Part II—New Concepts of Green Sand Technology

As Part I of this two-part article emphasized, molding sand tolerances have become much tighter since use of compaction by vibration has declined. Significant changes in sand properties and more molding problems are caused by increased core sand inflow, condensate accumulation, decreased temper moisture, faster sand recycling, reduced preparation times, and higher compaction. This concluding article addresses those problems, assesses production risks, and advises about better foundry practice.

By DR.-ING. DIETMAR BOENSCHEL / Gießerei-Institut der Rheinisch-Westfälischen Technischen Universität Aachen, and DIPL-ING. NORBERT RUHLAND / Daimler-Benz AG, Stuttgart, West Germany

DEFORMATION LIMITS of 13 production sands from different German foundries are shown in Fig. 16. The abscissa represents the active bentonite level, as determined by the methylene blue test. Points for these sands, which were free of additional starch binders, are connected by straight lines.

Fig. 16 also shows the relatively low deformation limits that all starch binder-free production sands represent. For example, at an active bentonite level of 10%, this diagram shows—in the compactibility range between 30 and 50%—deformation limits between 0.15 and 0.35 mm, or far below the possible optimal values. According to Fig. 4, deformation limits of 0.25 to 0.50 mm are obtained with good sand preparation. Production sands today are weakened significantly by high core sand inflow and other influences.

Without exception, all production sands are endangered at a compactibility level significantly below 40%. Because of the low plasticity of binder material below 40% compactibility, absolutely no effect of the active bentonite level can be observed (horizontal direction of the straight line at 30% compactibility).

When higher moisture levels raise compactibility over 40%, bentonite swells so much that the deformation limit reveals a relation to active clay content (straight line at 50% compactibility).

Deviations from this relationship which can be considerable, apparently are caused by such other factors as changing core sand mixtures, variations in mulling, differing sand grain sizes, and others. They can mask the effect of the active bentonite level.

The poor molding properties of excessively dry green sands with compactibilities below around 40% undoubtedly are an important reason that such low moisture levels are avoided as much as possible. Statistical studies of production sands from German foundries have demonstrated an average compactibility level of around 30 to 40%.

Critical Bentonite Content—The extrapolated point of intersection of the two straight lines in Fig. 16 is of practical significance. If molding sands contain less than about 6% active bentonite, they cannot be improved by increased moisture. Only a concentration higher than this "critical bentonite level" can raise the deformation limit of well-tempered green sands enough to obtain better molding properties. For this reason, production sands now generally contain more than about 8% active bentonite—to 10% and above.

To a considerable extent, the current increase in bentonite demand—expressed by a rather high "critical bentonite level"—is due to damage to the swelling capacity of bentonite particles. It is caused by condensates from lustrous carbon-forming additives and synthetic resins from cores.

The harmful effects of these "tramp" materials long have been known. They are held partly responsible for the significant increase in active bentonite levels over the years, during which major advances in synthetic resin-bonded cores took place. On the other hand, the important advantages provided by bentonite in green sands as a filter for harmful distillates from molds and cores should be considered.

Increased bentonite consumption is the price that must be paid for inadequate molding sand preparation. Mulling times often are far too short, and temper point moisture levels are too low to integrate the often considerable quantities of core sand additions into the molding sand (see Fig. 10).

Moreover, the temper point moisture level of production sands has decreased significantly since the introduction of high-pressure compaction. Swelling and dispersion of bentonite, as well as integration of core sand grains, are impaired. Additional bentonite consumption is the inevitable consequence, if satisfactory molding properties are to be ensured.

Foundry practice has attempted to improve the situation by using plasticizing additives. Five of the sands described in Fig. 16 contain organic swelling binders, but they are of widely varying effectiveness. The two products on the left in Fig. 16 (black dots and triangles) have nearly no effect, whereas those in the middle are effective even at reduced moisture levels. Those examples show clearly the importance of prior prod-

Fig. 16—Production sands require more than 7% active bentonite, at least 40% compactibility, and, in some instances, selected organic additives. Data are based on three runs of 13 different samples of production sands from West German iron foundries.
**GREEN SAND TECHNOLOGY**

The Defect Compass—in foundry production, an inadequate deformation limit has various consequences: molds can shift in the flask; segments can break off when patterns are stripped; sand edges can abrade and/or be crushed during core setting and mold closing; mold breakage can occur during pouring; and other defects are possible. Moreover, the deformation limit has even more significance in the evaluation and control of production sands. Deformation limit and strength are altered again and again and to different degrees by various factors. New insights into the behavior of molding sands, discovery of previously unrecognized relationships, correction of erroneous traditional concepts, and recently acquired knowledge of symbiotic interactions between significant factors make it possible to design a "defect compass" for green sands on the basis of the micrometer diagram. See Fig. 17.

