Green Foundry LIFE project

LIFE17 ENV/FI/173

Action B3 Test series of molds, cores and casts produced by inorganic and organic binder systems

Deliverable DeB3C FOM Tacconi and Karhula Foundry implementing the inorganic binder system in everyday practices

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Feasibility study on the implementation of inorganic binders in the production of Karhula Foundry

1. Background

This feasibility study is made to assess the practicality of using inorganic binder systems in moulding process at Karhula Foundry. Karhula Foundry produces middle to large size special castings for global casting markets, mainly made of special stainless steels and irons. Weight range of produced castings is from 1 kg to 30 tons per piece.

Karhula Foundry has two moulding lines and hand moulding for large castings. Currently organic binder system is in use ie. phenolic Alphaset.

The feasibility of the implementation of inorganic binders instead of present organic binders is studied from economic, technical and environmental point of view.

Assessments and experiences in this report are from the tested inorganic binder systems and test casts carried out at Karhula Foundry in 2018-2020 as well as from the waste sand cleaning methods tested in this project. All results are reported in separate deliverables in actions:

Action B1 "Emissions of different binder systems during small-scale test casts",
Action B3 "Test series of moulds, cores and casts produced by inorganic and organic binder systems" and
Action B4 "Recycling options and sand purification of inorganic surplus foundry sand, high concentration organic waste sand and dusts".

2. Economy of the inorganic binders

The cost of inorganic binders now available on market is known to be 15… higher than the cost of currently used organic binders in ferrous foundries (= furan, phenolic Alphaset and green sand).

One of the tested inorganic binder systems would require investments due to the need of drying at elevated temperature. This would mean construction of new ovens or other heating equipment such as hot air blowing line into moulding area. There would be also high investment cost for the present patterns and core boxes which are partly made of wood and resin. Resin patterns and core boxes would damage at the needed temperatures of 160…200 C°. Wooden patterns and core boxes are so good insulators that it was impossible to get cores and moulds hardened and dried inside them. The patterns and core packages should be replaced by new ones made of metallic or other heat resistant material. Investment into sand drying system would costs about 0,5 million €. Patterns and core boxes for a typical products like pump housings in sizes of 0,1 to 2 tons and impellers in sizes in 30 kilos to a few hundred kilos (with 5-7 different core boxes) would cost c. 50. -100.000 € per product. Karhula Foundry produces average 1200 different products per annum. To replace all patterns and core boxes would be an investment of 60-120 M€. The customers would not pay this.

The other two tested inorganic binder systems behave similar way as current Alphaset binder system, They are self-setting which means that they achieve the needed strength levels without drying at elevated temperature, and they would be usable in the present moulding lines without any new investments. This type of binders are the only ones possible to take into use in existing foundry by using existing wooden patterns and core boxes. These binders include some components, so, they are not 100 % inorganic. However, they could reduce organic impact by c. 80 %.

To be implemented on everyday practice inorganic binders must therefore give technical and environmental benefits to compensate higher initial cost. These aspects are addressed in next chapters.

3 Technical feasibility of inorganic binders in the production of Karhula Foundry

Karhula Foundry has two moulding lines and hand moulding for large castings. The current binder system in use is phenolic Alphaset. The melting capacity consists of 8 ton arc furnace and 8 ton, 1,5 ton and 0,5 ton induction furnaces. Karhula Foundry has an 8 ton AOD (Argon Oxygen Decarburization) converter for metal treatment.

The moulding sand is mainly pure high quality silica sand. For the most demanding castings the surfaces of moulds in contact with the melt are made of chromite sand. Sand is reclamed inhouse by mechanical vibrating table crushing system. Typical mixture in moulding is 70 % recycled sand and 30 % new sand.

The surplus sand has been disposed earlier locally, eg. by using it as a filler in local harbor area. Due to harmful impurities this surplus sand has been classified as waste and that's why is now prohibited by local authorities, and Alphaset surplus sand causes now a problem. The moulds and cores are typically coated by alcohol-based zircon coatings.

The technical experiences from the tested inorganic binders:

- Three inorganic binder systems were tested
- One tested inorganic binder system requires drying at elevated temperature at 150…200 C^o
- Two tested inorganic binder systems are of self-setting type behaving similar way as the current Alphaset binder system.

3.1 Experiences from the inorganic binder system nr. 1

The main challenge with this binder system was the need of heating to temperature of 160... 200 C° for drying and for achieving appropriate strength levels. Drying of the test moulds was made in available small ovens which limited the maximum size of tests castings to 500 kg.

