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The Open Hearth Conference Award is presented to the "runner-up" for the McKune Award. It was established in 1944 by the National Open Hearth Steel Committee.
Use of Low Manganese Hot Metal In Basic Oxygen Furnaces

by J. J. McCarthy and K. R. Bock

The purpose of this report is to evaluate the feasibility of blowing a low manganese hot metal in the basic oxygen steel shop at Fontana. Various operating and metallurgical factors are compared at several levels of hot metal manganese. The data in this report were generated by an initial trial in 1965, followed by another comparison in 1967.

HISTORY OF HOT METAL MANGANESE

Due to the low level of manganese in Eagle Mountain ore used in the blast furnaces at Fontana, the average hot metal manganese is 0.13%. In late 1958 the basic oxygen shop went on stream, and it was necessary to burden two blast furnaces with MnO to supply 0.45% Mn hot metal to the basic oxygen shop. A steel nitrogen level that jeopardized the reputation of basic oxygen steel accompanied by excessive sparking caused the hot metal manganese level to be raised quickly from 0.45% to 0.80%. At the 0.80% Mn level, ladle nitrogen decreased and remained at a satisfactory level. Due to improvements in blowing technique, the hot metal content was gradually decreased with no ill effects from 0.80% in 1959 to 0.55% in 1965 as shown in Fig. 1.

A single-hole lance was used from the shop start up until late 1963. At this time, trials with the three-hole lance were initiated, and during the summer of 1964 the three-hole lance became operational. Plant management decided to re-evaluate the costly practice of using a 0.50% aim hot metal Mn due to the marked improvement in blowing characteristics of the three-hole lance.

A trial was conducted from June 15 to Sept. 15, 1965, blowing heats at three levels of hot metal manganese (Mn < 0.20%, Mn 0.20% to 0.39%, and Mn > 0.39%). During the trial various levels of hot metal Mn were obtained by blending hot metal from No. 4 blast furnace (no MnO) with No. 2 blast furnace (MnO). After an evaluation of heats blown with low Mn hot metal, the use of MnO was discontinued. Hot metal with an average Mn content of 0.13% was blown from March 1966 to April 1967.

In April 1967, plant management decided that a stockpile of 9000 tons of MnO be consumed. This presented another comparison period of high and low hot metal manganese—the last full month of high hot metal Mn (Aug. 1967) is compared with the first month of low hot metal Mn (Oct. 1967).

FURNACE VOLUMES

Kaiser’s furnaces were designed for tapping 65-ton heats. Since start up, the refractory sidewall linings have been increased from 21 in. to 24 in. thickness; and the heat size has been increased to 110 tons. These factors caused a slag working volume of 16.91 cf per ingot ton, which is low when compared to the industry average of 24.24 cf per ingot ton. This design limitation results in less volume to contain slag and metal during the blow. The current 11,000 cfm blowing rate is relatively high for a 110-ton vessel. Consequently, there is a persistent slopping problem. However, there is considerably less slopping with the low Mn hot metal than with the higher Mn hot metals (Fig. 2).

OPERATING DATA

As shown in Fig. 3, the tons per hour increase significantly during the period of low Mn hot metal usage. The 12 tph improvement is attributed to reduced testing time and less furnace pit clean up delays. As the melter’s confidence improved with the nearly constant manganese residuals, heats were tapped with only the Leco carbon results. This alone saved 4 min per heat on those heats that would otherwise require laboratory manganese preliminaries, (i.e., an average of 60% of heats tapped). Furnace pit clean up delays were reduced because of the minimized slopping with low Mn hot metal.

It is probably unnecessary to point out that Kaiser's spar consumption was already too high with high Mn hot metal. However, the greater fluor spar consumption in pounds per ton was similar to the findings of Mr. Heaton at Great Lakes. There was an increase of 21.2%, or 5.2 lb per ton, during the Oct. 1967, period of low Mn hot metal usage.

As expected, the use of low Mn hot metal resulted in a higher per-
cent of hot metal in the charge. Hot metal usage increased 1%.
Lance life improvement, from 41.8 heats per lance during high Mn hot metal usage to 56.4 heats per lance during low Mn usage, requires further explanation.

