### 2013, 2120/B, and 2130/B

<table>
<thead>
<tr>
<th>Property</th>
<th>0.14-0.20 DIN</th>
<th>AFS 110-80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average sand grain size</td>
<td>3-4 sieves</td>
<td>1700-2100 p/cm²</td>
</tr>
<tr>
<td>Grain size distribution</td>
<td>25-30 psi</td>
<td>200 p/cm²</td>
</tr>
<tr>
<td>Green compression strength</td>
<td>&gt; 300 p/cm²</td>
<td>&gt; 0.3 psi</td>
</tr>
<tr>
<td>Green tensile strength</td>
<td>&gt; 20 p/cm²</td>
<td>&gt; 4.3 psi</td>
</tr>
<tr>
<td>Spalling strength</td>
<td>1700-2100 p/cm²</td>
<td>&gt; 2.9 psi</td>
</tr>
<tr>
<td>Wet tensile strength</td>
<td>over 50</td>
<td>40% ± 2%</td>
</tr>
<tr>
<td>Permeability</td>
<td>adjusted</td>
<td>40% ± 2%</td>
</tr>
<tr>
<td>Compactability</td>
<td>until a</td>
<td>until a</td>
</tr>
<tr>
<td>Moisture content</td>
<td>compactability of</td>
<td>compactability of</td>
</tr>
<tr>
<td>AFS clay content</td>
<td>11%-13%</td>
<td>11%-13%</td>
</tr>
<tr>
<td>Active clay content (MB)</td>
<td>&gt; 7%</td>
<td>&gt; 7%</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>3.5%-7.5%</td>
<td>3.5%-7.5%</td>
</tr>
<tr>
<td>Volatiles</td>
<td>1.5%-3%</td>
<td>1.5%-3%</td>
</tr>
</tbody>
</table>

*Fig. 1.01 Recommended physical properties for standard sand for the 2013, 2120/B, and 2130/B DISAMATIC Sand Molding System.*

### 2070, 2120/A, C, and 2130/A, C

<table>
<thead>
<tr>
<th>Property</th>
<th>0.14-0.18 DIN</th>
<th>AFS 110-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average sand grain size</td>
<td>3-4 sieves</td>
<td>2000-2500 p/cm²</td>
</tr>
<tr>
<td>Grain size distribution</td>
<td>25-36 psi</td>
<td>200 p/cm²</td>
</tr>
<tr>
<td>Green compression strength</td>
<td>&gt; 360 p/cm²</td>
<td>&gt; 5.4 psi</td>
</tr>
<tr>
<td>Green tensile strength</td>
<td>&gt; 2.9 psi</td>
<td>&gt; 4.3 psi</td>
</tr>
<tr>
<td>Spalling strength</td>
<td>2200-2500 p/cm²</td>
<td>&gt; 3.6 psi</td>
</tr>
<tr>
<td>Wet tensile strength</td>
<td>&gt; 20 p/cm²</td>
<td>&gt; 0.3 psi</td>
</tr>
<tr>
<td>Permeability</td>
<td>over 50</td>
<td>40% ± 2%</td>
</tr>
<tr>
<td>Compactability</td>
<td>adjusted</td>
<td>40% ± 2%</td>
</tr>
<tr>
<td>Moisture content</td>
<td>until a</td>
<td>until a</td>
</tr>
<tr>
<td>AFS clay content</td>
<td>11%-14%</td>
<td>11%-14%</td>
</tr>
<tr>
<td>Active clay content (MB)</td>
<td>&gt; 8%</td>
<td>&gt; 8%</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>3.5%-7.5%</td>
<td>3.5%-7.5%</td>
</tr>
<tr>
<td>Volatiles</td>
<td>1.5%-3%</td>
<td>1.5%-3%</td>
</tr>
</tbody>
</table>

*Fig. 1.02 Recommended physical properties for standard sand for the 2070, 2120/A/C, and 2130/A/C DISAMATIC Sand Molding System.*
High-Density Green Sand Molding

Compared with other sand molding methods using chemical binders, the cost of clay-bonded sand is much lower and the productivity and quality of the resulting castings are just as good or even better.

In order to achieve maximum efficiency in an automatic molding plant, it is crucial to establish an efficient process control system for the cooling, mixing and aerating operations. Sand control plays an important part in process control.

Keeping a continual check on sand properties will provide:

- Reduced scrap
- Better pattern draw
- Higher molding plant efficiency
- Reduced molding material costs
- Reduced fettling costs and time

Let us begin by listing the molding sand properties recommended by DISA for DISAMATIC molding systems (Figs. 1.01 and 1.02).
Fig. 1.03 The relation between average grain size and metallostatic pressure height of the casting in the mold at incipient metal penetration.
AVERAGE GRAIN SIZE

There are no strict average grain size requirements concerning sand for the DISAMATIC. However, it is a well-known fact, also from other molding processes, that the probability of metal penetration between sand grains increases with increasing average grain size. As the ferrostatic pressure height is varying in the mold, it is recommended to use an average grain size of between 0.14 and 0.20 mm (AFS 110-80) for 2013 Mk4 DMS and 2120/2130 DNS and 0.14–0.18 mm (AFS 110-90) for 2070 DMS. The diagram in Fig. 1.03 shows the dividing line between the area where metal penetration, combined with average grain size, can be expected, and the area where the mold sand structure is sufficiently tight to withstand influences from the ferrostatic pressure height in question.

Sand grains should be distributed over 3–4 sieves for sufficient uniformity of the packing structure.

MOLDING SAND STRENGTH

Molding sand strength depends on:

- proper content of active bentonite
- the quality of the bentonite
- proper moisture content
- content of inactive fines (inactive material less than 0.020 mm (0.0008")
- mixing efficiency
- sand temperature

Proper Content of Active Bentonite

The proper content of active bentonite in the molding sand is just as important as choosing the correct type of bentonite. Below are mentioned the reasons why it is important to use high-active bentonite-content in the molding sand:

- obtaining high green compression strength in order to produce stronger molds that are easier to convey, and in order to avoid mold deformation in the parting line.

- maintaining a high green tensile strength in order to avoid tear-off at stripping and weakened sand cores in the mold cavities.

- obtaining a higher wet tensile strength in order to avoid mold scabbing in the water condensation zone and sand expansion defects.

- ensuring good molding sand plasticity to avoid sand "springback" and that the sand starts flowing through the injection slot and down into the molding chamber between the shot operations.

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• stabilizing the mold cavity to avoid such casting defects as shrinkage and other porosities, casting expansions, sand erosion and sand inclusion.

The recommended content of active bentonite measured by means of the Methylene Blue test must be over 7% for 2013 DMS, and over 8% for 2070 and 2120/2130 DMS.

Bentonite Quality
The use of clay of optimum quality in an automatic molding system is one of the most important requirements. Normally, the following qualities are expected to be inherent in good-quality bentonite:

• it should develop good bonding properties when mixed or mulled with sand and water in the correct proportion.

• it should be able to resist reasonable heat influence, such that its bonding strength and plasticity properties are maintained.

• it should give the molding sand the correct consistency (moldability), which renders it possible for the sand to be conveyed, stored and handled in the correct way during processing.

• it should enable the molding sand to compensate for the thermal expansion of the silica grains, which counteracts casting expansion defects.

• it should give the molding sand the correct stability and plasticity, so that perfect lifting of pattern plates can be accomplished.

• it should make it possible for the sand to resist the influence from the heat shock, so that it is still economical to reuse the molding sand.

• in molding sand mixtures it should maintain sufficient sand bonding properties in dry and hot condition, so that the metal can be poured without any risk of casting defects, and such that the poured molds may be correctly conveyed, and still it should be economical to reuse the return sand.

• the molding sand mixture should collapse readily after casting and be reused.

• it should be economical in terms of price, transport, delivery and storage.

Properties of Use of Bentonite
DISA strongly recommends that bentonite employed for automatic high-density molding systems should have the following properties of use:

• effective build-up of high bonding properties in wet condition after being mixed with water by:
<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>Ca bentonite</th>
<th>Na bentonite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green compression strength</td>
<td>High</td>
<td>Lower</td>
</tr>
<tr>
<td>Mixability</td>
<td>Greater</td>
<td>Small</td>
</tr>
<tr>
<td>Dry compression strength</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Hot compression strength</td>
<td>Lower</td>
<td>High</td>
</tr>
<tr>
<td>Durability against dead-burning</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Thermal stability at high temperature</td>
<td>Poor</td>
<td>Very good</td>
</tr>
<tr>
<td>Flowability of molding sand</td>
<td>Good</td>
<td>Less good</td>
</tr>
<tr>
<td>Resistivity to sand expansion defects</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Mold breakability in shake-out</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

Fig. 1.04 Comparison between Na- and Ca-bentonites
a) as quickly as possible forming a film of clay/water around the grains at minimum water requirements.

b) requiring the lowest possible addition of clay to obtain the requisite bonding strength. If a large quantity of clay is to be added to obtain the requisite bonding strength, the water requirements of the molding sand increases, and its permeability declines.

- sufficient heat stability ensuring:
  a) that a limited quantity of dead-burnt clay is deposited. A large content of dead-burnt clay reduces the plasticity of the molding sand and increases its water requirements.
  b) that a higher strength is obtained at increased temperature, which counteracts a number of casting defects, such as metal penetration, expansion defects, rattails, etc.

