BATCH SINTERING TESTS WITH BETHLEHEM STEEL MIX AND VARIOUS FLUXES

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Introduction

A research program to evaluate the performance of Michigan Limestone Operations (MLO) fluxes in the Bethlehem Steel Corporation (BSC) sinter mix was carried out at the Coleraine Research Laboratory (CRL) during the period March 1 to April 10, 1989. This test work was conducted under a contract with MLO to provide the information required by Bethlehem Steel to consider a change in their current flux usage. The sintering tests were to include an evaluation of dolomite strata and size consist in addition to a comparison of BSC and MLO limestone.

Raw Materials

The raw materials used in the BSC sinter mix were shipped from Burns Harbor to CRL and were received on 2/17/89. This included samples of the current Presque Isle (PI) limestone and dolomite fluxes currently in use. Moisture and screen analyses of each material were determined on pipe samples taken from each drum and are given in Tables I and II. In addition, chemical analyses were carried out on the coke breeze and flux samples. The coke breeze contained only 72.5 percent fixed carbon and 20.0 percent ash. MLO provided one sample of Calcite limestone and 4 samples of dolomite that were received on 1/27/89. The samples were designed as E-1 coarse (H-1), E-1 fines (H-2), E-2 coarse (H-1), and E-2 fines (H-2). The materials were each mixed and representative samples were split out for moisture, size, and chemical analyses (Table II).

The range of raw material chemistry and the raw sinter mix composition were provided by BSC.

Test Program and Procedures

Shown in Table III is the approximate sintering-mix composition used in the test program. Slight adjustments in the blend were made for the change in coke breeze and flux chemistry. In most cases the differences in mix composition were very minor (i.e. 7.80 vs 7.83% stone) and with the material variability of these coarse materials were not adjusted. For example, the BOF slag was rather coarse (23% +1/4") and the sand contained large pieces of tramp material.

The mix carbon values are for coke carbon only and do not include any carbon from the mill scale and BOF slag. Target sinter basicity (B/A) was set by BSC at 2.6 $(CaO + MgO)/(SiO_2 + Al_2O_3)$ with 5.5 percent SiO_2, 3.5 percent MgO, and a B/S of 3.1. After several preliminary runs all the tests were made with 20 percent minus 1/4-inch returns (total dry mix basis). The returns were generated with a 30 revolution pre-tumble in the ASTM drum. For each mix, tests were run at different carbon levels to determine the carbon level required for balanced returns. At the 20 percent level of returns used in this program, the pre-tumble minus 1/4-inch returns generated was very sensitive to mix carbon level. Thus, the carbon addition was kept in a narrow range for each test series. The data were plotted to determine the mix carbon that gives an exact return balance. Then the tumble strength, Fe^{++}, and sintering time can be determined by interpolation for an exact returns balance. In this study, however, the range of mix carbon was quite small so these parameters did not always correlate with percent mix carbon and were usually fairly constant. Since the number of tests was limited, a mix moisture of 6.0 to 6.5 percent was used as a target based on the plant experience rather than running a moisture series.

The sintering tests were run in the CRL refractory-lined tapered sinter pot using a fine material as a wall seal to eliminate air leakage. A 2-inch hearth layer of minus 3/8 plus 1/4-inch material was used with a wet mix of 12 inches (125 lb) for a 14-inch total bed. Ignition was 2 minutes at 20 inches WC suction after which a windbox suction of 30 inches was maintained. Sintering time is defined as the time to reach peak windbox temperature which is recorded throughout the test. This time was used to calculate production rate.

After each test was completed, the cake was dumped and broken into several pieces for the pre-tumble test. Sinter quality was based on the ASTM tumble test on the plus 1/4-inch product and a target tumble index of 75 percent was set by BSC. Chemical analyses of the product were carried out for each test while RDI and reducibility were only conducted on selected products.

