RECYCLABLE

RECLAMATION OF INORGANIC BONDED SAND SYSTEMS TOWARDS A MORE SUSTAINABLE CORE PRODUCTION PROCESS

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An increasing number of automotive aluminum foundries are replacing organic with inorganic binder systems in order to reduce emissions of volatile organic compounds and ensure a more sustainable production process. If an efficient sand reclamation process for inorganic-bonded sand were developed, it would provide further benefits in terms of reduced emissions and energy consumption. This study presents an innovative process for reclaiming inorganic-bonded foundry sand, based on a mechanically-adsorptive process known as the CLUSTREG process. Results show that, even after 10 reclamation cycles, foundry sand derived from cores bonded with SOLOSIL* TX inorganic binder systems could be re-used, without detrimentally affecting the flowability of the sand mixture, or the mechanical properties and gas permeability of the manufactured cores. Although the pH value and conductivity did significantly increase after one reclamation cycle, this had no negative impact on the core quality of reclaimed sand.

INTRODUCTION

It is common knowledge that a large number of castings are manufactured in clay-bonded moulding materials [1]. For technical and economic reasons, the bentonite- or clay-bonded sand is now treated after use, with the result that most of the material can be re-used, reducing costs and environmental impact. This process is known as reclamation.

Separate to the above-mentioned clay-bonded sand systems, there is a large variety of organic binder systems for core and mould production [2]. These materials can also be reclaimed, using mechanical and thermal processes. The resin- or organic-bonded sand undergoes thermal exposure during casting and cooling, before the core residue is removed using a shake-out process. Some of the binder bridges close to the casting surface are exposed to high temperatures and are almost completely decomposed, which makes the shake-out less complicated. During mechanical reclamation, the binder can be relatively easily removed from the surface of the sand grains, as the strength of the organic binder bridges is quite low.

When using organic-bonded sand systems, emissions are mainly caused by burning off the organic binder components in the sand moulds or cores during the casting process. An increasing number of automotive aluminium foundries are therefore replacing organic with inorganic binder systems to reduce emissions of these volatile organic compounds, and to ensure a more sustainable production process [3]. If an efficient sand reclamation process for inorganic-bonded (IOB) sand could be developed, it would reduce emissions and energy consumption further still. However, the reclamation process for inorganic-bonded sand is, from a technical point of view, very different to that being developed for organic-bonded sand systems.

Aluminium automotive foundries use core packages consisting of base cores, inlet, outlet cores and water-jacket cores. The system is known as a mono-system, because only one binder system is used, with, if needed, two different grain sizes (distribution) of silica sand. During the foundry process, the core package faces mild thermal exposure only in certain areas, for example, the inlet, outlet cores and the water-jacket cores. As a result of the low thermal impact, some areas in the core package remain at room temperature, while other parts undergo very short thermal exposure at 500 °C, before rapidly cooling to 200 °C within approximately 30 minutes.

When using inorganic binder systems, the binder bridges are generally more rigid, with higher mechanical resistance, compared to organic binder bridges; indeed, the hardness of the cured inorganic binder is close to the hardness of silica. Based on the higher abrasion resistance of the cured binder, sand reclamation processes that comprise only grinding of the grains are not recommended.

This study focuses on the development of a sand reclamation process for SOLOSIL TX inorganic-bonded sand cores from an automotive foundry. After presenting the CLUSTREG sand reclamation process, results from 10 reclamation cycles will be highlighted, including sand characteristics (particle size [distribution], LOI, pH, conductivity), flowability of the sand mixture, bending strength values and gas permeability of the manufactured cores.

DESCRIPTION OF THE PROCESS FOR RECLAIMING INORGANIC-BONDED SAND

With the CLUSTREG process (Figure 1), KLEIN Anlagenbau AG (WO 2017/137113 AI, Method and Device for Regenerating Foundry Sand) has developed an innovative mechanically-adsorptive process for the reclamation of water glass-bonded foundry sand. The process comprises a sequence of three main steps.

