THE NEW COPPER CASTING-MACHINE: EXPERIENCES AT FERROATLANTICA

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ABSTRACT

Metal casting is one of the most important operations in ferroalloys factories. After the tapping of the furnace and the depuration of the metal, the preparation for customers with cooling, crushing and sizing begins. In total production costs, this contains around 8 % of the total cost of the metal, depending on the value of the fines and other important parameters. From an investment point of view, this represents around 20% of the total capital for a new furnace.

Casting onto a water-refrigerated copper plate is not new for molten metals. In steel, continuous casting machines are normal in every factory. Water granulation casting exists at some ferroalloys plants. However, the majority of plants and production technology still use the technology of lumping, crushing and sizing. This technology is time consuming, produces fines and requires a relatively large work force.

In 2001, Ferroatlantica put into operation a new water-cooled copper casting-machine, which seems to be a very convenient solution to solve all these problems. It is in operation at a silicon factory; the same place where the new ELSA electrode was developed for silicon metal production. This paper describes our experiences using it.

1. THE CURRENT SITUATION IN THE FERROALLOYS CASTING

Tapping and casting methods have a strong impact on metal quality with regards to grain structure, homogeneity and content of inclusions such as oxides, carbides and slag. The traditional system for casting ferroalloys consists of slow cooling of the metal from its molten temperature, around 1500ºC, to ambient temperature, which allows it to be used in crushing and sizing installations. Casting is normally done in 30 cm thick layers, using foundry smelting moulds or casting beds, normally used for more than one casting and prepared with fines of the same ferroalloy. The moulds are known as casting moulds and are subject to sudden expansions and contractions so that they have a short life span. In order to partly avoid this last problem, casting moulds are covered with fines of the same metal so as to absorb part of the heat given and protect the metal.

These processes system are currently commonly used in ferroalloys factories, but the major shortcomings are:

- The moulds are expensive to buy and maintain. The casting lines, which usually move the moulds, deteriorate with any fall of metal, and they need a lot of maintenance.
- The fines beds are cheaper than moulds since they are made from the same metal. However, they usually form very thick layers, which afterwards have to be processed using machinery. Thus, personnel and maintenance of machinery costs are high.
- Solidifying is slow, allowing impurities to get to the areas, which are the last to solidify. Like this, we get a bigger concentration, and therefore, a heterogeneous distribution of the impurities. [3, 5]
- The usage of fines causes contamination (they always have more impurities than molten metal) since they are partly incorporated into the metal, and will increase the heterogeneous distribution of the impurities.

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The importance of points c) and d) depends on the customer who receives the product. For example, in silicon metal these points are of great importance for a chemical-grade customer, who wants a very homogeneous material, and of less importance for an aluminium customer. The reason is that tramp elements in silicon affect the reaction with CH_3Cl in silicones production, and should be evenly distributed in the reactor. The tramp elements tend to solidify on the boundaries between the grains. With slow cooling, the silicon crystals will be larger than the grains in the powder, and many grains will be essentially single crystals without grain boundaries. With smaller crystals the grain boundaries will be more evenly distributed, and most grains will contain some phases with tramp elements [3].

In short, the standard system of casting needs the following operations:

- Casting from the ladle to the casting mould or to the fines beds.
- Waiting until the material is cold and solidified sufficiently.
- Moving the material from the cooling area to the breaking up area.
- Breaking up the material into the first sizes.
- Breaking the material down to the customer's requirements.
- Picking up the fines and storing them in their own stock area.
- Transporting the fines to the casting area and placing them into moulds.

