Evaluation of Tests for Control of Foundry-Sand Systems

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ABSTRACT

Three bentonite-bonded molded sand mixtures were subjected to repeated use. Rebinding bentonite, based on the tests under evaluation, was added as required. In two series bentonite additions were controlled by green compressive strength and the incidence of setting increased as the sand was aged. Casting quality correlated with set strength and effective clay content. Where bentonite additions were controlled by effective clay content, the deterioration of castings with repeated use of sand was much less marked but still present. When clay additions were based on casting quality the sand could be used indefinitely to produce good castings. The accumulation of dead-burnt clay does not necessarily limit the number of times a sand can be used. After repeated use the accumulation of dead-burnt clay interfered with wet-strength tests made on wet-tempered sand but it did not affect the usefulness of the wet-strength tests that were based on testing the moisture-contraction zone. Sand prepared for the first use by mixing gave poorer results than sand prepared by milling every time it was used, although the green-strength properties, effective clay content, and wet strength were superior.

Introduction—One of the problems encountered with synthetic sand systems is the deterioration of casting quality with repeated use, even when additions of bentonite are made to maintain the strength level. It is usually considered that casting quality cannot be maintained without adding sand to the system. The quantity of new sand required will vary with the type of casting; and, because burnt-out cores add sand to the system, less new sand will be required if there is much core work. In practice, additions to molding sand may be of new or reclaimed sand, added either as a facing sand or as a sand mixture on difficult jobs or directly to the system. The displaced material may be reclaimed by removing the coating on the sand grains, which consists of clay, dead-burnt clay and other sand additives.

The most commonly used test to control molding sand properties is green compressive strength. However, because sand burnout has less effect on this property than it does on other properties closely related to casting quality the tests do not predict how the sand will behave in practice. The foundryman finds that his best test is the casting itself; hence, although he uses sand tests to regulate bentonite additions he often adds new sand according to the appearance of the castings.

The first obvious deterioration of castings which occurs with prolonged use is the tendency to form scabs. The surfaces of the castings also become progressively rougher because of increased erosion. Sand removed by erosion and scabbing appears in cope surfaces, causing sand inclusions and pinholes.

In this study the quality of sand is estimated primarily by the degree of scabbing. Much work has been done in recent years on the subject of scabbing, and the work has been well summarized by A. D. Morgan. Several tests for scabbing tendency have been put forth and it was proposed in the present work to determine which of these would be best to use as a control to determine the deterioration of sand with use. It was also hoped that a means would be discovered of determining when clay additions would no longer rejuvenate the sand and new sand should be added.

In addition to the scabbing tendency the decrease in quality of casting surfaces as the sand was used was measured by a cast surface comparator (by Wheelcraft, Inc., now Precision Castings of California, Inc.) The roughness readings were averaged over the four scab plates and an effort was made to interpolate between C numbers.

Test Procedure

Sand Mixtures—Three sand mixtures were used in this investigation, 2 of which were used for 10 heats with controlled green compressive strength. For the third test, in which the sand was used for 30 heats, the effective clay content, as defined by Heine et al, was used as a control.

The sand, from Ottawa, Illinois, (bonded with Wyoming bentonite from a single shipment) had the following screen distribution:

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<th>US Screen No.</th>
<th>% Retained</th>
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</tr>
<tr>
<td>270</td>
<td>0.2</td>
</tr>
<tr>
<td>pan</td>
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</tr>
</tbody>
</table>

AFS Fineness No (gfn) 56.0

The mixtures were prepared as follows:

Mixture 1 (6 batches in 3-ft sand muller)
- 150 lb sand
- 1.5 lb gelatinized corn flour
- milled 1 min
- 2200 cc water
- milled 1 min
- 9.75 lb bentonite (sand:bentonite 100:6.5)
- milled 5 min
- moisture adjusted to give 75 moldability as defined by Dietert et al after aeration
- milled 1 min
- passed through aerator

Mixture 2 (9 batches prepared in a rapid mixer with an S-shaped mixing arm)

Fig. 1. Series 1, sand mullered for each use, bentonite additions controlled by green compressive strength.
100 lb sand
1 lb gelatinized corn flour
mixed 1 min
1450 cc water
mixed 1 min
6.5 lb bentonite
mixed 2 min
moisture adjusted to give 75 moldability
after aeration
mixed 1 min
passed through aerator

Mixture 3 (6 batches prepared in 3-ft muller)
The same as mixture 1, except that
rebounding bentonite additions were
adjusted by effective clay, as defined by Heine, and by the condition of the
castings instead of by green compres-
sive strength.

