Use of Arc Plasma in Metal Casting as a New Approach towards Energy Efficient Manufacturing

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Foundries constitute a segment that influences the supply chain of a several industrial segments by defining the quality and cost of manufacturing metallic primary products. Within this context, the encouragement of seeking for energy efficient processes is extremely encouraged, also to minimize the environmental collateral damage inferred by foundries. The present article explains and demonstrates the elaboration of a mechanism to compensate the temperature drop of the poured cast iron by pre-heating the cast iron pouring channel with the heat transfer from an arc plasma source placed above it. Besides requiring less energy to heat the post-poured molten metal, which impact has been measure after one year of operation of this innovative solution, it was possible to improve the metallurgical quality of the cast alloys and reduce defects thanks to a more accurate control of the molten metal temperature. The result obtained regard the design and implementation of a pioneer solution of heater inside a conventional sand casting foundry.

Keywords: *Foundry, sand casting, arc plasma, temperature control, energy efficiency.*

1. INTRODUCTION

Bearing in mind the financial return and the susta–inability that it can generate [1], the improvement of energy efficiency is a constant challenge to industries from all sectors, ranging from paper [2], to cement [3] and even urban mobility [4,5], embracing also the foun–dry industry, given its importance in the global eco–nomy [6].

The foundry processes are undoubtedly the first strategy developed by humankind to obtain metal tools and other metal details [7]. Already the first founders immediately realized how a good result is strictly linked to the two essential aspects of melting: chemical ele–ments and temperature profile. Times have certainly changed, but these two initial aspects remain also essential for the modern metallurgy, because they are inextricably linked to the physical-chemistry of the iron-carbon transformation [8-9]. This transformation, even if deeply known, is, in some ways, so intrinsically complex as to make the same casting process able to provide very different metal alloys with relatively small tricks and changes [10-13]. Cast iron and steel, in fact, only represent the main *labels* behind which an infinity of different alloys is grouped, according to charac–teristics and properties and usability [13-15]. Thanks to this great variety, when properly known and efficiently controlled [16], it is even possible to get to design the material on the basis of the final characteristics that are offered by the feedstock [17].

Rhodin et al. [18] investigated through a thorough survey which were the main barriers against the imple–mentation of energy-efficiency solutions in the Swedish foundry industry, concluding that the largest obstacle is limited access to capital, followed by technical risk (e.g. production disruptions or lack of budget funding). Furthermore, privately and group-owned foundries diverge in the sense that the first has its obstacles more strictly related to information diffusion, whereas the latter has predominantly organizational problems. On the other hand, the two predominant driving forces toward energy efficiency attainment are ambitious leaders and long-term energy strategies.

Thollander et al. [6], seemingly to Rhodin et al. [18], performed a broader study on drivers amd management practices for energy efficiency improvements surveying 65 foundries in 7 European countries with high-level of industrialization; reaffirming the major influence of financial restrictions and organizational problems, allowing the understanding of a continental pattern. A concerning statement of this research is that these foundries estimate an energy saving potential of up to 7.5% in their plants, which is nearly only one third of the European Union goal of 30% to be reached until 2030 [19]. Despite these numbers are insufficient, reaching them is not an easy task and requires it to gain a priority status on the company agenda [6].

Cagno et al. [20] analyzed that in Italy, particularly, although long-term benefits can be reached with energy efficient measures, the lack of investment in subsidies for technology constitutes the main barrier for development. Although, it is important to emphasize that the application of novel technologies is not the only parameter that could be improved: it accounts for

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approximately 20% of the energy savings potential; while management practices also represent up to 20% [21]. Another factor that must be taken into account, is the time that the companies take to actually implement those changes in their plants, as shown by Cornelis et al. [22], industries generally take action after a few years from the first energy audit.

More recently, Cagno et al. [23] performed a general study all over the north of Italy surveying 30 foundries to investigate the gap between innovative practices and ene–rgy efficiency. The first was analyzed in terms of Open Innovation practices [24,25], which manages innovation based on the internal research and development of the company by quantifying inbound processes (flows of knowledge to power internal innovation) and outbound processes (to expand the markets for external use of innovation); and the second was measured by specific energy consumption, barriers to energy efficiency and level of adoption of energy-efficient technologies. The study allowed to conclude that foundries that allied internal R&D with inbound practices are superior to others in all aspects, which means that the key to energy efficiency could be the diversification of innovation practices.

