THE CORED WIRE ASPECT OF IN-LADLE METALLURGY

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INTRODUCTION

During the last few years, the in-ladle treatment of steel, commonly referred to as LADLE METALLURGY, has played an important role in modern steelmaking. Utilization of Ladle Metallurgy has lead to increased production and improved steel quality. The furnace is now used primarily for melting under highly oxidizing conditions while refining and trimming additions are made in the ladle under reducing conditions.

An integral part of modern ladle metallurgy is the injection of various alloy elements as powder at the bottom of the steel bath. Such injection can be obtained by using cored wire which is made of a low carbon steel sheath into which the powdered elements to be injected are tightly encased.

The cored wire is fed vertically and deep down into the ladle of steel at constant speeds by means of a wire injector and guide tube. By using cored wire, contact surface and reaction between the liquid steel and the alloy addition are improved and unimpaired by air or slag. This injection method improves the efficiency and repeatability of the addition.

AVOIDING NOZZLE BLOCKAGE WHEN CONTINUOUS CASTING

One of the many problems requiring a solution during the world-wide growth of continuous casting and the production of ultra-clean aluminum killed steels, was the specific problem of rapid nozzle clogging. VALLOUREC, the parent company of AFFIVAL, makes tube rounds by the rotary continous casting process. This process uses a small nozzle with an inside diameter of 18 millimeters. It was to solve VALLOUREC's nozzle clogging problem that AFFIVAL perfected a new, patented cored wire which introduces calcium powder deep into the ladle of liquid steel to modify the nature of inclusions and, as a result, avoid nozzle clogging. The overall steelmaking practice developed by VALLOUREC to avoid nozzle clogging [2] [4] can be summarized as follows:

The electric arc furnace is used as a melting machine to melt steel scrap. An oxygen lance is used for improving the melting process and decarburizing by building a highly oxidizing slag.

After "slagging off" the steel is tapped slag free into a basic ladle where a new basic slag is used for desulfurization. The steel is immediately subjected to deoxidation by aluminum while the ladle is stirred by inert gas bubbling. Desulfurization, alloy additions, trimming, reheating for temperature control and homogenizing are all functions performed at the ladle treatment station. (Figure 1)

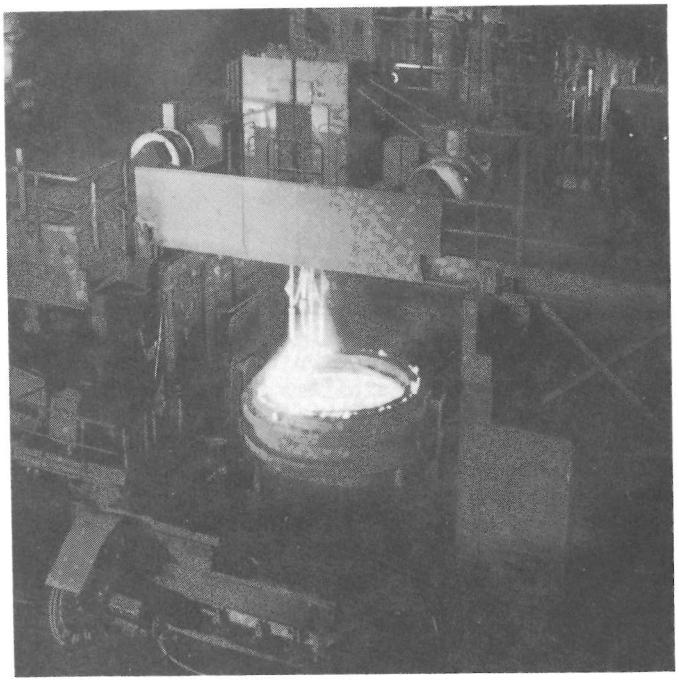


Figure 1. Ladle treatment station with vertical injectors, VALLOUREC, SAINT SAULVE, FRANCE.

