Metallurgy of steel castings

Earl Joesting McNely
METALLURGY OF STEEL CASTINGS

BY

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A Thesis submitted to the faculty of the School of Mines and Metallurgy of the University of Missouri in partial fulfillment of the work required for the degree of Metallurgical Engineer Rolla, Missouri 1920

Approved by

Chas. Clayton, Associate Professor of Metallurgy and Ore Dressing.
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</tr>
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<td>9-10</td>
</tr>
</tbody>
</table>
This Thesis is in the form of a report of the observations of the author while working in the American Steel Foundries plants in various departments. The parts of the report dealing with Moulding and Inspection of castings were written while in the Indiana Harbor Indiana plant. The parts dealing with the Laboratory and Furnace Operation were written while in the Granite City, Illinois plant. The company owns and operates six other plants but the material covered in this report will, in a general way cover the operations in these plants, also, in which foundry work is carried on.
METALLURGY OF STEEL CASTINGS

BASIC OPEN HEARTH STEEL FURNACE PRACTICE
At first glance, one not acquainted with the situation, might at once say that the whole Foundry depends mostly upon the production of steel. As important a part as the furnaces play, their importance is merely relative and their successful operation depends upon the co-operation of all other departments connected with casting and steel production. In actual production, it is difficult to say whether the furnace man or the molder comes first in importance. Opinions differ.

The best definition of furnace operation can be summed up as hard and hot work. Outside of the melter, highly skilled labor is not an essential.
YARD

Upon the Yard stocking boss and his crew, depends the satisfactory loading, assembling and delivery of heats to the furnace floor. To accomplish this in good form and with sufficient ease, the heats are made up in boxes on buggies. Enough buggies are used to have about three heats and a half in the cycle at a time, i.e., one heat on the platform; one on scales; and one in process of loading. To facilitate easy loading, the ground space in the yard is divided up into numbered sections. Between sections, tracks are laid so that material in any section can easily be loaded into the boxes.

The charge varies with the conditions of the heats, but at this particular time (January) 1917 the yard stock for a heat consisted of the following material.

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pig Iron-Mississippi Valley</td>
<td>14500 lbs.</td>
</tr>
<tr>
<td>Pickands-Brown or Algoma-Rails</td>
<td>8000 lbs.</td>
</tr>
<tr>
<td>Lime</td>
<td>10500 lbs.</td>
</tr>
<tr>
<td>Own &amp; Co-Miscellaneous</td>
<td>3750 lbs.</td>
</tr>
<tr>
<td></td>
<td>14500 lbs.</td>
</tr>
<tr>
<td></td>
<td>5500 lbs.</td>
</tr>
</tbody>
</table>
The lime is as a rule, loaded into the boxes directly from the car, thus saving double handling and storage. Pig Iron and miscellaneous are also thus loaded when possible. The rails are cut into suitable lengths and are loaded as far as possible as broken. The Own & Company consists of heads, gates, ingots and heads, scrap castings, wheels, skulls and drop steel. The heads and gates are picked up from the Foundry. The skulls, drop steel and scrap castings are a bugbear and must be loaded with the drane. This material must be handled on the floor, but it is both cumbersome and dangerous work.

About three hours are required to spot buggies, load, weigh and put same on platform.
OPEN HEARTH OPERATION

It is possible to differentiate the duties of first, second, third helpers and melter. But to show how they work together, a heat will be followed through, both in mechanical working and chemical analysis.

We will assume, that the furnace, the construction of which will be mentioned, has been running, was empty at the time of this operation, the heat on the floor, and ready to charge. The third helper took his place at the door opening apparatus and the charging began. Since the bottom of the furnace was in good condition, anything except the pig iron could have been charged first, depending on what the first helper wished to use. In this instance, four boxes of miscellaneous were charged, followed by the limestone and manganese ore. The manganese ore is added to help make a good slag. It is assumed that it is used to help eliminate the sulphur and make a liquid slag. The quantity is small and outside of helping to make the slag an oxidizing one, it does not play a very important part. In fact, heats run without the ore, are quite as good as those run with it, apparently experience has taught the men that the heats can be run without, as they all consider it so much dump material. The balance of the heat was added as shown by log of heat, but any order would have been O.K.
The oil was left off after the bottom and walls were made up so that it would chill. If the heat is charged too soon, or on a hot bottom, there is danger that the bottom will come up with the lime. As soon as the charger began, the first helper turned on the oil, the burners were raised so that the flame could pass over the piled scrap and a copious flame was sent over it to cut it down sufficiently to allow the addition of the pig. Within an hour, the pig was added. It is not wise to allow the scrap to melt down too far, because upon the addition of the pig in the molten mass, the impurities are violently attacked as the pig melts, causing a forming heat. Such a heat is hard to handle and will inevitably run out of the door. As the metal cut down, the burners were lowered gradually until the bath was level. The oil was reversed during this melting period about every half hour until the lime came up. From then on, it was reversed every 15 minutes, since the metal is covered with a heavy slag and lime coating and the heat is radiated to the walls and roof of the furnace. The air was cut down and the furnace walls watched very closely to keep them from burning. With a little experience, one can judge the correct or safe temperature, by referring the color of the walls to the color
of the flame. The flame at this point is quite white. The walls should be red in comparison. The flame was cut down so that it passed to the edge of the metal and slope. More is not necessary—only a waste.

During this period, the second and third helpers did their work. The second helper wheeled up mud and wood for his runner and the additions for the bath—80% ferro manganese, spiegelisen, 50% ferro silicon, aluminum, titanium, coal and 10% ferro silicon, the quantities of which are elsewhere mentioned.

The mud was made up very soft; the slag and steel cut from the runner and the runner remudded. The runner was set and the joint between the short spout and runner made with dry alum and mud to make it smooth. A wood fire was started in the runner to dry the joint and mudded runner. The runner and joint must be dry. In addition to the work on his own furnace, the second helper must help tap out, take care of tapping holes and do sundry jobs on the other furnaces.

The third helper hauled up fluorspar, bottom material and iron ore; swept the floor, took care of the rabbles and bleeders, opened the doors when necessary and helped on the other furnaces, especially while tapping out and making up walls and heats.

During this melting period, the flame had been busy
oxidizing impurities, sulphur and phosphorus and also the manganese, silicon and carbon. Almost all the silicon and about as much of the phosphorus and manganese as could be oxidized were oxidized and eliminated, while the carbon and sulphur depend on their elimination to a larger extent upon iron ore (hematite) additions. An examination of curves and data sheets will bear out these remarks.

As soon as all the lime was up, the heat was in condition to work. The first helper poured a spoon test into a test block and the second helper cooled and broke for fracture. From the fracture, the melter and first helper approximated the amount of ore to be added. A large quantity was not needed, so was added all at once. Should a larger quantity be required it should be added in two parts, otherwise the reaction will be so great that the heat will foam out of the doors. Unless the carbon is over 50% at this point, no ore is added. It is not absolutely necessary to use ore to obtain a good heat.

The iron ore, besides oxidizing the sulphur, manganese, phosphorus, silicon and carbon, also cuts up the unmelted lime and forms slag.
The reaction between the iron ore and carbon; is in its simplest form thus:

\[ 3C + Fe_2O_3 \rightarrow 3CO + 2Fe \]

and is an end \textit{othermic} reaction.

After the reaction subsided, say 15 or 20 minutes, another test was taken, cooled and fractured as before. This test about .50 or 0.60 carbon was sent to the laboratory for a preliminary test on phosphorus. In case about .02% to .03% phosphorus appears, more lime is added. The whistle was blown for the ladle stopper. The heat was working nicely and the slag began to open up. The bath was boiling or taking the heat and the slag had a creamy appearance. A few shovels of "spar" were added to facilitate the opening. It is not known just what the action of the spar is, but many conjecture. I believe Mr. Hamilton has a theory which is plausible. In general, a basic slag is fluid. The spar thins the slag. Some assume that the slag is more basic on account of this addition.

The first helper knows about how to judge his heat. Another test was taken and treated as before. A piece was sent to the laboratory for preliminary carbon, which was about 26%. Another test was immediately taken,
the whistle blown for the ladle and the 10% ferro silicon, previously broken up, by the second helper, was thrown in.

The Ferro Silicon has about 3-5% carbon content and holds the heat at the carbon content of the last test taken. It holds the heat until the test can be run, the 80% ferro manganese added, the ladle set and the tapping hole dug out. It checks the reduction of carbon by taking the oxygen for its own use as later shown. It also adds heat to the bath as the reaction is exothermic. Tests show that no silicon is gained by the steel from this addition. Carbon can be gained, depending on the length of time the heat is allowed to stand before tapping.

Four minutes after adding the 10% Ferro Silicon, the 80% Ferro manganese was added. Just about the time the manganese was added, two second helpers dug out the tapping hole enough to make it easy and safe to knock out from the front with a bleeder. Eight minutes after addition of manganese, the heat was tapped. It went out on about .25 carbon. As soon as the metal began to run, the melter went back of the furnace and put in ladle additions. The ladle additions are all figured on a .28% to .26% carbon bath content. That is, the manganese and silicon at that
carbon content, are as a rule the same and the additions are figured on that basis. The carbon on the last test was about .25%. The heats are supposed to be somewhere in the neighborhood of .28% carbon. Coal is added to bring this up. A bag of small nut hard coal weighing about 30 lbs. will bring up the steel .04% carbon or 4 points. Twenty pounds of coal were added when about a foot of metal covered the bottom of the ladle.

The shute additions were gradually added in the runner, and must all be in before the slag commences to come because the 50% ferro silicon attacks the basic slag and releases the phosphorus which has been eliminated and puts it back into the metal. The functions of the silicon and manganese additions are later explained. As the ladle filled, a large part of the slag ran over the lip of the ladle into the slag pit. About six inches of slag should remain in the ladle to act as a blanket to hold the heat in the metal. If there is not any slag on the metal, it should be covered with dolomite. As soon as the ladle was full, the cranneman removed it and pouring proceeded.

The second helpers took off the runner. The first helpers began to work on the bottom. The first and most important task is to see that the tapping hole is open and stays open. The heat was clean with very little slag and lime in the bottom. A rabble was put into the middle door.
and the bottom rabbled from end to end to locate any holes. There were no puddle holes. The little remaining slag that would not drain was dried up with bottom material. A rabble was placed in front of the tapping hole, the oil shut off and the front of and tapping hole, dried out by both first and second helpers in their respective places. The hole was shut up immediately with dolomite and an alum plug put in to hold it. The second helper is now ready to do his work for another heat.

While the second helpers were doing the above, closing the hole from the back, the first helper rammed the front of the hole and faced it with slag and syndolag. All the first helpers helped make up the back walls, breasts and bottom. The back walls and breasts were made up with shovels of material. But the breasts and slopes along the slag line were made up with the spoon, the third helpers carrying the material to the spoon. The slag always cuts the walls, slopes and breasts and it is necessary to repair them after each heat. The furnace is now ready to recharge as before outlined.

Understand that conditions on this particular heat approached the ideal, and are not always thus. At times the carbon refuses to come down, or comes down too
fast and it is necessary to add pig iron or spiegel to hold or raise the carbon. It is easier to raise and hold the carbon when it is about .30% than when it is .18 or .20%.

The slags at times refuse to cut up and lays in lumps; the bottom comes up with the lime leaving large puddle holes to be rabbled out and repaired; the tapping hole gets stopped up or is so large it must be piped by the second helpers; the short spout gets filled up, and troubles too many to mention.

One of the most serious troubles is a "boil". It is liable to occur at any place in the bottom, breasts, back walls, slope or tapping hole. If it occurs early in the heat, it is hard to handle and the heat may be lost. I recall seeing a heat boil out of a tapping hole a half hour before time to tap. Suppose a boil should occur on the breast about a half hour before tapping time. Ten percent Ferro Silicon is shoveled into the spot that is boiling to stop it for a time, until the 10% Ferro Silicon melts. As soon as it starts again, more is added until the heat is tapped. Just the other night a heat boiled out through the breasts on #6 furnace. There are other cases worse, but this gives an idea about how much might be handled.
Of the bottom materials used on the floor, the men differ in their opinion as to which they like the best. Next to the magnesite, they like syndolag. The price varies for the material used and it is needless to quote, but will put the materials down in the order in which the price ascends as follows: Raw dolomite, double burned dolomite, magnebrent, syndolag, magdolite, magnesite and kendymag, magnesite. Of course, these materials are all basic in reaction.
HISTORY OF HEAT NO. 40415

The heat was melted in the furnace, May 1917. The furnace was about at its maximum efficiency, as it had 352 heats on the slag pits and 149 on the second roof and back walls. The heat was melted and finished in about the average time allowed for the same. Two tests were taken at each period; one was water cooled for a fracture test; the other was allowed to cool slowly in air so that it would be soft enough to drill for chemical analysis. The slag was taken from the test spoon for slag analysis. The following is data covering the heat, including charge, additions, chemical analysis, etc.

<table>
<thead>
<tr>
<th>TIME</th>
<th>STOCK</th>
<th>QUANTITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:05 A.M.</td>
<td>Miscellaneous</td>
<td>10,500 lbs.</td>
</tr>
<tr>
<td>6:15 A.M.</td>
<td>Lime, Manganese Ore</td>
<td>3,850 lbs, 500 lbs.</td>
</tr>
<tr>
<td>6:25 A.M.</td>
<td>Bolsters</td>
<td>6,300 lbs.</td>
</tr>
<tr>
<td>7:00 A.M.</td>
<td>Rails</td>
<td>5,000 lbs.</td>
</tr>
<tr>
<td>7:05 A.M.</td>
<td>Own &amp; Co.</td>
<td>7,700 lbs.</td>
</tr>
<tr>
<td>7:55 A.M.</td>
<td>Pig Iron (Chicago 8000, Pickands) Brown-15500</td>
<td>23,500 lbs.</td>
</tr>
</tbody>
</table>

The miscellaneous stock consists of most everything-pieces of plows, pipe, rail plates, scrap plate, structural
steel, etc., and is usually high sulphur and phosphorus material. Bolsters and Own & Company are steel scrap. Rails are high in carbon. Pig Iron is the bulk of the material which must be purified or refined to make the steel. It runs about 0.4-5% carbon, 0.7%-1.00% silicon; 0.19% - 0.50% sulphur; and 0.15% - 0.25% phosphorus.

