# COLDMAG®, THE EASY WAY TO CAST

Iñigo X. García-Zubiri [(1)], Mikel Arandigoyen [(1)], Roiner Racedo [(1)], Presen Amezketa [(1)], Marcelo Lagier [(2)], Luciano Disante [(2)], Mariano Comas [(2)], Silvia Murialdo [(2)], Luciana Pucchio [(2)]

## ABSTRACT

The aim of this paper is to present this monolithic refractory mass development as the example of the easy and clean tundish work lining performance for a steel plant. This paper shows the development and implementation of this new material in a complex steel plant as Arcelor Mittal (AM) Acindar (Argentina).
The chemical and physical characterization of this refractory mass will be shown. X-ray fluorescence analysis, thermogravimetric and X-ray diffraction measurements, mechanical resistance and thermal conductivity determination among others, will be studied for this material.
Data for the energy and time efficiency enhancement will be present. As a self-hardening material it does not need to be heated for its application.
Details of the continuous mixer machine included for the application of this material will be shown. The easier and cleaner performance will be evidenced. The health and safety conditions improvement for system: no dust or vapors are produced. The steel cleanliness is also improved.
The modification of the refractory material according to the steel plant requirements are evidenced during the reading of this paper. The number of requirements for Acindar (the using of two kinds of nozzle systems, as well as its wide range of produced steel qualities) forced Magna to introduce interesting modifications in the current tundish performance. Goal sequences of 45 and 42 hours of casting for cold start and pre-heated respectively were reached during the first trials period.
Supported by reported results from AM Acindar, and other customers, as well as by the laboratory essays results, this paper will discuss the truly improvement in refractory masses and the real advantage for the steel casting that this Coldmag material implies.

**Keywords:** self-setting, environmentally-friendly, working refractory lining, tundish, cold application.

## INTRODUCTION

The objective for this development on the refractory masses is to be the easy and clean example for the application of tundish materials. This symposium contribution shows the development and the introduction of this new dry self-setting material in a steel-plant as complex as Arcelor Mittal Acindar (Argentina).

MAGNESITAS NAVARRAS, S.A. fabricates refractory masses and agricultural products commercialized under the MAGNA trademark, with an important and every day higher presence in the overseas market. The company exploits or works a magnesite mine located in Navarra (Spain) and transforms this mineral into different products in its Factory. The Magna's three main product lines are:

- Caustic Magnesia. Used as fertilizing or as raw material for compound feed.
- Sintered or Dead Burned Magnesia. Used as basic refractory material for Steel Industry mainly, and as slag regulator in steel making.
- Powder Magnesia. Fort the production of magnesium sulfate and environmental applications.

[(1)] MAGNESITAS NAVARRAS, S.A, Av. Roncesvalles, 31630, Zubiri, Navarra (Spain), tlf.: +34 948 466 408 i.garcia@magnesitasnavarras.es
[(2)] ARCELOR MITTAL ACINDAR, Ruta Provincial 21 N 4855 S2919GBC, Villa Constitución, Santa Fe (Argentina). Tel.: +54 (3400) 478200, LPucchio@acindar.com.ar

In this current moment of continuous energy saving pursuit, a monolithic refractories company as Magnesitas Navarras (MAGNA) could not have other target for its working lining tundish masses but the development of a material which implies room temperature hardening: setting without any heating requirement.

The idea of this self-setting material for tundish comes from the technology applied in the mold installation on foundries [1]. During the foundries history different bonding systems have been used for the hardening and shaping of the mold sands. Coldmag improves the concept of the working monolithic refractory materials for the continuous casting tundishes using one of these mentioned bonding systems.

Around 90% of the world Steel production goes through continuous casting process. Tundish is an indispensable component for the steel continuous casting process because is the last recipient lined with refractory material where the liquid steel passes through before solidify in the mold. Besides the role of distributor, the tundish is the unit which changes its lining most often in a steel-plant. The refractory lining uses to include an insulation layer, a safety lining layer made of bricks or refractory castable, and a working lining layer. The material which constituted this last layer is the one in direct contact with the melted steel. The product described by this paper is used in this last tundish lining layer.

