WHY IS SPRAY MIX STILL A DOMINANT TECHNOLOGY FOR TUNDISH COATING APPLICATION?

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ABSTRACT

Tundish is the final equipment in contact with liquid steel which may possibly affect steel quality. In this equipment the coating is responsible for keeping steel casting temperature and protecting the safety lining from premature wear while it avoids steel contamination by non-metallic inclusions. Despite the concerns about hydrogen pick up and excessive consumption of gas, spray mixes have been a dominant technology for tundish coating. Almost 80% of steel plants in South America use this kind of refractory lining. In the last 20 years other technologies came up to the market with the purpose of reducing or even eliminating the need for water and gas and increasing tundish availability. Although these new technologies present advantages over the spray mixes and are suitable for some specific operational conditions, spray mixes still have a strong presence in the market mainly due to benefits such as flexibility, easy and fast application, low cost, low consumption and high thermal insulation. Nowadays, some improvements have been made regarding the dry mixes and spray mixes in order to have a complete and suitable technology that fits most of the specific demands from the market.

Key words: Continuous casting; tundish working lining; spray mixes; dry vibe mixes; hot setting mixes; self hardening mixes, tundish coating

1. INTRODUCTION

Tundish is responsible for receiving the liquid steel from the ladle, subdividing into many strands and controlling the casting speed through flow control devices. This equipment importance has increased over time and nowadays it is considered a metallurgical reactor, in which a part of the refining of liquid steel can be carried out with safety and quality. Tundish is designed to promote inclusions flotation by maximizing residence time and minimizing short-circuit and dead zones; preventing thermal and chemical losses from the melt and offering the steelmaker an optimal design for quality and yield [1]. As such, the refractory industry had to anticipate this transformation and develop new products that can best fit the process demands.

Currently, different types of products are used as tundish working lining and it is possible for the steel maker to decide which type of material is the most appropriate to his process. Wet mixes applied by spray, hot setting dry mixes and self-hardening dry mixes are kinds of products available nowadays. Despite the fact that dry mixes came up to the market with the purpose of minimizing the disadvantages of spray mixes, the latter continue to be a dominant technology in South America.

The main objective of this paper is to discuss the advantages and disadvantages of each technology considering the real steel mill needs in order to fully understand the scenario of tundish working lining consumption and clarify some current myths.

2. SPRAY MIXES

During the 1980's the use of wet spray mixes was a major breakthrough in the development of tundish working linings [2]. This technology contains some special additives which lead to a product with very low density (1.1g/cm^3) and low thermal conductivity. These features added to an easy application, good flexibility during furniture installation, good performance and low cost made this technology very successful.

In order to evaluate the usage of each kind of tundish working lining, a market survey was conducted in 2016 at the 45 main steelworks in South America including integrated and mini mills plants. This research revealed that 78% of 38,500 tons of working material consumed in 2016, were spray mixes (Fig. 1).

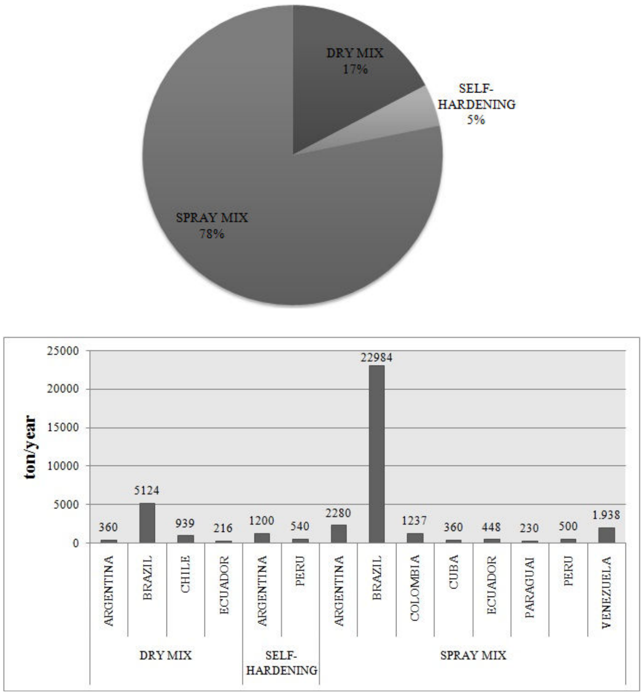

Fig. 1 - Market Share of tundish working lining in South America in 2016.