It is therefore possible to understand the high impor–tance attributed to the topic energy efficiency in foun–dries given by both industry an academia, once the potential of reduction of costs and emissions is noti–ceable and, simultaneously, there is still a lot to be imp–roved in this field in terms of technologies and mana–gement practices.

2. MANUFACTURING PROCESS

The foundry process on which the action intervened can be depicted as follows:

- Melting: takes place in a cupola furnace, with layers of coke and ignited with torches. When the coke is ignited, air is introduced to the coke bed through tuye–res in the sides, and when the coke is very hot, solid pieces of metal are charged into the furnace. The me–tal is alternated with additional layers of fresh coke.
- Molding: every day the production plan is sent to the molding line, and the parts to be cast during the day are indicated, with urgencies specified. The actual process of molding is implemented by exploiting the imprint left by the two halves of the pattern on the green sand that fills the lower and upper box.
- Pouring: the shapes are placed on the pouring line and then filled with molten iron.
- Shaking-out: after pouring the molten iron into the molds, these are transported along a cooling tunnel in which they remain until they reach the optimum tem–perature to allow the shake-out
- Shot blasting: to clean and polish castings investing them with a jet of steel shot.
- Finishing: the castings undergo to various sub-pro–cesses (fettling/deburring, painting, testing, etc.) in order to be ready for the final delivery.

In this kind of processes, which include the transfer ladle, a temperature decreasing up to 100 °C usually occurs in molten cast iron passage from the furnace to the moulding lines (Figure 1) and problems can arise if the temperature at the moulding line is not adequate.

2.1 Technology

The heating system is based on the plasma technology which allows to compensate the temperature drop of the poured cast iron. It consists in the heat transfer from an arc plasma source placed above the pouring channel to the cast iron.

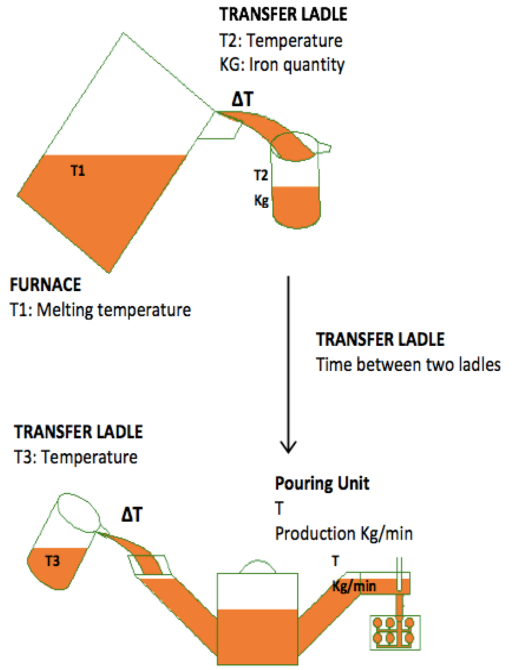

Figure 1. Cast iron passage from the furnace to the presspour.