- should collapse readily at shake-out.

Types of Bentonite

There are two types of clay, each with its specific properties. This makes them more or less useable as bonding materials: kaolin (fireclay) and montmorillonite clay.

Kaolin is not suitable for high-density molding sand, first and foremost because of low bonding strength, low durability when being heated, and low plasticity. Therefore, kaolin can only be used when it exists in semi-natural molding sand and should be enriched with montmorillonite.

Bentonite is a clay containing a minimum of 75% montmorillonite. DISA recommends the use of bentonite for automatic high-density greensand molding.

In nature there are two types of bentonite: sodium bentonite, which predominantly contains ions Na⁺ and calcium bentonite, which mainly consists of ions Ca⁺⁺.

The table (Fig. 1.04) compares features of Na- and Ca-bentonites. In spite of the great differences between the two types of bentonites, the one cannot be preferred to the other without taking into consideration the concrete job (casting type) in question. No one will choose a Ca-bentonite for steel castings, where the thermal load of the molding sand is very great, or use a pure Na-bentonite for thin-walled castings. For the same reason, Na-bentonite is not used for aluminum castings, which, on the other hand, must be added in great quantities for the production of thick-walled cast iron castings.

It is normally recommended to use both Na- and Ca-bentonite in a proportion corresponding to production conditions, so that both the correct mold stability is obtained, as well as correct sand consistency, green strength and dry strength, plus collapsibility in shake-out.
Some manufacturers of bentonites treat Ca-bentonites with caustic soda. In this way the amount of Na-ions increases, and the bentonite gains some of the good properties of Na-bentonites, such as durability when affected by heat, dry strength, and resistivity to expansion defects. At the same time they keep some good features of the Ca-bentonites, such as high green compression strength, high collapsibility at the mold shake-out, and good mixability.

The Ca-bentonites can be activated by the soda in water solutions and in dry state. The first method of activation seems to be more efficient and produces some really good products.

**Main Quality Data for Bentonite**

<table>
<thead>
<tr>
<th>Montmorillonite content:</th>
<th>min. 70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swelling index:</td>
<td></td>
</tr>
<tr>
<td>Ca-bentonite</td>
<td>6-10 ml</td>
</tr>
<tr>
<td>Na-bentonite</td>
<td>18-50 ml</td>
</tr>
<tr>
<td>Activated Ca-bentonite</td>
<td>10-20 ml</td>
</tr>
<tr>
<td>Water content:</td>
<td>max. 12%</td>
</tr>
<tr>
<td>pH-value:</td>
<td>min. 8.5</td>
</tr>
</tbody>
</table>

**Water Content**

Clay is the only easily obtainable material that becomes plastic when mixed with water. In the process of a green sand foundry the plastic clay/water mixture is used to bond together the grained and non-plastic material, as sand is, to a firm substance that can be conveyed, stored, and molded, and be capable of withstanding the heat influence of metal after pouring. At the same time the substance must be reusable.

However, the water content in molding sand should be kept as low as possible to:

- **ensure high bonding properties**

  All strength properties drop drastically when the water content is too high. A too low green tensile strength gives poor stripping and tear-offs.

  A too low green compression strength means mold handling problems and an unstable molding cavity.

  A too low wet tensile strength leads to mold disintegration in the water condensation zone, and thus a higher probability of sand expansion defects.

- **optimize the flowability of the molding sand**

  It must be possible for the molding sand to fill all spaces and pattern undercuts when it flows into the molding chamber from the sand hopper, so that maximum density is obtained already before squeezing, and the need for squeeze pressure is therefore reduced to a minimum. At the same time this leads to a constantly uniform mold density.
Fig. 1.05 The water vapor develops at an explosive rate in the iron/sand border area and presses the molten iron in between the sand grains, causing metal penetration.
• obtain the requisite plasticity of the molding sand

The molding sand plasticity drops with the increase of water content in excess of what is required to utilize the active clay in the sand.

Higher plasticity means more stable molds, thus preventing a number of casting defects, such as shrinkage, porosity and dimensional defects. A higher plasticity is also necessary to counteract heat expansion of the silica grains and the casting defects this may lead to. The more plastic the water/clay mixture is, the better it can absorb the internal mold movements. Finally, a too high water content makes the molding sand sticky. Sticky molding sand will easily adhere to the conveyor as well as to the walls of the sand silo and cause molding sand build-up in the silos and the sand funnel on the machine.

• avoiding too compressed molds

The compression rate of molding sand increases with increasing water content. Too wet sand leads to too hard molds. The harder the molds, the more work is required to break them at the shake-out.

• reducing steam generation after pouring to a minimum

The total volume of gas emitted from a green sand mold before and after molding is directly proportional to the water content in the molding sand.

Many well-known casting defects are a result of too high steam generation, such as gas blow-out and misrun. There is another sort of defect, which is due to a too high steam generation, viz. metal penetration. The steam generated at an explosive rate presses the molten iron in between the sand grains in the metal sand contact zone, as shown on Fig. 1.05. This is called explosion penetration.

Too much moisture in the molding sand also means that the water shifts away from the casting in the mold, influenced by the hot casting, and is condensed in the coldest sections of the mold. This leads to tear-off of large mold sections. The excessive steam may condensate on the underside of the mold, which then has a tendency to stick to the slideways of the PMC or the AMC.

Content of Inactive Fines

Inactive fines consist of all the particles smaller than 0.02 mm (0.0008"), which, when mixed with water, do not impart strength or plasticity to the molding sand; on the contrary, they serve to decrease it.

Inactive fines are normally composed of:

• dead-burnt bentonite (bentonite which has lost its water of crystallization)
• coal dust particles less than 0.02 mm (0.0008") in dia.
• dead-burnt coal dust (coke, ash)
• natural fines from the base sand
Fig. 1.06 A molding with a higher content of fines has wider moisture content tolerances (can compensate for greater water addition errors) at a constant compactability (example).
• crushed and thermally disrupted silica grains

Too high a content of inactive fines increases water consumption and brittleness of the molding sand and reduces its permeability. With excessive content of inactive fines, bonding strength drops steeply.

Increased water requirement leads to explosion penetrations and results in poor surface finish on the casting. This demands longer shot blasting time.

Generally, the inactive fines must be kept low. An easy method for determining inactive fines is to compare the green compression strength with the wet tensile strength. When there is an excessive amount of inactive fines combined with a high water content, the green compression strength remains unchanged, while the wet tensile strength drops drastically.

However, any molding sand has a need for inactive fines to close a number of the pores in the mold sand packing, thus reducing the possibility of metal penetration and improving the surface finish of the casting.

A certain amount of inactive fines is further necessary to make the consistency of the molding sand less sensitive to fluctuations in water additions (Fig. 1.06) by absorbing part of the surplus water, which would otherwise have made for a muddy molding sand consistency.

For this reason, the optimal fines content is a matter of tight-roping, like many other factors in the foundry process.

The inactive fines should be between 2.5 and 4%.

The inactive fines plus the active bentonite constitute the total content of fines (AST clay content).

**Mixing Efficiency**

Even the proper composition will not give the molding sand the optimal features, if it is not mixed properly. Drying mulling the clay must be properly mixed with water until a plastic water/clay mass is produced. The plastic mass must be distributed evenly over the surface of the sand grains, so that the bonding film can impart strength to the material after compaction.

Mixing efficiency tells how well the actual system sand has been mixed in relation to how well it could have been mixed with the same composition, but with a longer mixing period.

Mixing efficiency can be measured by testing either:

• wet tensile strength, or
• compactability

of the system sand directly, and after a period of 5 min. of additional mixing.
Fig. 1.07 The hotter the sand, the more water it takes to keep compactability (temper point) constant (example).
By using the formula:

\[
\text{Mixing efficiency} = \frac{\text{Wet tensile strength directly}}{\text{Wet tensile strength after 5 min. extra mixing}}
\]

it is possible to perform the measurement without taking into consideration the slight water content change during the additional mixing.

When using the formula:

\[
\text{Mixing efficiency} = \frac{\text{Compactability directly}}{\text{Compactability after 5 min. extra mixing}}
\]

it should be ensured that the water content was constant both before and after extra mixing, or a water loss factor should be introduced.

A prerequisite of the test is that the degree of compactability was kept between 35-55% throughout the entire test.

A result between 0.65-0.70: poorly mixed sand.

A result between 0.90-0.95: very intensively mixed sand.

The test determining the condition of the mixture is a good indication of whether the additives are utilized during the mixing, and whether the mixing time employed is optimal.

**Sand Temperature**

The temperature of the molding sand may not exceed 40°C (104°F). Too hot sand may cause:

- Non-uniform sand properties, especially strength and permeability
- Increased stickiness
- Superficial drying out
- Decreased resistance against sand erosion defects
- Displacement of the temper point or higher water requirements (cf. Fig. 1.07).
- Low plasticity, causing higher requirements for clay addition
- Decreased mixability

**Tensile and Spalling Strength**

Not all strength testing machines permit direct measurement of green tensile strength. Dr. Boenish's experimental work made it possible to test green tensile strength (δₜ) by testing spalling strength (δₛ), using standard sand test specimens located in the jaws of the testing machine, perpendicularly to the specimen position used for testing compression strength. δₜ can be easily calculated, when δₛ is known, using the equation:
Fig. 1.08 An easy method *) for determining green tensile strength through the spalling strength test. *) After Dr. Boenisch. Positioning of the test specimen in the testing machine. Inter-dependence of spalling strength and green tensile strength.

