Strategies Against Reoxidation of Liquid Steel in Billet Casting with Metering Nozzle

Jorge Madias[1], Alberto Moreno[2]

[1]metallon
9 de Julio 432, San Nicolas, Buenos Aires B2900HGJ, Argentina
Phone: 011 54 336 442 1318
Email: jorge.madias@metallon.com.ar

[2]TechnoConsultancy
Villa Constitucion, Santa Fe 2919, Argentina
Phone: 011 54 3400 477121
Email: alberto.f.moreno@gmail.com

Keywords: billet casting, metering nozzle, reoxidation, scum formation, strand breakout.

INTRODUCTION

Continuous casting of billets with metering nozzle and oil lubrication is an efficient tool for obtaining long products for civil construction, with high productivity, low cost, and a quality level acceptable for these applications. This includes rebar (straight and in coil), round and square bars for general purposes, as well as light and medium shapes, angles and flats.

Within current technical and economic framework, for these products the casting system with submerged nozzle and mold flux is not viable. This system is typical for caster involved with special bar quality and seamless pipes. The reason is that submerged casting still has one hand an inherent lower productivity, limited by relatively short SEN life and lower casting speed, and on the other hand higher costs derived from the more complex casting refractories and the use of mold flux.

Classic operation of open casting in billet casters was powered along the latest decades by the introduction of ladle furnaces, the improvements in mold design for increased casting speed, the high degree of automation and the implementation of automatic nozzle change systems. This system gives increased safety in case of an emergency, as well as flexibility for changing casting speed if the need arises or for changing the nozzle if erosion, cracking or clogging occurs.

Open casting means no steel jet protection during transfer from ladle to tundish and from tundish to molds, with an exception for low carbon steel. In some cases, the injection of aluminum wire into the mold is still practiced. This practice was developed in the 70s, when ladle furnaces were not that common in minimills, as a mean to complete deoxidation without the risk of nozzle clogging [1]. Another usual practice for this kind of operation is slag fishing, to remove scum formed in the meniscus under reoxidation conditions. Oil at ignition temperature lights and generates flames.

Nevertheless, lately some mills are employing for these steels gas shrouding between tundish and mold; ceramic shrouding between ladle and tundish for all steel grades produced (not only for low carbon); do not practice neither aluminum injection nor slag fishing into the mold.

It becomes interesting to compare from several points of view both practices, and how they influence on key issues like operators safety, productivity and quality, and the CAPEX and OPEX involved (figure 1).

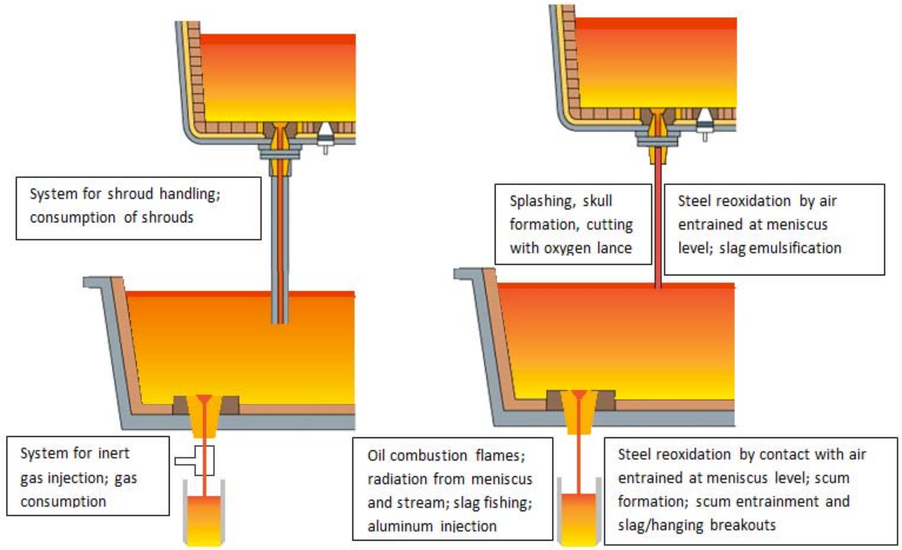

Figure 1. Two practices for casting with metering nozzle. Left: ceramic shrouding between ladle and tundish, and gaseous shrouding between tundish and mold. Right: fully open casting with no shrouding.

