Part I — New Concepts of Green Sand Technology

Technology advances in green sand molding machines are outpacing the sophistication of conventional sand testing practices. For instance, green strength alone is an inadequate measure of mold quality and can, in fact, lead to interpretation errors. Molding sands need to be monitored differently today than in the past. Innovative green sand testing technology is now available to match the capabilities of today’s state-of-the-art molding equipment.

**REVIEW**

GREEN STRENGTH—the basis of every molding sand evaluation—has been measured by testing devices and test conditions that have remained nearly unchanged for almost 60 years. Regardless of whether the compression, shear, or splitting strength is determined in the test, the results lead to identical conclusions. Only the green tensile strength provides additional information.

Molding sand test pieces (specimens) still are compacted using three rams, even though some molding machines today easily can produce a compaction level equivalent to 12 rams. Molding sands have been adapted to changed circumstances, but molding sand testing has not.

Today’s green sands have more complex compositions and are mixed more thoroughly. Thus, they often are more difficult to compact, and they develop adequate strengths only at compaction energy levels considerably higher than was the case with earlier sand mixes. Consequently, test pieces that have been compacted by only three rams are not indicative of the actual strength potential of a sand used in the molding machine. Present testing practices lead to evaluation errors and discredit molding sand testing as a whole.

Fig. 1 compares the shear strengths of two green molding sands after compaction by three and ten rams, respectively. Bentonite levels of the two sands were similar and measured about 10%. One is a problem-free system sand taken from an iron foundry equipped with impact molding machines. The other is a new sand mixed for 10 min in a laboratory muller.

The new sand mixture shows higher strength levels at three rams, and thus would appear to be of higher quality. However, molding tests with pattern equipment gave unacceptable results with very serious mold fracture when the pattern was stripped. This sand would be completely unsuitable for casting production.

The higher strength level of the new sand results from its high compactibility caused by insufficient dispersion of the bentonite particles. For that reason, high packing densities and, consequently, elevated strength levels, are obtained even at low levels of compaction.

In contrast, the difficult-to-work production sand requires higher compaction intensity and then is considerably superior to the new sand. Elevated strength levels can be observed in Fig. 1 in the upper curves for compaction levels of ten rams.

The example in Fig. 1 shows that molding sand tests cannot be limited to the use of a standard, constant number of rams. On the one hand, commercial molding machines produce various levels of compaction, and on the other hand the compaction distribution in the same corebox varies considerably. Difficult-to-work molding sands (those with low compactibility) are particularly hard to compact in the “shadow” areas of patterns. For these reasons, it is important to become aware of molding sand properties at various levels of compaction.

Completely different results are obtained when molding sand is evaluated at different levels of compaction. Compactibility is particularly important in the case of production sand. Therefore, the majority of the tests that will be described in this article series were performed using various numbers of rams.

However, even with that qualification, molding sands cannot be evaluated reliably on the basis of green strength alone. In fact, it can be shown by extrapolation of data in Fig. 1 that the strength levels of the two sands are similar at six to eight rams, but the two sands differ by several orders of magnitude under practical conditions. The new sand fails even at higher compaction levels and does not permit casting production adequate for today’s requirements. The scrap rates with that sand would be intolerably high.

For this reason, an additional parameter that would permit precise and practical differentiation was sought.

The Deformation Limit—The answer is a numerical quantity—the deformation limit—that describes the distance in millimeters in which a...
compacted sand body can be deformed before it loses its cohesion (when the strength level drops to zero). That variable, and its measurement, are influenced decisively by the plasticity of the molding sand binder. Therefore, this significant property should be incorporated into molding sand testing today.

The deformation limit can be determined reliably only under shear stresses. After extensive preliminary work, compression tests demonstrated the difficulty of obtaining a precise measurement. In fact, when test pieces made from highly plastic molding sand were subjected to forced deformation under pressure (compressive forces), they showed a rather wide range of deformation in which failure (disintegration) started, without proceeding to a final fracture. Tensile stress is also unsuitable for such a measurement because the degree of deformation is too small, and rigid clamping of the test piece is difficult.

Molding Sand Micrometer—The deformation limit is determined using the molding sand micrometer, Fig. 2. It is known in Europe as the PSV Shear Displacement Tester and is manufactured by Georg Fischer AG, Schaffhausen, Switzerland.

