AN INNOVATIVE SOLUTION FOR OPEN CONTINUOUS CASTING. FACTS AND FIGURES OF INDUSTRIAL APPLICATIONS.*

Andrea Giacobbe[1]
Ricccardo Carli [2]
Marco Alloni[3]
Simone Casagrande[5]

Abstract

The present paper provides an overview on design and development of a novel product, used as lubricant in the open casting process of steel. This new product is composed of a solid-liquid dispersion of specifically formulated continuous casting powder in highly customized synthetic oil and combines the performance advantages of casting powder with the easy handling properties of oil.
As usually experienced with traditional casting powders, the product has been tailored to customer conditions, such as steel grades, casting sections and speeds by adapting the solid part of the formulation.
Several benefits have been achieved by implementing different versions of this product, these benefits are the result of both an improved lubrication and heat extraction. Furthermore a reduced sparkling phenomena have been observed.
An overview of plant operations is described, keeping a close eye on dosing and mold feeding of this material.
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Keywords: Liquid powder, mold flux, open casting
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[1] *MsSc Chem, Product Manager, Flow contro Dpet.l, RHI Italia srl Via Corsica 14, 25125 Brescia Italy.*
[2] *Ph D.Chem, Head of Technical Dept, Prosimet spa, Via Rodi 10, 24040 Filago (BG) Italy*
[3] *MsSc Chem, Scientist, Technical Dept, Prosimet spa Via Rodi 10, 24040 Filago (BG) Italy*
[4] *MsSc Chem, Scientist, Technical Dept, Prosimet spa Via Rodi 10, 24040 Filago (BG) Italy*

1 INTRODUCTION

In continuous casting of steel, since the beginning of this technology oils of different nature have been employed as mold lubricants [1]. On top of other technological benefits, late use of mold flux resulted in a consistent increase of semis surface quality, which attained level of current benchmark of industrial applications. Nevertheless mold flux has seen implementation only in close casting technology while almost no advancement has been made on lubricants for open casting that is extensively used for billets casting.

This paper will illustrate results of a study concerning a new class of products which allows to extend use of casting powder to open casting, this new class of products is here named *liquid powders for continuous casting*.

Further, user friendly suitable pumping system has been developed and fully integrated with controls of casting machine.

2 DEVELOPMENT

a. Origin of the project

By exploring new possibilities for mold flux tecnology application, different powders to be used in open casting have been formulated. Most important feature of these products is a very fast melting with little consumption of heat. It has been observed that use of such product leads to advantages in the final quality of the billets such as:

- a decrease in rombohedricity;
- a decrease of the scale formation;
- a reduction of corner cracks occurence.

On the other hand a major holding point of using this type of powder is problematic mold feeding of powder itself resulting in erratic increase of NMI.

Due to promising results of concept application of specially formulated powders in open casting, it has been decided to overcome problem of mold feeding by mixing of these powders and in a specific liquid medium. Formulated product has been tested reporting outstanding performance [2]. Since original idea attained further confirmation, more in depth studies have been implemented aiming to get definition of optimal product formulation in terms of stability and technological performance.

b. Selection of liquid medium

Formulation of powder to be used in a liquid medium has been set up consistently with previous plant testing results [3]. Then the first step has been to select a suitable liquid medium in order to design a material with most suitable technological properties.

Different kinds of liquid media, essentially natural, mineral or synthetic oil, have been tested for the formulation of the product. Properties taken into account have beeen flash point, pour point, density and viscosity, considering following major criteria:

- Flash point should be as high as possible so that the liquid medium can work effectively as a carrier.
- Pour point should be as low as possible to avoid freezing of product in case of extreme environmental conditions.
- Both density and viscosity should be as high as possible, considering their influence on product stability.

