THE IMPROVEMENTS TO COPPER CASTING MACHINE FOR FERROALLOYS

J. Bullón, A. More[1] and J. M. Míguez

Ferroatlantica (I+D), Pol. Ind. Sabón, Arteixo, 15142, La Coruña, Spain
[1] Moresteel, Schweizertalstr,52/5, A 1130 Wien, Austria
Email: jbullon@ferroatlantica.es; jmmiguez@ferroatlantica.es; moresteel@nextra.at

ABSTRACT

In 2000 Ferroatlantica started a project with the aim to develop a new casting machine for silicon and other ferroalloys. Until now, it has been cast more than 25.000 tons of silicon for the chemical and metallurgical market. This system has improved the process yield, productivity and product quality which place's Ferroatlantica at the top of technology development in this field.

After the first presentation of the Ferroatlantica's casting machine at Infacon X, we would like to show the improvements in the control which have permitted us to increase the lifetime of the copper and to obtain, at the end of the machine, the right product size for the customer avoiding the current necessity of crushing and sizing the lumpy metal. Furthermore, we have improved the system in relation to the obtaining of smaller granulometries at the end of casting machine.

Not only is this kind of machine cost competitive for special silicon applications but also for other normal ferroalloys with different specifications of size and thickness.

1. BRIEF DESCRIPTION OF CASTING MACHINE

The basic machine consists of one copper table and two iron tables. The width and length of these tables have been designed 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 1500ºC. 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 are automatically controlled.

The copper and iron plates are placed on strong vibrating tables which have variable frequencies according to the needs of the operation. Since Ferroatlantica's market is both for aluminium as well as silicones producers, it has been considered necessary to cast with different thickness of silicon 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 continues 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 favoured 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.

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 500º C. 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 solidification occurs 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.

2. ARTIFICIAL VISION SYSTEM

The artificial vision system consists of two cameras (one working and another stand-by) that control the vibration of the casting machine. The operation can be explained this way: when the metal covers the rectangular area that it is shown in the figure 1, the vibration is activated and after few seconds this area is ready for receiving new metal.

