Mould compaction, moulding sand composition and their influences on the quality of iron castings

K. E. L. Nicholas, A.R.I.C., A.I.M. (Associate member) 
and W. R. Roberts, B.Sc., Ph.D. (Associate member)

The production of iron castings in greensand moulds to close dimensional tolerances with the ensuing benefit of improved soundness has been considered. The problem has been studied in relation to the phenomenon of mould wall movement. Practical measures to reduce mould wall movement include increasing the mould compaction and modifying the sand composition.

The actions of consecutive and simultaneous joint-squeeze moulding machines have been studied from the point of view of their relative ability to compact greensand moulds to high densities and produce dimensionally accurate castings. A study of high pressure squeeze moulding has been made using a test rig producing 12 in x 12 in x 6 in deep half moulds. Basic information concerning mould compaction and casting quality has been obtained using squeeze pressures on the mould of up to 400 lb/in². This work was extended to the production of 37 in x 37 in x 8 in deep moulds with a squeeze pressure of 200 lb/in² on the mould surface. The advantages of using sands responsive to squeeze compaction have been demonstrated; these are strong tough sands obtained either with high clay contents or with cereal additions such as durum. Substantial reductions in mould wall movement, with consequent improvement in dimensional accuracy, resulted from lowering the water content of greensand moulding sands and from the use of additives such as coal dust, pelletised pitch, peat, and woodflour. The importance of clay type and concentration was also considered.

What is the drawback to the use of the greensand process? It has the advantages of simplicity and cheapness, so why should it face competition from newer and more expensive processes such as Shell moulding? The answer is simple—lack of dimensional accuracy, and here it is pertinent to remember that although clamper for clamper recent moulding processes has been the higher accuracy obtainable when compared with conventional greensand practice.

Research has now advanced to a stage such that the reasons for this lack of dimensional accuracy can be understood. The main reason is 'mould wall movement', a phenomenon which occurs to varying degrees when molten metal is poured into greensand moulds. Mould wall movement occurs under the influence of ferrostatic pressure and heat, commencing while the casting is still liquid and resulting in an enlargement of the mould cavity, so that oversize castings are obtained. An additional, and most important, consequence of mould
TABLE I General specification of moulding machines

<table>
<thead>
<tr>
<th></th>
<th>C.J.S. machine</th>
<th>S.J.S. machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jolt capacity</td>
<td>450 lb</td>
<td>600 lb</td>
</tr>
<tr>
<td>Squeeze pressure</td>
<td>8550 lb</td>
<td>8500 lb</td>
</tr>
<tr>
<td>Squeeze piston diameter</td>
<td>11 in</td>
<td>11 in</td>
</tr>
<tr>
<td>Air consumption</td>
<td>12 ft³</td>
<td>12 ft³</td>
</tr>
<tr>
<td>Table size</td>
<td>26 in x 19 in</td>
<td>25 in x 12 in</td>
</tr>
<tr>
<td>Pattern draw</td>
<td>8 in</td>
<td>9 in</td>
</tr>
</tbody>
</table>

Jolt capacity and squeeze pressure calculated at 90 lb/in² air line pressure.

Wall movement is the creation of a demand for feed metal. In simple unfed castings, and in this category are many light section grey iron castings, this demand cannot be satisfied after the ingates have solidified. If mould wall movement continues apparent shrinkage defects will be formed, the volumes of which are directly proportional to the extent of the continued movement and increase in casting dimensions.

In castings with an external feeder head, liquid metal is drawn from the feeder head to satisfy the demand created by movement of the mould walls. If the feeder solidifies prematurely, or has insufficient capacity, piping into the casting will occur together with under-feeder porosity.

At this stage it is instructive to re-examine some of the data presented by Morgan and Greenhill on the subject of brake drum production in greensand moulds. Careful measurements on a batch of 40 drums, all from the same pattern, revealed differences in wall thickness of 0-080 in. On other occasions three batches of a different brake drum were examined and an overall variation in casting weight from 162 lb to 173 lb was recorded for a total of 119 castings. These differences in casting dimensions and weight are the direct consequence of mould wall movement. It must be realized that this is no isolated example and similar effects are frequently noted in castings weighing from several ounces to many hundred pounds and intended for very diverse applications.

In the opinion of the present investigators mould wall movement is a general phenomenon applying to all natural clay-bonded and synthetic greensands and occurs with all types of cast iron, grey flake graphite, nodular graphite, white and malleable irons.

The important question to ask at this stage is how can mould wall movement be reduced so that greensand moulds can be used to produce castings to close dimensional tolerances with the added benefit of improved soundness? If the greensand moulding process is considered there are two principal variables which are likely to affect mould wall movement. These are (a) mould compaction, and (b) moulding sand composition, and it is necessary to study both of these aspects in detail with the object of reducing mould wall movement.

The time is particularly opportune to study the effect of mould compaction in view of developments that are taking place, principally in America, and Russia, in the design of moulding machines. With the advent of automation in foundries new methods of mould compaction are being developed to achieve the higher rates of mould production required. Foremost among these new techniques is pressure squeeze moulding. For this reason both conventional types of moulding machines and the latest pressure squeeze techniques have been studied to determine their influence on mould wall movement and dimensional accuracy.

The dimensionally accurate castings produced in moulds made on conventional moulding machines

Two approaches have been made in this investigation, these are:

(a) Varying the method of mould compaction while maintaining a constant composition moulding sand. In this way the part played by mould compaction in the production of dimensionally accurate castings has been assessed, and

(b) changing the mould sand composition using a constant method of mould compaction. Thus information on the contribution of sand composition to the production of dimensionally accurate castings has been obtained.

Several different methods have been used for interpreting the results of these experiments. The most important is direct measurement of casting dimensions, which was used to investigate effects due both to mould compaction and sand composition. This technique can be used because with castings of the same metal composition which are poured at a constant temperature, the solidification volume changes remain constant and variations in casting dimensions are the result of changes in mould compaction and composition. Supplementary information on compaction of moulds was obtained by bulk density and mould hardness determinations. The mould hardness meter used throughout this work was a large ball hardness tester.

Mould compaction and dimensional accuracy

The majority of moulding machines in use in the foundry industry work on the jolt-squeeze principle. These are of two types: consecutive jolt-squeeze operation (referred to as C.J.S.) and simultaneous

TABLE II Physical properties of moulding sand, Redhill 117%, Wyoming bentonite

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content</td>
<td>2.6%</td>
</tr>
<tr>
<td>Green compression strength</td>
<td>10.8 lb/in³</td>
</tr>
<tr>
<td>Dry compression strength</td>
<td>77 lb/in³</td>
</tr>
<tr>
<td>Shatter index</td>
<td>70</td>
</tr>
<tr>
<td>Permeability no.</td>
<td>68</td>
</tr>
</tbody>
</table>

mould compaction, and (b) moulding sand composition, and it is necessary to study both of these aspects in detail with the object of reducing mould wall movement.
shockless jolt-squeeze operation (referred to as S.J.S.) and both types were investigated in this work. The machines were installed in the Association’s experimental foundry and the following moulding actions considered:

- S.J.S. machine
- Pre-jolt and simultaneous jolt-squeeze
- Simultaneous shockless jolt-squeeze
- Single squeeze
- Free jolt

These machines were selected because their characteristics, i.e. maximum table load, capacity, squeeze piston diameter, etc., were similar. The principal details of the machines are given in Table I.

