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Lean production as a tool for green production: the Green Foundry case study

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Abstract

Lean manufacturing techniques aim to improve the business processes. In recent times, the ever-increasing attention to aspects of economic, social and above all environmental sustainability, suggests that lean manufacturing is not only techniques for the reduction of business costs, but also for the sustainability improvement of the companies. Even the foundry industry presents technological changes aimed at improving processes but also due to environmental and climate regulations. The paper aims to analyze how technological innovations introduced to obtain economic, social and environmental sustainability influence the production process.

Keywords: agrifood logistics, supply chain management, industry 4.0

1. Introduction

In the past the concepts of lean production and green production were studied separately in overcoming the problems of the production process [1]. The lean concept was known as a manufacturing solution for achieving maximum added value through the identification of 8 types of losses (inventory, over-production, defect, waiting, motion, transportation, over-processing, human resources) and eliminating these losses ([2], [3]). The green concept answers the demands and necessity of the industry in the creation of manufacturing processes that are environmentally friendly, both ecological and social perspective not just following the economic profit [3], [4]. Thus, the integration of the two concepts is a necessity to obtain sustainable production processes economically, environmentally and socially. Improving productivity, the economic benefits increase [5], while focusing on the triple bottom line (people - profit-planet), sustainability get better ([6], [7], [8]).

In lean concept, the 8 types of losses are solved with 12 techniques (Kaizen, 5S, JIT, Visual Management, VSM, Andon, Gemba, TPM, Takt Time, SMED, SCM, Cellular Layout) ([2], [3]) increasing productivity and quality in a manufacturing system [9]. While green practice creates a sustainable manufacturing system due to the development of ecology, social and economy dimension [10], [11]. Ecology and economy have most direct relationship with lean ([12], [13], [14]), since they are attributed to “reduce-reuse-recycle” [15]. Social dimension of green is related to the safety workplace [16]. The concepts of lean and green can be applied in several stages of products and processes along the supply chain, starting from design, production, suppliers, and customers [17], [18].

Also, the foundry industry is moving towards the concepts of lean and green production. The foundry industry has an important role in the industrial sector and its environmental impact in significative: high gas emissions and waste generation make the foundry one of the most environmentally polluting type of production. Therefore, the increasing need to have green industrial sectors, leads to a continuous research on technologies that guarantee compliance with both technological and environmental parameters.

In the foundry industry most of the pollutants originate from combustion of organic binders in sand moulds after

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coming to contact with liquid metal in temperatures of over 1200°C. This causes hazardous emissions evaporation to the ambient air and indoor air. Moreover, a significant part of contaminants condensates back into moulds. Also, the binder residuals in the surplus foundry sand disposed in landfills, degrade and cause some GHGs to ambient air.

To overcome the problems listed above, the use of inorganic binders is introduced in the foundry industry: the emissions decrease and a more efficient use of sands is achieved. Moreover, the inorganic binder reducing some technological problems such as the poor knocking out, elasticity and reclamability [19].

However, it must be considered that the introduction of technological innovations, in particular of inorganic binders, causes different chemical behaviors during the production, affecting all the production line. In fact, in order to guarantee the quality of the pieces obtained with the technological innovation introduced, action must be taken on the entire process, making it as lean as possible.

The use of lean manufacturing tools in foundry industry is investigated in 300 Polish foundries through a survey [20]: only the 29% of the foundries have implemented any of the lean tools. However, some difficulties of implementing improvements in foundries production systems are overcome modifying the industrial layout and balancing the workload [21]. The pouring time [21], the WIP inventories and the production time [22] are reduced and the safety and productivities are improved using lean tools and techniques [22].

The foundry industry is therefore moving towards both the lean and green aspects. Since lean techniques are more difficult to implement in this particular sector, often the need to have more environmentally friendly processes predominates over the lean techniques. The paper aims to investigate whether the change in production processes towards a green perspective influences the same processes, involving the introduction of lean techniques.

The remaining of the paper is organized as follows: Section 2 is dedicated to the depiction of the methodology used. In Section 3 a case study is presented, while in Section 4 some preliminary considerations are made. Section 5 contains the conclusions.

2. Methodology

The research question that the work poses is:

- How can lean production support technological innovations useful for achieving green production?

To answer the question, supported by a European project, a foundry is analyzed. The Green Foundry LIFE project (LIFE17 ENV/FI/000173) introduces novel technologies for sand-moulding systems to cut emissions, improve indoor air quality and support the circular economy through re-use of foundry sand that is normally landfilled.

The research approach (see Fig. 1) is therefore based on a first foundry analysis to know the manufacturing processes. The second step consists in understanding, based on the particular production processes, where it is possible to replace the organic binders with the inorganic ones proposed by the Green Foundry LIFE project. The third step consists in identifying the changes generated in the production process by the use of new binders. Finally, some considerations are made.