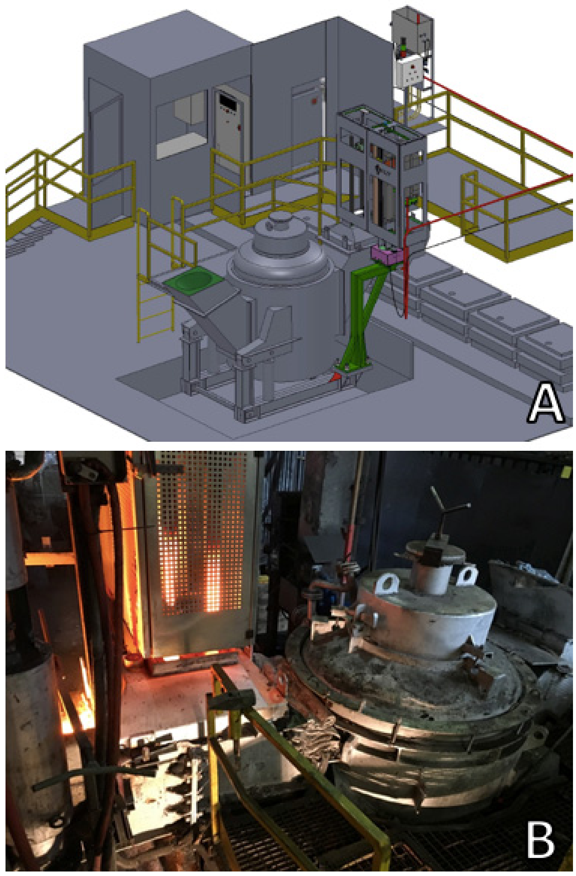

Figure 2. CAD representation (A) and photograph showing the positioning of the *heater* inside the casting zone and close to the presspour.

Applying a heating plasma technology directly on the pouring channel allows reheating the metal with maxi–mum flexibility: the power is immediately available and it can be used according to the user needs. Aiming to optimize the technology and assure that, the temperature of the molten iron is detected by a probe so that it can be adjusted by the technology in a feedback loop.

Moreover, the plasma technology grants a higher efficiency in the electricity-to-heat transformation pro–cess and, with a more stable pouring temperature, allo–ws to noticeably reduce costs related to quality issues. Basically, the system affects the thermal energy supply and the quality of the products. One of the consequences of the system installation is that the temperature of the molten iron delivered from the holding furnace can be lower, leading to corresponding energy savings.

2.2 Design and Realization

As first step, a new refractory design for the presspour was realized, including the pouring channel. Hence, the works at the metalwork and the refractory were carried out to rearrange respectively the interior and the exterior of the pouring channel. As for the plasma torch equipment support, a metallic stand was positioned close to the presspour (Figures 2). The platform has been realized properly to allow the centering of the electrodes into the slots of the pouring channel cover.

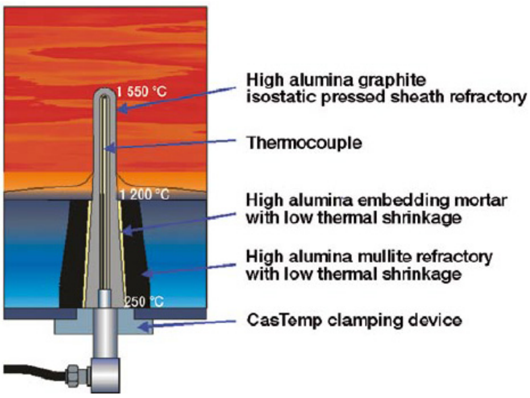

Figure 3. Temperature probe features in detail.

The temperature probe inside the heater has a tem–perature gradient that ranges from 250°C in the clam–ping device to 1200°C in the probe-molten metal sur–face to 1550°C on its tip, which is directly in contact with the metal and coated with a refractory layer of alu–mina graphite. This temperature is measured by a ther–mocouple embedded in the core of the probe, as seen in Figure 3.

As for the thermocouple location, an opening has been realized in one of the pouring channel sides (Figure 4A), so the support and the probe could be positioned (Figure 4B).

The pouring channel had to be closed by a cover (Figure 4C) with the slots for the electrodes in order to concentrate the thermal energy close to the plasma torch and to avoid hot material leaks. The metallic case of the cover to be positioned on the pouring channel was first realized, then fulfilled with the refractory material realizing a cavity in the refractory layer with a properly shaped core. This cavity allows the nitrogen to be close to the cathode and activate the plasma arch (Figure 5).