Reconditioning—For reuse, the sand, in-
cluding the scale which peeled from
the castings, was processed as follows:
(5 batches in 3-ft muller)
175 lb used sand
3.5 oz gelatinized corn flour
milled 1 min
moisture to give 75 moldability, after
aeration
milled 1 min
rebounding bentonite addition
milled 4 min
final moisture adjustment
milled 1 min
passed through aerator
The cereal addition of 3.5 oz (about
2.5 lb/ton of sand) was found to be
easy to maintain the gas evolution at
a constant level.
Mixture 2, prepared for the initial use
by mixing, was reconditioned in the
same way as others because the mixer
would not break up the lumps.

Test Casting—The test casting used in
this work was the scab block developed
by the Steel Founder's Society of America.

The molds were rammed by a pneu-
matic hand rammer to a mold hardness
of C90, as measured on a Dietert mold-
hardness tester.

Mild steel (0.30% C, from basic arc
furnace) was used to pour the castings.
Initial pouring temperatures ranged be-
tween 2950°F (1620°C) and 3040°F (1670°C).
There was a temperature drop of about
20°F (10°C) between molds. No rela-
tion between scabbing and temperature
was found in this range. Pouring time
was 8:10 sec. The castings were shaken
out 1 hr after they were poured.

The evaluation of test castings was
based on area of scabbing on the plate
surfaces. Scabs were rated in four
groups as follows:
Rating 1 — >0—0.5 in.²
Rating 2 — >0.5—2 in.²
Rating 3 — >2—6 in.²
Rating 4 — >6 in.²

Thus, for a single heat of four cast-
tings, the scab rating would range up to
32 if all four plates were completely
scabbed on both cope and drag sur-
faces. The worst rating obtained on
these tests was 18.

Representative castings from three of
these series are shown in Fig 1—3 in-
inclusive.
Description Tests—The following sand properties were evaluated to determine their suitability for use as control properties:
- green compressive strength
- green tensile strength
- relative green tensile strength
- effective-clay content
- wet compressive strength
- wet tensile strength
- hot wet tensile strength
- spalling resistance.

A description of the nonstandard tests follows:

Relative Green Tensile Strength—This test was proposed by Boenisch and is the ratio of green tensile strength to green compressive strength, in the same units, expressed as a percentage.

Effective Clay—Effective clay, as defined by Heine et al., is based on the relationship between green compressive strength and green shear strength. The effective clay content is interpolated from Heine's diagram, as shown in Fig. 4.

Wet Strength—The wet-strength tests are based on the work of various investigators, which has indicated that the strength properties of wet sand are important in that scabbing is caused by weakness in a high-moisture zone. This zone is formed below the mold surface by the condensation of steam vaporized near the surface by the heat of the metal.

Hoffman's work showed that molding-sand mixtures differed in their sensitivity to high-moisture conditions. He made his wet tests at 6% moisture, which he considered to be about three times optimum temper. In the present work, wet compressive and wet tensile strengths were determined on tempered sand, milled for one more minute in an 18-in. machine with enough moisture to give 8% after passing through a 14-in. screen. However, in series 3, heats 11—30, the wet strengths were determined at three times the moisture used to temper the sand to the moldability.

Hot Wet Tensile Strength—Boenisch was one of the investigators who found a relationship between scabbing and wet tensile strength. His wet-strength test was made on a specimen in which the wet zone was formed by condensation beneath a heated sand surface. It thus conformed more closely to casting conditions than tests made on sand milled and rammed wet.

The test used in the present investigation was based on Boenisch's proposed test simplified in order to use available equipment. A sand specimen was prepared in a standard tensile-specimen tube and the bottom surface heated over a gas flame. The steel specimen tube was cooled by a water jacket to prevent the steel from conducting heat and drying out the sand. Thus, the high-moisture zone advanced evenly from the surface on which the flame impinged. After this zone had advanced 1 in, to the split in the specimen tube,
the specimen was removed and broken in the strength machine. The moisture zone required 5.25 min to migrate to the split in the tube, as determined by the minimum strength result and the appearance of the break. The surface below the break was entirely dry; above the break, it was wet.

This test was not introduced as an improvement on Boenisch's test but to evaluate how useful such a test would be. It was called the hot wet tensile strength to distinguish it from the tests on sand prepared wet.

Boenisch used his wet tensile test in conjunction with a "compressive stress" test to determine scabbing time. The compressive stress test measures the stress generated within the sand by expansion forces as it is heated. The equipment for this test was not available for our work.

Spalling Resistance—A test specimen based on Lavelink's work was used to determine the spalling resistance. The design of this test specimen is shown in Fig. 5. An open sand mold was made and the square frame containing the sand specimen was placed over this. When the mold was pressed the specimen was held by the core 3 in. from the metal surface. An overflow on the mold governed the height of the metal. Pouring time was from 4 to 5 sec.