TRANSFERRING LIQUID STEEL FROM THE LADLE TO THE TUNDISH

Open casting simplifies the operation of starting-up the sequence, and the ladle changes, as there is no need for tube removal from the empty ladle, oxygen injection for cleaning the tube for reuse nor the adjustment of the tube to a new ladle. From the point of view of caster design, there is no need for a large height between ladle and tundish, and/or shifting, to make shroud adjustment easier.

In absence of the shroud there are some negative consequences. Steel splashing takes place, particularly during tundish filling/refilling, affecting working conditions at the tundish level and eventually in the casting platform (figure 2). Sticking of steel droplets may occur in both tundish sides, close to the jet. This may lead to skull formation along the sequence, requiring periodical oxygen lancing for cleaning, with inherent safety risk [2].

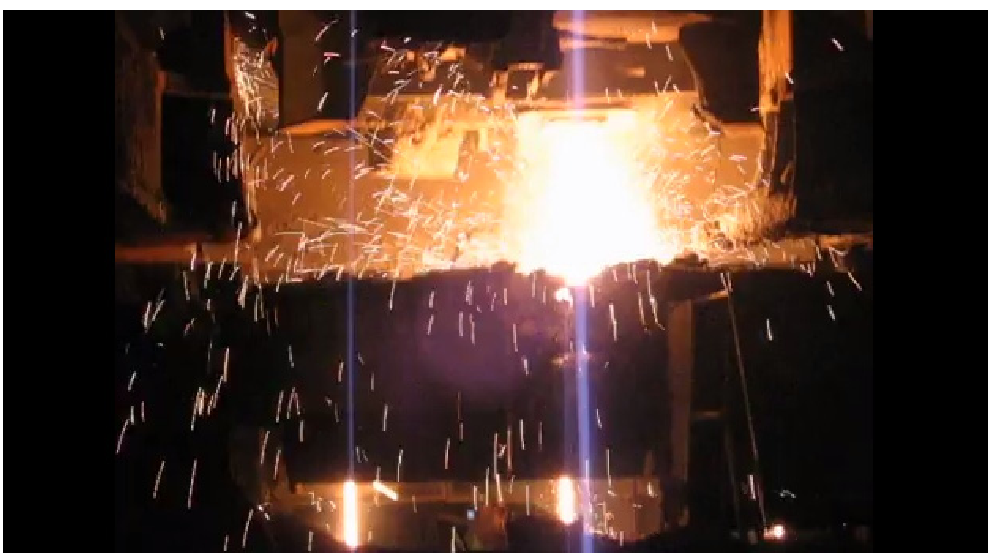

Figure 2. Open casting between ladle and tundish, with a 65 ton ladle. Splashing during tundish filling [3].

The shroud is usually made of alumina-graphite, using isostatic pressure (figure 3). It does not require reheating. In some cases, to prevent tundish slag attack, it has a zircon oxide. At tube top, in the joint with the lower ladle nozzle, the force of the descending jet generates depression (Venturi effect) and air may be entrained into the shroud. To prevent this, a gasket is used for sealing the joint.

To improve sealing, Argon injection is implemented, by means of an annular pipe or a porous head in the shroud itself (figure 3). But this is not usual for casting of silicon – manganese killed steels.

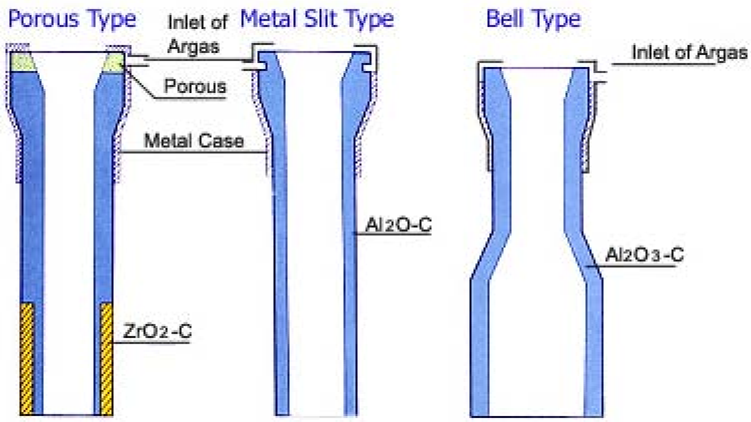

Figure 3. Three types of shrouding. Left: Shroud with porous head for argon injection and zircon oxide-carbon insert in slag line. Middle: Shroud with slit for argon injection. Right: Bell-type shroud, to allow valve opening with the shroud already submerged [4].