The 3-phase test program for the sinter pot tests was outlined in a letter to BSC by Mr. Al Bessen of MLO.[1)*] Essentially, the first objective was to evaluate the Cedarville dolomite E-1 and E-2 strata using a size consist similar to the BSC dolomite (70/30 mix of H-1/H-2) in combination with Presque Isle limestone. The second phase was to evaluate the dolomite size consist using Cedarville H-1 and H-2 materials with Presque Isle stone. Finally, the third phase would be to evaluate the hi-calcium limestone from MLO in comparison with the PI stone.

Test Results

The first series of tests after several preliminary runs was conducted with the limestone and dolomite samples received from BSC. Results of these base case tests are given in Table IV for Tests 2 through 7. The carbon addition was adjusted from 1.6 to 2.3 percent (total dry mix basis) to achieve a returns balance. In Test 4 the returns produced was 101.7 percent of the returns in the feed which is considered a good balance (±5%). Two additional tests (5 and 6) were run with this composition to determine the variability of the test results. In test 7 the carbon level was 2.3 percent and the returns balance was 94.0 percent. Figure 1 shows the pre-tumble and ASTM tumble results as a function of carbon addition. An exact returns balance would correspond to a 2.18 percent C addition as shown in Figure 1. At 72.5 percent fixed carbon this would be equivalent to 3.75 percent coke breeze in the raw mix. The tumble index for the repeat tests ranged from 74.8 to 76.0 percent plus 1/4 inch with an average of 75.4 percent. The other tests with plus or minus 0.2 percent C also had product quality within this same range. The production rate averaged 2.80 NTPD/ft^2 (±6%) for Tests 4 through 6. The B/A for these tests averaged 2.54 which was considered close enough to the target 2.6. Since the B/S was 3.12 and the target 3.1 no further adjustments to B/A were made.

Comparison of E-2 and E-1 Dolomite

A comparison of the sintering characteristics of the E-2 and E-1 dolomite strata at MLO was made in Tests 8 through 13. For these tests a mixture of 70 percent H-1 and 30 percent H-2 sized dolomite was used with the PI limestone as recommended by MLO. Each flux combination was tested at 2.1, 2.3, and 2.5 percent C to determine the carbon level required for balanced returns. The results of these tests as given in Table V show very little difference between the performance of the E-2 and E-1 materials. The carbon requirements for balanced returns were 2.23 percent for E-2 versus 2.28 percent for E-1. At the 20 percent returns balance, however, the E-1 dolomite produced a slightly lower quality as the average tumble index was 73.9 percent plus 1/4-inch compared with 75.6 percent for the E-2 material. Over the carbon ranges tested the ASTM tumble quality did not correlate with carbon level, however; the E-1 quality was consistently lower as shown on Figure 2. Production rates were similar with E-1 having a slightly higher (5%) rate at 3.13 versus 2.97 NTPD/ft^2.

The E-1 tests had a faster burn-through time and also had a slightly higher weight recovery. In comparison to the base case tests, the performance of the E-2 (H-1/H-2) material appeared very similar to the plant dolomite sample. However, the plant flux had a much finer size consist (65 vs 27% -10 mesh) than the 70/30 (H-1/H-2) blend.

Comparison of H-1 and H-2 Sized Dolomite

The effect of the dolomite size consist was evaluated in tests 14 through 19 and the results are given in Table VI. Initially, the E-2 dolomite was chosen for the comparison based on the results of the previous tests. Thus, tests were carried out at two carbon levels with the coarser size (H-1) in tests 14 and 15 while the finer size (H-2) was used in tests 16 and 17. As shown in Table II, the minus 10 mesh in these samples was 9.3 versus 77.7 percent and as such they provide a large change in size. However, based on the silica analyses of 0.16 percent (H-1) and 1.27 percent (H-2) it appeared that the E-2 (H-2) sample might be E-1. Differential thermal analysis (DTA) of the two samples seemed to confirm this to be the case. Therefore, an additional test was made using E-2 (H-1) that was crushed to produce the same H-2 size as used in tests 16 and 17. The results of test 19 with the new H-2 (E-2) sample indicate that a slightly lower tumble index (72.8%) is obtained with the finer material (Figure 3). All other aspects of the tests such as carbon level for 20 percent balanced return and production rate were the same.