When steel is killed with aluminum, solid alumina inclusions are formed which tend to gather on the walls of the nozzle and progressively restrict the flow of molten steel until the nozzle is completely closed.

By treating the liquid steel with calcium, solid alumina and silico-aluminates formed by aluminum deoxidation are transformed into calcium aluminates which are liquid at casting temperatures. In clean steels these aluminates are covered by a thin layer of complex sulfides of manganese and calcium. (Figure 2) [7]

Calcium treatment is achieved by injecting cored wire containing calcium-silicon powder into the ladle. This is the best injection technique for calcium considering its low solubility, low density, high vapor pressure and its great affinity for oxygen.

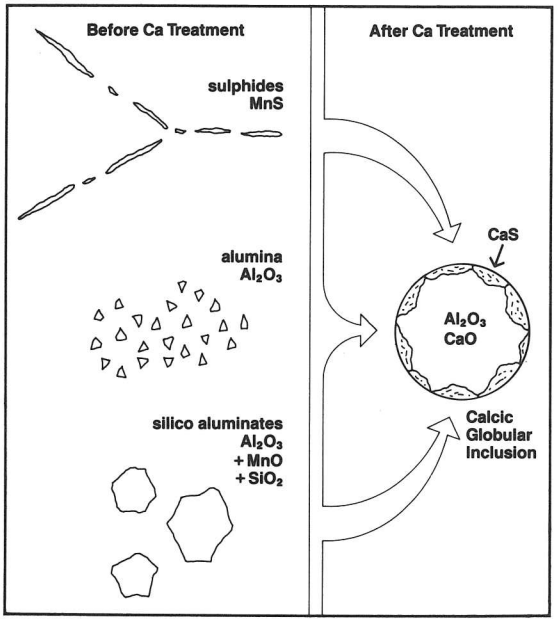


Figure 2. Modification of nature and morphology of inclusions obtained with calcium treatment.

Progressive melting of the cored wire steel sheath frees calcium powder at the bottom of the ladle. This brings about a pressure increase in the melting area, large contact surface between powder and liquid steel, suppression of any contact with air - all of which improves calcium utilization.

CHARACTERISTICS OF CORED WIRE

AFFIVAL cored wire is characterized by a well-defined compaction of powder to obtain a good uniformity and a regular weight per meter. This compaction is produced by a unique and controlled deformation of a round cross section. AFFIVAL cored wire is produced in various sizes, round or rectangular, depending on the application and customer's preference. It is supplied level wound on reels or in cages. Some typical AFFIVAL cored wires are shown in Figure 3.

Cages are recommended when large repetitive injections are required. Connecting the wire together from cage to cage provides a simple continuous injection process. Reels are recommended when less powder is required or small trim additions are being made. The uncoiler is designed so that changing reels is a simple process.

Because of greater yield and better reproducibility, cored wire is used more and more in place of bulk addition to introduce elements into the ladle. In particular, reactive elements such as calcium silicon or calcium without silicon may be injected as cored wire.