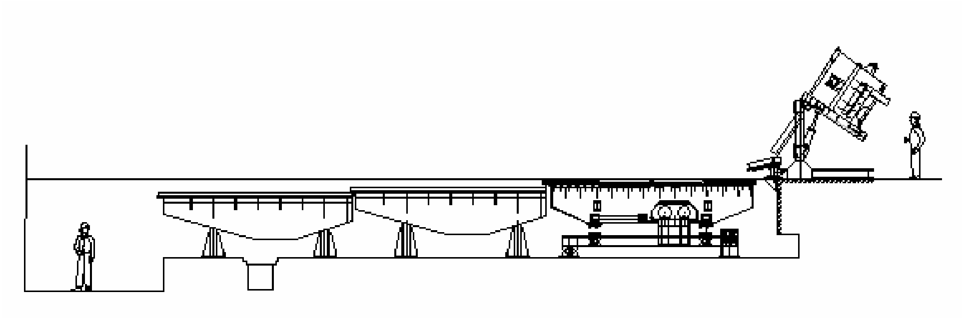

Figure 1: Scheme of the casting machine at Ferroatlantica's Sabon plant

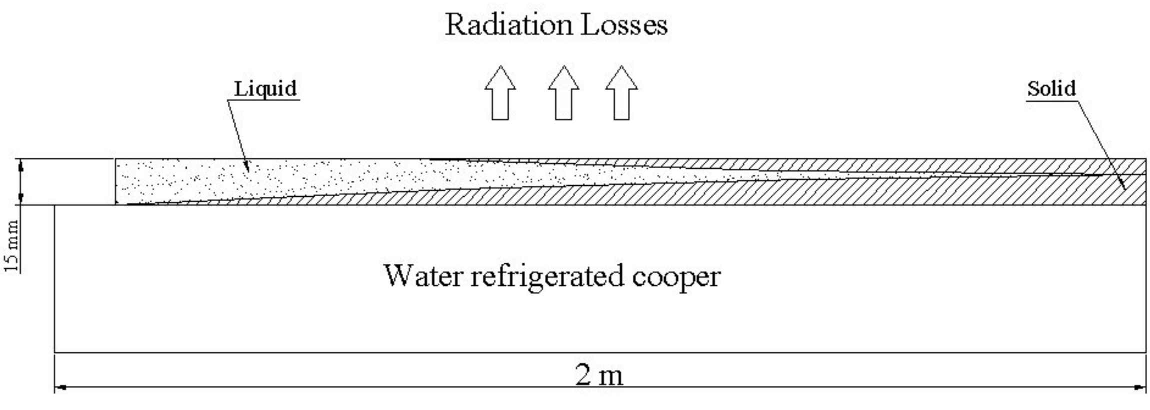

Figure 2: Scheme of silicon solidification on the water-refrigerated copper plate

However, the artificial vision system actually controls more than just vibration because it intervenes in the control of the thickness of the material and in the casting speed. Since the installation of the camera, the continuity in the silicon layer is nearly perfect and this is an important fact for the increase in the lifetime of the copper table.

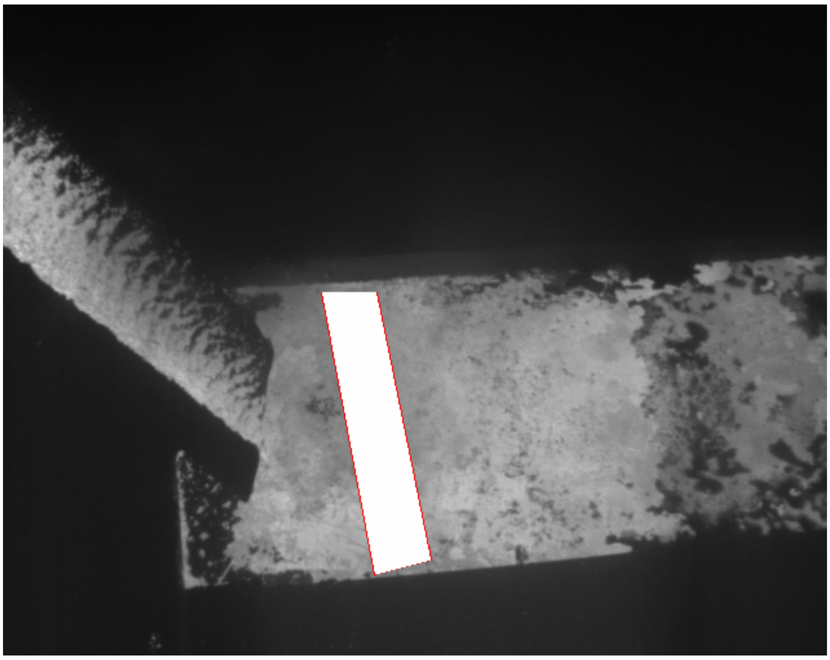

Figure 3: Sensor that controls vibration of the system

Table 1: Increase of the lifetime of copper tables

Date	*Tonnes of metal silicon cast*
1st campaign	8.000
2nd campaign	12.400
3 rd campaign	5.500[1]

[1] Still in operation

In the table 1, we show the amount of silicon cast onto the copper plates until we considered we had to change them. At this point, it is important to say that those figures only represent half of the life of the copper plates due to the fact the copper plates are symmetric and they are only worn out in the area where the metal is poured. Hence, when the copper plate is used on one side, we stop and turn the plate around to go on working with the same plate. The first campaign was done without camera and we changed the copper plate when we reached the objective in relation to the thickness of the plate. In the second campaign, with the camera incorporated to the control system, we could cast 55% more than in the previous campaign. Furthermore, this figure suggests that is possible to cast more than 30.000 tons of silicon just with one set of copper tables.

The reason of that increase is that the continuity in the silicon layer prevents the formation of layers thicker than 5 cm which then, when moving along the copper table, leave marks for abrasion.