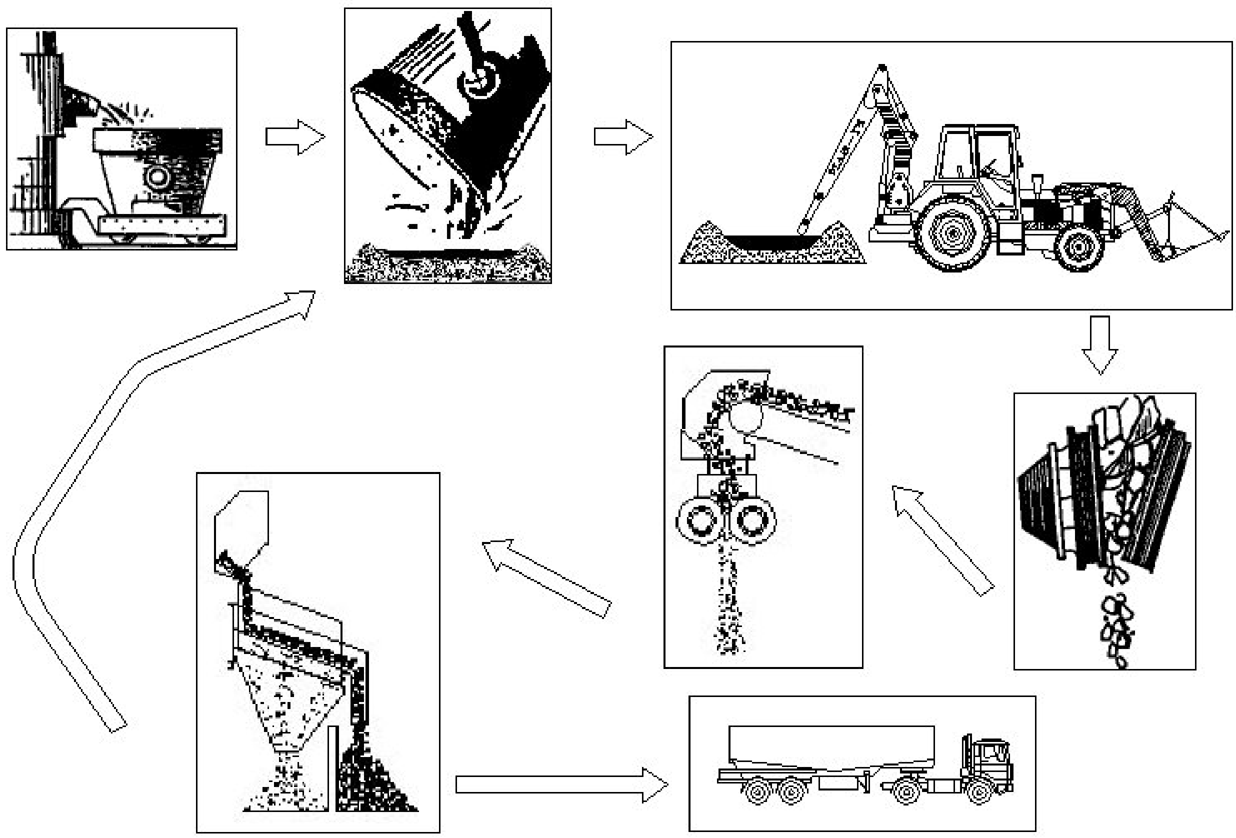

Figure 1. Conventional processing technology in a ferroalloys factory after metal tapping.

Solidified ferroalloys need to be further crushed down to small lumps of up to 100 mm for use in customers' processes. This means it should go through two crushing processes and at least another two for sizing. The first is normally done in jaw crushers and the second in roll crushers. These operations normally generate significant amounts of fines, which are undesirable for their bigger impurities content because the dominant fractures are transgranular. The production of fines is usually about 10%, taking into account that the material is under 5 mm.

These fines are either sold at a discount of about 20% to lumpy product, or are resmelted in the same factory in the furnace, in the bed, or in the casting mould. Fines constitute the main part of the impurities and frequently the customer, who is concerned about chemical purity, asks for the percentage of fines to be resmelted in the casting moulds to be minimal.

From the point of view of capital investment, space is needed for all these intermediate stocks, cooling places, etc., also for transporting machinery, such as bulldozers, travelling cranes and the breaking up installations in its two stages. In general all this takes up 25% of the area of a factory, and in a new factory means 20% of the investment.

Staff and maintenance costs for all these operations obviously depend on each factory. In silicon factories, an average figure of about 8% would be reasonable for the total cost for auxiliary works in the making of the product.