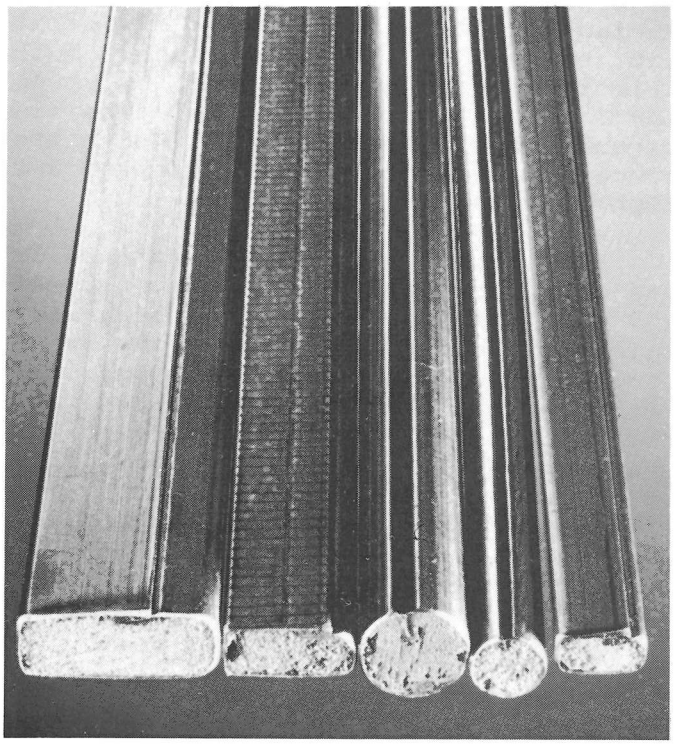


Figure 3. Some typical AFFIVAL cored wires.

TRIMMING CAPABILITIES

Trimming of base chemistry elements like carbon, manganese, silicon, and chromium has resulted in dramatic melt-shop and customer benefits, such as:

- -Reduced rejection rates of off-analysis heats. [8]
- -Stringent customer specifications can be met. [8]
- -Parameters for heat treatment in subsequent manufacturing processes can be more easily established and controlled. [2] [7]
- -Precise sulfur additions can be made to improve machinability. [6]
- -When grade compositions overlap, one analysis range can be cast. This is of particular importance for arranging sequences in continuous casting. [2] [7]
- -Control of microalloying elements such as vanadium, columbium, titanium, and boron. [5]

TABLE I summarizes recovery and standard deviations obtained in the VALLOUREC INDUSTRIES plants for some elements injected by means of the AFFIVAL cored wire technique. These results are much better than those usually obtained with the bulk alloy addition method; not only are recovery levels higher, but reproducibility is also achieved. [2] [3] [7]. The main advantage of cored wire injection of manganese and chromium is closer control of composition, which is very important for many end use applications.

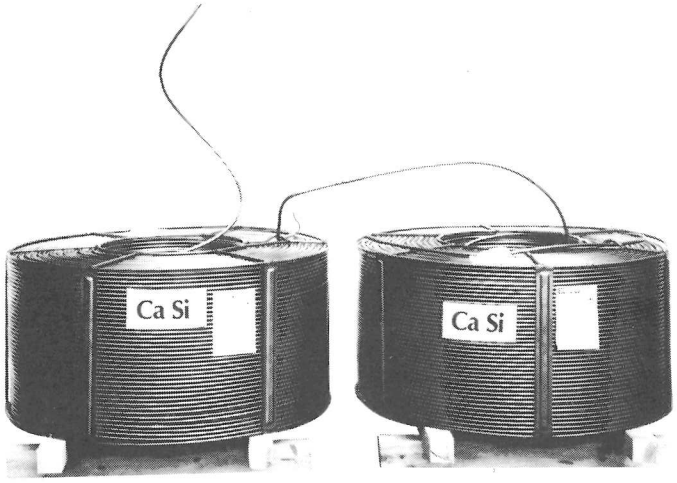
Table I.

Trimming additions
Recovery and standard deviation

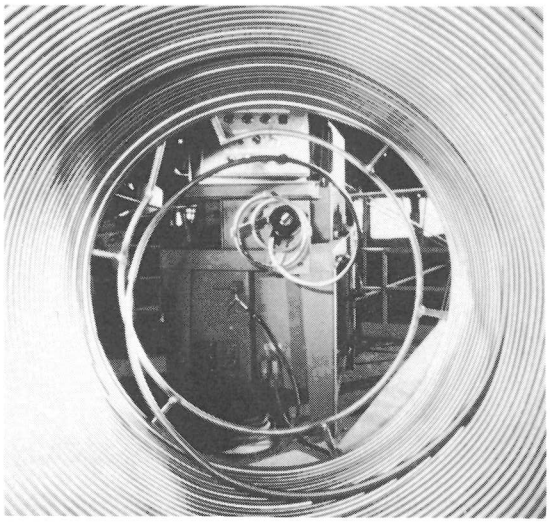
Injected element	Analytical limits investigated %	Average recovery %	σ Standard deviation % (1)	Prior deoxidation
C	0.10 - 0.30	100	0.0060	Si + Al
C	0.70	100	0.0085	Si + Al
Mn	0.5 - 1.5	100	0.0220	Si + Al
Si	0.1 - 0.4	100	0.0050	Si + Al
Cr	0.9 - 2.25	100	0.0200	Si + Al
Al	0.02 - 0.07	100 90	0.0017 0.0025	Si + Al Si
S	0.015 - 0.050	80	0.0045	Si + Al
Ti	0.010 - 0.040	90	0.0025	Si + Al
B	10 to 15 ppm	80	0.0001	Si + Al + Ti