All the work carried out in this section of the investigation used a constant synthetic sand mixture consisting of Redhill II silica sand bonded with 7% Wyoming bentonite and 2-6% water. This mixture was milled in a roller action mill for 10 min and then disintegrated prior to use. The physical properties of this moulding sand are shown in Table II.

Three different types of pattern were used:

1. A 3 inch sphere moulded in two 12 in x 12 in x 3 in deep boxes.
2. A double step-block pattern in which the height of the step-blocks was 6 in, the two blocks being separated by a 3 in wide core. This pattern was moulded in a 16 in x 14 in x 8 in deep box.
3. A keel block 8 in deep, moulded in a box 12 in x 12 in x 9 in deep.

Because the dimensions of castings vary with metal composition it was important to maintain a constant composition iron for these experiments. The iron selected for the experiments was a nodular graphite type of the following composition:

```
T.C., % Si, % Mn, % S, % P, % Ni, % Mg, %
3.5 2.0 0.5 0.012 0.02 0.80 0.06
```

Melting and casting techniques were standardized and a constant pouring temperature of 1350°C was adopted.

1. The compaction of moulds in 3 in deep boxes

This depth of box is representative of that used for many small, light section iron castings. The test casting used for this section of the investigation was a pair of unlined 3 in spheres joined by a common gating system at the parting line; the design of this casting is shown in Fig. 1. The dimensions of this casting were checked by measurements on each sphere in three dimensions mutually at right angles. The volume of shrinkage pipe in the cope surface of each casting was determined directly.

Standard procedures were adopted in the production of the moulds. The air line pressure was controlled, usually at 90 lb/in², from a 30 ft³ air receiver near to the moulding machines. By means of valves, air pressure to the machines could be varied to any required value within the range from 30 to 120 lb/in². Inaccuracies which could arise due to the method of filling the moulding box with sand were avoided by sieving sand into each box and using a 3 in high upset frame. The sand was levelled with the top of the upset frame and no hand tucking occurred.

Each type of machine operation, with the exception of the single squeeze, was studied over a range of jolt times varying from 2 s to 2 min. The back surfaces of each mould were then struck level with the moulding
box and the weight of the mould determined. Knowing the volumes of the moulding boxes and pattern and the initial box weight, the bulk density of each individual mould could be calculated. Additional information was provided by mould hardness determinations made at fixed locations on the parting surface of each half mould.

As a result of varying the moulding action the mean diameters of the test castings varied over the range 3.005 to 3.051 inches. Increasing both the mould bulk density and hardness progressively reduced casting size as shown in Figs. 2 and 3. The smallest casting, 3.005 in diameter, was produced from a mould rammed to a bulk density of 1.54 g/cm³ and a hardness of 94, and the largest casting, 3.051 in, from a mould of 1.23 g/cm³ density and hardness 67. These moulds were obtained by the normal operation of the moulding machines and represent a typical range of density and hardness such as might be obtained under production conditions, and no deliberate attempt was made to produce soft moulds.

As might be expected the various machine actions produced widely differing castings. This is shown in Figs. 4 and 5 where mould bulk density and hardness are related to jolting times extending from 2 s to 2 min. The following conclusions may be drawn from these results:

1. The castings produced by the actions of the two moulding machines differ considerably. For a particular jolting cycle the compaction decreased as the machine action was changed in the following order:
   - Simultaneous jolt-squeeze (S.J.S.)
   - Consecutive jolt-squeeze (C.J.S.)
   - Single squeeze

2. The effect of increasing the jolting time was different with the various actions.
   - (a) With simultaneous jolt-squeeze (S.J.S.) action, compaction increased to its maximum level after 30 s operation and no further increase was recorded.
   - (b) With the consecutive jolt-squeeze action of the C.J.S. machine jolting time over the range 2 s to 2 min had no influence upon mould compaction.
   - (c) Different characteristics were produced by the two free jolting actions. With the S.J.S. machine compaction increased over the whole range of jolting times studied, but with the C.J.S. machine compaction increased rapidly with increase in jolting time up to 30 s, but little additional compaction was obtained by further prolonging the jolting time.

It is common practice to operate a machine of the S.J.S. simultaneous jolt-squeeze type with a short free jolt before the simultaneous jolt-squeeze action. For this reason a further series of moulds was prepared using pre-jolt cycles of 5 and 20 s duration followed by a simultaneous jolt-squeeze action. The bulk densities of the moulds obtained with these actions are shown in Fig. 6. It is apparent that for small moulds of this type the slight increase in compaction achieved by pre-jolt operation is not warranted by the additional time involved in preparing a mould; in fact on the basis of the total time to prepare a mould the use of a pre-jolt cycle for small moulds of this type has no advantage.

2. The compaction of moulds in 16 in x 14 in x 8 in deep boxes

With the 3 in deep boxes and the sphere casting it is a relatively simple matter to produce uniformly compacted moulds. However, most patterns are of more complicated design and necessitate the use of deeper
Fig. 5—Effect of moulding machine action on mould hardness (12 in x 12 in x 3 in box)

Fig. 6—Influence of pre-jolt followed by simultaneous jolt-squeeze action on mould bulk density (12 in x 12 in x 3 in box)

Fig. 7—Design of double step-block pattern for 16 in x 14 in x 8 in box

boxes. For these reasons it is necessary to study compaction characteristics on horizontal and vertical pattern faces at several different levels within a deep mould. In order to do this the double step-block pattern shown in Fig. 7 was developed. This pattern provides a 3 in wide, 6 in deep cut between two step-blocks; the step-blocks themselves being designed to provide information on compaction at depths up to 6 in from the box parting line. Castings were not produced from this pattern which was intended only for the study of compaction characteristics.

The moulding sand composition and the technique of weighing moulds to determine bulk density were similar to those employed in the previous experiments. In this case, however, a detailed hardness survey was carried out on all vertical and horizontal mould faces. A 6 in upset frame of sand was used in preparing each mould. For certain of the operations, i.e. simultaneous jolt-squeeze, this upset was insufficient for the longer jolting cycles and additional sand was necessary. The machine actions considered remained the same as for the previous section of the investigation; each action was considered over jolting cycles extending from $7\frac{1}{2}$ s to 2 min. The results of this work, in terms of mould bulk density, are illustrated in Fig. 8.

The conclusions drawn from these results are:
(1) The level of bulk density obtained with this combination of pattern and moulding box is considerably less than that achieved with the more shallow 3 in deep boxes; the maximum bulk density obtained with the step-block pattern was only 1.38 g/cm³ as compared with a maximum of 1.53 g/cm³ for the 3 in deep boxes.
(2) The degree of mould compaction, in terms of bulk density, decreases as the actions changed in the following order:

Pre-jolt followed by simultaneous jolt-squeeze, S.J.S.

Consecutive jolt-squeeze C.J.S.

Single squeeze,

Free jolt, C.J.S., and

Free jolt, S.J.S.

With one important difference this is a similar order to that obtained with the 3 in boxes. The exception is the advantageous effect of pre-jolting before the simultaneous jolt-squeeze operation; on a time basis better compaction is now achieved by incorporating a period of pre-jolt in the compaction cycle, and the maximum compaction obtainable is also appreciably higher when the simultaneous jolt-squeeze action is preceded by a period of free jolting.