To make a comparison of size effect with the E-1 strata a test with H-1 (E-1) was also run. Comparing the results of tests 16 and 18 it appears the change size consist had no effect on the sinter results with the E-1 material. Both produced a 73.6 percent tumble index with balanced returns at 2.3 percent C. Production rates were also close at 3.11 and 3.26 NTPD/ft^2.

These results are also very similar to the E-1 and E-2 series with the 70/30 (H-1/H-2) size blend. Thus, it appears that the effect of dolomite size consist is very minor in the BSC sinter mix. This is partly due to the rather low 4 percent dolomite addition in the raw mix.

Evaluation of Calcite

The last series of sinter tests were run to study the effect of replacing PI limestone with MLO calcite. The CaO plus MgO is about the same for each with the MLO stone having 0.9 percent less SiO_2. In tests 20 to 22 the mix contained MLO limestone and E-2 (H-1) dolomite. The results of these tests as presented in Table VII were compared with Tests 14 and 15 using PI stone and the same E-2 (H-1) dolomite. As seen in Figure 4 the returns balance for the MLO calcite was at 1.97 percent C compared with 2.26 percent C for the PI stone. Product quality (74.8 and 75.0% TI) and production rates (3.29 and 3.17 NTPD/ft^2) were very close for the MLO and PI materials. Overall, the series with the MLO calcite showed the lowest sinter burn-through time (highest production) and lowest carbon requirement of the tests conducted.

Metallurgical Quality

The reduction degradation index (RDI), reducibility (R_{40}), and free CaO content were measured on sinter product from selected tests. These results are given in Table VIII and indicate very little difference with the various fluxes tested. For example, free lime was low in all the products ranging from 0.24 to 0.36 percent. Thus, the coarser sized material did not produce a problem with unassimulated lime. The RDI values ranged from 11.8 to 15.9 percent minus 3 mm and do not appear dependent on flux type or size. A slightly larger range of values was found in the R_{40} measurements at 1.04 to 1.32 percent/minute. In general, the R_{40} decreases with increased Fe^{++} (FeO) as seen in the base case series with a R_{40} of 1.32 to 1.12 percent/minute corresponding to an increase from 5.22 to 5.70 Fe^{++}.

Summary and Conclusions

A summary of the sinter pot test results is given in Table IX for the various fluxes evaluated. These results are calculated for balanced returns (20 percent) over a small range in carbon addition to achieve a sinter quality of about 75 percent plus 1/4 inch in the ASTM tumble test. In general, the differences in sinter quality and production are small regardless of the flux used. For dolomite, the E-2 strata and H-1 size seem to produce a slight benefit in sinter quality (tumble index) over the E-1 strata and H-2 size. However, the base case size, the 70/30 (E-2) mixture, and H-1 (E-2) alone all had very similar product in quality indicating there can be a fairly large range in size. The larger size may give a little better production (2.89, 2.97, and 3.17 NTPD/ft^2) when looking at the same three cases. This 10 percent increase should be verified with replicate tests at each condition.

When comparing MLO calcite with PI limestone it appears the calcite would give slightly higher production (+4%) at a lower carbon level. However, the combination of calcite and H-1 dolomite showed an increase in production of 14 percent over the base case with 10 percent less carbon. Although the trend of these improvements appears sound, a verification with replicate tests is recommended to determine the exact magnitude of the improvement.

Metallurgical quality of the sinter was generally good and did not seem to correlate with flux changes. Normally, the basicity, silica, and FeO control the metallurgical quality of the sinter product.