The key instrument components in the micrometer are identified in Fig. 2. A test piece, 50 mm long and 50 mm in diameter, connects the test piece tube with the measuring ring, which is sheared slowly and continuously from left to right by means of a micrometer screw during the course of the testing procedure. Prior to each test, the test piece tube is clamped into a holder. When the crank is turned, the pressure point advances and executes the measuring operation. The length of advance is read from the micrometer scale. The dial indicator shows the force transferred over the sheared area of the test piece and records the maximum value, which represents the shear strength of the sand.

To complete the test, the technician should continue to turn the crank slowly even after the maximum value on the dial indicator has been passed. As the sand structure is broken up increasingly, the force required decreases continuously. Those changes are illustrated in Fig. 3a for several examples, each of which varies with the characteristics for each individual molding sand composition.

Once the deformation limit is reached, the measuring ring drops off, and is removed through a side opening in the testing device housing. The result of the test can be read from the micrometer scale.

**Micrometer Diagram**—The micrometer test allows rapid and simple simultaneous determination of two important characteristic values with a single test piece, which considerably extends, simplifies, and accelerates molding sand testing. The shear strength in N/cm² and the deformation limit in mm are juxtaposed in a so-called micrometer diagram, which affords interesting opportunities for a novel molding sand evaluation.

Fig. 3 illustrates several results schematically. The typical characteristics of new molding sand, characterized by a low deformation limit, may be recognized in sands A and B. New sands are "short," i.e., have low plasticity. Sand B contains more bentonite than sand A. Sand C displays a balanced relationship of the two values to

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**Fig. 2**—Innovative molding sand micrometer (manufactured by Georg Fischer AG, Schaffhausen, Switzerland) measures deformation limits of green molding sand test pieces (50 mm long and 50 mm in diameter). Instrument components include 1) test piece tube, 2) measuring ring, 3) test piece tube holder, 4) crank, 5) pressure point, 6) micrometer scale, and 7) dial indicator. For more information on molding sand micrometer, circle 460 on CAST INFO card.

**Fig. 3**—Schematic shear stress vs deformation curves (a) plotted for measurements with molding sand micrometer. Micrometer diagram (b) shows shear strength vs deformation limits for four different sands.
Fig. 4—Micrometer diagram shows striking differences between production sands and new sands. Level of activated bentonite in both sands was approximately 10 PBW (parts by weight).

Fig. 5—Increasing amount of compaction shortens and widens intergranular binder bridges. Schematics shown prior to deformation.

one another, such as is often seen in well-conditioned production sands. Finally, sand D corresponds to a highly plastic system sand liable to a number of defects which will be detailed farther along.

The plasticity of green sand is one of its most important properties, and determines, within wide limits, its working behavior positively or negatively. Parameters that shift the deformation limit by altering the plasticity are 1) molding sand moisture level, 2) bentonite level, 3) montmorillonite level, 4) degree of bentonite activation, 5) sand preparation, 6) grain size of silica sand, 7) condensate from core sand binders and lustrous carbon formers, and 8) molding sand additives. The effects of these variables will be demonstrated in individual examples, and will be described later in a summarized form for foundry practice in the so-called “Defect Compass for Green Sands.” A number of paths can be taken to determine an optimal deformation limit for casting production.

Molding Sand Moisture—The level of molding sand moisture increases the deformation limit more than any other parameter (variable), because it increases the plasticity of the bentonite through swelling. On the other hand, strength is changed only insignificantly, Fig. 1.

Strength levels and deformation limits for the same sands are juxtaposed in a micrometer diagram in Fig. 4 to demonstrate important differences in sand properties more clearly than in Fig. 1. The test pieces were compacted with three, six, ten, fifteen, and twenty rams. The sloping curves running from the upper left to the lower right connect measurements at identical sand moisture levels, in this case characterized by compatibility. The nearly vertical connecting lines which run from top to bottom describe the influence of moisture level on strength at constant number of rams.

Fig. 4 shows the drastic difference in behavior between an established production sand and a new molding sand in contrast to Fig. 1. The decisive difference is in the deformability limit. Also, Fig. 4 reveals the large compaction “reserve” of the production sand, whose family of curves extends far to the right, whereas that of the new sand is narrow and sharply decreases at a low level.

The considerable differences in plasticity of the two sands, which are apparent in spite of identical bentonite levels and bentonite quality, are caused by several factors. The primary factors are sand preparation effects, but certainly also include the condensates from lustrous carbonforming additives and synthetic resins.