(3) With each action except plain single squeeze, mould compaction increased with increase in the duration of the operation.
The bulk density values reported give an overall picture of the compaction achieved but important differences exist in the uniformity of compaction obtained with the various actions which are not revealed by the bulk density measurements. For example, with a time of 30 s, the S.J.S. simultaneous jolt-squeeze action produced a mould of density 1.27 g/cm³ in comparison with 1.23 g/cm³ achieved by the C.J.S. consecutive jolt-squeeze action. However, hardness surveys showed that the uniformity of compaction in the two moulds differed considerably and the S.J.S. mould was not consistently harder at all locations than the corresponding C.J.S. mould. In fact in the pockets between the vertical faces of the pattern and the walls of the moulding box the hardness values of the moulds produced on S.J.S. were appreciably lower. The difference in hardness and uniformity can be seen in the illustrations shown, in Figs. 9 and 10. The reason why these differences were not shown up by the bulk density measurements is that they were overshadowed by other effects. If Figs. 9 and 10, showing the hardness surveys, are studied, it is found that compaction next to the squeeze head is greater with the simultaneous jolt-squeeze action than with the consecutive jolt-squeeze action. Since there was a 2 in depth of sand between the top of the pattern and the top surface of the mould, the higher bulk density of this sand more than counteracts the lower bulk density of the sand between the vertical faces of the pattern and the moulding box walls.

The uniformity of compaction achieved with the simultaneous jolt-squeeze action can be markedly increased by having a period of free jolt prior to the main action. An example of this is shown in Fig. 11, and the hardness values indicate that the general level of mould compaction is higher and more uniform with the pre-jolt. The reason for this improvement is that the free jolt action gave adequate compaction near to the pattern plate.

However, the most effective method of increasing the degree of compaction of these moulds is to raise the air line pressure. With each of the moulding actions studied it was found that raising the air line pressure to 120 lb/in² increased the degree and uniformity of compaction of the moulds. This is shown in Fig. 12 for a mould produced on the S.J.S. machine with a 30 s pre-jolt and 30 s simultaneous jolt-squeeze using an air line pressure of 120 lb/in² as compared with 90 lb/in² used for the mould in Fig. 11.

3. Kelt block castings in 9 in deep boxes
Castings were not made with the double step pattern used in the previous experiments, so further experiments were carried out using an 8 in deep keel block rammed in a 12 in × 12 in × 9 in flask; the weight of this casting is approximately 45 lb. The full range of actions of the S.J.S. and C.J.S. machines was employed in preparing a series of moulds whose bulk density varied

Fig. 10—Mould hardness distribution; compaction by C.J.S. 30 s consecutive jolt-squeeze action, 90 lb/in² air line pressure.
TABLE III  Moulding sand properties, Erith silica sand bonded with Wyoming bentonite

<table>
<thead>
<tr>
<th>Clay content, %</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content, %</td>
<td>1.7</td>
<td>2.0</td>
<td>2.5</td>
<td>3.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Green compression strength, lb/in²</td>
<td>3.8</td>
<td>8.0</td>
<td>14.0</td>
<td>18.2</td>
<td>25.8</td>
</tr>
<tr>
<td>Dry compression strength, lb/in²</td>
<td>39</td>
<td>39</td>
<td>45</td>
<td>87</td>
<td>87</td>
</tr>
<tr>
<td>Shatter index</td>
<td>44</td>
<td>54</td>
<td>70</td>
<td>126</td>
<td>100</td>
</tr>
<tr>
<td>Permeability no.</td>
<td>165</td>
<td>150</td>
<td>136</td>
<td>136</td>
<td>88</td>
</tr>
</tbody>
</table>

from 1.58 to 1.24 g/cm³. Castings obtained from these moulds differed appreciably in terms of dimensional accuracy and volume of shrinkage, the ranges being as follows:

- Keel dimension 0.018 to 9.17 in over pattern dimension.
- Feeder head pipe volume 89m³ to 198m³.

The castings became larger and as a consequence the volume of shrinkage increased as the bulk density of the mould decreased. These relationships are shown in Figs. 13 and 14. An indication of the improvement in dimensional accuracy and soundness that can be achieved in this casting by raising the bulk density of the mould is given by the sections of the two keel blocks shown in Fig. 15.

It should be noted that the composition of the moulding sand and that of the metal were the same as those used in the earlier sections of this investigation.

Moulding sand composition and dimensional accuracy

A second approach to the problem of reducing mould wall movement is to vary the composition of the moulding sand. There is no doubt that a specific treatment made to a foundry system sand with the object of reducing mould wall movement, would be a practical proposition in all foundries possessing adequate means of sand control. The production of such a moulding sand requires firstly an assessment of the effects of the common variables in a green sand mixture, i.e. water and clay contents, on mould wall movement and secondly the investigation of materials which could be added to a moulding sand with the specific intention of reducing mould wall movement.

There is published information to suggest that mould wall movement and consequently casting dimensions are strongly influenced by moulding sand composition. Investigators are in general agreement on the need for low water contents and the benefits of adding carbonaceous materials such as coal dust to green moulding sands. On the subject of clay content there is some disagreement, and it is probable that the type of clay employed has an important bearing on the extent of mould wall movement.

However, much information is still required before a quantitative assessment can be made of the extent to which mould sand composition, additions and physical properties influence mould wall movement. This information can only be obtained from direct measure-

TABLE IV  Physical properties of Erith silica sand bonded with various clays

<table>
<thead>
<tr>
<th>Clay type</th>
<th>Water content, %</th>
<th>Green compressive strength, lb/in²</th>
<th>Shatter index</th>
<th>Permeability no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% Wyoming bentonite</td>
<td>1.8</td>
<td>9.0</td>
<td>32</td>
<td>50</td>
</tr>
<tr>
<td>6% calcium</td>
<td>2.2</td>
<td>6.7</td>
<td>57</td>
<td>62</td>
</tr>
<tr>
<td>montmorillonite</td>
<td>2.9</td>
<td>6.8</td>
<td>58</td>
<td>62</td>
</tr>
<tr>
<td>5% clay A</td>
<td>3.8</td>
<td>4.3</td>
<td>4.1</td>
<td>97</td>
</tr>
<tr>
<td>5% clay B</td>
<td>2.0</td>
<td>11.2</td>
<td>7.5</td>
<td>63</td>
</tr>
<tr>
<td>6% calcium</td>
<td>2.4</td>
<td>5.6</td>
<td>60</td>
<td>55</td>
</tr>
<tr>
<td>montmorillonite</td>
<td>3.4</td>
<td>4.2</td>
<td>90</td>
<td>57</td>
</tr>
<tr>
<td>5% clay A</td>
<td>3.8</td>
<td>3.5</td>
<td>105</td>
<td>55</td>
</tr>
<tr>
<td>5% clay B</td>
<td>2.0</td>
<td>11.2</td>
<td>7.5</td>
<td>63</td>
</tr>
</tbody>
</table>

TABLE V  Data for malleable iron castings produced in Redhill H sand bonded with Wyoming bentonite

