MOLD SAND, SAND ADDITIVES & SAND PROPERTIES

Collection and Selection
by
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IUST
Casting 1
Flow Chart of a Metal Casting System

- **Ignots & Alloys**
  - **Metal**
  - **Fuel**
  - **Flux**
  - **Furnace**

- **Pour**
  - **Cooling**
  - **Shakout**
  - **Cores**
  - **Mould**

- **Sand Mixer**
  - **Sand**
  - **Binder**
  - **Additives**

- **Sand Reclamation**

- **Scrap**
  - **Off-Site Scrap**
  - **Castings**
  - **Fettling**
  - **Cleaning**
  - **Heat Treatment**
  - **Inspection**
  - **Finishing**

- **Finished Casting**
Sand Casting of Metals

Mold Materials

Topics covered:

- Molding sand
- Constituents of molding sand
- Property requirements of molding sand
- Testing of sand properties

Compiled by Prof. Amruta A. Rane (Asst. Prof., DJSCE)
Mold Material

- The mold material is the one out of which the mold is made.
- The mold material should be such that casting should be able to retain its shape till the molten metal has solidified.

Types of molds:

- **Permanent molds:** They are made up of **ferrous metals** and alloys (Steel, Grey CI, etc.).
- **Temporary refractory molds:** They are made of refractory sands and resins.
- Molds made of **wax, plastic, Plaster of Paris, carbon, ceramics** are also employed.
## Mold Material

<table>
<thead>
<tr>
<th>Permanent molds</th>
<th>Temporary refractory molds</th>
</tr>
</thead>
<tbody>
<tr>
<td>They are employed for casting low melting point materials</td>
<td>Since they are made of refractory sands, the temporary refractory molds employed for casting high melting point materials</td>
</tr>
<tr>
<td>They are costly.</td>
<td>They are cheaper.</td>
</tr>
<tr>
<td>They are employed to produce objects smaller in size.</td>
<td>They are employed to produce objects bigger in size.</td>
</tr>
<tr>
<td>They produce casting with better surface finish, quality and dimensional accuracy.</td>
<td>The surface finish, quality and dimensional accuracy of the casting produced by temporary molds is poor.</td>
</tr>
</tbody>
</table>

Compiled by Prof. Amruta A. Rane (Asst. Prof., DJSCE)
Properties of Molding Material

Flowability –

- It is ability of molding sand to get compacted to a uniform density. Flowability assists molding sand to flow and pack all around the pattern and take up the required shape.
- The sand mold should respond to different molding processes.
- Flowability increases as the clay and water content increases.

Green Strength -

- The molding sand that contains moisture is termed as green sand. The strength of the sand in green or moist state is termed as green strength.
- A mold with adequate green strength will be able to retain its shape and will not distort or collapse.
- The green sand particles have the ability to cling to each other to impart sufficient strength to the mold.

Collapsibility -

- It is property due to which the sand mold automatically gets collapsed after casting solidifies.
- The molding sand should also have collapsibility so that during the contraction of the casting it does not provide any resistance, which may result in the cracks in the casting.
Properties of Molding Material

Dry Strength -

- It is the strength of the molding sand in dry conditions.
- When the molten metal is poured in the mold, the sand around the mold cavity is quickly converted into dry sand as the moisture in the sand evaporates due to the heat of the molten metal.
- At this stage the molding sand must possess the sufficient strength to retain the exact shape of the mold cavity and at the same time it must be able to withstand the metallostatic pressure of the liquid material.
- Dry sand strength is related to grain size, binder and water content.

Permeability -

- During pouring and subsequent solidification of a casting, a large amount of gases and steam is generated. These gases are those that have been absorbed by the metal during melting, air absorbed from the atmosphere and the steam generated by the molding and core sand. The binder, additives, etc. present in the molding sand also produce steam and other gases.
- If these gases are not allowed to escape from the mold, they would be entrapped inside the casting and cause casting defects.
- To overcome this problem the molding material must be porous or permeable to provide path for the escape of gases. Proper venting of the mold also helps in escaping the gases that are generated inside the mold cavity.
- Sand with Coarse grains exhibit more permeability.
- In absence of permeability the defects like surface blows, gas holes, etc. may be experienced.
Properties of Molding Material

Hot Strength -

- It is strength of the sand above 212°F.
- As soon as the moisture is eliminated, the sand would reach at a high temperature when the metal in the mold is still in liquid state.
- The strength of the sand that is required to hold the shape of the cavity is called hot strength.
- In absence of hot strength the mold may enlarge, break, erode or get cracked.

Durability –

- The molding sand should possess the capacity to withstand repeated cycles of heating and cooling during casting process
- Molding sand should be chemically immune to molten metals.
- Should be reusable.
- It should be easy to prepare and control.
Properties of Molding Material

Refractoriness -

- It is the ability of the molding material to withstand the temperature of the liquid metal to be poured so that it does not get cracked, fused with the metal or experience any major physical change.
- Refractoriness is essential while casting high melting point materials.
- The refractoriness of the silica sand is highest.

Fineness –

- Finer sand molds resists metal penetration and produces smooth casting surface.
- Fineness and permeability are in conflict with each other and hence they must be balanced for optimum results.

Bench Life –

- It is ability of the molding sand to retain its properties during storage.