COMPARATIVE LANCE LIFE

Oxygen lance failures and causes for failure are compared in Fig. 4. In either case, during high or low Mn hot metal usage, lance life performance must be rated as poor; but for the periods studied, an increase of 14.6 heats per lance, as shown in the previous slide, was experienced during the use of low Mn iron. Although this is contrary to results reported by others for lance life with low Mn hot metal, it is not considered that the difference is enough to be truly significant.

Lance failures were classified as: 1) skulled, 2) mechanical, 3) lance water leaks, and 4) nozzle water leaks. Lances taken out of service for reasons other than skulls for both low and high Mn hot metal were all because of nozzle water leaks with the exception of one for mechanical causes and one with a lance water leak.

A definite increase in the frequency of skulled lances was found with low Mn hot metal. A breakdown of the causes for lance failures showed that 52.1% were taken out of service because of heavy skulls when using low Mn iron as compared to 26.6% with high Mn hot metal.

Table I shows that, unlike the results reported in Stel by Zhigulin and Rubinski, and Karpinski at Ford, there was found no correlation between hot metal manganese level and refractory life. Research into the improved lining life of Sept., 1967, through Nov., 1967, uncovered the interesting statistics on dolomitic lime consumption. Lining life improved dramatically with an increase in the usage of dolomitic lime as the only outstanding variable.

FURNACE YIELD

Prime ingot yield is a consideration that cannot be overlooked. As shown in Fig. 5, there is a significant variance between the high and low Mn hot metal levels. The greater than 2% gain from the low Mn hot metal is partially due to less slopping.

There are at least two other contributing factors. Less metallic loss due to manganese lost to slag with low Mn hot metal and a substitution of limestone for ore pellets as a hot metal temperature adjustment accounted for an indefinite gain in yield during Oct. 1967.

It should also be mentioned that there is an increase in blast furnace production as pointed out by Zhigulin and Rubinski. The difference in blast furnace yield is somewhat more than indicated by hot metal analysis due to the low (54%) Mn content of the ore.

PERCENT HOT METAL SULFUR REMOVAL

Hot metal manganese level is claimed to be a factor in sulfur removal by some authorities. However, similar to Heaton at Great Lakes' and Karpinski at Ford, hot metal Mn content, as illustrated in Fig. 6, showed no influence on hot metal sulfur removal. In fact,

Table I. Manganese Level Effect on Refractory Life

<table>
<thead>
<tr>
<th>Mn level, %</th>
<th>Months</th>
<th>Hits per campaign</th>
<th>Lb Dolomite Lime/ton of steel</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13</td>
<td>13</td>
<td>404</td>
<td>7.1</td>
<td>3/66-3/67</td>
</tr>
<tr>
<td>0.82</td>
<td>5</td>
<td>403</td>
<td>7.1</td>
<td>4/67-8/67</td>
</tr>
<tr>
<td>0.13</td>
<td>3</td>
<td>490</td>
<td>13.0</td>
<td>9/67-11/67</td>
</tr>
</tbody>
</table>

Fig. 3—Operating data: production rate, fluorspar consumption, lance life.

Fig. 4—Oxygen lance failures.

Fig. 5—Furnace yield.

Fig. 6—Per cent hot metal sulfur removal.
slightly better average sulfur removal—48.1% as compared to 46.8%—occurred on the low Mn hot metal heats. It is interesting to note that percent hot metal sulfur removal increased as hot metal sulfur increased. The increase in sulfur removal is due to two factors: sulfur in the scrap is neglected in the calculation for per cent sulfur removal and lowers the sulfur removal per cent at low hot metal sulfur contents; and at high hot metal sulfur levels, extra burnt lime is charged above that necessary for the normal 3.2 V ratio.