Within this percentage there are two very important concepts, which are not included:

- Losses of fines as a consequence of movements of stocks.
- The loss of profits when the fines are sold at market prices, which are usually 20% below the commercial prices.

In brief, all the treatments of the metal (from its molten state to its delivery to the customer) make up one of the most important costs for a ferroalloy factory. Many efforts have been made to reduce such costs and to improve the quality and homogeneity of the product, for example water granulation. Casting onto copper plates is an existing solution, the same as continuous casting was for steel.

2. REASONS FOR THE COPPER CASTING-MACHINE

The decision to set up a copper casting machine was taken when Ferroatlantica went into the chemical-grade silicon market. The objective was to cast a thin layer (about 10/15 mm thick), to solidify this quickly, and not to use fines since they pollute part of the metal. Thus, a very pure and homogeneous metal would be obtained both in its liquid and solid states. Therefore, we got in touch with Dr. Anton More, who has a patent on this system and who had had previous experience with it when he worked for the Wacker-Chemie company in Germany before his retirement. Ferroatlantica I+D, the R&D company of the Ferroatlantica Group, reached an agreement with him, and the design for a machine which would allow for the casting of all of the factory production was begun. This machine would also cast at different layer thicknesses and so cater not only for the chemical market, which requires thin layers, but also the aluminium one with thicker layers.

The casting machine has been designed with enough capacity to cast all the production of the plant at a casting speed of around 150 kg/min. At Ferroatlantica (I+D), we have carried out, and are continuing to do so, many studies and improvements with the object of achieving the most automatic and safest installation possible. The machine has been running at normal production level since some months ago, and although we have still not reached the full level of casting from the three furnaces, our customers are being supplied with products cast using it.

3. MAIN FEATURES OF THE FERROATLANTICA COPPER CASTING-MACHINE

The basic machine consists of one copper table and two iron tables. The width and length of these tables have been calculated so that the cooling of the elements is very efficient and the copper, whose melting point is somewhat more than 1000ºC can receive the molten metal which arrives at 1500 º C. The flow and speed of the water are very important parameters for the life span of the cooper plate and these were achieved thanks to a very adequate design of the refrigeration circuit. Thermocouples have been installed to measure both the temperature of all the water circuits as well as of the copper plate where the metal falls onto it. All this data is controlled by a PLC, and one by one all the different operations have been changed over to automatic.

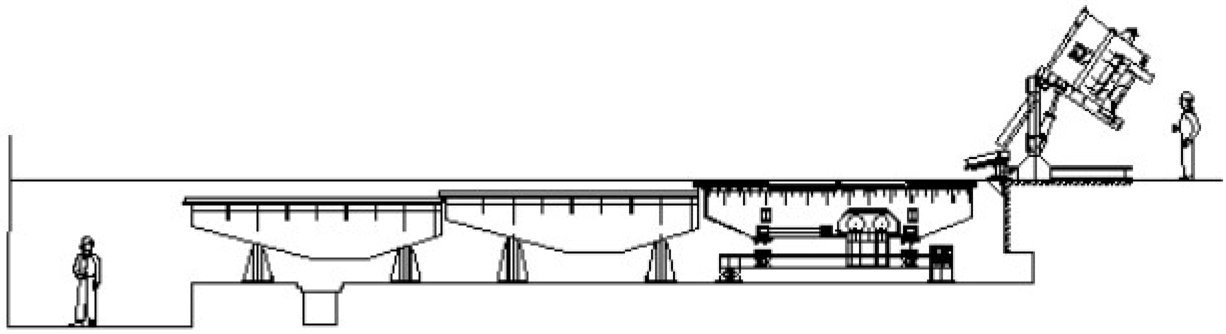

Figure 2. Scheme of the casting machine at Ferroatlantica's Sabon plant.

The copper and iron plates are placed on strong vibrating tables which have variable frequencies according to the needs of the operation. Since Ferroatlantica markets to both aluminum and silicones producers, a requirement was the ability to cast to different thicknesses of silicon in order to satisfy the requirements of each customer.