Despite the large consumption of spray mixes, the fact that approximately 25% of water is used to apply this material is still a point of concern.

The first inconvenience related to the amount of water used for spray mixes application is the need of drying the coating which leads to a high gas consumption. This kind of material are commonly dried up to 550°C for at least 3 hours to eliminate the water content. Fig. 2 shows a suggested drying curve, which can be adjusted according to the needs of each steel plant. Fortunately, the disadvantage of high consumption of natural gas can be minimized by using gas from blast furnace or hot start casting practices.

The second point of concern regarding the amount of water is the possibility of hydrogen pick up. The presence of this element in steel is considered harmful and is a common cause of defects such as cracking and embrittlement[3].

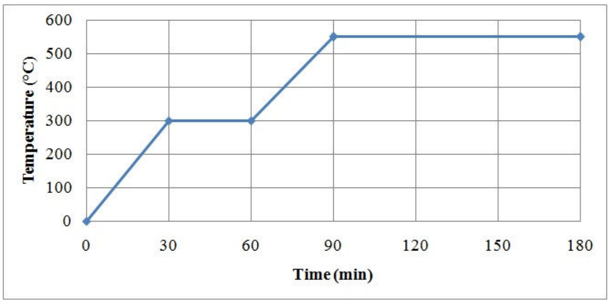

Fig. 2 - Suggested spray mix dry out curve.

There are numerous of hydrogen sources during primary and secondary refining and casting. These sources include scrap, hot metal, stirring gases, carburizers, wet alloys, ladle slag additions and the atmosphere. It is believed that the working lining can also be a source of hydrogen [4]. The water vapor present in the pores of the refractory material can dissociates when in contact with the liquid steel according to Equation 1 and the atomic hydrogen formed can easily be incorporated into the steel during its production process. It happens because of the great mobility of hydrogen into the iron crystalline network, since its atomic radius is approximately eight times smaller than the atomic iron radius (r_H=25pm; r_{Fe}=140 pm) [5].

$$H_2O \leftrightarrow 2[H] + [O] \qquad \text{(Equation 1)}$$

To verify the potential of steel contamination by water used to apply the spray mixes, tests were carried out in different steel plants in order to monitor the tundish drying. During these trials three thermocouples were installed in the interface between the tundish safety and working linings and the temperature in each of them is measured as a function of the drying time (Fig. 3). The obtained data showed that all tracked points reached temperatures above 100°C after a period of thermal stability. This stable period corresponds to the latent heat region during which the energy supplied to the system is consumed by water phase change. When the temperature reaches values greater than 100°C the entire moisture content in the working lining was transformed into gaseous water and easily removed through the pores of the coating. Thus, it can be concluded that a suitable drying curve guarantees the complete water removal, ensuring quality in the process. It is important to note that the drying curve is only sufficient to remove free water from the system. It is believed that the amount of bound water is not considerable, since the tundish is usually dried right after application and there is insufficient time for brucite formation. However, if brucite formation occurs, hydration water will be eliminated during tundish heating.

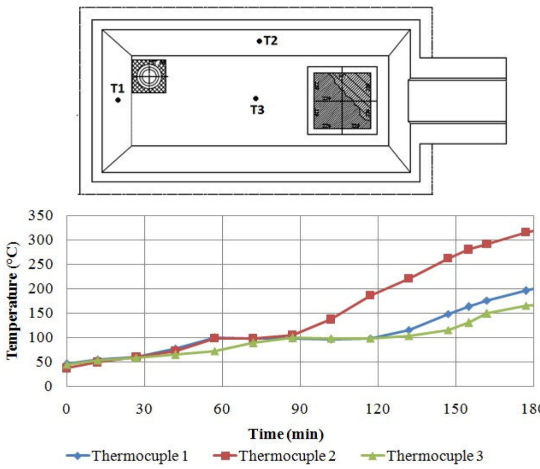

Fig. 3 - Temperature tracking during tundish dry out.