The development of this product in South America was born in a kindly cooperation between Magna and AM Acindar. The requirements of Acindar forced Magna to introduce interesting modifications into the current tundish application process. The presence of two nozzle systems in AM Acindar, as well as a wide range of produced steel qualities, makes this plant the most exigent place for testing the yield or the response of this new material development for tundish.

Located in Villa Constitución (Argentina), after more than 60 years of history, Acindar is part of the Arcelor Mittal group which employs more than 320.000 people around the world and includes productive plants in 27 countries. In this way, Arcelor Mittal Acindar is one of the private companies, producer of non-planes steels, who leads the Argentinian market and has international presence. Nowadays, it has a participation of more tan 50% in the argentine market and offers more than 200 product lines for constructions, agriculture and industry. More than two thousand people are working in Acindar, achieving a production capacity of 1.700.000 steel tons per year.

Actually the tundish materials can be divided, according to their application mode, in: wet systems (gunning or sprayable materials), being the most popular with presence in approximately 70% of the steel-plants around the world; and dry systems. Gunning materials imply the use of a high amount of water and the corresponding energetic waste for the drying. The use of water is avoiding working with dry systems. Until the last years the more extended and known dry system, Dry Vibe kind, implies a energetic cost reduction because due to its dry mass nature this material does not require any previous drying, but it needs a cure process for the material shaping. So this Dry Vibe kind could be called “hot-setting dry mixes”. The cold plates system is still being used in some steel-plants, despite its especially complex installation process.

The system proposed by Magna, which is the objective of this study, is a dry material hardened and shaped at room temperature (cold-setting material). In this way, the use of water as well as any heating for the curing or shaping of the mass is eliminated. This material is applied in the Steel plant easily and cleanly thanks to the use of a mixer machine. The working time per tundish and person is reduced. The no presence of powder and vapors improves the safety and healthy working conditions. The idea of Coldmag is to become the most ecological way to tundish, helped moreover by the adequate binder system. Besides, it tries to reduce the tundishes turn-around times at minimum for increasing the availability of tundishes for the steel-plant.

This close collaboration between Magna and AM Acindar has reported good results as this paper will show. The results, bucked up by the large number of previous laboratory essays, will confirm during these pages how this studied self-setting product is a true improvement in the refractory masses and implies a real advantage for the steel continuous casting: the product has fulfilled the previous expectations.

(1) MAGNESITAS NAVARRAS, S.A, Av. Roncesvalles, 31630, Zubiri, Navarra (Spain), Tel.: +34 948 466 408 i.garcia@magnesitasnavarras.es
(2) ARCELOR MITTAL ACINDAR, Ruta Provincial 21 N 4855 S2919GBC, Villa Constitución, Santa Fe (Argentina). Tel.: +54 (3400) 478200, LPucchio@acindar.com.ar

**PROCEDURE / DEVELOPMENT**

This implementation work of a new lining product for the continuous casting tundishes carried out in the Arcelor Mittal Acindar installations is preceded by a wide study for the correct formulation of this material.

The developed product is basically formed or constituted by sintered magnesia in an adequate grain size distribution and a special liquid binders system added for sharpening the mass. The mix is setting at room temperature due to the hardened action of one of the additives added as binder, induced by the second additive which acts as the hardening reaction catalyst. This additives system allows us to modulate the speed of reaction, as well as the achieving mechanical strength, depending on the additive kind used and its quantity.

The characterization and development of this refractory mass included X-Ray Fluorescence, thermogravimetry, X-Ray Diffraction, and thermal conductivity determination among others.

The material must be molded. In the laboratory, this fact is solved by using molds, like the one showed in the Figure 1, in order to obtain the test probes which are tested later. In the Steel-plant, the presence of a concentric mold for the tundish is required, as it will be seen pages after.