**DEVIATION FROM AIM LADLE MANGANESE**

The deviation from aim ladle manganese is illustrated in Fig. 7. Tap manganese is closely related to hot metal manganese and tap carbon. Inasmuch as the tap Mn from low Mn hot metal can be consistently estimated, many low carbon, rimmed, and bottle-top heats are tapped without Mn prelims using shop Leco carbons. Of course, the hot metal sulfur content must be reasonably low. Despite fewer heats with preliminary Mn analysis, the graph shows that heats blown with low Mn hot metal resulted in slightly better conformance to aim ladle Mn. It is noted that both high and low Mn hot metal deviation was to the plus side of the aim. Standard deviation is used to more fully explore the range of variation. In the period of low Mn hot metal, there was 34% more line pipe tonnage melted with the aim ladle Mn in the 1.10% to 1.30% level. Even so, the standard deviation was slightly favorable with low Mn hot metal.

**LADLE NITROGEN AVERAGE**

A major obstacle in basic oxygen steel production at Kaiser Steel was the initial high steel ladle nitrogen content on heats blown with a single-hole lance, coupled with poor blowing characteristics. Fig. 8 shows that heats blown with a three-hole lance and at various levels of hot metal Mn show little difference in average ladle N. This is believed to be a result of greatly improved blowability with the three-hole lance and compares similarly to Karpinski’s findings at Ford. Heathon of Great Lakes Steel has reported a 0.00018% increase in N for low Mn hot metal.

**SLAB SURFACE QUALITY**

In today’s competitive steel market, slab surface quality is a vital factor, not only with regard to quality, but it also is directly related to cost considerations and customer service. In addition to these factors, metallurgical studies have consistently shown that a slab requiring hand conditioning results in an inferior product. Sponge is a major slab surface defect that requires costly hand conditioning. Fig. 9 exhibits a marked improvement in per cent sponge for heats blown with low Mn hot metal in rimmed, low C bottle top and high C bottle top grades produced at Fontana. In order that the difference between the per cent sponge of rimmed and low C bottle top steel slabs from low Mn hot metal be understood, it is necessary to point out that 61% of rimmed heats are high C (i.e., 0.15% C).

The improved per cent sponge resulting from the use of low Mn hot metal is attributed to the uniform level of tap Mn. This factor accounts for less variation in the level of bath oxidation at a given carbon. Since ladle deoxidation at Kaiser Steel is based upon tap carbon, less variation in rimming action was experienced.

**TIN MILL EVALUATION OF LOW MANGANESE HOT METAL**

Since most of the tin plate at Fontana is produced in the basic oxygen shop, tin mill evaluation of steel made from low Mn hot metal was essential. A total of 169 heats blown at three levels of hot metal Mn (Mn < 0.20%, Mn 0.20% to 0.39%, and Mn > 0.39%) were evaluated. The middle ingot of the 169 heats was coded and followed through the tin mill. Both conventional and double-reduced tin plate were compared. Factors evaluated included temper mill performance, electrolytic line steel defects and pin holes, nitrogen content, and in-
ternal cleanliness. Also, both prime and waste-waste sheets were examined to determine if any defects peculiar to the low or intermediate Mn range were present.

Fig. 10 shows that for double-reduced tinplate, pinholes per 1000 ft and per cent steel defects were peculiar to the low or intermediate Mn range were present. A similar relationship was present for conventional tinplate steel defects except that the overall level of defects was lower.

There was no significant difference in temper mill performance (rerolls for temper or shape) among the three hot metal Mn ranges. Only one coil from the regular Mn range was rerolled for temper and one coil from each Mn range for shape. Nitrogen contents were similar. The surface of prime sheets was thoroughly inspected and micro specimens were prepared from any area with minute ruptures that could possibly be a defect termed "Zit" (a subsurface iron alumina spinel). No defects of this nature were observed.

In conclusion, a thorough tin mill investigation of heats blown with low Mn hot metal revealed that:

A. A substantial cost saving resulting from the use of low Mn hot metal. During this period, the hot metal manganese was as low as 0.17% against an ordered range of 0.50% minimum.

B. Maximum flexibility in scheduling hot metal from four blast furnaces that supply both the basic oxygen and open hearth steelmaking facilities.

C. A prime ingot yield gain.

D. An oxygen furnace productivity improvement of 12 tph.

E. A marked decrease in sponge on slab product.

Hot metal Mn level had little or no influence on:

A. Furnace refractory consumption.

B. Conformance to aim ladle analysis.

C. Ladle nitrogen level.

D. Hot metal sulfur removal.

E. Tin mill defects.

On the negative side, fluorospar consumption increased five lb per ton, a higher percent of hot metal in the charge and more lance skilling resulted from the use of low Mn hot metal.