A further key parameter taken into consideration in the choice of the liquid medium has been environmental compatibility in terms of biodegradability and non-toxicity of the combustion fumes produced during the casting process.
Liquid media tested are depicted in table 1

Table 1. Liquid medium features

Liquid media	Flash Point (°C)	Pour point (°C)	Density (g/cm3)	Kinematic viscosity 40°C (cSt)
Polialkilbenzol	182	ND	0,86 - 0,88	20 - 26
Polialphaolephine #1	225	-51	0,86	68
Polialphaolephine #2	260	-15	0,870	84,8
Glyceric ester of oleic acid #1	**300**	**-30**	**0,930**	**68**
Glyceric ester of oleic acid #2	300	-30	0,950	150
Glyceric ester of oleic acid #3	300	-10	0,935	61,5 - 68,5
Glyceric ester of fat acids #1	320	-24	0,920	34,92
Glyceric ester of fat acids #2	300	-12	0,925	65

Several laboratory tests have been performed to evaluate the characteristics of liquid media and related liquid medium-powder mixtures. As a conclusion a pool of selected liquid media have been found more suitable to the formulation of the mixture. In particular, the fluid #1 glyceric ester of oleic acid has been chosen for the formulation of the mixture to be used in industrial tests. In the following, terms as liquid medium and oil are used indifferently.

c. Properties of the mixture

The oil-powder mixture should be formulated to comply with two main properties closely interwinded.

Viscosity must be low enough to ensure pumpability and at the same time high enough to ensure a low rate of *Sedimentation*.

Viscosity

In Table 1, reference is made to the kinematic viscosity of liquid medium, expressed in cStokes, since this figure is generally reported in technical data sheets of oils used in open casting. The relationship between dinamic viscosity and kinematic viscosity is given by the following equation:

$$\eta = \frac{\mu}{d} \tag{1}$$

where η (Stokes) is cinemativc viscosity, μ (dPa*s) is dinamic viscosity and d (g/cm^3) is density [3].

Several measurements of viscosity of mixture and liquid media were performed. Experimental apparatus and extensive results have been previously reported [3].

These measurements pointed out that oil-powder mixture behaves as a non-Newtonian fluid with a marked tendency to shear-thinning viscosity, i.e. dispersion viscosity decreases with increasing shear-rate.

Moreover it has been observed that viscosity of oil-powder mixture depends on several factors such as viscosity of the oil, addition of certain additives, and the amount of powder in the mixture, see as an example data depicted in Fig 1.