Besides these specific properties the molding material should be cheap, reusable, coefficient of expansion, durability and should have good thermal conductivity.
# Molding Sands: Sources, Types, Ingredients

<table>
<thead>
<tr>
<th>Sources:</th>
<th>Types:</th>
<th>Ingredients:</th>
</tr>
</thead>
<tbody>
<tr>
<td>River beds</td>
<td>Natural sands</td>
<td>Refractory sand grains</td>
</tr>
<tr>
<td>Sea</td>
<td>Synthetic sands</td>
<td>Binders</td>
</tr>
<tr>
<td>Lakes</td>
<td>Loam sands</td>
<td>Water (moisture)</td>
</tr>
<tr>
<td>Desert</td>
<td></td>
<td>Additives</td>
</tr>
</tbody>
</table>

Compiled by Prof. Amruta A. Rane (Asst. Prof., DJSCE)
Natural Sands

- It can be used as soon as received from source.

- **It contains binding material (5-20%), water (5-8%) and considerable amount of organic matter.**

- It can maintain moisture content for long time.

- The finishing obtained on natural sand molds is good.

- It is cheaper compared to other sands.

- It has lesser refractoriness.

- It is employed for casting **CI and non-ferrous metals.**

- Molds made of natural sand can be easily repaired.

- When mixed with **Bentonite**, the properties of the sand get improved and it gets properties like **Synthetic sand.**
Synthetic Sands

- A synthetic sand consists of natural sand with or without clay, **binder** and moisture.
- **The organic matter** is not present in synthetic sand.
- Synthetic sand is **a formulated sand**, formulation is done to impart certain desired properties not possessed by natural sand.
- Possesses **good refractoriness, high permeability, uniform grain size** as compared to natural sand.
- It is more suitable for mass production and mechanized foundries.
Loam Sands

- It contains much more **clay (50% or more)** as compared to ordinary sand.
- The ingredients of Loam sand may be fine sand, clay, finely ground refractories, graphite and fibrous reinforcement.
Refractory Sands

1. Silica sand
2. Magnite
3. Zircon
4. Dolomite
5. Olivine
6. Silimanite
7. Graphite / Carbon
Properties of Refractory Sands

- They maintain their **shape and other characteristics** at high temperature.
- When packed to produce the mold cavity, they remain sufficiently **porous or permeable** to give out gases produced during solidification of molten material.
- They can be molded into **intricate shapes**.
- They are **chemically immune** to molten metals.
- They can be used **repeatedly** to make molds.
- They are **inexpensive**.
- They can be **made available** without much difficulty.
Molding Sand Composition

**Base Sand**
- **Silica sand** is most commonly used base sand.
- Other base sands that are also used for making mold are **zircon sand, Chromite sand and olivine sand**.
- Silica sand is cheapest among all types of base sand and it is **easily available**.

**Binder**
- Binders are of many types such as, Clay binders, Organic binders and Inorganic binders.
- Clay binders are most commonly used binding agents mixed with the molding sands to **provide the strength**.
- The most popular clay types are: **Kaolinite or fire clay** (Al$_2$O$_3$ 2SiO$_2$ 2H$_2$O) and **Bentonite** (Al$_2$O$_3$ 4SiO$_2$ nH$_2$O).
- Bentonite can absorb more water than fire clay which increases its **bonding power**.

**Water (Moisture)**
- Clay acquires its **bonding action** only in the presence of the required amount of moisture.
- When water is added to clay, it penetrates the mixture and forms a **microfilm**, which **coats the surface of each flake** of the clay.
- The amount of water used should be properly controlled.
- This is because a part of the water, which coats the surface of the clay flakes, helps in bonding, while the remainder helps in improving the **plasticity**.
# Molding Sand Composition

## Typical Composition of Molding Sand

<table>
<thead>
<tr>
<th>Molding Sand Constituent</th>
<th>Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica sand</td>
<td>92</td>
</tr>
<tr>
<td>Clay (Sodium Bentonite)</td>
<td>8</td>
</tr>
<tr>
<td>Water</td>
<td>4</td>
</tr>
</tbody>
</table>

Compiled by Prof. Amruta A. Rane (Asst. Prof., DJSCE)
Grain Size

- The grain shape and size of molding sand defines the total surface area of grains contained in unit mass.
- Total surface area is known as Specific Surface.
- Specific surface gives rough idea of amount of binder needed to coat the grains of molding sand.
Grain Size

- The grain size and distribution influences many sand properties such as *permeability, flowability, refractoriness, surface fineness and strength*.

- **The finer** the sand grains, the finer is the molding sand as whole.

- Fine grain sands give good *surface finish* but possess low permeability.

- For same clay content, the *green strength* is higher in case of *fine sands* as compared to coarse sands.

- **Coarse and uniformly graded sand** imparts high permeability, good refractoriness and high flowability.

- Normally the foundry sand possess the grain size between 0.1 to 1.0 mm

- The fine grained sands are used to make *intricate and small size castings*.

- Coarse grained sands are used to make *large castings*. 
Fig. 1 Two sizes of rounded sand grains. 35×.
Grain shape

Grain shape is defined in terms of angularity and sphericity. Sand grains vary from well rounded to rounded, sub-rounded, sub-angular, angular and very angular. Within each angularity band, grains may have high, medium or low sphericity. The angularity of sand is estimated by visual examination with a low power microscope and comparing with published charts, Fig. 12.1.

The best foundry sands have grains which are rounded with medium to high sphericity giving good flowability and permeability with high strength at low binder additions. More angular and lower sphericity sands require higher binder additions, have lower packing density and poorer flowability.
Figure 12.1  Classification of grain shapes.
Casting Sands

- *Silica Sands*
- *Zircon*
- *Olivine*
- *Chromite*
- *Aluminum Silicates*
**Silica Sands**

- Most green sand molds consist of silica sands bonded with a bentonite-water mixture. (The term green means that the mold, which is tempered with water, is not dried or baked.) The composition, size, size distribution, purity, and shape of the sand are important to the success of the mold making operation.
• Sands are sometimes referred to as natural or synthetic.