***Figure 1:*** *Self-setting material after hardening and molding*

The X-ray Fluorescence analysis results are shown in the Table 1. The material presents a grain size distribution up to 2 mm. This distribution is determined by a light scattering measurement (Particle Size Analyzer Mastersizer 2000). The different used granulometries make easy the product implementation or establishment into the customer depending on the requirements of each steel-plant's production process. Acindar needs a versatile product which can be used for cold casting entrance and at the same time for a hot entrance: with a pre-heating of the material above 1000ºC before the introduction of the liquid Steel from the ladle to the tundish.

| Análisis Químico | Contenido (%) |
|---|---|
| $SiO_2$ | 3,4 |
| CaO | 7,0 |
| $Fe_2O_3$ | 3,3 |
| MgO | 86,1 |
| L.O.I. (1000ºC) | 0,2 |

***Table 1:*** *X-Ray Fluorescence analysis for the studied refractory material*

Elemental analysis determinations were carried out in order to know exactly the amounts of carbon, hydrogen and nitrogen. The analyzer used for this study was a LECO CHN-2000 Macroanalyzer, using samples around 0,180 g. of weight. The possibility of analyzing relatively higher sample sizes with this instrument than with other analyzers reduces the measurement errors. The admissible error range is ±0,4% for each kind of atom. According to the elemental analysis, the founded contents for C and H in the shaped product are not significant (c.a. 0.16 and 0.14 % respectively; being inside the error range). As expected, the samples do not show nitrogen content anytime. The substances included in the catalysts are formed by carbon, hydrogen and oxygen, with proportions from 40 to 47% for C and from 5.0 to 6.5 % of H, being the rest principally oxygen.

The thermogravimetric study shows a thermal curve pattern like the one in the Figure 2.

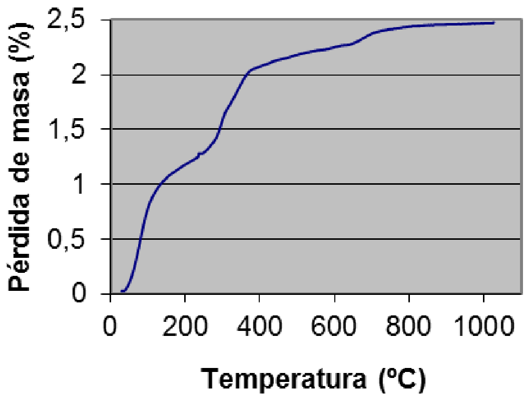


***Figure 2:*** *Thermogravimetric curve for the Self-setting material*

The Thermal conductivity studies show average values of around 1,640 W/mK at 1200ºC for the Thermal Conductivity of the cold-setting Magna materials (see figure 3). The preparation of the samples for these essays needs the conformation of the material into the adequate dimensioned test brick shape, according to the UNE-EN 993-15 rule. For a better comparison between these test probes or bricks and the material applied directly into the tundish, the same current additives were used for the preparation of mentioned probes. This UNE rule considers the determination at four temperatures: 400, 700, 1000 y 1200ºC.