Fig. 1.09 Progress of expansion defect (top)
Schematic view of measurement of wet tensile strength (bottom)
\[ \delta_t = 0.65 \delta_s \]

Fig. 1.08 shows the way of locating the specimen in the testing machine (A) and the dependency between \( \delta_s \) and \( \delta_t \) (B).

**Wet Tensile Strength**

Wet tensile strength is crucial for sand resistance to scabbing and other expansion defects. The expansion defects occur on the iron-sand face just after pouring. Water from the sand layer next to the casting moves away from the casting surface, thereby creating a water condensation zone between the dry and the still wet sand (Fig. 1.09A). The shell of the dry sand (0.25-0.3 mm or 0.010-0.012") separates from the rest of the sand in the border area of the condensation zone, as a result of heat expansion of the silica sand grains on one side, and weakened sand structure in the border area between the wet (condensed) and the dry sand layer (Fig. 1.09B). The molten metal presses into the space thus formed, and in this way a scab is "created" on the casting (Fig. 1.09C). The strength of the sand in the layer of condensed water is called wet tensile strength (cf. Fig. 1.09).

The more active clay, and especially Na-bentonite, there is in the sand, the stronger will be the wet sand layer, and the more plastic will be the dry sand layer. Plasticity of the dry sand layer counteracts the silica sand expansion movements. Therefore, the wet tensile strength is an excellent measure of how much the active clay contributes to the total content of fines (all particles with a dia. less than 0.02 mm or 0.0008") in the sand.

Wet tensile strength also gives good information about the quality of bentonite used.

**Green Compression Strength**

Green compression strength increases fast, like all strength properties, with increasing active clay content. But some of the active clay dead-burns after pouring by losing part of its water of crystallization, which is chiefly responsible for the plastic properties of the clay. Too much burnt clay causes the sand to seem dry and brittle, and it loses its strength. Often more water is added, and the sand may seem stronger, but the fact is that lower strength and plasticity are the result. If one starts with green strength and keeps it constant, difficulties will arise, since the green strength alone does not provide a correct picture of the sand properties. However, a comparison of green compression and wet tensile strength will show that while green strength remains constant, wet tensile strength drops considerably. Thus, if too much burnt clay (inactive fines) is present in the sand and this is combined with a high moisture percentage, a false picture of the sand in the green state will be obtained. The fact that the same total amount of fines is retained is no guarantee that the sand contains the right amount of active clay, since the active and inactive (burnt) clay are evaluated together in the test for total fines content. (APS clay).
PERMEABILITY

The lowest limit for average grain sizes is mainly connected with the reduction of permeability and flowability of the sand. The permeability must be viewed in relation to the amount of gas produced in the mold (water, carbonaceous materials, etc.), as well as its degree of compaction and sufficiently high iron temperature. On the other hand, permeability is not only dependent upon average grain size but also on total fines content (grains under 0.02 mm) as well as sand grain distribution and average grain size. Normally, permeability over 50 is sufficient for adequate mold ventilation.

COMPACTABILITY

Compactability testing measures a property of molding sands which is of decisive practical importance in establishing their behavior on modern automated molding machines. It determines the percentage decrease of height from the original constant level of the loose sand under the influence of squeeze compaction. Being strictly volumetric, the compactability test is independent of the specific gravity of the sand. The drier a sand is tempered, the less its height will decrease under the influence of a compacting force, and the lower its compactability percentage. The influence of the degree of temper is far more important than that of the squeeze pressure, a statement which also holds true for modern molding machines.

Compactability is an accurate indicator of degree of temper, practically independent of sand composition. It therefore has much in common with moldability.

Compactability testing permits an accurate adaption of a sand to the compaction characteristics of a given molding machine. More than that, it offers a good basis of reference when the actual moisture content is replaced by percent compactability for plotting sand test data. The water requirement of the sand is considered and can be measured as well as the degree of mulling.

The compactability test eliminates the subjectivity of the old-fashioned "hand test", which was previously mastered by few people only, since the compactability test can be performed by anybody.

The compactability test provides a very accurately reproducible and objective possibility of determining, by means of experiments, the degree of moisture of a sand, and hence its green-sand condition, with no limits to sensitivity on either the dry or the moist side.

The compactability test makes it possible to determine, using a simple procedure, a reference water content that will enable comparisons of the properties of different sands to be made. This is important in appraising the properties of different foundry sands, especially those of test mixtures for the testing of binder clay.

Thanks to the compactability test it is possible at any time to reproduce a specific degree of moisture independently of the water re-
Fig. 1.10 Compressability factor = \( \frac{C - T}{C} \times 100\% \)
requireds. A specific green-sand condition means a specific degree of moisture and a specific compactability.

Some Laws Relating to Molding-Sand Compactability

The compactability of volumetrically dosed molding sand is dependent upon its initial weight when heaped, and hence on the degree of moisture. The heaped weight of a specific sand is the lower the moister it is. Commensurately therewith, however, its compactability increases very markedly. Different sands have different water requirements. Consequently, they will have the same green-sand condition at very different individual water contents. The lower the fines content, the greater the water sensitivity. On the other hand, coal-dust-containing foundry sands and, for example, also natural sands are far less water-sensitive and have higher processing tolerance. However, what is of decisive importance is the fact that the compactability of widely different sands is always the same at the same degree of moisture (not water content).

Compressability Factor

From a simple observation that each time the DISAMATIC produces a mold it carries out a compactability test in the molding chamber, one can conclude that the molding machine itself gives information about the sand quality pushing a newly produced mold out of the chamber.

In terms of percentage figures, the compressibility factor of a sand in the chamber is a mold thickness reduction from the prior state and to its state after the squeezing operation.

Compressability can be calculated according to the following equation:

Compressability in % = \frac{True \ Chamber \ Depth \ (C) - Mold \ Thickness \ (T)}{True \ Chamber \ Depth \ (C)} \times 100\%

where the true chamber depth is the actual distance between the faces of the two pattern plates before the squeeze operation, and mold thickness can be periodically measured by the machine operator, (cf. Fig. 1.10).

The compressibility factor determines whether the available compacting energy of the DISAMATIC is utilized in the best possible manner, or in other words whether the sand consistency suits the characteristic of the molding machine.

If the sand has the correct moisture content, the compressibility should be:

18 - 24%

depending on the model of DISAMATIC and machine settings such as blow pressure, blow time, squeeze pressure, squeeze time, sand aeration, etc.
Fig. 1.11 The dependence of strength of a molding sand on its moisture content or its temper point (Example).
The influence of the moisture degree on the compressability factor is far more important than that of blow or squeeze pressure. However, in judging the compressability figure, reference must be made to the actual machine settings.

The compressability factor can be successfully applied as a quick method of checking the quality of molding sand. The chamber depth is always constant for a certain set of pattern plates and should be indicated on the Casting Production Sheet together with all the remaining production parameters, including the machine settings for this particular set of plates (as shown on Fig. 1.13 of the manual entitled "Process"). The machine operator can easily ascertain even the slightest changes of compactability of the molding sand by comparing the thickness of the mold presently produced with the optimal mold thickness indicated on the production sheet for the pattern plates in question. Any deviation from the temper point of the sand will result in a change of the mold thickness and consequently the compressability factor. The more moisture above the temper point, the thinner the mold. A quick feedback from the machine operator to the mixer operator will cause a fast response by correction of the moisture content of the next sand batch in the mullor.

The method described above is very practical but can absolutely not replace the regular routine check of the molding sand properties.

The compactability and the compressability factors indicate the consistency of the molding sand. At a given composition, only the correct moisture content will provide optimum strength and flowability. This moisture content is called temper moisture.

**Definition of Temper Point**

A sand is said to be in temper point when it has a moisture content that is 10-20% higher than that which gives maximum green compression strength or a compactability of 40% ± 2%, depending on sand composition.

The surplus of 10-20% of water is destined for being consumed by the inactive fines, which are always contained in a molding sand. If the sand had only contained the active clay, its temper point would have corresponded to the maximum of the green strength curve (cf. Fig. 1.11).

Checking the moisture content is extremely important, and the variation should never exceed ± 0.25%. Therefore, the temperature of the used sand should not exceed 40°C (104°F). In order to keep this variation at a minimum, the moisture addition in the sand mixer should be carried out automatically.

The return sand should be cooled down in a cooler to maintain a constant sand-moisture relationship. This is not possible if the sand temperature is high or varies too much.
Fig. 1.12 Increasing the active clay will increase the water requirements of the molding sand to maintain the optimal consistency (compactability 40 ± 2%), i.e. the temper point shifts to the right.

Fig. 1.13 Increase of total fines content at constant active bentonite. Moisture requirement increases with decreasing green compression strength.
AFS CLAY CONTENT (Total Fines Content)

Fines are defined as all the grained particles that are smaller than 0.02 mm (0.0008").

