# Powder dosing with mould temperature feedback control in continuous casting of stainless steel for high quality billet surfaces

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Ergolines has a consolidated experience in the implementation of closed-loop mould powder feeding with inductive or optical sensors. In the recent years, Ergolines has also implemented closed-loop mold powder thickness control based on the ultrasonic sensor (ULD). The present installations of UT-MAP are working to measure and control mould powder thickness, providing a feedback signal to the automatic powder feeders (MPF). The temperature trends were cross-correlated with the results of steel quality analysis on tracked billets: billets cast under manual powder feeding featured several occurrences of bleedings and powder entrapment events caused by the saw-tooth meniscus perturbation. ULD+MPF was installed in Cogne Acciai Speciali CAS, Aosta Plant (Italy), in April 2019 and the application was developed by CAS Technicians. Evidences are that thermal data obtained by ultrasonic sensor are strictly related to chemical composition of the steel and to casting process parameters. A fine tuning quality control, based on thermal data (ULD) controlling automatic powder feeding (MPF), was developed in Cogne Acciai Speciali. The optimization of the powder quantity according to CAS specific know how was targeted to minimize powder entrapment phenomena, providing a more stable steel meniscus temperature. Defects occurrence on billet surfaces were reduced by 75%. On Final products, bright bars 100% eddy current controlled, the scrape rate due to cracks related to entrapment phenomena has been reduced by 50%.

**KEYWORDS:** MOLD THERMAL MAPPING, ULTRASONIC SENSOR, MOLD POWDER THICKNESS CONTROL, STAINLESS STEEL, HIGH QUALITY, TECHNOLOGY, INNOVATION;

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## INTRODUCTION

The crucial impact of the initial solidification on steel quality is well-established[1-2]. Furthermore, the occurrence of defects in the cast products is directly related with the dynamics of the fluid flow in the mold and with meniscus stability[3,4]. The temperature distribution along the copper tube in the meniscus region provides key data on heat transfer, skin formation and meniscus stability. However, traditional techniques to measure the copper temperature involve invasive probes such as thermocouples (TC) or optical fibre cables (OFC)[5], which require expensive machining of each single copper tube and complex management of multiple cable outlets in a critical area. Due to these drawbacks, TC- or OFC-based mold thermal monitoring is typically limited to slab casting and plate molds, being not feasible in the everyday casting practice of small sections. In fact, due to installation criticalities and costs, TC and OFC application to billets and blooms is typically restricted to research projects and validation of simulation models for scientific purposes. In order to overcome these limitations, Ergolines developed an ultrasonic sensor (ULD) able to measure the copper temperature in a fully contactless way, without the need to machine the copper tube. In fact, the ULD sensor is installed within the water jacket and features one single cable outlet.

The ULD measures the copper temperature at several locations along the mold wall, providing real-time data on the meniscus thermal profile and copper temperature trends over time.

Historic ULD data collected on the steel plant database can be correlated with the quality control data acquired on tracked billets. These data can in turn be analyzed and exploited by the CCM specialists to improve the casting practice, leading to significantly improved steel quality. Furthermore, the temperature trends provide important information on the skin formation and heat transfer in the mold, potentially enabling to fine-tune key casting parameters such as casting speed, primary cooling and mold lubrication to minimize the breakout risk and enhance productivity. The ULD sensor therefore represents a key tool to Metallurgists, Quality Control experts and Productivity Managers[6-10].

## ULD INSTALLATION

In contrast to TC or OFC, which require expensive machining of the copper tube and feature several cable outlets, Ergolines' ULD is installed within the water jacket, requiring no machining of the copper tube at all. Furthermore, the ULD has one single cable outlet, enabling a fast connection and disconnection of the signal cables (Fig. 1). The front side of the sensor is aligned with the inner wall of the water jacket, enabling the primary cooling water to flow in front of the sensor.