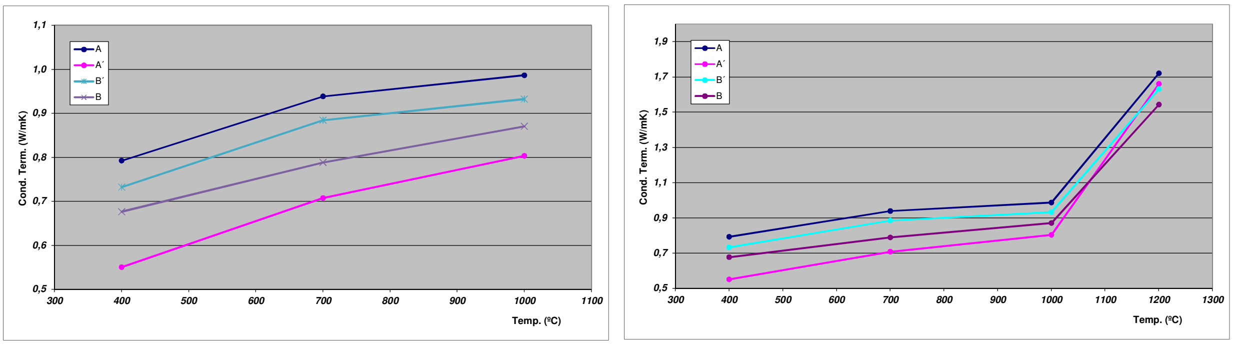


***Figure 3:*** *Thermal Conductivity for some Self-setting material formulations at 400, 700, 1000 y 1200ºC*

| A | B | B´ |
|---|---|---|
| 3,57 | 2,77 | 3,22 |
| 7,02 | 4,01 | 5,81 |
| 3,29 | 2,14 | 2,83 |
| 0,49 | 0,52 | 0,50 |
| 85,45 | 90,22 | 87,40 |
| 0,18 | 0,35 | 0,24 |
| **100,00** | **100,00** | **100,00** |

***Table 2:*** *X-Ray Fluorescence analysis for possible used materials*

These graphs become evident how Magna is able to modify the thermal conductivity of this self-setting product according to the ramming grade or the conforming way of the mass and to the raw material used for it.

The Infrared Spectroscopy study was carried out by a “Nicolet FTIR Avatar 360 model” FTIR spectrophotometer with a GOLDEN GATE ATR (Attenuated Total Reflectance) accessory with temperature control ranged from 20 to 200ºC. The infrared spectrum is determined, by Fourier transform helped by an OMNIC E.S.P [2] software, from the milled simple in the case of the refractory mass and directly in their liquid state for the catalysts.

The X-Ray Diffraction was used principally for evaluating the refractory material in the development of the self-hardening material. The spectra of powdered samples were registered by a Bruker D8 Advance X-Ray Diffractometer, provided by a X Kristalloflex K760 X-ray generator, using $K_{\alpha 1}$ of Cu ($\lambda$=1,5417 Å) radiation, an increment of $2\theta$ = 0,02º and 1 s/step, in a $2\theta$ range from 2º to 40º.

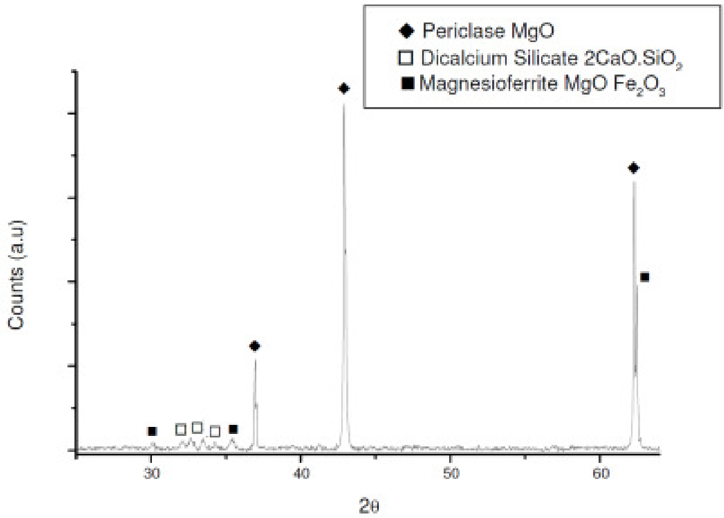


**Figura 4:** Espectro de Difracción de Rayos X del material refractario a estudio
*.**Figure 4:** X-Ray Diffraction Spectra of the studied refractory material*

The mineralogical phases founded in these diffractograms for this refractory material were, principally: Periclase, Dicalcium silicate and Magnesium ferrite, as Figure 4 shows.

## RESULTS / CONCLUSION

The usual application of this product in AM Acindar starts with the necessary on ground installation of the adequate machine. This machine is a mixer machine which makes much easier and cleaner, avoiding the powders generation of other systems, the use of this material. Magna counts with a high experience in this kind of machinery (see Figure 5) as well as in other automatism solutions for the application or installation of refractory materials.