Reference

1. Letter, Alan R. Bessen (MLO) to Norman D. Hodgson (BSC), December 20, 1988.

Table I

Size Consist of Sinter Raw Materials From Bethlehem Steel

Screen, mesh	Cumulative Weight % Passing					
	CVRD	Mill Scale	Pelsin	BOF Slag	Sand	Coke
3	95.7	93.3	99.0	76.8	99.5	99.6
4	86.7	88.4	91.1	63.1	98.9	94.0
6	79.2	83.8	79.3	54.7	98.8	83.9
8	70.4	77.4	66.1	47.1	98.6	75.3
10	61.5	68.3	52.6	39.6	98.3	66.5
14	54.3	59.7	43.2	34.5	98.1	59.8
20	48.2	50.5	35.6	30.3	97.8	53.0
28	42.8	41.6	29.7	26.9	97.0	46.3
35	37.7	32.8	24.8	23.8	93.9	39.1
48	33.2	25.6	21.0	21.1	84.3	32.8
65	28.3	19.0	16.9	18.1	37.0	26.6
100	23.7	14.0	13.4	15.3	9.7	21.5
150	19.7	10.4	11.2	12.2	5.2	17.6
200	16.2	7.5	9.3	8.9	3.9	14.0
270	14.2	6.1	7.8	6.6	3.3	11.5
325	13.9	5.7	7.6	6.3	3.1	11.1
Moisture, %	5.81	4.23	2.40	2.80	4.71	13.65

Table II

Chemistry and Size Analyses of Fluxes for Bethlehem Steel Sinter Tests

	Bethlehem Steel		Michigan Limestone Operations, LTD						
			Limestone	Cedarville Dolomite				70/30 Blends	
Chemistry	Limestone	Dolomite	H Prod	E-1/H-1	E-1/H-2	E-2/H-1	E-2/H-2	E-1	E-2
CaO, %	52.8	30.9	53.2	30.9	30.6	30.9	30.3	30.8	30.7
MgO, %	1.18	21.4	0.81	21.5	21.5	21.4	21.5	21.5	21.4
SiO_2, %	1.33	0.38	0.47	1.00	1.31	0.16	1.27	1.09	0.49
Al_2O_3, %	0.30	0.10	0.15	0.18	0.21	0.09	0.18	0.19	0.12
Fe, %	0.30	0.34	0.13	0.14	0.10	0.16	0.12	0.13	0.15
H_2O, %	5.26	3.89	4.65	0.06	2.06	0.04	1.32	0.66	0.42
Screen, M	Cumulative Weight % Passing								
3	99.4	99.4	99.9	99.8	-	99.7	-	99.9	99.8
4	93.8	97.1	99.0	91.0	99.6	90.7	99.8	93.6	93.4
6	85.4	89.7	94.6	58.4	97.6	60.9	98.3	70.2	72.1
8	75.1	78.4	78.2	21.9	92.0	24.4	91.6	42.9	44.6
10	63.6	65.3	58.5	6.7	75.6	9.3	77.7	27.4	29.8
14	54.9	55.2	44.3	2.9	60.3	3.6	65.5	20.1	22.2
20	47.1	46.7	33.7	1.5	47.2	2.3	55.0	15.2	18.1
28	40.9	39.9	25.4	1.0	37.0	1.9	46.3	11.8	15.2
35	35.7	33.3	18.6	0.8	28.6	1.6	38.0	9.1	12.5
48	31.9	27.2	13.6	0.7	23.2	1.4	30.7	7.5	10.2
65	28.7	20.5	10.6	0.6	19.1	1.2	23.0	6.2	7.7
100	26.3	14.7	8.3	0.5	16.1	1.0	16.7	5.2	5.7
150	24.3	10.5	7.0	-	13.5	-	12.2	-	-
200	22.4	7.3	6.1	-	10.5	-	8.6	-	-
270	21.0	5.5	5.6	-	8.3	-	6.5	-	-
325	20.8	5.3	5.5	-	7.8	-	6.2	-	-

Table III

Sinter Mix Composition Used in the Test Program With Bethlehem Steel Raw Materials

Raw Material	Raw Mix Wt, % (Dry)
Ore - CVRD	33.1 - 33.6
Pelsin*	16.4 - 16.8
BOF Slag	16.4 - 16.8
Mill Scale	16.0 - 16.4
Limestone	7.8 -
Dolomite	4.0
Sand	2.0
Coke Breeze	2.7 - 4.0
Sinter Pot Feed	
Raw Mix	80
Returns	20

* Combination of pellet and sinter fines.

