Discussion of the Scabbing Tendencies of Green Sand

Scabs are the direct result of a mold defect originating during either restrained or unrestrained formation of a "shell" layer.

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Abstract

In this investigation into the causes of green sand scabbing, it has been discovered that scab formation on castings is brought about by two processes during the pouring of the mold. To begin with, a condensed moisture zone is formed a few thousandths of an inch under the mold surface. Coincidently with the formation of this zone, a compressive stress (caused by silica sand expansion) is created within the thin mold layer of dried sand between the mold surface and the condensation zone. The exact mechanics of this interaction are succinctly described.

Introduction—Mechanics of Scab Formation

The formation of scab defects has been investigated by many authors in recent years. According to the most recent such work, scabs occur as a result of a formation of a shell of dried sand on the hot mold surface. Such sand layers are commonly from ten to twelve thousandths in. in thickness. They separate from the remaining sand mold at the zone of condensed moisture as a result of compressive stresses during the expansion of the quartz or silica sand. The adhering strength of the sand in this high moisture layer, referred to as wet tensile strength, counteracts the stress and reduces the scabbing formation. Scabs, then, are the direct result of a mold defect originating during either restrained or unrestrained formation of a shell layer. The restrained expansion produces a buck-le-type scab while the unrestrained may have the general appearance of a plate-type scab. This mechanism of shell formation is shown schematically in Fig. 1.

Figure 1 illustrates a means by which the heat of radiation from the liquid metal drives the moisture away from the mold surface to a point of condensation in the deeper layer of sand. The concentration of moisture in the condensation layer reduces the strength of the sand to a marked extent. This is the situation shown in Fig. 1-a and 1-f. An increase in the compressive loading or stress of the dried surface layer produces a movement as indicated in Fig. 1-b and 1-g. As the level of molten metal continues to rise toward the cope surface, the mechanism is readily followed in c, d, h, and i. The result is illustrated in 1-e and 1-k.

The scabbing tendency of the sand is indicated by the frequency with which the defect occurs, the size of the scab and the time during which the sand can withstand the radiant heat without filling. This degree or tendency to scab can be approximated by the following rule:

Tendency to scab proportional to

\[
\text{Compressive Stress} \propto \frac{\text{Wet Tensile Strength}}{\text{Thickness}}
\]

The tendency to produce a scab in green sand is marked when the compressive stress from expansion is high and the wet tensile strength is low. A tendency toward the defect, conversely, is reduced when the compressive stress is low and the wet tensile strength is high. As a result, the scabbing tendency may remain unchanged even under those conditions in which both the compressive stress and the wet tensile strength are changed, provided the ratio between them remains a constant. Practical techniques used to reduce the tendency toward the scabbing defect are successful only if

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Note: the term "pend" (which appears in some of the figures) is equivalent to a beam.

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the ratio of compressive stress to wet tensile strength is reduced.

The proportional formula used above serves only to outline the relationship. It is qualitative rather than quantitative. To become quantitative, the relationship would have to be extended to include factors involving mold shape, casting temperature, sand composition, molding density and other such factors. The inherent tendency of the sand to permit a scabbing defect is a definable sand characteristic in spite of the fact that it will manifest itself differently in variously shaped and sized castings.

Modern sand testing is largely confined to test specimens or the pouring of test castings. This does permit determining the condition of the sand, per se. However, test castings to demonstrate the sand characteris-
tics of expansion and scabbing defects, are expensive and not convenient accessories in actual foundry practice. If the compressive force and the wet tensile strength can be measured in the laboratory, then an economical and production-oriented testing technique will be possible.

The Scabbing Test Casting

There are several types of test castings described in the literature. The authors find them to be of inadequate sensitivity to study this particular problem. In most cases, the tests described indicate only whether a sand scabbed or did not scab. A quantitative measure of the tendency to the formation of the defect was not obtainable.

At the Giesserei Institute of Aachen, a test casting has been developed which indicates the degree of scabbing tendency as a relationship of the scab size. In Fig. 2, we see the pattern equipment for this test and in Fig. 3, the drawing of the test piece complete with dimensions. Figure 4 outlines the correct pouring procedure.

Pouring Time Test Casting

The tendency of a green sand toward scabbing can be defined by two separate factors. One measurement or factor is the size or frequency with which this defect occurs on the cope of the scab test casting. The other factor which may be measured is the time after which the scab formation occurs. To avoid a scabbing defect, a mold would have to be filled within the permissible time interval. If the time interval is exceeded (pouring is too slow), shell formation and scabbing do take place. With increasingly slow pour, the defect increases in size and intensity. To study both of these effects, the authors use a slightly modified test casting which measures the influence of pouring time. The modified casting is indicated in Fig. 5. In place of the riser B used in the scabbing test casting, the pouring time test uses an inclined opening in the cope through which the mold cope can be observed during the pouring process. The formation of the shell of sand always starts at the very tip of the cope surface under observation.