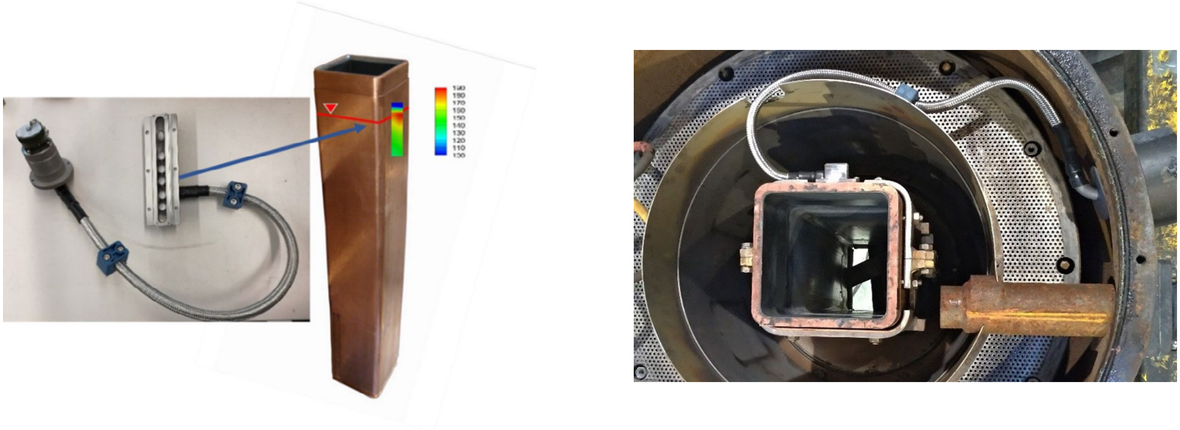

**Fig.1** - Ergolines' ultrasonic sensor (ULD): Non-invasive installation in the water jacket.

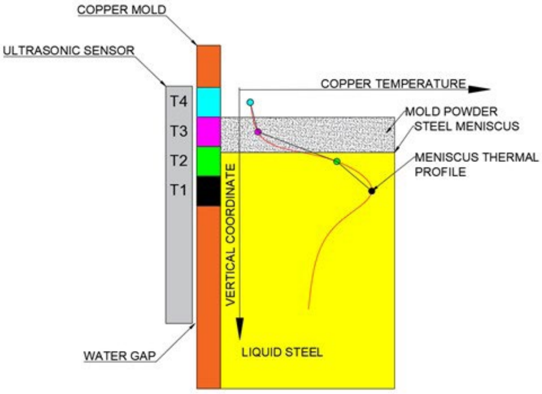

**Fig.2** - Concept of Meniscus Thermal Profile. Colors are used to associate thermal profile points with copper volumes.

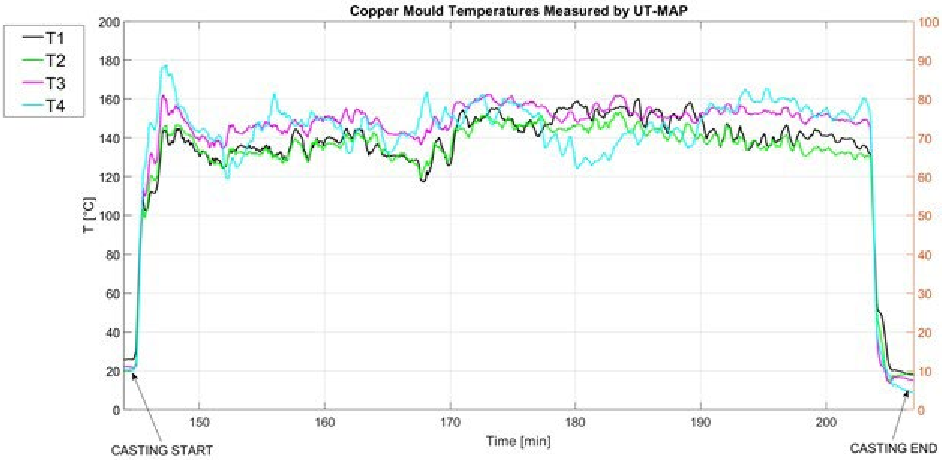

**Fig.3** - Temperature trends measured by a 4-points ULD sensor. Color code is the same as the one used in Fig. 2 (T4 corresponds to the volume which is the closest to the top of copper).