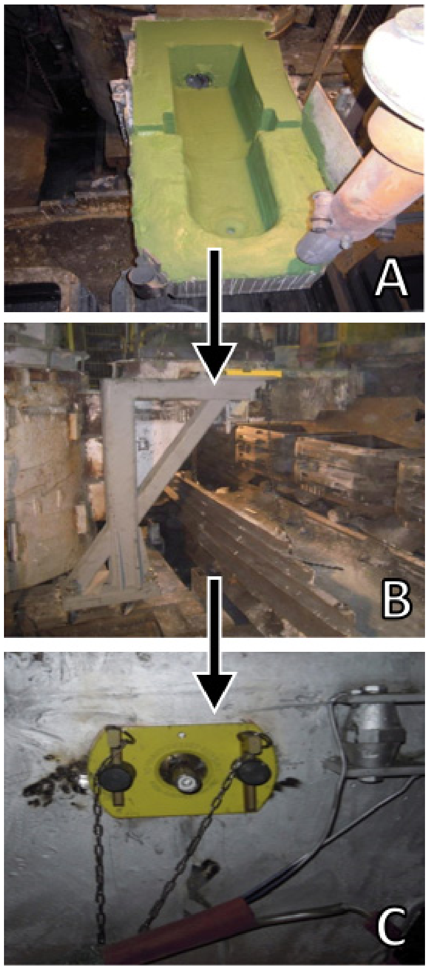

Figure 4. Details regarding the installation of the heater and the thermocouple: opening on the sides of the pouring channel (A), positioning of the support and the probe (B) and cover (C).

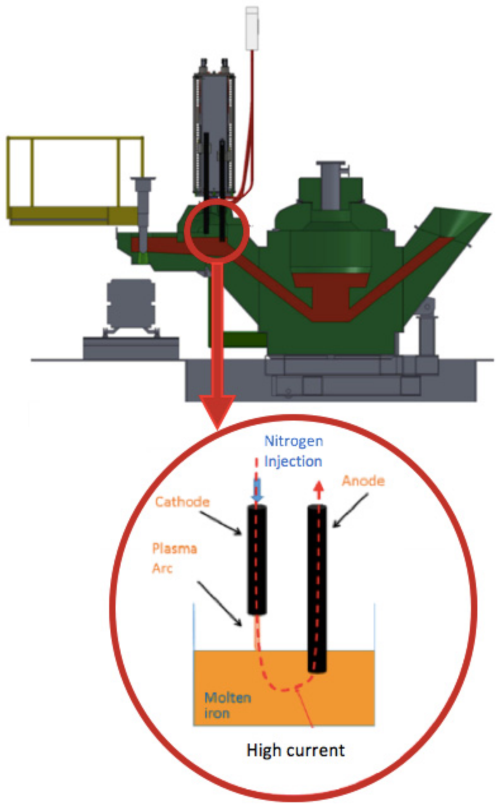

Figure 5. Heater and plasma arc mechanism in detail.

Aiming to work with the torch, the cover of the pouring channel had to be located centering the bolts. Once the cap is positioned, the cleanness of the ope–nings has been verified and the nitrogen cap has been positioned on the casings.

Once the cover has been positioned on the pouring cannel, the plasma torch has been positioned with a crane on the elevated structure that is directly based on the presspour. The operation has been facilitated having removed the covering of the plasma torch equipment.

Once the equipment was on the pouring channel, the electrodes were positioned over the centering caps setting the position by means of the different screws and servomotors. The plant was ready for casting (Figure 6).

Figure 6. Final phase of the casting process with an active control of the temperature of molten iron.

3. VALIDATION TEST

A test was performed in order to verify that the system allows to keep the temperature of the iron to be poured in a range of tolerance within the quality of the final product is acceptable. During the acceptance test the working conditions had been confirmed and any devi–ation taken into account for evaluations (Table 1).

First the process operated without using the heater with the aim at measuring the temperature of the mel–ting iron to be poured. After 3 ladles, the heater was turned on and since that moment, the temperature in the pouring channel increased thanks to the electrodes that started lightning the plasma arch.

Table 2. Acceptance test targets

CRITERIA	TEST (target)
Ladle Temperature	1.450 +/-5ºC
Pouring Tª Plasma OFF	1.400 +/-15ºC
Pouring Tª Plasma ON	1.400 +/-5ºC
Production (Tn/hour)	5.5 Tn/hour
Ladle arriving	800kg

During this validation test the temperature of the iron in the pouring channel was continuously monitored and compared to the target temperature. The electric power required by the electrodes was also monitored. Their trends are reported in Figure 7.

In the graphs, the iron temperature is represented by the red line while the green line is the target temperature and the blue line the power absorbed by the plasmapour.