(1) For an average content C_o analytical dispersion is between $C_o + 2\sigma$ and $C_o - 2\sigma$ for 95% of results.

Using cored wire injection for trimming results in lower melt-shop costs, lower costs for the end user, and improvements in steel quality.



AFFIVAL cored wire in cages allows utmost flexibility and simplicity in the feeding process where platform space is limited, or additional wire capability is needed, or for high volume feeding. Wire pays out from center of coil into injector. Cored wire can feed into injector from "eye-to-sky" payout position above, or from "eye-horizontal" position, below.



INJECTION EQUIPMENT

AFFIVAL not only makes cored wire but also a variety of wire injection equipment. The concept is simple. The cored wire is fed through a wire injector into a guide tube for vertical entry into the liquid steel.

Injectors have 3 to 5 driven rolls and an equal number of free top rolls on a movable support. Closing of top rolls over the wire is obtained by pneumatic pressure. Selection of speed settings depends on wire size, thickness of metal sheath, ladle depth and ladle size. Injection speed may be selected from 45 to 1200 feet per minute.

AFFIVAL manufactures various types of injectors adapted to the specific application and layout of a particular steel shop - for instance a horizontal injector when the ladle is beyond the pouring floor - or a vertical injector when the ladle is moving under the floor. Different types of guide tubes - hinged or fixed - allow vertical introduction of the wire into the ladle.

A three roll AFFIVAL double injector is shown in Figure 4. This double injector enables the operator to make single, sequential, or simultaneous injection of additivies. To help the operator monitor the injection, the control panel can be swiveled from side to side.

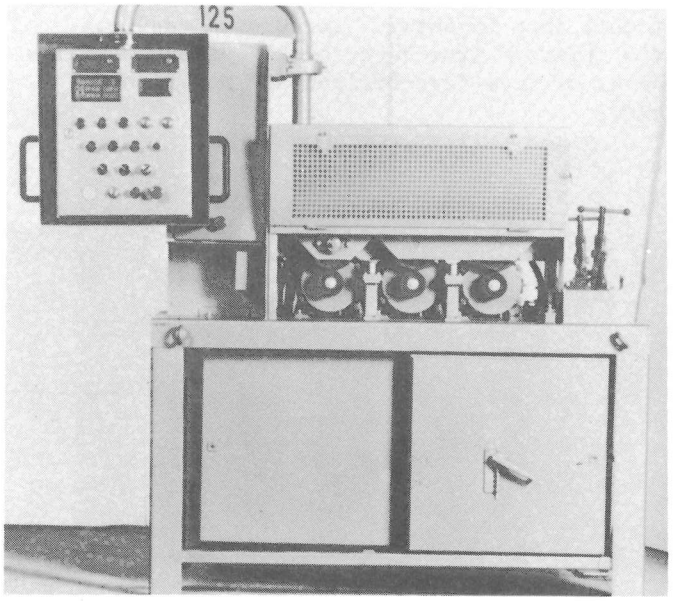


Figure 4. Three roll AFFIVAL double injector with swivel control panel to facilitate injection from either side.