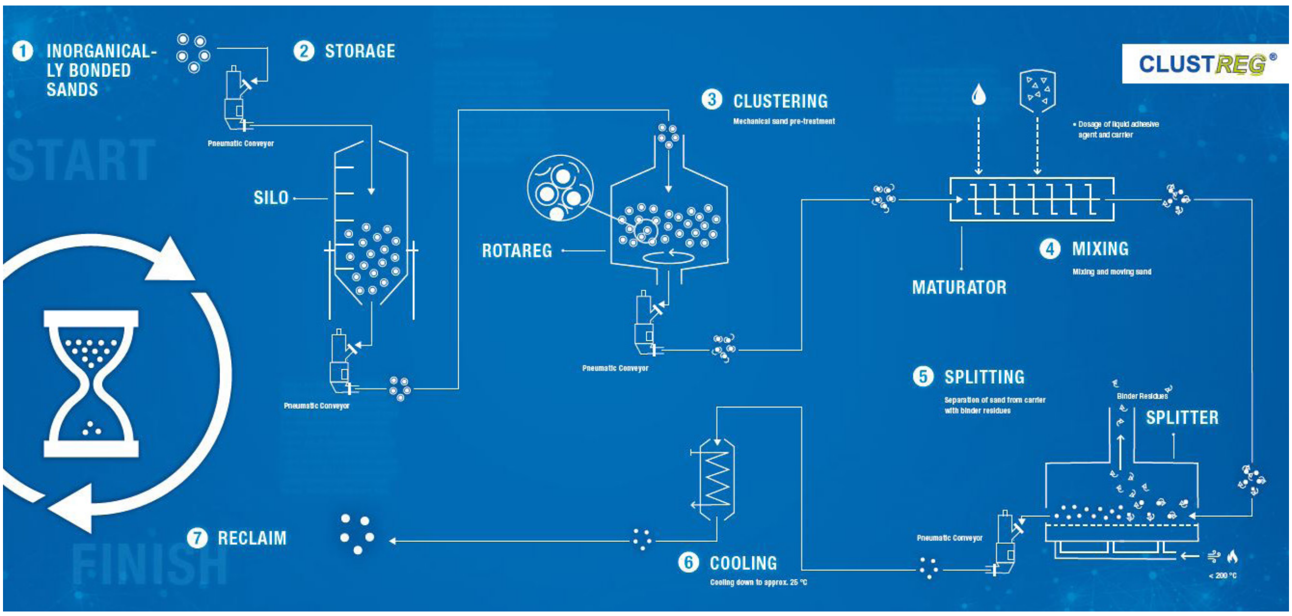

Figure 1. The CLUSTREG process

In the first step, the used sand is processed in a ROTAREG mechanical pre-cleaning unit (Figure 2). During this stage, the binder residues, additives and quartz dust (if present) are loosened from the sand grains and dedusted in a first dedusting stage. The used sand falls vertically from the top with a defined mass flow (10 t/h) to a rapidly rotating turntable. This accelerates the sand outwards and shoots it almost radially into a sand bed. The sand is cleaned by the impact and by rubbing the sand grains against each other. Depending on the desired degree of cleaning, the sand can circulate several times in the pre-cleaning unit. An initial pre-dedusting stage is integrated into the processing chamber.

After this mechanical treatment step, the sand is again intensively dedusted in a classifier. The main advantages of the ROTAREG are the gentle sand treatment, the robust and inexpensive plant technology and its ability to process many different binder systems, especially for water glass-bonded foundry sands.

In the innovative second step, the mechanically pre-treated sand is mixed with an adhesive agent and a carrier material in a specific way in a maturator. Binder residues and dust particles are bound to the carrier material in the used sand-adhesive agent-carrier mixture. The grain surface is also cleaned of fine dust particles. After the mixture has passed through the maturator, it enters the third treatment stage, the splitter.