The system for shroud positioning consists in a simple, manually operated manipulator with a counterweight to keep it against the lower nozzle. This is enough in most cases, but there is also more sophisticated devices including hydraulic cylinders for easier manipulation (see figure 3); and robots for this purpose and for ladle valve movement.

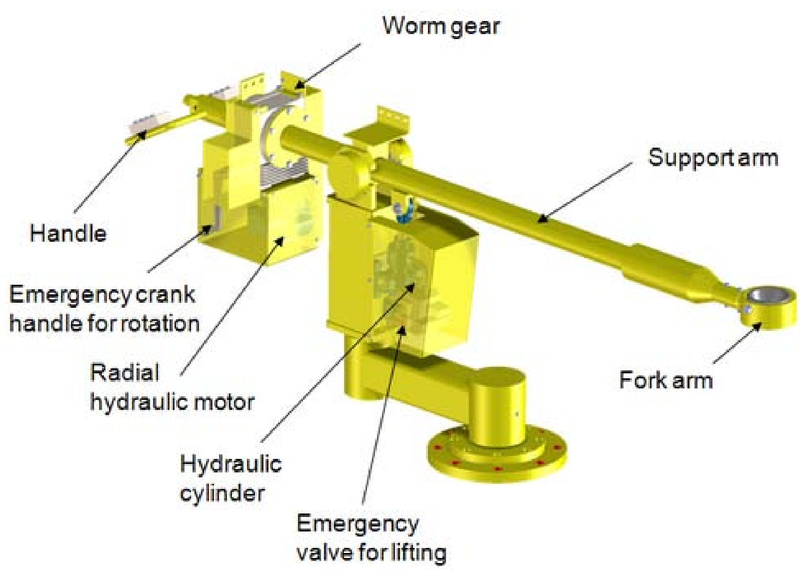

Figure 3. System for positioning and removal of shrouding [5].

The tube must have some minimal immersion into the steel, to guarantee against reoxidation and slag emulsification. If immersion depth is low, steel may be exposed to air around the tube, and emulsification of slag may occur (almost non-reversible phenomena).

An important item is to achieve longer shrouding life, to decrease its impact on cost. A typical duration is eight heats. Often, the breakage of the tube during handling for removal or cleaning has more incidence than the wear due to cleaning operations and the slag line attack.

The shrouding, once positioned, prevents splashing, skull formation and the need for oxygen cleaning the skulls. In case of no free opening, usually the tube is removed, oxygen is lanced to open the valve, and then, after tundish refilling, the tube is relocated, with the valve plate not fully closed. In the event of a ladle nozzle clogging, the tube should be removed, and relocated after ladle nozzle cleaning.

TRANSFERRING LIQUID STEEL FROM THE TUNDISH TO THE MOLDS

Although jet height and diameter are smaller, at mold meniscus the phenomenon is quite similar to that already described for the ladle stream. Here, the start-up with open casting is easier, too. Positioning of the bellows / pollard and opening inert gas valves is not necessary after casting starts. As operation is continuous during the sequence, there is no incidence of ladle changes as in the tundish.

Gaseous shrouding consists of a piping system with regulating valves to have even gas rate in all strands, be it argon or nitrogen, and a cover to make possible keep an inert atmosphere on the meniscus and around the stream. This can be achieved with Pollard or bellow, see figure 5. Typical specific gas consumption is in the order of 0.2 Nm^3/ton of liquid steel.

Several points to take into account if the system is designed in house are mold oscillation, cooling of the automatic nozzle changer, space to introduce the channel in case of an emergency that cannot be overcome with a blind nozzle (particularly in the start-up). Although proper deoxidation practice in the ladle furnace and right operation of shrouding during casting let us avoid aluminum injection and slag fishing, there may occur situations where access to nozzle or meniscus is necessary.