<table>
<thead>
<tr>
<th>Sand composition</th>
<th>Casting data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content, %</td>
<td>Pitch addition, %</td>
</tr>
<tr>
<td>3% Wyoming bentonite</td>
<td>1.4</td>
</tr>
<tr>
<td>2.3</td>
<td>3.0</td>
</tr>
<tr>
<td>5.0</td>
<td>3.005</td>
</tr>
<tr>
<td>10% Wyoming bentonite</td>
<td>3.7</td>
</tr>
<tr>
<td>4.9</td>
<td>7.5</td>
</tr>
<tr>
<td>5.5</td>
<td>3.010</td>
</tr>
<tr>
<td>3% Wyoming bentonite</td>
<td>1.4</td>
</tr>
<tr>
<td>2.4</td>
<td>2.444</td>
</tr>
<tr>
<td>3.1</td>
<td>2.045</td>
</tr>
<tr>
<td>10% Wyoming bentonite</td>
<td>3.9</td>
</tr>
<tr>
<td>4.8</td>
<td>3</td>
</tr>
<tr>
<td>5.5</td>
<td>3</td>
</tr>
</tbody>
</table>
TABLE VI Compositions and properties of sands used for high pressure moulding

<table>
<thead>
<tr>
<th>Wyoming bentonite, %</th>
<th>Water compress-compression, lb/in²</th>
<th>Green compress-compression, lb/in²</th>
<th>Permeability, index</th>
<th>Shatterability, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1-5</td>
<td>3-2</td>
<td>42</td>
<td>48</td>
</tr>
<tr>
<td>5</td>
<td>2-2</td>
<td>7-9</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td>10</td>
<td>3-6</td>
<td>18-0</td>
<td>67</td>
<td>97</td>
</tr>
<tr>
<td>20</td>
<td>5-3</td>
<td>30-1</td>
<td>120</td>
<td>100</td>
</tr>
</tbody>
</table>

(2) A synthetic sand, based upon Erith silica sand bonded with 5 per cent Wyoming bentonite, was used in preference to a natural clay-bonded sand because of the closer control possible over composition and properties. Each sand was freshly prepared from base materials.

(3) For the major part of the investigation a nodular graphite iron of the following composition, cast at 1350°C was used:

T.C., % Si, % Mn, % S, % P, % Ni, % Mg, %

3.5 2.0 0.5 0.012 0.02 0.03 0.05

Certain experiments were repeated using a blackheart malleable iron, the composition of which was:

T.C., % Si, % Mn, % S, % P, %

2.25 1.2 0.35 0.10 0.03

and for this iron the pouring temperature was raised to 1480°C.

(4) As a control a mould made from a standard sand mixture and compacted using the standard action was included in each experiment.

Since the metal composition, pouring temperature and mould preparation technique were kept constant, the mean diameter of each pair of spheres was a measure of the relative ability of each type of moulding sand to produce dimensionally accurate castings, i.e. a measure of mould wall movement.

The extent to which mould wall movement can occur, given these ideal experimental conditions, is shown in Fig. 16. This shows that casting dimensions varied over the range 2-966 in to 3-061 in, with a corresponding variation in the volume of shrinkage present. This was the direct consequence of the changes in moulding sand composition which are discussed in the following sections. It should be noted that the pattern is a true sphere of diameter 3-000 in.

Effects of additions on mould wall movement:

The most common variable in a foundry moulding sand is the water content and there are quite wide limits, depending upon the clay content and type, to the water contents that can be used in a sand to produce acceptable moulds. For this reason alterations in mould wall movement which resulted from incorporating additives in a sand mixture had to be studied over a wide range of water contents.

Water content and carbonaceous additions

With the base sand mixture containing 5% Wyoming bentonite, the limits of water content were 1-8% and 4-3%. Within this range mould wall movement increased progressively as the water content increased and casting dimensions increased over the range 3-010 in to 3-052 in. A further series of sands was then prepared which contained additions of 2, 4 and 6% coal dust by weight. The following important points emerged from these experiments, the results of which are shown in Fig. 17.

(1) With each sand mixture casting dimensions increase with rise in water content.

(2) At a constant water content an increase in coal dust content reduced casting dimensions.

However there are important side effects of adding coal dust to green moulding sands. These are changes that occur in the physical properties of the sand (see Figs. 18 and 19) to which its moulding characteristics can be related. The properties which confer mouldability on a sand are green compression strength and green deformability. The mould must have sufficient green strength so that it will not collapse under its own weight and the deformability of the sand must permit the mould to be stripped from the pattern without cracking. The green compression strength of a sand is measured as a routine test but the green deformability is not. Parke, however, has shown that the product of green strength and deformability is proportional to the toughness of a sand, and toughness under impact is measured by another routine test, the shatter index. Thus, if the shatter index of a sand is constant an increase in green compression strength will indicate a decrease in green deformability. On the other hand, if the green compression strength is constant but the shatter index of a sand decreases, this again is indicative of a decrease in green deformability. To return to the sands in question it will be seen from Figs. 18 and 19 that the green strength/sand and shatter index/water curves move in the direction of higher water content as a consequence of adding coal dust. Thus to retain a mouldable sand the water content must be increased when coal dust is added to a sand. In part these changes in properties can be explained by the adsorption of water by the coal dust, thereby reducing the water available for bonding with the clay. However the changes in effective water content do not fully explain the large reductions in casting dimensions that occur when an addition of coal dust is made to a moulding sand.

Some of the reduction in casting dimensions must occur due to the carbonaceous nature of the coal dust and the high temperature reactions that occur in contact with hot metal immediately after pouring. This is clearly demonstrated when additions of 2 and 3%
Fig. 11—Mould hardness distribution; compaction by S.J.S. 30 s pre-jolt followed by 30 s simultaneous jolt-squeeze action, 90 lb/in² air line pressure

Fig. 12—Mould hardness distribution; compaction by S.J.S. 30 s pre-jolt followed by 30 s simultaneous jolt-squeeze action, 120 lb/in² air line pressure

Pelleted pitch are substituted for coal dust in a moulding sand. It was found that these additions greatly reduced mould wall movement in sands with water contents ranging from 1-8 to 4-3%. The extent of the improvement in the dimensions of the 3 in diameter test casting is shown in Fig. 20, castings as small as 2.986 in diameter being obtained. An interesting effect of the addition of pitch is the comparatively slight effects produced on moulding properties, see Figs. 21 and 22. Additions of 2% pitch had very marginal effects on the green strength/water and shatter index/water relationships. It is evident that pitch has at least two valuable properties when added to a moulding sand: it permits low moisture content sands to be used which retain good moulding characteristics and in addition reduces mould wall movement in greensand moulds.

Woodflour and peat

Woodflour and peat are added to green moulding sands with the express intention of preventing the occurrence of expansion type defects such as scabs and ruffles. Experiments involving additions of 1% woodflour and 3% peat showed that both of these materials effect an improvement in casting dimensions, the extent of which is apparent from Fig. 23. Both woodflour and peat affect the physical properties of a moulding sand in much the same manner as has been reported for coal dust additions, i.e. the sand property/water curves are displaced in the direction of higher water content. Obviously woodflour and peat are valuable moulding sand additives since they prevent expansion type defects and at the same time reduce mould wall movement.