In the splitter, the sand and the carrier material, now with the binder residues and dust components bound to it, are separated from each other. To do so, the mixture is passed over a fluidized bed, through which heated air (< 200°C) flows from below. Due to the fluidization and specific suction, as well as the low density of the carrier material compared to the sand, the carrier material, binder residues and dust particles are discharged upwards and removed. After the sand has passed through the splitter, the regeneration process is complete and reclaimed sand can be re-used in the core making process.

During process development, great importance was attached to the fact that the plant technology is simple and robust and that, apart from the usual hardened wear parts required for sand treatment, no special materials are required (e.g., no heat-resistant steels, special sealing materials, etc.). It is also important to note that energy consumption is only about 20% of that of thermal reclamation plants for the reclamation of water glass-bonded foundry sands. Moreover, CLUSTREG plants are characterized by very encouraging regeneration results, including low sand loss.

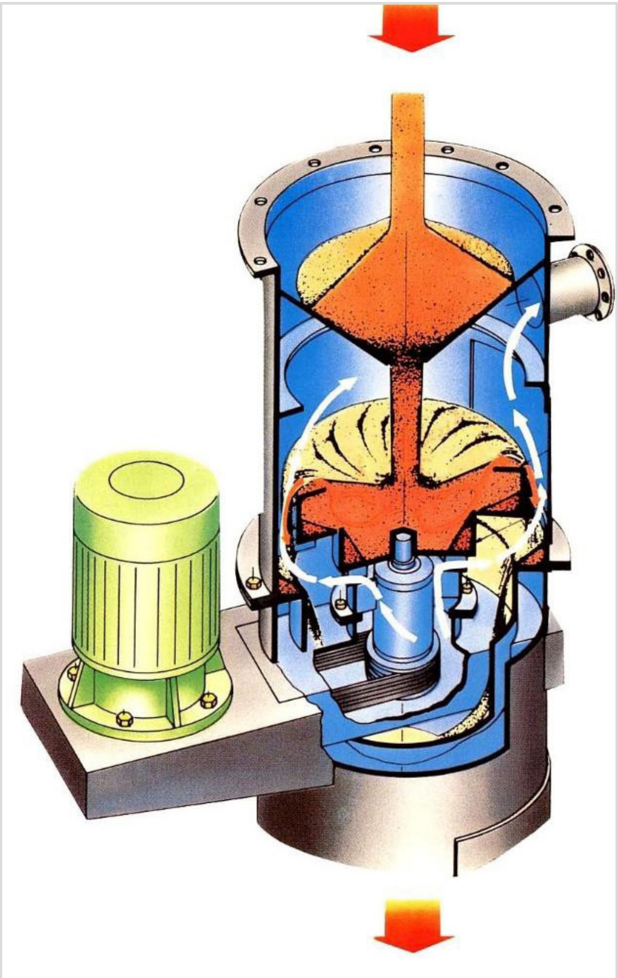

Figure 2. ROTAREG process principle, KLEIN Anlagenbau AG.

MATCHING PROCESSING PARAMETERS

For trials of the reclamation process, sand cores were manufactured on a Laempe core shooter. To provide a challenge, the sand cores were hot cured only, without any post-heat treatment. The process was carried out on inorganic-bonded sand cores with fully-developed mechanical strength.

As noted above, the process is characterised by various input parameters, which must be optimized to the type of inorganic-bonded sand cores. After some initial testing and analysis, including determining the optimized processing parameters, a first series of reclamation trials were started, each with 20 kg of used inorganic-bonded sand. During these cycles, the machine and processing parameters were kept constant.

METHODOLOGY AND RESULTS

In this section, several test methods will be presented and the results discussed in more detail. However, the intention is not to present all available results, which is beyond the scope of this paper, but to collect the most relevant data from the reclamation process for further managing sand systems in the foundry industry. As such, results from 10 reclamation cycles will be presented, including sand characteristics (particle size [distribution], LOI, pH, and conductivity), flowability of the sand mixture, flexural strength values, and gas permeability of the manufactured cores.