The camera has shown a great robustness because it has been working for 4 years (since it was installed) without any technical problem. The only maintenance operation is the cleaning of the box where the camera is housed.

3. MONITORING OF MAIN PARAMETERS OF THE CASTING

The PLC that controls the casting machine sends every data to a computer which stored them in a database. From this database we can take the data and study the evolution of the main parameters of the machine in each casting. Although we have this system just from the beginning of the project, we have improved it and it has led to significant learning from the machine and its performance.

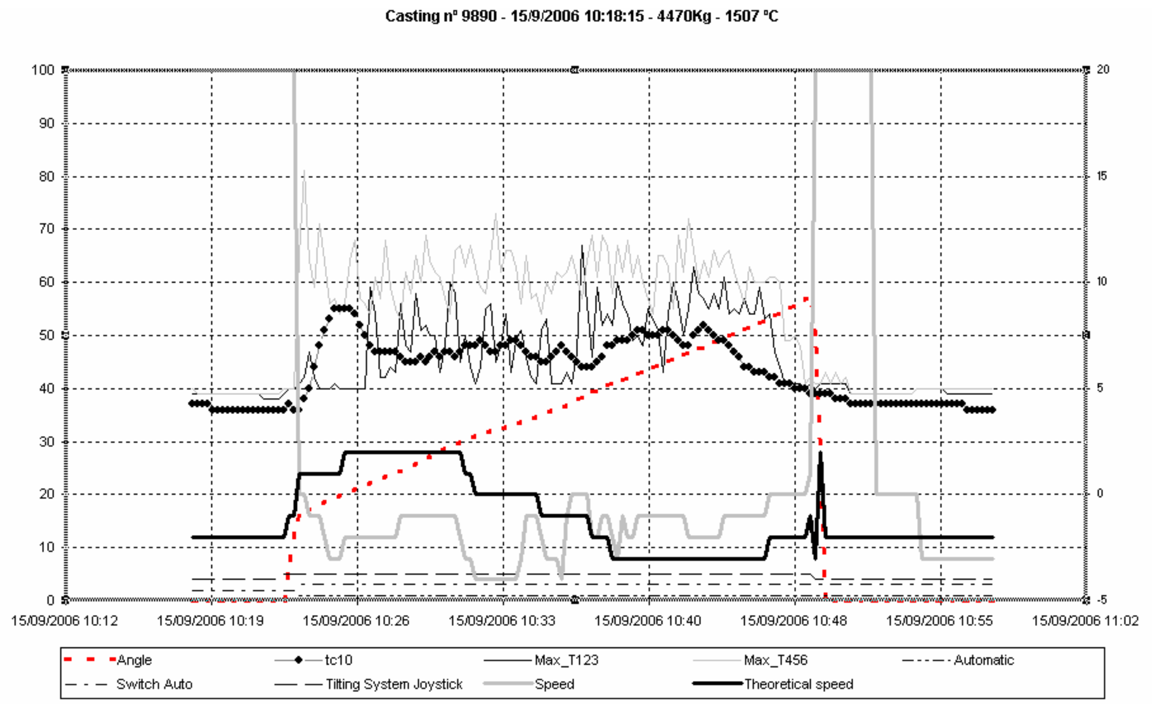

Figure 4: Typical graph with the representation of the main parameters

When there is a problem we can detect the cause analyzing these graphs and then we can take the right measures to prevent it from happening again.

4. NEW IMPROVEMENTS OF THE CASTING MACHINE

We continuously develop new ideas to keep this machine as cutting-edge technology and make it even more cost effective. One of these ideas is the installation of a grinder at the end of the second iron table to achieve lower granulometries.

In the next installation we have proposed to set up a new grinding system which would permit to automate in one machine the process of casting, cooling and crushing of ferroalloys.