Spalling resistance was measured as percentage of sand surface that did not spall.

Four spalling tests were made with each heat and the results averaged. Typical results from a single heat are shown in Fig. 6.

Correlation of Tests—The record of the bentonite additions is shown in Fig. 7 and 8. The moldability and moisture contents for series 3 are shown in Fig. 9.

The scab ratings are shown in Fig. 10 and 11. Scabbing increased with use when green compressive strength was

Fig. 6. Typical results with spalling-resistance test, from a single heat; spalled sand surface colored white.

Fig. 7. Bentonite additions for series 1 and 2.

Fig. 8. Bentonite additions for series 3.
used to regulate bentonite additions (Fig. 10). It was controlled for the series in which larger amounts of bentonite, based finally on the condition of the castings, were used, (Fig. 11, use numbers 22—30).

The series for which the sand was mulled each time had fewer scabs than the one for which the mixer was used for the initial preparation.

Figures 12 and 13 show the surface-finish ratings. There was no significant difference between the two series controlled by green compressive strength, but the series with larger bentonite addition had superior surface finish on the drag, even after 30 heats.

Green Compressive Strength—The results for green compressive strength are shown in Fig. 14 and 15. It is apparent that green compressive strength is not a useful indicator of sand deterioration.

Green Tensile Strength—Boenisch pointed out that since the greatest stresses applied to sand in the mold are in tension and since sand is weakest in tension the tensile test should be used in preference to the compressive test to control sand properties.

Figures 14 and 16 show the progression of the tensile strength results as the sand is used. It can be seen that green tensile strength is no better than green compressive strength as an indicator of sand burnout.

Relative Green Tensile Strength—The relative green tensile strengths are shown in Fig. 14 and 16. They do not indicate the degree of sand burnout.

Effective Clay—The effective-clay test proposed by Heine as a measure of sand quality is based on the ratio of green shear stress to green compressive strength. Figure 17 shows the results for the two series in which green compressive strength was used to control clay additions. The effective clay test correctly indicates that the sands deteriorated with use. However, it incorrectly indicated that series 2, mixed for the initial use, would be better than series 1, mulled throughout, whereas it was, in fact, worse. Thus, the effective clay test does not appear to be a reliable indicator of the best mixing procedure.

The results of the effective clay test for the extended-use series (3) are shown in Fig. 15. In correlating these with the scabbing results (Fig. 11) it is seen that the castings become gradually worse, although the effective clay has not decreased. When extra bentonite, based on the appearance of the castings, was added for the 22d, 23d and 28th uses the castings improved, although there was not much change in effective clay. Thus, the effective clay test appears to be less sensitive than the castings to sand deterioration.

Wet-Strength Tests—The charts for the wet-strength tests are shown in Fig. 17-20 inclusive. All the tests indicate that the sand for series 1 and 2 deteri-
orates with use. Like the effective-clay test, all of the wet tests incorrectly indicated that series 2 should be better than series 1. Therefore, they cannot be used by themselves to compare mixing procedures.

In the extended-use test the wet-strength tests at room temperature failed in the presence of large amounts of dead-burnt clay, in that they indicated a large increase in strength (Fig. 19). This occurred despite the fact that the moisture level was increased as the water required to temper the sand for molding increased. The hot wet tensile strength was not increased by the presence of dead-burnt clay (Fig. 20) and, therefore, it appears to be a better test.

The test results indicate that the wet-tensile test overestimates the strength of the sand under the conditions which exist in the mold.

Spalling Resistance—The spalling-resistance tests (Fig. 21) show that the sands deteriorate with use. This test was not a very good indicator of the relative performance of the sands, nor was it sensitive to changes after the first heat. Surprisingly, it did not even correlate with cope scabs. An explanation may be that the castings were poured in 8 or 9 sec, whereas the test specimens were left over the metal for 10 min.

Evaluation of Tests—From this investigation it appears that the best test to indicate the degree of sand burnout is the hot wet tensile test as proposed by Boenisch. The effective clay test proposed by Heine is also useful, although it may not be sensitive enough for control purposes. Tensile and compressive tests on wet-tempered sand are useful in determining clay quality and in evaluating the results of clay-activation treatments, but are less useful in the presence of dead-burnt clay.

Effect of Treatment Variables—As outlined above, primary purpose of this investigation was to determine the best test of sand deterioration on burnout. However, an analysis of the results obtained with series 1 and 2 also permits a useful comparison of the effects of mulling and of mixing, and series 3 can be used to show the effect of the accumulation of dead-burnt clay.

Effect of Mulling—A higher value for effective clay is obtained with 3-min mixing than with 6-min mulling. A probable explanation of this surprising result is that mixing concentrates the clay at the contact points of the sand and mulling spreads it more evenly over the grains. These results also indicate that the initial method of applying the clay to the sand is very important. The influence of the procedure used at that time remains through subsequent reconditioning. Apparently the original positioning of the clay on the sand grains is difficult to change with re-mulling.