• **Natural or Synthetic**

  • Natural sands contain enough naturally occurring clays that they can be mixed with water and used for sand molding.

  • Synthetic sands have been washed to remove clay and other impurities, carefully screened and classified to give a desired size distribution, and then reblended with clays and other materials to produce an optimized sand for the casting being produced.

  • Because of the demands of modern high-pressure molding machines and the necessity to exercise close control over every aspect of casting production, most foundries use only synthetic sands.
Composition

- Foundry sands are composed almost entirely of silica (SiO2) in the form of quartz. Some impurities may be present, such as ilmenite (FeO-TiO2), magnetite (Fe3O4), or olivine, which is composed of magnesium and ferrous orthosilicate [(Mg,Fe) SiO4]. Silica sand is used primarily because it is readily available and inexpensive.
• Quartz undergoes a series of crystallographic transitions as it is heated. The first, at 573 °C, is accompanied by expansion, which can cause mold spalling. Above 870 °C, quartz transforms to tridymite, and the sand may actually contract upon heating. At still higher temperatures (> 1470 °C), tridymite transforms to cristobalite.
MECHANISM OF EXPANSION

When quartz, tridymite, or cristobalite is heated, a change in crystalline form occurs at a particular transition temperature.

**QUARTZ**

\[ \alpha \xleftrightarrow{573\degree C} \beta \]

low form  High form

**CRISTOBALITE**

\[ \alpha \xleftrightarrow{200-270\degree C} \beta \]

As \( \alpha \) form changes to \( \beta \) form when heated DENSITY \( \downarrow \), resulting in VOLUME \( \rightarrow \) leading to increase in the linear expansion.
• The quartz form of silica is found abundantly in nature, and it can be converted to cristobalite and tridymite on heating through which bonds are broken and a new crystal structure is formed.
• These transitions are shown in the following equation.
Figure 11.4  The expansion/temperature relations for iron-based die materials, and silica and zircon sand moulding materials. (J. Campbell, Foundry International, March 1992)
Shape and Distribution of Sand Grains

• The size, size distribution, and shape of the sand grains are important in controlling the quality of the mold. Most mold aggregates are mixtures of new sand and reclaimed sand, which contain not only reclaimed molding sand but also core sands. In determining the size, shape, and distribution of the sand grains, it is important to realize that the grain shape contributes to the amount of sand surface area and that the grain size distribution controls the permeability of the mold.
• As the sand surface area increases, the amount of bonding material (normally clay and water) must increase if the sand is to be properly bonded. Thus, a change in surface area, perhaps due to a change in sand shape or the percentage of core sand being reclaimed, will result in a corresponding change in the amount of bond required.

• Rounded grains have a low surface-area-to-volume ratio and are therefore preferred for making cores because they require the least amount of binder. However, when they are recycled into the molding sand system, their shape can be a disadvantage if the molding system normally uses a high percentage of clay and water to facilitate rapid, automatic molding. This is because rounded grains require less binder than the rest of the system sand.
• Angular sands have the greatest surface area (except for sands that fracture easily and produce a large percentage of small grains and fines) and therefore require more mulling, bond, and moisture. The angularity of a sand increases with use because the sand is broken down by thermal and mechanical shock.

• The porosity of the mold controls its permeability, which is the ability of the mold to allow gases generated during pouring to escape through the mold. The highest porosity will result from grains that are all approximately the same size.

• As the size distribution broadens, there are more grains that are small enough to fill the spaces between large grains. As grains break down through repeated recycling, there are more and more of the smaller grains, and the porosity of the mold decreases.
• However, if the porosity of the mold is too great, metal may penetrate the sand grains and cause a burn-in defect.
• Therefore, it is necessary to balance the base sand distribution and continue to screen the sand and use dust collectors during recycling to remove fines and to determine the proper bond addition.
• Most foundries in the United States use the American Foundrymens' Society (AFS) grain fineness number as a general indication of sand fineness. The AFS grain fineness number of sand is approximately the number of openings per inch of a given sieve that would just pass the sample if its grains were of uniform size, that is, the weighted average of the sizes of grains in the sample. It is approximately proportional to the surface area per unit weight of sand exclusive of clay.
Calculation of average grain size

The adoption of the ISO metric sieves means that the old AFS grain fineness number can no longer be calculated. Instead, the average grain size, expressed as micrometres (µm) is now used. This is determined as follows:

1. Weigh a 100 g sample of dry sand.
2. Place the sample into the top sieve of a nest of ISO sieves on a vibrator. Vibrate for 15 minutes.
3. Remove the sieves and, beginning with the top sieve, weigh the quantity of sand remaining on each sieve.
4. Calculate the percentage of the sample weight retained on each sieve, and arrange in a column as shown in the example.
5. Multiply the percentage retained by the appropriate multiplier and add the products.
6. Divide by the total of the percentages retained to give the average grain size.
<table>
<thead>
<tr>
<th>ISO aperture (μm)</th>
<th>Percentage retained</th>
<th>Multiplier</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥710</td>
<td>trace</td>
<td>1180</td>
<td>0</td>
</tr>
<tr>
<td>500</td>
<td>0.3</td>
<td>600</td>
<td>180</td>
</tr>
<tr>
<td>355</td>
<td>1.9</td>
<td>425</td>
<td>808</td>
</tr>
<tr>
<td>250</td>
<td>17.2</td>
<td>300</td>
<td>5160</td>
</tr>
<tr>
<td>212</td>
<td>25.3</td>
<td>212</td>
<td>5364</td>
</tr>
<tr>
<td>180</td>
<td>16.7</td>
<td>212</td>
<td>3540</td>
</tr>
<tr>
<td>150</td>
<td>19.2</td>
<td>150</td>
<td>2880</td>
</tr>
<tr>
<td>125</td>
<td>10.6</td>
<td>150</td>
<td>1590</td>
</tr>
<tr>
<td>90</td>
<td>6.5</td>
<td>106</td>
<td>689</td>
</tr>
<tr>
<td>63</td>
<td>1.4</td>
<td>75</td>
<td>105</td>
</tr>
<tr>
<td>≤63</td>
<td>0.5</td>
<td>38</td>
<td>19</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>99.6</strong></td>
<td><strong>-</strong></td>
<td><strong>20335</strong></td>
</tr>
</tbody>
</table>