The first piece of equipment of the machine is a tilting device. The ladle coming from the furnace is attached to this. Using an automatic program the ladle is tilted so that the quantity of metal that falls onto the plate is constant. Before reaching the plate the metal passes through a runner which distributes it over the width of the plate. The molten metal comes into contact with the water-cooled copper and begins to solidify at this point as can be seen in Figure 3. When a certain thickness of solid metal is reached, the vibrations of the table cause the metal, which is still molten on top, to begin to move along the copper table. As can be seen in Figure 3, the solidification continuous from the bottom of the layer until it reaches a point where it meets with the solidification done by the radiation losses at the top of the silicon. Before reaching the end of the table, the metal is solidified but still red-hot on top (about 1100º C). When falling from the copper plate onto the first iron plate, the metal begins to break up which is favored by the vibrations of said table which, on one hand, transports the metal along it and at the same time breaks it up into pieces.

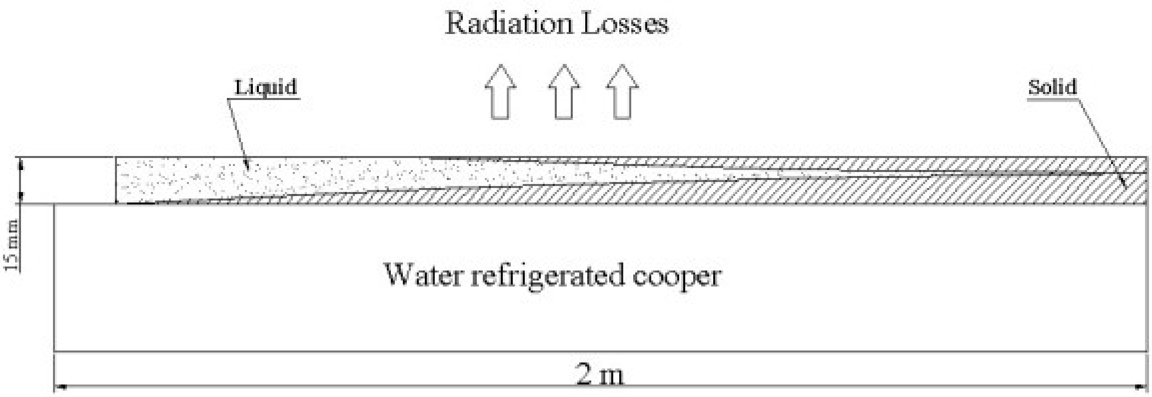

Figure 3. Schematic of silicon solidification on the water-cooled copper plate.

The same thing happens when the metal passes on to the second iron table, such that on reaching the end of this table the metal is almost completely broken up and is down to a temperature of 500ºC. Finally the metal falls into a metal bin where all the material from the ladle is stored and then taken to the stock area according to its quality.

The copper and iron plates remain perfectly clean and without any remains of the casting. Since no type of fines were incorporated, there is only and exclusively the material from the ladle in the bin.

Using this new casting machine, the metal stays on the copper plate about 80 seconds and the solidifying is carried out in the first 30 seconds. The metal which first fell out onto the copper plate reaches the metal bin in around 4 minutes and is now solid and broken up.

3.1 Safety and Video-Control System.

It is a well-known fact that the reaction of molten metal on water can cause explosions. Using the system of direct casting into water there have been negative experiences of this type. However, these have been solved using various improvements and new technologies. These are now running in many factories. In fact, all the systems of continuous casting in the steel industry have been able to overcome this potential problem.

At Ferroatlantica, we have placed great importance on this risk, and, in the little more than a year that we have had this machine running, we have had no negative experience in this sense. From the beginning of the trials, we have automated all the installations to a maximum in order to eradicate the human error factor. The improvements have been incorporated step by step following the strictest principles for the safety of people and installations.

In this regard, in the last few months we have incorporated a video-control system, which has automated all possible operations in the casting system. The system analyses all the images received from the video and gives the appropriate orders so as to increase or reduce the speed of the tilt of the ladle thus affecting the amount of metal, which falls onto the table. When the required amount of metal is on the table, the vibration system is started up, thus taking away this metal and leaving space for liquid metal. The technical possibilities of this type of video control are very important and, in the future, it seems logical to also carry out vigilance control using this type of feature.