The following ingredients contribute to the total fines content:

* Active bentonite
* Dead-burnt bentonite
* Coal dust
* Dead-burnt coal dust (coke, ash)
* Natural fines from the base sand

Both active and inactive fines require water, and this is the reason why an increase of fines content increases moisture requirements of the sand (temper water increase) at a constant compactability of 40% ± 2%.

Fig. 1.12 shows that the more of the active bentonite there is, the higher will be the green compression strength as well as the temper point (moisture requirement) at constant rate of the inactive fines.

Fig. 1.13 shows that the higher total fines content (at constant active bentonite content), the higher will be the content of inactive fines, and the higher the moisture requirement at decreasing green compression strength.

DISA recommends that the AFS clay content (total fines content) should be kept between 11-13% for 2013 and 11-14% for 2070 & 2120/2130.

LOSS ON IGNITION

Loss on ignition tells how much combustible material there is in the sand.

During the test, the following material is extracted on ignition:

* carbonaceous material
* dead-burnt carbonaceous material (coke)
* residual core binder
* water of crystallization from the active bentonite

Loss on ignition should be kept at 3.5-7.5%, depending on production program.

VOLATILES

The test of volatile material tells how much gas the dried, heat-affected sand can generate.
<table>
<thead>
<tr>
<th>Properties</th>
<th>Traditional coal dust</th>
<th>Substitution materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water consumption from molding sand</td>
<td>Great</td>
<td>Small</td>
</tr>
<tr>
<td>Sensitivity to changes in water content</td>
<td>Small</td>
<td>Great</td>
</tr>
<tr>
<td>Mixing process</td>
<td>Easy</td>
<td>More difficult</td>
</tr>
<tr>
<td>Danger of local concentration in the sand structure</td>
<td>Small</td>
<td>Great</td>
</tr>
<tr>
<td>Amounts added</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Risk of dosing error</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Depositing of residuals in sand</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Dust content in sand system</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Gas generation</td>
<td>Small</td>
<td>Large</td>
</tr>
</tbody>
</table>

Fig. 1.14 Comparison between coal dust and substitution materials.
Volatile material can consist of:

- volatiles from the active carbonaceous material
- volatiles from the residual coring binder
- water of crystallization from the active bentonite

The volatile material of the molding sand should be kept between 1.5 - 3%.

CARBONACEOUS MATERIALS

Main Quality Criteria

Water content: max. 3%
Content of ashes: max. 10%
Volatile ingredients: min. 30% max. 40%
Sulphur content: max. 1%
Grain size: grains > 0.18 (AFS 90) : max. 10%
          grains > 0.5 (AFS 35) : 0%

Fig. 1.14 compares coal dust with substitution products such as oils, bitumen, pitch, and plastics:

By using a mixture of pit coal dusts and the substitution materials, properties can be obtained which the additives cannot obtain individually.

BASE SAND

Most automatic molding plants use synthetic molding sand, where the system sand is produced by addition of montmorillonite clay, carbonaceous materials and water to the classified and washed base sand. Nonetheless, natural sand may be used under certain special circumstances, but in such cases it is strongly recommended to add a sufficient quantity of bentonite, so as to obtain correct bonding properties. Pit sand modified in that way is often called semi-synthetic sand.

The sand should also be free of calcium and humus. On account of the requisite high temperature stability, it is recommended that the sintering temperature is at least 1350°C (2462°F) and that the SiO₂ content is over 90%. (For pouring of steel: 98%).

In order to be able to keep the total fines content in the molding sand at the correct level, the fines content in the base sand should not exceed 0.5%.

Alcalinity of the new sand should not be lower than pH = 8.5.

For average grain size and distribution – see molding sand specification.
Fig. 1.15 Composition of molding sand with indication of the standard tests used for determining the components in question.

Fig. 1.16 The dead-burnt bentonite can be partly suppressed from the system sand by adding new materials.
SAND TESTING

A description of a standard test for molding sand will be given in section "Molding materials testing practice". However, Fig. 1.15 shows molding sand composition and the tests applied.

RECONDITIONING OF THE MOLDING SAND

If we consider a new mixed batch of sand prepared of new materials and subject it to pouring, some of the material will be more or less directly exposed to thermal shock, causing:

1. Thermal destruction of silica grains.
2. Dead-burning of the bentonite.
3. Dead-burning of the carbonaceous material.
4. Evaporation of water.
5. Heating the whole sand mixture.

the mentioned phenomena make the new batch of molding sand change its composition.

Compensation for:

- destructed materials
- excessive build-up of inactive fines
- loss of moisture
- elevation of sand temperature
- sand conglomeration

has to be provided in order to bring the return sand into usable conditions.

By adding new materials to the return sand during reconditioning, compensation for destroyed silica sand, bentonite and carbonaceous material is provided as well as suppression of excessive fines.

Fig. 1.16 shows schematically the process of partly dead-burnt bentonite suppression from the system sand by adding new materials.

Depending on sand-to-metal ratio, casting geometry, quality of the molding sand, etc., the consumption of additives during the sand reconditioning process will be:

- bentonite 0.1 - 1.0%
- sea coal 0.1 - 0.5%
- new sand 0.5 - 5.0%

Any core sand breakdown material should be considered as new sand addition to the system sand.
Fig. 1.17 Diagram for determining new material additions for reconditioning of a molding sand with a green compression strength of 2000 p/cm² at its optimum consistency (for iron alloys only).

NB!
New coal dust addition is calculated as 60% of new bentonite.
In the case of the synthetic carbon materials the new additions must be made in accordance with the volatile content.
Fig. 1.17 can be helpful in determining new material additions for reconditioning of a molding sand with green compression strength of approx. 2000 p/cm². As shown on the diagram, necessary new sand and new bentonite addition can be found from the inorganic fines content and sand/metal ratio. The amount of new coal dust to be added is normally calculated as 60% of the new bentonite added (does not apply to the substituted carbonaceous materials). It should be noted that the diagram is true only for iron alloys.

**SAND CONTROL ROUTINE**

Personnel responsible for operation of a mechanized high density green sand molding line must establish a molding sand checking routine. The sand properties tested regularly are used for:

- current sand quality control
- casting defects diagnostics

Molding sand control consists of two steps:

1. Control of moisture, new sand, bentonite, and carbonaceous material addition to predetermined amount of return sand during the sand mixing process in order to obtain a certain, predefined consistency.

2. Control of molding sand composition, strength and packing properties.

The first step is carried out by mixer, either manually by a sand mixer operator, or by means of an automatic sand moisture controlling device.

The second step takes place at the sand laboratory according to a specific testing program.

**Control of Sand Consistency at the Mixer**

This part of sand processing control consists of a regular check to determine whether:

a) dosing of new materials and return sand into the mixer corresponds to the predetermined values

b) return sand receives the necessary degree of dispersion before it enters the mixer and during mixing

c) the amount of water added during mixing results in predetermined sand consistency at a given sand composition after ended mixing process

The dosing control method depends on the way in which the new materials are transported and measured when introduced into the mixer.

The dispersion degree of the molding sand depends on the type of mixer and proper maintenance of the sand plant, especially the sand mixer.
### Property Test | Test Interval | Testing Equipment
--- | --- | ---
Sand content | Moisture | Hourly | Moisture tester
Active bentonite content | | | Titration equipment /balance 0.01 g accuracy
Total fines content | | Daily | Vessel/syphon pipe
Loss on ignition | | Daily | Elutriator or wet sieve device
Grain size and distribution | | Weekly | Furnace (1000°C)
Green strength | Compression str. | Hourly | Strength tester
tensile str.* | | Hourly | testing tubes
Spalling str. | | Hourly | ramming device
Wet tensile str. | | Hourly | Balance, 1 g accuracy
Packing and consistency | Permeability | Hourly | Permeability tester, ramming device
Compactability | | Hourly | 3 mm mesh sieve, tripod and ramming device.

*) Calculated: Tensile str. = 0.65 x spalling strength.

Fig. 1.18 Testing program for DISAMATIC molding sand. The last column gives a list of the minimum testing equipment required.

### DAILY SAND CONTROL SHEET

<table>
<thead>
<tr>
<th>Type of machine:</th>
<th>Date</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISAMATIC</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Strength features</strong></td>
<td><strong>Packing features</strong></td>
<td><strong>Composition features</strong></td>
</tr>
<tr>
<td>Compression strength (psi)</td>
<td>Spalling strength (psi)</td>
<td>Tensile strength (psi)</td>
</tr>
<tr>
<td>Methylene blue</td>
<td>Active Bentonite content</td>
<td>Active Bentonite content</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The amount of added moisture must be controlled by testing the consistency of the sand. DISA recommends control of compactability as the most independent method, but riddled density can also be used. The sand mixer operator should check compactability and water content of freshly mixed sand every 3rd - 5th batch, if sand consistency is checked manually.

Several automatic sand moisture control devices are available. But it is recommended to use those based on measuring sand consistency (compactability or riddled density) as one of input values.

**Laboratory Sand Testing**

Quick control of the molding sand consistency is very important, but nothing can replace full laboratory test of composition, packing and strength properties of the molding sand.

DISA recommends the sampling of sand every hour of approx. 5 kgs, to be put into a coverable container just before the sand falls into the DISAMATIC sand hopper and perform a test to determine:

- compression strength
- spalling strength or tensile strength
- compactability
- permeability
- water content

The wet tensile strength test may be applied hourly in combination with the above tests.