Average grain size = \( \frac{20335}{99.6} \)

= 204 μm
Calculation of AFS grain fineness number

Using either the old BS sieves or AFS sieves, follow, steps 1–4 above.
5 Arrange the results as shown in the example below.
6 Multiply each percentage weight by the preceding sieve mesh number.
7 Divide by the total of the percentages to give the AFS grain fineness number.
### Example

<table>
<thead>
<tr>
<th>BS sieve number</th>
<th>% sand retained on sieve</th>
<th>Multiplied by previous sieve no.</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>nil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>nil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>0.2</td>
<td>16</td>
<td>3.2</td>
</tr>
<tr>
<td>30</td>
<td>0.8</td>
<td>22</td>
<td>17.6</td>
</tr>
<tr>
<td>44</td>
<td>6.7</td>
<td>30</td>
<td>201.0</td>
</tr>
<tr>
<td>60</td>
<td>22.6</td>
<td>44</td>
<td>1104.4</td>
</tr>
<tr>
<td>100</td>
<td>48.3</td>
<td>60</td>
<td>2898.0</td>
</tr>
<tr>
<td>150</td>
<td>15.6</td>
<td>100</td>
<td>1560.0</td>
</tr>
<tr>
<td>200</td>
<td>1.8</td>
<td>150</td>
<td>270.0</td>
</tr>
<tr>
<td>pan</td>
<td>4.0</td>
<td>200</td>
<td>800.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
<td></td>
<td><strong>6854.2</strong></td>
</tr>
</tbody>
</table>

AFS grain fineness number = \( \frac{6854.2}{100} \)

= 68.5 or 68 AFS
Foundry sands usually fall into the range 150–400 μm, with 220–250 μm being the most commonly used. Direct conversion between average grain size and AFS grain fineness number is not possible, but an approximate relation is shown below:

<table>
<thead>
<tr>
<th>AFS grain fineness no.</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>80</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average grain size (μm)</td>
<td>390</td>
<td>340</td>
<td>300</td>
<td>280</td>
<td>240</td>
<td>220</td>
<td>210</td>
<td>195</td>
<td>170</td>
<td>150</td>
</tr>
</tbody>
</table>

While average grain size and AFS grain fineness number are useful parameters, choice of sand should be based on particle size distribution.
Table 12.1 gives size gradings of typical foundry sands used in the UK and Germany.

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Sand type</th>
<th>UK sands</th>
<th>German sands</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Chelford 50</td>
<td>Chelford 60</td>
</tr>
<tr>
<td>microns</td>
<td>BSS no.</td>
<td>Trace</td>
<td>nil</td>
</tr>
<tr>
<td>1000</td>
<td>16</td>
<td>Trace</td>
<td>nil</td>
</tr>
<tr>
<td>700</td>
<td>22</td>
<td>4.5</td>
<td>2.3</td>
</tr>
<tr>
<td>500</td>
<td>30</td>
<td>19.8</td>
<td>10.0</td>
</tr>
<tr>
<td>355</td>
<td>44</td>
<td>44.6</td>
<td>25.7</td>
</tr>
<tr>
<td>250</td>
<td>60</td>
<td>21.6</td>
<td>23.8</td>
</tr>
<tr>
<td>210</td>
<td>72</td>
<td>8.2</td>
<td>28.7</td>
</tr>
<tr>
<td>150</td>
<td>100</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>150</td>
<td>nil</td>
<td>1.3</td>
</tr>
<tr>
<td>75</td>
<td>200</td>
<td>nil</td>
<td>0.2</td>
</tr>
<tr>
<td>75</td>
<td>200</td>
<td>nil</td>
<td>nil</td>
</tr>
<tr>
<td>AFS grain fineness no.</td>
<td>46</td>
<td>59</td>
<td>51</td>
</tr>
<tr>
<td>Average grain size mm</td>
<td>0.275</td>
<td>0.23</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Note: Haltern 32, 33 and Frechen 32 are commonly used, high quality German sands. German sieve gradings are based on ISO sieves. The German sands have rounder grains and are distributed on fewer sieves than UK sands, they require significantly less binder to achieve the required core strength.
Sieve grading of Chelford 60 sand:

<table>
<thead>
<tr>
<th>Aperture size (μm)</th>
<th>BSS mesh no.</th>
<th>% wt. retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>16</td>
<td>nil</td>
</tr>
<tr>
<td>700</td>
<td>22</td>
<td>0.4</td>
</tr>
<tr>
<td>500</td>
<td>30</td>
<td>2.3</td>
</tr>
<tr>
<td>355</td>
<td>44</td>
<td>10.0</td>
</tr>
<tr>
<td>250</td>
<td>60</td>
<td>25.7</td>
</tr>
<tr>
<td>210</td>
<td>72</td>
<td>23.8</td>
</tr>
<tr>
<td>150</td>
<td>100</td>
<td>28.7</td>
</tr>
<tr>
<td>105</td>
<td>150</td>
<td>7.6</td>
</tr>
<tr>
<td>75</td>
<td>200</td>
<td>1.3</td>
</tr>
<tr>
<td>-75</td>
<td>-200</td>
<td>0.2</td>
</tr>
</tbody>
</table>