In addition to the large amount of water used in the application, another concern related to the spray mixes is the possibility of alumina inclusions in the steel due to the presence of silica binders in the refractory composition. The Equation 2 shows that the free silica contained in the refractory lining is reduced by the aluminum dissolved in the metal, which leads to the formation of an additional amount of alumina inclusions[6]. This equation occurs spontaneously since, according to the Ellingham diagram, the free energy to form the oxide Al_2O_3 is lower than to form SiO_2.

$$3SiO_2 + 4[Al] \rightarrow 3[Si] + 2Al_2O_3 \qquad \text{(Equation 2)}$$

Despite this concern regarding the presence of free silica in the spray mixes, previous study showed that the increase in the oxygen amount brought by the reduction of SiO_2 is negligible compared to the reoxidation due to environmental air contact, and the oxygen brought by the reduction of Fe_2O_3 present in the refractory material, as shown in Fig. 4 [7]. To minimize the effect of Fe_2O_3, products using a high-purity raw materials have been developed and offered to steel mills that need to eliminate this oxygen source.

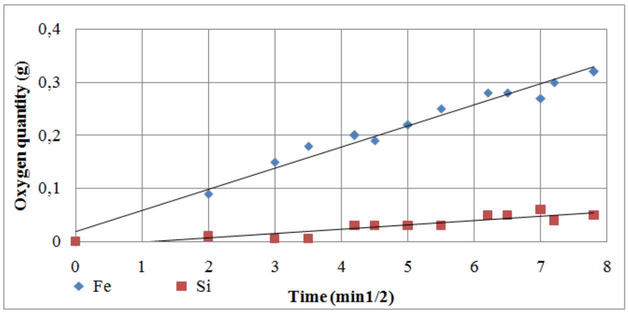

Fig. 4- Evolution of the amount oxygen brought by Fe_2O_3 and SiO_2 reduction as a function of the square root of the time the metal was in contact with the refractory[7].

Therefore, hydrogen pick up due to the presence of water and inclusions of alumina due to the presence of silica should not be reasons to rule out spray mixes when selecting a suitable tundish lining.

3. HOT SETTING DRY VIBRATED MIXES

The dry vibrated mixes emerged in the market with the purpose of reducing or even eliminating the need for water and gas and increasing tundish availability.

Indeed, the use of this type of material substantially reduces the gas consumption since its application occurs without the presence of water. This type of material only requires gas to heat the mold up to 300 °C approximately (Fig. 5) and promote binder (resin or glucose) polymerization.

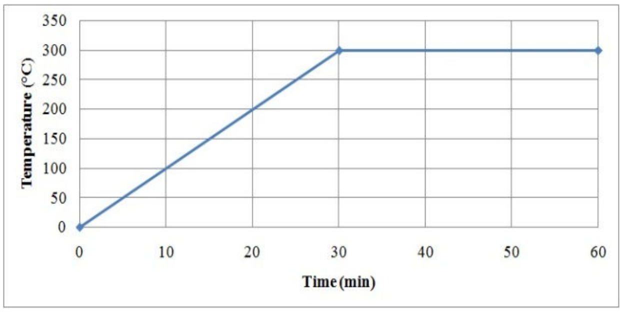

Fig. 5 - Suggested dry mix polymerization curve.

Moreover, the use of dry mix can substantially increase tundish availability. Data from different plants in South America where more than one type of working lining were used were collected during tundish assembly. These data were compiled and are shown in the Tab. 1. As can be seen, the preparation steps are different for each type of product used and the equipment is ready 70 minutes faster when using the dry material. Considering one plant that assembles four tundishes/day, for example, this represents an economy of 131 hours/month.

Tab. 1 - Net time spent for tundish assembly.

	Spray Mixes	Dry Mixes
Time to apply 2ton (min)	60	40
Dry out (min)	180	-
Cure (min)	-	60
Cooling to remove the mold (min)	-	60
Remove the mold (min)	-	10
Total (min/tundish)	**240**	**170**

Despite the fact that the dry mixes reduce gas consumption and the time to prepare the tundish, this kind of product has been supplied only in a few plants in South America. One of them has chosen the dry mixes because of the high price of natural gas. Two others plants hope that the dry material would be better in terms of steel quality, although it has not been proved that the spray material would not meet the quality requirements. The small percentage of plants using dry mix tundish linings is due to some disadvantages that make this type of product not very attractive.