Heating caused some damages to resin patterns. If this inorganic binder system would be taken into everyday practice, all patterns and core boxes should be replaced by the ones made of metallic or other heat resistant material.

Other challenge was to find the right mixing time and the right recipe for the contents of the binder and the promotor. Estimation of the needed heating times was also difficult and ca. 25% of test moulds and cores broke during stripping because of improper drying and they could not be used for test casts.

When proper parameters for mixing time, recipe of binder and promotor, and heating times were found for the test moulds, the quality of moulds was comparable with current Alphaset moulds.

After the casting stainless steel into test moulds, it was found that significantly less fumes were emitted from these test mould compared to the fumes from the Alphaset moulds.
Actually the difference is so big that we can say the moulds are fumeless.

The breaking of the moulds after cooling was easy and the present vibration equipment would suit to this binder system.

The quality of the successful test casts was good and comparable with the present castings made by using Alphaset binder system. In the moulds with cores the risk for gas bubble defects with inorganic moulds is diminished compared with Alphaset moulds, and the quality in this respect is even better. For good surface quality both inorganic and organic Alphaset binder moulds must be coated.

3.2 Experiences from the inorganic binder system nr. 2

This binder system behaves similar way as the current organic Alphaset binder system in use, and it reaches the required strength levels at room temperature. The minimum room temperature for hardening is 10 C°. The binder itself is 100% inorganic material, but the hardener is organic ester mixture.

The main challenges in achieving the good quality moulds was to demonstrate the proper parameters for the mixing time and the contents of binder and hardener for the tested amount of sand batch. The hardening reaction must not start during the mixing or filling of the moulds, and the binder + hardener recipe must give the required strength levels. There are different formulas of harder for shorter and longer moulding time.

After founding the proper parameters for mixing time and the recipe of binder and hardener, the quality of moulds was found to be comparable with the current Alphaset moulds.

After the casting stainless steel into the test moulds, it was found that significantly less fumes were emitted also from these test mould compared to the fumes from the Alphaset moulds. Some more gas formation was expected with this binder system compared to the inorganic binder system nr. 1 due to the use of organic hardener and this was demonstrated by the chamber test made later. The results are addressed in the next chapter.

The shake-out of the moulds after cooling was easy and the present vibration equipment would suit to this binder system.

The quality of the successful test castings was good and comparable with the present castings made by using Alphaset binder system. In the moulds with cores the risk for gas bubble defects with inorganic moulds is diminished compared with Alphaset moulds, and the quality in this respect is even better.

For good surface quality both the inorganic binder system nr. 2 and Alphaset binder moulds must be coated.

3.3 Experiences from the inorganic binder system nr. 3

The compositions of inorganic binders are different in inorganic binders nr. 2 and 3. However, inorganic binder system nr. 3 also uses similar organic hardener as inorganic binder system 2, and therefore it behaves similarly compared to the current organic Alphaset binder system in us. The minimum room temperature for hardening is 10 C^{o}.

The main challenges also with this binder system in achieving good quality moulds was to demonstrate the proper parameters for the mixing time and the contents of binder and hardener for the tested amount of sand batch.

After founding the proper parameters for mixing time and the recipe of binder and hardener, the quality of moulds was found to be comparable with the current Alphaset moulds.

After the casting stainless steel into the test moulds, it was found that significantly less fumes were emitted also from these test mould compared to the fumes from the Alphaset moulds.

The breaking of the moulds after cooling was easy and the present vibration equipment would suit to this binder system.

The quality of the successful test casts was good and comparable with the present castings made by using Alphaset binder system. In the moulds with cores the risk for gas bubble defects with inorganic moulds is diminished compared with Alphaset moulds, and the quality in this respect is even better.

For good surface quality both the inorganic binder system nr. 2 and Alphaset binder moulds must be coated.

4. Environmental aspects of inorganic binder systems

The environmental aspects of inorganic binders are addressed and compered with the current organic phenolic Alphaset binder system based on the results from:

- Emission measurements in the chamber tests in Action B1 “Emissions of different binder systems during small-scale test casts”
- Results from the Action B4 “Recycling options and sand purification of inorganic surplus foundry sand, high concentration organic waste sand and dusts”.

The results show that all inorganic binders will produce significantly less fumes in casting process. Additionally, the fumes do not contain toxic components. Surplus sand does not include environmentally harmful components. It maybe is possible to use directly as building and landfilling material. The only problem would be that it still is categorized as “waste”.