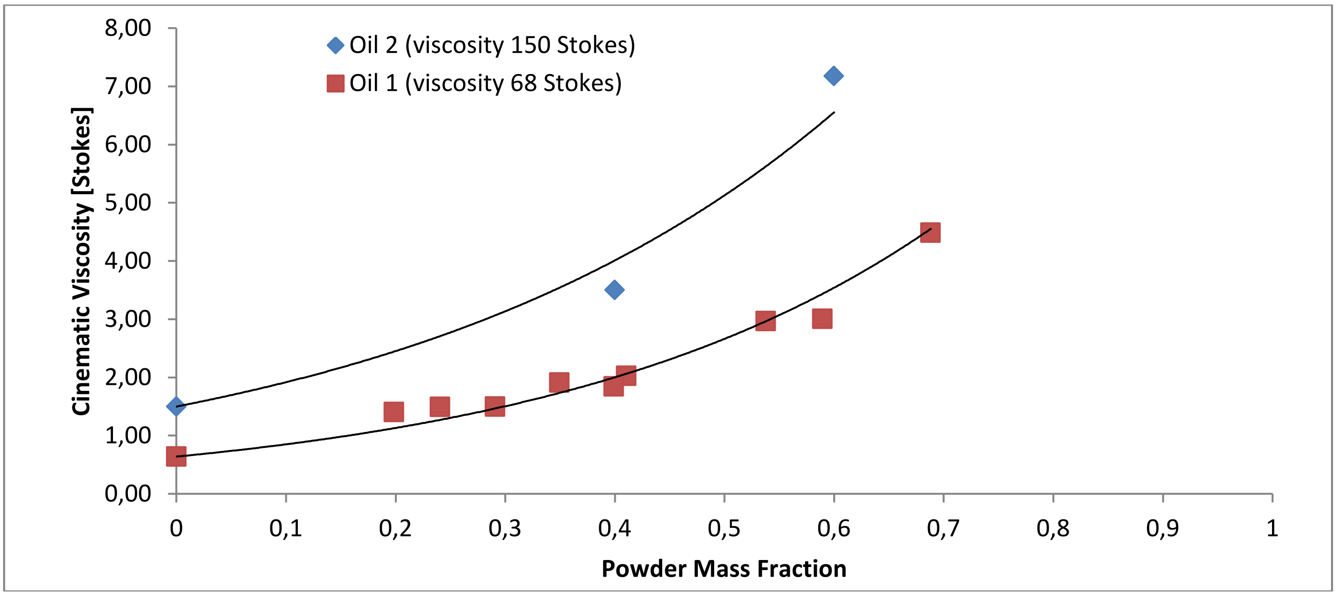


Fig 1 Trend of viscosity with increasing mass fraction of solid for mixtures prepared with oils with 68 and with 150 cStokes viscosity at 40°C.

Better reference to viscosity when measured for solid-liquid dispersions is trend of relative viscosity [4,5] with solid mass fraction. Relative viscosity is defined as

$$\eta_r = \frac{\eta}{\eta_0} \tag{2}$$

where η (Stokes) is the kinematic viscosity of the mixture, η_r is the relative viscosity and η_0 (Stokes) is the kinematic viscosity of the fluid in which solid is dispersed. Mass fraction is defined as

$$x = \frac{m_s}{m_{tot}} \quad (3)$$

where x is the mass fraction, m_s (kg) is the mass of solid in the dispersion and m_{tot} (kg) is the total mass of the dispersion. The data in figure 1 reported to relative viscosity lie on a single curve as depicted in Fig 2.