Clay concentration

Fluctuations in clay concentration are a problem facing foundries employing either natural or synthetic moulding sands. To determine to what extent wide changes in clay concentration affect mould wall movement a series of synthetic sands was prepared containing 3, 5, 7, 10 and 20% Wyoming bentonite. Using these sands the relationships between casting dimensions and water content shown in Fig. 24 were obtained. At each particular clay concentration the usual increase in casting dimensions consequent on raising the water content is apparent, but particular attention should be paid to the position of curves relative to one another. Within the ranges of water contents studied the effect of increasing the clay concentration is merely to displace the curves in the direction of higher water content but—and this is most important—the size range over which casting dimensions vary is the same for the whole series of sands. The water contents used in these sands were such that the highest and lowest values were on the wet and dry

Fig. 13—Relationship between heel block dimensions and mould bulk density (12 in × 12 in × 9 in box)
sides, respectively, of the water contents that would normally be used for greensand moulding.

From the practical viewpoint what is of most importance is the dimensions of castings produced in the moulds made from the sands of different clay contents, at the water contents at which they would be used in a foundry. In previous work with Erlite silica sand bonded with Wyoming bentonite it was found that at clay contents of 3, 5, 7, 10 and 20%, optimum water contents were 1.8, 2.2, 2.6, 3.2 and 5.4%, respectively.

![Fig. 15-Sections of heel block castings A and B; mould bulk density g/cm³, A 1.58; B 1.24](image)

![Fig. 14—Relationship between volume of pipe defect in heel block castings and mould density (12 in × 12 in × 9 in box)](image)

![Fig. 16—Overall relationship between casting size and volume of top surface pipe in sphere casting](image)

If sphere diameters corresponding to these water contents are read off from Fig. 24, values of 3.028, 3.025, 3.029, 3.027 and 3.028 in are obtained. Thus, in the present experiments, if the sands of different clay contents are considered at these water contents the actual clay content has no effect upon mould wall movement.

To confirm this conclusion a series of sands was prepared all bonded with Wyoming bentonite but with clay contents of 3, 5, 7, 10 and 20%. The water contents of these sands were chosen with reference to Fig. 24 and were such that moulds produced in the sands should have identical stabilities. The dimensions of the sphere test castings confirmed that the mould wall movements that occurred with moulds produced from the sands were very similar, i.e.:

<table>
<thead>
<tr>
<th>Clay concentration, %</th>
<th>Water content, %</th>
<th>Casting diameter, in</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1.7</td>
<td>3.016</td>
</tr>
<tr>
<td>5</td>
<td>2.0</td>
<td>3.014</td>
</tr>
<tr>
<td>7</td>
<td>2.5</td>
<td>3.018</td>
</tr>
<tr>
<td>10</td>
<td>3.5</td>
<td>3.022</td>
</tr>
<tr>
<td>20</td>
<td>5.1</td>
<td>3.020</td>
</tr>
</tbody>
</table>

It is particularly important to consider the physical properties of these sands, see Table III, since although when compacted under standard conditions they produced moulds with almost identical mould stabilities,
the physical properties of the sands, as determined in the laboratory, varied over a wide range; the green compression strength from 3.8 to 25.8 lb/in², the dry compression strength from 39 to 87 lb/in² and the shatter index from 44 to 100. This suggests that there is no direct relationship between the physical properties of a moulding sand, as determined by the conventional routine tests, and its ability to make moulds in which dimensionally accurate castings can be produced.

These results must, however, be treated with caution. In this work the pattern used was a particularly simple one and uniformly compacted moulds were easily prepared with each of the sands by using the jolt-squeeze action. It is doubtful whether with a more complex pattern the jolt-squeeze action would be capable of producing uniformly compacted moulds, particularly with the sands of high clay content (and therefore high green strengths and shatter indices). With these high clay content sands an increase in mould wall movement could be expected due to a reduction in bulk density.

Clay type

What happens when the type of clay is changed from a Wyoming bentonite (naturally occurring sodium montmorillonite) to one of the other clays used in the foundry industry, such as natural calcium montmorillonite or chemically produced sodium montmorillonite? There are many reports⁸ and claims that casting quality can be affected by the particular type of clay used in a moulding sand, so it was necessary to include a consideration of some of these clays in the present investigation.

Sands were prepared in which 5% Wyoming bentonite was replaced by either 6% calcium montmorillonite or 5% of chemically produced sodium montmorillonites (clays A and B). Each type of moulding sand was again studied over a wide range of water contents and Table IV shows the physical properties of the sands. As would be expected these properties show that the sands bonded with the chemically treated clays have the highest green compression strengths. Sphere castings were produced in these sands and from the relationships shown in Fig. 25 it is apparent that clay type has an appreciable effect upon casting dimensions. At a constant water content mould wall movement was greatest using the sands bonded with the calcium montmorillonite, and least when the two chemically treated clays were used, the moulds prepared with sands containing Wyoming bentonite occupying an intermediate position.

Although these experiments involving changes in moulding sand composition were limited to considering a nodular graphite iron and synthetic sand mixtures, it is considered that the results apply more widely and are generally valid for natural clay-bonded greensands and all grey iron compositions. This opinion is based on the results of this and previous investigations, one of which was concerned with a combination of natural sands and flake graphite irons, where in all cases there was a reduction in shrinkage type defect as the extent of mould wall movement decreased.

MOULD WALL MOVEMENT WITH WHITE CAST IRONS

All previous examples of mould wall movement phenomena have applied to grey cast irons, but recently it has been shown that extensive mould wall movement can occur with white cast irons. This work employed a
blackheart malleable iron of the following composition:

<table>
<thead>
<tr>
<th>T.C.</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.25</td>
<td>1.2</td>
<td>0.35</td>
<td>0.10</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Although the 3 in sphere was retained as the test casting, the moulding sand was changed to a synthetic mixture based upon Redhill H silica sand bonded with Wyoming bentonite. Several series of sands of increasing water content were prepared using 3% and 10% concentrations of clay; a replicate series of sands was then prepared containing additions of 3% pelleted pitch. The compositions of the sands and the data concerning the test castings are shown in Table V. The changes in casting dimensions that occurred with each type of moulding sand composition are illustrated in Fig. 26. It is apparent that, for a particular type of sand mixture, raising the water content results in a progressive increase in mould wall movement and casting dimensions. The most noticeable reduction in mould wall movement resulted from adding pelleted pitch to the various sand mixtures. All the results follow closely the trends already established for grey iron and, in a similar way, a reduction in mould wall movement improves casting soundness. As proof of this the volume of top surface shrinkage in the malleable iron castings decreased from 9.8 cm³ to 2.3 cm³, as the casting dimensions diminished over the range 3.010 in to 2.931 in; this relationship is illustrated in Fig. 27. For comparison purposes it should be noted that a casting of the same composition poured in a dry sand mould had a diameter of 2.938 in and contained a pipe defect of 3.3 cm³.