Table IV

Coleraine Sinter Pot Test Results With the Bethlehem Steel Sintering Mix

Test No.	2	3	4	5	6	7
Flux (Raw Mix)						
Limestone - %	7.8	7.8	7.8	7.8	7.8	7.8
Type	PI	PI	PI	PI	PI	PI
Dolomite - %	4.0	4.0	4.0	4.0	4.0	4.0
Type	BSC	BSC	BSC	BSC	BSC	BSC
Size	*	*	*	*	*	*
Mix Moisture, Wt %	5.5	6.1	6.0	6.2	6.3	6.4
Returns (Total Dry Mix Basis), %	20.0	20.0	20.0	20.0	20.0	20.0
Pretumble (30 Rev), Wt % +1/4 Inch	69.2	74.2	77.5	77.8	76.7	79.3
ASTM Tumble, Wt % +1/4 Inch	70.8	76.0	75.6	76.0	74.8	75.2
Weight Recovery (Excluding Returns), %	89.7	86.9	88.5	89.8	88.8	88.8
Returns Balance, Wt % (Out/In)	141.5	115.3	101.7	101.7	106.0	94.0
Burn-Through Time, Minutes	22.5	22.8	21.3	23.2	20.3	20.1
Production Rate, NTPD/ft^2	2.71	2.58	2.82	2.62	2.95	2.98
Mix Carbon (Dry), Wt %	1.6	1.9	2.1	2.1	2.1	2.3
Sinter Basicity	2.50	2.52	2.55	2.55	2.49	2.54
Fe, %	50.8	50.0	50.8	50.0	50.4	50.9
Fe^{++}, %	4.41	4.66	5.22	5.32	5.10	5.70
SiO_2, %	5.75	5.80	5.82	6.01	6.01	6.00
Al_2O_3, %	1.55	1.90	1.41	1.40	1.40	1.36
CaO, %	14.84	15.80	15.05	15.56	14.89	15.21
MgO, %	3.40	3.62	3.36	3.36	3.53	3.47

* Dolomite size as received from BSC is similar to MLO H-2.

Table V

Coleraine Sinter Pot Test Results With Various Fluxes in the Bethlehem Steel Sintering Mix

Test No.	8	9	10	12	11	13
Flux (Raw Mix)						
Limestone - %	7.8	7.8	7.8	7.8	7.8	7.8
Type	PI	PI	PI	PI	PI	PI
Dolomite - %	4.0	4.0	4.0	4.0	4.0	4.0
Type	E-2	E-2	E-2	E-1	E-1	E-1
Size H-1/H-2	70/30	70/30	70/30	70/30	70/30	70/30
Mix Moisture, Wt %	5.99	6.43	6.33	6.44	6.67	5.84
Returns (Total Dry Mix Basis), %	20	20	20	20	20	20
Pretumble (30 Rev), Wt % +1/4 Inch	77.4	78.9	79.8	76.8	78.9	79.8
ASTM Tumble, Wt % +1/4 Inch	74.8	76.4	75.6	74.0	73.6	74.0
Weight Recovery (Excluding Returns), %	89.1	89.4	88.5	91.1	90.5	89.5
Returns Balance, Wt % (Out/In)	105.0	96.6	91.9	107.8	97.6	92.8
Burn-Through Time, Minutes	19.42	21.25	20.25	19.25	19.17	20.10
Production Rate, NTPD/ft^2	3.11	2.84	2.95	3.19	3.17	3.02
Mix Carbon (Dry), Wt. %	2.1	2.3	2.5	2.1	2.3	2.5
Sinter Basicity	2.56	2.58	2.48	2.54	2.48	2.52
Fe, %	50.1	50.5	50.6	50.6	50.6	50.8
Fe^{++}, %	5.82	5.55	5.96	5.32	5.81	6.12
SiO_2, %	5.92	6.02	6.01	5.94	6.03	5.77
Al_2O_3, %	1.32	1.38	1.47	1.39	1.50	1.40
CaO, %	14.90	15.44	15.04	15.15	15.21	14.65
MgO, %	3.60	3.65	3.50	3.48	3.48	3.43