**ECONOMIC BENEFITS**

In order to determine the economic gain resulting from the use of low Mn hot metal in the basic oxygen furnaces, the cost of using Mn for a 0.50% aim Mn hot metal must first be established.

Under the conditions at Kaiser Steel, this cost amounts to 52¢ per ton of steel. The cost of additional ladle FeMn necessary during low Mn hot metal usage was calculated at 20¢ per ton of steel. Therefore, the saving is 32¢ per ton of steel as theoretical calculations show in A, B, and C.

A. Cost of Using Mn Ore for .50% Aim Mn Hot Metal.

Cost of Mn Ore/ton of hot metal = 62¢/ton.

For a 110 ton heat 122 tons of Mn ore were charged.

Average percent hot metal is 75%.

Cost of Mn Ore = (122 tons of Mn ore) (75% HM) (62¢/ton HM)/110 tons steel = 52¢/ton steel.

**B. Cost of Additional Ladle FeMn using Low Manganese Hot Metal.**

For heats where a tap Mn was available the following estimating equation was determined.

Tap Mn = 0.15 + 0.50 (Tap C) + 0.14 (Hot Metal Mn).

For Hot Metal Mn = 0.20, the average Mn was 52%.

For Hot Metal Mn < 0.20, the average Mn was .12%.

The average difference in tap Mn is .06%.

Cost of regular FeMn is 8.6¢ per pound.

For 110 ton heat 42# FeMn per point (0.1%) is typical. Cost/ton of steel = (6 points) (8.6¢/lb.)/110 ton = 20¢/ton of steel.

**C. Estimated Cost Savings Using Low Manganese Hot Metal.**

Savings = Cost of manganese ore — Cost of additional ladle FeMn.

Savings = 52¢/ton of steel — 20¢/ton of steel.

Savings = 32¢/ton of steel.

**CHECK ON ESTIMATED SAVINGS**

Inasmuch as the term "manganese" is a function of tap carbon as well as hot metal Mn, Table II depicts a cross-section of steel grades tapped at Kaiser, and the table established that the estimated additional ladle FeMn is conservative.

The average ladle FeMn difference in all three cases is considerably less than predicted by the estimating equation.

**SUMMARY**

An extensive comparison between heats blown with low Mn hot metal (Mn < 0.20%) and high Mn hot metal (Mn ≥ 0.20%) showed the following advantages for low Mn hot metal:

A. A substantial cost saving through elimination of MnO in the blast furnace burden. There was also blast furnace yield improvement.

B. Maximum flexibility in scheduling hot metal from the four blast furnaces that supply both the basic oxygen and open hearth steelmaking facilities.

C. A prime ingot yield gain.

D. An oxygen furnace productivity improvement of 12 tph.

E. A marked decrease in sponge on slab product.

Hot metal Mn level had little or no influence on:

A. Furnace refractory consumption.

B. Conformance to aim ladle analysis.

C. Ladle nitrogen level.

D. Hot metal sulfur removal.

E. Tin mill defects.

On the negative side, fluorospar consumption increased five lb per ton, a higher percent of hot metal in the charge and more lance skilling resulted from the use of low Mn hot metal.

**CONCLUSION**

Based on the marked advantages of low Mn hot metal, management at Kaiser Steel has discontinued the use of MnO in the blast furnaces.

**REFERENCES**


**Table II. Verification of Estimated Additional FeMn**

<table>
<thead>
<tr>
<th>Aim analysis</th>
<th>H.M. Mn ≤ 0.20</th>
<th>H.M. Mn &gt; 0.20</th>
<th>Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Ladle FeMn</td>
<td>1246 lb</td>
<td>1156 lb</td>
<td>90 lb</td>
</tr>
<tr>
<td>Heats</td>
<td>24</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Average Ladle FeMn</td>
<td>1699</td>
<td>1654</td>
<td>45 lb</td>
</tr>
<tr>
<td>Heats</td>
<td>122</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>Average Ladle FeMn</td>
<td>1245</td>
<td>1060</td>
<td>185 lb</td>
</tr>
<tr>
<td>Heats</td>
<td>39</td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>

**DISCUSSION**

by E. J. Sobey

Prior to 1964, several comprehensive trials at the Cleveland Blast Furnaces resulted in the production of low manganese hot metal. During these periods, the hot metal manganese was as low as 0.17% against an ordered range of 0.50% minimum.