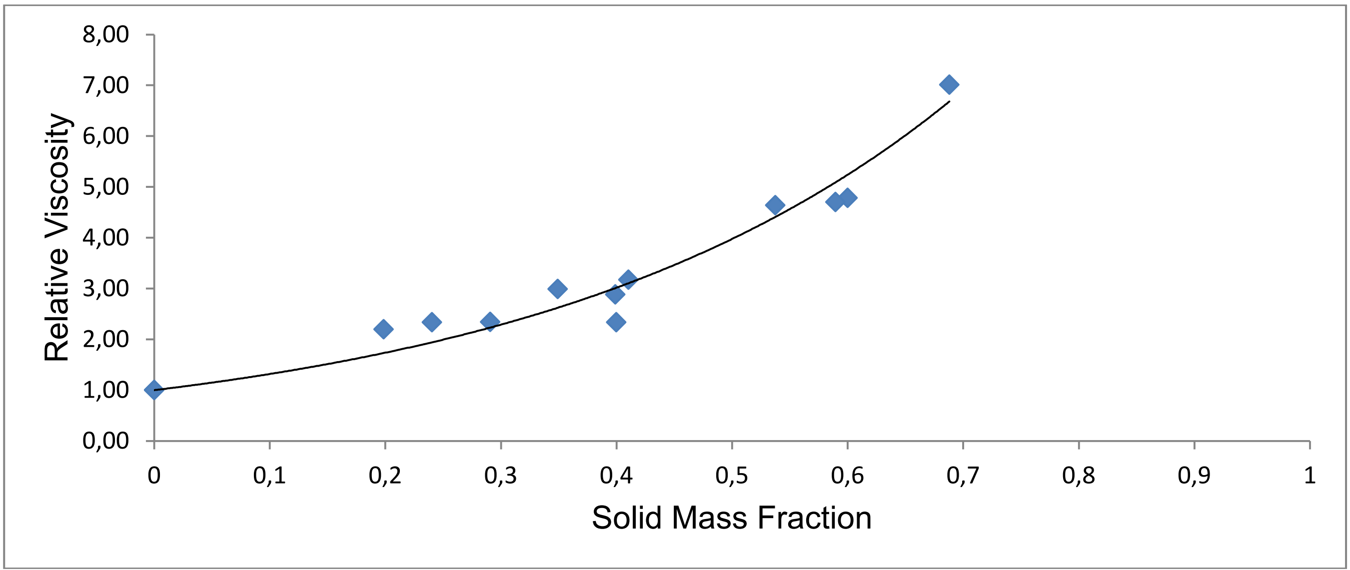


Fig. 2. Trend of relative viscosity with increasing mass fraction of solid.

Sedimentation

Dispersions undergo sedimentation due to various parameters. For very dilute suspensions consisting of non-interacting particles the sedimentation speed ,v_0 (m/s), is expressed by equation 4.

$$v_0 = \frac{2}{9}\frac{R^2 \Delta\rho g}{\eta} \quad (4)$$

where R (m) is the radius of the particles, $\Delta\rho$ (kg/m^3) is the difference in density between particles and medium, g (m/s^2) is the acceleration of gravity, and η (m^2/s) is the kinematic viscosity of the dispersion [4]. In case of concentrated suspensions the equation becomes more complex comprising effects of volume fraction of dispersed solid. Nevertheless, from a qualitative point of view, equation 4 indicates that the viscosity of the mixture and the density difference between the components are two main factors which must be taken into account in the formulation of an adequately stable dispersion.

If selection of proper liquid medium, as previously shown is affecting both viscosity and density, standard technological approach to stabilize liquid-solid dispersions is use of additives. Data reported in Fig 3 show variation of the de mixing over time by addition of different additives. Among the additives improving the stability of the dispersion those named B and C lead to a significant decrease of sedimentation rate due to a marked effect of thickening.