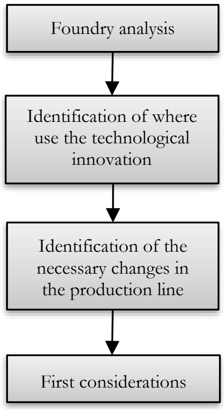

Fig. 1. Research approach

2.1. The Green Foundry LIFE Project

The main objective of the Green Foundry project is the decrease of the environmental impact by introducing new technologies for sand molding systems. In particular, the use of inorganic binders in ferrous foundries applied in sand molding systems improves the environmental and economic impact and also increases competitiveness of the industry. The use of new inorganic binders hazardous air emissions, casting fumes and fine particles like binder aerosols from the casting process are reduced. Moreover, the indoor air quality is improved.

Another objective of the project is to be encouraging example for other foundries on an EU level: producing the necessary practical and information tools, a systemic use of inorganic binders and technologies in ferrous foundries could be obtained.

To achieve the objectives, several actions are to be implemented. Small scale test casts are made to measure the emissions of the casting processes, using both organic and inorganic binders. Total emissions of five foundries will be measured and compared: one iron and steel foundry using organic binder system; one iron foundry using organic binder system and two aluminium foundries using inorganic binder system; one steel foundry using water glass binder system. Also, indoor air quality will be measured and compared in four of the foundries mentioned above. Moreover, foundry sand recycling options will be tested and compared for inorganic and organic binder sands.

2.2. The inorganic binders

In the past decades though many inorganic binder systems were common, their use was dominated by the more developed organic binder systems. Some examples of "old" inorganic binders are waterglass + heat, waterglass + CO_2, waterglass-ester (hybrid) and cement. The first inorganic binder mentioned present several problems such as weak (initial) strengths, bad flowability, long cycle times and the issues of decomposition after casting combined with poor reclaimability. The second inorganic binder (waterglass + CO_2), in addition to the problems listed for the first, presents problems of permeability to gases in the mold necessary to guarantee their hardening. Waterglass-ester (hybrid) has problems with the initial strengths and the issues of decomposition after casting. The utilization of cement as inorganic binder implies the decomposition after casting and non-reclaimability of the moulding sand.

Due to these technical disadvantages, the organic binders have replaced old type inorganic binders in many foundries. But, even if the organic binders (like phenolic and furan binder systems) have good technical properties, they have many environmental and work hygiene disadvantages.

New inorganic binders are introduced first in aluminium foundries: Inotec™by ASK Chemical, Cordis by Hüttenes-Albertus, GEOPOL® by Sandteam CZ and inorganic system developed among the Gietech-Go project are the inorganic binders which are in commercial use or in trial phase.

Inotec binder system consists of a binder (i.e. alkali silicates, a modified blend of waterglass) and a promotor 100% inorganic, consisting of minerals and synthetic raw materials. Curing of Inotec binder system moulds and cores is made by heating, with an optimum temperature about 170-175°C. The recycling of Inotec sand must be made by thermal reclamation. Inotec has mainly been used in aluminium foundries but some trials have been made in ferrous foundries.

Cordis system is essentially like Inotec. Two components are needed: Cordis binder (modified alkali silicate solution) + Anorgit additive (synthetic, inorganic additives). Curing by heating to 130-200°C must be applied. Coating is necessary for ferrous castings: water based coatings can be used, but drying must be made instantly after painting, otherwise humidity destroys the strength. Cordis system has taken hold in about all foundries, especially in those serving automotive industry but in ferrous foundries. Cordis is still in a trial phase.

Geopol is the inorganic system of binding on the bases of geopolymers: inorganic materials, belonging to alkaline aluminosilicates. These materials contain silicon and aluminium and – stabilizing them – alkaline elements such as sodium or potassium. Geopolymers under an influence of liquid hardeners undergoes polymerization, forming polymers of a high binding ability. This geopolymer binder can be also hardened by means of CO_2. Heating is not applied for curing. The Geopol binder can be applied for making moulds and cores for castings of iron, cast steel and non-ferrous metals.

Another inorganic binder system is tested in EU funded project "Gietech-Go" and marketed with the brand name "CAST CLEAN® Binder System". Green Foundry LIFE and Gietech-Go project will do cooperation during the projects.

All the considerations in this section are made by the authors also in [23].

3. Case study

Within the Green Foundry LIFE project, one Italian foundry interested in inorganic binders is examined. The potential benefits that this industry wants to obtain from the use of the new binders are:

- minimal gas formation should improve quality by diminishing the risk for casting defects and make moulding simpler due to less need for ventilation pins;
- emissions from the foundry would decrease and indoor air quality would improve.

The foundry industry considered (plant layout is shown in Fig. 2) is a small company manufacturing automotive parts such as: Turbines Housing (2.5 million items/year), Bearing Housing (3.2 million items/year) and Manifold (1 million/year). Such kind of product are, in foundry industry, small and quite complex in term of qualitative standard of the foundry operations. It is necessary a high-quality standard concerning tolerance.