Sand characteristics

The starting point was a thermally-reclaimed organic-bonded sand based on LA32. Previous tests showed that the data / results of this thermally-treated sand are identical to new sand. Sand cores were manufactured using a Laempe-type core blower with additions of 1.70 wt% SOLOSIL TX (liquid binder) and 0.80 wt% SOLOSIL TX (additive); all percentages are based on sand. Table 1 lists the average particle size of the recycled sand together with the pH, conductivity and LOI values.

From this table, it can be seen that the particle size after reclamation was only slightly lower (AFS = 53-54) than the zero sample (i.e., the thermally-treated organic-bonded sand) with an AFS of 51.

More interesting were the pH and conductivity of the reclaimed sand. After the first reclamation cycle, the pH increased to values above 10, whereas the conductivity increased towards about 200 µS/cm. After two reclamation cycles, the pH was about 11, while conductivity increased towards values higher than 300 µS/cm. These high values can be explained by the use of an alkaline-type inorganic binder system, mainly based on sodium silicate. It is likely that a small amount of the binder residue remained present on the surface of the sand grains. There was however no negative impact on the strength data, as can be seen in Table 2. The LOI values remained relatively low, independent of the number of reclamation cycles, due to the use of the inorganic binder system.

As already mentioned, the particle size distribution was stable, without significant changes. Figure 3 shows micrographs of the sand after 0, 5 and 10 reclamation cycles. Interestingly, even after 10 cycles, the sand grains are still bright and shiny, an indication of the effectiveness of the sand reclamation process. It was found that the lower the brightness of the sand grains, the lower the mechanical strength and flowability of the sand mixture, which detrimentally affected the performance of the recycled sand. This can be observed from Figure 4, in which two batches are shown, the left part after maturation time 1 and the right part after maturation time 2, where maturation time 2 is less than maturation time 1.

Sample (cycli)	Av. Part. Size (AFS)	pH	Conductivity	LOI
00 – Foundry sand	272 µm (51)	6.1	4 µS/cm	0.18 %
01 – EN 1275	266 µm (52)	10.8	198 µS/cm	0.25 %
02 – EN 1305	260 µm (53)	10.8	358 µS/cm	0.22 %
03 – EN 1313	255 µm (54)	11.2	323 µS/cm	0.26 %
04 – EN 1317	254 µm (54)	11.0	326 µS/cm	0.28 %
05 – EN 1334	258 µm (54)	11.0	291 µS/cm	0.35 %
06 – EN 1478	262 µm (53)	11.4	372 µS/cm	0.34 %
07 – EN 1497	266 µm (52)	11.2	424 µS/cm	0.40 %
08 – EN 1531	263 µm (53)	11.6	438 µS/cm	0.41 %
09 – EN 1544	262 µm (53)	11.6	478 µS/cm	0.52 %
10 – EN 1578	253 µm (54)	11.0	417 µS/cm	0.42 %

Table 1. Average particle size, pH, conductivity and LOI as a function of the reclamation cycle. Foundry sand was always LA32.