## ULD WORKING PRINCIPLE

The copper temperature across the meniscus is characterized by a marked gradient, corresponding to the meniscus thermal profile (Fig. 2). The profile typically displays a maximum slightly below the meniscus, while skin detachment generally corresponds to a temperature decrease in the area immediately below the profile peak. The ULD generates an ultrasonic beam which crosses the water gap and propagates along the copper wall of the mold. The ultrasound is then collected by an array of receivers and the signals are processed by a dedicated inversion algorithm developed by Ergolines. Since ultrasound velocity in copper depends on temperature, copper temperatures can be determined by signal processing based on mathematical inversion. The algorithm determines the copper temperatures at several locations along the mold wall in the meniscus region. The scheme in Fig. 2 explains this concept in the case of four temperature points. Due to the physical dimension of the ultrasonic beam, each temperature is averaged over a copper volume of typically 2 cm$^3$ (colored copper regions in Fig 2). The meniscus thermal profile is obtained by plotting the copper temperatures measured by the ULD against the vertical coordinate of the corresponding copper volume. This concept is explained in Fig. 2 by assigning to each profile point the same color as the copper volume over which the temperature is averaged.

Furthermore, each copper temperature can be plotted against time, providing the copper temperature trends. An example of copper temperature trends measured over time is displayed in Fig. 3. The four temperature points are labelled T1, T2, T3 and T4, where T4 conventionally corresponds to the volume which is the closest to the top of the copper tube. Casting start and casting end are clearly seen by a sharp increase and decrease in the temperature trends, respectively, while temperature variations during casting reflect the dynamics of the steel meniscus and casting powder.

The copper temperature data measured by the ULD can be stored in the steel plant database and correlated with the results of Quality Control analysis on tracked billets, providing crucial information to Metallurgists and CCM experts. In fact, by analyzing the ULD data, the casting specialists can fine-tune key casting parameters including mold powder thickness, casting speed and primary water cooling, leading to an optimized casting practice and improved steel quality.

### Application of ULD to Automatic Mold Powder Feeding

Ergolines has a well-established experience on the design of automated powder feeders and in the implementation of closed-loop powder thickness control based on dedicated sensors (electromagnetic, optical and ultrasonic sensors)[11-19]. Besides providing real-time mold thermal mapping, the ULD signal can be used to close the control loop of an automated powder feeding machine, enabling accurate and real-time control of the mold powder thickness (PTC-Powder Thickness Control). Closed-loop PTC based on the ULD can be implemented either on pre-installed powder feeding machines or on Ergolines' Mold Powder Feeders (MPF, Fig. 4). The MPF option enables to fine-tune the powder thickness in real-time with high accuracy, based on an innovative powder dosing technology developed by Ergolines16. In fact, it is well-known that the ability to keep the powder thickness constant during casting is crucial to obtain high quality steel based on a reproducible process[12,15]. By combining ultrasonic mold thermal mapping with ULD-based automatic powder feeding, the metallurgists can determine the optimal value of powder thickness for each steel grade and keep the powder thickness constant with Ergolines' MPF technology, leading to enhanced and reproducible steel quality.

**Fig.4** - An example of Ergolines' Mold Powder Feeder (MPF).

## INDUSTRIAL OPERATION

The closed-loop powder thickness control, ULD+MPF, was implemented in Cogne Acciai Speciali, Aosta Plant (Italy), targeting the scrap reduction on final products through the improvement of billets surface quality.

The Continuous Casting machine in which the system was tested has features listed hereafter:

- 80 Tons ladle; 15 Tons tundish;
- Curved machine 10 m radius; 4 strands;
- Sliding gate + radioactive Metacom-Berthold for level control;
- Hydraulic oscillation;
- M-EMS + F-EMS;
- Level2 automation.

CAS casts only Stainless Steel grades, in three different billet sizes:

- 160 mm x 160 mm;
- 220 mm x 270 mm;
- 280 mm x 340 mm.

