Olivine Sand and the FENOTEC binder process for the production of Manganese Steel Castings
The FENOTEC process

Olivine Sand

Case Study : Metso Foundry
The FENOTEC process
THE FENOTEC PROCESS

- FENOTEC is a 2 part binder process.

  - An aqueous alkali phenolic resin solution
  - An ester based liquid hardener

- The chemical reaction is complex but involves pH reduction and hydrolysis.

- The set time is adjusted by altering the ester grade using a constant addition rate.
THE FENOTEC PROCESS

Molecular Diagram

PF Resole + Ester → Polymerised PF Resole + K⁺ COOCR + R⁺ OH

(SALT) (ALCOHOL)
THE FENOTEC PROCESS

- A cold setting alkaline phenolic resin based sand system for the production of moulds and cores.

- Introduced to the foundry market 35 years ago, this alkaline phenolic ester cured resin binder process has proved very popular in all casting segments, in particular the Steel Foundry sector due to the reduction of gas and hot tearing defects.

- The FENOTEC binder process was developed as an environmental friendly mould and core making system, key features being low odour on mixing and casting.
THE FENOTEC PROCESS

• The FENOTEC binder process is an alkali system and as such is one of the few chemical binder processes that is compatible with Olivine sand.

• Other processes such as Furan and PUNB are not compatible for use with Olivine sand due to acid neutralisation with the former and uncontrollable rapid curing with the latter process.

• However, one limitation of this binder process is the low reclaim levels achieved using conventional dry attrition techniques due to the build-up of alkali salts on the sand grain which ultimately cause a reduction in re-bonding properties. To overcome this constant additions of new sand are required.
<table>
<thead>
<tr>
<th>Process</th>
<th>Average Reclaim</th>
<th>Maximum Reclaim *</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALKALINE PHENOLIC (FENOTEC)</td>
<td>75%</td>
<td>85%</td>
</tr>
<tr>
<td>FURAN</td>
<td>85%</td>
<td>95%</td>
</tr>
<tr>
<td>POLYURETHANE SELF SET</td>
<td>85%</td>
<td>90%</td>
</tr>
</tbody>
</table>

* Maximum reclaim levels achievable in foundries where excellent control systems combined with good thermal breakdown within the mould cavity exist.
Olivine Sand
OLIVINE SAND

- Olivine sand is an ideal mineral to use for the production of Manganese Steel Castings as it is chemically less reactive than silica sand.

- $\text{SiO}_2$ reacts with $\text{MnO}$ in the steel to form a $\text{MnSiO}_3$ slag resulting in serious burn on defects.

- A further advantage is that Olivine sand has a low thermal expansion rate compared to silica sand and its high thermal shock resistance furthermore reduces sand expansion problems.
OLIVINE SAND

Typical chemical composition of Olivine Sand

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MgO</td>
<td>50.12%</td>
<td>Na$_2$O</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>41.53%</td>
<td>K$_2$O</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>7.50%</td>
<td>CaO</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>0.42%</td>
<td>MnO</td>
</tr>
</tbody>
</table>

Olivine Sand Grain Shape

Olivine Sand Grain Size Distribution (Mesh Size μm)
OLIVINE SAND

Olivine sand is, however, a difficult sand to use successfully in a foundry environment for the following reasons:

- High alkali content, typical pH range 9 to 10.
- Angular grain shape and poor grain size distribution leading to a high binder requirement and poor sand compaction.
- Not easily sourced and quality can be variable depending on location.
- Expensive compared with silica sand.
## Strength comparison, Olivine sand vs Silica Sand

<table>
<thead>
<tr>
<th></th>
<th>2 Hours</th>
<th>4 Hours</th>
<th>24 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Olivine Sand</strong>&lt;br&gt;1.3% Binder</td>
<td>69</td>
<td>85</td>
<td>102</td>
</tr>
<tr>
<td><strong>H32 Silica Sand</strong>&lt;br&gt;1.3% Binder</td>
<td>208</td>
<td>235</td>
<td>310</td>
</tr>
</tbody>
</table>

– all values Compression N / cm²
Strength comparison, Olivine sand vs Silica Sand

- all values Compression N / cm²
Case Study: Metso Foundry, Czech Republic
CASE STUDY

- METSO Steel Foundry, Přerov, in the Czech Republic.

- Manufacture Manganese and Chrome Molybdenum Steel castings for the mining and construction industries.

- Castings range from 300 kgs to 5 tonnes in weight.