Another improvement that we have carried out is the installation of a load cell under the ladle to control the flow rate of silicon that is being cast onto the copper table perfectly. So far, the cast has been carried out following a theoretical curve that specifies the tilting speed in each moment of the casting. That curve is based on the shape of the ladle. Apart from this, the casting speed can be corrected in some way by the camera or

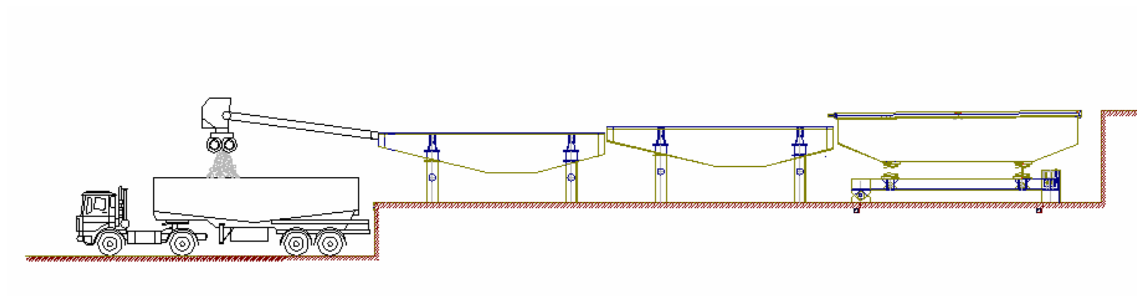

Figure 5: New grinding system

the temperature of the copper table or the sidewalls. We believe this improvement is going to help to lengthen more the lifetime of the copper table and to get better the control of the thickness of the cast material.

5. ADVANTAGES OF THE CASTING MACHINE

The main advantages of the casting machine are the following ones:

5.1 From the Metal Quality Point of View

It is well known that the solidification processes are very important for the alloy structure and hence the qualities of the alloy. Normally, rapid solidification leads to small grains and high alloy strength. In the Ferroatlantica's Casting Machine, the solidification occurs fast. Such fast cooling results in a very homogeneous product that could improve the performance of the same in certain downstream processing. Indeed, the solidification speed directly influences the primary impurity distribution of the silicon (=formation and composition of intermetallics). As impurities have less time to segregate, and always occur in the same way, the uniformity of the chemical distribution of each piece is much higher than traditionally cast silicon.

The silicon cast on this machine is very suitable for the chemical industry. The decision to set up a copper casting machine was taken when Ferroatlantica decided to enter the chemical-grade silicon market. Some important parameters of silicon metal quality that may influence the Direct Process for making methylclorosilanes are the chemical composition, level of impurities, the intermetallic structures and grain sizes. All these variables are influenced by the refining, the slag/metal separation, the casting process and crushing/sizing. This casting machine allows rapid and controlled solidification in a clean environment and a very good slag/metal separation so it is very suitable for production of silicon metal for the Direct Process.

In a paper presented by B. Pachaly [1] in 1994 at the second "Silicon for the Chemical Industry" conference, it was shown how different casting techniques could influence on the distribution of trace elements. He defined a new parameter called Structure Index Number abridged to QF. Samples of silicon produced with different casting methods were studied in a microscope and QF was defined as the ratio:

QF = Intermetallic phases at grain boundaries/Intermetallic phases in primary silicon (1)
The results are presented in table 2.

Table 2: Structure Index Number (QF) for different solidification processes. From [1]

Nº.	Solidification Process	QF
1	Mould cast 50 cm very good insulated	0,10
2	Mould cast 50 cm medium insulated	0,25
3	Mould cast 40 cm on thick fines layer	0,26
4	Mould cast 40 cm on thin fines layer	1,58

Table 2: Structure Index Number (QF) for different solidification processes. From [1] (Continued)

5	Mould cast 30 cm on thin fines layer	2,34
6	Multiple layer cast 15 cm	3,19
7	Mould cast 15 cm on thin fines layer	4,13
8	Mould cast 10 cm on thin fines layer	6,02
9	Mould cast 8 cm, no fines, water cooled	7,86
10	Continues cast 10 mm on copper	10,09
11	Water granulated 10 to 15 mm	23,21
12	Water granulated 5 to 10 mm	29,55
13	Air granulated	42,60
14	Atomized	63,92