Typical casting speeds range from 1,2 m/min to 1,6 m/min with a superheat of about +40°C.

### Product Quality Improvement

As discussed before, the goal of the project started in Cogne Acciai Speciali was the improvement of the quality in the final product, with particular reference to defects arising in peeled bars and coming from the steelmaking process.

On peeled bars, typical anomalies due to casting and put into evidence at final eddy current control are the "crack with powder entrapment". Although the only analysis of the surface morphology of the defect, fig.5, and even the eddy current itself cannot clearly identify the nature of the defect, the SEM exam, fig.6, reveals the root cause: continuous casting powder entrapped.

**Fig.5** - Cracks on peeled bar.

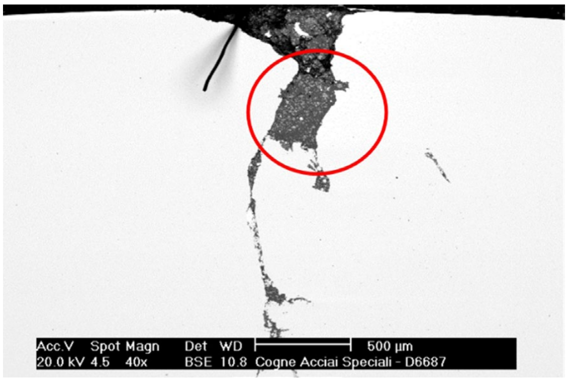

**Fig.6** - Powder entrapment (micro etching).

The powder entrapment that generates the defect on peeled bar, evidently comes from the continuous casted billet. In fact in some occasions anomalies are already evident there: in fig.5 a billet with a surface defect is presented. This type of defect is visually detected on billet surface and it is generated by lack of powder lubrication in the mould during casting.

The defect presented in fig.5 is extremely evident, and a countermeasure could be to remove it by grinding.

But, even not considering the loose of productivity due to grinding, in many cases powder entrapments are subcortical and their presence is subtle and not ascertainable with a visual check. That is why Cogne Acciai Speciali decided to investigate the phenomenon and to counteract it at root: in mould.

**Fig.7** - Cracks with powder entrapment.

## PROCESS KEY-PARAMETERS

To prevent powder entrapment during continuous casting operations, there are many key-parameters to take in account:

1. Steel level control;
2. Powder type (viscosity, basicity, melting temperature, %C free);
3. Powder feeding control;
4. Casting speed;
5. Casting temperature;
6. Oscillation control (stroke, frequency);
7. Primary cooling rate;
8. SEN geometry and immersion depth;
9. Mould geometry (taper, corner radius).

Moreover all the parameters must be set in agreement with steel chemical composition.

Cogne Acciai Speciali, CAS, worked in order to stabilize the "Powder Feeding Control" parameter by joining the ULD system with the MPF system, both systems installed in Cogne Continuous Casting Machine.

The main idea was to set the Powder Dosing on the MPF (automatic powder feeding) according to the temperature measured by the ULD sensor The approach suggested by CAS was implemented by Ergolines trough a software update, so that tests were industrially operated in the Cogne Plant.

## SYSTEM APPLICATION IN INDUSTRIAL OPERATION

From April 2019 in Cogne Acciai Speciali, Aosta Plant (Italy), the UT-MAP system (ULD) is working to measure and control mould powder thickness, providing a feedback signal to the automatic powder feeders (MPF).

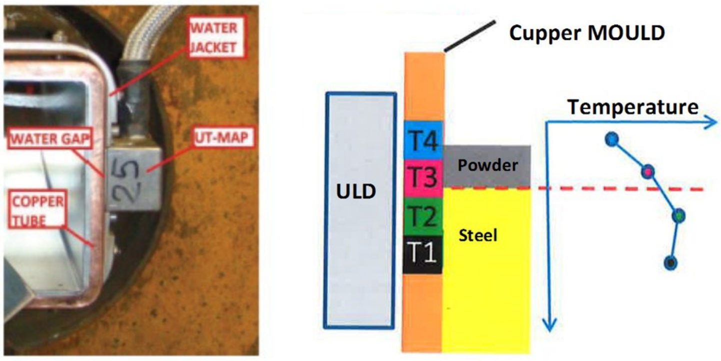

**Fig.8** - Ultrasonic sensor installation and working principle.

ULD Sensor is set in each mould water jacket on lateral side.