AFS grain fineness no. 59
Base permeability: 106
Size distribution

The size distribution of the sand affects the quality of the castings. Coarse-grained sands allow metal penetration into moulds and cores giving poor surface finish to the castings. Fine-grained sands yield better surface finish but need higher binder content and the low permeability may cause gas defects in castings. Most foundry sands fall within the following size range:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain fineness number</td>
<td>50–60 AFS</td>
<td>Yields good surface finish at low binder levels</td>
</tr>
<tr>
<td>Average grain size</td>
<td>220–250 microns</td>
<td></td>
</tr>
<tr>
<td>Fines content, below 200 mesh</td>
<td>2% max</td>
<td>Allows low binder level to be used</td>
</tr>
<tr>
<td>Clay content, below 20 microns</td>
<td>0.5% max</td>
<td>Allows low binder levels</td>
</tr>
<tr>
<td>Size spread</td>
<td>95% on 4 or 5 screens</td>
<td>Gives good packing and resistance to expansion defects</td>
</tr>
<tr>
<td>Specific surface area</td>
<td>120–140 cm²/g</td>
<td>Allows low binder levels</td>
</tr>
<tr>
<td>Dry permeability</td>
<td>100–150</td>
<td>Reduces gas defects</td>
</tr>
</tbody>
</table>
Safe handling of silica sand

Fine silica sand (below 5 microns) can give rise to respiratory troubles. Modern foundry sands are washed to remove the dangerous size fractions and do not present a hazard as delivered. It must be recognised, however, that certain foundry operations such as shot blasting, grinding of sand covered castings or sand reclamation can degrade the sand grains, producing a fine quartz dust having particle size in the harmful range below 5 microns. Operators must be protected by the use of adequate ventilation and the wearing of suitable face masks.
Zircon

- Zircon is zirconium silicate (ZrSiO4). It is highly refractory and possesses excellent foundry characteristics. Its primary advantages are a very low thermal expansion, high thermal conductivity and bulk density (which gives it a chilling rate about four times that of quartz), and very low reactivity with molten metal. Zircon requires less binder than other sands because its grains are rounded. The very high dimensional and thermal stabilities exhibited by zircon are the reasons it is widely used in steel foundries and investment foundries making high-temperature alloy components.
Olivine

- Olivine minerals (so called because of their characteristic green color) are a solid solution of forsterite (Mg2SiO4) and fayalite (Fe2SiO4). Their physical properties vary with their chemical compositions; therefore, the composition of the olivine used must be specified to control the reproducibility of the sand mixture. Care must be taken to calcine the olivine sand before use to decompose the serpentine content, which contains water.

- The specific heat of olivine is similar to that of silica, but its thermal expansion is far less. Therefore, olivine is used for steel casting to control mold dimensions. Olivine is somewhat less durable than silica, and it is an angular sand.
Chromite

- Chromite (FeCr2O4), a black, angular sand, is highly refractory and chemically unreactive, and it has good thermal stability and excellent chilling properties. However, it has twice the thermal expansion of zircon sand, and it often contains hydrous impurities that cause pinholing and gas defects in castings. It is necessary to specify the calcium oxide (CaO) and silicon dioxide (SiO2) limits in chromite sand to avoid sintering reactions and reactions with molten metal that cause burn-in.
Aluminum Silicates

- Aluminum silicate (Al2SiO5) occurs in three common forms: kyanite, sillimanite, and andalusite. All break down at high temperatures to form mullite and silica. Therefore, aluminum silicates for foundry use are produced by calcining these minerals. Depending on the sintering cycle, the silica may be present as cristobalite or as amorphous silica. The grains are highly angular. These materials have high refractoriness, low thermal expansion, and high resistance to thermal shock. They are widely used in precision investment foundries, often in combination with zircon.
**Bulk density** = The mass of powdered or granulated solid material per unit of volume

<table>
<thead>
<tr>
<th>Property</th>
<th>Silica</th>
<th>Zircon</th>
<th>Chromite</th>
<th>Olivine</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFS grain size no.</td>
<td>60</td>
<td>102</td>
<td>74</td>
<td>65</td>
</tr>
<tr>
<td>Grain shape</td>
<td>rounded</td>
<td>rounded</td>
<td>angular</td>
<td>angular</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>2.65</td>
<td>4.66</td>
<td>4.52</td>
<td>3.3</td>
</tr>
<tr>
<td>Bulk density (kg/m$^3$)</td>
<td>1490</td>
<td>2770</td>
<td>2670</td>
<td>1700</td>
</tr>
<tr>
<td>Bulk density (lb/ft$^3$)</td>
<td>93</td>
<td>173</td>
<td>167</td>
<td>106</td>
</tr>
<tr>
<td>Thermal expansion 20–1200°C</td>
<td>1.9%</td>
<td>0.45%</td>
<td>0.6%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Application</td>
<td>general</td>
<td>refractoriness chill</td>
<td>resistance to penetration chill</td>
<td>Mn steel</td>
</tr>
</tbody>
</table>
Figure 12.2 Thermal expansion characteristics of zircon, chromite and olivine sands compared with silica sand.
SAND ADDITIVES