Table VI

Coleraine Sinter Pot Test Results With Different Size Flux in the Bethlehem Steel Sintering Mix

Test No.	14	15	16	17	18	19
Flux (Raw Mix)						
Limestone - %	7.8	7.8	7.8	7.8	7.8	7.8
Type	PI	PI	PI	PI	PI	PI
Dolomite - %	4.0	4.0	4.0	4.0	4.0	4.0
Type	E-2	E-2	E-2*	E-2*	E-1	E-2**
Size	H-1	H-1	H-2	H-2	H-1	H-2
Mix Moisture, Wt %	6.4	6.1	6.3	6.4	6.2	6.4
Returns (Total Dry Mix Basis), %	20.0	20.0	20.0	20.0	20.0	20.0
Pretumble (30 Rev), Wt % +1/4 Inch	78.3	79.4	78.4	79.9	78.0	79.0
ASTM Tumble, Wt % +1/4 Inch	74.8	75.2	73.6	75.2	73.6	72.8
Weight Recovery (Excluding Returns), %	89.1	90.2	89.1	89.0	89.0	89.5
Return Balance, Wt % (Out/In)	99.1	94.0	100.2	91.7	100.0	96.2
Burn-Through Time, Minutes	20.1	18.1	19.8	19.8	18.4	19.4
Production Rate, NTPD/ft^2	2.99	3.34	3.11	3.04	3.26	3.11
Mix Carbon (Dry), Wt %	2.3	2.5	2.3	2.5	2.3	2.3
Sinter Basicity	2.50	2.55	2.54	2.56	2.56	2.53
Fe, %	50.5	50.4	50.4	50.1	50.4	50.6
Fe^{++}, %	5.68	5.96	5.81	5.81	5.52	5.59
SiO_2, %	6.06	6.05	5.95	5.94	5.99	5.85
Al_2O_3, %	1.45	1.47	1.49	1.50	1.48	1.44
CaO, %	15.18	15.44	15.36	15.47	15.48	15.01
MgO, %	3.63	3.73	3.55	3.63	3.66	3.40

* As received E-2/H-2 flux sample which appears to be E-1 type flux based on DTA and chemistry.

** E-2/H-2 flux generated by crushing E-2/H-1 sample.

Table VII

Coleraine Sinter Pot Test Results With MLO Calcite and Dolomite in the Bethlehem Steel Sintering Mix

Test No.	20	21	22
Flux (Raw Mix)			
Limestone - %	7.8	7.8	7.8
Type	MLO	MLO	MLO
Dolomite - %	4.0	4.0	4.0
Type	E-2	E-2	E-2
Size	H-1	H-1	H-1
Mix Moisture, Wt %	6.0	6.5	6.4
Returns (Total Dry Mix Basis), %	20.0	20.0	20.0
Pretumble (30 Rev), Wt % +1/4 Inch	78.8	79.3	80.3
ASTM Tumble, Wt % +1/4 Inch	75.6	74.0	74.8
Weight Recovery (Excluding Returns), %	89.6	91.0	89.5
Returns Balance, Wt % (Out/In)	97.0	96.2	90.2
Burn-Through Time, Minutes	19.1	18.1	18.1
Production Rate, NTPD/ft^2	3.17	3.38	3.33
Mix Carbon (Dry), Wt %	2.1	2.3	2.5
Sinter Basicity	2.54	2.56	2.61
Fe, %	50.7	50.7	50.2
Fe^{++}, %	5.77	5.81	6.28
SiO_2, %	5.98	5.94	6.03
Al_2O_3, %	1.49	1.49	1.45
CaO, %	15.46	15.42	15.94
MgO, %	3.55	3.60	3.62