There are four point of temperature detection (T1, T2, T3, T4) on the mould for Cogne ULD (see Fig.8).

T3 is the temperature at the meniscus point.

ULD system measures the temperature profile and calculates a % of Powder Dose. Each casting strand (4 in Cogne CC machine) has a MPF powder feeder. We set a % of Powder Dose on the ULD+MPF HMI. The ULD measure the instantaneous mold Powder Dose (%), serving as feedback to drive MPF (automatic mold powder feeder) in closed-loop mode.

Data collected in casting clearly show that T3 (meniscus temperature) changes with %Powder Dose (see Fig.9). In particular the trend of Fig.9 put into evidence how:

Low Powder Dose% -> Low lubricating layer thickness -> Steel attached to the mould -> High T3 temperature.

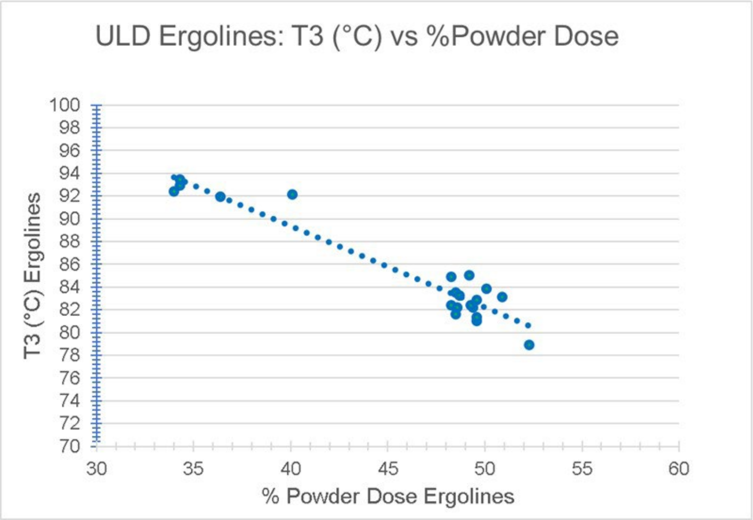

**Fig.9** - T3 (°C) vs %Powder Dose.

This approach makes it possible, setting the correct %Powder Dose, the optimization of the lubrication inside the mould. The optimal %Powder Dose parameter is function of the behavior in solidification of different steel grades, so finding the way of predicting its correct value (analytically or by experience) is the key to improve the billet quality surface.

During Cogne analysis, from May to December 2019 in more than 700 heats, all the temperature data were collected and managed in LEVEL2 automation with a dedicated report.

Collected data show that the optimization of the powder quantity obtained with the use of the ULD+MPF system in conjunction with the correct %Powder Dose guarantee a more stable steel meniscus temperature (see Fig.10) with respect to the manual powder adduction. In CAS experience the only MPF system, automatic powder feeding, without feed-back from ULD, not guarantee the same stability of steel meniscus temperature.

Moreover, the implementation of the ULD+MPF makes it possible, managing the data, to put the casting process under an additional control, also using control chart to control powder feeding stability (Fig.11), so that minimizing powder entrapment phenomena.