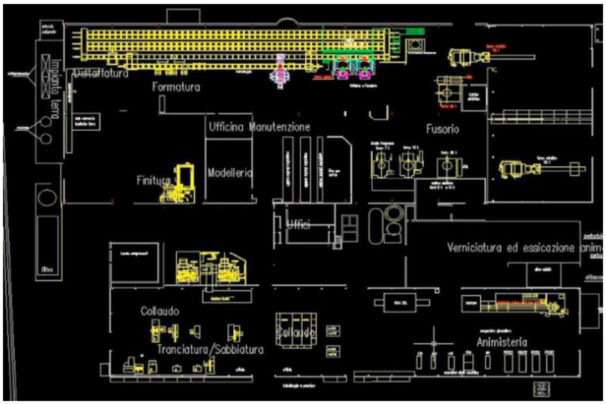

Fig. 2. Plant layout

Analyzing the entire company production, the technological innovations (use of inorganic binders), introduced by the Green Foundry LIFE project, are not a simple question since still the development of an operative solution takes longtime. However, it is possible to verify the use of the new binders in the core shop department (in Fig. 2 the core shop department is on the lower right).

3.1. The core shop department

In the foundry industry, the cores are 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. The cores are arranged before the mold is closed, but, depending on the casting technique, the core can also be completely integrated into the mold. The cores must be made in such a way as to minimize the formation of burrs, satisfying 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 [24].

To guarantee the right mechanical resistance of the sand cores, binders are used: chemical mixtures that adhere to the grains provide mechanical resistance to the core. The content of binders is from 1% to 3%, while the remaining 97-99% is sand.

In recent years, the land industry has seen environmental standards become increasingly restrictive ([25], [26]). In particular, the traditional binders used for the cores, despite their reduced content in terms of percentages, emit up to 70% of volatile foundry compounds (VOC) [27]. For this reason, the goal is to replace them with lower-emission binders, which guarantee comparable physical and mechanical properties at high temperatures.

There are different processes for forming the cores but the foundry under study uses the cold box method. The cold-box process, also known as the Ashland process, was tested in 1965 in U.S.A. and was presented in Europe only in 1968. This process allows the production of cores without using heat. The cores are produced in a few seconds and ready for immediate use. The most important features of the process are the following:

- Use of an organic binder that can give to the sand good qualities of cold and hot resistance, and, at the same time, excellent crumbling after casting.
- Reactivity at ambient temperature, without the need for heating: this implies simplicity of use, handling, lower equipment and operating costs.
- Fast and definitive hardening which allows a production rate with high dimensional precision of the castings.

Figure 3 shows the production line of the cores of the analyzed foundry. Proceeding in the image from right to left there are three silos each containing a different type of sand, a synthetic sand, a French sand and a national sand that is sent in mixture to core blowing machine. The sand is mixed for a time between one and two minutes, based on the core that is to be produced and at ambient temperature, with a two-component binder: a phenol formaldehyde resin and a poly-isocyanate. Afterwards the mixture of sand and binder enters the core blowing machine that goes to produce the core. The line consists of three core blowing machines that share the same feeding duct for the sand, but each machine has an independent mixer to produce different types of core independently.

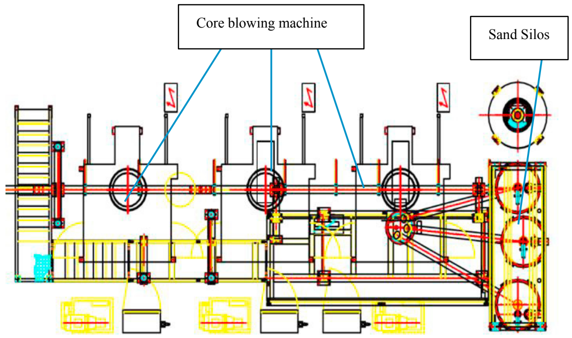

Fig. 3. Cores production line

4. Results and discussions

The use of inorganic binders in the core shop department as a substitute for the current organic binders, entails some precautions.

First, measurements must be made to verify the mechanical properties of the cores obtained with the new binders, collaborating with companies that produce inorganic binders. Moreover, this collaboration led to the knowledge that the new cores have a very low shelf life. It goes from a 4-day storage to a single day. This implies a strong intervention in the entire production of the plant and a reconfiguration of the entire line. Moving therefore towards a greener production implies also moving towards a leaner production. If the use of inorganic binders to produce the cores wants to be introduced, the repercussion in the production line must be considered. Being in the first steps of the research it is not possible to proceed to develop a new layout of the department nor to make a comparison of the layout in the configurations as is - to be.

In any case, the first result obtained shows that movement towards a more environmentally friendly production, involves a modification of the current production system, if not overall, at least for the part of production that involves the insertion of the technological innovation.

Therefore, it is possible to give a first answer to the RQ set by the paper. In the productive sectors where lean techniques are more difficult to implement, they become necessary to respond to the production changes dictated by green production.

5. Conclusions

The paper analyzes the consequences that occur on the production line of a foundry industry when changes are introduced to make production more environmental-friendly.

The study is in the initial part. Future developments will concern on one hand the analysis of various inorganic binders to identify the best, on the other hand the changes to be implemented on the production line to respect the shorter storage times, moving towards a lean production. Tt will also be interesting to analyze which lean techniques can be introduced in the specific reality of the foundry.

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