Once a day tests for:
- active bentonite content
- loss on ignition

must be made.

Tests of total fines contents and sand grain distribution should be performed weekly.

The above testing program must be supplemented with sieve analysis performed approximately once a week. The table on Fig. 1.18 shows the testing program, testing frequency and testing equipment applied.

The list of testing equipment applied can also be understood as the minimum sand laboratory equipment required for testing DISAMATIC molding sand.

The test results will be collected in a "Daily Sand Control Sheet" shown on Fig. 1.19.
Molding Materials Testing Practice

A detailed description of all testing procedures is beyond the framework of the present section the purpose is to give the readers some guidelines for molding material tests, which are most frequently used, and to bring their attention to certain important details and hints.

MOLDING SAND TESTING

Sampling
Sand samples should be taken as close as possible to the part of the process for which the sand will be used. In other words, a sand sample for a routine laboratory check must be taken before it reaches the molding machine; however, a sample for testing residual water content of the pre-conditioned return sand must be taken just before charging into the mixer. The samples are to be kept in vessels with tightly fitting lids in order to prevent moisture evaporation. It is always useful to keep some residual sand form each sample until the castings poured into the sand represented by the respective samples have been examined. It is extremely helpful when making a casting defect diagnosis to be able to recheck some of the suspicious-looking sand results. The vessels containing the samples should be carefully marked with date, hour and place of sampling.

Specimen Rammer
The specimen rammer, whether hydraulic or mechanical, is used not only for producing strength and permeability samples, but also for compactability measurement. When ordering a rammer, make sure that the attachable ruler for compactability measurement is included. The ruler may be selfmade, but note that the specimen tubes are available in two heights, 100 mm and 120 mm, the ruler having to suit the one required.

In order to obtain uniform and consistent results, the rammer must be mounted on a proper base.

Strength Properties
Before carrying out any kind of strength test, make sure that the testing machine is properly calibrated. Normally, a special calibration set is available as an option from the manufacturers of the testing machines.

The existing devices for strength determination make it possible to measure green and dry compression, shear strength and spalling strength. A direct determination of the tensile strength requires special equipment, which is not always available. However, Dr. Boenisch’s comprehensive experimental work has shown that there is an excellent indirect method of green tensile strength determination by using the standard strength testing machine to carry out a spalling test ($\delta_s$) as
Fig. 1.20 Compaction degree of molding sands of different moisture content, screened and unscreened.

Fig. 1.21 Principle of measuring compactability.
shown on the Fig. 1.08. The green tensile strength ($\delta_t$) can easily be calculated according to formula:

$$\delta_t = 0.65 \times \delta_s.$$

**Wet Tensile Strength**

Testing wet tensile strength is one of the auxiliary checks. It helps to determine (relatively quickly) how much the active clay content contributes to the total fines content (AFS clay content). The wet tensile test also gives a picture of the quality of the bentonite. A good Na-bentonite and Ca-bentonite activated by soda in solution remains around 30 g/cm². A Ca-bentonite activated by soda in any state yields between 20-25 g/cm², whereas a pure Ca-bentonite lies around 15 g/cm².

**Compactability**

Sand compactability can be determined very accurately with a compactability tester. The sand is filled, always under the same conditions (screened or unscreened), loosely into a test specimen tube, scraped to an accurate height and then squeeze-compacted, applying a force of 10 kg/cm² (140 psi). Another compaction method is the so-called three-rams method. On Fig. 1.20 compactability of sand with different moisture content has been tested in screened and unscreened conditions. The compactability of the unscreened sand corresponds roughly to a DISAMATIC sand which is not aerated before flowing into the molding chamber.

Screened sand shows somewhat lower ultimate compaction heights than unscreened sand. For testing the degree of sand moisture alone, conventional screening using 3 mm mesh size is recommended; for examinations in direct relation to the molding machine, unscreened sand (sand in the state in which it is fed into the molding chamber) can be tested. (See Fig. 1.21 showing the standard sand screening equipment).

**Riddled Density**

Riddled density is the weight of one liter of standard screened sand. Riddled density can be used besides the compactability as a method of temper control. There is a linear dependence between the compactability and the riddled density (see Fig. 1.22) for a given molding sand.

Fig. 1.23 shows the principle of measuring the riddled density.

**Moisture Content**

Particular care must be taken to ensure that the sand specimen for moisture testing is stored in vessels covered with a tightly fitting lid. The large specific sand grain surface and an elevated sand temperature above ambient makes it very easy for the moisture to evaporate before the test is completed.

For a quick moisture testing at the sand mixer a "Speedy" sand tester is recommended. It works on a chemical principle, and an accuracy ± 0.1%
Fig. 1.22 Relationship between compactability and riddled density.

Fig. 1.23 Principle of measuring the riddled density.
of moisture is fully acceptable. However, for routine laboratory moisture testing a higher accuracy of approx. 0.01 % is required.

Determination of Active Bentonite Content
This method of investigation is based on the capacity of active clay to absorb part of the coloring matter from methylene blue. This capacity to absorb depends on the type of clay. For this reason, a calibration curve must be drawn up for each individual type of clay to be investigated.

Preparation of Methylene Blue Solution
The standard test solution is 0.4 %. It means that 4 grams of methylene blue crystals should be dissolved in 996 milliliters of distilled water. First stir 496 milliliters of water with the crystals with a magnetic stirrer for half an hour and then add the remaining 500 milliliters of water to the solution.

Preparation of 2 % Solution of Na₄P₂O₇.
Dissolve 20 grams of the white tetrascumodium pyrophosphate crystals in 480 ml of distilled water. Stir in a magnetic stirrer, then add the residual 500 ml water to the solution.

Preparation of 0.5 N Solution of H₂SO₄.
Dissolve 13.8 ml of concentrated H₂SO₄ (normally between 96-98%) in 486.2 ml distilled water (always add the acid into the water, not opposite) and fill up to 1000 ml with an additional 500 ml distilled water.

Establishing the Calibration Curve
It is necessary to know the Methylene Blue adsorption capacity of the bentonite used in the molding sand. Determination of the calibration curve takes place for a sand/clay mixture containing 10 % of bentonite.

1. To 4.5 g of new sand add 0.5 g of the clay (dried at 110°C) (230°F) to be investigated. For weighing out the materials, use an Erlenmeyer flask. Weighing accuracy must be within ± 0.05 g.

2. Add 50 ml of distilled water and 50 ml of the 2 % tetrascumadium pyrophosphate (Na₄P₂O₇) solution, which acts as a deflocculant. Boil the mixture for min. 5 minutes.

3. Cool the mixture down to ambient temperature and add 2 ml of H₂SO₄, 0.5N.

4. Add 5 ml of methylene-blue solution, and stir the contents of the flask for a minute in a mixer. Then, using a glass rod, place one drop of the solution on filter paper.

If a dark blue round spot appears on the paper, the clay can absorb methylene blue, and the experiment can be carried out. If, on the other hand, no dark blue spot appears, but a bluish green patch, the clay cannot absorb methylene blue, and the experiment must be abandoned.
Fig. 1.24 Typical calibration curve for newly tested bentonite. Some other popular bentonites are shown for comparison (example).
5. After it has been ascertained that addition of 5 ml methylene-blue solution results in the appearance of a dark blue spot, add more methylene-blue solution, but now only at a rate of 2 ml at a time.

Upon addition of each dose of methylene blue, stir for one minute. Continue addition in this manner until a bluish-green halo develops around the dark blue spot. When this halo appears the first time, stir for another two minutes without adding further methylene blue, and check to see if the bluish-green halo disappears.

If the bluish-green halo disappears, add another 1 ml of methylene blue, and stir for two minutes. Then place a drop on the filter paper. Continue this process until the bluish-green halo around the dark blue spot re-appears.

The final stage has now been reached, and calibration curve for the clay sample in question can be drawn up.

The calibration curve can be drawn up most conveniently by plotting on millimeter-scale paper the quantity of methylene-blue solution (1 cm = 2 ml) and the clay content as abscissa (2 cm = 1 % clay). Thus, having one point of the calibration curve, viz. the quantity of methylene-blue solution (in ml) corresponding to 10 % clay, and knowing that the curve is a straight line through the origin, we can draw the curve.

The calibration curve for the clay in question is plotted on Fig. 1.24. The curves for different, known bentonites are plotted for the sake of reference (not to be scaled). The calibration curve should be determined each time after receiving a new delivery of bentonite. The results can vary significantly from delivery to delivery.

When applying a mixture of two or more bentonites to the molding sand, a corresponding mixture must be used for establishing the calibration curve.

Testing the Active Clay Content of a Molding Sand

1. Weigh out 5 g + 0,05 g (dried sample) of the sand sample with unknown clay content.

2. Add 50 ml of distilled water and 50 ml of the 2 % tetrasodium pyrophosphate (Na₄P₂O₇) solution, which acts as a deflocculant. Boil the mixture for 5 minutes.

3. After cooling to ambient temperature, add 2 ml H₂SO₄, 0,5N and approx. 25 ml methylene-blue solution, and stir the contents of the flask for two minutes; then place a drop on the filter paper and ascertain whether the bluish-green halo around the dark blue spot appears, as previously mentioned.