- In 2009 a decision was taken to extend the production capability of the foundry from 5000 to 16000 tonnes per annum.

- To achieve this target a complete sand process change was required to achieve the required productivity levels. The original processes were a combination of traditional greensand moulding and CO₂ cured sodium silicate binders.
CASE STUDY

• A requisite for the new process was that high levels of reclamation were required to minimise new sand purchase and waste sand disposal costs.

• METSO decided that to achieve these goals a unit sand system based on Olivine sand bonded with the FENOTEC binder process would be the best option.

• The moulding process would be based on a fast loop system and the sand reclamation plant would consist of primary, secondary and thermal reclamation techniques.

• Core manufacture would also be based on Olivine sand using a gas cured alkaline phenolic binder, the ECOLOTEC process, although core volumes would be low based on the types of castings produced.

• The use of Olivine sand and the FENOTEC binder process in combination would create some challenging technical obstacles if high levels of reclamation were to be achieved.
CASE STUDY

- A mould strip time of 45 minutes is required and can be achieved consistently using a PLC controlled hardener blender process based on medium and slow curing esters.

- Binder addition rates can be optimised so that the minimum level of resin and hardener can be added to give the required properties.

- Binder addition rates are important in respect to achieving the desired strength necessary for mould handling, the casting process and to ensure the lowest amount of residual binder in preparation for sand reclamation.

- The residual binder in the sand influences the re bonding properties of the sand. If the residual binder levels are too high the strength development is significantly reduced and furthermore it will also have a detrimental effect on casting performance.
CASE STUDY

- The normal way of measuring this residual binder is to determine the Loss of Ignition and % of Alkali in the reclaimed sand. These tests indicate the level of organic and inorganic binder left in the sand and as such can be used to determine how much clean sand is required to maintain equilibrium in the sand system.

- Loss on Ignition is a common test method used by foundries, however, the % of alkali in the sand is normally conducted by the binder supplier or a specialist analytical laboratory.

- Unfortunately as Olivine sand is already alkali then standard titration methods are not suitable. As such a method based on electrical conductivity was required.

- Electrical conductivity is the measure of the total concentration of dissolved salts in water. When salts dissolve in water they give off electrically charged ions that conduct electricity, the more ions in the water the higher the conductivity. It can be seen from this that a relationship between residual alkali salts in the sand and electrical conductivity can be established as a means of controlling this alkali residue.
CASE STUDY

Electrical Conductivity values for new and reclaimed sand

<table>
<thead>
<tr>
<th>Sand Type</th>
<th>Conductivity Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>H32 Silica</td>
<td>Less than 10 µS/cm</td>
</tr>
<tr>
<td>New Olivine</td>
<td>Less than 75 µS/cm</td>
</tr>
<tr>
<td>Reclaimed : Low Alkali</td>
<td>100-200 µS/cm</td>
</tr>
<tr>
<td>Reclaimed : Medium Alkali</td>
<td>200-350 µS/cm</td>
</tr>
<tr>
<td>Reclaimed : High Alkali</td>
<td>Above 350 µS/cm</td>
</tr>
</tbody>
</table>
CASE STUDY

The Sand Reclamation System at Metso

• The function of a sand reclamation system is to take lumps of used foundry sand and process it back to sand grains that are suitable for rebonding. Sand that has been reclaimed must have similar properties to that of new sand.

• To achieve the maximum level of sand reuse, Metso installed a 3 part system based on conventional primary dry attrition, secondary attrition and thermal reclamation processes.

• Primary dry attrition uses high intensity vibration to reduce the sand lumps down to grain size. This vibration helps to break the bond between each sand grain but only removes a small amount of the binder film coating the sand grain. Vibrating screens help to control the grain size distribution by removing large agglomerate’s and metallic contaminants.

• Sand from this process alone, however, will only allow low levels of reuse due to the high levels of residual binder present in the sand.
CASE STUDY

The Sand Reclamation System at Metso

• To overcome this a more vigorous secondary attrition process is used to remove additional binder film from the sand grain. This is achieved by sand from the dry attrition process being scrubbed between high speed rollers and the side walls of the attrition chamber causing the sand grains to impact with each other.

• Sand taken from the secondary attrition unit is then fluidised with cold air to remove dust particles and cool the sand to ambient temperature. This sand is suitable for rebonding at the moulding station.