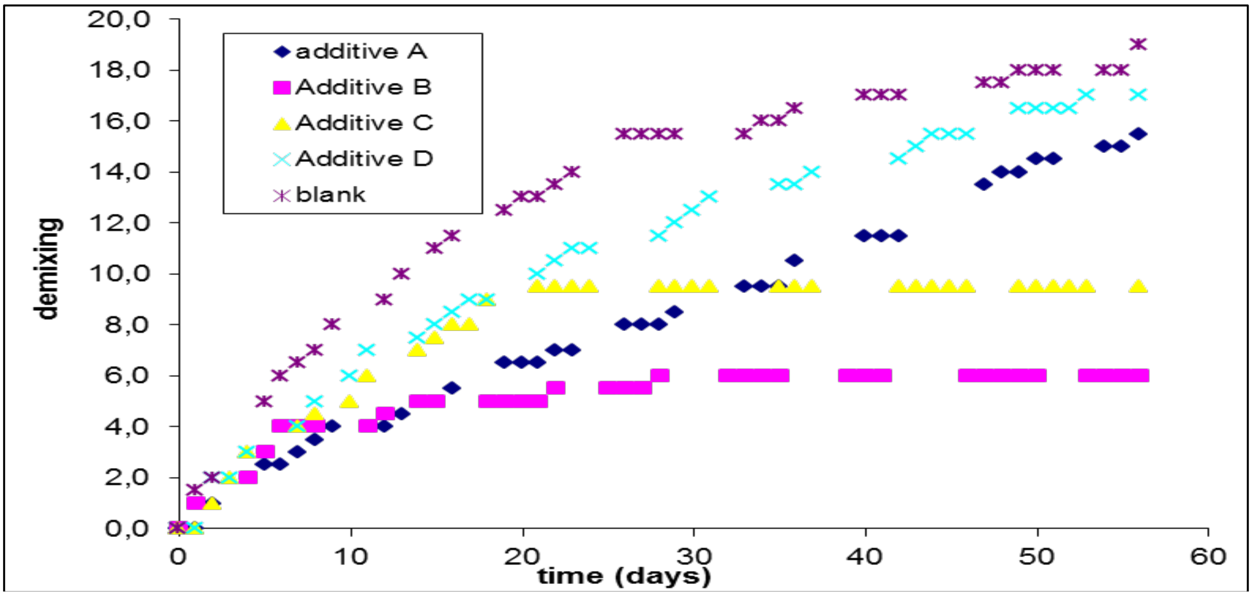


Fig. 3 Trend of sedimentation in time using different additives

In conclusion, extensive lab research has been performed to select most suitable components of oil-powder mixture for optimal technological properties.


Fig. 4 The liquid powder, how it looks like

d. Liquid powder how it works.

Best definition of this material is offered by its name: it is a powder, in this case a casting powder, with characteristics of a liquid. More precisely this product is working as a liquid slag of a casting powder pumped at room temperature into the mold. This is possible due to the fact that solid component of this solid-liquid dispersion of conveniently formulated casting powder in synthetic oil, is melting very rapidly at the expenses of heat produced by burning-off of liquid medium.

This feature is perfectly matching normal operations of continuous casting of long products in open steel stream, where thermal insulation of liquid steel bath is not an issue. The advantage resides in the fact that a liquid powder is not a compromise like oil, which is burning in contact with liquid steel. Liquid powder actually provides a liquid slag with all known properties of commercial casting powder for continuous casting in close steel stream. Change introduced by such a product in present technology is by any perspective a radical one.
As depicted in simple scheme of Figure 5, the liquid powder is feed through a head especially designed to fit specific mold size and shape.

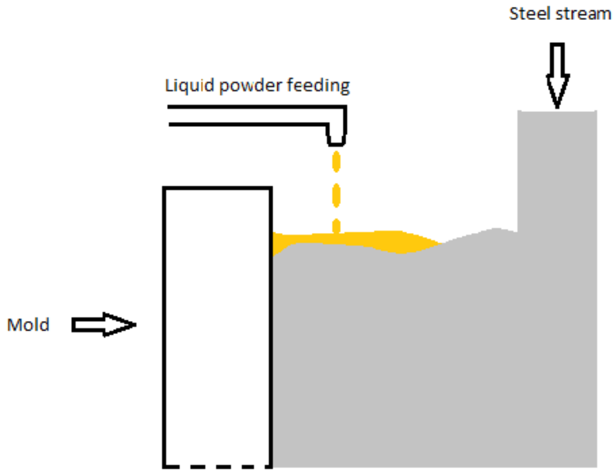


Figure 5: scheme of liquid powder functioning in mold.

Consistently, mold flange structure can be extremely simplified, being of no need usual internal channeling and gap to distribute lubricant on all faces of the mold. Indeed, the liquid powder in contact with liquid steel is spreading across the entire surface laying entirely close to meniscus area. This effect is a result of pressure produce by first impact wave of steel stream which push slag toward mold wall and some specific characteristics of slag. In particular, slag surface tension and viscosity have to be carefully balance to endow proper wettability and spreadability, avoiding potential slag entrapment. It has been observed as a general consequence that feeding rate fixed below a critical limit does not give any interference with liquid steel stream, dumping possible slag entrapment.

It's easy now to explain one of first phenomenon observed when liquid powder is used which is strong reduction of pyroclastic activity or sparkling, event normally dangerous for operators and tedious at the same time, requiring frequent cleaning of mold exposed surface particularly in flange gap area. See Figure 6

Fig. 6 Sparkling mold during casting. In left hand side strand liquid powder is used.

In spite of all important advantages above described, nothing is comparable with tremendous improvement of general casting process quality due to infiltration of liquid slag into gap between strand shell and mold wall, when the liquid powder starts working as a standard casting powder used for continuous casting in close steel stream.