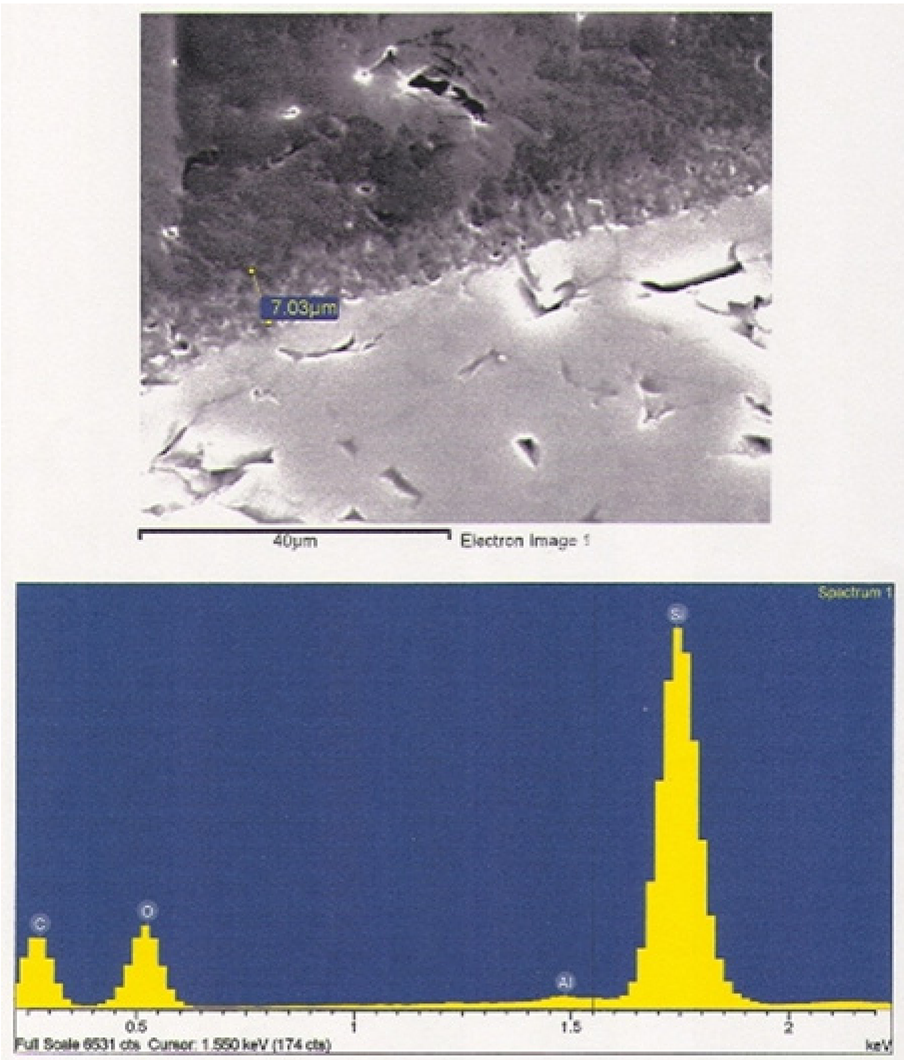

Figure 6: Oxidised layer on the top of a silicon chunk cast onto the casting machine

B. Pachaly explained that Wacker-Chemie found an optimum combination of productivity and selectivity in their methylchlorosilane (MCS) process with QF = 25 to 35. They concluded that the optimal structure can be achieved by water granulation, air-beam-granulation or continuous casting to diameter/thickness of 3 to 10 mm which can be done perfectly with the copper casting machine.

