plant trials, below are presented and compared the steel cleanliness results of analyzed samples from both applied tundish working lining technologies. For their better classification and interpretation, two main categories of investigated spinels (Al$_2$O$_3$ x MgO
based inclusions) were defined, according to their dimensions. Whereas Fig. 5 represents the average number and area fraction of spinel inclusions below 10µm, Fig. 6 represents the average number and area fraction of spinel inclusions above 10µm in individual sampled heats cast in sequence in tundish.

![Number of Al₂O₃ x MgO inclusions below 10 µm](image1)

![Area fraction of Al₂O₃ x MgO inclusions below 10 µm](image2)

**Fig. 5** Comparison of number and area fraction of spinel inclusions below 10 µm of individual heats in tundish

![Number of Al₂O₃ x MgO inclusions above 10 µm](image3)

![Area fraction of Al₂O₃ x MgO inclusions above 10 µm](image4)

**Fig. 6** Comparison of number and area fraction of spinel inclusions above 10 µm of individual heats in tundish

As seen from the results, both monitored steel cleanliness evaluation criteria, i.e. average number and area fraction of spinels, in both compared methods of applied tundish working lining were similar, except the first heat in tundish, where the expected higher portion of spinels below 10 µm was confirmed by dry tundish lining with subsequent cold start casting. However, this is not limitation factor of its application, since the most of slabs cast from the first heat in tundish are even thought qualitatively downgraded due to worse overall cleanliness in accordance with current applicable casting procedures. In addition, inspection of casting conditions and monitored casting operational parameters did not confirm in any case the worsened trend of their castability, or indication of problems with clogging of well nozzles during casting. Furthermore, as confirmed by Fig. 6, the occurrence of these types of inclusions above 10 µm is practically negligible in the all analyzed samples.
Nevertheless, given the recent research finding in this area, for a more detailed analysis we examined also the occurrence of certain "limit" contents of these inclusions in terms of possible problems during casting of investigated steel grades. Based on longer-term researches, the limit is magnesium content above 10 atomic percent in spinel inclusions [19].

In the light of these finding, we also analyzed the portion of spinel inclusions with magnesium content below, as well as above 10 atomic percent, again, for both investigated types of tundish working lining. From results presented in Fig. 7 it is clear, that overall occurrence of spinels with Mg content below 10 at% is really on low level, even lower for dry tundish working lining application with cold start casting. In addition, especially in case of “limit” types of spinels with Mg content above 10 at%, their overall occurrence under the given production and casting conditions approaching to zero.

Based on these results it can be concluded, that the application of dry mixture in the tundish working lining dress-up with cold start of casting, in comparison with the regularly used method (wet gunning with intense preheating) doesn’t have negative influence on the cleanliness and was recommended for standard use also during casting of analyzed tin steel grades under the given production conditions.

### 4 Conclusions

This research study was focused on investigation of influence of dry mixture of tundish working lining and cold start casting on steel cleanliness of tin steel grades and its direct comparison with regularly used wet tundish working lining concept. The initial measurements and evaluation of hydrogen pickup during casting, when the dry mixtures with subsequent cold start of casting was applied confirmed, that the real hydrogen pickup of the first heat in tundish ranged from 1 - 1.9 ppm and in case of the second heat it was 0.7 - 1.2 ppm. According to presented steel cleanliness results of tin steel grades samples analyzed on ASCAT it was confirmed, that tested dry mixture of tundish working lining and subsequent cold start casting hasn’t negative influence on steel cleanliness or possible occurrence of clogging issues under given production conditions and from this point of view is comparable with regularly used wet tundish working lining technology practice.
References


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