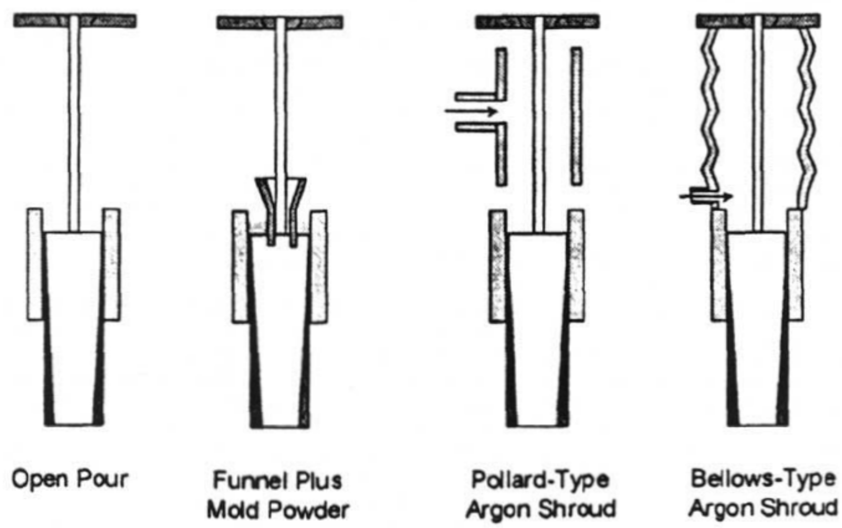

Figure 5. Some systems for shrouding the tundish stream with inert gas in casting with metering nozzle [6].

A good deal of the systems currently in use have been developed in-house, generally with participation of the caster operators, but there also equipment and installation options in the market. In figure 6, a detail is presented of a bellows system with three positions: working, nozzle inspection and mold inspection.

To check the efficiency of the shrouding, a direct control of the atmosphere on the meniscus is possible, by means of a potable gas analyzer. Less than 0.5% oxygen is recommended, above the meniscus.

The use of argon or nitrogen depends on relative costs, availability and the fulfillment of nitrogen specification. It must be taken into account that for low carbon, Si-Mn killed steel, with high oxygen activity, nitrogen pick-up in tundish-mold transfer is low.

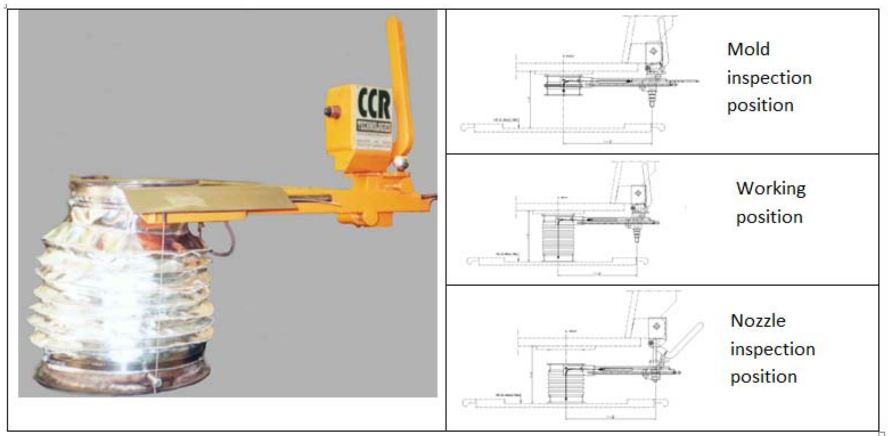

Figure 6. Stream shrouding with inert gas by bellows. Left: Aspect of bellows and device for handling. Right: bellows position for operation, nozzle inspection and mold inspection [7].

REOXIDATION, MACROINCLUSIONS AND SCUM FORMATION

Studies by Maddever, McLean and others [8-9], made possible to understand the mechanism involved in the reoxidation of steel by contact with air. Around the stream, where it impacts the meniscus, a ring is formed that gives place periodically to the entraining of air bubbles into the steel. These bubbles follow a path into the steel, and then emerge (figure 7). The formation of these bubbles implies a large surface for reaction between oxygen in air and liquid steel. This means that, even in case of and even stream, with low exposure to air, reoxidation takes place, particularly below the stream. It has been calculated that the amount of oxygen introduced by the falling stream into the meniscus is 100 time larger than the amount absorbed by mass transfer in the interface stream-air, for an even stream.

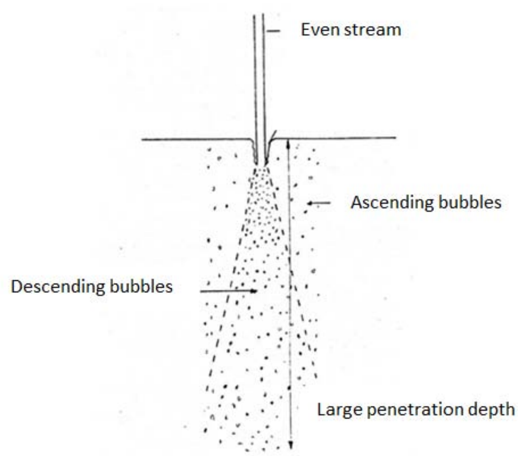

Figure 7. Mechanism for reoxidation of steel by contact with oxygen in air during open casting, with an even stream [9].