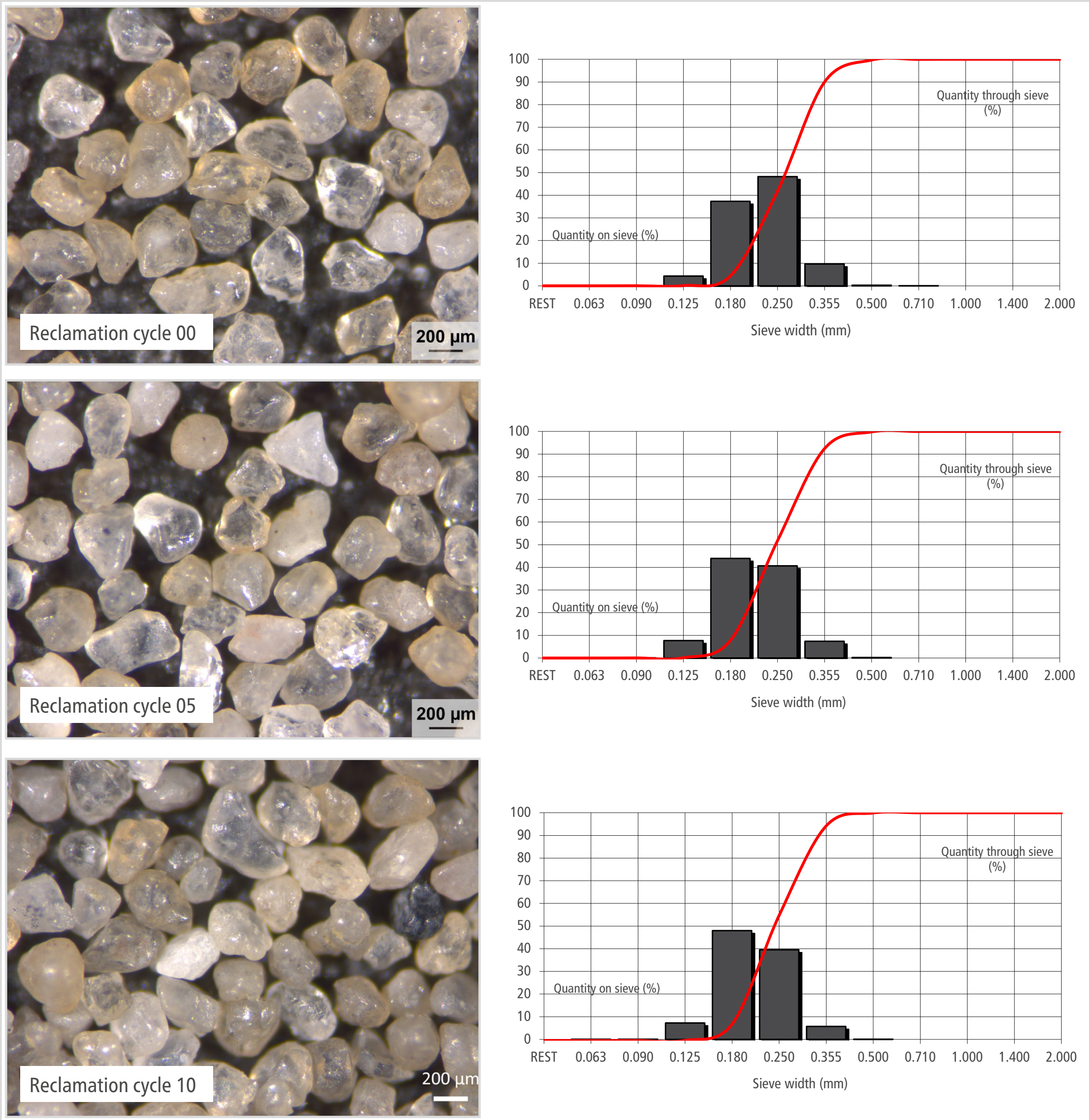

Figure 3. Microscope pictures of recycled sand, including grain size distribution. Top: after 0 cycles; middle: after 5 cycles; bottom: after 10 cycles.