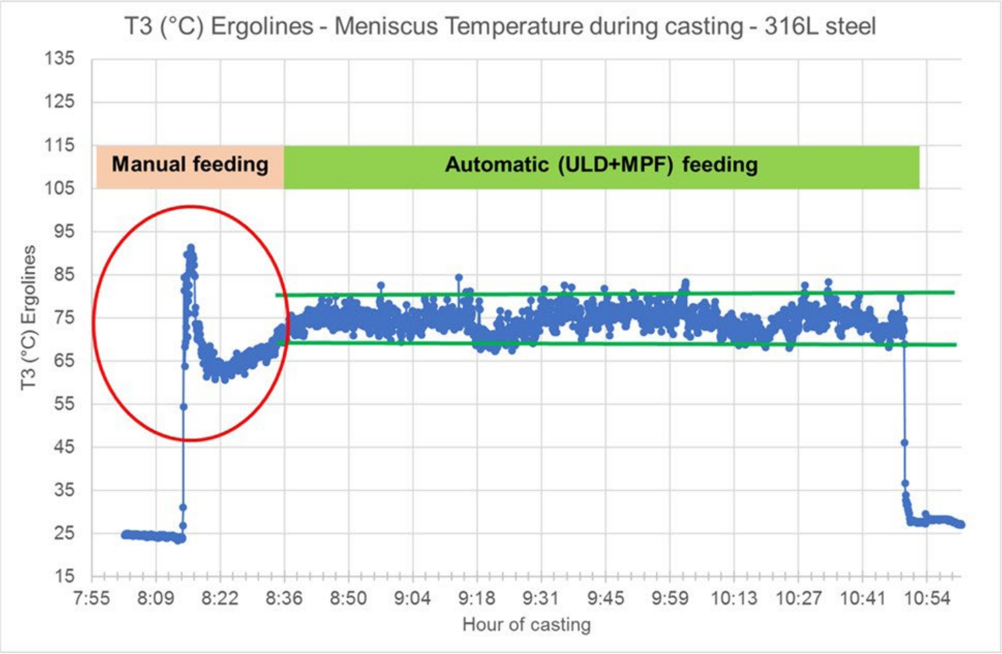

**Fig.10** - ULD Plant Data.

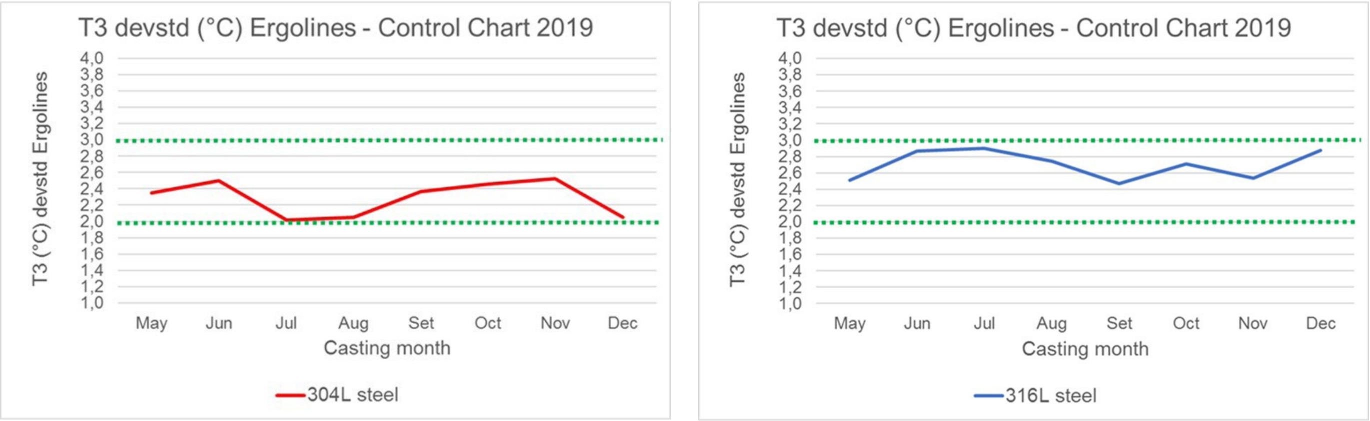

**Fig.11** - Control Chart – T3 standard deviation vs Casting month.

## INDUSTRIAL DATA KNOW-HOW

With ULD+MPF we are able to optimize powder feeding according to steel because we have a measure very sensible to process parameters variation.

As discussed before in general terms for all the grades, for austenitic stainless steel the meniscus temperature is strictly correlated to steel grade (chemical composition, ferrite content), because the chemistry control the shrinkage of solid steel shell in the mould (see Fig.12).

In this case the phenomenon could be interpreted as follows:

Low Ferrite content -> Low shrinkage -> Steel attached to the mould -> High T3 temperature.