Water

• Water
• H₂O
SAND ADDITIVES

Clays

• Clays

• Bentonite, Southern (Ca-Bentonite)
• Bentonite, Western (Na-Bentonite)
• Fireclay
• Kaolin Clay
The most common clays used in bonding green sand molds are bentonites, which are forms of montmorillonite or hydrated aluminum silicate. Montmorillonite is built up of alternating tetrahedra of silicon atoms surrounded by oxygen atoms, and aluminum atoms surrounded by oxygen atoms, as shown in Fig. 1. This is a layered structure, and it produces clay particles that are flat plates. Water is adsorbed on the surfaces of these plates, and this causes bentonite to expand in the presence of water and to contract when dried.
**Fig. 1** Structure of montmorillonite. Large closed circles are aluminum, magnesium, sodium, or calcium. Small closed circles are silicon. Large open circles are hydroxyls. Small open circles are oxygen.
BENTONITE, SOUTHERN
(INORGANIC)

Description .......... (Ca⁺⁺ calcium bentonite)
also known as nonswelling bentonite.
Typical Color .......... cream, tan, bluish gray
Purpose .......... basic bond in green sand system. To
promote good green strength, moderate dry and
hot compression strengths. Gives higher green,
lower dry and hot strengths and promotes
better flowability than western bentonite.

Bulk Density .................. 52 lb/ft³
Typical Sizing ...... 60-90% thru USA Sieve 200
pH ......................... 4.0-8.5
Fusion Point ................. 1900-2440F (1038-1338°C)
% Volatile @ 900F (482C) ............ 0°
% Volatile @ 1800F (982°C) ........... 0.5
% Total Combustibles ............. 0.5°

Effective Temperature of
Destruction .................. 1292F (700°C)
Effect on:
Green Compression Strength .......... increases
Dry Compression Strength ............ increases
Hot Compression Strength ............ increases

Miscellaneous Data or Observations
Typical base exchange (in me/100 g) .... Na(<5),
K(2.8), Ca(74.7), Mg(1.0)

*Does not include chemically or mechanically held water.

Typical Chemical Analysis (Percent)

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>56-59</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>18-21</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>5.4-9.1</td>
</tr>
<tr>
<td>MgO</td>
<td>3.0-3.3</td>
</tr>
<tr>
<td>CaO</td>
<td>1.2-3.5</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.34-4.6</td>
</tr>
<tr>
<td>H₂O, as</td>
<td>shipped</td>
</tr>
</tbody>
</table>

SAND ADDITIVES  Clays
BENTONITE, WESTERN
(INORGANIC)

Description.................. powdered (Na⁺ sodium bentonite). Also known as Wyoming bentonite, high-swelling bentonite.

Typical Color ........ bluish, cream, gray, light yellow

Purpose .......... basic bond in a green sand system.

To promote green, dry and hot compression strengths. To prevent erosion, cuts, washes, and allow for silica sand expansion.

Bulk Density ................ 54 lb/ft³

Typical Sizing .......... 60-92% thru USA Sieve 200

pH ........................................ 9.0-10.0

Fusion Point ............. 1900-2440°F (1038-1338°C)

% Volatile @ 900°F (842°C) ............. 0*

% Volatile @ 1800°F (982°C) .......... 5

(H₂O of hydration driven off @ 1292°F (700°C).
Lattice destroyed @ 1832°F (1000°C).

% Total Combustibles ............... 0.5*

Effective Temperature of Destruction ................. 1832°F (1000°C)

Effect on:

- Green Compression Strength .......... increases
- Dry Compression Strength ............ increases
- Hot Compression Strength ........... increases

Miscellaneous Data or Observations

1) Base exchange (in me/100 g)

   Total Na, K, Ca & Mg ................. 85-100
   Combined Na & K ions .............. 60.0% min.
   Combined Ca & Mg ions ............. 40.0% max.

2) Consists primarily of the mineral montmorillonite.

3) Various other grinds available.

*Does not include chemically or mechanically held water.

Typical Chemical Analysis
(Percent)

<table>
<thead>
<tr>
<th></th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>60-62</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>21-23</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3-4</td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.5-2.7</td>
</tr>
<tr>
<td>MgO</td>
<td>0.2-3</td>
</tr>
<tr>
<td>CaO</td>
<td>0.5-1.5</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.4-0.45</td>
</tr>
<tr>
<td>H₂O, as shipped</td>
<td>5.0-9.0</td>
</tr>
</tbody>
</table>
Sand Properties

- Green Compression Strength
- Dry Compression Strength
- Hot Compression Strength
- Moisture (water)
- Permeability
- Flowability
- Refractoriness
- Thermal Stability
- Collapsibility
- Produces good casting finish
- Mold Hardness
- Deformation
- Is reusable
- Remove heat from the cooling casting
GENERAL PROPERTIES OF MOLDING SANDS

- From a general viewpoint, the molding sand must be readily moldable and produce defect-free castings if it is to qualify as a good one. Certain specific properties have been identified, and testing procedures adapted for their quantitative description.
- The AFS "Foundry Sand Hand-book"\(^1\) sets forth the standard conditions of testing the sand properties. Those properties of most obvious importance include:
GENERAL PROPERTIES OF MOLDING SANDS

1. Green strength. The green sand, after water has been mixed into it, must have adequate strength and plasticity for making and handling of the mold.