Steels for casting with metering nozzle are usually killed with silicon, manganese and a small amount of aluminum. Aluminum may be added purposely, as is normal in low carbon Steel, or via ferroalloys. The elements that will oxidize faster are aluminum (present in low concentration), silicon and manganese (much larger contents). The result is that reoxidation inclusions are formed, rich in silica and manganese oxide, but with lower alumina content in comparison with microinclusiones, as early described by Farrell and Hilty (figure 8, left).

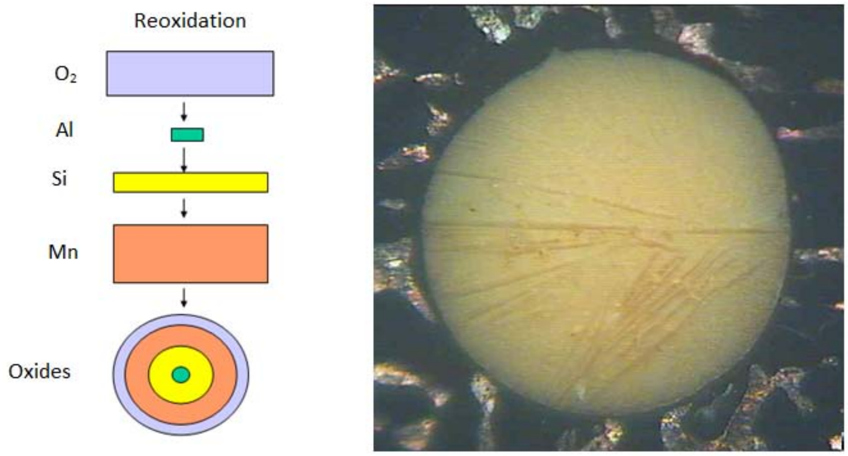

Figure 8. Reoxidation macroinclusions in Si-Mn-Low Al killed steels. Left: Interpretation of the chemical composition [10]. Right: Reoxidation macroinclusion in billet. Vitreous matrix (Mn-Al silicate), and rodhonite needles. Observation in light microscope, under polarized light.

Contact of steel with air also favors nitrogen pick-up, than may be deleterious from the point of view of blowholes and in some steels for strain aging during drawing. Nitrogen pick-up is promoted by the absence of dissolved oxygen and sulfur.

Excessive formation of macroinclusions may give place to scum formation in the meniscus, by floatation and accumulation (figure 9). This scum, if entrained, may originate slag patches or strand breakouts, in particular when a solid phase precipitates, increasing scum viscosity. This happens in two typical situations: silica or alumina precipitation. The formation of silica depends on the equilibrium between the steel, with its dissolved silicon and manganese, and the scum, at a given temperature (figure 10). A simplified way to express the need to avoid precipitation is limiting Mn/Si ratio to a minimum of three.

Alumina precipitation is typical of the practice of aluminum injection in the mold (figure 11).

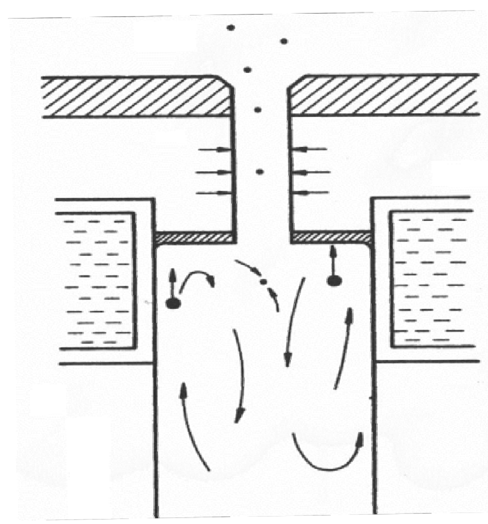

Figure 9. Mechanism of scum formation in the meniscus, by accumulation of reoxidation macroinclusions.