So, we can say that concerning working conditions inside the foundry and the fume and smoke emissions from the foundry, inorganic binders will solve all problems.
Some specifications re. surplus sand need to be changed so that it can be used easier than today’s surplus sands with organic binders residuals.

Feasibility study on the implementation of inorganic binders in the production of FOM Tacconi (currently Fonderie Assisi)

5. Background

This feasibility study is made to assess the practicality of using inorganic binder systems in the core making process in FOM Tacconi (the company is now named F.A. Spa and in the following we will use the term F.A.). F.A. is a cast and steel iron foundry skilled in automotive parts. So they make parts of engine and of the distribution systems. Usually those parts are medium and small in dimensions but with high volumes of production. In Italy the industry of automotive foundry has been important in the past as suppliers of components for car making companies (Fiat above all) and other vehicle making companies: for transportation like lorries, for agricultural like tractors, for construction like scrapers and so on. Today foundry industry operates in a very challenging environment at European and International level, with high levels of sustainability to achieve. Furthermore, the main car making company, Fiat, belongs to a very international group, Stellantis and it is not anymore main clienf of foundries. In this context F.A. is looking forward any improvement in its production system, especially concerning the reduction of environmental impact. This because F.A. is located in one of the most important Italian town for tourism, Assisi, Unesco world heritage site. In this sense the possibility of using inorganic binder is a must for the company, both for the reduction of pollution and for the reduction of odor emissions ,

6. The production system of F.A. Spa.

F.A. produces automotive parts such as turbines housing (2.5 million items/year), bearing housing (3.2 million items/year) and manifold (1 million/year).

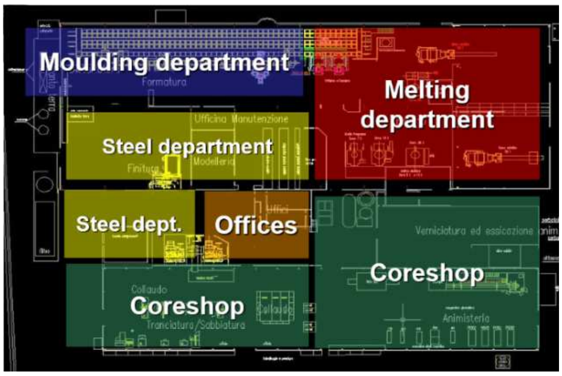

Fig. 1. *Plant layout*

Fig. 1 shows the foundry plant layout. In the analysis, three foundry areas (see Fig. 2 for their schematization) are considered because they are the departments that allow a greater possibility of intervention to improve industrial processes:

- the coreshop department: the area for the cores production;
- the moulding department: the area for mould preparation and for all operations before casting;
- the melting department: the area for the melting and treatment of metal.

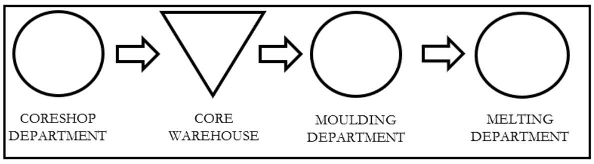

Fig. 2. *Production flow*

The cores, elements used to create internal cavities where the melted metal does not have to penetrate, for functional reasons of the piece or to reduce its overall weight, are produced in the coreshop department. The produced cores must minimize the formation of burrs, satisfy certain requirements, which vary according to the casting technique. After the solidification of the metal, the jet is extracted, and the core is removed by dirt.

Fig. 3 shows one of the cores production lines. There are three silos each containing a different type of sand (a synthetic sand, a French sand and a national sand) sent in mixture to core blowing machine. The sand is mixed for a time between one and two minutes, with a two-component binder: a phenol formaldehyde resin and a poly-isocyanate. Then the mixture enters the core blowing machine to produce the cores. The line in Figure 3 consists of three core blowing machines: even if they share the same feeding duct for the sand, each machine has an independent mixer to produce different types of cores.