The first disadvantage of the dry vibrated mixes is related to the binding system. Phenolic resin is the original binder used in this technology and there are several drawbacks regarding its use. The high price and the ammonia odor during resin polymerization as well as the problems by carbon pick up in the steel are concerning points [4]. The increase in carbon content in steel is not desirable in IF steel as it strongly affects the steel quality and its forming characteristics[8]. Alternative environmentally friendly binder systems have been developed, nevertheless, higher cost and the carbon pick up problem persists. Krausz et al compared different tundish linings (Fig. 6) and found out that carbon pickup from spray mix compositions was considerably lower than from dry mixes[9]. This result indicates the limitations of dry material for ULC steel casting, for instance.

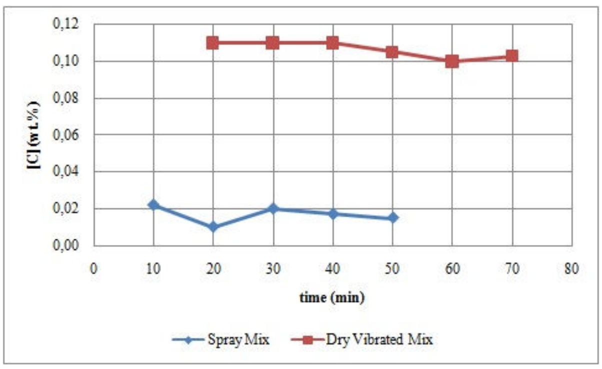

Fig. 6 - Carbon content of the steel as a function of sampling time[9].

Another disadvantage of dry mixes is related to the higher density (1.7 g/cm^3) compared to spray material (1.1 g/ cm^3), that leads to a higher consumption considering the same thickness. Data from steel plants in Brazil showed an increase of approximately 30% in consumption when replacing spray mixes by dry mixes.

Taking into account the higher price due to the binder and the higher consumption due to the higher density, there is a cost increase of approximately 56% to prepare one tundish using dry mixes products in comparison with the spray mixes, as can be seen in Tab. 2.

Tab. 2 - Relative price and consumption comparison between spray mixes and dry mixes.

	Price (R$/ton)	Consumption (ton/tundish)	Total (R$/tundish)
Spray Mixes	100	1.0	100
Dry Mixes	120	1.3	156

In addition to the higher density, the consumption can also increase during the safety lining campaign (Fig. 7). As the safety lining wears off, the gap between the mold and the safety lining increases, also increasing the mix consumption. Even the use of an adjustable mold is not enough to keep consumption steady during the campaign. Data from customers in Brazil revealed that the consumption can duplicate at the end of the safety lining campaign. Sometimes it is preferable to end the tundish campaign prematurely than to have this increase in the working lining consumption.

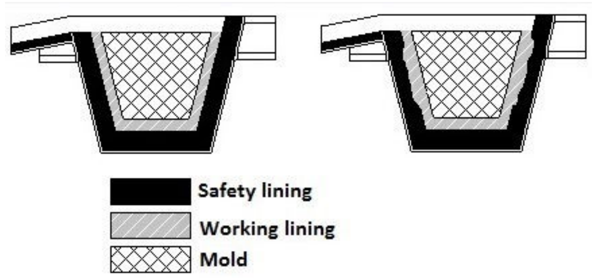

Fig. 7 - Tundish profile showing the increase in dry mixes consumption due to safety lining wear.

The use of dry mixes despite of their higher cost and consumption rate is only feasible in two situations. First of all, when there are not enough tundish metallic shells and the preparation time has considerable impact on the steel production. Secondly when the casting sequence has long duration. The high density of the dry material is responsible for an optimal pack and consequently low erosion rates. Data from a steelmaking plant in Brazil indicates that the wear rate of the dry material is approximately 0.016mm/min versus 0.025mm/min of the spray mixes. Even so, it is important to note that the peak hour with respect to the supply of electricity in some plants prevents the use of the tundish for longer casting sequences and the spray mixes can withstand a 30-hour sequence satisfactorily, provided a suitable layer is applied.