The heat was melted at the time of the first test 10;15 A.M.. It melted somewhat earlier than usual— in about four hours. It usually takes about 5 hours. Some of the recorded tests were taken independent of the test which the melter took for his fracture tests in order to get them spaced at suitable time intervals.
LOG OF HEAT

Started charging- 6:05 AM
Finished charging- 8:05 AM
Melted at- 10:15 AM
#1 Test Taken 10:15 AM
#2 Test Taken- 11:15 AM
#3 Test Taken- 12:15 PM
200 lbs. Iron Ore added at- 12:45 PM
Whistle for stopper 1:00 PM
#4 Test Taken- 1:05 PM
100 lbs. shop scrap added after #4 test was taken- 1:05 PM
75 lbs. spar added- 1:12 PM
Whistle for ladle- 1:25 PM
Test for preliminary carbon- 1:28 PM
60 lbs. spar added- 1:25 PM
500 lbs. 10% Ferro Silicon added- 1:31 PM
Test #5 taken before adding- 1:30 PM
10% Ferro Silicon- 1:35 PM
260 lbs. 80% Ferro Manganese added- 1:38 PM
75 lbs. spar added- 1:42 PM
Tapped at-
LADLE ADDITIONS

400 lbs. 50% Ferro Silicon
125 lbs. 80% Ferro Manganese
48 lbs. Aluminum- and titanium
20 lbs. coal

Bottom material used to make up bottom after tapping.

Raw dolomite- 400 lbs.
Magnebrent- 2500 lbs.
The following photographs show the fracture tests. The fracture depends entirely upon the carbon content. When the carbon is high, the structure is fine grained and dull gray in appearance. As the carbon content decreases the granular structure becomes larger and more metallic in appearance. With some experience one can exactly predict the carbon content by a fracture test.
Test No. 1  Time Taken- 10:15 A.M.

**CHEMICAL ANALYSIS**

<table>
<thead>
<tr>
<th>SLAG</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO</td>
<td>FeO</td>
<td>MnO</td>
<td>P</td>
<td>AlO</td>
<td>CaO</td>
<td>MgO</td>
<td>S</td>
</tr>
<tr>
<td>25.68%</td>
<td>12.60%</td>
<td>12.41%</td>
<td>1.71%</td>
<td>1.01%</td>
<td>33.40%</td>
<td>7.78%</td>
<td>0.014%</td>
</tr>
</tbody>
</table>

**STEEL ANALYSIS**

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.28%</td>
<td>0.34%</td>
<td>0.031%</td>
<td>0.038%</td>
<td>0.052%</td>
</tr>
</tbody>
</table>
Test No 2  Time Taken- 11:15 A.M.

**CHEMICAL ANALYSIS**

<table>
<thead>
<tr>
<th>S I L A G</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>15.78%</td>
</tr>
</tbody>
</table>

**METAL**

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.20%</td>
<td>0.36%</td>
<td>0.022%</td>
<td>0.035%</td>
<td>0.028%</td>
</tr>
</tbody>
</table>
Test No. 3 Time Taken- 12:15 P.M.

CHEMICAL ANALYSIS

SLAG

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>FeO</th>
<th>MnO</th>
<th>P₂O₅</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.00%</td>
<td>19.70%</td>
<td>10.60%</td>
<td>1.79%</td>
<td>0.82%</td>
<td>49.30%</td>
<td>7.32%</td>
<td>0.022%</td>
</tr>
</tbody>
</table>

METAL

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.84%</td>
<td>0.30%</td>
<td>0.022%</td>
<td>0.032%</td>
<td>0.014%</td>
</tr>
</tbody>
</table>
Test No. 4  Time Taken- 1:05 P.M.

**CHEMICAL ANALYSIS**

**SLAG**

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>FeO</th>
<th>MnO</th>
<th>P₂O₅</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>15.00%</td>
<td>15.99%</td>
<td>11.01%</td>
<td>1.82%</td>
<td>0.98%</td>
<td>47.30%</td>
<td>7.10%</td>
<td>0.038%</td>
</tr>
</tbody>
</table>

**STEEL**

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>0.38%</td>
<td>0.28%</td>
<td>0.024%</td>
<td>0.025%</td>
<td>0.008%</td>
</tr>
</tbody>
</table>
Test No. 5  Time Taken-  1:30 P.M.

CHEMICAL ANALYSIS

SLAG

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>FeO</th>
<th>MnO</th>
<th>P₂O₅</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15.00%</td>
<td>17.04%</td>
<td>8.64%</td>
<td>1.49%</td>
<td>1.04%</td>
<td>43.71%</td>
<td>7.24%</td>
<td>0.041%</td>
</tr>
</tbody>
</table>

METAL

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.22%</td>
<td>0.28%</td>
<td>0.022%</td>
<td>0.026%</td>
<td>0.009%</td>
</tr>
</tbody>
</table>
PLATE 1

Carbon Time Curve - Steel

Test #1

Test #2

Test #3

Ore Added 12:45 p.m.

Test #4

Test #5

% Carbon

12:15 p.m.

11:15 a.m.

10:15 a.m.
**PLATE II**

**Sulphur Time Curve - Steel**

- **Test #1**
- **Test #2**
- **Test #3**

@ Ore Added 12:45 p.m.

**Sulphur Time Curve - Slag**

- **Test #4**
- **Test #5**

10:15 a.m.  11:15 a.m.  12:15 p.m.  1:05 p.m.  1:30 p.m.
### Slags

<table>
<thead>
<tr>
<th>Test</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>25.68%</td>
<td>15.78%</td>
<td>11.00%</td>
<td>16.00%</td>
<td>15.00%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>12.60</td>
<td>28.21</td>
<td>14.70</td>
<td>15.99</td>
<td>17.04</td>
</tr>
<tr>
<td>MnO</td>
<td>1.21</td>
<td>10.11</td>
<td>10.60</td>
<td>11.01</td>
<td>8.64</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>1.71</td>
<td>2.77</td>
<td>1.79</td>
<td>1.82</td>
<td>1.49</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>1.01</td>
<td>0.89</td>
<td>0.82</td>
<td>0.98</td>
<td>1.04</td>
</tr>
<tr>
<td>CaO</td>
<td>38.40</td>
<td>45.10</td>
<td>49.30</td>
<td>47.30</td>
<td>48.71</td>
</tr>
<tr>
<td>MgO</td>
<td>7.78</td>
<td>6.05</td>
<td>7.32</td>
<td>7.10</td>
<td>7.24</td>
</tr>
<tr>
<td>S</td>
<td>0.014</td>
<td>0.021</td>
<td>0.022</td>
<td>0.038</td>
<td>0.041</td>
</tr>
</tbody>
</table>

### Metal

| C    | 1.28  | 1.20  | 0.84  | 0.38  | 0.22  |
| Mn   | 0.34  | 0.36  | 0.30  | 0.28  | 0.28  |
| S₁   | 0.021 | 0.022 | 0.022 | 0.024 | 0.022 |
| S    | 0.036 | 0.036 | 0.032 | 0.025 | 0.026 |
| P    | 0.082 | 0.022 | 0.014 | 0.008 | 0.009 |

### Metal as Poured

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>S₁</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Test</td>
<td>0.27</td>
<td>0.60</td>
<td>0.028</td>
<td>0.020</td>
</tr>
<tr>
<td>Gate Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION OF CURVES

Carbon is removed from the metal both by the oxygen in the air, oil, slag and iron ore, and the CO generated by the limestone where used. On this particular heat, the carbon was almost reduced by the air and oil. In fact, by the time the ore was added, the carbon was leaving the bath at a rate which was not apparently hastened by the addition of the ore. Note Plate 1.

The carbon enters the bath in the rails, scrap and especially the pig. It leaves the bath in the form of CO₂.

\[ C + O₂ = CO₂ \]

\[ 2CO + O₂ = 2 CO₂ \]

The reaction is exothermic and as a consequence gives heat to the bath. It is customary to reduce the carbon to a point just at the carbon content wanted or just below and then bring back by adding coal. It is assumed that by bringing the carbon low, it gives the impurities a better chance to become oxidized, since the carbon is then almost removed and less active. However, a glance at the analysis shows that anywhere between 0.84% and 0.22% carbon, the manganese, silicon, phosphorus and sulphur are practically as low as they go. Other data taken on another heat shows that
between 0.66% and 0.18% carbon, the silicon and manganese about at their lowest limits and phosphorus and sulphur relatively low. (0.010% - 0.005% phos.; 0.035% - 0.030% Sulphur). What would be against tapping out ingot heats at the desired carbon content? A number of tests could be made to determine how uniform the heats are in that region. More titanium could be used for a deoxidizer to replace the manganese used from the Spiegeleisen and the 1950 lbs. of spiegeleisen saved. The usual run of sand heats are about 0.28% carbon and give the desired tensile, strength, elastic limit, elongation and reduction of area.

SULPHUR

Referring to Plate 2, some idea may be obtained as to how the sulphur is eliminated. Apparently it is removed after the bath is within an hour of tapping and after ore has been added. There is a corresponding elimination from the metal and increase in sulphur content of slag. It is understood that sulphur elimination is very erratic; but there is nothing to indicate it in the data obtained, except that it is evidently mostly removed at the time there is an excess of oxygen present in the bath, due to the iron ore. As the ore causes the bath to boil very violently, it brings the metal more in contact with the flame and air. This additional surface exposed may be
another reason for its elimination at this point.

The sulphur enters the bath in the pig iron (0.015% - 0.04%), in the scrap which is relatively low except in cast iron scrap which contains about 0.08% - 0.1%.

In some instances, it is held that sulphur enters from the flame. It is quite probably, but forces are at work in the furnace which oppose this. The sulphur to remain in stable form should enter the slag as CaS. But before it takes this form, it combines with the manganese for which it has a greater affinity and forms MnS. MnS in turn is soluble in the slag and metal, but in both slag and metal, there exists free oxygen, and MnS in contact with free O₂ has the property to give off SO₂ and SO₂ is volatile. Evidently this is not the only consideration we have to deal with as the sulphur content of the slag increases as the percentage in the metal decreases. Some of the sulphur remains in the slag as CaS.

Another place from which sulphur may come, is the bottom material. It is known that iron reduces calcium sulphate:

\[ \text{CaSO}_4 + 4 \text{Fe} = \text{FeS} + \text{CaO} + 3 \text{FeO}. \]

Hence, should any calcium sulphate be present in the bottom materials with which the slag line is repaired, it is reasonable to expect that sulphur will
enter the bath. The fact of the matter is that several carloads of magnebrent were received and used. The sulphur began to run high in the heats. The bottom materials were analyzed and magnebrent was found to contain 1% sulphur. Whether this existed as CaSO₄ or CaS was not determined, but no doubt it did as CaSO₄ for tests seemed to prove that the material increased the sulphur in the metal.

PHOSPHORUS

Reference to Plate 3, will give some idea how phosphorus is eliminated from the metal. It is rapidly removed at first and then slowly toward the end of the heat. At Test #2 a corresponding decrease in the phosphorus in the metal and increase in the slag takes place. From this point on, both metal and slag decrease in phosphorus content. Two explanations may be given, one that the phosphorus is being carried away by the hot gases passing over the slag and that the bulk of slag has increased—more lime, iron ore, silica and spar have gone into solution to form slag. The percentage of phosphorus is so small that the additional slag decreased the percentage.

Phosphorus enters the bath mostly from the pig iron (0.15% - 0.25%), as all steel scrap is low in that impurity. Although the lime assists in eliminating the
sulphur, it is an essential to reduce the phosphorus. Phosphorus exists in the metal as \( \text{Fe}_3\text{P} \). In the presence of metallic oxides, the phosphorus is oxidized to \( \text{P}_2\text{O}_5 \). The phosphide passes to the slag where it is converted to calcium phosphate, provided, however, that the slag is basic with \( \text{CaO} \). Otherwise the acid present in the slag will reduce the phosphate and the phosphorus will return to the metal. The oxidizing reactions of Phosphorus to \( \text{P}_2\text{O}_5 \) and the phosphide to a calcium phosphate are exothermic.

There is always a difference in the phosphorus and silicon content between the first mold and last mold. The phosphorus increases and the silicon decreases. The increase in phosphorus is due to the reduction of the calcium phosphate by silica. The decrease in silicon is due to the deoxidizing action the silicon has on the metal, forming silica which in turn passes to the slag and reduces the calcium phosphate.

The phosphorus content of the metal should not run above 0.05% on riser test, otherwise the steel may be cold short due to large crystals which the phosphorus produces in the cooling steel.

MANGANESE

According to Dickman, when the ratios between
The iron oxide and manganese oxide in the slag is such that the manganese oxide percentage is greater, manganese passes from the slag to the metal and vice versa. But curves on plate 4 and results on Plate 5 do not bear out his theory. However, it is not permissible to draw a conclusion against him with but one result at hand. In every instance, the iron oxide was greater than the manganese oxide. Both metal and slag show a decrease. However, this is quite probably due to the increased bulk of slag as before stated.

The manganese enters the bath in the scrap and pig. It is considered advisable to have the manganese content of the bath about 1% when about melted. The charge used runs about 0.82% before melting. The manganese is oxidized and used by the sulphur in its elimination. The manganese exists in the steel as MnS and Mn3C. The American Steel Foundries run about 0.70% in manganese and in this percentage, improves the quality of the steel.
DEOXIDIZERS

Oxygen enters the steel from the highly oxidizing slag. It also is present in the form of iron oxide due to the addition of iron ore which does not always have sufficient time allowed it to completely work its way out of the metal. This gas makes the steel wild and must be removed before it can be successfully poured into castings. This operation is known as deoxidization.