Unlike the scab test which is poured to completion, the pouring time test mold is half filled. A sand mark indicates the half full position and this mark is molded in such a way that it can be observed through the inclined pouring opening. The correct procedure for the pouring of the test casting as indicated in Fig. 4, is also valid for the pouring time test. In the pouring time test, the time measured is that between the beginning of the pouring up to the separation of the sand tip.

The meaning of this test is obvious in foundry practice. It is well known that a rapid filling of the mold is one of the most important requirements, if the foundryman is to avoid such defects as scabs, rat tails, bubble, and similar so-called expansion defects. From the techniques described by the authors, it is possible to determine the critical pouring time of a given sand without an actual casting trial. It also provides a tool for determining the effect of various sand controls upon the critical pouring time.

Wet Tensile Strength and Compressive Stress

As described previously, the relationship between the compressive stress or load and the wet tensile strength of the sand determines the tendency toward expansion scab defects. These two factors are quite independent of each other. They may even vary by different amounts for different sands. Commonly used molding sands exhibit wet tensile strengths ranging from 0.07 to 0.7 psi. The compressive stresses or loads exerted may vary from 1.4 to 140 psi. It is obvious then, that the scabbing tendency of commonly used sands varies over a wide range.

In previous years, insufficient resistance to scabbing defects could be compensated for by the skill and
experience of a good molder. There are many examples of good castings being produced in sands which do demonstrate a high tendency toward casting defects by utilizing the skill in gating of the mold, setting mold nails, varying mold hardness, etc. Today, however, the increased demand for high production and the relatively low level of qualified skilled personnel forces the foundryman to maintain and develop sands with minimum tendency toward casting defects. The wet tensile strength and the compressive stress values which can be measured in the laboratory can serve to characterize the tendency toward the expansion defect. Therefore, the new testing procedures are not advisable only for foundries with considerable scrap or swamping tendencies but also for those foundries who desire the maximum ability to properly supervise their molding sand properties. Green sand, as it is used in the foundry, is a complex material which is changing.
continuously and continually by the influx of other molding and core sands, core sand dilution, etc. CO₂ process sands, hot-back sands, shell molding sands and similar modern techniques vary in the type of material, the burn-out of the binder and other factors which lead to a continuing change of the wet tensile strength and compressive forces which may lead to ultimate deterioration of a properly compounded sand.

Wet Strength Testing Apparatus

A laboratory equipment has been developed to measure wet tensile strength of molding sand as well as the compressive stresses. This instrument has been described in previous papers by the authors in 1961 and 1964. The test is made up of two phases. First, a cylindrical standard specimen is heated from only one end until a zone of condensation moisture has formed as illustrated in Fig. 6-a. Using a split specimen tube, it is then possible to apply an increasing tensile load to the surface as indicated in Fig. 6-b until fracture occurs as illustrated in 6-c. The wet tensile strength is then recorded in psi. Figure 7 illustrates the recently developed testing apparatus for measuring wet tensile strength.

Compressive Stress Testing Equipment

The compressive stress is measured as illustrated in Fig. 8, using a circular sand shell rimmed to 5 mm thickness and concave on the side to be heated. As illustrated in Fig. 8, the specimen is held at the cir...
Figure 7. Wet strength testing apparatus.

Scab Diagram

A scab diagram can be drawn showing the wet tensile strength on the x-axis and the compressive stress on the y-axis. A diagram can be divided into 7 areas of relative scabbing tendency by drawing 6 curves of equal scabbing time as developed by empirical casting trials. As follows:

One hundred seventy production sand and laboratory mixes were tested for both wet tensile strength and compressive stress with the equipment previously described. The tendency of these sands to create the defect was determined by pouring the scabbing time test casting using gray iron at the pouring temperature of 2410 to 2510°F (1321 to 1377°C). The chemical composition of the gray iron is of no significant influence on the scabbing results. Figure 9 shows the wet tensile strength, the compressive stress and the scabbing times of the 170 sands investigated. The areas or zones of scabbing are illustrated by numbers from 1 to 7 and indicate scabbing times ranging from less than 10 seconds to longer than 40 seconds.