4. If the bluish-green halo does appear, proceed with addition of 5 ml of methylene-blue solution per dose, stirring for 1 minute, and inspection of the filter paper, until the halo appears.

5. The testing procedure is now repeated, the amount of methylene blue now to be added should be 10 ml below the change-over point found by the first test. Stir for two minutes.
Then add 2 ml of methylene-blue solution, and stir for one minute. Repeat this process until the change-over point has been reached.

6. Using the quantity of methylene-blue solution added (in ml) as ordinate, draw a horizontal line through the point reached until it intersects the curve previously drawn up; from the point of intersection, draw a vertical line till it intersects the horizontal coordinate axis. The point of intersection thus found represents the content of active clay in the sample.

Accuracy of Test: ±5%

Influence on Results:

No variation of the results has been observed to be a consequence of addition of the following materials:

- Coal dust
- Graphite
- Extra water

**AFS-Clay Content** (Total content of fines)
Grains smaller than 20 microns (0.02 mm or 0.0008") are considered as fine material.

**Testing Procedure**

1. Weigh out approx. 70 g of representative sand sample.

2. Dry the sample for 1 hour at a temperature not lower than 105°C (220°F), but not higher than 110°C (230°F); spread the sand over a large area for better moisture expelling.

3. Weigh 50 g of the dried sand, add 450 ml tap water at approx. 20°C and add 50 cm³ of a standard 2% solution of tetrasodium pyrophosphate (Na₄P₂O₇). This is used as a deflocculant instead of NaOH, used previously, because of the tendency for NaOH to cause settling problems, preventing sand grains from settling properly. The tetrasodium pyrophosphate is made by dissolving 20.3 g of Na₄P₂O₇ in distilled water and diluting it to a volume of 1000 cm³.

4. Add the sand sample to the water solution and stir for 5 min. in order to separate the clay or other materials from the sand grains. Wash the adhering sand from the stirrer to the beaker (see the geometry of the beaker and the siphon tube on fig. 1.25 A) with distilled water and fill up to a level of 150 mm (6"). Normally a standard vessel has a mark at the 150 mm level.

5. Stir the sand and water mixture and then allow it to settle for a period of exactly 10 minutes.

6. Using the siphon tube (fig. 1.25A) reduce the water/sand suspension down to a level of 25 mm (1") above the bottom of the vessel.

7. Refill the vessel with water to the 150 mm mark, stir again and allow it to settle for 10 min. Then siphon the water down to the 25 mm level.

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Fig. 1.25 Different determination methods of the total fines content.
A: Siphon tube; B: elutriator; C: wet screen.
8. Repeat this procedure again and again, allowing a settling time of 5 min., until perfectly clear water is contained in the upper 125 mm (5").

This now means that all particles bigger than 0.02 mm (0.0008") stay within 25 mm (1") from the bottom, in suspension. All fines (smaller than 0.02 mm) would not be able to settle with a speed of 25 mm/min. (1"/min.) and will have been extracted.

9. Evaporate the water out of the remaining sand and weigh the washed, dry sample.

10. The total fines content is calculated as a percentage loss of weight of the sample before and after the washing procedure.

It is always desirable to carry out two parallel tests for averaging purposes.

When using an elutriator apparatus for continuous washing, the principle of the test is the same, but obviously the manual work will be omitted (fig. 1.25B). For the instruction of use refer to the manufacturer.

Another and faster method is called the wet screen method. A screen with 0.02 mm mesh is installed on a standard sieve analysis vibrator, and an arrangement for water flushing is installed above and beneath the screen (Fig. 1.25C). The sand sample treated as in the syphon pipe method is vibrated for 15 min. with simultaneous water flushing. Then the sample is dried and weighed as previously described.

Assuming that the total fines figure is roughly only a sum of active clay and inactive silt (dead-burnt clay included), the amount of dead-burnt clay can be determined by subtracting the active clay content (methylene blue test) from the total fines content.

The dried washed sand obtained after the total fines content test can be used directly for the sieve analysis.

**Loss on Ignition**

The loss on ignition test is a measure of the presence of organic substances. In the molding sand the following materials can burn on ignition.

- Active carbonic material
- Dead-burnt carbonic material (coke)
- Core sand binder remains
- Combined water from the active clay (normally between 1-2 %)

One of the main test conditions is to provide access for free air to the heated samples in order to enable total combustion.
Testing Procedure

1. Take a representative sample of the sand to be tested, and dry at least 50 g at 105-110°C for 2 hours.

2. Weigh, dry and clean a silica crucible and record weight (W_1).

3. Weigh 20 g of the sand into the silica crucible (W_2).

4. Carefully put the crucible containing the sand into the muffle furnace, avoiding shock-heating which might eject some sand grains.

5. Keep the sample at a temperature of 925°C for 2 hours, with a supply of air to the muffle furnace by a loose-fitting door or small vent.

6. Remove sample from the muffle furnace and cool to room temperature.

7. Weigh crucible and sand (W_3). As the sample cannot be weighed before it is cool, prevent moisture pick-up by storing in a desiccator.

8. Work out the result as shown below:

<table>
<thead>
<tr>
<th>Weight of crucible</th>
<th>W_1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of sample</td>
<td>20 g</td>
</tr>
<tr>
<td>Total weight</td>
<td>W_2 = W_1 + 20 g</td>
</tr>
<tr>
<td>Weight of sample</td>
<td>W_3</td>
</tr>
<tr>
<td>after ignition</td>
<td></td>
</tr>
<tr>
<td>Loss on weight</td>
<td>W = W_2 - W_3</td>
</tr>
</tbody>
</table>

To convert W to a percentage multiply W by 5. In this way the loss on ignition (L.O.I.) is:

L.O.I. = W x 5

Accuracy of the method ±0.1%

For better accuracy, two samples should be treated parallely and the result averaged.

Volatile Matter

The amount of volatile in a sand system has a marked influence on casting quality. The percentage of volatiles also provides a useful indication of the amount of non-cooked organic components present in the sand.
The test should be run very carefully with careful attention to details. The most difficult problem can be in weighing accurately. The sand sample has a tendency to reabsorb water after drying. It may be necessary therefore to weigh the crucibles when still warm. It is important to keep the air away of the sample, as we are not interested in burning the material, but merely getting rid of the volatile matter.

An inert atmosphere can be created either by covering the crucibles tightly or by using a special furnace to generate a nitrogen atmosphere in the heating chamber.

**Testing Procedure**

1. Dry the sand as for the loss-on-ignition test.
2. Weigh a clean dry nickel boat \( V_1 \).
3. 5 g of sand sample \( V_2 \) weigh into the boat.
4. Cover the investigated sample with a layer of glazed and dried new sand.
5. Dip a couple of drops of benzene to create strictly reducing atmosphere. (Nitrogen flushing through the furnace can be used alternatively).
6. Push boat to hot zone, which should be at a temperature of 925°C, and leave for 7 min.
7. Push boat into cooling zone and cool for 10 min. Then remove it from furnace and cool to room temperature.
8. Re-weigh sample plus nickel boat \( V_3 \) and work out result as shown.

\[
\begin{align*}
\text{Weight of the boat} & \quad V_1 \\
\text{Weight of the sample} & \quad 5 \text{ g} \\
\text{Total weight} & \quad V_2 = V_1 + 5 \text{ g} \\
\text{Weight after heating} & \quad V_3 \\
\text{Loss in weight} & \quad V' = V_2 - V_3
\end{align*}
\]

To convert to a percentage, multiply \( V' \) by 20.

Thus the volatile is:

\[ V = V' \times 20 \]

The accuracy of the test +0.1 %.

According to standard testing procedures in different countries, the heat-
### Fig. 1.26 Comparison of standard sieves.

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<td>200</td>
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<td>E 185</td>
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ing temperature, and time for testing. Loss-on-Ignition and Volatiles are slightly different. Investigations show, however, that there are no significant differences between these methods in the final results.

NOTE:
A simplified but slightly less accurate testing method may be applied if coverable ceramic crucibles are used, and items 4, 5, 6 and 7 replaces as follows:

4a) Place the covered crucible with the sand sample in the furnace.

5a) Leave it at a temperature of 925°C for 7 minutes.

6a) Transfer the crucible as quickly as possible (still covered) into the desiccator and cool to room temperature.

7a) Reweight the sample, uncovered, and work out the results as previously.

Practical Conclus. from Volatiles and Loss-on-Ignition Tests
Assuming knowledge of:

- the active clay content (MB)
- the loss-on-ignition (LOI)
- volatiles (V)
- the volatile matter content in the active carbonic material (V')
- water combined in the active clay (around 1.5%)
- there is no core additive in the molding sand

the following can be calculated:

CONTENT OF ACTIVE CARBONIC MATERIAL IN MOLDING SAND (CA):

\[
CA = \frac{100}{V'} (V - 1,5\%)
\]

CONTENT OF COKED DEGASSIFIED MATERIAL IN THE MOLDING SAND (CS):

\[
CS = LOI - CA - 1,5 \%
\]

Sieve Analysis
The purpose of the sieve analysis is to determine the average grain size and distribution of the sand.

Washed and dried sand must be used for the test. It is most practical to use the final product of the APS clay test (total fines content).