Embrittlement by Compaction—Deformation limits drop with increasing compaction. This clearly shows that plasticity of the molding sand binder is not the only decisive influencing factor, because this property cannot be changed by compaction. The decreasing deformation limit indicates that molding sands become more and more brittle with increasing compaction. That embrittlement is especially dangerous in the case of highly compressible molding sands with “new sand” character, since their deformation limit is low anyway and is further reduced by increasing compaction, Fig. 4.

Length of binder bridges between silica sand grains is probably the main cause of that phenomenon. Those bridges become shorter and winder with increasing compaction, Fig. 5. Length of the binder bridges primarily influences the deformation limit; their width, on the other hand, affects strength.

At a certain deformation level of the compacted sand body, the individual element of a long bridge is deformed less strongly than that of a short bridge; compare Fig. 6a to 6b. Therefore, at equal binder plasticity, the long bridge can withstand a higher sand deformation rate of the sand mold before it fails. In practice, the deformation limit is determined jointly by geometry and plasticity of the binder bridges, as is shown in Fig. 6.

Bentonite and Montmorillonite Levels—Based on the assumption of identical compaction intensity, increasing bentonite levels in molding sand and raising montmorillonite levels in bentonite will increase the deformability limit, as curves b and c in Fig. 7 show. Molding sands with low binder content are highly deflection prone even when bentonites high in montmorillonite are used; they allow formation of only short, poorly structured binder bridges. The bentonite

Fig. 6—Schematic presentation of deformation limit of green molding sand increasing with higher plasticity and longer bridge length.
level acts primarily by influencing the distance between sand grains and thus the bridge length. As is known, increasing those levels reduces packing density of the silica sand grains in the mold, indicating longer bridges. Increasing montmorillonite levels in bentonite raises its bonding power as well as its plasticity. Like the bentonite level, an increase in the bonding power increases the distance between sand grains after compaction, thus lengthening the binder bridges.

In foundry practice, it would be impractical to demand extremely high montmorillonite levels solely to improve the deformation limit. Montmorillonite-rich bentonites occur naturally to only a limited extent, and according to recent findings also have disadvantages. Their high bonding power leads to molding sands with low compactibility, coupled with a low packing density of the silica grains. Furthermore, more effective ways of increasing the plasticity—such as improved molding sand preparation—are available.

Bentonite Activation—The sodium bentonites presently preferred occur either naturally in Wyoming, or are converted from calcium bentonites to sodium bentonites by “activation.” For this purpose, the calcium bentonite is milled with a definite amount of soda under moist conditions, whereby the ion-exchange process termed “activation” takes place.

Commercial activated sodium bentonites are treated with soda shortly after they are mined, and prior to grinding by the producers. However, a calcium bentonite can also be converted to a sodium bentonite at a later time by addition of soda during mulling in the foundry (so-called “activation during preparation”). Studies of the deformation limit demonstrate the greater efficacy of the former type of direct activation.

Fig. 8 shows the deformation limits of a calcium bentonite and the sodium bentonite obtained from the same raw material using these two processes (curves a and b). The directly activated, commercial sodium bentonite (curve a) shows significantly higher deformation limits.

The limited swelling capacity of calcium bentonite is the reason why no significant improvement can be obtained by increasing molding sand moisture levels. Only the ion-exchange process and the conversion into a sodium bentonite increase plasticity significantly. When water is added, sodium bentonite easily disintegrates into its elementary particles, as manifested by a large increase in the deformation limit.

Near temper water content (i.e., at a water level of around 2.5%), all bentonites exhibit similar deformation limits. That clearly indicates the vital role played by the molding sand moisture level in swelling and plasticizing bentonites, processes which are basic prerequisites for any improvement in the deformation limit of a green sand.

Low moisture levels, which are frequently encountered in many high-pressure molding sands, can create a significant disadvantage in modern molding technology. Bentonites swell insufficiently. Dispersion of bentonite particles is inhibited. Considerable amounts of bentonite surface area are ineffective; the high potential in bonding power and plasticity is not utilized.

Plasticizing Molding Sand Additives—Increasingly, organic plasticizing agents are added to molding sands to counteract the production difficulties caused by a low deformation limit. Those additives in many cases also demand higher moisture levels, but have only a limited effect at the lower moisture levels usual in today’s high-pressure molding machines. In addition, a number of the products offered have proved to be useless. Prior testing with the molding sand micrometer is advisable.