Manganese is one of the best deoxidizers. It possesses greater affinity for oxygen and sulphur than iron. A small percentage of manganese in the metal improves it. In determining tensile strength 0.10% Mn is equal to 0.010% carbon. The reactions are exothermic:

\[ 2 \text{Mn} + \text{O}_2 = 2 \text{MnO} ; \text{Mn} + \text{S} = \text{MnS} \]

H. H. Campbell found that about 1.00% manganese must be added to gain 0.60% manganese in metal or 40% for deoxidization. A smaller percentage gave only 0.20% for deoxidization.

Manganese is added as 80% Ferro Manganese and in the American Steel Foundries additions are about 70% efficient toward raising the manganese content of the steel, thus, the total charge is 53000 lbs. metal.
Allowing 10% furnace loss, brings the available metal at end of heat to 47,700 lbs. 260 lbs. Ferro Manganese is added in the furnace and 125 lbs in the ladle, making a total addition of 385 lbs, or 308 manganese. 308 - 47,700 gives 0.62% manganese if all went to metal. On the average, the manganese in the bath before additions is about 0.28% and the steel finishes at 0.070%. 0.70% - 0.28% gives 0.42% due to the addition which enters the metal. 0.42 - 0.62 x 100 gives 70% approximate efficiency and 30% used for oxidization.

50% Ferro Silicon is also used. It has a much feebler action than manganese and if used in excess is detrimental to the steel. The reaction is exothermic.

\[ \text{Si} - \text{O}_2 = \text{SiO}_2 \]

Using the same figuring as for manganese, the 50% ferro-silicon is 80% efficient in adding silicon to the metal and 20% for oxidization.

Both aluminum and silicon possess a property which manganese does not. They both hold gases dissolved in metal in solution, so that these are retained in solidification.

Eight pounds aluminum are added. The reaction is exothermic and is as follows:

\[ 4 \text{AL} - 3 \text{O}_2 = 2 \text{Al}_2\text{O}_3 \]

The alumina formed is light in weight and should
rise to the slag, but as in all other deoxidizers, some is included in the metal.

Ferro-Aluminum-titanium is considered one of the best deoxidizers since this titanium eliminates the nitrogen which heretofore has been considered of no especial detriment ot the steel. 48 lbs. are added instead of aluminum in ingot heats and in sand heats when no aluminum is on hand. The alloy runs about 10-14% Al. and 6 - 8% titanium.

Per pound of material used, aluminum takes care of more oxygen.

If the iron ore added is given the proper length of time to work through the heat, and the slag is of the proper consistency in oxygen, etc., the metal should not need very much of any of the materials mentioned. In addition to adding deoxidizers to the ladle, aluminum is added to each mold as the steel is poured. It insures a sound casting and prevents a wild heat from coming back.
The open hearth furnace used by the American Steel Foundries is a Siemens-Martin type. Its construction is familiar and detailed construction and size will not be entered into, except to mention the principal parts, i.e.:

Chimney, sewers, steel work, butterfly valve for air and discharge gases, flues, checkers, slag pits, ports for oil and discharge gases, monkeys, slopes, breasts, doors, walls, tapping hole, short spout, runner, and oil burners.

The checkers are built of fire clay brick. The balance of the furnace is built of good grade of silica fire brick with the exception of the bottom and slag line. Fire clay brick is used on the bottom over which is laid chrome or neutral brick. On the back and front walls along the slag line, a little above and below and all around the tapping hole, neutral brick is used on account of the basic steel process. The slag is basic. If the walls about the slag line or the bottom were silica brick, it would be but a matter of time until the walls could be cut through.

Upon completion of the brick work, a slow wood fire is built on the hearth and one at the base of the
stack to induce a draft. After 24 to 36 hours, a slow oil fire is started and gradually increased. As soon as the furnace is hot, the bottom is built up. The first bottom is usually made out of the best material; magnesite. When the bottom is built up to the necessary height, a long six inch pipe is tamped in place in the tapping hole with magnesite and tar. Some use chrome ore, but it is not as satisfactory as tarred magnesite. When the furnace is hot enough, within a week or ten days, the tapping hole is closed and the furnace charged as elsewhere described.

The slag pockets are good for 600 to 800 heats; the walls and roof from 100 to 250 and are torn out and repaired two or three times before it becomes necessary to close a campaign on a furnace for complete repair of checkers, slag pockets, walls and roof. The bottom lasts for several years without being rebuilt. When the walls and roof are rebuilt, the bottom is given a good washing by running several cinder heats, cleaning out the old lime and slag. The bottom slope, back walls and breasts are put in good shape. Within four to six days the furnace is running again. Small holes in roof or walls, back or side walls and arches are repaired without shutting down the furnace.
So far as construction is concerned, the acid and basic furnaces are the same with exception of the bottom material. On the acid bottom silica sand is used and put on the same as on the basic bottom. The acid furnace does not eliminate the detrimental impurities—phosphorus and sulphur. Hence to make acid steel, it is necessary to make the charge up with scrap and pig of low phosphorus and sulphur content. It only requires about four hours to complete an acid heat.

LADLES

A ladle is in reality a large sheet steel bucket. The essential parts are the bail, trunnions, lip, slide, nozzle, dogs, feet and lining. The ladle is lined first with a layer of fire clay brick laid on the 4" side. Another layer is laid over this on the 2" side; the first layer extends the full depth of the ladle. The second layer within a foot and a half from the top or just above the metal line.

A mix consisting of fire clay brick dust and fire clay was used for a coating over the brick. Out of such a mix only 12 - 24 heats were poured before it became necessary to rebrick the ladle. With some experimenting the present mix used, consisting of graphite and special clay in definite proportions, 3 clay, 1 graphite, on side and 6 clay, 1 graphite, on
bottom, better results have been secured. A greater number of heards are poured, from 50 to 60 per lining, with occasional patching. The skull, so pronounced with old lining has practically disappeared. The graphite in the lining has no effect on carbon content of the steel.

The collar holding the nozzle is first placed in position in the bottom of the ladle; about five or six inches of bottom mix rammed in so that it tapers toward the nozzle; and, the sides are nuddled and smooth with a brush. In a new ladle a wood fire is kept burning for about 12 hours before placing in an oil fire. The fire should be kept in long enough to heat the ladle well. When the melter blows the first whistle, the stopper is set. It consists of a rod, stopper head made of graphite, stopper pin, lower and upper sleeve made of fire clay, washer, and couple of nuts to fasten on the sleeves and goose neck. The stopper is raised over the ladle with a jib crane, lowered into position and fastened in the slide. The slide is set so that the stopper hits the back of the nozzle and slides into rest. This method of setting is considered best. The stopper is held tightly in place and tightened to hold it while the ladle is being filled with the heat.
A little sand is thrown around the nozzle, and if any goes through, is caught on a shovel previously placed under it. If none goes through the stopper is properly set. At the second whistle the crane takes the ladle and puts it in position under the furnace runner.
REMARKS AND SUGGESTIONS

In making up back walls, slag line and breasts, it is an essential to have a binder for the bottom material used. Slag is such a binder. Once in a great while, a little slag is ground and sent to the furnace floor. About 1/3 to 1/4 slag should be mixed with this bottom material. It not only makes a stronger slag line, but saves bottom material. It is only a question of grinding the slag and sending it to the furnace platform. Figure out the amount of dollars saved, if 1/3 or 1/4 of the bottom material used were slag. It is an item worth looking into.

The overflow slag runs into the furnace pit and necessitates a gang of men to clean it out. Why not use the slag pots provided for catching the slag as it runs over the ladle lip? The slag could be easily dumped out of the pot with one handling. Of course men would be needed to clean the pit just the same but not so many men. Dollars saved.

The burners badly need a mechanical device to hold them in place. At present, bricks, rods and wire are the only means and this method is cumbersome and unsatisfactory.

The 50% Ferro Silicon is ground up in a grinding
machine. The machine is set at one end of the Foundry in such a way that the ground material falls below the furnace platform. The 50% Ferro Silicon comes in barrels and is unloaded at the other end of the platform. Two men are employed to wheel the material from one end of the platform to the mill, grind it, go down into the Foundry and wheel the ground material up onto the center of the platform. More time is actually spent in wheeling than in grinding, due to the way the material and mill are located. Why not at least put the ground material box and unground material near the mill? It ought then only take one man to do the work.

The second helpers ought to be able to grind the material if they had a small gyratory or Dodge crushing machine on the floor.

When it is necessary to pig steel, a large hole is made in the sand floor and the steel poured in. It is either necessary to break the pig with the drop, or if not broken, is cumbersome to handle on the floor as skeleton. Why not have a specific spot in which to pour the steel and have suitable holes already dug similar to pig iron runs? It appears that it would be as advisable.
METALLURGY OF STEEL CASTINGS

LABORATORY PRACTICE
The Laboratory plays an important part in the Foundry, especially in the production and final analysis of the steel. In fact, a large amount of the analysis is on material, such as lime, spiegeleisen, pig iron, manganese ore, iron ore, 30%, 50%, and 80% Ferro-manganese, 10% and 50% Ferro-silicon; dolomite, fluorspar, fire clay, Al-Ti, oil, etc., which has some part to play in the steel manufacture, rather than on the final product. It is from this stock analysis that the charge for the furnace is calculated and some idea is obtained as to what the steel will contain in the product condition. However, the analysis of the product is of as much importance, because the results obtained determine whether the steel falls within the purchasing company's specification.

Metallographic analysis is auxiliary to chemical and is employed in the determination of the proper heat treatment to produce a steel of proper ductility, high strength and elastic limit, all of which properties depend on the proper steel structure. At the time this report was written no metallographic analysis was being done in the Granite City laboratory.

No attempt will be made to give every method
employed in the Granite City Laboratory, since any of
them can be copied from books on the subject. Enough
will be included to indicate a speaking acquaintance
with the American Steel Foundries' methods.

SAMPLES

Samples are made on all stock material which
comes in.

On pig iron, 50% and 90% Ferro manganese and
spiegeleisen, two pieces are taken from each end of a
carload. On manganese ore, iron ore and lime, two
pieces in each end of a carload are broken up and the
center pieces taken. A grab sample is made from ten
different places in cars of Dolomite, magdolite, fluor-
spar, syndolite, magnobrent, fire clay and sand; and
from ten sacks of flour and aluminum-titanium. Samples
are taken from the top, middle and bottom of four barrels
of 50% Ferro-silicon, etc. All these samples are only
rough ones, but are quite satisfactory for the nature of
the analysis. They are reduced to a small fraction of
the whole, pulverized where necessary and put through
a 100-mesh sieve, except the clay and sand, to make an
assay sample.

A few years ago, standard ladle tests were
adopted. At present they are not strictly adhered to,
but a statement of them will give an idea about what is
being done.
1. The test ingot should be of a designated size.

2. Three tests per melt should be taken on all melts of various sizes.

3. Drillings from each ingot analyzed separately. When consumer desires report of analysis, the ingot taken from the center of the heat should be used.

4. Ingot tests should be taken as follows:
   1. After 5th mold, or when about 2000 pounds of steel has been poured.
   2. After half the heat has been poured.
   3. At the last of the heat and if more than 2000# is poured, the gate on the last mold is taken for a test instead of the third ingot.
   4. The drill hole should be bored at the centre of the bottom of the ingot.
   5. A half inch drill should be used.
   6. The drillings for 1/4" should be rejected.
   7. The depth of drill in ingot representing drillings taken for analysis should be 1-3/4".
Tests on the ingot heats are taken where wanted and analysis made per instructions, which vary for different heats, being on the first, middle or last of the heat. On sand heats the complete analysis is made on the center of the heat and only a phosphorus determination made of the last part.

The test ingots on the ingot heats are allowed to cool in the atmosphere until cool enough to be handled, or about two hours. Not so much care is taken with the sand heat test ingots.

STEEL ANALYSIS

The steel analysis consists of a determination of the carbon, phosphorous, manganese, silicon and
lphur content. Outside of a small percentage of
oxidized impurities, such as oxides, sulphides, and
carbonates of iron and gaseous impurities such as
hydrogen, nitrogen and carbon monoxide, the balance of
the steel is iron. The first five elements mentioned run
a rule about as follows: C .24% - .30%: Mn .60% to .80%;
.2% - .4%; Phos. 015% - .05%; S .025% - .045%. So the largest
part of the steel is iron. The oxidized or gaseous impuri-
ties in commercial work are seldom determined since their
effects are about nil on the physical properties of steel.

Occasionally an alloy or a high carbon steel is
used but as a rule, the steels fall within the soft and
malleable high carbon. The carbon exists in the steel as
iron and manganese carbides Fe₃C and Mn₃C. It is upon
the carbon content which the annealing or any subsequent
heat treatment depends and the heat treatment, upon the
addition in which the steel is wanted—whether soft and
malleable or high strength and elastic limit with fair
utility.

It is not definitely known whether the silicon
exists merely in solution in the steel or as an iron
carbonate, Fe₃Si. In whichever form it may exist, it is
known that up to several tenths of one per cent, silicon
does not materially affect the properties of steel.
Steel of satisfactory quality contains from a trace to 0.1 per cent of phosphorus. It is held in solution in the iron as an iron phosphide, Fe₃P. Phosphorus above the percentage mentioned makes steel very brittle. This brittleness is due to the enlargement of the grains of the steel and possibly to the fact that the phosphide is segregated.

Steel of a satisfactory commercial quality may contain from a mere trace to 0.1 per cent sulphur, but specifications usually call for 0.05 per cent or less. It exists as manganese sulphide, MnS, or as an iron manganese sulphide Fe₃Mn₂S₅. It is a well known fact that manganese and sulphur when brought together at a high temperature, have a very great affinity for each other and combine readily to form MnS. The MnS as such or MnS and FeS in Fe₃Mn₂S₅ are present in the steel as mechanical inclusions. If sufficient manganese is not present to take care of the sulphur, which is seldom if ever the case, an iron sulphide is formed which causes the steel to become weak and brittle.