AFFIVAL wire injection equipment can be computerized. The feed control on the injector precisely measures the length and the speed of the injected wire and can supply impulses to a computer to drive or monitor the wire injection.

AFFIVAL has manufactured and placed in operation more than 200 wire injection equipment systems around the world.

STEEL QUALITY IMPROVEMENTS

The treatment of liquid steel by calcium, using calcium silicon or calcium without silicon, is now a common practice in many melt shops. It is interesting to observe the influence of calcium on the steel quality improvements. [7] [8]

When calcium has been added to the aluminum-killed steel, calcium aluminates are formed which remain globular during rolling. The transverse ductility approximates the longitudinal ductility. The steel is more isotropic.[2] [7] [8]

Calcium treatment improves other steel properties - for example, impact strength (Figure 5), drawability, cold-die forgeability and resistance to corrosion. [7]

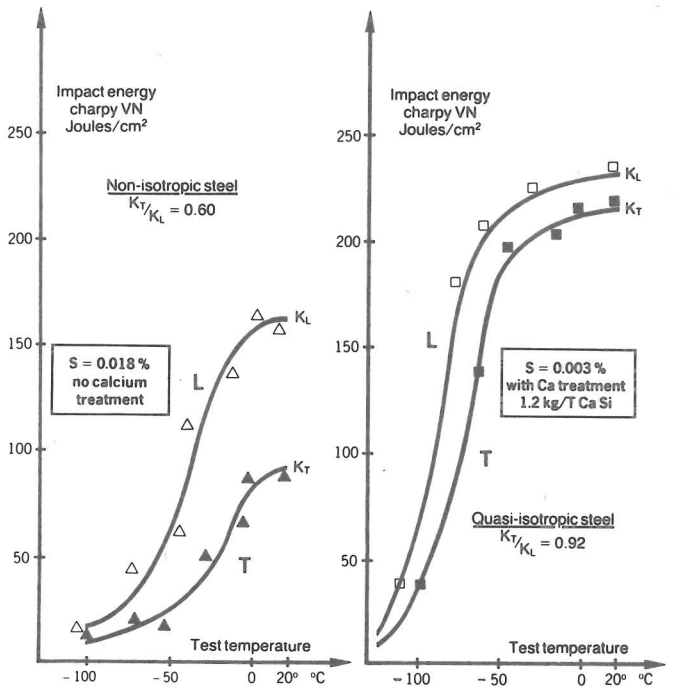


Figure 5. Influence of sulfur and inclusion shape control on impact toughness and transition temperature. Steel grade, 25MC5: C 0.25%, Mn 1.25%, Cr 0.7%, Al 0.035%. Test results on tube, 12-mm thick, water quenched and tempered to 700°C. Elongation ratio from ingot to tube 12:1. L -- longitudinal and T -- transverse.

Calcium treatment also improves machinability. When machining with carbide tools at high cutting speeds, the main problem is the wear of the

cutting edge by highly abrasive oxides, such as alumina. The conversion of crystalline alumina into globular calcium aluminate inclusions, coated with a layer of sulfides leads to a considerable machinability improvement. [6]

CORED WIRE INJECTION VERSUS GAS INJECTION OF POWDER

Compared to gas injection of powder, cored wire injection has the advantage of being a relatively quiet metallurgical treatment with limited stirring and agitation, thereby eliminating introduction of gases such as oxygen, hydrogen, or nitrogen. It improves the yield of additions and reduces fumes and splashing.