Apart from Structure Index Number (QF) another important process parameter is the oxygen content. As Lars Nygaard mentions in his article 'Silicon Solidification Techniques for the Chemical Industry' [2], it is important to limit the content of oxygen since oxidized silicon is lost and disturbs the MCS process. In figure

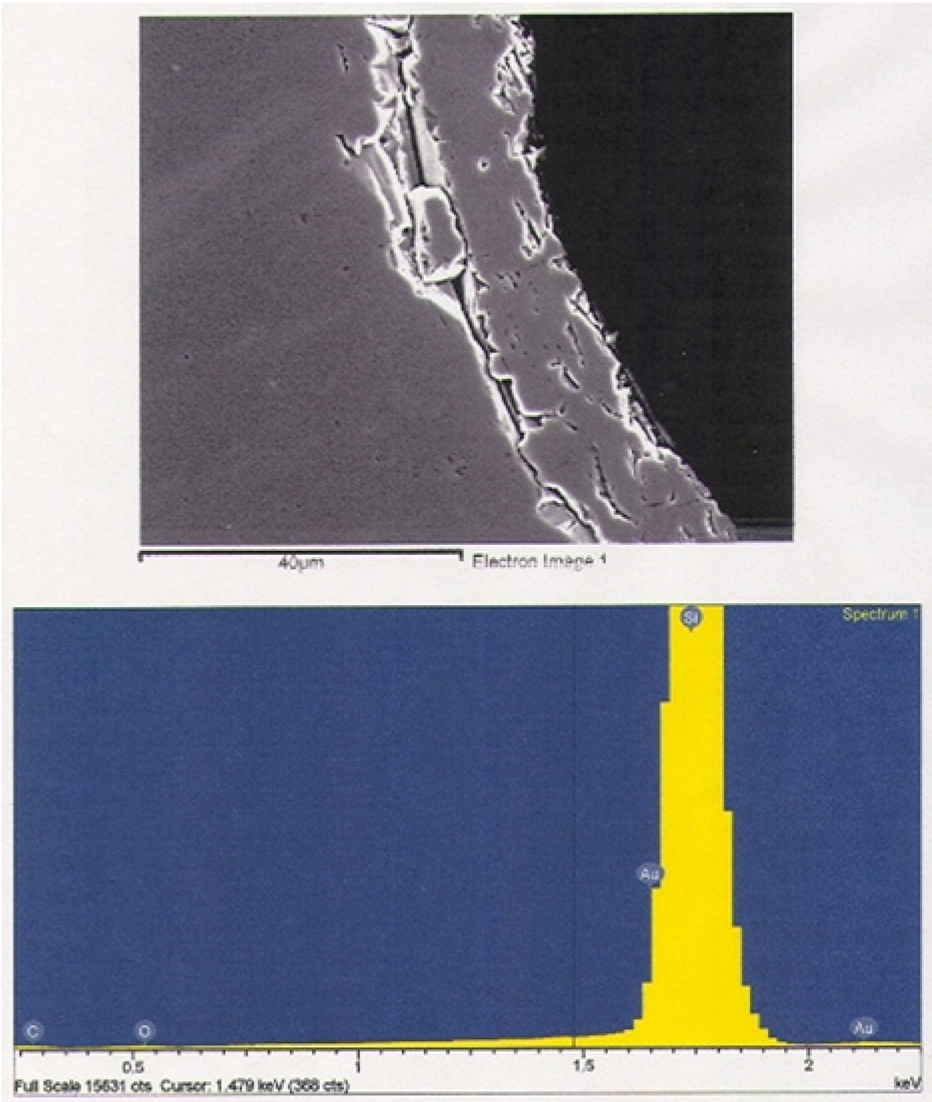

Figure 7: Sample of silicon cast avoiding the formation of the top oxidised layer

6, it can be seen that the thickness of the oxidised layer in the silicon cast onto the casting machine is about 7 µm which represents, according to our analysis and confirmed by a very important silicones producers, 0,15% of oxygen. Apart from this amount of silicon, the oxygen coming from slag only means 0,03% oxygen in the chemical analysis of silicon cast onto the casting machine.