4. SELF HARDENING MIXES

The continuous need of decreasing energy consumption and increasing tundish availability, has led to the development of self hardening mixes. This material uses a sodium silicate solution as a binder combined with an ester. The two liquids are continuously mixed with the dry material at the moment of application and filled into the gap between safety lining and the mold. A more complex machine (in comparison to the hot setting material) is required for this application, which must include pumping system for the liquids and a mixing unit. This makes the investment much higher than for the previous technologies.

In this system, the ester reacts with the sodium silicate solution, removing Na_2O from the system. This increases the SiO_2/Na_2O ratio, forming a viscous phase responsible for the hardening of the product at room temperature. Although a liquid binder is used to apply the material, the water present in the binder solution is consumed during the hardening reaction. Thus, no drying of the material is required after application and the consumption of gas is totally eliminated.

The elimination of gas is the most important factor that leads to the use of this material. Consumers to whom the self-hardening mixes are most interesting technically speaking are those that have no gas availability or face its prohibitive price. This usually occurs mainly during winter in some countries like Argentina and Chile.

Moreover, the promise of ready-to-use tundishes is not really an advantage of this technology. The tundish is assembled 60 min faster than the dry mixes, however, it is necessary to wait for the safety lining to cool down (below 40°C) before applying the working lining. This happens because temperatures above 40°C greatly increase the kinetics of the reaction and the material tends to collapse. Hence, the saved time in the assembly, is spent waiting for the safety lining to cool down.

In addition, the self hardening mixes has the same disadvantages of the dry vibrated mixes when compared to the spray mixes: higher density, higher consumption and higher cost. It is because of these disadvantages that the consumption of this type of material in South America is still small when compared to the spray mixes, as can be seen in Fig. 1

5. SUMMARY

The main purpose of this paper was to discuss about the current status of tundish working lining consumption in South America. In general, the three technologies are able to withstand standard quality production and can be used for both cold and hot start casting practices. Each technology has its specific advantages and disadvantages that are summarized in Tab. 3.

Tab. 3 - Comparison between the tree technologies.

	Spray mixes	**Hot setting dry mixes**	**Self hardening mixes**
Application	Spray with 25% of water	Poured completely dry	Poured with 5% of liquid additives
Drying/Curing	3h / 550°C	1h / 300°C	1h / Room Temperature
Gas consumption	High	Moderate	None
Density	Low	High	High
Insulating properties	Good	Moderate	Moderate
Time to prepare (min)	240	170	110
Tundish Availability	Moderate	High	Moderate
Casting Sequence	Up to 30 hours	More than 30 hours	More than 30 hours
Investment on equipment	Low	Moderate	High
Cost	Low	Moderate	High
Product consumption	Low	High	High
Steel Quality	Possibility of [H] pick up	Possibility of [C] pick up	-

These three technologies are available in the market and the decision of which product should be used depends on the steel mill requirements.

At first, the absence of water in the dry mixes instigated the market curiosity. In some plants, the use of this kind of products proved to be interesting due to the need for reducing or eliminating gas consumption. In some countries, especially during winter, the availability of natural gas is low and the price is prohibitive. Another occasion in which dry mixes can be indicated is when tundish availability has considerable impact on the steel production and the casting sequence has long duration.

Despite the advantages of dry mixes, the market continues to be dominated by spray mixes. The understanding of this scenario requires the knowledge about the process of each plant and the real needs for each one.

In general, the total cost of investment and product are key points to determine the use of a tundish working lining. In this case the spray mixes is the most advantageous technology. Besides low cost, low investment and low consumption, this kind of product has better insulation properties than the other technologies presented and meets most of the plants on steel quality. In addition, most plants in South America have enough tundish shells available, a relatively low sequence time and the possibility of using gas from blast-furnace, which minimizes the need for dry mixes.

The main conclusion is that the spray mixes are more suitable for the operational scenario of most of the steel mills in South America and the dry mixes have important advantages for some specific plants and special process procedures.

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