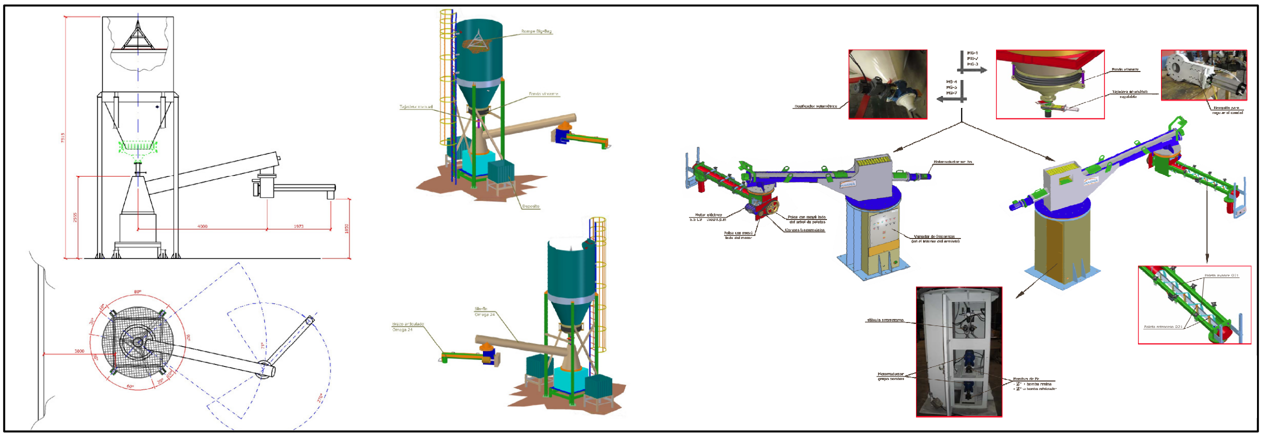

***Figure 5:** An example of the layouts of the Magna's mixer machine for the cold-setting Coldmag material*

As Figure 6 shows, the tundish installation begins with the lining of its bottom in refractory material poured by the mixer machine (Figure 7) where the mass, in the hopper, is mixed in a mixer screw with both needed additives for the material self-hardening. After the bottom application, the mold is located (Figure 6) and the space between the mold and the safety lining of the tundish is filled up with the material. The result can be seen in Figure 7. The remaining time for hardening can vary from 20 minutes to 2 hours depending on the different conditions, and after taking out the mold the tundish is presented as the last image in the Figure 7. The material shapes under a cold safety wall as well as under a hot one, affecting to the curing time only. High temperatures reduce the curing time due to the acceleration of the binder hardening process, but working below 90ºC is suggested as the usual performance.

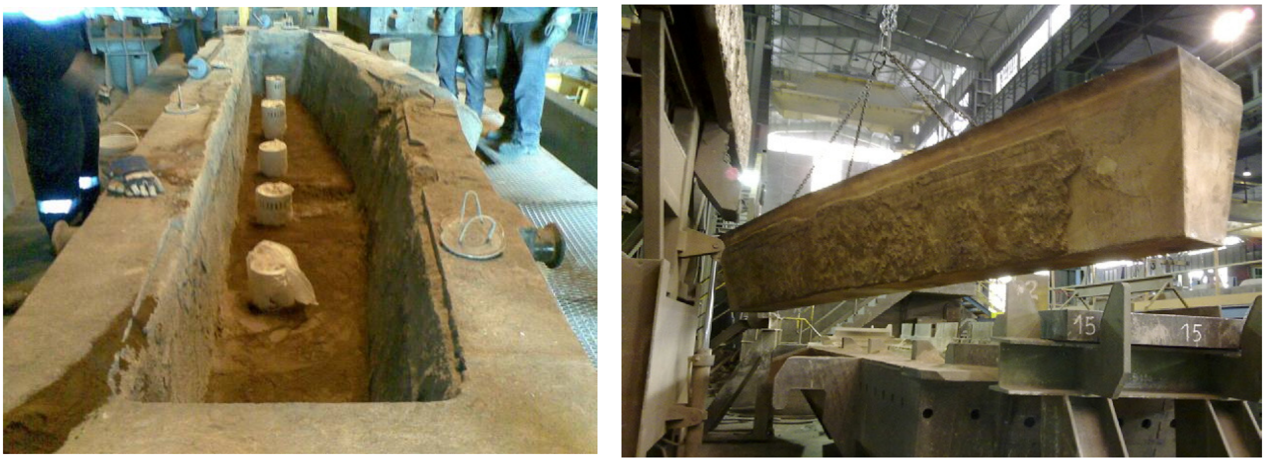


***Figure 6:*** *Performance of the Magna's cold-setting material in Acindar (1)*

The required time for the material application was reduced from 28 to 23 minutes during the Acindar's trial period. According to these data, the used material amount for the lining was between 2200 Kg to 1800 Kg respectively.