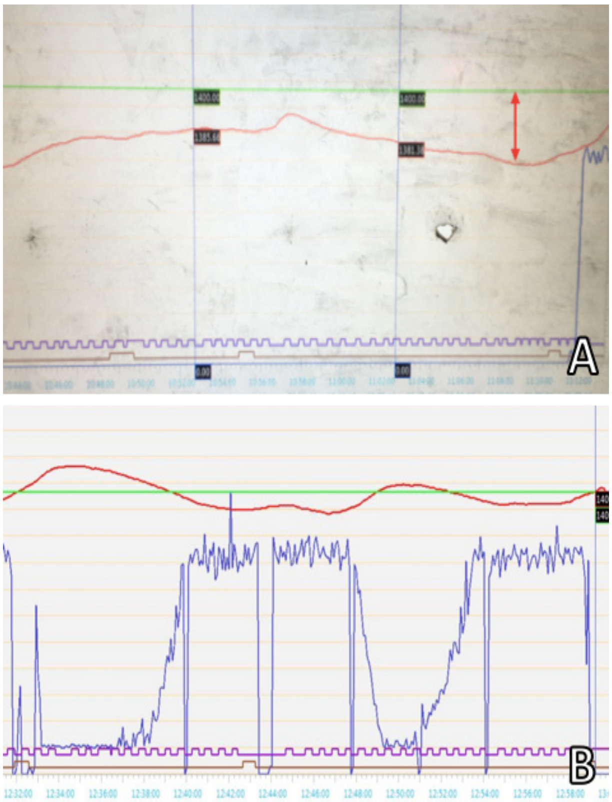

Figure 7. Parameters trends during the acceptance test before (A) and after (B) the plasmapour started working.

It can be noted that, in the first phase, before the plasmapour activation (Figure 7a), the iron temperature is, on average, 20 °C lower than the target temperature. The power absorbed by the plasmapour is, of course, zero. After its activation (Figure 7b), the plasmapour started to absorb energy and the iron temperature to fluctuate close to the target.

It was possible, then, to verify the positive effect of the plasma heater in stabilizing the real temperature of metal closer to the target value. Adding, considering the energy power, it was also possible to verify that, once the temperature was in the range, the power consum–ption decreased to values reasonably in line with the productive process.

After one year of operation, the main results of this plant enhancement can be summarized in two topics:

- The overall specific energy consumption did not increase, even if no attempt has been made in terms of decreasing the holding furnace power;
- Over 100 tons of carbon dioxide were saved due to the quality improvements made.

Financially, this improvement in energy efficiency allows the industrial plant to save up to 60.000 €/year, which means that payback can be achieved in less than 5 years; an interesting outcome considering the simplicity of implementation of the arc plasma heating system.

4. CONCLUSION

The foundry industry is relevant for many other indus–trial segments worldwide, so research and development is such an embracing area must be encouraged given that it affects a broad supply chain and may impact several processes, the quality and the cost of products.