From the preceding work with both grey and white cast irons it is apparent that the extent of mould wall movement, as measured by changes in casting dimensions, is very dependent upon moulding sand composition. The overall ranges in casting dimensions, from 2.986 in to 3.051 in (a difference of 0.075 in) for the grey iron and 2.931 in to 3.010 in (a difference of 0.079 in) for the white iron, are the best indications of the magnitude of this effect. It is difficult to interpret this reduction in mould wall movement in general terms applicable to a wider range of castings. However, it seems probable that, by appropriate control of sand composition, mould wall movement could be reduced to an extent that castings would be obtained with a degree of dimensional accuracy comparable to that now achieved from dry sand practice. This view is based on evidence from the present investigations since castings have been obtained from greensand moulds having dimensions very similar to those obtained from dry sand moulds, i.e.:

<table>
<thead>
<tr>
<th>Casting dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Greensand mould</strong></td>
</tr>
<tr>
<td>Grey nodular graphite iron</td>
</tr>
<tr>
<td>White malleable iron</td>
</tr>
</tbody>
</table>

In view of these results, what changes in moulding sand composition should foundries consider as a means of reducing mould wall movement? This problem faces all foundries using greensand practice whether the sand is naturally bonded or a synthetic type. The first object must be to produce a sand of constant composition,
especially in regard of water content. The simplest change in sand composition, yet probably the most effective in reducing mould wall movement, would be a reduction in water content as far as is consistent with the retention of good moulding characteristics. The additives discussed in this report are common constituents of green moulding sands and are normally present either to improve surface finish or reduce expansion type defects. It has now been shown that materials such as coal dust, peat, and wood flour, have the added advantage of reducing mould wall movement but use of these materials may necessitate slightly higher water contents to maintain good moulding characteristics. In this respect pelleted pitch additions have an advantage since the moulding properties of a sand are hardly affected and low water contents can be used. With white and malleable cast irons some caution is necessary, since it has recently been shown that hot tear defects are sensitive to changes in moulding sand composition and may be severe in pitch-containing sands. Small variations in clay concentration are not likely to affect mould wall movement provided that the water content is altered accordingly. Changes in the type of clay will be of concern only to foundries using synthetic mixtures and in this connection the use of chemically-treated sodium montmorillonite clays, instead of naturally occurring sodium and calcium montmorillonites, is favoured because of the reduced tendency for mould wall movement.

HIGH-PRESSURE SQUEEZE MOLDING

The experimental results in the previous section of this paper have shown that one way of reducing mould wall movement, and therefore improving casting accuracy and soundness, is to produce high density moulds.

One method which is claimed to produce such moulds is high pressure squeeze moulding: This is a process which compacts moulds using squeeze pressures of between 100 and 450 lb/in², and to put the process into perspective it must be remembered that with a normal jolt-squeeze moulding machine, the squeeze pressure exerted on the mould is generally of the order of 30 lb/in².

High pressure squeeze moulding is at present arousing considerable interest in the foundry industry since its aims are to form, at high rates of production, dense compacted green sand moulds in which castings of high quality can be produced. However, basic data are still required before a complete evaluation of this moulding method can be realized and, from the moulding materials and casting quality viewpoint, information is required on the following aspects:

1. The extent to which wall movement occurs in moulds compacted by squeeze pressure.
2. The degree of compaction achieved with different squeeze pressures.
3. The properties of moulds compacted by squeeze pressure.

FIG. 25—Influence of the type of bonding clay on casting size
The response of different sands to compaction by squeezing has been obtained using several different experimental techniques. These have involved studying the properties of sand compacts produced at squeeze pressures up to 1,600 lb/in² and preparing 12 in × 12 in × 3 in moulds at squeeze pressures up to 400 lb/in². The work culminated in the production of 37 in × 31 in × 8 in deep moulds using one of the commercial high pressure squeeze moulding machines now coming into use in the ironfoundry industry.

Results

Pressure squeeze compaction of 12 in × 12 in × 3 in moulds

In these experiments, hydraulic pressure was used to compact the moulds using a modified tensile test machine shown in Fig. 28. With this machine squeeze pressures up to 400 lb/in² upon the mould surface were employed for the production of 12 in × 12 in × 3 in moulds. This is equivalent to a total load of 25-8 tons.

The experimental technique involved raising the horizontal cross beam, pattern, moulding box and sand against a fixed squeeze head which consisted of an 11 in square steel plate rigidly attached to the cross head of the machine. After the required squeeze pressure was applied, the mould was stripped by clamping the moulding box to the head of the machine and lowering the beam and pattern to the rest position. The nodular graphite composition iron and the 3 in sphere test casting employed for the work with the conventional action moulding machines were retained in the present experiments.

The sand used for this work was a synthetic sand consisting of Erith silica sand bonded with Wyoming bentonite. The moulding sands studied were selected after preliminary tests with 2 in high by 2 in diameter compacts produced by squeeze pressures up to 1,600 lb/in². In these experiments a wide range of sand compositions was studied, the clay contents varying from 3–20%, Wyoming bentonite. The curves relating squeeze pressure and mould hardness for each of these sands are reproduced in Fig. 29. It was concluded from these curves that there was no practical advantage in using sands of clay content higher than 10%, and also that 400 lb/in² would be the maximum pressure studied in the subsequent experiments since the majority of the property changes occurred below this squeeze pressure. The compositions and properties of these sands are listed in Table VI.

In view of the large differences in moulding sand composition that were involved measurements of mould bulk density were omitted. Instead the quality of each mould was assessed by hardness surveys at fixed locations on the parting faces of cope and drag sections of the mould. As in the previous experiments the extent of the mould wall movement occurring was determined indirectly from measurements of sphere casting diameter.

With each composition sand a series of moulds was prepared using the following squeeze pressures:

- 50 lb/in²
- 100 lb/in²
- 200 lb/in²
- 400 lb/in²

Fig. 26—Relationship between dimensions of white iron castings and moulding sand composition

Fig. 27—Relationship between top surface pipe volume and white iron casting size
The changes in casting dimensions corresponding to the different sand compositions and squeeze pressures are shown in Fig. 30. The following important conclusions may be drawn from this:

1. With each composition sand an increase in squeeze pressure results in a decrease in casting size. Most of the reduction in casting dimensions occurs before the squeeze pressure reaches 200 lb/in².

2. At any squeeze pressure raising the clay concentration reduced mould wall movement and casting dimensions. This is most pronounced at the higher squeeze pressures. It should be noted that castings true to pattern size were only obtained using the strongest sand at squeeze pressures in excess of 200 lb/in².

The relationships between mould hardness and squeeze pressure, see Fig. 31, are of great interest since they show that although mould hardness rises with increase in squeeze pressure there is a maximum hardness that can be developed for each particular sand. This maximum hardness is higher the greater the clay concentration in the moulding sand.

As might be expected from the results reported in previous sections linear relationships exist between mould hardness and casting dimensions, Fig. 32, for each of the sands studied. It is important to note that the relationship is not the same for each sand and that the mould hardness corresponding to a particular casting size, and therefore to a particular amount of mould wall movement, increases as the clay content of the sand increases; for example in the present experiments castings of 3-025 in diameter were obtained under the following conditions:

<table>
<thead>
<tr>
<th>Clay content, %</th>
<th>Mould hardness no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>5</td>
<td>79</td>
</tr>
<tr>
<td>10</td>
<td>87</td>
</tr>
</tbody>
</table>

High pressure moulding machines

The preceding experiments have shown that by using pressure squeeze compaction techniques mould wall movement can be reduced. This work was limited to ramming simple contour moulds in 12 in × 12 in × 3 in boxes, and information is now required regarding the quality of moulds produced from more complex patterns by pressure squeeze moulding. This information was obtained using a commercial design of high pressure moulding machine.