The Coldmag bonding system, which permits the hardening at room temperature, implies, as expected, that the material hardens inside the mixing chamber, too. But on the other hand this additives system facilitates the cleaning by using pressurized water and screw rotation into this chamber. The possible speed reaction modulation makes the cleaning process easy, too.

The continuous casting experiences in AM Acindar steel plant included tundishes in its both casting systems: open nozzle, using cold starts as well as some soft pre-heating of the material; and submerged nozzle where a material pre-heating up to a maximum of 1200ºC is always required for special steels in this plant.

***Figure 7:*** *Performance of the Magna's cold-setting material in Acindar (2)*

When Acindar started with the development trials of this Magna material, all of the entrances to the continuous casting machine were made with previous pre-heating of the tundishes. The first trials for this material were carried out in that way for open nozzle. The initial pre-heating curve for these tundishes implied no more than 1000ºC, being reduced to 850ºC after some tests. Just only this change implied a reduction from the current pre-heating process used for the previous gunning lining material of the tundish. Then, Magna went further with the cold starting trails for natural hardness steel, by modifying the exit temperature from ladle furnace. These trials were very successful, and today this is the defined procedure for this self-setting refractory material and these mentioned steel qualities.
The result of the development and the modifications of work refractory lining thickness for this dry material in Acindar was 37 to 42 hours of casting (representing between 40 and 45 steel heats) in open nozzle casting system, whether with cold start or with previous pre-heating of the tundish. This difference in casting hours does not correspond to the material behavior but the particular production needs of the steel plant.

As an example, in Figure 9 some thermographs of the tundish shell in several regions are shown. This quality control is carried out for assuring the temperatures are within the normal parameters for a safe and adequate casting process. Anyway, it is always necessary to take into account the thermal profile of the refractory lining used, as well as the safety lining condition and the existed insulation material, for determining these normal parameters. A tundish which sequenced 38 heats showed shell temperatures below 340ºC for the hottest spot, between 3rd and 4th lines. Other example was an open nozzle tundish which made 40 heats or ladles (more than 37 hours casting) and the temperatures on the same hottest point did not exceed 300ºC.