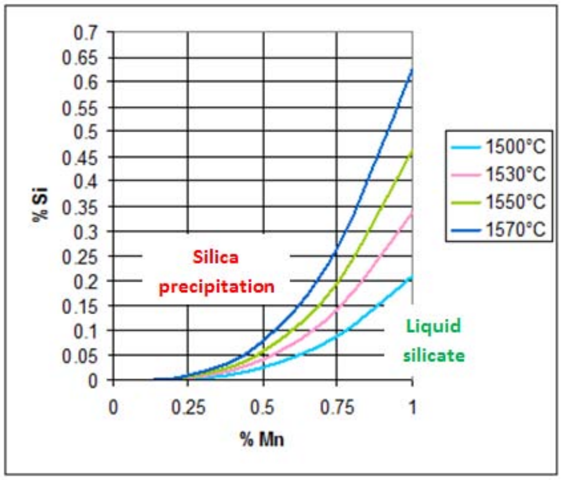

Figure 10. Equilibrium between Si-Mn low carbon steel and mold scum at different temperatures. Silica precipitation takes place for steel chemistries lying above the curve [11].

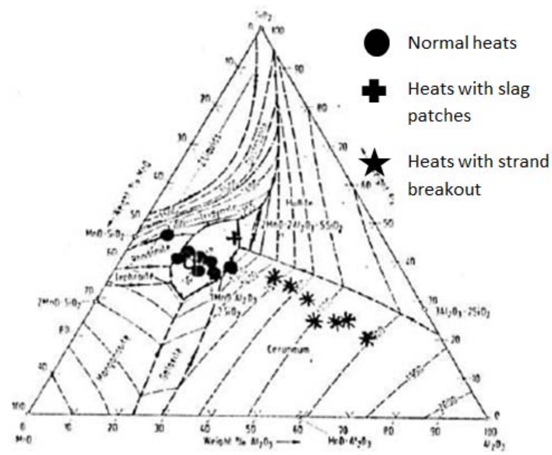

Figure 11. Location in the $MnO-SiO_2-Al_2O_3$ phase diagram, of mold scum formed during open casting of blooms, with aluminum injection [11]. Normal heats, heats presenting slag patches and heats with strand breakouts.

OIL BEHAVIOR

The effective use of stream protection in transfer of steel from tundish to mold, has an influence on oil behavior. Flames of oil combustion with air above the mold generate on one hand a worsened working environment and on the other hand, if addition is too high, may bring about reheating of the automatic nozzle mechanism. If there is no oxygen, combustion is minimal, flames are reduced, and less oil should be needed for the same lubrication effect.

COMPARATIVE ANALYSIS

A qualitative comparison between both practices is attempted in table 1, taking into account safety and working environment, investment cost, operating cost, caster productivity and billet quality. 100% shrouding implies certain investment and operating cost, but favors personnel safety, a cleaner environment and better surface and inner product quality. Regarding labor, it seems that it is more demanded in sequence start and ladle changes, and less demanded during stationary operation.

It is important to have in mind that for practice optimization (including cost minimization) it is not the same to use shrouding some heats per month (low carbon, for instance) than to cast all heats the same way.

	Safety and environment	CAPEX	OPEX	Productivity	Quality
Open stream	Splashing Skulls in tundish that need to be cut Oil combustion flames Exposition to heat radiation during slag fishing	System for aluminum injection (optional)	Aluminum wire Higher oil consumption Operator per strand to control Al injection and to fish slag	Similar Strand breakouts due to slag entrainment or hanging may occur	Much more macroinclusions ($>20/dm^2$) Slag patches Pencil line (Al in billet surface)
Ceramic shroud and bellows/ pollard	Some risk in shroud positioning if system is bad or if distance between ladle bottom and tundish is too short, and in tube cleansing with oxygen	Shroud handling system Bellows/Pollard and system for gas transport and control	Shroud; gasket; Argon or Nitrogen Less oil consumption No aluminum injection Personnel for shroud and bellows/Pollard positioning	Similar	Less macroinclusiones ($<3/dm^2$) Slag patches and strand breakouts less likely No pencil line Steels with Mn/Si<3 castable

Table 1. Comparative analysis between two strategies of casting with metering nozzles.

CONCLUSIONS

Two strategies for billet casting with metering nozzle and oil lubrication are presented. 100% heats with ceramic and gaseous shrouding imply some investment and some operating costs. Instead, it offers a safer and cleaner working environment and higher billet surface and inner quality.

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