The cross-hatched area in Fig. 17 contains the results of tests on laboratory and production molding sands, including some of extreme composition. When results lie inside this area, sands are usable, although with varying degrees of success, depending on production requirements.

The position of pairs of property values (deformation limit and shear strength) within the cross-hatched area depends on the compaction level. That fact indicates an important reason for selecting this type of representation. The purpose, after all, is to determine magnitude and direction of change in properties with increasing compaction. Sand molds also are compacted to different levels of strength as a function of the type of molding machine and the pattern equipment.

The values obtained after weak compaction by two or three rams are on the left side of the cross-hatched area. With increasing compaction, the pairs of properties shift downward and to the right, in the direction of the small arrows, as was shown in Fig. 4. The properties of highly plastic sands run approximately in the direction of the upper arrows, whereas those of "short" molding materials with low plasticity follow the lower arrows.

The defect compass is not intended to provide quantitative prediction of the defects of any given production sand. Mold and casting defects are dependent not only on the two plotted molding sand properties and the compaction level, but also on other production conditions (pattern geometry, pattern arrangement, flask size, metal cast, etc.).

Instead, the defect compass is a "tendency diagram" that shows the basic structure of a sand and its tendency to cause certain types of defects, under unfavorable conditions, as a function of deformation limit and green strength values. The basic character of a sand becomes especially apparent not only when the compaction is changed, but when other, often changing production parameters are modified additionally: the shift of pairs of property values is observed in the defect compass. The parameters referred to are primarily molding sand moisture level (corresponding to 30, 40, and 50% compactibility) and sand temperature (10, 20, and 40°C). The degree to which a sand tends in the direction of a specific defect then becomes apparent.

If, for instance, the micrometer curves in the defect compass fall steeply, like those of the new sand in Fig. 4, a low-plasticity sand with inadequate grain bonding and a low level of bentonite dispersion is indicated. Such a "short" molding material, Fig. 18a, is contrasted with one representing ideal preparation and correspondingly good plasticity, Fig. 18b.

Considerable production difficulties can be expected with a sand such as that in Fig. 18a, which tends to cause the type of defects described at the bottom of Fig. 17. At a low level of compaction and low compactibility, another sand with good production properties can exhibit similar pairs of
property values. It thus hardly differs from the previously described new sand in the conventional test with three rams.

At rising compaction levels, however, its pairs of values extend to the right and shift only slightly downward, as indicated by the production sand in Fig. 4. Its deformation limit is impaired only slightly by increasing compaction, but the strength level increases significantly. Those tests show whether a sand has either the low plastic character of a new sand or that of a well prepared, highly plastic production sand with binder structure like that of the sand in Fig. 18b. However, the ideal conditioning of Fig. 18b obviously never can be achieved in practice.

Taken by themselves, low deformation limits at low moisture levels are not a sign of an unsatisfactory molding material. At a compaction of around 70%, the low-quality sand differs significantly from a high-quality production sand (Fig. 4). More extensive knowledge of sand quality and the degree to which bentonite is damaged can be gained only from tests at higher moisture levels. Nonswelling organic binders should be present then, however, since they could simulate quality of bentonite.

In any event, organic plasticizing additives are inferior molding sand binders and cannot replace a good bentonite basis. Their use is indicated only for emergency action in exceptional problem cases. Increasing attention to organic binders can be viewed only as an indication of increasing difficulties with green sands.

If moisture during brief mulling is increased to a level corresponding to a compatibility of 50%, for example, a "healthy" bentonite is capable of strong swelling and can improve the deformation limit (upper straight line in Fig. 16). Several factors can act simultaneously. However, if the increased moisture level does not improve the deformation limit or if the improvement is slight, additional tests then are required to uncover shortcomings in detail.

Increasing Bentonite—In the next testing stage, the bentonite level is increased, for example, two parts by weight. If the deformation limit at 50% compatibility rises by a reasonable amount, the bentonite level previously was too low. A slight increase can be a sign of bentonite damage by condensates. The newly added bentonite is kneaded into the damaged mass of bentonite and becomes damaged itself by condensate uptake. A bentonite that has degenerated in this way cannot be regenerated; it can only be diluted by adding large amounts of new bentonite, but then excessive fines can occur, with detrimental effects on the casting surface.