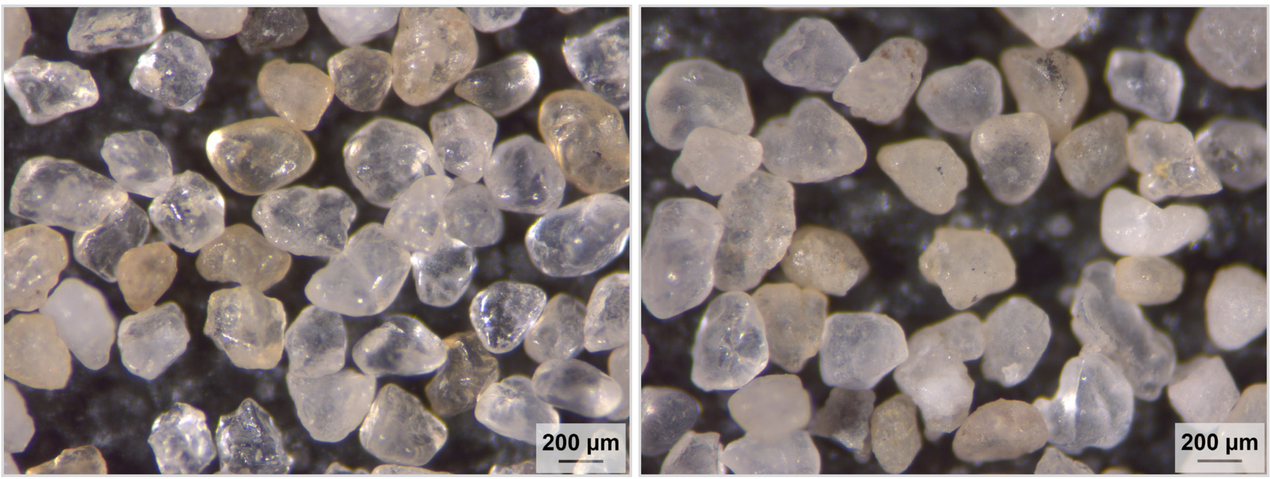

Figure 4. Appearance of sand grains: sample taken after maturation time 1 (left) and maturation time 2 (right) where maturation time 2 is less than maturation time 1.

Flowability

The flowability of the sand mixture was measured using a Brookfield Powder Flow Tester (PFT). This was initially developed to characterize the flow behavior of solid powder material with particle sizes up to a maximum of about 1 mm. As there was also a need to determine and to define the flowability of sand mixtures with a relatively small amount of a liquid, the PFT was used for these applications.

To compare different types of sand mixtures, the results are published in a flow function plot, as per Schulze [4]. This flow function plot shows the flowability of various types of samples over different 'consolidation stresses', these being considered as compressive stress. This plot shows various regions starting with free flowing and progressing through easy flowing, cohesive, very cohesive and non-flowing. The lower the curve, the higher the measured flowability. Figure 5 shows the unconfined failure strength (kPa) as a function of the major principal consolidating stress (kPa). Results from the sand mixtures show clearly that, irrespective of the number of reclamation cycles, under the highest compressive stress and in all cases, the sand mixture was easy flowing. The highest flowability was achieved with the zero-reclaimed sand mixture.

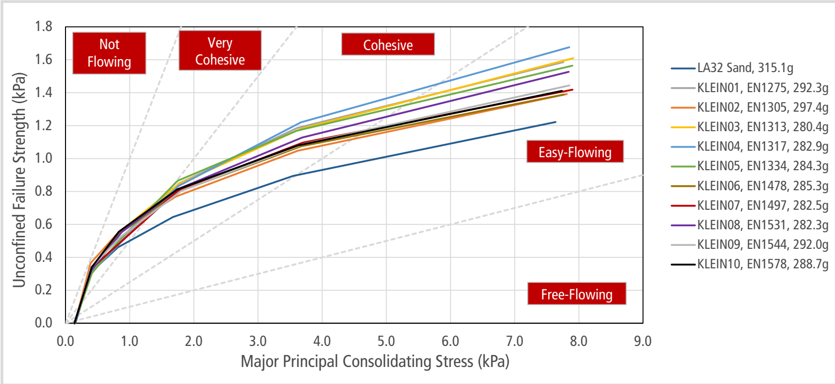

Figure 5. Flowability of sand mixtures after various reclamation cycles.

In relation to this, the weight of the sand mixture placed in the sample holder can also be an indirect indication of flowability.

In this case, the Hausner ratio [5] or the Carr index C [6] is sometimes used to obtain a more quantitative value of the flowability. The weight of the as-received sample (without reclamation) in this case was 315 g, while for the other sand mixtures, the weight was lower than 300 g, indicating slightly lower compaction, corresponding to slightly lower flowability.