Curves of equal scabbing times were obtained by outlining those zones in which the same numbers are located indicating similar tendencies toward expansion defects by different sands. In the area represented by scabbing times of longer than 40 seconds, there was no subdivision made. Most molds which reached 40 seconds without a shell formation succeeded in resisting scabbing tendencies completely. There were a few exceptions of molds which scabbed even though they could withstand the temperature for 50 seconds, and in rare instances 60 seconds, in this test.

This scabbing diagram is offered as proof of the generalization of the relationship between wet tensile strength and compressive stress as an indication of the tendency for the defect under both laboratory and plant conditions.

Curves of equal scabbing time show a very steep rise with increasing compressive stress, particularly when the wet tensile strength is low (the measure "pond" is relatively synonymous with the English word, gram). The change in curvature indicates that the wet tensile strength and the compressive stress do not affect the expansion defect equally. The wet tensile strength acts principally as a stronger influence over the final defect than does the compressive stress. With low compressive stresses, the influence of wet tensile strength is greater than in the case of high compressive stresses. As a result, economical measures taken to improve the sand are possible only when the compressive stresses are low. For example, the tendency for scabbing within 30 seconds had a stress of 71 psi and can be compensated for with 0.45 psi wet tensile strength but if the compressive stress is only 28 psi (approximately ¼), the wet tensile strength required is 0.25 psi (more than half). The reduction from 0.45 psi wet tensile to 0.28 psi wet tensile represents a significant savings in bentonite. If the compressive stress of a sand is high, freedom from defects can be reached only by a high wet tensile strength. High wet tensile strength values, however, require large amounts of high quality bentonite. To obtain 0.426 psi
Fig. 8. Compressive stress test (schematically).

Fig. 9. Scab diagram—170 different laboratory and production sands.

The diagram illustrates the relationship between compressive stress, wet tensile strength, and scubbing time in seconds. The 170 different sands are color-coded, with each color representing a different sand type. The axes are labeled as follows:

- Compressive stress in kilopounds/cm²
- Wet tensile strength in pond/cm² (1 pond/cm² = 0.01425 p.s.i.)
- Scubbing time in seconds

The data points are plotted to show how these factors interact, with the majority of the data points falling in the lower stress, lower tensile strength, and longer scubbing time categories.
Wet tensile strength in pond/cm² (1 pond/cm² = 0.01425 p.s.i.)

Reproducibility

Figure 11 shows the properties of 11 different batches of sand of the same type, individually prepared in the same muller (black circles). The compressive stresses under heat (not to be confused with green compression strength) range from 47 to 70 psi, while the wet tensile strengths range from 0.42 to 0.49 psi. In the case of the compressive stresses, the individual values deviate from the mean by ±20%, while the wet tensile strengths deviate from the mean by ±6%. The large spread in compressive stress is due to the method of preparation. It is difficult to reproduce the conditions of preparation of each sand even with the mulling time and the moisture contents during mulling held constant for all sands. Large deviations of the compressive stresses are inevitable. In contrast, the values developed on a number of different samples...
from the same sand mix are more reproducible. The deviations in wet tensile strength under these conditions are normally less than \( \pm 5\% \) and the deviations in compressive stress and scabbing time show a maximum of \( \pm 7\% \).

The 11 sands referred to in Fig. 11 were prepared with 6\% of an activated sodium bentonite. Three other sands were prepared with 6\% calcium bentonite which was activated in the muller by the addition of soda ash. The properties of these 3 sands (white circles) are similar to those of the sodium bentonite sands. It is apparently immaterial, therefore, whether the activation with soda ash is carried out prior to the mulling process or during the preparation of the sand in the muller. Two additional sand mixes were prepared in a paddle mixer as contrasted to a muller. Their property values are distinctly lower since the bonding properties of the clay are not adequately developed by this type of mixing. This test indicates that the kneading action of the muller tends to reduce the scabbing tendency of the sand. It will be noted that the two mixed sands showed scabbing in slightly less than 25 seconds, whereas the other sands range from 30 to 40 seconds.

**Various Bentonites**

In Fig. 12, the values for 21 different molding sands prepared using bentonites from various countries, are compared. The differences exhibited are principally the result of the percentage of montmorillonite contained in each bentonite and the degree of activation. All bentonites investigated are either natural Wyoming sodium bentonite or sodium bentonite prepared by activation with soda ash.

**Bentonite (montmorillonite) Content**

The tendency toward scabbing defect may be reduced in many cases by the use of higher or larger additions of bentonite. This effect is shown in Fig. 13. Five different bentonites ranging in percentage from 5 to 11\% were added to silica sand. As the percentage of bentonite increases, the tendency toward the scabbing decreases. In this illustration, bentonite A is a calcium bentonite while the bentonites B through E are sodium bentonites.