4. METAL QUALITY ADVANTAGES WITH THE COPPER CASTING-MACHINE

The first advantage to be considered is the purity of the product obtained. This is due to the following points:

- Neither resmelted fines nor any other mould protection product are used.
- The pouring or tilting process time is very long, 15 minutes, compared to the standard process, 5 minutes, this allows for a better segregation of slag.
- Slag in silicon is of a greater density and more viscous than the metal. Because of this, it remains in the runner and does not fall onto the copper plate.

The second advantage is the cooling speed. The product, as mentioned before, solidifies in a few seconds. It is not as fast as water granulation but is much quicker than solidifying in casting mould. This has an immediate influence on the size of the crystal in the pieces of silicon. The grain size in the silicon coming from the casting mould is about 300 microns, whereas the one from the copper plate is only 100 microns. Apart from this, in the former the grains closely follow the direction of the cooling. However, in the casting mould the crystals are totally disorganized, and their size, presence and orientation are different when comparing a piece from the center of the mould, from a side-piece with fines or from the surface, which is in contact with the air.

The metal cast onto this machine is called “grain orientated” and the uniformity in each of the final pieces is much greater than in silicon casting in moulds. The high solidification rate modifies the intermetallic phases distribution which becomes more uniform. This is associated with a smaller grain size. In the photo (Figure 4), you can see the normal thickness of a thin layer, typical in the chemical market. In the photo (Figure 5) is a thicker layer, typical in the aluminium market. The crystals are really perpendicular to the copper until they reach the material solidified by radiation losses. At this area it is possible to see the end of the crystal with some small holes where the concentration of impurities is higher. All the pieces are of similar physical and chemical characteristics.

Figure 4. Thin layer silicon cast onto the machine.

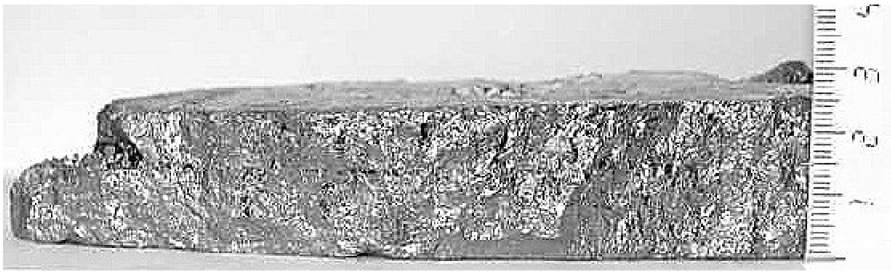

Figure 5. Thicker layer silicon cast onto the machine.

The third big advantage is the reduction of fines. Using this system, you can get a layer, which is constant from a thickness point of view due to manipulating the cooling speed and the vibration on the table. Thus, for further processing you must only address the other two dimensions. This can be done by a mechanical hammer, turning it round, at the end of the machine and when the majority of the pieces have been broken up automatically by themselves.

As the material is broken up, some fines are to be found in sizes of less than 5 mm. However, *on producing the breaking up of the pieces, instead of mechanical crushing them*, their percentage is much lower than that when using conventional silicon casting mould. Our experience is reflected in table 1. Taking into account that the fines come from the same ladle and its *percentage* is low (as is also the percentage of the very small fines), we aim to sell the copper plate cast material as a sized by down product, i.e. X – 0mm, where X is the top size requirement of the customer. We are also committing our customers to accept this sizing for the material cast using copper plate technology.

Table 1. Sieve analysis after crushing to product size 0-120 mm, depending on the casting method.

Casting method	**Conventional**	**Casting machine**
Residue on sieve 5 mm	**90%**	**97%**
Residue on sieve 1 mm	96%	99%

5. IMPROVEMENTS IN THE FACTORY PROCESS

The introduction of this casting machine completely changes the organization of the department, which is in charge of the outlet of the finished product; that is to say, they receive the material from the production department and do the processing treatment until it is dispatched from the factory by lorry. Both the crushing of big pieces and then the second crushing are eliminated. By reaching an agreement on equal sizing for different customers, you can even eliminate screening and classification. At factories already in operation, the introduction of this technology requires a coordinated effort of the organization of the processes, of the commercial division and of the customers. This is not always easy to achieve. In green fields projects, the factory itself must be built taking into account the existence of this type of machine opposed to the traditional ones in our sector. The ideal would be to have only one department where casting and storage are carried out instead of the two departments, which exist at the present: one for casting and the other for the classification silos.