• Whilst this secondary attrited sand is suitable for moulding, the system still requires a low level input of clean sand to ensure that residual binder levels in the sand remain consistent.
Primary dry attrition and secondary attrition reclamation schematic layout

KEY:
1. SHAKE-OUT PLANT WITH PRE-RECLAIMER
2. DUST SUCTION HOOD
3. FILTER FOR DUST REMOVAL
4. PNEUMATIC TRANSPORT TO THE SURGE SILO
5. SURGE SILO
6. SURGE SILO DUST FILTER
7. RECLAMATION TOWER
8. EVAPORATIVE TOWER
9. CIRCULATION PUMP
10. SLEEVE FILTER FOR DUST REMOVAL
11. PNEUMATIC TRANSPORT TO USER LOCATIONS
12. RECLAIMED SAND SILO
CASE STUDY

The Sand Reclamation System at Metso

• To achieve this clean sand a thermal pant is used to remove all of the organic binder from the sand.

• Sand is taken from the primary dry attrition stage and fed into a gas fired fluidised thermal plant. The thermal bed temperature is maintained at 600°C to ensure total combustion of the organic components in the sand. The calorific value of the binder helps to reduce the energy required to maintain temperature and also helps to ensure that the exhaust gases are clean. Sand is cooled and fines extracted prior to transferring into the clean sand hopper.

• No special additives are required to prevent sand fusion as would be normal practice with silica based sands, as no fusion occurs with olivine sand at the operating temperatures required to run the thermal bed.
Thermal plant schematic layout
## CASE STUDY

Comparison of physical properties, Olivine, Reclaimed and Thermal Olivine sands

<table>
<thead>
<tr>
<th>Sand Type</th>
<th>Loss on Ignition</th>
<th>Electrical Conductivity</th>
<th>AFS</th>
<th>Average Grain Size</th>
<th>Fines % (90 - 63 μm)</th>
<th>Dust % (&lt; 63 μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Olivine</td>
<td>0.13%</td>
<td>72 μS/cm</td>
<td>44</td>
<td>323μm</td>
<td>4.08%</td>
<td>0.76%</td>
</tr>
<tr>
<td>Reclaimed Olivine</td>
<td>0.71%</td>
<td>323 μS/cm</td>
<td>47</td>
<td>366 μm</td>
<td>1.57%</td>
<td>0.22%</td>
</tr>
<tr>
<td>Thermal Reclaimed</td>
<td>0.05%</td>
<td>100 μS/cm</td>
<td>46</td>
<td>338 μm</td>
<td>0.58%</td>
<td>Zero</td>
</tr>
</tbody>
</table>
Strength development comparison, Olivine, Reclaimed and Thermal Olivine sands

<table>
<thead>
<tr>
<th></th>
<th>45 Minutes</th>
<th>2 Hours</th>
<th>24 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Olivine</td>
<td>46</td>
<td>69</td>
<td>102</td>
</tr>
<tr>
<td>1.3% Binder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reclaimed Olivine</td>
<td>27</td>
<td>67</td>
<td>77</td>
</tr>
<tr>
<td>Secondary Attrition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5% Binder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal reclaimed</td>
<td>79</td>
<td>128</td>
<td>185</td>
</tr>
<tr>
<td>1.3% Binder</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

– all values Compression N / cm²
Strength development comparison, Olivine, Reclaimed and Thermal Olivine sands

- all values Compression N/cm²
CASE STUDY

• The moulding process at METSO

• A 50 tonne and 10 tonne per hour dual continuous mixer.

• Capability to run multiple sand recipes including variable resin binder addition rates.

• The resin is maintained at a constant temperature of 25°C to reduce viscosity variation and thus improve mixing efficiency.
**CASE STUDY**

- Moulds are prepared using a standard recipe based on 85% reclaimed sand + 15% thermally reclaimed sand.

<table>
<thead>
<tr>
<th>Recipe</th>
<th>Sand Type</th>
<th>Sand Ratio</th>
<th>Resin %</th>
<th>Ester %</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Moulding</td>
<td>Reclaimed Sand + Thermal Olivine</td>
<td>85 / 15</td>
<td>1.25</td>
<td>25</td>
</tr>
<tr>
<td>Special Backing Sand</td>
<td>Reclaimed Sand</td>
<td>100</td>
<td>1.25</td>
<td>25</td>
</tr>
</tbody>
</table>
CASE STUDY

The Moulding Line
CASE STUDY

Typical mould component

Moulds in the casting bay
CASE STUDY

The sand reclamation plant
CASE STUDY

- By careful control of the sand system and by utilising the FENOTEC binder process, METSO have shown it is possible to produce quality Manganese Steel Castings using very high levels of reclaimed sand based on Olivine sand.