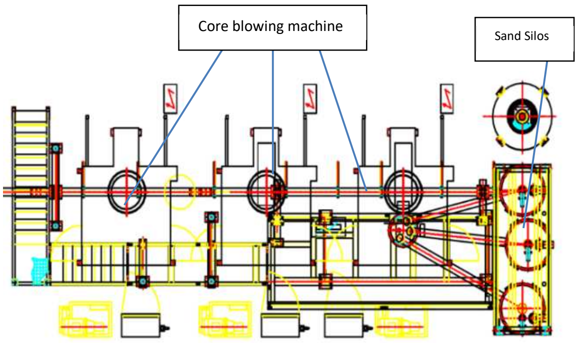

Fig. 3. *Cores production line*

Once produced, the cores are stored in a warehouse waiting to be used in the moulding department (see Fig. 4 for its operation) where the moulds to produce pieces are assembled and the cores are manually inserted by an operator.

Finally, the mould is sent to the melting department. The right mechanical resistance of the cores is ensured by binders: chemical mixtures, with a content from 1% to 3% (the remaining 97-99% is sand) that adhere to the grains.

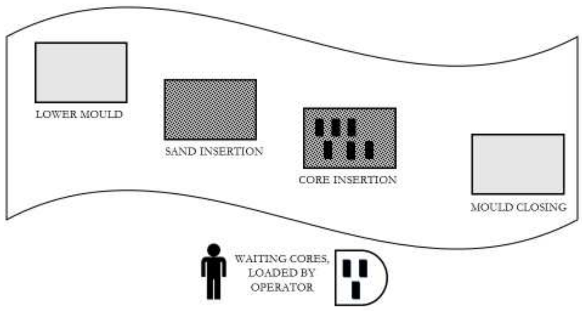

Fig. 4. *Moulding department*

7. Technical feasibility of inorganic binder in FA

First of all F.A. tested inorganic binder in its producions system with results reported in separate deliverables in actions:

- Action B1 “Emissions of different binder systems during small-scale test casts”,
- Action B3 “Test series of moulds, cores and casts produced by inorganic and organic binder systems” and
- Action B4 “Recycling options and sand purification of inorganic surplus foundry sand, high concentration organic waste sand and dusts”.

Two kinds of inorganic binders were tested: Cordis (supplier Huttens Albertus) and INOTEC (supplier ASK chemical). The supplier of tested cores is VA, a making cores company skilled in inorganic binder cores (mainly for aluminium production). The cores are used as internal cores (to make “cavities”) in the metallic product. This is a valid test case, because the face the de-coring problem, main issue in inorganic binders used.

Number of casted iron items: 320 with 96 de-cored manually and 224 de-cored in an automatic machine (de-sanding machine).

In the figure 5 products after fusion are shown. In figure 6 products before decoring are shown. After decoring the quality of the product was very good, exactly as organic binders products.

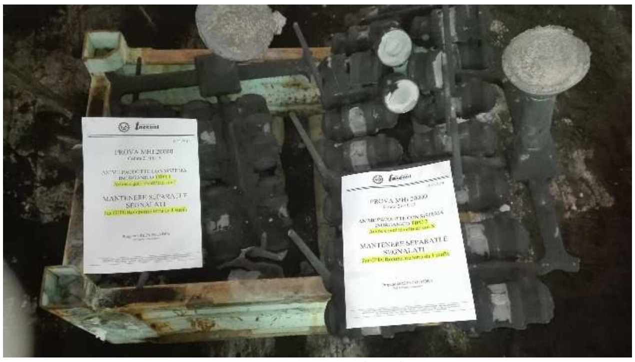

Fig. 5 casted product after fusion

fig. 6 detailed of products before de-coring

8. Feasibility study on the implementation of inorganic binders in the production of F.A

To obtain a more environmentally sustainable production, inorganic binders can therefore be introduced. But their use influences the production process to be implemented.

Many foundries, and the analysed foundry too, use the cold box method to form the cores. The cold-box process, known as the Ashland process, tested in 1965 in U.S.A., was presented in Europe only in 1968. The process allows the production of cores in a few seconds and ready for immediate use without using heat.

The traditional process (cold box) undergoes changes if new inorganic binders are introduced: the core blowing machines currently used for the cores must be modified or it is necessary to purchase new machines suitable for the new process.

Cores obtained with inorganic binders are hygroscopic, i.e. they are prone to water absorption causing their rapid deterioration. To solve the problem of the hygroscopicity of the cores, several measures concerning their storage are possible.

Another problem linked to the introduction of the inorganic binder is that it does not burn in contact with the casting metal remaining entirely attached to the sand used to create the mould. So, the inorganic binder must be recirculated together with the sand, using a land recirculation plant.

Fig. 7 shows the necessary plant and process modifications for the introduction of inorganic binders.