Standard sieve column is used for the tests. Fig. 1.26 shows some commonly used sieve mesh size systems. A standard vibration device is used for sieving purposes.
Fig. 1.27 Sand composition sheet for recording the sand composition data.
To convert the A.P.S. standard sand grading to the European standard, see Fig. 1.30.

**Testing Procedure**

1. Build up the sieve column in the right mesh size order.

2. Pour the washed, dried, and weighed sand sample onto the uppermost sieve.

3. Cover the column and fix it on the vibrator.

4. Sieve the sand for 20 minutes, using a stop-watch.

5. Detach the sieve column from the vibrator.

6. Detach the upper sieve with the coarsest sand fraction and weigh it \( G_1 \) together with the sand grains.

7. Brush the sand grains away carefully onto a large sheet of paper and weigh the sieve again \( G_2 \). Mark the heap of sand on the paper with the mesh size of the sieve.

8. Calculate the weight of the coarsest fraction by subtracting \( G_2 \) from \( G_1 \).

\[
G = G_1 - G_2
\]

9. Repeat activities from point 6, 7 and 8 for all the sieves in the column. Keep the sand heaps until the test is finished for possible rechecking of the results and further sand grain investigations.

10. Fill in the Sand Composition Sheet (Fig. 1.27).

   - column 2: the weighing results of each fraction
   - column 3: percentage of each fraction calculated in relation to the total weight
   - column 4: cumulative percentage of each fraction when the weight is considered as 100 %
   - column 5: product of figures from column 3 and column 5. Column 5 contains conversion factors which are an inverted value of the mesh size of the preceding sieve

11. Calculate the Average Grain Size (AGS) using the formula:

\[
AGS = \frac{100}{\text{sum of column 6}}
\]

12. Plot histogram column into diagram shown on Fig. 1.27 (Sand Composition Sheet) using figures from column 3.

13. Plot the cumulative curve into diagram (Fig. 1.27) using figures from the column 4.

14. Determine the sand distribution as shown in Fig. 1.28 by determining the number of sieves on which 90 % of the sand is distributed. This
Fig. 1.28 The sand is distributed over 3,5 sieves.

Fig. 1.29 Uniformity (Gleichmässigkeit) of this sand is $U = 72$, providing the average grain size (AGS) of 0.21 mm.
method aims at eliminating 5% of the finest and 5% of the coarsest material on the cumulative sand distribution curve. It is then easy to determine the number of sieves on which the residual material rests. The sand shown on the example is distributed on 3.5 sieves.

15. The sand fractions kept on the paper can now be investigated by microscope for:

- sand grain shape
- presence of foreign particles
- degree of oolitisation
- creation of conglomerates (aggregates)

In Germany, another term for sand distribution is used called uniformity (Gleichmässigkeit). In order to determine the uniformity (U), the average grain size value (AGS) is used. The purpose is to eliminate part of the coarsest material corresponding to 1.33 x AGS and part of the finest material corresponding to 0.67 x AGS on the cumulative distribution curve. Fig. 1.29 illustrates the uniformity (U) of a sand of AGS = 0.21 mm, which appears to be 72. The uniformity of DISAMATIC sand should stay between 60 and 80.

Water Sensitivity of Molding Sand
(Sensitivity of sand consistency on variation of moisture content)

Water sensitivity of molding sand expresses how large a variation of moisture content the sand can bear, without a major change in its consistency. Water sensitivity is expressed as a percentage change in compactability per percentagewise change of water content.

Testing Procedure

1. Take a representative specimen of optimally mixed system sand.

2. Take a test of its compactability (C₁) and moisture content (W₁).

3. Add a little water and mix in a little.

4. Take a test of compactability (C₂) and moisture content (W₂).

The water sensitivity (WS) is:

\[ WS = \frac{C₂ - C₁}{W₂ - W₁} \]

Interpretation

WS between 35-55%, highly sensitive sand
WS between 15-20%, low sensitivity
Fig. 1.30 Conversion chart from AFS average grain size to DIN according to the formula $\log F = -0.92 \log k + 1.26$. 

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Remarks

1. The test has to be carried out on sand that has been optimally mixed, which means that the clay is developed maximally.

2. \((C_2 - C_1)\) should be minimally 5 %.

3. Variation between \(C_1\) and \(C_2\) occurrence in the area between 35-55%.

4. Accuracy of measurement of the moisture content should be min. \(\pm 0.05\%\).

5. Accuracy for compactability measurement min. \(\pm 0.5\%\).

The water sensitivity test for a given sand indicates:

- how big a change of water content will cause a significant change of sand consistency (compactability).

- how accurately the water addition has to be made (of special significance when using automatic water addition in the sand plant)

- how to compensate for water evaporation during the test for mixing efficiency.

Mixing Efficiency

Mixing efficiency test shown how well the actual system sand has been mulled compared with how well it could be mulled. The test can be carried out either by reference to:

1) change of compactability

   or

2) change of wet tensile strength.

Compactability Change Method

1. Make the water content \((W_1)\) and compactability \((C_1)\) test of a representative specimen of a cooled system sand, previously stored for a min. of 1 hour.

2. Mix the sand additionally for 5 minutes in a correctly adjusted laboratory mixer. Water content has to be kept constant during the mixing process, i.e. compensation for water evaporated should be constantly adjusted.

3. Make the compactability \((C_2)\) and water content \((W_2)\) test of a cooled and stored specimen after the additional mulling.

The mixing efficiency \((ME)\) is calculated as:

\[
ME = \frac{C_1}{C_2}
\]
If the difference in water content between the constant before and after mixing exceeds 0.3 \%, it is necessary to compensate the "ME" result for the water sensitivity of the sand in question. It is necessary to "convert" the \( W_2 \) back to \( W_1 \), using the water sensitivity (WS) expressed as a percentage of compactability change per water content change. See also the section on testing water sensitivity. The conversion is made as follows:

\[
C_{2\text{converted}} = C_2 - (W_1 - W_2) \times WS
\]

Then the mixing efficiency will be:

\[
ME = \frac{C_1}{C_{2\text{converted}}}
\]

**Remarks**

1. The water content should be measured with an accuracy of \( \pm 0.05 \% \).
2. The compactability should be kept between 35-55 \%.

**Wet Tensile Strength Change Method**

1. Make a wet tensile strength (WTS\(_1\)) test of a representative specimen of a cooled system sand previously stored for 1 hour.
2. Mix the sand additionally for 5 minutes in a correctly adjusted laboratory mixer. No water control is necessary.
3. Make wet tensile strength (WTS\(_2\)) test of the additionally mixed sand.

The mixing efficiency is calculated by:

\[
ME = \frac{\text{WTS}_1}{\text{WTS}_2}
\]

**Interpretation**

Mixing efficiency between 0.65 - 0.70 - inefficiently milled sand.
Mixing efficiency between 0.90 - 0.95 - very vigorously milled sand.

As can be seen from the above, the wet tensile strength method is much faster as it is much less sensitive and has less effect on the moisture content. On the other hand, the compactability change method is easier to carry out as the equipment required is always accessible.

A too low mixing efficiency can be caused by:

- poor maintenance of the sand mixer
- too short mulling time
- too low effect of the mixer motor in relation to the sand charge size
TESTING RAW MATERIALS

Consistent molding sand properties depend directly on the quality of the raw materials. Therefore, it is very important to make sure that freshly delivered molding materials correspond with the standards of the foundry.

Bentonite Testing

Many different data exist concerning quality of bentonite, which can be checked, especially in connection with spot checking of raw materials. The tests shown in the present section represent a choice for detecting the most essential properties of clay, such as:

- water content
- type of clay (Na- or Ca-bentonite)
- content of montmorillonite
- degree of activation
- alcalinity (pH)

Water Content

One of the simple but important tests is water content. The correct water content should be checked for three main reasons:

- too wet clay is difficult to handle in the dosing and transporting devices and harder to disperse in the mixer
- too wet clay can effect the moisture content of the molding sand
- economical reasons

Testing Procedure

Weigh out 10 g of a clay sample on a precision balance (accuracy ±0.01 g) in a closed vessel and dry in a constant temperature oven at 110°C (230°F) for 2 hours. Cool in a desiccator.

The water content is the percentage of water loss of the sample.

A moisture level between 8-12% is considered acceptable.

Swelling Index

The bentonites gain their plastic and binding features only after absorbing water in between the clay particles. This causes swelling of bentonite.

Since different types of bentonite swell differently when absorbing water, the test detects roughly the type of bentonite used.
Fig. 1.31 Bentonite particles absorbing water increase in volume (swell).

Fig. 1.32 Test for sedimentation index. 1) Measuring glass with suspended bentonite. 2) Curves plotted as examples.
Testing Procedure (see Fig. 1.31).

Fill a measuring glass with 100 ml of water and let 2 g of bentonite with a known moisture content (\%M) fall so slowly down into the water that the clay gets time to form a sediment. The time for clay addition should not exceed 1 hour. The total testing time from the start to the reading is 2 hours.

Register the swelled volume \( (V^1) \) of the clay in the measuring glass.