As the percentage of bentonite increases, both the wet tensile strength and the compressive stress increase, but at different rates. A calcium bentonite (A) changes the scabbing tendency to only a negligible extent. Its property curve is essentially parallel to the scabbing curves of 15 and 20 seconds. Only the additions of sodium-type bentonites are found to decrease the tendency toward scabbing defects.

In the case of the sodium bentonites, all of the curves of increasing bentonite content intersect the curves of equal scabbing time and thereby decrease the tendency toward scabbing defects. This is particularly noticeable in the lower clay content levels. Bentonite B showed the greatest influence followed by C, D and E. It is desirable that foundrymen should choose a bentonite which provides the greatest possible increase in wet tensile strength with the least increase in compressive stress (not to be confused with compression strength).
Activation

Modification of a calcium-type bentonite to a fully activated sodium-type bentonite is the best and most economical method of decreasing the tendency toward scabbing defects. It is known that the wet tensile strength of a sand bonded with calcium-type bentonite increases drastically when treated with soda ash additions, reaches a maximum level with complete sodium ion adsorption and drops again as a result of over-activation. (This was reported by the authors in Gessurei in 1961.) It is advisable to activate each clay only to the optimum extent and to avoid over- or under-activation. This includes the clays of natural sands, such as kaolinite, illite, glauconite, etc. The increase in wet tensile strength, resulting in a definite reduction in scabbing, is illustrated by comparing bentonite A and bentonite B of Fig. 13.

In Fig. 14, the values for sands with equal bentonite contents are connected by a dotted line. This illustrates the influence of activation. For example, the activation of an 8% bentonite sand increased the scabbing time from 16 seconds to 50 seconds. In this case, 4 grams of soda ash to 100 grams of bentonite were required for complete activation. Figure 15 relates the scabbing tendency to the amount of activation. The numbers written next to the tests in the diagram represent the amounts of soda ash added to the sand during milling in milli equivalents per 100 grams.
of bentonite. Two different calcium bentonites of German origin were the basis of the study.

It is clearly indicated that the most favorable condition for foundry use is obtained by complete activation. Both over-activation and under-activation are detrimental and lead to a deterioration of sand quality. It is desirable and necessary to continuously check the degree of activation of the bonding clay being used. Soda ash is the most widely known means of such activation.

Figure 16 shows the scabbing properties as developed after activation with differing salts. Each base sand contains 8% of calcium bentonite. 80 milli equivalents of the salt tested per 100 grams of bentonite were added to each mix to reach optimum activation. The salts contained different cations with equal anions in one test (solid line) and in the other test (dotted line) the series show equal cation contents with differing anions.

The tendency of a sand to show scabbing defects is reduced with reduction in the area of adsorbed cations and reduced water solubility of the calcium compound containing the anion of the activation salt.

Technically, the best activation is obtained from lithium-carbonate but this is impractical because of its cost. Good and equally effective materials for activation are sodium carbonate, sodium oxalate, and sodium hydroxide.

**CO₂ Sand**

Used sand from the CO₂ process contains both sodium silicate and soda ash which results from the hardening reaction with CO₂ gas. Both sodium silicate and the soda ash are strong activating agents for bentonite. An influx of CO₂ sand into the system may, therefore, either reduce or increase the tendency of the molding sand to provide scabbing-type defects. The introduction of CO₂ shakeout sand into a system...
containing fully activated bentonite would result in over-activation. Introduction of the sand into a system in which the bentonite is under-activated would increase the degree of activation. In Fig. 17 are plotted the sand with varying weights of bentonite sand and CO₂ sand. The base sand in each case contains 6% bentonite, while the CO₂ sand was prepared with 5% sodium silicate and hardened with CO₂ gas. The dotted lines (in white circles) show the change of properties of the sand bonded with calcium bentonite as affected by additions of the CO₂ sand. The calcium bentonite becomes fully activated through the addition of 30% of the CO₂ bonded sand. Comparison of this curve with those from Fig. 15 (solid lines) shows equally low scabbing tendencies in both cases in the completely activated condition (scabbing time approximately 38 seconds).

An additional series shows the influence of CO₂ sand dilution to a green sand containing fully activated bentonite (solid lines, black circles). In this case, the CO₂ sand acted to increase the tendency toward scabbing because it resulted in the bentonite becoming over-activated. This tendency could be compensated for by an addition of calcium bentonite which would reduce the level of activation. A sand with 6% sodium bentonite to which 40% of the CO₂ sand was introduced, was mixed with 3% and 6% of a sodium and a calcium bentonite resulting in the scabbing time being markedly increased (the scabbing tendency decreased). The calcium bentonite gives a higher strength in this case than does the sodium bentonite because the calcium bentonite absorbs a much larger amount of the excess activation materials. These tests indicate that with CO₂ shakeout, sand being introduced into a clay bonded sand, significant improvements may be obtained provided the condition or level of activation is continuously checked.