Another important fact that has to be taken into account is that meniscus temperature is also correlated to Powder Viscosity, because the flux reology control the lubricating layer thickness between solid shell and the mould (see Fig.13). The interpretation makes reference to the following relations:

Low Viscosity -> Low lubricating layer thickness -> Steel attached to the mould -> High T3 temperature.

Also, it is noticed that meniscus temperature is correlated to oscillation parameters which control powder consumption during lubrication in the mould (see Fig.14), so that High frequency -> High powder consumption -> Low lubricating layer thickness -> Steel attached to the mould -> High T3 temperature.

By analyzing a real-time thermal map of the copper mould, we have the possibility to understand deeply the most critical topics about the initial solidification and to propose effective solutions, including fine-tuning of the casting key-parameters, improvement of the operative casting practice and optimized billet surface.

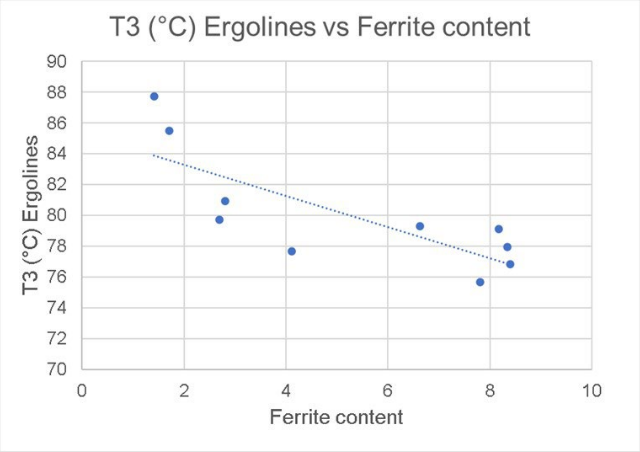

**Fig.12** - T3 (°C) vs Ferrite content.

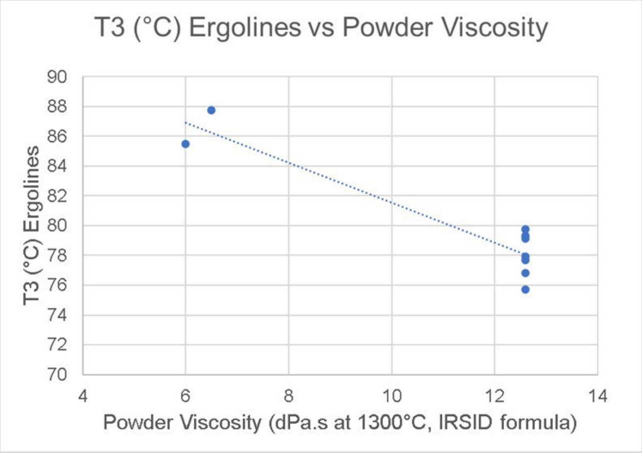

**Fig.13** -T3 (°C) vs Powder viscosity (dPa.s).

## DEFECT OCCURRENCE

Using ULD+MPF system, from May 2019 to December 2019, there was a reduction of 75% of powder entrapment defects on billet surface and by 50% the scrape rate due to cracks on final peeled bars.

## CONCLUSIONS

ULD+MPF (Ergolines system) was installed in Cogne Acciai Speciali CAS, Aosta Plant (Italy), in April 2019. A fine tuning quality monitoring, based on thermal data (ULD) controlling automatic powder feeding (MPF), was developed according to CAS specific know how. CAS plant data, more than 700 heats, show that the optimization of the powder quantity really minimize powder entrapment phenomena, providing a more stable steel meniscus temperature.

We have confidence that ULD data, collected in CAS plant, can be useful for a future development of this system. We want to set alarm on Continuous Casting LEVEL2 automation to separate billets when the meniscus temperature (T3 Ergolines) is out of optimal range, defined by very fine tuning of several plant data (chemical analysis, continuous casting parameters, billet surface defects, scrape rate on final peeled bars).

In this way we plan to reduce even more the scrape on final product.

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