In comparison with normal natural or synthetic oil used in open steel stream, liquid powder is surely adding effective lubrication and more important control capability of heat transfer between strand e mold wall, resulting in mild homogenous cooling and in a significant increase of effective length of the mold. See figure 7a 7b. Consequence of this situation is a large tide of noteworthy effects such as:

- strong rombhohedricity reduction,
- considerable drop in scale formation
- major increase of casting speed.

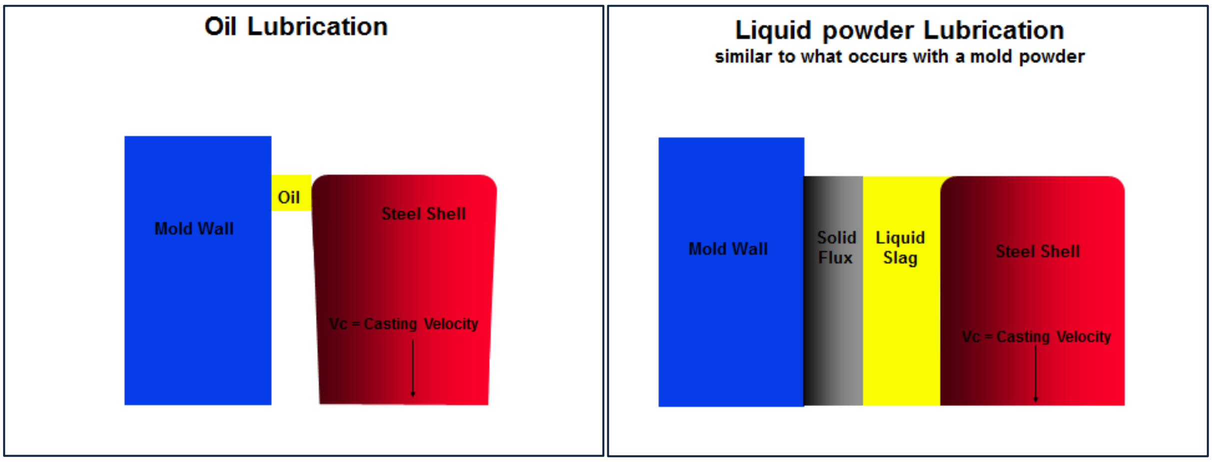


Fig. 7a & 7b oil and Liquid powder lubrication

e. Use of the liquid powder in existing continuous caster set-up.

Pumping system

Most important issue for practical application of a liquid powder has been selection of a suitable pumping system in terms of reliability, working life and cost. During this development stage at least a dozen of pumps, different for pumping mechanism and materials, worked simultaneously under intensive load 24 hours a day for weeks on a lab testing bench; diaphragm ones prove to be the most suitable.

These experiments allow identification of two systems with different purposes: one to be used for preliminary trials, when metering accuracy is essential in defining most suitable feeding parameters singular from case to case, and one for industrial applications, when reliability and robustness play key role.

In particular robustness has been extremely challenging due to the fact that the liquid powder carries exceptional erosion capability and conventional bodies do not fit; further in order to dose the correct amount into the mold the pump must be electric actuated and inverter controlled.

Interstop recently developed a friendly user trolley for testing purpose. See figure 8

Fig .8: Interstop test trolley

Non-Newtonian fluid: flow through cylindrical pipes

Then, selected pumping system had to be appropriately sized matching characteristics of pipes required in transferring the liquid powder from a reservoir vessel to a casting mold. Therefore, piping and pumping systems have to be designed based on knowledge of head pressure requirement for a given transfer duty. Clearly, the scope is to maintain stable flow of the liquid powder to a mold. In order to define the best dosing system it is crucial considering the fluid as a *Non-Newtonian,* with such a fluid the typical laminar flow regime doesn't apply. As a direct consequence operational viscosity depends on both temperature and applied shear stress and the product behaves as thixotropic material. See figure 9.