Core characteristics

Table 2 lists the core weight, bending strength, flexural modulus and gas permeability as a function of the number of reclamation cycles. Measurements of the cores were done after 12 h storage at 25 °C and 30% RH.

This table clearly shows that the weight of the samples did not significantly change with the number of reclamation cycles and was always between 146 g and 143 g, indicative of compaction / good flowability of the sand mixture. Bending strength values started at 477 N/cm² (compared to a target value of 475 N/cm²) and increased slightly after reclamation. Irrespective of the number of reclamation cycles, strength values were always between 500 and 540 N/cm².

The reason for the slight increase in strength was the removal of fines during the process. The flexural modulus showed no relation to the number of reclamation cycles and was always between 4.1 and 5.4 Mpa. Gas permeability started to increase initially after reclamation but stabilized around 150 mD.

Sample (cycli)	Core weight	Bending strength	Flexural Modulus	Gas Permeability
00 – Foundry sand	145.6 ± 0.3 g	477 ± 7 N/cm²	4.3 ± 0.4 Mpa	140 ± 1 mD
01 – EN 1275	144.7 ± 0.2 g	495 ± 2 N/cm²	5.4 ± 0.1 Mpa	157 ± 3 mD
02 – EN 1305	144.7 ± 0.2 g	531 ± 12 N/cm²	4.9 ± 0.1 Mpa	147 ± 2 mD
03 – EN 1313	142.5 ± 0.1 g	537 ± 18 N/cm²	4.7 ± 0.1 Mpa	153 ± 4 mD
04 – EN 1317	142.6 ± 0.1 g	505 ± 11 N/cm²	4.9 ± 0.1 Mpa	159 ± 2 mD
05 – EN 1334	142.6 ± 0.2 g	519 ± 9 N/cm²	5.1 ± 0.2 Mpa	155 ± 1 mD
06 – EN 1478	143.9 ± 0.2 g	504 ± 11 N/cm²	4.4 ± 0.1 Mpa	142 ± 1 mD
07 – EN 1497	142.8 ± 0.2 g	508 ± 17 N/cm²	4.1 ± 0.2 Mpa	148 ± 1 mD
08 – EN 1531	143.6 ± 0.2 g	498 ± 5 N/cm²	4.1 ± 0.1 Mpa	158 ± 1 mD
09 – EN 1544	144.3 ± 0.3 g	500 ± 23 N/cm²	4.1 ± 0.2 Mpa	139 ± 1 mD
10 – EN 1578	143.8 ± 0.4 g	521 ± 32 N/cm²	4.4 ± 0.1 Mpa	138 ± 2 mD

Table 2. Core weight, bending strength, flexural modulus and gas permeability as a function of the reclamation cycle. Foundry sand was always LA32.

SUMMARY

This study presents an innovative process for the reclamation of inorganic-bonded foundry sand, based on a mechanically-adsorptive process called the CLUSTREG process [7]. After pre-testing with different processing conditions to optimize the various processing parameters, 10 reclamation cycles were performed while maintaining constant machine parameters. Results from these 10 reclamation cycles are presented, including sand characteristics (particle size [distribution], LOI, pH, conductivity), flowability of the sand mixture, bending strength values and gas permeability of the manufactured cores. It was found that, even after 10 reclamation cycles, foundry sand derived from cores with inorganic binder systems could be re-used, without detrimentally affecting flowability of the sand mixture, and the mechanical properties and gas permeability of the manufactured cores. Although the pH and conductivity did increase significantly after one reclamation cycle, this had no negative impact on the core quality of reclaimed sand.

From these results, it can be concluded that, after starting with the most challenging parameters to stress the process and installation, and with the support of laboratory results to optimize the machine parameters, improved processing parameters could be determined. With this set of processing parameters, no issues occurred with this type of SOLOSIL TX inorganic-bonded sand after 10 reclamation cycles.

In future, a smaller project is planned to include five reclamation cycles with cores that will face a thermal load comparable to foundry conditions.

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