Furthermore, we have developed a method to avoid the formation of this upper oxidised layer and made the material even more pure from the oxygen content point of view. The figure 7 shows the image of a sample of this material with the corresponding analysis. As can be seen, no oxygen content was detected on the surface and that means that the silicon cast on the casting machine following this method only has the oxygen coming from the slag inclusions.

5.2 From the Economical Point of View

In crushing refined and cast silicon metal ingots to customer size specifications, fine metal is generated which can be as high as 10 percent of the mass of the crushed ingot. This metal is regarded as non-commercial product since it is less than 5 mm in size and also normally contaminated. The product is either sold at a substantial discount or recycled back to the sumerged-arc furnace where smelting losses occur. With the copper casting machine, the amount of fines is reduced to less than 3% what means a great economical improvement. Not only have the machine decreased the amount of fines, but these fines are of a better quality so that our customers accept the 100% of our product except the dust.

Another advantage of the casting machine is its flexibility allowing different thicknesses and granulometries to satisfy the customer's requirements. This is possible because the machine is completely automated with several programs tailored design to obtain the different products. As a result crushing and sizing operations can be avoided.

As mentioned at the beginning of this article, by increasing the life span of the copper table it is possible to cast more than 30.000 tons of silicon with the same set of copper tables. Economically speaking, this means that copper cost is around 2€ton. Furthermore, this machine requires very little maintenance operations in comparison with the maintenance required with conventional installation of ingot casting, crushing, grinding and sieving the material. The main maintenance expense is the replacement or turn (due to the symmetry of the plates) of the copper plate.

6. CONCLUSIONS

Since the start-up of the copper casting machine for producing commercial silicon at Ferroatlantica Sabón's plant, about 25.000 tons of silicon metal has been processed either for the chemical industry or the aluminium industry. This is a highly automated machine which requires little maintenance operation and the main cost is doubtless the copper. Due to the fact that the price of copper has skyrocketed in the last years, it has been necessary to improve the control system in order to lengthen the life span of each table. According to the results of the first two campaigns, we are in the right way (the lifetime was increased ~~a~~55%) and we hope that the results will be better in the future owing to the last changes we have carried out.

From the quality point of view, the product is purer because fines are not necessary in this kind of casting and solidifying is a lot faster, which means less segregation. The thickness of the layer can be done in different ways, but the material, which appears flat, is always easier to break up and on the 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.

REFERENCES

[1] B. Pachaly, *Process Development in the MCS-Production: For Example Watergranulated Silicon Metal*, Silicon for the Chemical Industry I, Trondheim, Norway, 1994, p55.

[2] Lars Nigaard, *Silicon Solidification Techniques for the Chemical Industry*, Silicon for the Chemical Industry VIII, Trondheim, Norway, 2006.

[3] T. Margaria, *Influence of cooling on silicon structure,* Silicon for the Chemical Industry III, 1996.

[4] Tor Mühlbradt,, *Cast to shape: a new method to cast silicon metal,* Elkem Technology, Silicon for the Chemical Industry III, 1996, pag. 57-65.

[5] Schei A., Tuset, J., Tveit H., *Production of high silicon alloys*, Tapir Forlag, Trondheim, 1998, pp. 301-315.

[6] Halvorsen, G., Schussler, G., *Silicon metal qualities for the aluminium industry*, Elkem.
[7] Vogelaar, G.C., *Analysis of Intermetallic Phases in Silicon Ingots of Different Thickness*, Silicon for Chemical Industry III, 1996, pp. 95-112.
[8] J. Bullon, A. More, *Experiences at Ferroátlantica using the New Casting Machine*, Silicon for the Chemical Industry, Trondheim, Norway, 2002, pp. 47.
[9] J. Bullon, A. More, *The New Copper Casting Machine: Experiences at Ferroatlantica*, Infacon X, 2004, pp. 147-153.
[10] R. Boisvert, D. Leblanc, D. Ksinsik and C. Roche, *Casting and Cooling/Crushing of Silicon Meta land Silicon Alloy at Bécancour Silicon Inc.*, Infacon X, 2004, pp. 138-146.