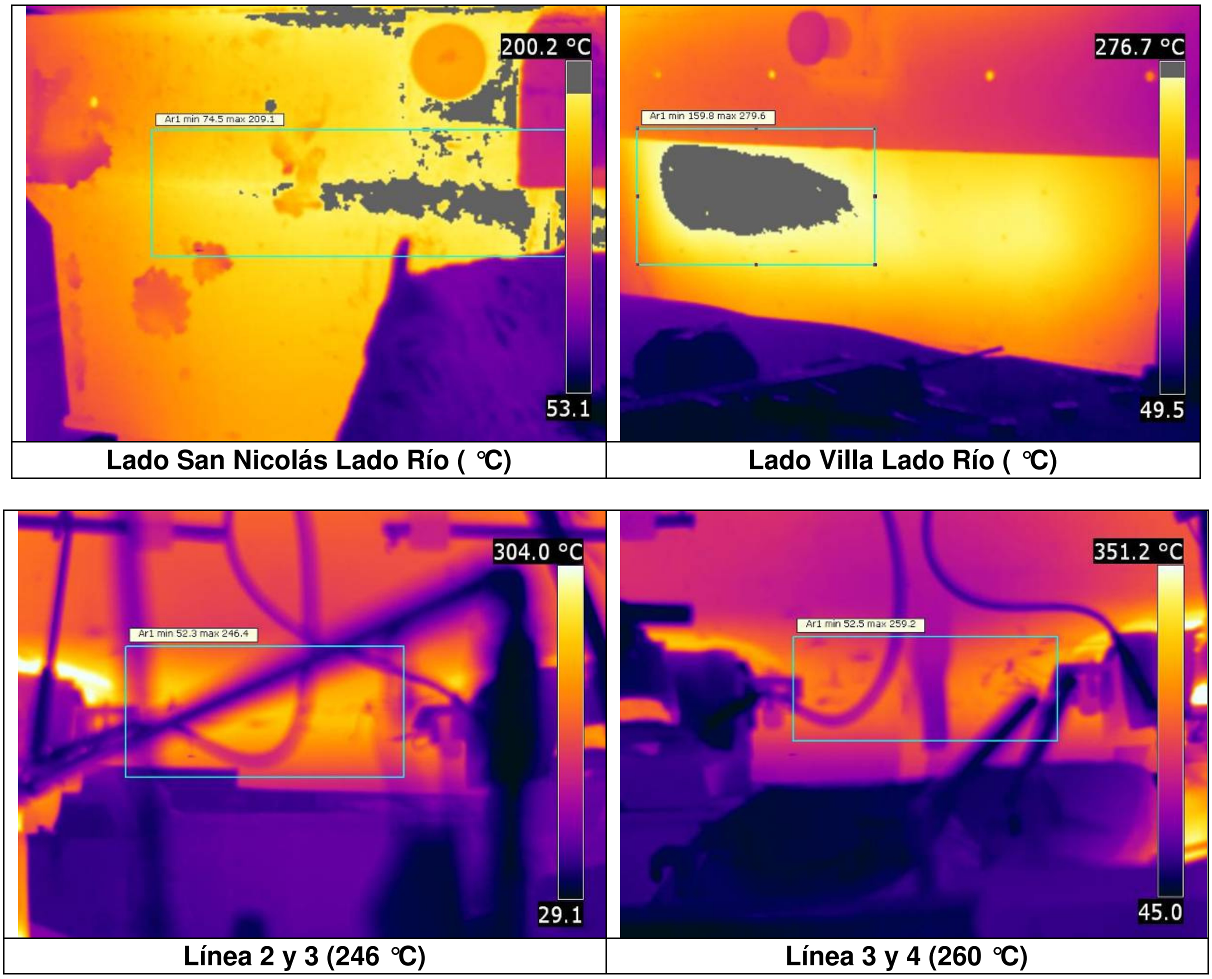


***Figure 8:*** *Thermography of an Acindar's tundish with Magna's cold-setting material, as an example*

Several steel qualities aluminum killed, vanadium-chrome blended or re- sulfured and with lead have been produced using tundishes lined by Coldmag. For these qualities, with a submerged nozzle casting system requirement, a previous pre-heating is needed for the tundish. Here is where this cold-setting material suffers the maximum exigent requirement. During the different heating tests, the curves and the temperatures were modified until achieving the adequate behavior of the material with pre-heating at 600ºC for a variable time period according to the production program and followed by 150 minutes more of heating up to 1200ºC.

Another important factor in this development was the tundish deskulling. In all cases, whether casting with submerged nozzle, open nozzle, with cold start or pre-heating, the tundishes were dumped with no difficulties.

Since the beginning of the development in cooperation with Acindar, it was known that the sequences for the submerged nozzle tundishes were shorter than the objectivized or expected for open nozzle. However, during this trials period, the plant was able to increase the sequencing index even doubling the usual amount of heats using this tundish work lining. The obtained results in the study of this self-setting Coldmag material showed a good disposition for being used with special steels in long sequences. Experiences in other steel-plants support this statement, too.
The steel cleanliness is even improved in comparison with other systems. The correct shape achieved for the tundish material assures the no presence of inclusions due to fluidized carried out refractory particles. Besides, lower hydrogen contents have been reported in the first steel ladle with this pre-heated material than with other

systems after pre-heating, too. Likewise, similar or better hydrogen pick-up results have been founded for this new material in a Cold start without pre-heating in comparison with, for example, gunning materials that have been cured by heating and even have suffered some previous pre-heating treatment. So, the hydrogen and carbon contents are adequate for cold casting entrances as well as after pre-heating of the tundish. This condition has been demonstrated in AM Acindar, as well as in the rest of the steel-plants where this cold-setting material has been evaluated and is being used, because no hydrogen pick-up cases have been reported.