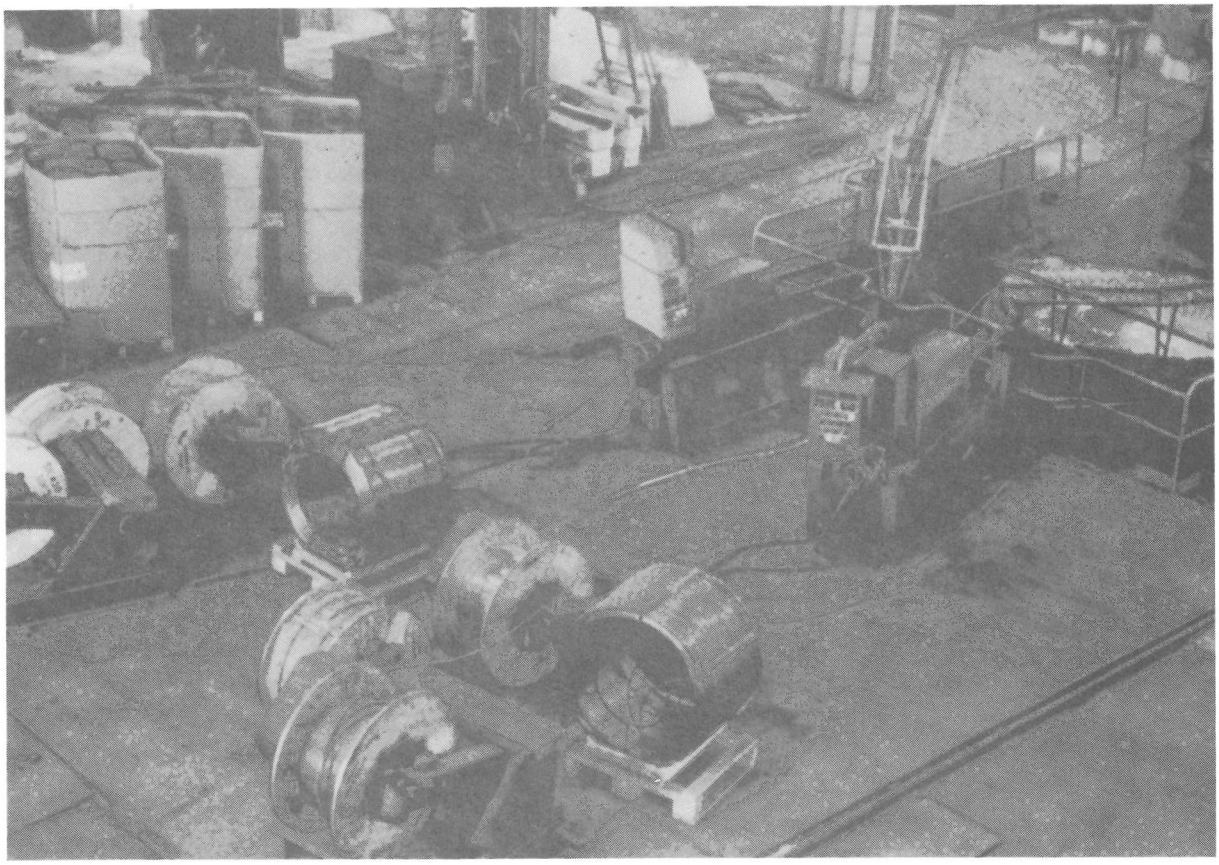
As can be expected because of the minimal turbulence resulting from cored wire injection, the temperature drop is dramatically less with cored wire injection than with lance (gas) injection. Lance injection requires more powder consumption and longer treatment time. These factors increase the temperature drop when using lance injection. This is a significant production control factor, particularly when continuous casting follows. [3]

Wire injection is simple. It also makes good economic sense, because of its lower capital costs. [3] [7] [8]

CONCLUSIONS

Injection using cored wire is a low cost, effective and integral part of today's ladle treatment technology. Cored wire injection can be used to control the nature and morphology of inclusions. This control improves end use properties and also avoids nozzle clogging during continuous casting. Cored wire injection increases the yield and reproducibility of various additions into liquid steel. It brings to the melt shop a simple solution for precise trimming of the chemical analysis of the steel, including microalloying.

In summary, cored wire injection is a practical, cost effective way of increasing productivity and steel quality.



High production in-ladle efficiency — Vallourec, Anzin, France: both reels and cages are used to make single, simultaneous or sequential injection of additives.

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