Testing Sand Preparation—At this point, the degree of sand preparation should be checked. Tests with extended mulling times at compatibilities above 40% indicate the "preparation reserve." A pronounced increase in the deformability limit indicates unsatisfactory bentonite dispersion as well as insufficient bonding of sand grains, as in Fig. 1a. If mulling time in the foundry cannot be increased, the aggregate requires higher bentonite levels.

Additional mulling cycles, over the weekend, for instance, generally represent a technically and economically superior solution. Caution is advised, however, when the plasticity at elevated moisture levels suddenly jumps. That jump can lead to molding problems. Sands with a large "preparation reserve" should be brought into a higher plasticity range gradually, and corrections should be made by reducing or even temporarily stopping bentonite additions. If a sand develops deformation limits far above 0.3 mm, as in Fig. 10, particular attention should be focused on decreasing active bentonite. Both excessively low and excessively high deformation limits can cause molding problems, as shown in the upper group of defects in Fig. 17.

The Molding Sand Tightrope—The true purpose of the defect compass is long-term monitoring of the production sand in the foundry. Wide fluctuations in the pairs of property values indicate the danger of unexpected production hazards. Long-term changes in the basic structure of the sand also can be recognized—for instance, when either the amount of core sand inflow or the thermal stress of the system sand changes.

Property changes in direction A (Fig. 17) are particularly dangerous if molding sand properties plotted in the defect compass already are near the bottom of the cross-hatched area. Unfortunately, such unfavorable production conditions are present in many current molding sands, as Fig. 16 shows. In spite of often high green strengths, low deformation limits are predominant. Exceptionally low values, resulting for instance from premature moisture loss from hot sands, have immediate detrimental effects.

The demands of high-pressure compaction and increasing use of synthetic, resin-bonded sand cores have lowered molding sand properties in recent years. The relatively high brittleness of green sand molds has become an important basic problem.

High levels of active bentonite and other clayey substances (fines) become necessary. They reduce refractoriness of the molding sand and increase the danger of reactions between metal and molding sand. That condition in turn compels the development and use of highly active, lustrous-carbon-forming additives at high levels. Oil products of this type, as well as their condensates, stick the bentonite particles together and reduce their swelling capacity, with results described in this study.

It is pointless to demand high bentonite quality with high levels of montmorillonite if the bentonite is used poorly and is weakened further by inappropriate processing. More and more frequently, foundry engineers see no better solution than to use organic, non-bentonite plasticizing additives. Such additives can make the molding sand acidic, leading to additional damage to the bentonite and reducing wet strength.

Degenerative Factors—On the whole, it is apparent that green sands now are exposed to degenerative factors from various sources that reduce bentonite bonding power. Casting production is getting increasingly troublesome areas. The significantly higher current level of active ben-
tonite in the sand, and the relatively low wet tensile strengths of average production sands despite this (0.18 N/mm² instead of 0.34 N/mm²), are two indicators.

The weak plasticity of many production sands is aggravated by present compaction technology. Modern molding machines compress sand grains to a high packing density with great force, and brittleness of the compacted sand mold rises. The result is mold breakage during pattern stripping or during casting.

Strong thermal expansion of the surface layers of highly compacted sand molds can exceed the deformation limit, favoring expansion defects (direction C in Fig. 17). Brittle sand molds tend to cause tearing, edge abrasion, and crushed sand sections. Bentonite degeneration also favors erosion defects because the counteracting dry strength is reduced by the low degree of bentonite swelling at low temper water contents.

At present, no convincing remedial measures are in sight. Primarily, they would have to lead to longer mulling times and higher molding sand moisture levels. Such changes appear highly unlikely as long as the special requirements of high-pressure compaction (molding) are met. The defect compass demonstrates the constraints imposed on current molding sand technology.

No Jolting—Present high-pressure molding machines must operate without the compensating effect of jolting. Flowability becomes increasingly important because it insures that green sands remain easily conveyable to shooting and vacuum-squeeze molding machines.

An additional constraint is that the flask must be filled as evenly as possible, particularly in "shadow areas" between tightly arranged patterns and between them and the flask wall. Flasks increasingly are filled tightly with patterns, magnifying problems encountered in flask filling. Sand flowability, which can be obtained only through moisture level reduction, plays an increasingly important role. Current green sands increasingly fall into the extreme lower section of Fig. 17, with the described consequences.

Defect directions A and B in Fig. 17 are opposed diametrically. Higher moisture levels and longer mulling times, with consequently rising molding sand plasticity, point in defect direction B, where increasing difficulties in flask filling are encountered. Conditions leading to poorer edge compaction and substantial strength and hardness variations in the compacted sand mold are created and prevent meeting stringent requirements.