The operation safety and the energy and tundish preparation time efficiencies are enhanced by using a self-setting material like this. A self-hardening material does not require to be heated for its application. With the crescent convincement of the possibility to enter to the continuous casting in a "cold" way, a lot of steel makers are using this new material with no heating before the casting. This "cold" start or entrance implies an additional energy saving [3]. In other cases, the reduction of the required pre-heating curves has been also reported in the Steel plants where this material is being used.

In the beginning, the hardening or curing time assumed in Acindar was 2 hours for safety, especially due to the dimensions of the tundish. Actually, after introducing some controls and modifications, the mold can be removed in one hour allowing the worker to have a tundish ready in 2 hours of total time. The material setting time by hardening goes from 20 minutes to 2 hours, depending on the requirements of the steelmaker and the thickness of the tundish walls. Some parameters, like the safety lining temperature, affect especially to this setting time. This system permits somehow to play and control these parameters by using, for example, the adequate catalyst. The use of different catalyst makes possible the modulation of the hardening or shaping reaction speed for this refractory material. In such way the material can be used over both cold and hot safety linings.

The dumping after the casting is especially easy: the self-hardening material (Coldmag) is completely separated from the safety lining normally in one piece. So, no previous cleaning is needed for the next tundish installation. The damages to the safety lining are minimized in comparison to other systems.

| \$ - Economical<br>\$\$ - Moderate<br>\$\$\$ - Expensive | **Silica Boards** | **Spray / Gunning Mixes** | **Dry Vibe** | **Cold Mag** |
|---|---|---|---|---|
| Equipment required | **0** | **\$\$\$** | **\$\$\$** | **\$\$** |
| Energy required (gas, electricity,...) | **0** | **\$\$\$** | **\$\$** | **0** |
| Time of application and manpower | **\$\$\$** | **\$\$\$** | **\$\$** | **\$** |
| Drying time | **0** | **\$\$\$** | **\$\$** | **\$** |

***Table 3:*** *Comparison of the requirements for the different tundish masses*

The results in Acindar have implied the introduction of this material in South America in the same way that happened in other continents being now with very good results present in steel plants of more than fifteen countries. The continuous development for adapting this product to the steelmaker requirements, involving always new research studies, makes this material a material in continuous evolution. All of this collaboration study between Magna and Acindar, guaranteed by the large number of previous laboratory essays and the experiences in all of the steel-plants where this self-setting material is present, allows us to confirm that Coldmag is a true improvement in the refractory masses and implies a real advantage for the steel continuous casting.

The cold-setting Magna system, Coldmag, demonstrate to be:
The fastest, cleanest and easiest method for the work lining of the tundish, improving the safety and health conditions and reducing the required time per person/tundish;

The system which reduces at maximum the complete tundish cycle time, allowing the maximum tundish availability for the steel plant: reduction of the application time, curing or hardening time, and the time for the deskulling;
The energy saving is maximum by using this lining system. Because of all of these, it becomes into the most ecological way to tundish.

**ACKNOWLEDGEMENTS**

The authors acknowledge to the IAS for the acceptation of this paper as a presentation during the conference Refractory Materials'11 and for its publication in the corresponding proceedings book. Iñigo X. García-Zubiri, in representation of Magnesitas Navarras, S.A. company, wants to thank Arcelor Mittal Acindar, especially Luciana Pucchio, Silvia Murialdo, Marcelo Lagier, Luciano Disante y Mariano Comas, all of the given support during the implementation of this material development in their plant, which finally permitted the fulfillment of this collaboration work.

**REFERENCES**

1- Stevenson J., Machin J. and Dyke D.L., "Sand Reclamation" US Patent 4416694 (1983)
2- OMNIC v. 5.1. Nicolet Instrument Corp. Madison, WI, USA.
3- Kirschen M., Badr K., Cappel J. and Drescher A. "A Cost-Effective Method to Reduce Energy Consumption and $CO_2$ Emissions in Steelmaking" Stahl und Eisen., 129, No. 9, 20–28 (2009).