Whatever manganese is left, after the sulphur is taken care of, goes to form a manganese carbide, Mn₃C. It is associated with the iron carbide in forming cementite.
In the small percentage in which the manganese exists it improved the quality of the steel. The higher percentages, say from 2% to 6%, manganese steel is very brittle unless properly heat treated.

Having the chemical analysis of a steel and knowing how the elements act which have been mentioned, with the aid of atomic weights, the probable chemical composition of a steel can be estimated. Using a steel of about an average chemical analysis, say 0.85 per cent carbon, 0.70 per cent manganese, 0.045 per cent sulphur, 0.05 per cent phosphorus and 0.03 per cent silicon, the following chemical composition may be expected:

\[
\begin{align*}
C & \quad 0.25\% - \quad (Fe_3C - 3.08\%)
Mn & \quad 0.70\% - \quad Mn_2C - 0.67\%
S & \quad 0.045\% - \quad MnS - 0.12\%
P & \quad 0.05\% - \quad Fe_3P - 0.30\%
Si & \quad 0.30\% - \quad FeSi - 0.90\%
Fe (by diff) & \quad 94.93\%
\end{align*}
\]

About a half hour before a heat is tapped, a preliminary test is sent into the laboratory for a phosphorus determination.
A 1½ gram sample is taken and put into a 250 c.c. Erlenmeyer flask and 35 c.c. (5) of nitric acid added. After violent action is over caused by addition of acid, the flask is placed on the hot plate until the steel is entirely digested. About 2 c.c. of chromic acid (10) are added to completely oxidize the phosphorus to $\text{P}_2\text{O}_5$. The solution is put into a Goetz tube in which about 30 c.c. of molybdic acid solution has been poured. The tube is placed in a centrifugal settler and run for a few minutes. If any phosphorus is present, it will appear as a yellow precipitate in the bottom of the graduated stem of the bulb where it can be roughly calculated in hundredth of a per cent. If more than a trace is present, it is reported to the melter.

As the heat nears completion, tests are sent in for preliminary carbon determinations. These tests are conducted in about the same manner as the regular carbon determination, so will be explained with it.
PHOSPHORUS

2 grams drillings are dissolved in 35 c.c. nitric acid (5) in a 250 c.c. Erlenmeyer flask. After violent action is over due to addition of acid, the flask is placed on a hot plate at a gentle heat until the steel is digested. 3 c.c. KMnO₄ solution (6) are added to complete the oxidation of the phosphorus to P₂O₅ and the excess reduced with tartaric acid (7). When the solution becomes clear, it is removed from the hot plate and allowed to cool until the solution is about 85 degrees C. 60 c.c. Ammonium Molydate (8) is added and the phosphorus comes down as ammonium phosphododeca molybdate. A good many conditions accompany this determination and it must be carefully done. The ppt. is allowed to settle, filtered, washed well with cold water until acid free, and ppt. and filter placed in the same flask in which it was ppted. 10 c. c. more or less of potassium hydroxide solution (9) are added from a burette, or sufficient to dissolve the ppt. The paper is thoroughly masticated 30-50 c.c. of neutral CO₂ free water and 3 drops of phenolphthalein (12) added and the excess potassium hydroxide titrated against a nitric acid solution (11)
Combustion Carbon Apparatus

- Oxygen
- Mercury
- KOH
- Pressure Bulb
- Cell
- Burner Pressure Tube
- Calcium Carbide
- Soda Lime
- Boat
- Asbestos
- Hot Plates
- Shell
- Frog
- Fleming Bulb
- 110V, 4.5amps
- Hoskins Furnace
which exactly matches the potassium hydroxide. The difference between the number of c.c. of hydroxide added and the number of c.c. of acid used X factor if any, gives percentage of Phosphorus in 0.01th%.

**CARBON**

Carbon on sand heats is determined by color; on ingot and high carbon heats, by combustion. The color method depends upon the fact that combined carbon imparts a characteristic brown color to nitric acid.

A standard steel of the same kind and same heat treatment and within 3 or 4 points on either side of the steel to be compared, is necessary. A 0.26% carbon standard is used in the Granite City Plant. Nickel, Chromium and manganese in any appreciable amount affect the test. Since the test is on combined carbon, to get a correct comparison, it is necessary that the steels being compared have the same heat treatment.

On preliminary tests 0.2 gram samples and on final determinations 0.3 gram samples are used. The other difference is that the preliminary is hastened on a sand bath while the final is completed on a hot water bath and given more time. A preliminary test must be made within three to five minutes. A sample of both a standard and steel under test are weighed and placed in separate 30-50 c.c. test tubes.
and 5 c.c. of nitric acid (5) added to each; after
ciolent action in over, if a preliminary, it is placed
on a sand bath and a final in a hot water bath. As soon
as the steel is digested, the tubes are cooled and the
solutions transferred to graduated comparison tubes and
the color compared by means of a colorimeter.

The standards is diluted to 13 C.C. making
each c.c. equal to two points carbon. The carbon
solution under test is gradually diluted until the
colors are matched by means of a colorimeter. The carbon
contents are proportional to the volumes. Hence each c.c.
of carbon solution under test is equal to two points carbon.

Carbon by combustion depends upon the fact that
at a high temperature, about 960°C and above, carbon in
an atmosphere of oxygen burns to \( \text{CO}_2 \) carbon dioxide.
Carbon dioxide can be caught in various ways, two of
the most practical being in potassium hydroxide solution
and powdered soda lime. Soda lime is here used.

The apparatus consists of a train in which a
pressure tube a KOH tube for catching any \( \text{CO}_2 \) in the
oxygen before entering a CaCl2 calcium chloride tube to take
up any moisture and a mercury back pressure tube, precede
the Heskin's Electric Furnace heating chamber and following
the furnace, a zinc tube to catch any sulphur which might
pass over, a P$_2$O$_5$ tower to take up any moisture, the Fleming Tube which contains the soda lime to catch the CO$_2$; and P$_2$O$_5$ to keep the weight of the tube constant by catching any moisture which might leave the soda lime, and a KOH tube following the Fleming tube to prevent any CO$_2$ entering the tube from the air. About 2 - 3% moisture is supposed to be present in the soda lime. But it has been used with just a little more success with about 5% moisture. In the delivery end of the combustion tube, a mat of asbestos is placed to insure the complete combustion of (CO) carbon monoxide to (CO$_2$) carbon dioxide. Some consider this unnecessary.

A factor weight 2.73 grams, of steel drillings is used and placed in a nickel boat previously burned to constant weight. The drillings must be fine and in small pieces. The bottom of the boat is covered with a thin layer of aluminum and the drillings finally covered with it to protect the boat. The boat is placed in the furnace, proper connections made, and enough oxygen is passed through to slowly burn the carbon. It takes about 20 minutes to make a determination. The Fleming bulb is weighed and the difference between that weight and the weight previous to starting
the combustion gives the carbon content direct in percentage. A blank is usually run on the bulb to determine whether it is picking up weight from any other source except the CO₂.

The oxygen comes under about 2000 lbs. pressure and is reduced to 30# or 40# and used at about 3 lbs. It is practically free from any injurious impurities.
SILICON

A factor weight, 2.35 grams of drillings is put into a 250 c.c. casserole and digested in 35 c.c. of silicon mixture (1). It is evaporated to dryness and baked until SO₃ fumes are given off to insure complete oxidation of Si to SiO₂ and total reduction of H₂SiO₃. About 35 c.c. of water and 35 c.c. HCl (2) are added after cooling, to put residue in solution. The solution is filtered hot and the ppt. is washed with hot HCl (2) to dissolve any iron salts remaining on filter paper. After washing with hot water until free from acid, the filter and ppt. is placed in a platinum crucible and ignited. Each 10.0 milligram SiO₂ represents 0.10 x 2% Si.

In case of an accurate assay, SiO₂ should be purified by putting a drop of H₂SO₄ and 3 or 4 c.c. of HF on the SiO₂ in the platinum crucible and Si driven off as SiF₄. The difference of weight of crucible after purifying and before, gives the true weight of the SiO₂.

MANGANESE

0.1 gram of drillings are dissolved in a 1"xl2" test tube with 10 c.c. of nitric acid (5). The tube is placed in a hot water bath until the steel is digested. 10 c.c. silver nitrate (13) which simply acts as a catalizer and 5 grams (14) of ammonium persulphate are added
and the tube replaced in the hot water bath. The persulphate reduces the manganese nitrate to permanganic acid which imparts a pink color to the solution. When the persulphate is about gone, the test tube is placed in an ice cold water bath and allowed to cool. The solution is transferred to a 150 c.c. extraction flask and titrated to a pea green end point with an arsenite solution (15). Each cc arsenite solution used is equal to 0.1 of one per cent manganese. The manganese solution should be titrated while cold and quite rapidly because the end point is a returning one.

**SULPHUR**

5 grams of drilling are placed in a 250 c.c. Johnson flask fitted with thistle tube and discharge tube. The delivery tube is led into a 500 c.c. jar containing about 250 c.c. of water and 15 c.c. of CdCl₂ Cadmium Chloride Solution (4) About 85 c.c. of HCl (2) are added to the flask by means of the thistle tube, the flask placed on the hot plate, and the jar at a convenient distance from same, to keep the Cd Cl₂ solution from becoming hot. This solution should be cold, otherwise the standard iodine solution against which
it is titrated volatilizes, giving high sulphur results. The sulphur present passes over as H₂S and is converted into CdS in the jar. When the steel is completely digested, the apparatus is disconnected, 100 c.c. HCl (2) added to the jar and the resultant H₂S titrated immediately against the standard iodine solution (3) to a distinct blue end point. The number of c.c. x the factor of the solution, if any, gives the percentage of sulphur in hundredths of one per cent. (0.01)
SOLUTIONS

1. SILICON MIXTURE:

385 c.c.s Nitric Acid (1.4) sp.
gravity
250 c.c.s Sulphuric Acid
1150 c.c.s Water

2. HYDROGEN CHLORIDE: 1 part strong acid, 1 part water.

3. IODINE SOLUTION:

Iodine 9.15 grams
Potassium Iodide 20.6 grams (Put in solution in 30 c.c.
of water.
2000 c.c. water.
Solution is standardised against a standard steel of known sulphur content and the factor estimated.

4. CADMIUM CHLORIDE SOLUTION:

Cadmium Chloride- 50 grams dissolved in 500 c.c. water
Ammonium Hydroxide- 2500 c.c.
Water 800 c.c.
Starch- 12 grams
A paste if made of the starch and added to 200 c.c. of boiling water and it to the solution.

5. NITRIC ACID: 1.2 sp. gravity:
   4200 c.c. water
   3000 c.c. Nitric Acid, 1.42 sp. gravity

6. POTASSIUM PERMANGANATE- K\textsubscript{2}MnO\textsubscript{4}
   10\% Solution.

7. TARTARIC ACID:
   10\% Solution

8. AMMONIUM MOLYBDATE:
   Molybdic Acid- 225 grams
   Ammonium Hydroxide- 500 c.c.
   Water- 500 c.c.
   The above mix added slowly to 2500 c.c. of Nitric Acid (1.2 sp. gravity) stirred and cooled during operation. Add 3 c.c. of a 10\% solution of microscopic salt, allow to settle and filter.

9. POTASSIUM HYDROXIDE SOLUTION:
   10\% Solution

10. CHROMIC ACID:
   CrO\textsubscript{3} - 125 grams
    Water - 75 c.c.s
11. NITRIC ACID:

10% Solution
No. 9 and 11 are matched and standatized against a steel of a known phosphorus content and the factor estimated.

12. PHENOLPHTHALEIN:

1 gram
100 c.c. grain alcohol

13. SILVER NITRATE:

Silver Nitrate Crystals C.P.
33.25 grams } stock solution
  Water- 500 c.c.

20 c.c. Stock Solution } Desk solution
  1000 c.c. water

14. PERSULPHATE:

Crystals C.P.

15. ARSENITE SOLUTION:

Sodium Carbonate- 36 grams } Boil and filter
Arsenious Acid- 10 grams
Water- 1000 c.c
Stock Solution- 68 c.c. } Desk solution
Water- 2000 c.c. 
  71
Solution is standardize against a steel of known Manganese content and the factor estimated.

16. RECLAMATION OF MOLYBDIC ACID FROM PHOSPHORUS DETERMINATION FILTRATE:

Add to 2 liters of filtrate, 45 grams of Sodium biphosphate. Stir and allow to settle. Decant and wash ppt. by decantation three or four times. Dry and store.

Preparation of Solution

175 grams yellow ppt. added to 500 c.c. water and after shaking well add 750 c.c. strong ammonium hydroxide and 30 grams Magnesium Nitrate in 100 c.c. of water. Filter and add filtrate slowly to 1200 c.c. of strong nitric acid add 700 c.c. water.

Beside the above solutions for heat work, other standards are kept on hand for general work.

17. TENTH NORMAL SOLUTION OF POTASSIUM PERMANGANATE:

3.16 grams C.P. KMnO4 crystals
1000 c.c. water.

Standardized against Ferrous Ammonium Sulphate. Used for iron, antimony, chromium, and manganese determinations.

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18. TENTH NORMAL POTASSIUM DICHROMATE:

4.9 grams C.P. Potassium Dichromate crystals
1000 c.c. Water.

Standardize against iron wire and Ferrous Ammonium Sulphate. Used for iron determinations.

19. TENTH NORMAL IODINE SOLUTION:

12.9 grams Iodine C.P. Crystals
25 grams C.P. Potassium Iodine crystals
30 c.c. water
1000 c.c. water.

Standardized against a standard dichromate solution along with a Thiosulphate standard. Used on tin determinations.