A random selection of commercial dextrin binders, starches, etc., was studied. The effects of those studies appear in Fig. 9. Basically, the deformation limit increases almost linearly with the addition level.

The causes responsible for the various effects of the individual products will not be detailed at this point. However, it is important to note that these differences can be very large, and necessitate a prior selection of the best products. Because of their negative effects on molding sand, plasticizing agents should only be used in small amounts.

Molding Sand Preparation—According to the results of this work, reconditioning of system sands is one of the most difficult steps in molding sand technology. Added bentonite and water preferentially settle on the molding sand grains which are coated already. Binder requirements to coat

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**Fig. 7**—Molding sand moisture (a), bentonite level (b), and increasing montmorillonite level (c) all increase deformation limits by increasing plasticity. (Based on work by A.R. Brönie.)

**Fig. 8**—High swelling capability of sodium bentonite improves deformation limits only after sufficient moisture is added. Test pieces were produced with three rams.
Fig. 9—Curves depict the varying effects of several organic additives used to improve molding sand plasticity. Specifications for test pieces in each case were 6 PBW bentonite, 50% compatibility, and three rams.

Fig. 10—Micrometer diagram shows the dramatic effects of changes in molding sand preparation for a whirl mixer and a muller and changes in number of rams. Test pieces were made of 80% production sand and 20% new silica sand, with 40% compatibility.

Fig. 11—Higher moisture contents during sand preparation favor the bridge structures and thus increase deformation limits. Test pieces are produced from production sand with three rams. Testing moisture level corresponds to a compatibility of 40% in each case.
mation limit to structural changes of
the binder bridges is also manifested
in the influence of the sand preparation
moisture content. This level is
generally somewhat higher than the
testing or processing moisture levels.
Sand preparation at higher water lev-
els than temper moisture content
smoothes the binder coatings of the sil-
ica grains and produces more favor-
able binder structures as well as lon-
ger binder bridges after compac-
tion. The structures produced can be
reversibly altered. An excessively
dry, so-called “hard” molding sand
preparation process again roughens
the binder coatings and leads to re-
verse changes in the deformation
limit.

A molding sand mixture was first
prepared and also tested at a moisture
level corresponding to 40% compa-
quotibility. (Refer to curve a in Fig. 11).
The same mixture was subsequently
milled at 60% compactivity, and then
dried to a testing moisture level
corresponding to 40% compactivity.
Despite the identical moisture level
during the test, curve b in Fig. 11 lies
significantly higher, and the sand
mixture is more plastic. Finally, prepa-
rations were carried out at 60% com-
putability, followed by drying the ag-
eggregate to a free-flowing state; the
mixture was then remilled to a level
 correponding to 40% compactivity in a
mix muller and tested as shown in curve
c, Fig. 11. The deforma-
tion limit is low again.

These test results agree with earlier
findings on the principles of molding
sand preparation. The difficulty of op-
imum conditioning—in which Plaza-
ticity of the molding material binder
plays a decisive role—and the inter-
play between roughening and
smoothing of the binder coatings al-
ready were recognized as important
influencing factors at an early stage;
that realization is also confirmed by
the changes in the deformation limit.
The relatively low moisture levels at
which present high-pressure molding
 sands are compacted and thus also
mixed decrease the deformation limit
via an impaired sand preparation pro-
cess. Since introduction of high-pres-
sure molding technology, the “quality
of life” for green sand has become con-
siderably poorer in a number of re-
spects.

Grain Size—In light of this dis-
cussion, the influence of silica grain
size is predictable. The deformation
limit increases significantly with in-
creasing sand grain size, Fig. 12. In this
situation, the same amount of ben-
tonite is distributed over a smaller
sand grain surface area. The binder
shells (envelopes) become thicker and
the binder bridges longer. Sand made
with coarse sand can be de-
formed to a greater extent than those
made with fine sands; the latter may
feel smoother because of the small
sand grains, but are nevertheless less
deformable.

Meshing of Binder Bridges—Fo-
llowing discovery of effects caused by
bridge length and plasticity of binder
material, a third factor influencing
the deformation limit was found:
Dusts or finely ground solids, gener-
ated by either molding sand attrition
or intentional additives, collect in the
binder bridges and exert a significant
influence. Their particle size plays an
important role.

As Fig. 13a shows, seascoal increases
the strength to some extent, but af-
ects the deformation limit only
slightly. On the other hand, fine dust
from dead-burned bentonite reduces

Fig. 12—Coarse silica sand
increases deformation limit of
molding sand. Test pieces contained
10 PBW bentonite and were rammed
three times.