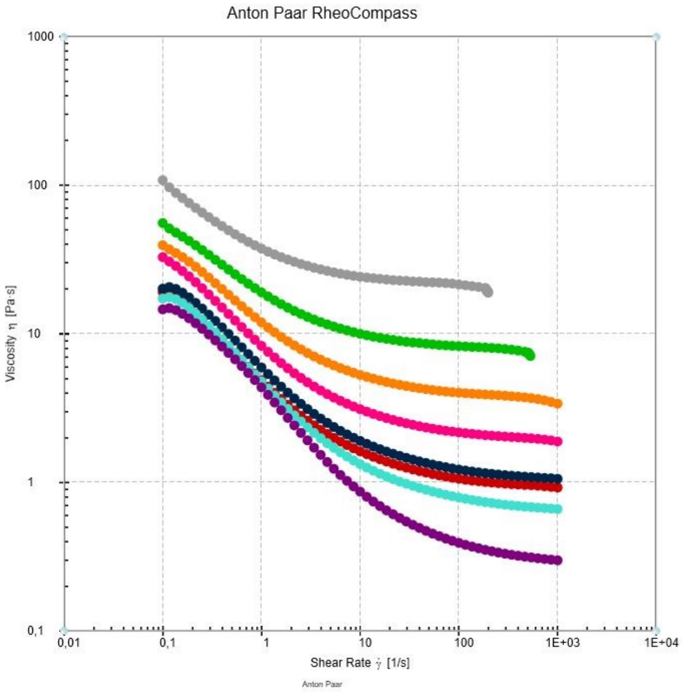


Fig .9: viscosity versus shear rate

Final setup for plant use

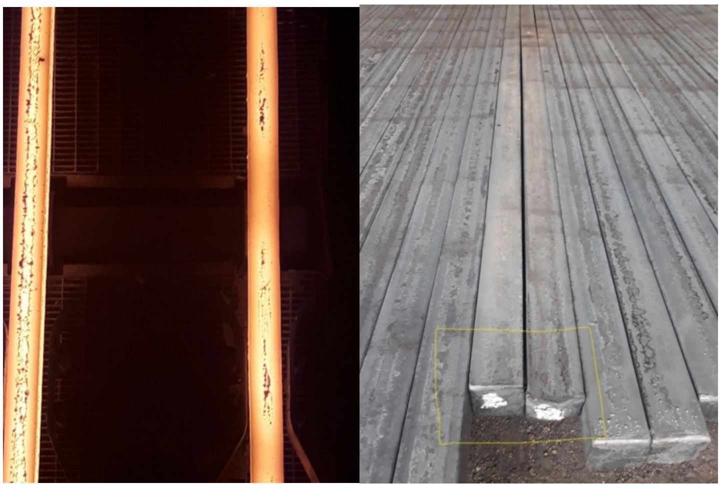
The outcome of this extensive effort dispensed in all development steps has been the possibility to provide a potential end user with suitable liquid powder and feeding system at the lowest interference with existing continuous caster set-up, in order to facilitate industrial scale tests or definitive installation and usage.

In particular, a final pumping system is presently constituted by a group of pumps, one for each strand, with all necessary piping and vessel reservoirs. A single pump is controlled by inverter and the system itself is regulated by a PLC for eventual full automatic mode, working on a feed-back cycle based on actual strand casting speed.

3 CONCLUSION

Exploring new possibilities for mold flux technology application has been the input to create a new class of products which combines the advantages oil and mold flux. Studies have been conducted to find the best components for optimal technological characteristic of finished product. Once selected the most suitable formulation, many industrial trials have been performed with following major results.

- the chance to increase casting speed or reduce cooling
- an improved quality surface with a strong rombohedricity reduction
- a significant decrease in scale formation (see figure 10a 10b)
- a reduced sparkling occurence


Figures 10a 10 b scale reduction

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