20. TENTH NORMAL THIOSULPHATE SOLUTION:

16.0 grams C.P. Thiosulphate crystals
1000 c.c. water.

Standardized as indicated in 19. Used on copper determinations.

21. SILICON SOLUTION FOR 10% FERRO SILICON:

Water- 725 c.c.
Nitric Acid-325 c.c.
Sulphuric Acid-125 c.c.
Hydrochloric Acid-50 c.c.
STOCK ANALYSIS

Under the head of stock analysis will be included, beside stock material, pig iron, coal, coke and fuel oil. A number of the determinations on stock material are similar with some variations to steel. For instance, pig iron, with a few differences in assay sample weights and minor points in method. Determinations only will be indicated on the following:

**Pig Iron**—sulphur, silicon, phosphorus and manganese. Pig is bought from several companies and buying specifications call for about the following analysis: S—0.05% or under; Mn—1.0% or over; Si—1.3—1.6% or under; Phos—0.5% or under.

**Spiegeleisen**—manganese, which should fall between 18. and 22.0%; silicon between 1.4—4.6% and Phos. 1—5. Some grades run up as high as 60% Mn.

**Sand**—fineness which should run about 35.

**Clay**—fineness or in the figures indicated in the following.

**Flour**—Ash running about 1.2 to 2.0%.

**Al-Ti**—Aluminum 12—15%; Titanium 4—8%; and the balance iron.

**10% Ferro Silicon**—Silicon approximately 10%.

**50% Ferro Silicon**—Silicon between 48—50%, depending on what grade it is.
Iron Ore - Fe falling between 55% to 76%;
Silica 1 to 5%; Phos. up to 0.5%. A complete analysis
is not madw which would be more extensive. The iron
ore is either Hematite or Magnetite.

Manganese Ore - Mn falling between 28% to 51%;
Silica 1% to 5%; Phos. up to 0.5%. The most common
ores of manganese are pyrolusite and brawnite.

Ferro-Manganese - Mn various percentages up to
80%, depending upon the grade.

Lime - Loss on ignition; Silica; R₂O₃ consisting
of Al₂O₃, P₂O₅, FeO and any other oxides of this group;
MgO and CaO of which lime contains a very large per cent,
say between 77% and 93%, depending upon the quality of
the material.

Slag - FeO; P₂O₅; MnO; CaO; SiO₂; Al₂O₃; MgO.
A slag analysis is only run for slag control in case it
is running bad. It is very essential that the slag
contain a large excess of CaO or lime to take care of
the excess phosphorus or rather to eliminate it from
the steel bath.

Magnesbrent - R₂O₃; CaO; MgO; SiO₂; loss on
ignition.

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STOCK ANALYSIS  (Continued)

Dolomite, magnesite, syenite- Loss on ignition; SiO2.

Coal and coke analysis is seldom made, but when so, only an approximate analysis. On coal, it consists in the determination of moisture, volatile matter, fixed carbon and ash; on coke, ash and porosity.

On Fuel Oil the Baumé or specific gravity is taken. To be of the proper quality it should run about 27.00 Baumé at 60°C. Modern conditions demand that any fuels should be bought on B.T.U. basis rather than on a tonnage basis, for coal and coke, and gallon or barrel basis for oil.

Some analyses are only occasionally done and will be simply mentioned as follows:

Babbit metals, solder, aluminum in steel, fluorspar, impurities in aluminum, linseed oil, nickel in steel, bauxite, and some which have already been alluded to. For any of these just mentioned or any of the analyses, flow sheets are available.

Most stock is bought under specifications, as has been already indicated and the analysis on such is made to determine if it falls within the limits or is up to standard. As a rule, material "comes in", but occasionally something must be rejected.
ANNElING

Steel when melted in the open hearth attains a temperature approximating 1800-2000° C. Upon being poured into a mould, the metal next the sand is cooled to the solid condition at once, while the inner and larger mass of metal remains molten for varying lengths of time, depending on the size of the casting.

On account of the outside shell cooling quickly, the crystals, making up the structure are smaller than those which form in the interior of the casting, owing to the difference in time allowed for growth from the liquid state. These crystals grow under peculiar conditions. The metal while in the liquid state has increased in volume from the solid. With the formation of the shell on the outside at once, and the molten mass in the center, the shell will be relatively larger than the total shrinkage of the hot metal to solid. Making due allowance for the head to feed metal to the interior forming crystals, nevertheless, there will be a tendency for the crystals to pull upon each other as the center becomes solid, causing internal strains.

Besides the time allowed for the growth of crystals, the metal cools from a high temperature through a range in which large crystals are pronounced, with a resultant brittleness and hardness. Some idea of how
brittle the metal is, may be gained from flogging floor practice. On small heads and gates it is only necessary to nick and strike them a hard blow to remove them from the casting, leaving an almost true surface with but little grinding.

To reduce the internal strains, brittleness and extreme hardness, is the purpose of annealing. Annealing operating consists of three distinct steps: (1) heating the metal, (2) keeping its temperature constantly at the annealing temperature and (3) cooling from the annealing to atmospheric temperature.

It will not be necessary to go into detail of the annealing from a physical chemistry standpoint, except to say that every different "C" content steel has a different temperature to which it should be heated. The proper temperature to which it should be heated is that temperature or critical point at which there is a change in the steel, completely changing the previous structure from coarse grained, brittle and hard steel, to fine grained, ductile and soft steel. A few critical temperatures are as follows:

<table>
<thead>
<tr>
<th>&quot;C&quot; Content</th>
<th>Temperature - Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>.12 - .25</td>
<td>1544° - 1598° F.</td>
</tr>
<tr>
<td>.50 - .49</td>
<td>1499° - 1544° F.</td>
</tr>
<tr>
<td>.50 - 1.00</td>
<td>1454° - 1499° F.</td>
</tr>
</tbody>
</table>
The usual run of steel in the foundry, except on special heats lies between .25 - .50 "C" content, and should be heated to the temperature indicated.

In case of cast steel it has been found that it is necessary to heat slightly above the critical temperature or there will be no desired annealing effect.

To obtain the proper results the furnace charge should be brought to the proper temperature slowly, allowing all castings to become heated evenly throughout. The time to accomplish this varies with the size of the casting. If castings of any magnitude are heated too rapidly, the structural changes will be so uneven that the resulting casting will be warped and cracked. After the steel has been brought to the desired temperature it is necessary to hold it at that point at least an hour or more varying with the size of the piece.

The rate of cooling depends upon the nature of the effect desired. If softness and ductility are wanted (for ease in machining) at the sacrifice of strength and elasticity, the cooling should be slow and in the furnace in which heated. If hardness for
wearing power, strength and elasticity at the
sacrifice of ductility, the cooling should be in
air or in a quenching agent such as oil, brine, or
even water.

The castings should be racked in such a
way that they do not rest upon each other. The
furnace should be constructed so that the hot gases
pass through and about the castings freely and not
have all the flame buck up against one side of the
racked material, resulting in too rapid and over
heated castings on one side and under heated on the
other.

Since heating and cooling has much to do
with the proper annealing result, small castings and
large castings should be racked separately and anneal-
ed separately. The different size pieces need entirely
different heat treatment. Should they be annealed
together, the result is apparent.

If the fuel used is oxidizing in its effect
upon the casting surface, the castings should be placed
in pits and packed so that the gases cannot attack the
metal because the oxides formed upon the castings tend
to decarburize the steel.

The ideal appearance of a casting, after
being annealed, is a reddish hue. If blue, it has been over-oxidized.

**Testing**

Following are a few of the most important A. S. T. M. standard specifications for steel castings.

<table>
<thead>
<tr>
<th></th>
<th>Hard # per sq. in.</th>
<th>Medium # per sq. in.</th>
<th>Soft # per sq. in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile</td>
<td>80000</td>
<td>70000</td>
<td>60000</td>
</tr>
<tr>
<td>Elastic Limit</td>
<td>36000</td>
<td>31500</td>
<td>27000</td>
</tr>
<tr>
<td>Elongation in 2&quot;</td>
<td>15 %</td>
<td>18 %</td>
<td>22 %</td>
</tr>
<tr>
<td>Red. of Area</td>
<td>20 %</td>
<td>25 %</td>
<td>30 %</td>
</tr>
<tr>
<td>Bend Test</td>
<td>none</td>
<td>90°</td>
<td>120°</td>
</tr>
</tbody>
</table>
CHEMICAL ANALYSIS

<table>
<thead>
<tr>
<th></th>
<th>.05</th>
<th>.05</th>
<th>.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>.05</td>
<td>.05</td>
<td>.05</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>Not Specified</td>
</tr>
</tbody>
</table>

Process must be the open hearth.
Analysis shall be taken from ladle.
Yield point shall be determined by drop beam.
Fracture must be silky or fine granular.
Bend specimens shall be 1" x ½" in section.
Tension specimens shall be 2½" x ½" in section.

The purpose in giving the foregoing, is because most companies have their own specifications, all of which are governed by the A. S. T. M. standard, and approximate, as a fair average, the standard. Some have adopted the standard: H. Y. C. All companies specify the chemical analysis and a corresponding physical test.

The average run of the American Steel Foundry steel is about,

Physical,

<table>
<thead>
<tr>
<th>Tensile</th>
<th>El. Limit</th>
<th>Elongation</th>
<th>Red. of Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>70200</td>
<td>37600</td>
<td>28.8</td>
<td>45.4</td>
</tr>
</tbody>
</table>

Chemical,

<table>
<thead>
<tr>
<th>C.</th>
<th>Mn.</th>
<th>Si</th>
<th>P.</th>
<th>S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>.286</td>
<td>.633</td>
<td>.28</td>
<td>.0396</td>
<td>.0323</td>
</tr>
</tbody>
</table>
On all castings requiring a test, a test coupon is cast on the casting unless too small and then a test block of the same heat is made. The coupon is put through the same heat treatment as the casting so that it will approximate the steel under test. Before the coupon is knocked off the casting, it is numbered and the corresponding number painted on the casting. The numbers are consecutive in the filling schemes, and are independent of any of the company marks. Any necessary information, such as name of customer, date cast, pattern number, nature of casting, is filed with the number so that it is easily identified. After the bars are tested, the remaining part which has not been machined is matched on the casting to assure the foreign inspector that the bar in question belongs to the casting. The machine used in pulling tests is a Riehle' Bros. 300,000# capacity and operated upon laboratory principles.
METALLURGY OF STEEL CASTINGS

MOULDING PRACTICE
DRY FLOOR MOULDING

It would be an endless task to give the names of all the castings, the moulds of which are made in any department, but on the dry floor, large work is mostly handled such as wheel-centers, rolls, driving boxes and bridge blocks all sizes, ladle trunions, cylinders, cylinder heads, deck plates, annealing vats and trays, blank gears, spur wheels and bevel gears all sizes, motor and engine frames, globe valves, elbows, all sizes, riding rings, coupling boxes, ladles, hammer blocks, hammer arms, forge dies, and others too numerous to mention.

The moulder's tools and materials are first essentials in moulding. A trowel, stick, hammer, lifter, hand and air rammer and shovel are necessary tools. The wood or metal frames containing the mould are called flasks. The mould is made up of two parts, and sometimes three or more called cope, cheek and drag. The cope consists of the top flasks, the cheek any center, and the drag the bottom flasks. Other materials are follow boards, gaggers, rods, clamps, wedges, nails, paste, plates, bars, heads, burnt and facing sand, molasses and silica wash.

The moulding of a particular elbow for a blast
furnace will first be considered. The pattern is split and has a number of loose pieces called draw-outs attached with dowel pins. The pattern, if new, and sometimes even though old, is first oiled with kerosene oil. The oil keeps the facing sand from sticking to the new or old pattern, but is not used to any great extent.

In a symmetrical pattern like a pipe, it is immaterial which part of the pattern, as far as the draft is concerned, is placed in a four foot drag, with the exception that the half containing the joining dowel pins is left for the cope. The drag half of the pattern is placed on a follow board, joint down. A gate consisting of a piece of 2½ inch pips is set in place so that a bottom gate can be cut. Facing sand, about an inch and a half thick is carefully placed about the pattern. About ten inches of burnt sand is thrown on, and after kneading with the hand rammer, the air rammer is used. About one ramming will bring the sand up to the loose pieces. These are carefully put in their places and facing rammed by hand about them. The dowel pins which extend through the parts are withdrawn. The burnt sand which has been forced about the pattern is cleaned away and more facing and burnt sand added. This ramming brings the sand high enough to give more attention to the gate.
Gates are of various kinds. The most important are bottom gates, side gates, end gates and swirl gates. Whatever kind, it is necessary to make a gate so that it will break the onrush of the ingoing metal and save the mould. By much experimenting, it has been found that a shallow wide gate, with a slight indentation where the metal first hits the bottom is best. In placing gates, they should be set with reference to the risers. The metal should find its way through the mould before finding the head.

In this particular case, a bottom gate is used. A piece of 1" x 3" board is set vertical on one of the flanges and facing about 3 inches thick rammed about it. The facing is leveled off and both stick and pipe are withdrawn. A channel about 1" x 2" is cut from the opening left by the stick to the opening left by the pipe. The channel is washed with silica wash, covered with slab cores or fire clay brick, another flask is added and the ramming proceeds until the whole pattern is covered and the sand is level with the bottom of the flask. The sand is smoothed off, a plate is set in place, and both it and the follow board are clamped on.

With the assistance of a crane, the drag is rolled over. The follow board is taken off and the mould's
surface smoothed down. The other half of the pattern is set, a flask put on and set to the pin holes. Bars are placed on the flask about and free from the pattern, leaving places for risers about 5" x 9" on the flanges. Parting sand is thrown over the drag to keep the facing of the drag and the facing in the cope from sticking.