There are several types of machine currently available which are intended to operate at squeeze pressures of 200 lb/in² and above. These machines are either entirely hydraulic in operation or rely on a combination of hydraulic and pneumatic operations to achieve the necessary squeeze compaction. Apart from the technique of applying squeeze pressure to a mould, the essential difference between the various machines is the provision of either a flat squeeze head or a self-contouring squeeze head. The machine used in this work is shown in Fig. 33, producing a mould in a 37 in × 31 in × 8 in deep box.

The principle of the machine is that squeeze pressure is applied to the back of a mould area a series of small feet each of which is actuated by a separate hydraulic cylinder. These feet form a self-contouring squeeze head.

![Fig. 28](image1.png)  
**Fig. 28**—Test rig for high pressure squeeze moulding

12 in × 12 in × 3 in boxes using pressures up to 400 lb/in².

![Fig. 29](image2.png)  
**Fig. 29**—The effect of clay content upon the squeeze pressure/mould hardness relationship.

![Fig. 30](image3.png)  
**Fig. 30**—The effect of sand composition and squeeze pressure on casting size.
Fig. 31—The effect of squeeze pressure on mould hardness. Since these feet are forced into the moulding sand by hydraulic pressure, they automatically adjust themselves according to pattern contour. The particular machine used for these experiments employed 48 squeeze feet, each of \( 4\frac{1}{2} \times 4\frac{1}{2} \) in area, arranged in an 8 ft \( \times \) 6 ft block. When the moulding box was in position the squeeze feet descended on to the back of the mould applying full squeeze pressure, which in the present experiments was a uniform pressure of 200 lb/in\(^2\) over the mould area. The extent of the self-contouring that occurs is apparent from Fig. 34 which illustrates the reverse side of a mould.

Two step-block patterns, one of which was previously used with the conventional action machines, were mounted on the pattern plate as shown in Fig. 35 to provide a suitable pattern for the 37 in \( \times \) 31 in \( \times \) 8 in deep moulding box used on the pressure squeeze machine. The degree of compaction was assessed by hardness surveys at vertical and horizontal faces throughout the mould and by trepanning sections through each mould to determine local bulk densities. As shown in Fig. 35 these were at critical locations in the mould, such as the cod between the two six inch deep pockets (X2) and near to the moulding box wall (X3) and box corner (X4).

The Redhill H sand bonded with 7% Wyoming bentonite, previously used for the experiments with conventional action machines, was again used for this experiment with the pressure squeeze machine. The degree of compaction achieved with the double step pattern at a squeeze pressure of 200 lb/in\(^2\) is shown by the mould hardness values in Fig. 36. The bulk densities in the four samples trepanned from this mould were:

- Location: X1 Centre between patterns
  - Bulk density, g/cm\(^3\): 1.56
- Location: X2 Middle of cod section
  - Bulk density, g/cm\(^3\): 1.51
- Location: X3 1 in from box wall
  - Bulk density, g/cm\(^3\): 1.58
- Location: X4 Corner of moulding box
  - Bulk density, g/cm\(^3\): 1.59

and indicate the uniformity of mould compaction obtained.

The moulding sand used to produce this mould is typical of one that would be used with normal moulding machines. However work at the BCIRA has indicated that if the best results are to be obtained with high pressure squeeze moulding then special sands should be used. This is evident from Fig. 31, since raising the clay content of a moulding sand over the range 3%–10% increases the response of the sand to squeeze pressure. Instead of raising the clay content, recent work\(^{18}\) has shown that another method of producing a moulding sand which is responsive to squeeze compaction is to incorporate dextrin in the sand mixture.

The previous experiment was therefore repeated using a dextrin-containing sand of the following composition:

---

Fig. 32—The effect of clay content upon the relationship between mould hardness and casting size.
Fig. 34.—Back surface of mould produced by high pressure squeeze machine at 200 lb/ft² squeeze pressure

Redhill 11 silica sand
7% Wyoming bentonite
1% dextrin
2.7% water

The physical properties of this mixture are described in Table VII. Using this dextrin-containing sand and a squeeze pressure of 200 lb/ft² mould hardness increased at every location in the mould, see Fig. 37. The most important increase in hardness occurred on vertical faces and in the 6 in deep cod hardness increased by as much as 7 points.

The experiments with the commercial design of pressure squeeze machine were limited to examining the quality of the moulds by hardness and bulk density methods. At this stage of the investigation it was not possible to produce castings appropriate to the large size of moulding box involved.

To what extent then is casting quality likely to be improved by using sands which are especially sensitive to squeeze compaction? To answer this question it was necessary to produce moulds in 12 in x 12 in x 3 in boxes using the modified tensile test machine and to pour sphere castings in sands with and without a dextrin addition. Using an Erith silica sand bonded with 5% Wyoming bentonite as the base mixture the following results were obtained:

<table>
<thead>
<tr>
<th>Mould hardness diameter, in</th>
<th>Casting hardness</th>
<th>Casting weight, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>No dextrin addition</td>
<td>86</td>
<td>3.011</td>
</tr>
<tr>
<td>1% dextrin addition</td>
<td>95</td>
<td>2.998</td>
</tr>
</tbody>
</table>

From these and the preceding results it is clear that foundries wishing to obtain the maximum benefit from high pressure squeeze moulding machines must pay special attention to the control and composition of their moulding sands. This will be necessary for another reason. Expansion type defects, such as scabs and rat-tails, are common on castings which have been poured into high density greensand moulds. It is common experience that ramming moulds hard is likely to increase the severity of this type of defect. This is well illustrated by the series of 8 in x 8 in blocks shown in Fig. 31. The moulds for these castings were rammed in a sand of constant composition using jolt-squeeze and pressure squeeze machines to obtain moulds, the hardness values of which varied within the range 50 to 92. Scabbing was most severe with the two moulds rammed on the squeeze machine at pressures of 100 lb/ft² and 400 lb/ft² to hardness values of 85 and 92 respectively.

There are two remedies to this type of defect, to ram...
softer or make an appropriate addition of an anti-scabbing material to the sand. However, to the foundry interested in producing quality castings there is only one possible line of action—to ram moulds hard and include an appropriate anti-scabbing additive in the moulding sand mixture. Two materials which are in common use for this purpose are woodflour and ground peat. The result of adding either 2% woodflour or 2% ground peat to the sand used for the 3in × 8in blocks is shown in Fig. 39. Both moulds were produced by pressure squeeze ramming at 400 lb/in², but the castings were free from expansion defects. The presence of the woodflour and peat decreased mould hardnesses to 84 and 88 respectively and, since it had the least effect upon mould hardness, the use of ground peat as an anti-scabbing addition is therefore favoured.


describe conclusions regarding high pressure moulding

There are many practical conclusions that can be drawn from this investigation regarding the successful operation of high pressure squeeze moulding machines for the production of high quality moulds and castings. For convenience sake they are listed below under appropriate sub-headings.

Moulding sand composition and control

(1) Sands of high clay concentration are necessary to
desire moulds of high mould hardness and castings of
close dimensional accuracy. In the interest of economy
and desirable moulding properties there may be practical
limits to the clay concentration, for example in the
present work a 10% clay content was adequate. It is
also necessary to use sands responsive to squeeze
compaction and this is achieved with high clay concen-
trations or additions of dextrin.