Single-hole lances were in use
at that time and the adverse effect on the blowing characteristics was very evident. The incidence of heavy sparking was markedly increased, as shown in Table I. Evaluation of 416 heats indicated a ferric yield loss of 1.7% on heats with heavy sparking. Of great concern were large buildups whose removal resulted in delay time as well as decreasing lance life. As previously reported, the excessive erosion of refractories in the cone area was the controlling factor in the termination of every campaign. Heavy sparking accelerated the wear of refractories by abrasion in this critical section.

As a result of these evaluations, the blast furnace dept. was urged to maintain a 0.50% minimum Mn. In June and July 1966, hot metal Mn levels decreased to as low as 0.38%, which is considerably below the normal 0.60 to 0.90% range. With the use of three-hole lances, the effect on blowing characteristics was not as pronounced; however, buildups were again a problem. Another evaluation was therefore made to re-establish the minimum hot metal Mn requirements for three-hole lance practice.

To evaluate the effect of hot metal Mn level on three-hole lance practice, heats produced during June and July 1966 were investigated. Selected for study were heats blown for low carbon applications with turn down hot metal Si levels did not affect the results to the same extent.

**SUMMARY**

The results of investigations briefly reported here as well as other work indicate the following:

1. The frequency of lance buildups increased substantially when hot metal Mn levels were below 0.50%.

2. The hot metal Mn level had no effect on heavy sparking conditions; the greatest effect was on heavy slopping.

3. With three-hole lance practice, hot metal Mn content has no effect on furnace refractory life. Increased refractory life has been the result of better operating techniques and improved refractories.

4. The purchase of high priced ores for Mn recoveries are difficult to justify economically. The Cleveland Works Blast Furnaces use 75 to 125 lb of BOF slag per ton of hot metal for recovery of lime, iron, and manganese.

5. Hot metal Mn levels appear to have little, if any, effect on final N contents.

6. The current aim range of 0.60 to 0.90% Mn in our hot metal is a realistic specification.

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**DISCUSSION**

by E. W. Olson

A truly objective discussion of Messrs. McCarthy and Bock's fine presentation is most difficult, in view of the fact that few operators are called upon to use hot metal at Kaiser's iron ore manganese level. Consequently, except for certain observations reported by R. S. Miltenberger in his paper on an experimental BOP and in other papers, 1 and 2, we at Great Lakes are presenting a comparison based on our own operating experience. Through this experience, we feel it necessary to aim for a 0.60% hot metal manganese for optimum yields, lance life, and sulphur removal, along with maximum lining life through minimum fluorspar usage.

In further discussion of lance life we concur with Kaiser that low Mn metal is the chief contributor to lance skulls. We also have observed an increase in lance failure with regard to internal leaks at the tip during periods of low Mn hot metal usage. We feel the reason for this is the slower slag formation that accompanies the use of low Mn metal. This slow slag formation also contributes to increased yield loss since it causes the vessel to spark early, and it continues to spark until proper steel bath coverage is achieved. To prevent, or at least to lessen, the effect of early and prolonged sparking, we increased our spar. This has often caused increased heavy slopping, further effecting yield.

With increased spar usage, we also have experienced a drop in lining life. However with the cooperation of our blast furnace division, through its ability to maintain our 0.60% aim Mn, we have, in fact, been able to decrease our spar by 5 lb per ingot ton, with a resulting increase in lining life.

It is interesting to note the reverse of this at Kaiser where they increased spar by 5 lb per ingot ton and still increased lining life. It should also be noted, however, that dolomitic lime usage almost doubled during this same period, which may have aided lining life, offsetting the detrimental effects of increased spar usage.

**REFERENCES**

1. R. Heaton: Steel Works Metallurgist, G.L.S.