Extended Use Test—Series 3 was extended to 30 heats to supply answers to

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**Fig. 11.** Scab ratings for series 3.

**Fig. 12.** Surface-finish ratings for series 1 and 2 (ratings based on cast surface comparator from Wheelcraft Inc. (now Precision Castings of California, Inc.).
the following questions:

1) was the effective clay test sufficient to use as a basis for clay additions?

2) how long can a sand system be maintained, with the addition of bentonite, cereal and water only to produce good castings?

3) at what point are new clay additions no longer able to maintain the sand?

4) how much new sand should be added?

The series was begun with 967.5 lb of sand, including binder, to which 135 lb of bentonite was later added. In order to maintain enough sand for 5 batches, additions had to be made after 25 heats to replace losses. Thereafter, these amounted to 2 or 3 lb per heat and were taken from another heap of old sand. The dry weight of the sand heap after 30 heats was about 360 lb.

The series was terminated after 30 heats. At this point the sand had been used to make a total casting weight, with the gates, of 6,350 lb. Assuming a plant yield of 50%, this would be a total weight of 3,175 lb of finished castings or 3.5 tons per ton of sand. A commonly accepted figure in the industry is 1 ton of finished castings per ton of sand. The figure of 3.5 in this test is probably never approached in practice. Corroborating this is the fact that, despite care to recover all of the sand, our tests should have required the addition of new sand to compensate for losses. Instead, only a small amount of used sand was added and the system was allowed to lose about 10% of its weight. It can be concluded, therefore, that build-up of dead-burnt clay is not necessarily harmful. This agrees with Yearley, who found that dead clay had no effect on the tendency to scab, provided that active clay was kept at a constant level. Probably the ratio of sand to clay is more important than that of sand to metal. If the test had been continued indefinitely, the sand would have eventually contained over 50% dead-burnt clay, and trouble would be expected. However, it is not feasible to carry out such lengthy laboratory experiments.

Thus, only one of the proposed four questions was answered by this test:

1) as described above, the effective clay test does not appear to be sensitive enough to use as a basis for adding clay for extended use of sand

2) the sand can be used too long to determine its life in a laboratory test

3 and 4) more severe conditions—such as, possibly, a) deactivation of bentonite by addition of harmful ions, b) use of insufficient mulling or c) addition of silica flour—would be required to answer these questions.

Effect of Dead-Burnt Clay—Analyzing the sand for active clay by the methylene-blue method before the first and thirtieth times the sand was used gave the following results:

before 1st use ........................ 5.6%
(by calculation, based on dry clay)
before 30th use ........................ 6.7%
(by comparison).
Fig. 15. Green compressive strength and effective clay for series 3.

Fig. 16. Green tensile strength and relative green tensile strength for series 3.
Fig. 17. Hot wet tensile strength and effective clay for series 1 and 2.

Fig. 18. Wet compressive and tensile strengths for series 1 and 2.

The total clay content by Al.ysis before the 30th heat was 21.6% and the dead-burnt clay by dliii was 16.1%.

It is assumed that most of the differences in properties between the first and thirtieth heats are caused by the presence of dead-burnt clay. The differences are, for the thirtieth heat:
1) Increase in moisture requirement from a minimum of 2.2% for the first use to 4% for the thirtieth use (2)
2) Increase in green strength (compressive, tensile, and shear)
3) Decrease in hot wet tensile strength
4) The casting surface had a higher casting surface temperature C10 to C85.

The accumulation of dead-burnt clay had little effect on permeability.

The number of runs to obtain a hardness of 90 on the AFS 2-in. test piece, and the weights were:

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<tr>
<th>Use No.</th>
<th>Rams</th>
<th>Weight</th>
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Summary
1. Of the tests evaluated, the ones which had a significant relationship to sanding in a hard sand mix were the wet tensile strength (tested on a Buch's principle) and effective clay tested by Heine. It is assumed that active clay, as tested by the methylene blue test, or by settling would correlate with casting quality.
2. The wet tensile strength and effective clay content, as determined herein, were not sufficiently sensitive to use as bases for making clay additions over a series of 30 uses. Better results were obtained when the clay additions were based on the quality of clay obtained.
3. The initial method of preparing the sand is very important because
fects persist throughout subsequent re-conditionings and are evident in the quality of the castings as long as the sand is used.

4. Accumulation of dead-burnt clay in a sand system does not necessarily limit the length of time a sand can be used, provided that it is adequately replaced with new bentonite additions. However, other factors which were not tested may limit the number of times a sand can be used.

References