We have already stated that the casting process can be done automatically. The operative only carries out vigilance work of the process and it is foreseeable in the near future that said operative will carry out others tasks in the area during the casting time leaving the vigilance work to the video machines.

On leaving the table, the material is stored in metal bins. Following the same principle of automation, in this case using a traveling crane, said bins can be emptied into the silo which corresponds to the quality which has been cast at that moment. It is even possible to directly fill the containers, which will leave the factory, thus avoiding any human intervention whatsoever. Since no traces of material are left on the table, there is no contamination between different product qualities and you can cast two different products alternately, taking the same either to different silos or to different containers.

All this allows for an important reduction of personnel in the finished products department and a considerable saving in costs of the final product, besides improving product quality. To do this, it is necessary to have at least two machines in the factory so as to avoid reverting back to the traditional method if there is a stoppage on one machine. This traditional method requires a large work force and the factory might still not be ready for this.

6. OTHERS SAVINGS

Another big advantage is the savings compared to present day situations. In the new casting machine, the most cost effective part of the whole casting machine is the life span of the copper plate, and in this, the most critical area is where the liquid silicon, at about 1500ºC, meets the surface of the copper. We have made a very special design of the water-cooling of the copper following the recommendations of Dr. Anton More and, at the moment, with more than 3.000 heating we have not experienced any problems, due to the quality of the copper and the very good cooling capacity, and only very little mechanical erosion. Last year we expected a life span of the copper plate of at least 20.000 t of silicon, including the possibility we have to turn the two copper plates around 180º and make the change between them. Today's experience shows the life of the copper plate is clearly longer and we are in close contact with the maker to improve this life span as much as possible with different surface treatments. The next target is to think about a life span of 30.000 t, always with good maintenance control and following the recommendations received from the supplier. With the vibrating machines, which are really strong, we have not experienced any problems and it needs very little maintenance. Lastly, it is difficult to expect expensive problems with the two steel plates.

Present day costs for all the different processes, from the casting moulds till when the material is put onto the lorry, depend, of course, a lot on the different plants, but, in our experience it is about 60 €/t. With the new casting machine, many of the personnel, maintenance costs and losses of material in the breaking, crushing and sizing can be avoided and the cost can be reduced to 30 € /t. For a yearly production of 30.000 t, it means a total saving of 900.000 €/year plus the 7% less fines production contribute to a large cost saving since it does not have to be sold at a discount or remelted.

Overall, the maintenance costs for the copper machine are less than those for existing crushing, sizing and classifying installations, with less noise, less dust, no fines and significantly less personnel.

7. CONCLUSIONS

Except for water granulation, casting is still done today using the same technology as 50 years ago. It is an expensive technology with high requirement of personnel, equipment, material movements and losses in fines. In steel and some other metals industries, this kind of casting technology has been replaced since many years ago, but it still used in silicon and other ferroalloys.

Casting silicon, and also other ferroalloys, on a refrigerated copper plate on an industrial scale is not only possible but also very recommendable. The installation can easily be automated and the number of operations and movements are highly reduced in comparison with existing cast mould technology.

The product is purer because fines are not necessary in this kind of casting and solidifying is a lot faster, which means less segregation of impurities. The thickness of the layer can be adjusted in different ways, but the material, which appears flat, is always easier to break up and on reaching the end of the machine the majority of the material is already broken up. The size of the crystal, due to fast solidifying, is, on average, a third of that using the casting mould.

The new casting machine developed and in operation at Ferroatlantica is an industrial machine with a casting rate of around 150 kg/min of capacity. It is the adaptation of continuous casting machines to our sector and has a lot of advantages and seems to be the future.

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