(2) Close control of water content is necessary if
moulds of reproducible hardness and bulk density are
to be obtained. Water contents should be lower than
those used for jolt-squeeze moulding.

Design of moulding machines and boxes

(3) Squeeze pressures of 200 to 400 lb/in² are necessary
to develop the full potentialities of a moulding sand.
Unless the production of very deep moulds is contemplated
the power requirements of moulding machines
should be limited to operate within this range of pressures.

(4) Very strong moulding boxes are required which
will only give a small deflection under the applied
squeeze pressure. Failure to meet this requirement will
result in stripping problems and broken moulds.

Mould quality

(5) A very sharp mould definition is obtained by this
method of moulding. Minor imperfections in the pattern
equipment are faithfully reproduced so that high quality patterns are essential.

(6) Moulds of very uniform hardness and density are obtained which are difficult to equal by jolt-squeeze moulding.

Casting quality

(7) Closer dimensional accuracy can be achieved for a particular moulding sand composition than is normally obtained with jolt-squeeze moulding. The accurate reproduction of the spelter pressure is assured.

(8) Castings show a greater freedom from shrinkage defects.

(9) An excellent surface finish is obtained even without the addition of carbonaceous materials to the moulding sand.

DISCUSSION

The extent to which mould wall movement can occur in greensand moulds, and its dependence upon moulding sand composition and compaction, has been examined with the object of providing foundries with basic information so that mould and casting quality can be improved.

Mould wall movement is a subject of major importance to all foundrymen using greensand practice, and the information in this paper is intended as much for the small jobbing foundry as for the large mechanized foundry operating or intending to operate high pressure squeeze moulding machines. Action to reduce mould wall movement is probably the most effective measure that foundries can adopt to reduce scrap caused by shrinkage defects. Very considerable effort is at present directed to controlling metal compositions and pouring temperature as means of combating shrinkage defects, and the same attention must now be paid to controlling moulding sand composition and compaction. There is no doubt that to produce castings of consistent quality it is necessary for foundries to study the preparation of their moulding sand in detail to ensure the production of a sand with good moulding characteristics that will give the minimum mould wall movement. In addition to the work reported in this paper there is considerable information available on the subject of moulding sand composition in relation to mould wall movement18 which should assist all foundries anxious to improve their moulding sand.

From a practical viewpoint what control measures can foundries introduce to reduce mould wall movement? There is only one test, a direct measurement of casting dimensions or weight, which takes into account all factors of sand composition and mould compaction and the present investigation has been based on such measurements. The physical properties of a moulding sand cannot be relied upon as control measures for mould wall movement since they are too dependent upon variations in water and clay contents. In a similar manner measurements of bulk density and mould hardness are meaningless as control tests for mould wall movement if the sand composition varies. Only when moulding sand composition is held to very close compositional limits can determinations of bulk density or mould hardness be employed to predict the extent of mould wall movement.

To revert to the subject of moulding machines and mould production—what other factors will contribute
to a general improvement in mould quality. Reference to Figs. 4 and 8 indicates that optimum compaction with jolt-squeeze action machines is only attained after prolonged jolting cycles. In the case of the simultaneous jolt-squeeze action with the 12 in × 12 in × 3 in moulds, and both the simultaneous and consecutive jolt-squeeze actions with 16 in × 14 in × 8 in moulds, jolting cycles of approximately 30 seconds duration were necessary to achieve optimum compaction. This compares with the following times that have been recorded in several foundries operating similar types of machines:

<table>
<thead>
<tr>
<th>Size of Mould</th>
<th>Jolting Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 in × 12 in × 3 in box</td>
<td>24 s</td>
</tr>
<tr>
<td>19 in × 13 in × 4 in box</td>
<td>24 s</td>
</tr>
<tr>
<td>14 in × 14 in × 4 in box</td>
<td>35 s</td>
</tr>
</tbody>
</table>

To achieve the best results from a particular combination of moulding sand and machine the present machine operating procedure should be critically examined. It is realised that increased jolting or simultaneous jolt-squeeze times may reduce the output from a machine but in special circumstances, where castings of close dimensional accuracy are required, the extra time may be warranted. One simple measure that all foundries could adopt is an increase in air line pressure to pneumatically operated machines. Unquestionably this is the most effective method of improving the compaction characteristics of any moulding machine. It is known that compaction characteristics rapidly fall off as air line pressure decreases or table load increases, but how many foundries know the actual air pressure at a moulding machine or install large air receivers near to machines to ensure an adequate supply of compressed air? Although most moulding machines are rated to operate at 80 or 90 lbf/in² air line pressure far better results could be achieved by operating at higher pressures such as 120 lbf/in². Foundries with compressors capable of delivering air at these higher pressures should discuss with moulding machine manufacturers the practicability of operating particular machines at pressures above the normal machine rating.

The introduction of pressure squeeze moulding machines to the iron foundry industry is already resulting in the production of castings to higher standards of accuracy with considerable saving in metal weight. An example of the economy in metal that can be achieved has been provided by a thin wall, domestic casting which when moulded on a jolt-squeeze machine weighed between 42 and 46 lb but which is now produced by a pressure squeeze moulding technique to a weight of 37½ lb. Although much of the interest in pressure squeeze moulding is currently concentrated in foundries supplying the automobile industry it is certain that many more varied applications for this type of moulding will arise in the future. To cater for this wider interest machines must be developed which are more suitable for use in the smaller type of foundry. Such machines must accept relatively small sized moulding boxes and be capable of installation in foundries which only possess a modest degree of mechanization.

**Conclusions**

1. The quality of iron castings produced from green-sand moulds can be improved if mould wall movement is reduced. Mould wall movement is a general phenomenon occurring to varying extents with all types of grey and white cast irons and with all synthetic and naturally bonded green moulding sands.

2. Mould wall movement can be reduced, with improvements to casting dimensional accuracy and soundness, by increasing the degree of mould compaction and modifying the moulding sand composition.

3. With conventional jolt-squeeze action moulding machines the degree of mould compaction achieved depends upon the type of machine action. With the patterns and moulding boxes used in this investigation mould compaction decreased as the action changed in the following order:

   - Simultaneous shockless jolt-squeeze
   - Consecutive anvil jolt-squeeze
   - Plain squeeze
   - Free jolt

4. With conventional pneumatic operation jolt-squeeze machines uniformly compacted moulds of maximum hardness can only be obtained by using very long jolting cycles and high air line pressures, both of which are far in excess of those normally used in iron foundries.

5. Pressure squeeze moulding, using pressures of 200 to 400 lbf/in² on a mould surface, provides a method of producing moulds of high density and hardness. Since this method of compaction involves a single squeeze operation it is also suited to high rates of production.

6. By close control of the concentration and type of clay in a moulding sand, the use of carbonaceous additions and a low water content, substantial reductions in mould wall movement can be obtained. The compaction obtained with high pressure squeeze moulding techniques can be increased by the use of strong, tough sands obtained with high clay contents and additives.

**Acknowledgments**

The authors wish to express their thanks to the director and council of the British Cast Iron Research Association for permission to publish this work and to the British Moulding Machine Company for the generous loan of a simultaneous jolt-squeeze action moulding machine. Their grateful appreciation is extended also to Pnolec Ltd who provided facilities for experiments with a high pressure moulding machine.

**References**