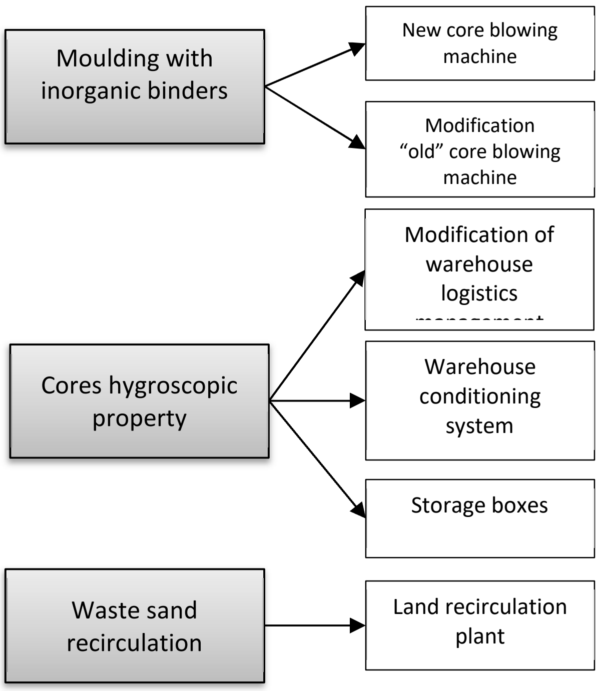

Fig. 7. Necessary changes and technological innovations in the production processes

Therefore, as said before and shown in Fig. 7, the areas where it is necessary to make changes to the processes to allow the use of inorganic binders, concern the moulding process, the recirculation process of the waste sand and a series of possible interventions that take into account the hygroscopicity of the new cores. In this way, thanks to a technological innovation and thanks to a leaner production, it is possible to insert a green production process inside the foundry. a lean production combined with technological innovations also allows a green process with a lower emission of pollutants.

9. Economy of the inorganic binders

In this section we want to discuss in detail the changes in the production processes and in the plant that should be introduced following the choice to use inorganic binders.

The first innovation necessary for the production of inorganic cores is the core blowing machines modification within the coreshop department. It is possible to purchase a new machine specifically designed for use with the inorganic process or reconvert and modify the existing machines used for cold-box process. The process with the inorganic binders requires a special mixer that allows to combine sand, liquid binder and additive. The mixer must be discontinuous and closed to minimize the evaporation of the binder during the formation of the mixture. The metal core boxes must be heated to 150-200°C and it is necessary to have a core drying system with hot air at about 200°C in order to speed up the hardening process directly in the core box. The needed changes for the core blowing machines are the following:

- some components of the machine must be cooled
- the sand loading hopper must be closed
- a hopper cooling system must be present
- a core box heating system is required
- a hot air generator must be provided for drying the cores

To evaluate the best choice between purchase and modification, an economic evaluation takes place. The modification of the soul box is a common cost item both for the purchase of new machines and for the modification of the machines already used. The core boxes are the containers inside which the cores are created. They are not independent of the type of machine used, but it is necessary to modify them by changing from a cold-box process to a hot box one. Considering all the costs, the percentage increase to buy a new machine compared to the costs to modify an existing one is equal to about 66% (105000 € to purchase a new machine, 63000 € to make changes to the current machine).

To solve the problem of hygroscopicity of the inorganic cores and, at the same time, to optimize the cast iron production line in the plant, it was decided to reset production according to the just-in-time (JIT) approach. Since the inorganic cores require an extremely low storage time in order to preserve their mechanical characteristics, we want to proceed by innovating the production line making it more efficient. The coreshop department has a slower production rate than the moulding department, respectively 20 pieces/hour for each core blowing machine and 140 pieces/hour for the moulding line. For this reason, the storage of cores in a large warehouse (about 6.000 m3) is necessary with an average storage time of a week. This high storage time is induced by some constraints in the production of cores:

1. setup time for each core blowing machine of 2 hours;
2. core box cost: the high cost of the core box involves the difficulty of producing the same product in parallel on separate core blowing machines (only for large productions there are multiple moulds).

The first analysis of the production processes highlights the possibility of intervening on the warehouse management: the long storage time and the large size of the warehouse are critical situations on which it is necessary to operate in order to make production leaner. A simulation model is developed to simulate the cores production line to obtain a leaner warehouse, with fewer pieces and with a storage time reduced to 8 hours. The introduction of a JIT policy in the production system leads the system towards leaner production. This therefore allows to insert inorganic binders that makes production green. Thus, the concepts of lean and green are closely connected.