2. Dry strength. As a casting is poured, sand adjacent to the hot metal quickly loses its water as steam. The dry sand must have strength to resist erosion, and also the metallostatic pressure of the molten metal, or else the mold may enlarge.
GENERAL PROPERTIES OF MOLDING SANDS

3. Hot strength. After the moisture has evaporated, the sand may be required to possess strength at some elevated temperature, above 100 °C. Metallostatic pressure of the liquid-metal bearing against the mold walls may cause mold enlargement, or if the metal is still flowing, erosion, cracks, or breakage may occur unless the sand possesses adequate hot strength.

4. Permeability. Heat from the casting causes a green-sand mold to evolve a great deal of steam and other gases. The mold must be permeable, i.e. porous, to permit the gases to pass off, or the casting will contain gas holes.
GENERAL PROPERTIES OF MOLDING SANDS

5. Thermal stability. Heat from the casting causes rapid expansion of the sand surface at the mold-metal interface. The mold surface may then crack, buckle, or flake off (scab) unless the molding sand is relatively stable dimensionally under rapid heating.

6. Refractoriness. Higher pouring temperatures, such as those for ferrous alloys at 2400 to 3200 F, require greater refractoriness of the sand. Low-pouring-temperature metals, for example, aluminum, poured at 1300 F, do not require a high degree of refractoriness from the sand.
GENERAL PROPERTIES OF MOLDING SANDS

7. Flowability. The sand should respond to molding processes.
8. Produces good casting finish.
9. Collapsibility. Heated sand which becomes hard and rocklike is difficult to remove from the casting and may cause the contracting metal to tear or crack.
10. Is reusable.
11. Offers ease of sand preparation and control.
12. Removes heat from the cooling casting.

This list by no means includes all the properties which might be desirable. Obviously, the most important characteristic of a molding sand is that it facilitate the economic production of good castings.
(a) Southern bentonite.
(b) Western bentonite.
Sand Tests

Generally the following tests are performed to judge the molding and casting characteristics of foundry sands:

1. Moisture content Test
2. Clay content Test
3. Chemical composition of sand
4. Grain shape and surface texture of sand.
5. Grain size distribution of sand
6. Refractoriness of sand
7. Strength Test
8. Permeability Test
9. Flowability Test
10. Shatter index Test
11. Mould hardness Test
SAND ADDITIVES

• Clays
• Water
• Carbons
• Cellulose
• Oil-Chemicals
• Refrakteries
• Starches-Solubles (Nişasta)
SAND ADDITIVES

Clays

- Clays
- Bentonite, Southern (Ca-Bentonite)
- Bentonite, Western (Na-Bentonite)
- Fireclay
- Kaolin Clay
**BENTONITE, SOUTHERN**

*(INORGANIC)*

**Description** .......... (Ca\(^{++}\) calcium bentonite) also known as nonswellin bentonite.

**Typical Color** .......... cream, tan, bluish gray

**Purpose** .......... basic bond in green sand system. To promote good green strength, moderate dry and hot compression strengths. Gives higher green, lower dry and hot strengths and promotes better flowability than western bentonite.

**Bulk Density** ................. 52 lb/ft\(^3\)

**Typical Sizing** .......... 60-90% thru USA Sieve 200

**pH** .......................... 4.0-8.5

**Fusion Point** .......... 1900-2440F (1038-1338C)

**% Volatile @ 900F (482C)** ................. 0*

**% Volatile @ 1800F (982C)** ................. 0.5

**% Total Combustibles** ................. 0.5*

**Effective Temperature of Destruction** .......... 1292F (700C)

**Effect on:**

- **Green Compression Strength** .......... increases
- **Dry Compression Strength** .......... increases
- **Hot Compression Strength** .......... increases

**Miscellaneous Data or Observations**

Typical base exchange (in me/100 g) .... Na(<5), K(2.8), Ca(74.7), Mg(1.0)

*Does not include chemically or mechanically held water.

**Typical Chemical Analysis (Percent)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO(_2)</td>
<td>56-59</td>
</tr>
<tr>
<td>Al(_2)O(_3)</td>
<td>18-21</td>
</tr>
<tr>
<td>Fe(_2)O(_3)</td>
<td>5.4-9.1</td>
</tr>
<tr>
<td>MgO</td>
<td>3.0-3.3</td>
</tr>
<tr>
<td>CaO</td>
<td>1.2-35</td>
</tr>
<tr>
<td>Na(_2)O</td>
<td>0.34-46</td>
</tr>
<tr>
<td>H(_2)O, as</td>
<td></td>
</tr>
<tr>
<td>shipped</td>
<td>5.0-8.0</td>
</tr>
</tbody>
</table>
BENTONITE, WESTERN
(INORGANIC)

Description............. powdered (Na⁺ sodium bentonite). Also known as Wyoming bentonite, high-swelling bentonite.

Typical Color .......... bluish, cream, gray, light yellow

Purpose ............... basic bond in a green sand system. To promote green, dry and hot compression strengths. To prevent erosion, cuts, washes, and allow for silica sand expansion.

Bulk Density ............ 54 lb/ft³

Typical Sizing .......... 60-92% thru USA Sieve 200

pH .......................... 9.0-10.0

Fusion Point ............. 1900-2440°F (1038-1338°C)

% Volatile @ 900°F (842°C) ............... 0*

% Volatile @ 1800°F (982°C) ............... 5

(H₂O of hydration driven off @ 1292°F (700°C). Lattice destroyed @ 1832°F (1000°C).

% Total Combustibles .......... 0.5 *

Effective Temperature of Destruction ............. 1832°F (1000°C)

Effect on:

Green Compression Strength ........ increases
Dry Compression Strength .......... increases
Hot Compression Strength .......... increases

Miscellaneous Data or Observations

1) Base exchange (in me/100 g)
   Total Na, K, Ca & Mg ............... 85-100
   Combined Na & K ions ............... 60.0% min.
   Combined Ca & Mg ions ............... 40.0% max.