Fig. 13—Influence of seascoal and graphite dust additives (a); dead clay,
chamote, and silica flour additives (b); and with and without extra additives
on new and production sand mixtures (c). All sands contain about 10 PBW
activated bentonite with 40% compactibility in each case.
the deformation limit by decreasing the binder plasticity. Refer to curve I in Fig. 13b. In contrast to this, the deformation limit is increased by addition of chamotte flour produced from a fired clay by milling as curve II in Fig. 13b indicates. Such a product is of different grain shape and is significantly coarser than dead-burned bentonite. This indicates a mechanism that was studied further by additions of silica flour of various fineness.

Silica flours can significantly improve the deformation limit. The smaller their particle size, the stronger their effect. Silica flour grade A contains 35%, grade B 25%, and grade C 97% particles with sizes finer than 10 μ. According to the results illustrated in Fig. 13b, silica flours primarily influence the deformation limit at low compaction levels, whereas the strength is increasingly affected at high compaction levels.

During mulling, fine particles are kneaded into the binder bridges, and apparently are capable of linking neighboring sand grains even after breakage of the bridges, Fig. 14b. The deformation limit is thus extended. The reason why silica flour is particularly effective is probably because it is built up of SiO₂ tetrahedra, as are the bentonite particles, and can strongly bond with these due to its structural similarity. Judging from Fig. 13b, many small linking points are apparently better than a few large ones. However, excessively fine particles, particularly those having a leaflet-shaped structure, are again unfavorable. As demonstrated by the example of the dead-burned bentonite, they are incapable of undergoing linkage. Thus, it is necessary to differentiate between the positive effect produced by addition of fine-grained materials such as silica flour, and the negative effect engendered by increasing the level of nonbonding, leaflet-shaped clay material in the binder bridges, which only dilutes the bond.

Additions of Silica Flour—Additions of silica flour to production sands are helpful only when they are incorporated into "short" sands with normally poor plasticity. The stronger the resemblance of the production sand to a new sand system, the better its effect.

The large-scale effects in new sand of low plasticity have already been demonstrated in Fig. 13b. Also compare the lower part of curves in Fig. 13c. On the other hand, a foundry sand of good plasticity is not further improved by addition of silica flour to production sand B in Fig. 13c. However, medium-grade sands containing, for instance, high levels of fines (finer than 20 microns) and dead-burned bentonite which are in a state of insufficient conditioning, are improved as shown by production sand B in Fig. 13c. The trick of adding silica flour is only of some use if molding sands cause production problems, due to an excessively low deformation limit.

Influence of Compaction Velocity—Today's production sands are compacted at differing speeds. Conventional and vacuum squeegee molding machines compress slowly, whereas impulse molding machines compact with a single stroke within only 0.01 to 0.02 sec. Testing was necessary to determine the effects engendered by the compaction rate. The micrometer diagram is particularly suited to this purpose, since the two parameters—compaction speed and green sand strength—can be obtained at very different compaction velocities. An influence should manifest itself by a divergence in the micrometer curves.

Molding sand test pieces were compacted on the one hand very slowly with a hydraulic press, and on the other hand very quickly with a single-blown ramming device. This consists of a long guide in which the familiar ram weight travels and falls on the test piece from various heights. In this case, the compaction level is not expressed as the number of rams, but as the "ramming equivalent." The tests were carried out with new sands at various bentonite levels.

At high bentonite levels, the micrometer curves in Fig. 15 run together for the most part; in contrast, they diverge at low bentonite levels. At bentonite levels of 8 PBW and especially 6 PBW, impact compaction shows several disadvantages compared to conventional squeezing compaction. Although the deformation limit drops in both test series with increasing compaction according to these results, development of the strength level is different. This is always increased by squeezing, but only at high bentonite levels by impact compaction.

Binder-deficient molding sands do not show an increase in strength, but only a drop in the deformation limit. The elasticity apparently has a more pronounced effect in a sudden stroke compaction, increasing the dangers resulting from the spring-back phenomenon. Particularly in these cases, low deformation limits and a steep drop in the micrometer curves indicate endangered molding sands, which tend to cause production problems. Such production sands should be closely monitored, protected against a drop in the sand moisture level, and supported by cautious addition of plasticizing agents.

(To Be Concluded)