The gate pipe is put in its place. A thin layer of facing about an inch, is scattered over the pattern and mould. Gaggers are then pasted with mud and set so that they set firmly against the bars and joint. The ramming process goes on as before, first kneading well with the hand rammer. The sand is rammed some harder than in the drag to insure a good lift. There is such a thing as ramming solid but not too hard. If too hard, the pattern will not draw clean; if not hard enough, the sand may fall out. After the first ram, the bars are pasted and another flask added. Since the pattern extends into the cope and the heads are placed on the flanges, they are not set until the ramming brings the sand up to about where they are placed. Small risers called pop heads are set on the projections on the cope side to take care of any gas which might keep the metal from rising into the cavity. Two ramnings fill the flasks. The gate and heads are withdrawn, a little
facing placed in the head hole and rammed down. The risers and gate are washed with silica wash. The two cope flasks are clamped together and if pins have not been used at the joint two or three chisel marks extending over the joint edge of the drag and cope are cut at equal intervals on the flasks to facilitate correct closing.

The cope is lifted and turned over. Molasses water is sprinkled around the edge of the pattern. The pattern is rapped with a block of wood and hammer to loosen it from the sand. It is withdrawn with the aid of woodscrews and is sometimes rapped as it is being withdrawn. Some care must be exercised in drawing the draw-outs. The facing is cut out of the opening or neck to the heads and made elliptical in shape tapering toward the top of the head. The heads are cut this shape to give ease in removing the head metal.

The metal when hot has increased in volume and will decrease when it becomes cold. The cooling takes place slowly from the outside, which becomes a shell almost immediately, to the center.
Should a casting be poured without a riser, when it cools it would be scrap because of the shrink holes in it. The head is made large enough to carry a mass of hot molten metal to feed the gradually cooling casting. The neck of the head is made correspondingly large, so that it will stay open as long as the casting.

Filletts are put on any sharp edges to cause the metal to lay against the mould better. The edge of the mould is finished off smoothly and any breaks patched. Ten penny nails and finishing nails are tacked all over the surface of the cope. In the drag finishing nails are large enough and a large number are placed at the gate entrance to keep the ingoing metal from cutting the mould. These nails answer two purposes: one to give a clean casting; and two, to help keep the sand from the cope from being drawn down by the hot metal.

Brackets are cut between the flange and pipe. A bracket is simply a small slit about \( \frac{1}{2} \)" wide, various lengths, cut into the mould. When the metal flows into it, it cools at once.

Brackets are used very much and it is easier to explain their purpose by referring to a wheel hub. Note figure.
Where the spokes join the hub, there is a greater mass of metal than in any one spoke alone. Hence the spoke cools faster and consequently shrinks faster than the hub. Any cracking usually takes place when the metal is in its transformation stage between the liquid and solid when it is more like paste. The spoke passes this point before the hub and is stronger, and since it is shrinking faster, tends to pull on the pasty mass which gives readily. Here the bracket plays its part. It is strong metal before either hub or spoke and keeps the stronger from destroying the weaker. This explanation will hold true for most any bracket.

The dirt is cleaned out of the mould and molasses water sprinkled over it to act, when it dries, as a binder. The mould is washed with a silica wash, consisting of silica, salt, molasses and water. The wash when dry gives a smooth surface for the metal to lie on and tends to produce a cleaner casting.
The mould is now ready for the oven. It is placed on iron carts and pulled into the drying oven. The temperature is gradually brought up to between 600 degrees Fahr. and 700 degrees Fahr. and the mould is left there about 8 or 12 hours, depending on the size of the mould. From the oven it is pulled out to the dry floor.

Before passing to the dry floor a few more types of moulds will be considered.

Some patterns are not so easily placed on the follow board as the one first described; for instance, a bevel gear large enough to require a four foot flask.

Experience has taught that it is best to put the tooth section in the drag. It is apparent from the rough sketch that to do this it would be necessary to turn the spoke side down on the follow board. But the spoke side is constructed so that it would not be advantageous to do so unless a special follow board was made.
There are various ways to overcome this, one of which would be to fill a flask with burnt sand and ram up about the shape of the spoke side. Add enough loose sand to permit the pattern to be "batted" in so that the base of the teeth would be even with the top edge of the flask. Another flask is added.

A special facing, made for gears of all kinds, and large flat surfaces and pockets is placed about the teeth. This facing is made stronger and gives a cleaner casting. Nails are placed between the teeth to strengthen them. In modern practice, nails are being discarded to some extent. Roll facing is placed about the balance of the pattern, a bottom gate cut, feeding through the hub on each side of the core, more burnt sand added until ramming is finished, follow plate put on and clamped, and the flasks clamped together. The flasks are rolled over and the follow flask removed including the burnt sand. The spoke side is now up and the operations of adding cope flasks, facing, gaggers and heads are similar to what has been explained. Three heads about 5" x 9" are placed on the rim of the gear and a larger one at the hub. On account of the head at the hub it is necessary to place a ring of soft iron about the core print to hold the core when the neck of the head is out. The
pattern is lifted with the cope with the assistance of wood screws which are put through convenient places in the cope and fastened. The usual finishing is done and the mould is ready for the oven.

Rolls are made with a sweep pattern. The pattern consists of a long 1½" board, cut the shape of the roll. It is centered on a shaft and the shaft centered in the mould on cross bars. The gate is made of fire clay tile and enters the mould at the bottom through the gate cavity. An enormous head is necessary. The flask is filled with burnt sand and facing and rammed even with the joint edge of the flask. A cut is made through the facing about the width and length of the pattern. The pattern is fixed in place and by means of a handle is swung down on the sand. An outline of the pattern is thus made and more facing is cut out following the lines of the pattern. The sweep is again forced down and by this cut and try method, the facing is gradually swept out to the shape of the mould. In the cope side, rods, paste, nails and hemp rope are used to hold the sand in place. The drag has only paste
and nails on the mould surface. After being smoothed down with slick and trowel and the wabbler put in, the usual finishing is done and the completed mould is placed in the oven.

There are occasions when moulds are made from a skeleton pattern. A large elbow, about 5 ft. inside diameter and containing about 2½ inches of surface metal, flange on each end, was cast. The pattern was only an outline of the casting. Instead of making a core box for the core part, the core was made in the mould. A large arbor to carry the weight of the core was first made. It consisted of a frame of metal bars cast to the shape of the elbow.

The drag was rammed up about the shape of the pattern. The drag half of the pattern was placed in and the drag completed, bringing the facing through the skeleton even with the inner surface. A bottom gate in the flange was used. Parting powder was sprinkled over the surface of the mould, the arbor hung in place and the drag half of the core made. The cope half of the pattern was set and the core built up, bringing the facing through even with the outside of the skeleton. The cope was completed, using two large heads, one on each flange, and lifted. The facing on the core part
was cut out to the inside of the skeleton and the cope half of the pattern drawn. The finishing touches were added to this part and the whole core lifted and the other half finished and the whole dried by building a fire under it. The facing in the drag was cut to the outside of the pattern and the pattern drawn. Both cope and drag were finished and dried with charcoal since the mould was too large for the oven.

The necessary means for carrying off the gases were provided. When the metal is poured into the moulds, gases and also steam in green moulds are evolved. It is essential that they be carried away or they will ruin the casting by making blow holes in the hot metal. In large moulds that are not put in the oven, and also in some that are, a layer of cinders is first placed in the drag to act as vents. In green sand, vents are put in the cope with a vent rod. In dry sand the sand is practically free from moisture and permits the gases to escape through the sand recesses. Since vents are placed in the cores, vents to convey the gas from them must be made in the mould. This is done on the dry floor.

There is no end of ways to do moulding. These few methods were used to give some idea how it is done. Just a few general remarks.
A large number of blank gears are made. Some are cast vertical and some horizontal. The arguments in favor of the vertical are that it saves head metal and gives a more sound casting. The head is cut as shown and shows to some extent why a better casting is the result of this method. The neck is free to contract with the casting, doing away with any possibility of cracking due to this cause. Each part above feeds the part below which is another reason. If all heads could be cut thus it would do away with "digging out" heads.

In any pockets, nails, if small, and gaggers, if large, are used in the drag to strengthen and in the cope, to help lift.

In case there are a number of ribs on a casting causing deep large pockets, a mixture of saw dust and sand is used in them to insure give in the mould when the metal cools and shrinks to keep the casting from cracking. In the panels between the
spokes of wheel centers and large spur wheels and blank gears, the sand is dug out and loosened to some extent for the same purpose. A parting powder, made of bone ash is used instead of parting sand for parting purposes.

A large number of moulds are merely outlines of a casting, since the cores form the larger part. For instance in a certain deck plate mould there were 16 cores both large and small.

**DRIY FLOOR**

The moulds are drawn out of the oven on the dry floor side and placed on the floor by means of cranes.

The elbow before mentioned is brushed out to loosen any dirt which may be sticking to the mould. The core is dressed down to cut away any rough corners and set in place and braced by chaplets.

Chaplets are of various kinds, the two most used are the perforated and spool shaped. They are made of tin-plated iron. The tin plate acts as a solder. The perforated ones can be bent to most any shape and are especially advantageous because the metal can run through the perforations.
Oil is sprayed over the surface of the cope to act as an additional bond and make the mould surface harder. The heads in most cases, are built up to insure a large enough mass of metal to feed the casting.

The dirt is blown out of the mould and the gate drained thoroughly. Flour is scattered around the edge of the drag to make it possible to see where the cope sets too hard on the drag. Clay balls are placed on top of the elbow core to indicate the height of chaplets on the cope side. The cope is set and then lifted. A dry mould is always lifted to catch any crushing. The crushed places, if any, are patched and the high places filed down. Again the dirt is blown out. Dough is rolled out in long strips and laid about the edge of the pattern print in order to seal the mould when the mould is closed. The clay balls are replaced by chaplets. Several 20 penny nails are driven between the cope and drag at equal intervals to keep the joint from crushing when the mould is clamped. A cup is set over the gate and the mould is ready to be poured.

The rough edges on all cores should be filed off before they are set in place. Care should be exercised to see that proper vents are provided to carry the gases from the cores.
When there are any inside ribs in a mould, chill rods and nails should be set. An explanation of the chill rod would be similar to that of the bracket with the exception that the chill rod and nail perform their function within the casting, while the bracket without. The chill rod simply equalizes the rate of cooling in heavy and light parts of a casting thus preventing cracking, while the bracket holds together the parts cooling at a different rate.

In wheel centers, gears and blank gears or any casting having a hub core, it is essential to have the core centered. When possible, such cores should be tried in both cope and drag to keep them from crushing when the mould is closed. Any cores extending into the cope should be tapered some to allow for proper clearance; otherwise both cope and core may be crushed.

Some moulds do not have any cores, for instance most rolls do not. They are closed as usual, the cope and drag bolted together, the joint luted up with mud and the mould set in a pit to facilitate pouring. A roll runs anywhere from 6 to 24 tons including head when cast. Other moulds are all core.

A casting free from cracks is sometimes due to the care used after the metal is cast. On large castings
the sand about the head is always dug out to keep the heads from binding on the hard sand. The copes on large flat castings and wheel centers are lifted a few inches while the metal is quite hot, to take the cope weight off.
GREEN SAND MOULDING

As far as actual operations are concerned, green sand moulding is like dry sand with some exceptions.

On small work, the cores, if any, are set and the moulds closed at once. Molasses water is used sparingly and only when the mould is skin dried. Dough is seldom used to seal the joint, but flour is used on skin dried moulds.

The flasks are made of wood; and nails used in the cope bars and short sticks instead of as many gaggers as are used on dry work.

Silica wash is not used and the facing called center plate is harder to work than roll facing.

Castings that do not require very much machining are cast in green sand. Small orders and intricate patterns are handled on the floor while large orders on castings such as rail joints, buffers, center plates, Studebaker hubs, spur wheels, locks, yokes, tooth racks and others too numerous to mention are made on machines.

The automatic machines used are called bumpers and are operated by compressed air. The pattern is fastened to a match board to which the flask fits exactly. Necessary gaggers are set, facing and burnt sand added.
and the air turned on. The bumping does the sand ramming. The balance of the operation is similar to other moulding.

Comparison Table for Green and Dry Sand Moulding.

<table>
<thead>
<tr>
<th></th>
<th>Green</th>
<th>Dry</th>
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</thead>
<tbody>
<tr>
<td>1. Cost</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>2. Time in handling</td>
<td>short</td>
<td>long</td>
</tr>
<tr>
<td>3. Moulds lost</td>
<td>few</td>
<td>many</td>
</tr>
<tr>
<td>4. Gas in mould</td>
<td>much</td>
<td>little</td>
</tr>
<tr>
<td>5. Nature of work handled</td>
<td>little machining on casting</td>
<td>much machining on casting</td>
</tr>
</tbody>
</table>

Metal lays better in a dry mould than in a green.

**BENCH MOULDING**

Most all bench work, except small orders, is done on match boards. Anyone who can ram sand and handle a shovel can do it. The matchboard includes pattern, gate and head runners. The work runs something like this: a flask is fitted to the drag matchboard, necessary sands are added and rammed up, mould rolled over, pattern drawn, very little finishing done and cores set, mould set on channel irons and in some cases skin dried. The cope is finished in about the same hurry and the mould is
closed at once unless it is to be dried. The mould is clamped and is ready for the metal.

**GENERAL REMARKS**

Leaky and worn out air valves in air rammers and air line represent per hours - energy lost - Dollars. New valves would save their cost in a short time. Plenty leaky valves can be found in most foundries.

Air once compressed can be increased in motive value by heating it. It is very apparent that there are numerous places where large quantities of heat are being dissipated.

Increase the temperature of the compressed air 100 degrees Fahr. and you increase your energy 20%; increase it 300 degrees Fahr. and your energy is increased 45%. Lubrication only limits the temperature. A 20 - 45% increase in energy in your air means a reduction of 20 - 45% in your electrical bill. The proper installation could only be used for the machines as the men could not handle the air rammers. Even so, more air is used by the machines than by the air rammers.