**Molding Sand Additives**

Figure 18 illustrates the effect of various typical sand additives. The numbers indicate the amounts added as a per cent by weight. These additives may change the molding sand over rather wide limits in either a favorable or unfavorable manner as far as scabbing is concerned. The intensity and the direction of the effect of the various amounts of additives are demonstrated by the scabbing diagram, Fig. 18.

Large amounts of burnt bentonite (b) tend to raise the compressive stress and lower the wet tensile strength. This tends to increase the scabbing tendencies.

The moisture content (d) shows only a small effect in the range between 3% and 4% but a marked reduction in scabbing tendencies as the moisture is reduced from 3% to 1.5%.

The seacoal curve (e) between 1% and 5% seacoal is essentially parallel to the 40 second curve. In this test, the seacoal did not further improve the reasonably scab resistant base sand.

Swelling Binders (f, h and k) showed the entirely
different types of actions, and, therefore, the exact binder should be checked in each case. In some cases, they may acidify the molding sand and thereby lower the wet tensile strength and increase the scabbing tendency.

Of the additives (other than bentonite) peat flour showed the greatest tendency to reduce scabbing defects because it was the best additive for reducing the level of compressive stress.

The distinctly different effects of the many additives indicate how strongly the tendency toward scabbing may change as a result of repeated use of the molding sand. The simultaneous influence of many differing factors may lead, in the final analysis, to a large variation in the tendency of foundry sands to scab.

**Sand Grain**

The influence of grain size and shape is relatively small as indicated in the Table.

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**TABLE: Scabbing Time (sec.) as a Result of using Different Sand Grain Sizes and Angularities.**

<table>
<thead>
<tr>
<th>Grain Size in Microns</th>
<th>1.1</th>
<th>1.3</th>
<th>1.5</th>
<th>1.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>One screen sands</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100-200</td>
<td>27</td>
<td>28</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>200-300</td>
<td>28</td>
<td>25</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>300-400</td>
<td>29</td>
<td>25</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>Five screen sands</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Grain Size &gt; 200</td>
<td>33</td>
<td>35</td>
<td>37</td>
<td>39</td>
</tr>
</tbody>
</table>

Round grain sands (low angularity) indicate slightly higher scabbing times than do angular sands but the actual difference in scabbing time measured is insignificant. Grain size has a somewhat greater effect. Fine sands have a greater tendency toward scabbing defects than do the coarser sands as shown in the Table. The fine screen sand is superior to the single grain sand. The single screen sand with the size ranging from 200 to 300 microns shows a scabbing time of
Fig. 17. Scab diagram—fluence of different amounts of CO₂-sand.

38 seconds while the five screen sand of comparable grain size (230 microns) withstood the molten metal for 33 seconds, an improvement of approximately 20%.

Sand Compaction

A synthetic sand containing 6% bentonite was jolted for varying time intervals to develop a range of rammed density. Figure 19 shows the influence of jolting time on the tendency for scab defects. In the early stages of ramming (up to 20 seconds jolt) the tendency toward scabbing increases markedly but the longer jolt times are without influence. This test indicates that the tendency of a molding sand toward scabbing is but little affected in the higher ranges of compaction. Other techniques for avoiding scabbing are much more effective than reduction of jolt time in the normal range.

Conclusions

The formation of scabs on castings made in green sand is determined by two processes during the pouring of the mold. First, a zone of condensed moisture is formed a few thousandths of an inch under the mold surface. This zone of high moisture from condensation has a very low strength, which is referred to as wet strength. At the same time, a compressive stress is created within the thin mold layer of dried sand between the mold surface and the condensation zone. This compressive stress is created by the expansion of the silica sand. If the nature of the sand is to demonstrate a high compressive stress under heating and a low wet tensile strength in the condensation zone, the stressed surface layers peel off as a so-called "shell". These mold defects result in a defect on the casting known as a scab.

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then provides a simple determination of the scabbing tendency or the critical pouring time by relating the wet tensile strength and the compressive stress.

The intensity and the direction (toward more defect or less defect) of many variables which influence the formation of scabs are examined in this paper. These variables included type and quantity of bentonite, degree of activation, sand additives such as CO₂ sand, sawdust, pitch, wood flour, peat, straw, cereal binder, etc., together with moisture, grain size and distribution, and ram density. Conclusions from such tests permit economical composition of molding sands in the foundry.

References