The swelling index \( (SI) \) is calculated as:

\[
SI = \frac{V^1 \times 100}{100-M}
\]

A typical Ca-bentonite has a swelling index between 6-10 ml, and Na-Bentonite between 18-50 ml. Some swelling indices for known bentonites are shown below:

- Panther Creek (Ca): 6-7 ml
- Berkbond (activated Ca): 13 ml
- Geko (activated Ca): 16 ml
- Volclay (Na): 26 ml

Sedimentation Index (Fig. 1.32)

This test indicates the amount of active \( Na^+ \) ions available in the bentonite. Per definition the amount of these ions is high in a pure sodium bentonite (see the curve). Working with Na activated Ca bentonites, the amount of active \( Na^+ \) ions can be of decisive importance.

Testing Procedure

1. Mix 2 g bentonite "as delivered" with 180 ml demineralized water in 5 min.
2. Add 20 ml 1N solution of ammonium chloride (\( NH_4CL \)).
3. Mix additionally 1 min.
4. Pour 100 ml of the suspension into two measuring glasses scaled in ml.
5. Read the volume (ml) of the settled sediment after 15 min., 30 min., 1 hour, 2 hours, 4 hours, 8 hours, 24 hours, 48 hours, 73 hours.
6. Plot a diagram as the one shown on fig. 1.32.

Interpretation:

After 72 hours the Sedimentation Index for a well activated Ca bentonite should stay between 25-35 ml. At any rate an activated Ca bentonite should not stay below 20 ml. A pure Na bentonite stays normally above 40 ml. The test can be repeated for samples of the same bentonite heated to the temperature of 100°C, 200°C, 300°C, 400°C, and 500°C to indicate its thermal durability.
Fig. 1.33 The montmorillonite content can be read from the curve if the sedimentation value is known.

Fig. 1.34 Determining soda content in bentonite.
The test can be used for indicating how much more the bentonite can be activated by mixing it with different amounts of soda ash (Na₂CO₃). This is a good way of controlling the quality of the delivered bentonite.

Montmorillonite Content

Montmorillonite is a compound which gives clay its excellent features as a molding sand binder. The montmorillonite has thin blade-like particles which, due to their lamellar structure, and thus large specific surface, can absorb water. In this way it will be more plastic which gives the binding forces.

The montmorillonite content in the bentonite for high density molding should be as high as possible and not lower than 75 %.

Testing Procedure (see Fig. 1.33).

1. Prepare an alcoholic solution of bromoform (CHBr₃) with a specific density of 2,10 g/cm³.

2. Dry the bentonite at 110° (230°F) for 2 hours. Add the heavy alcohol/bromoform solution into the graduated test tube (density 2.10 g/cm³) up to a level of 10 ml.

3. Put 1 g of the dried bentonite into the test tube and shake until a homogeneous suspension is obtained.

4. Stand the measuring glass still for 30 minutes to allow sedimentation, after which the volume of the floating matter can be determined on the scale of the measuring glass.

5. Determine the montmorillonite content from the curve on Fig. 1.33.

Content of Water-Soluble Carbonates

This test gives an indication of whether or not the bentonite is a pure Na-bentonite or soda (Na₂CO₃) activated Ca-bentonite.

Testing Procedure (see Fig. 1.34)

1. Weigh 5 g of dried bentonite, mix it with 100 ml distilled water and mix thoroughly (glass A).

2. Pour 10 ml of the suspension into an Erlenmeyer glass (B), add 40 ml of distilled water and 4 drops of phenolphthalein.

3. Titrate the suspension with 0.1 N solution of hydrochloric acid (HCl) until the red colour disappears. Register the consumed amount of the acid "a" (ml).

The content of water soluble carbonates is calculated as:

Content of water soluble carbonate = "a" x 2.12 %.
This figure is normally equivalent with the content of soda in the bentonite.

**Interpretation**
Content of water soluble carbonates:

less than 0.4 % - pure Na-bentonite  
more than 0.4 % - soda activated Ca-bentonite

The test should be carried out rather quickly or the acid will attack the other carbonates.

**Acidity (pH-value)**
The pH-value of bentonite should stay well in the base area. Too acid bentonite has deteriorated bonding properties.

The test is carried through with a pH-meter. The usual solution is 8 g of tested material in 100 ml H₂O. The pH of the bentonite, just like for the sand, must be higher than 8.5.

**Testing Carbonic Materials**
Normally, the following tests should be made in connection with the control of recently delivered raw materials:

- grain size (if grainy type)
- water content
- content of volatiles
- ash content
- sulphur content

**Grain Size**
Normally the average grain size of the carbonic material should not exceed the grain size of the base sand. That is why some of the national standards of raw material control set up a limit of max. 10 % of particles which are larger than 0.18 mm.

Another limitation concerns very coarse grains, which create concentrated local gas generating spots. That is why a grain share larger than the average size of molding sand grains should not be present.

**Water Content**
Water content is measured on a 10 g sample (accuracy +0.01g) which is heated for 2 hours in a constant temperature oven at 110°C (230°F). The percentage of loss on weight is the measure for the moisture content.

Higher accuracy can be obtained when drying in an atmosphere free of acid. Maximal acceptable moisture content is 5 %.
Volatiles Content

Volatile content is an indirect measure of the lustreous carbon generation.

Testing Procedure

1. Put 1 g of dried carbonic material in a porcelain crucible furnished with a tightly fitting lid.

2. Heat the sample in a furnace at 925°C.

3. Check after 2-3 minutes (when most of the gasses have escaped) if the lid still closes tightly, and put the sample back into the furnace.

4. Transfer the sample to a desiccator after 7 minutes total heating time. Cool it down to room temperature and then weigh (a).

The volatile content (V) is calculated as follows:

\[ V = \frac{1 - a}{1} \times 100\% \]

Minimum volatiles should be 30%.

Ash Content

In this test the carbonic material is completely combusted so that the residual inorganic material (ash) will be deposited as fines in the molding sand structure.

Testing Procedure

1. Weigh out 2 g of dried material and place it in a flat porcelain crucible.

2. Heat the sample initially for 1-2 hours at 500°C and then for 2-3 hours at 900-950°C.

3. Cool the sample in a desiccator and determine the loss of weight (a).

The ash content (A) is calculated as follows:

\[ A = \frac{2 - a}{2} \times 100\% \]

Sulphur Content

Sulphur reduces the binding properties of the molding sand.
Testing Procedure

1. Prepare an Eschka-mixture by mixing two parts of dried MgO with one part of Na₂CO₃ free from water (by weight). Both compounds should be purified for analytical use.

2. Mix 1 g of dried carbonic material with 3 g of Eschka mixture, place in a porcelain crucible, and cover with 1 g of Eschka mixture.

3. Place the crucible in a furnace at a temperature of 600°C and increase the temperature gradually to 800°C +25°C drying for one hour. Keep the sample at this temperature for approx. 1.5 hour, until all the black particles disappear (stir the sample from time to time with a platinum or nickel wire to expose all the particles to the heat).

4. Transfer the sample to a 250 ml glass beaker, add 100 ml hot distilled water and leave it for approx. 30 min.

5. Oxidize the filtrate, which now amounts to approx. 250 ml, with 5 ml of 10 % hydrogen peroxide (H₂O₂) solution or 5 ml saturated bromine solution and then add 5 ml of concentrated hydrochloric acid (HCl) in order to make the solution acidic. Boil the solution for a while.

6. Add a couple of droplets of methyl orange as an indicator and neutralize the solution with NaOH of Na₂CO₃. After neutralization add 1 ml of 1 N HCl and bring it to the boil.

7. With a pipette add 10 ml of 10 % BaCl₂ solution, stirring constantly. Continue the boiling for 15 minutes and leave the solution overnight.

8. Filter the solution through a filter, free it from ash of the "OH" type. Clean with hot distilled water.

9. Repeat filtering until the filtrate does not precipitate with AgNO₃.

10. Transfer the precipitate, which consists of BaSO₄, to a weighed crucible, dry, incinerate at 500-600°C and heat it at 900°C, until it has a constant weight (a).

The sulphur content (S.C.) is calculated as follows:

\[
S.C. = \frac{a \times 0.1373}{1} \times 100 \%
\]

The maximal allowable sulphur content in the carbonic material is 1 %.

Swelling Index (for sea-coal only)

It was observed that coaldust subjected to high temperatures swells. This is to be expected to:

- counteract the thermal expansion of the silica grains
- prevent metal penetration to some extent by closing the spaces in the molding sand structure

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Fig. 1.35  Seacoal heated in a standard crucible is baked and swells into solid "buttons" of different heights.
Testing Procedure

1. Weigh out 1 g of dried coal dust. Place it in a cold crucible and level the sample by tapping the crucible lightly 12 times on a solid surface, rotating between taps.

2. Cover the crucible with a lid and place it upright in the silica triangle supported by a draft shield directly over the gas flame. Heat the covered crucible in the gas flame until the flame of the burning volatile matter dies out, but in any case for not less than 2½ min.

3. Remove the coke button carefully, and remove the carbon residue in the crucible. Four buttons should be made in this manner for each sample of coal tested.

4. Inspect each coke button through the sight tube and compare it with the series of standard profiles shown on Fig. 1.35. Place the standard profile with which the button is to be compared exactly in the centre of the field of vision as viewed from the top of the tube. Place the button on the profile and rotate it on its axis until, as viewed with the eye placed immediately over the top of the tube, the maximum cross-sectional area is obtained.

Normally, a coal dust with swelling index 4 or higher is considered acceptable.