Wood flour is used as a plastic. Whether it would serve the purpose that flour does now is only a matter of experiment. At any rate it was quoted at about $12 or $13 a ton not long ago against $29 a ton for flour.
A nail making equipment costs but about $100, quoted directly in an article in the American Machinist, as follows:

"A suitable moulding machine plate could be made for less than $100, whereby one moulder could easily produce 125,000 nails per day."

Silica wash is a mixture of silica and molasses and water.

There are not sufficient tools, such as shovels, hand and air ramblers, heads, wedges, clamps and sledge hammers on the dry moulding floor. Much time is lost in looking for and waiting on such materials. In a short time more tools would pay for themselves in time saved.

SAND MILL

Facing Mixtures.

Roll Facing - Formula

<table>
<thead>
<tr>
<th></th>
<th>A.</th>
<th>B.</th>
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<tr>
<td></td>
<td>40 shovel new sand</td>
<td>30 shovel new sand</td>
</tr>
<tr>
<td></td>
<td>1/2 &quot; silica</td>
<td>10 &quot; old sand</td>
</tr>
<tr>
<td></td>
<td>3/4 &quot; flour</td>
<td>2 &quot; silica</td>
</tr>
<tr>
<td></td>
<td>2-3½ &quot; clay</td>
<td>2½ &quot; clay</td>
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<tr>
<td></td>
<td></td>
<td>1 &quot; flour</td>
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</table>

105
Roll facing - now in use.

#1 fdry. Dry floor  #1 fdry. Green sand side
40 shovel new sand 16 shovel new sand
3 " silica 2 " silica
5 " clay 2 " clay
2 quarts flour

#2 Foundry
40 shovel new sand
8 " silica
5 " clay
1 " flour

Center Plate - Formula

#1 Foundry  #2 Foundry
16 shovel new sand 18 shovel new sand
$4-1\frac{1}{2}$ " clay $4-1\frac{1}{2}$ " clay
1 quart flour 1 " silica
1 quart flour

Center Plate - now in use.

#1 Foundry - Dry Floor  #1 Foundry - Green sand side
40 shovel new sand 17 shovel new sand
$2\frac{1}{2}$ " clay 2 " clay
1 quart flour

#2 Foundry
30 shovel new sand
10 " old sand
$2\frac{1}{2}-5$ " clay
1 " flour
**Special Roll**

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<tbody>
<tr>
<td>40 shovel new sand</td>
<td>45 shovel new sand</td>
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<tr>
<td>8 &quot; silica</td>
<td>4 &quot; silica</td>
<td></td>
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<tr>
<td>1 &quot; flour</td>
<td>1½ &quot; flour</td>
<td></td>
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<tr>
<td>3 &quot; clay</td>
<td>3 &quot; clay</td>
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**Roll, Wabbler, Dies and Gears**

**Wabbler**

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<tbody>
<tr>
<td>10 shovels new sand</td>
<td>6 shovels silica</td>
<td></td>
</tr>
<tr>
<td>5 &quot; silica</td>
<td>2 &quot; graphite</td>
<td></td>
</tr>
<tr>
<td>2 quarts clay</td>
<td></td>
<td></td>
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<tr>
<td>3 pts. Linseed oil</td>
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**Die Pocket**

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<tr>
<td>6 shovels silica</td>
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<tr>
<td>2 &quot; graphite</td>
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<tr>
<td>2 quarts clay</td>
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<tr>
<td>3 pts. Linseed oil</td>
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**Special Die**

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<tbody>
<tr>
<td>16 shovels new sand</td>
<td>35 shovels new sand</td>
<td>5 shovel new sand</td>
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<tr>
<td>1 &quot; clay</td>
<td>1 &quot; silica</td>
<td>6 &quot; silica</td>
<td></td>
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<tr>
<td>1 &quot; silica</td>
<td>1 &quot; clay</td>
<td>½ &quot; clay</td>
<td></td>
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<tr>
<td>1 quart flour</td>
<td></td>
<td>3 pts. Linseed oil</td>
<td></td>
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<tr>
<td>1 &quot; salt</td>
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**Pocket Facing**

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<tbody>
<tr>
<td>35 shovels new sand</td>
<td>5 shovel new sand</td>
<td></td>
</tr>
<tr>
<td>1 &quot; silica</td>
<td>6 &quot; silica</td>
<td></td>
</tr>
<tr>
<td>1 &quot; clay</td>
<td>½ &quot; clay</td>
<td></td>
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<tr>
<td>3 pts. Linseed oil</td>
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**Tooth Facing**

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<tr>
<td>5 shovel new sand</td>
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<tr>
<td>6 &quot; silica</td>
<td></td>
<td></td>
</tr>
<tr>
<td>½ &quot; clay</td>
<td></td>
<td></td>
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<tr>
<td>3 pts. Linseed oil</td>
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**Half and Half**

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<tbody>
<tr>
<td>8 shovels new sand</td>
<td>25 shovels new sand</td>
<td></td>
</tr>
<tr>
<td>8 &quot; old sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 &quot; clay</td>
<td>1 &quot; clay</td>
<td></td>
</tr>
<tr>
<td>½ &quot; dextrine</td>
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**Dextrine Facing**

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<tr>
<td>25 shovels new sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 &quot; clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>½ &quot; dextrine</td>
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Only enough moisture should be used to hold the sands together.
The formulas vary, depending on the conditions of the sand and fire clay and upon the men who handle the scoop.

One of the main essentials of a good facing is that it should peel from the castings readily. The flour acts as a peeling agent.

The mills used for mixing the molding sands are chillian dry pan.
Cores

Cores play an important part in moulding. Almost without exception cores of some kind or description are used in every mould. They are all hand made and vary in size from a small pin core weighing a fraction of an ounce to larger cores weighing several hundred pounds.

Small cores are made by ramming core facings into core boxes, putting a few nails into them for strengthening them, a few vents in permit gases to escape and drying them in the oven. Larger cores require nails and rods of various lengths and paste to give them sufficient strength to permit handling.

All cores are sprayed with a glutrine or molasses water solution before being placed in the oven. The spray is supposed to act as a binder and give the cores a smooth surface. In order to determine the value of glutrine water spray a special investigation was carried on, the results of which follow after core discussion.

The cores are placed in an oven heated either by coal, coke or oil. The oil gives the best results as a more even temperature can be maintained and there is less trouble in handling. The oven is held at a temperature of about 600° F. Higher temperatures burn the cores.
and fail to dry them. The length of time that cores stay in the ovens varies with the size, running on average about 3/4 hour.

After passing through the ovens the cores are stored in racks until needed. Large quantities of cores are lost in handling running sometimes as high as 50%. The cores are made by piece workers making $5 to $7 a day. Some idea can be gained as to the amount of dollars lost with such large percentage of breakage. Closer supervision in handling would eliminate a large amount of this waste.

The core boxes are made of wood or metal, mostly aluminum.

MOISTURE ABSORPTION STUDY OF CORES IN GREEN SAND MOLDS.

Mr. Begley, Chief Chemist, Granite City Plant, had his attention called to the moisture absorption of a core mixture which he had suggested for use. Because the cores made from it, after standing in the closed molds for several hours, absorbed moisture, word came from the Core Department that the mixture was "no good". In order to find out if this mixture really absorbed more moisture than the other in use, Mr. Begley decided to try a simple comparison experiment. He took a 1 1/2" x 7" pin core made out of the mixture in question and a similar core made out
of another mixture and placed the end of each one in separate jars, partially filled with foundry facing and sealed the jars. After standing several hours, the jars were opened and the cores examined. Both core mixtures had absorbed moisture. The question was raised whether or not and to what extent, all the mixtures absorbed moisture upon standing in closed molds. A description of the work done to decide this question follows and numerical results are tabulated.

Pin cores, 1\(\frac{1}{8}\)" x 7" were made of six standard Foundry core mixtures, the formulas of which are found elsewhere. The mixtures were taken from the mill as made. Samples were taken for moisture determination, the results of which are found in table. The cores were sprayed with glutrine water as in practice, and were placed in the same core oven on the same shelf, and left in about a half hour. Six bricks per mixture of the same mixture were also made. Three of these sprayed with glutrine water and three were not and were dried under the same conditions as the cores.
500 grams of Foundry facing were placed in a 64 oz. preservation jar and quickly sealed. Two sets of six each were made. In each jar a pin core was set horizontally to the depth of two inches, the facing tamped snugly about it and the jar sealed. Twelve pin cores were used, two from each mixture, making two sets. One set was set aside for 24 hours and the other for 48 hours. At the end of these periods, the cores were taken out cut in halves, (with one exception), designated the top half and lower half, the halves quickly crushed and placed in air tight sample bottles. The exception, the car wheel mixture core, was cut into four equal parts, as indicated in figure #2, samples quickly made and sealed in air tight sample bottles. Ten gram samples were run for moisture, the results of which are found in the table at end of discussion.

Six cores, one from each mixture were broken and the centers run for moisture. The results are found in the table.
Twelve cores, two of each mixture, were placed on a stock shelf in the core room. One set of six was left for eight days and the other for sixteen days. The cores were broken up at the end of these periods and run for moisture. Results are found in the table.

The brickets were tested for their relative strength and results are tabulated. The results appear to be erratic. A second set of brickets were made and tested with but little difference in results.
DISCUSSION AND REMARKS

Since some parts of this work are supplementary to the real purpose indicated in this paper, they will be discussed in brief.

It is considered good practice to have about 3½% moisture in the core mixtures. By reference to the table, a moisture content of from 0.95% to 5.02% is indicated. The two lowest, 1.98% and 0.95% can be accounted for since the mixtures in question are both oil mixtures—the oil is part of the moisture when the sand is being mixed and is not driven off when the moisture test is made. The core from #3 Flour Mixture is the only one which shows any appreciable amount of moisture in its center. And at most, it is negligible in it and all other core centers. The cores placed in the Foundry do not show any absorption of moisture in either the eight-day or sixteen-day set, which would be of any consequence.

On the 24-hour and 48-hour test, the figures indicate that the lower half of the cores or that part which came in contact with the foundry facing absorbed more moisture than the upper half. To consider the figures only, one might get the impression that the cores did not take up much moisture. But the sample
taken for the moisture determination represents the whole half, when in reality the moisture was very pronounced only on the surface where the steel comes in contact with the core.

In connection with this surface absorption, more moisture was absorbed by the sand sprayed with glutrine than without. Due to the method of spraying the cores, with glutrine water, this discovery was made. Only half of the pin cores, or the side up, receives any glutrine water. In order to ascertain whether the glutrine side really did absorb more than the dry side, the car wheel mixture core, on both the 24-hour and 48-hour test were cut as before indicated. The figures indicate that the glutrine side absorbs the moisture.

To further substantiate these figures, a skin sample was taken from the bottom half of the oil mixture core, run 48 hours from both the glutrine and dry side and the moisture estimated. On the dry side 2.19% moisture was absorbed while on the glutrine side 5.05%, which again indicates that glutrine has a tendency to cause water absorption and that to a great extent. These figures further show how much moisture is absorbed by the surface in comparison with the whole half, varying from 2.19, 5.19, 5.05% on the surface to 0.61%, 1.15% on the
whole half. In as much as the steel must come in contact with the surface of the core, this surface absorption might prove to be quite serious. Although most of the moisture appears to be on the surface of the cores, the whole core is affected, as indicated in the way that they crumbled when crushed.

It is contended that it is absolutely necessary to spray the cores with glutrine water to make them hold up. The brickets were made and tested to see what difference if any, the glutrine water made. A definite conclusion can hardly be drawn from the results obtained, but from all indications and figures too, the glutrine water effect is nil. The glutrine wet only one side and penetrated to a depth of but about 1/8".

In connection with this work, a study of the sand mill operations was carried on. As a result, a set of standard operation sheets have been compiled, one for each mixture, indicating the formula, how ingredients should be added and total time of milling.

Just a brief summary:

Cores placed in green sand mold and allowed to stand, absorb moisture sufficient to ruin the core. The amount of moisture absorbed, increasing with length of period of standing.
Most of the moisture is absorbed by the surface of the cores.

Glutrine water increases tendency to absorb moisture.

Glutrine water does not strengthen small cores as contended.

Cores standing in foundry on stock shelves show no moisture absorption.

CORE FACING

#1 and #3- Car wheel and Linseed Oil.

720 lbs. New Sand
3 lbs. Dextrin
7½ lbs. Fire Clay
7½ lbs. Linseed Oil

Tempered with glutrine water. #1 is mixed in large sand mill. #3 is mixed in oil sand mill. #3 used for hub cores for Davis wheels and on small cores where strength is required.

#2- Dextrin and rosin.
650 lbs. New Sand
500 lbs. Old Sand
7 lbs. Dextrin
14 lbs. Fire Clay
4 lbs. Rosin

Tempered with Glutrine water 1-20. Used on center and end cores on side frames.
#4- Rosin

650 lbs. New Sand
500 lbs. Heap Sand
14 lbs. Fire Clay
20 lbs. Rosin

Tempered with clear water. Used on Journal lug, and Brake Hanger Cores.

#5- #3 Flour

650 lbs. New Sand
500 lbs. Heap Sand
14 lbs. Fire Clay
20 lbs. Flour

Tempered with glutrine water 1-20. Used on Davis Wheel Cups.

#6- Core Compound

800 lbs. Old Cores
350 lbs. New Sand
14 lbs. Fire Clay
19 lbs. Core Compound

Tempered with Goulac water 1-20. Used for pouring cups on side frames and bolsters.

Foundry Facing.