- Since the introduction of the new moulding process, 5 years ago, METSO have significantly improved productivity and casting quality and reduced process costs dramatically.

Sand consumption values for 2013 and 2014

<table>
<thead>
<tr>
<th>Year</th>
<th>New Olivine Sand</th>
<th>Reclaimed Sand</th>
<th>Thermal Sand</th>
<th>Total Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>942 Tonnes (3.7%)</td>
<td>20,591 Tonnes (82%)</td>
<td>3,634 Tonnes (14.3%)</td>
<td>25,167 Tonnes</td>
</tr>
<tr>
<td>2014</td>
<td>250 Tonnes (0.6%)</td>
<td>39,752 Tonnes (87%)</td>
<td>5,774 Tonnes (12.4%)</td>
<td>45,776 Tonnes</td>
</tr>
</tbody>
</table>

- New Olivine sand usage in the foundry is extremely low, indicating total reclaim levels consistently above 95%.
CASE STUDY

Olivine sand and the FENOTECH binder process for the production of Manganese Steel Castings at Metso Steel Foundry

Introduction

Metso Steel Foundry, Pilsen based in the Czech Republic was established in 2008 for the production of manganese and chrome molybdenum steel castings for the mining and construction industries. They can produce finished castings ranging from 300 lugs to 5 tonnes in weight.

Mould and core production is mainly controlled by a combination of traditional green sand and CO₂ cured sodium silicate binder processes. In 2009 a decision was taken to extend the production capability of the foundry from 5000 to 16000 tonnes. To achieve this goal a complete process change was required to achieve the required productivity levels and to improve the quality of the castings produced. A decision was taken to install an IMF fast loop moulding system and an IMF sand regeneration system utilising a chemically bonded binder process. The sand regeneration plant was built in 2 stages, initially a primary and secondary attrition unit and finally the addition of a thermal regeneration system.

Sand disposal is becoming more and more difficult due to tighter environmental legislation and higher transportation costs and taxation. In addition the purchase of new sand is becoming more costly due to rising energy prices and the decreasing availability of locally sourced high quality material.

To reduce the impact of these sand costs, a requisite for the new moulding system was that high levels of regeneration were required to minimise new sand input and waste sand output from the process.

Metso decided that to achieve these goals a unit sand system based on Olivine sand bonded with the FENOTECH binder process would be the best option.

The use of Olivine sand and the FENOTECH binder process in combination would create some challenging technical obstacles if high levels of regeneration were to be achieved. This article shows what methods were employed to ensure that these obstacles were overcome.

Olivine Sand

Olivine sand is an ideal mineral to use for the production of Manganese Steel Castings as it is chemically less reactive than silica sand. SiO₂ reacts with MnO in the steel to form a Mn₃SiO₅ slag resulting in serious burn on steels. A further advantage is that Olivine sand has a low thermal expansion

rate compared to silica sand and its high thermal shock resistance furthermore reduces sand expansion problems.

Olivine sand is, however, a difficult sand to use successfully in a foundry environment for the following reasons:

- High alkali content (Typical pH range 9 to 10, thus restricting its use with certain chemical binder processes).
- Angular grain shape and poor grain size distribution leading to a high binder requirement and poor sand compaction.
- Not easily sourced and quality can be variable depending on location.
- Expensive compared with silica sand.

Table 1: Typical chemical composition of Olivine Sand

| SiO₂ | 42.1% |
| CaO | 20.6% |
| MgO | 25.1% |
| Fe₂O₃ | 4.3% |

MgO and SiO₂ are not free but combined as Forsterite Mg₂SiO₄ and Fayalite Fe₂SiO₄ (approximate, ratio 90/10).

Figure 1: Olivine Sand Grain Shape

Table 1: Typical chemical composition of Olivine Sand

- High alkali content (Typical pH range 9 to 10).
- Angular grain shape and poor grain size distribution.
- Not easily sourced and quality can be variable depending on location.
- Expensive compared with silica sand.

Manganese and Chrome Molybdenum Steel Castings

Table 2: Typical chemical composition of Manganese and Chrome Molybdenum Steel Castings

| MnO | 17% |
| Cr₂O₃ | 13% |
| SiO₂ | 18% |

Table 2: Typical chemical composition of Manganese and Chrome Molybdenum Steel Castings

- High MnO content (17%).
- High Cr₂O₃ content (13%).
- High SiO₂ content (18%).

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