At the present time, many production sands are "walking a tightrope." Large deviations in either direction A or B must be avoided to prevent one or the other group of defects from becoming prominent. An average deformation limit, which can vary individually in accordance with production requirements, must be adhered to.

Quality assurance requires constant monitoring of molding sand. The molding sand micrometer is available for this purpose.

At present, the defect group for direction C in Fig. 17 has no outstanding significance. Although increasing strength levels as a consequence of rising compaction in direction C indicate higher packing densities of sand grains and increasing compressive stresses generated by heat of the metal, the overall level is held down because of reduced moisture contents.

In addition, ease of shakeout—
based on current requirements—probably presents no extraordinary problems. German grades of bentonite, on the average, do not develop excessive dry strengths, and those values remain at reasonable levels because of low moisture content. The relationship between compression stress, dry strength, and molding sand moisture level is known.

Summary—During their production, assembly, and pouring, bentonite-bonded green sand molds unavoidably—and frequently even intentionally—are subjected to slight deformation. The deformation limit under shear stress is only a few tenths of a millimeter, however, and must not be exceeded. Large strength losses—caused by weakening the sand grain bond, crushed sand edges, tearing, and other defects—are attributable to deformation, with drastic consequences for casting quality.

Deformation limit and rupture strength are measured simultaneously on a single test piece with the molding sand micrometer. Comparison of the two parameters in the micrometer diagram offers a simple and practical opportunity to choose raw materials and to evaluate, control, and optimize green sand molds.

Compaction, molding sand binder plasticity, and type of ultrafine material affect the deformation limit to a large degree. Numerous findings indicate that bentonite degenerates under current production requirements and no longer can develop its inherently high bonding power fully. In this context, the great significance of bentonite's swelling capacity, as reflected in the deformation limit, again becomes apparent.

Molding sands with identical strength levels often show considerably different deformation limits. This parameter—but not green strength—is weakened decisively by core sand influx, condensate burden, lack of moisture, rapid sand recycling, inadequate bentonite dispersion, and poor sand grain bonding.

Although the level of compaction achieved on modern molding machines increases molding sand strength, the molds are embrittled. Organic plasticizing additives are used with increasing frequency, but must remain a last resort because of their detrimental side effects.

The significance of the deformation limit in the formation of numerous mold and casting defects is represented in the "defect compass." It points out the effects of many variables, as well as the problems that increasingly are aggravated by improper bentonite treatment.

Indications are mounting that production methodology today contributes to increasingly narrower property tolerances and a more and more difficult "tightrope walk" by green sands. At present, relatively small slips are much more likely to lead to production difficulties than they did previously.

Molding sands therefore must be monitored more thoroughly and from new points of view. Under current conditions, properties developed by different procedures are of increasing significance. By itself, green strength for some time has been an inadequate measure of quality. In fact, it often leads to erroneous conclusions. The deformation limit is suggested as an important extension of molding sand testing. This study describes the relationships and consequences for foundry practice.

Acknowledgment—The authors wish to thank Süd-Chemie AG, Munich, for support of this work.

"Quality metal. Good prices. Excellent delivery."

Jim Hunt, President of Southern Aluminum Castings in Mobile, Alabama, tells why he chooses Schaefer furnaces for his ultramodern automotive foundry.

"We produce intake manifolds for major U.S. car and truck makers, utilizing automated molding machines and ladling robots. There's very little manpower in the operation of this foundry, so we rely on the best technology we can get.

"This year alone we've put in two rotary molding machines, a couple of new ladlers, and a new Schaefer reverberatory molder with automatic filtration and degassing.

"That makes three Schaefer we've got, and they handle 75% of our melting. It doesn't make sense to deal with 3 or 4 furnace manufacturers and stock different parts. You've got to pick your best product and stick with it... and that's Schaefer.

"They deliver the metal quality we need, the cost is right, the service is good, and delivery time is excellent. They're flexible, and that's a strong advantage.

"Right now we're pouring 319, and the Schaefer filtration system gives us continuous quality metal. That's essential, because our customers insist on using statistical process control, and the metal quality has to stay within very tight control limits.

"If anybody asked me, I'd definitely recommend these furnaces. The folks at Schaefer make a good product, and they're good people to work with."

See for yourself. Call or write today for free literature.

FRANK W. SCHAEFER, INC.
PO. BOX 1508 • DAYTON, OHIO 45401
PHONE 513-253-3342