400 lbs. New Sand
300 lbs. Old Sand
30 lbs. Clay

Tempered with clear water.
## MOISTURE ABSORPTION TABLE

<table>
<thead>
<tr>
<th>Sand Mixture</th>
<th>Moisture in Mix</th>
<th>Moisture in Dry Core</th>
<th>Moisture after 24 hr. test Upper Half</th>
<th>Moisture after 24 hr. test Lower Half</th>
<th>Moisture after 48 hr. test Upper Half</th>
<th>Moisture after 48 hr. test Lower Half</th>
<th>Moisture after standing in Foundry 8 Days</th>
<th>Moisture after standing in Foundry 16 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car Wheel #1</td>
<td>1.98%</td>
<td>0.18%</td>
<td>0.58 W</td>
<td>0.38 W</td>
<td>0.78%</td>
<td>1.50%</td>
<td>0.24%</td>
<td>0.18%</td>
</tr>
<tr>
<td>Dextrin &amp; Rosin #2</td>
<td>3.75%</td>
<td>0.17%</td>
<td>0.54%</td>
<td>0.69%</td>
<td>0.78%</td>
<td>0.61%</td>
<td>0.20%</td>
<td>0.20%</td>
</tr>
<tr>
<td>Oil #3</td>
<td>0.95%</td>
<td>0.17%</td>
<td>0.54%</td>
<td>0.08%</td>
<td>0.61%</td>
<td>1.15%</td>
<td>0.24%</td>
<td>0.16%</td>
</tr>
<tr>
<td>Rosin #4</td>
<td>2.85%</td>
<td>0.10%</td>
<td>0.50%</td>
<td>1.18%</td>
<td>0.72%</td>
<td>1.30%</td>
<td>0.17%</td>
<td>0.16%</td>
</tr>
<tr>
<td>#3 Flour #5</td>
<td>5.02%</td>
<td>0.66%</td>
<td>0.99%</td>
<td>1.85%</td>
<td>0.74%</td>
<td>1.47%</td>
<td>0.39%</td>
<td>0.37%</td>
</tr>
<tr>
<td>Core Compound #6</td>
<td>4.20%</td>
<td>0.08%</td>
<td>0.49%</td>
<td>1.30%</td>
<td>1.54%</td>
<td>2.64%</td>
<td>0.20%</td>
<td>0.16%</td>
</tr>
<tr>
<td>Foundry Facing #7</td>
<td>3.49%</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

W- Wet with glutrine water.
D- As made
### MOISTURE ABSORPTION TABLE

<table>
<thead>
<tr>
<th>Sand Mixture</th>
<th>Test Sand</th>
<th>Check Sand</th>
<th>Test Wet</th>
<th>Check Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
<td>Dry</td>
<td>Wet</td>
</tr>
<tr>
<td>Car Wheel #1</td>
<td>416</td>
<td>435</td>
<td>198</td>
<td>154</td>
</tr>
<tr>
<td>Dextrin &amp; Rosin #2</td>
<td>101</td>
<td>126</td>
<td>90</td>
<td>108</td>
</tr>
<tr>
<td>Oil #3</td>
<td>195</td>
<td>172</td>
<td>69</td>
<td>51</td>
</tr>
<tr>
<td>Rosin #4</td>
<td>68</td>
<td>85</td>
<td>109</td>
<td>81</td>
</tr>
<tr>
<td>#3 Flour #5</td>
<td>196</td>
<td>213</td>
<td>95</td>
<td>115</td>
</tr>
<tr>
<td>Core Compound #6</td>
<td>75</td>
<td>112</td>
<td>86</td>
<td>91</td>
</tr>
<tr>
<td>Foundry Facing</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

W= Wet with glutrine water.
D= As made.
FLOW SHEET
SHOWING BRIEFLY MOLDING PROCESS FROM BLUE PRINT TO COMPLETED CASTING

Blue Print
Pattern Shop
Pattern to Storage for Record

Nails, Gages, Rods, Molds, Water, Silica, Flash.

Pattern to Molding Floor

Facing, Burnt, Parting Sands.

Pattern to Drag Cores Flashs

Cape Lifted; Pattern Drawn, Mould Finished, Nailed; Brackets Cut; Proper Silica and Molds; Treatment

Moulder Does Most of His Work Here.

Molds

Oven Dried 8-12 hrs. 600-700°F

Green Skin Dried

Proper with Oil

Place with Charcoal

Brackets Cut, Chill Rods, Nails and Cores Set, using Nails, Hooks and Rats.

Molds Closed

Dry Molds
Dry Lifted to Catch Crushing.
Closed Again, Dough to Seal Joints; Clamped.
Cups Set.

Green Sand
Clamped, Clamped Cups Set.

Metal Pouring

Large Castings
Sand Looseened about Hours to Permit Shrinkage

Small Castings

Snake Out Floor

Casters, Nails, Gages, Clamps, Picked up by Helpers, Kios, Moulder

To Molding Floor

SAND Molds, Plates

To Drop

Dump Molding Floor

Castings Cleaning Floor

Large Castings
Rolls, Wheel Casters - Mechmed.

Inspection

Small Castings

Scrap

Annealing Pit

Inspection

Scrap

To Stamping Floor

To Furnace

To Customer
METALLURGY OF STEEL CASTINGS

INSPECTION OF CASTINGS
Inspection is the last word on castings before they reach the shipping floor. The work consists of surface inspection on castings which are not machined and a more careful inspection on castings to be machined.

It is almost impossible to find a perfect casting: one which does not contain some of the imperfections to be mentioned. The perfect casting is an ideal toward which to work.

In surface inspection, sand drop, sand holes, apparent gas and shrink holes, cold run, fins, core and cope shift, crooked, dirty and scabby castings, cracks and gage specification, (where necessary) are given attention.

When machined castings are under consideration, non-apparent gas and shrink holes are sought for in addition to other defects mentioned.

Almost all these defects can be traced to the moulding department. A sand drop is the result of sand falling from the cope into the drag. The casting has a hole where the sand fell and a chunk of metal from where the sand fell. Sand holes are caused by sand drop and dirty mould. Gas holes leave holes of various sizes and are found when the mould is not properly vented. These holes are more injurious to
small castings than to large, and to machined than those
which are not machined. Shrink holes are due either
to the condition of the metal when poured or to the use
of too small heads. Cold run explains itself and leaves
some part of the casting ragged and possibly causes it
to be scrapped. Fins are produced when the joint is too
wide and also by loose cores. Core and cope shift are
caused by improper core setting and closing, and both
leave the castings in bad condition. Badly shifted
center cores on blank gears and spur wheels are quite
frequently the cause of scrapping important and expen-
sive castings. Dirty and poorly mailed moulds give
scabby castings. Some cracks are due to the metal
shrinking about cores or included parts of the mould,
while others are caused in annealing and to different
rates of cooling in the casting. Bent castings are the
result of shrinking, warping in annealing, and handling
while hot. The best example of using a gage is found in
center plate inspection. All center plates must be
gaged. The gages are made so that 1/16" is allowed
over outside dimensions, and under inside dimensions
while the height is made exact. The height can be 1/16"
maximum or minimum size. The large majority of castings
do not need to pass a gage.
Whenever any of these defects appear, all except a bad center core or cope shift can be remedied by the welder, grinder, chipper or pressman, depending upon their nature and extent. On large castings where welding is necessary and permissible, the casting should be re-annealed, especially if the weld is located in a vital part of the casting.

It is the duty of the welder to weld gas and shrink holes and serious cracks. The grinder takes down the rough surfaces made when gates and heads are flogged, sawed and burned off (in case of large heads) with oxy-acetylene burner. The chipper cuts off any fins, cleans any holes, cuts off brackets, in fact makes a good looking casting. The pressman straightens and opens or closes sprung and warped castings.

The large castings are usually checked for important dimensions. Where machining is necessary about $\frac{1}{4}$" metal is allowed over exact dimension.

All castings, whether they be R. E. J. Locks and small castings, center plates and other car castings and miscellaneous castings are covered in a general way by the above discussion.
SAMPLE CASTINGS

Not all castings are checked before they are run, but a large number require a check on a sample before the order is completed, even going so far as sending a sample to the customer to obtain his O. K., or corrections, if any.

When a new pattern is sent into the foundry, the casting of which requires a check, the pattern shop Foreman makes out a sample report sheet and sends it with the blue print to the general foundry foreman. The general foundry foreman supervises, as a rule, the work of making the mould. After the mould is made, the report is forwarded to the cleaning department. The cleaning department sends the completed casting with the report, to the checking inspector. The casting is checked with the blue print for all dimensions, the weight of the casting found, a report made and sent to the pattern foreman who makes any necessary changes. Usually the castings check O. K. in all except a few minor points or dimensions.
DAILY SAMPLES

On large orders which run for several days and weeks, a daily sample is submitted, upon which a report is made. These samples are put through the usual cleaning process and sent to the surface table, where gages are tried, dimensions checked, defects noted, and the necessary changes, if any, reported. It is quite often the case, that a pattern, after several days use will become loose or worn, and throw the casting off. Immediate attention is given such defects to keep any more casting coming through in this manner.

DEFECTIVE CASTINGS

Defective castings may fall under two heads; (1) those which are found so in the foundry, and (2) those which are shipped and returned. A casting is not considered defective unless it is so bad that it cannot be repaired to meet specifications.

The defects which send a casting to the scrap heap have been mentioned before in the first part of this report, and are the more serious forms of cold run, short run, miss run, slag, bad cope and center.
core shift, bad and deep cracks, important dimensions off on account of shrinkage (the last case rare) and others.

Seldom does an unmachined casting return unless it should be on account of dimensions or flaws which the inspection department failed to catch, and this is quite probable. A man who inspect castings 100% well is rare.

Most returned castings are machined ones. Non-apparent gas and shrink holes, cope shift and cracks are causes which send most machined castings back; a large number of blank gears, at times after the teeth have been almost completely cut; cylinders on account of cracks. In some instances these defects are not of any consequence or in a vital point and can be (and it is quite permissible to do so) welded and reshipped.

The chief foundry clerk makes a record of the defective castings and sends a daily report to the Superintendent and Main Office so that % good castings can be figured. From 3% to 5% of the castings are scrapped.
There are gages of various kinds and used for various reasons, but those of most importance are the contour and spacing. These are made of wood and sheet metal, mostly of the latter on account of wear. Both maximum and minimum templates are made but as a rule only minimum are used, and any variations from the minimum being left to the justment of the inspectors in charge.

The method of making the most common contour gage has been previously mentioned: center plate. All gages, unless otherwise specified, are made so that outside dimensions are 1/16" over and inside dimensions are 1/16" under size. In case of an exact dimension gage, it is necessary to allow a 1/64" or 1/32" over, otherwise the gage will not fit the dimension in question, as it is impossible to put an exact dimension gage over an exact dimension.

In course of time the gages become worn, and it is necessary to recheck them for wear, and perhaps make a new one, in case the old is off any appreciable amount.

A spacing gage is used to check hole centers for correct measurement. Others are used for blast furnace segments to measure arcs and angles; buffers;
exact dimensions: as Hercules Pedestals; French rail joints; center fillers and in fact, any casting have exact and important specifications.

Flow sheet #1 shows the ideal route of a casting from the Flogging Floor to customer. It is not possible to have all castings follow this route, but it is probable that the majority could.

Flow sheet #2 shows as near as possible how the castings do go. It is apparent that some of the steps following inspection might be eliminated. All castings should be sand blasted or rattled before they reach the chipper and inspectors, with a disappearance of step (1) one. A more rigid demand on grinders and chippers would cut #2 and #3 out entirely. It is not necessary to anneal all castings, but a number do find their way to the inspector and even to the shipping floor that should be annealed. More care in inspection and on the flogging floor would leave this step out. A large number of castings can be cast so that they will shrink straight rather than bent. A little more time and care could be used in handling castings while hot. Care in racking and handling in annealing would prevent warping and bending. The pattern on castings which flare could be
SHOWING IDEAL PATH OF CASTING FROM FLOGGING FLOOR TO CUSTOMER

FLOW SHEET #1

FLOGGING FLOOR

ANNEALING PIT

SCRAP

SAND BLAST

GRINDER

CHIPPER

INSPECTION

SCRAP

SHIPPING FLOOR

CUSTOMER
FLOW SHEET #2
SHOWING ACTUAL AND VARIOUS PATHS TAKEN BY CASTINGS FROM FLOGGING FLOOR TO CUSTOMER.

FLOGGING FLOOR

SAMPLES SCRAP

ANNEALING PIT

SAND BLAST

GRINDER

CHIPPER

INSPECTION

AND BLAST GRINDER CHIPPER ANNEALER PRESS DRILL PRESS WELDER SCRAP

INSPECTION

INSPECTION

SCRAP

SCRAP

SHIPPING FLOOR

CUSTOMER
so made that the most of the flare could be taken out.
Presswork, the most of it, is due to some of the few conditions mentioned. Drill press work is due to high joints and poor hole cores and coring. It is quite hard to get around welding, yet a large amount is necessary on account of heads not being large enough causing shrink holes under the heads and in other parts of the castings.

Where foreign inspection is necessary, it is needless to say that a few castings will find their way back through some one of these steps and possibly be rejected.

The main point in question in this discussion, besides those mentioned, is that all this repeated work means additional handling of the same castings by the truckers, where once after reaching the inspector, in most cases, should be sufficient.

There are many kinds of castings,— castings of every description passing through the foundry. In order to give some idea in a small way of the variety, the castings for one car are mentioned below:

Buffer; Draft, Rigging and Lugs; Yoke; Side Wedge; Follow Block; Cam Block; Carriers;
Center Plates, Truck Columns; Journal Boxes; Wedges; Knuckle; Locks; Links; Safety Hooks; Door Hinges; Door Roller Bracket; Side Bearings; Center Filler; Struts; Break Fulcrum; Break Wheel; Break Shoe; Roping Iron; Pole Sockets and, no doubt, some few which failed to catch my attention.

Suggestions from Philip E. Langworthy and assistance of Frank James Assistant Chief Chemist at Granite City Plant are acknowledged in work on Open Hearth Practice.
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Metallurgical Analysis......................Lord and Demorest
Chemical Analysis of Special Steels, Steel
making alloys and graphites.................Johnson