Another possible solution that allows to counteract the tendency of the inorganic cores to absorb humidity is the conditioning of the core storage warehouse, by controlling the temperature and relative humidity. In particular, it is assumed that the relative humidity is kept constant in the range between 30% and 50%, while the temperature in the range between 17 and 23°C. As the environment to be air conditioned has large dimensions (6000 m3) and the hygrometric conditions that must be kept uniform, the air conditioning system is of the "full air" type. The air is sent to the environment through a distribution system, consisting of a network of delivery channels and the relative input terminals, vents, haemostats or linear diffusers. By designing the air conditioning system, a necessary power of 720 kW is obtained with an initial investment cost of 263.000 €.

In any case, the air conditioning of the warehouse presents a critical aspect: difficulty in keeping the climatic conditions of the warehouse fixed, due to the frequent opening and closing of the doors to allow the storage and removal of the cores.

The hypothesis of storage of the cores in containers that have excellent characteristics as regards insulation from the outside, regarding water and humidity, is analysed. The material chosen is EPP expanded polypropylene, which being an apolar polymer, exhibits excellent thermal insulating properties with low thermal conductivity and high mechanical strength which allows to protect the cores from possible impacts. Furthermore, this material is totally recyclable. The most important advantage of this solution lies in the possibility of minimizing the humidity absorbed by the core, without the need to condition the warehouse and therefore without any energy consumption due to storage. The main disadvantages are instead of imposing on the production cycle a further operation for storage, which does not increase the value of the product, and entails an increase in the volume needed inside the warehouse. Especially for high production volumes, the solution appears to be not very functional, although highly effective in terms of maintaining the correct mechanical and resistance properties. The solution of the insulating boxes is the most economical solution, even if it is difficult to make a precise quantification about the costs. However, due to the large production volumes of the company and the several types of cores, the use of different containers is entailed, and this solution is difficult to implement. Storage boxes can only be a solution for small orders, where the company's priority is represented by the quality and maintenance of the optimal conditions of the soul.

The mixture of exhausted sand is made up of green sand, with which the mould is composed, of silica sand and of the binders necessary for the cores. The sand can be regenerated to be used again in a subsequent production cycle. For mixed sands, recovery and regeneration are more difficult and less controllable than in the case where the sands are monotype. In addition, a further difficulty in the regeneration process is caused by the presence of the inorganic binders since they are less subject to thermal degradation. For the steel castings, in which the casting takes place in shell and the same sand is used both in the mould and in the cores, it is possible to regenerate the monotype sand with inorganic binder. There are already plants that are used with excellent results and which allow the reuse of almost all the sand. The green sand regeneration process, on the other hand, is still in the initial phase and it is not yet known how, with the increase in the regeneration cycles, the chemical characteristics of the inorganic binder affects the green sand. In this regard, there are no known layouts of plants for the regeneration of the sand for cast iron foundries. Within the Green Foundry LIFE project, the analysis of the sands, coming from the casting tests, is started to understand how the green sand is modified by the presence of sodium silicates (inorganic binders). The current state of the regeneration technology is therefore in the initial state of study: it will be necessary to analyse the technical characteristics that the plant will have to provide and then, through pilot plants, to test the actual operation after several repetitions of the recirculation cycle. Currently the problem of the management of waste sand certainly represents the greatest obstacle to the diffusion of this technology for use in large series productions. Instead, it is possible to use inorganic binders for small productions, as the mixture sands will be in much lower percentage than the mixture composed of green sand and organic binders, so the effect of the inorganic binders on the characteristics of the sands is neglected.

The first solution to be adopted will be the introduction in the existing production line of a new core making machining with necessary equipment for using inorganic binders. In this manner it will possible to maintain the investment in mouldings (more than 1000) by using both inorganic and organic binders. Furthermore it will possible to avoid the problem about the exhausted sand (by using a limited amount of inorganic binders the characteristics of present regenerated sand are kept). Then a progressive transition towards inorganic binders will be made. Total investment costs will be around 1500 k€ for the machine. For new moulds the costs will be around 500 k€, while production costs will be more or less the same.

10. Environmental aspects of inorganic binder systems

With inorganic Binders F.A. can give clear signal about the aim of reducing any kind of emissions. In this manner it will possible for the company to develop within a competitive environment while keeping its productive roots in the city of Assisi.