2) Consists primarily of the mineral montmorillonite.

3) Various other grinds available.

*Does not include chemically or mechanically held water.

<table>
<thead>
<tr>
<th>Typical Chemical Analysis (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂.............................................. 60-62</td>
</tr>
<tr>
<td>Al₂O₃............................................. 21-23</td>
</tr>
<tr>
<td>Fe₂O₃............................................. 3-4</td>
</tr>
<tr>
<td>Na₂O............................................. 2.5-2.7</td>
</tr>
<tr>
<td>MgO.............................................. 0.2-3</td>
</tr>
<tr>
<td>CaO.............................................. 0.5-1.5</td>
</tr>
<tr>
<td>K₂O.............................................. 0.4-0.45</td>
</tr>
<tr>
<td>H₂O, as shipped......................... 5.0-9.0</td>
</tr>
</tbody>
</table>
FIRECLAY
(INORGANIC)

Description ............................................. 50 mesh
Typical Color ........................................... gray
Purpose ............................................. basic bond in a green sand system.
  Increases green, dry and hot strengths. Used particularly to increase dry and hot properties.
Bulk Density ........................................... 60 lb/ft³
pH .......................................................... 4-5
Fusion Point ........................................... 3000°F (1649°C)
% Volatile @ 900°F (482°C) ............ varies
% Volatile @ 1800°F (982°C) .......... 9.0
% Total Combustibles .................. 9.39*
Effective Temperature of Destruction ........................................... 3055°F (1679°C)
Effect on:
Green Compression Strength ............. increases
Dry Compression Strength ............... increases
Hot Compression Strength .............. increases

Miscellaneous Data or Observations
PCE Cone 31 ........................................... 3055°F (1679°C)
AFS GFN ........................................... 180
Finer and coarser grinds also available.

*Includes approximately 4-5% H₂O as shipped.

<table>
<thead>
<tr>
<th>Typical U.S.A.</th>
<th>Typical Chemical Analysis (Percent)</th>
</tr>
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<tbody>
<tr>
<td>Sieve Analysis</td>
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<tr>
<td>(Percent Retained)</td>
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<tr>
<td>30 ..........</td>
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<tr>
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<td>1.7</td>
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<tr>
<td>50 ..........</td>
<td>5.3</td>
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<td>9.5</td>
</tr>
<tr>
<td>100 ..........</td>
<td>13.5</td>
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<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
KAOLIN CLAY
(INORGANIC)

Description ..................... also called “China Clay”
although China Clay is primarily used in the

ceramic industry, and is slightly different.

Typical Color .................... gray

Purpose ................................ primarily increases dry

and hot compression strengths

Bulk Density .......................... 30 lb/ft³

pH ..................................... 4.5

Fusion Point ....................... 2921F (1605C)

% Volatile @ 1800F (982C) .......... 14.2

% Total Combustibles ............... 14.2

Effective Temperature of

Deployment .......................... 3000F (1649C)

Effect on:

Green Compression Strength .......... increases

Dry Compression Strength .......... increases

Hot Compression Strength .......... increases

Miscellaneous Data or Observations

Modulus of rupture .................. 75 psi

H₂O of plasticity ................... 32.7%

*Includes H₂O as shipped.

<table>
<thead>
<tr>
<th>Typical Chemical Analysis (Percent)</th>
<th>Typical Particle Size Analysis</th>
<th>Typical Particle Size Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂ ................................</td>
<td>% Finer</td>
<td>Microns</td>
</tr>
<tr>
<td>Al₂O₃ ................................</td>
<td>98 ..........</td>
<td>26.6</td>
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<tr>
<td>Fe₂O₃ ................................</td>
<td>95.7 ......</td>
<td>8.5</td>
</tr>
<tr>
<td>TiO₂ ................................</td>
<td>90.5 ......</td>
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</tr>
<tr>
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<td>81.5 ......</td>
<td>3.9</td>
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<tr>
<td>MgO ................................</td>
<td>69.7 ......</td>
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</tr>
<tr>
<td>Na₂O ................................</td>
<td>55.4 ......</td>
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</tr>
<tr>
<td>K₂O ................................</td>
<td>39.7 ......</td>
<td>0.44</td>
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<tr>
<td>% Finer ................................</td>
<td>20.1</td>
<td>0.32</td>
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</table>
SAND ADDITIVES

Water

- Water
- $\text{H}_2\text{O}$
SAND ADDITIVES
Carbons

- Carbons
- Asphalt
- Gilsonite (a kind of asphalt)
- Graphite
- Lamp Black (lamba isi)
- Lignite (brown coal)
- Pitch, Coal Tar (zift, kömür katranı)
- Seacoal (pulverized coal)
• Carbon is added to the mold to provide a reducing atmosphere and a gas film during pouring that protects against oxidation of the metal and reduces burn-in.

• Carbon can be added in the form of seacoal (finely ground bituminous coal), asphalt, gilsonite (a naturally occurring asphaltite), or proprietary petroleum products.

• Seacoal changes to coke at high temperatures expanding three times as it does so; this action fills voids at the mold/metal interface. Too much carbon in the mold gives smoke, fumes, and gas defects, and the use of asphalt products must be controlled closely because their overuse waterproofs the sand.

• The addition of carbonaceous materials will give improved surface finish to castings. Best results are achieved with such materials as seacoal and pitch, which volatilize and deposit a pyrolytic (lustrous) carbon layer on sand at the casting surface.