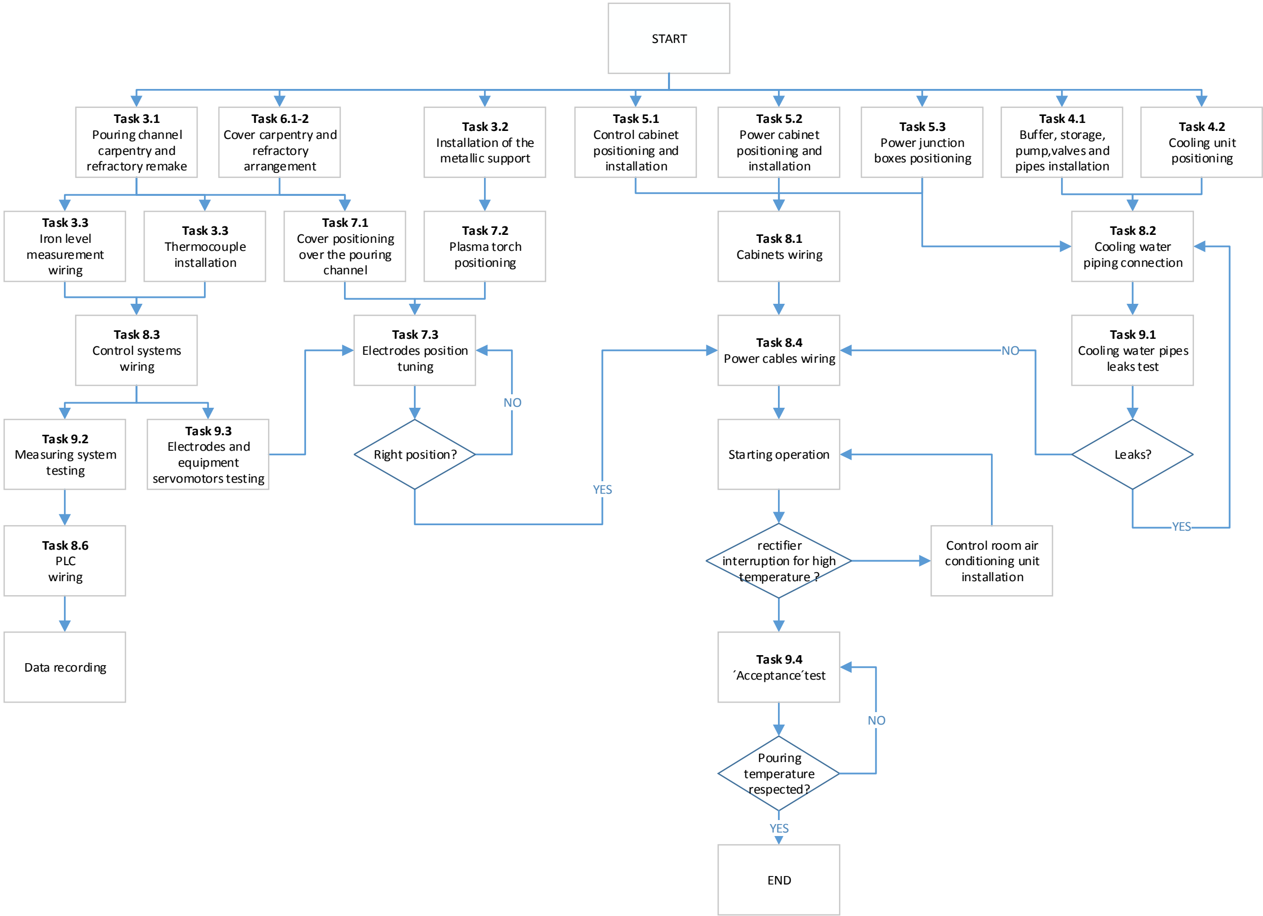

Chart 1. Plasmapour commissioning steps flowchart.

The state-of-the-art review allowed to conclude that energy efficiency, particularly in foundries, is a current concern worldwide, whereas the identification of its most prominent barriers has already been conducted, which not necessarily eases the implementation of ene–rgy efficient technologies and practices. The current baseline in which the foundry industry stands has shown some evolution in the last decade, but there is still a long way to go in order to achieve emission reduction standards from international agreements.

The present work aimed at compensating the temperature drop of the poured cast iron by heat transfer from an arc plasma placed above the pouring channel, demanding less energy to reheat the metal. Interesting financial outcomes have been achieved through a relatively simple adaptation, whereas its ease of replicability must stimulate other foundries in seeking more energy efficient processes. The flowchart showing each step of plant realisation is available in (Figure 8).

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КОРИШЋЕЊЕ ЛУК ПЛАЗМЕ У МЕТАЛНОМ ЛИВЕЊУ КАО НОВИ ПРИСТУП У ЕНЕРГЕТСКО ЕФИКАСНОЈ ПРОИЗВОДЊИ

С. Кучети, Е. Савини. Ђ. Луђисано

Ливнице представљају сегмент који утиче на ланац снабдевања неколико индустријских сегмената дефинисањем квалитета и трошкова производње металних примарних производа. У том контексту, охрабрује потицање потражње за енергетски ефикасним процесима изузетно је подстакнуто, а такође и минимизирати колатерална штета животне средине која произилази из ливница. Овај чланак објашњава и демонстрира израду механизма за надокнађивање падова температуре ливеног гвожђа сагревањем предгријевањем канала за ливење ливених гвожђа са преносом топлоте из извора пламенског лука постављеног изнад њега. Осим што захтијева мање енергије за загревање постољег стаљеног метала, чији је утјецај након једне године рада овог иновативног рјешења, могуће је побољшати металуршки квалитет ливених легура и смањити недостатке захваљујући прецизнијој контроли температура растопљеног метала. Добијени резултати односе се на дизајн и имплементацију пионирског раствора грејача унутар конвенционалног ливијара за ливење пијеска.