Table VIII

Summary of Additional Product Quality Data for Selected Tests

Test No.	RDI, % -3 mm	RDI, % -1 mm	ISO R_{40}, %/min	Free CaO, %
4	14.7	6.6	1.32	0.24
5	15.9	6.9	1.18	-
7	12.0	5.2	1.12	-
9	14.4	6.5	1.05	0.29
11	13.9	6.2	1.13	0.31
14	14.1	6.2	1.04	0.36
15	12.4	5.6	1.07	-
16	11.8	5.4	1.22	-
18	-	-	-	0.34
19	13.5	5.8	1.09	0.32
20	13.8	6.0	1.21	0.36
22	-	-	-	0.32

Table IX

Summary of Coleraine Sinter Pot Test Results With Various Fluxes in the Bethlehem Steel Sintering Mix

	BSC Base Case	Dolomite E-2 Versus E-1		E-2 Dolomite H-1 Versus H-2		Limestone PI Versus MLO		E-1 Dolomite H-1 Versus H-2	
Flux (Raw Mix)									
Limestone - %	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Type	PI	PI	PI	PI	PI	PI	MLO	PI	PI
Dolomite - %	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Type	BSC	E-2	E-1	E-2	E-2	E-2	E-2	E-1	E-1**
Size	-	H-1/H-2*	H-1/H-2*	H-1	H-2	H-1	H-1	H-1	H-2
Mix Moisture, Wt %	6.3	6.2	6.3	6.3	6.4	6.3	6.3	6.2	6.4
Returns (Total Dry Mix Basis), %	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Pretumble (30 Rev), Wt % +1/4 Inch	78.2	78.0	77.7	78.2	79.0	78.2	78.3	78.0	78.4
ASTM Tumble, Wt % +1/4 Inch	75.4	75.6	73.9	75.0	72.8	75.0	74.8	73.6	73.6
Weight Recovery (Excluding Returns), %	88.9	89.0	90.4	89.6	89.5	89.6	90.0	89.0	89.1
Returns Balance, Wt % (Out/In)	100.0	100.0	100.0	100.0	96.2	100.0	100.0	100.0	100.0
Burn-Through Time, Minutes	20.6	20.3	19.5	19.1	19.4	19.1	18.4	18.4	19.8
Production Rate, NTPD/ft^2	2.89	2.97	3.13	3.17	3.11	3.17	3.29	3.26	3.11
Mix Carbon (Dry), Wt. %	2.18	2.23	2.28	2.26	2.30	2.26	1.97	2.30	2.30
Sinter Basicity	2.54	2.54	2.51	2.52	2.53	2.52	2.57	2.53	2.54
Fe, %	50.4	50.4	50.7	50.4	50.3	50.4	50.5	50.6	50.1
Fe^{++}, %	5.41	5.41	5.71	5.62	5.81	5.62	5.53	5.59	5.81
SiO_2, %	5.95	5.98	5.91	6.06	5.94	6.06	5.98	5.85	5.95
Al_2O_3, %	1.40	1.39	1.43	1.46	1.50	1.46	1.47	1.44	1.49
CaO, %	15.17	15.13	15.00	15.31	15.42	15.31	15.61	15.01	15.36
MgO, %	3.42	3.58	3.46	3.68	3.59	3.68	3.60	3.40	3.55

* H-1/H-2 in 70/30 ratio.

** E-2 flux sample which appears to be E-1 based on DTA and chemistry.

EFFECT OF SINTER MIX CARBON ON RETURNS AND PRODUCT TUMBLE INDEX

BSC MIX-BASE CASE TESTS

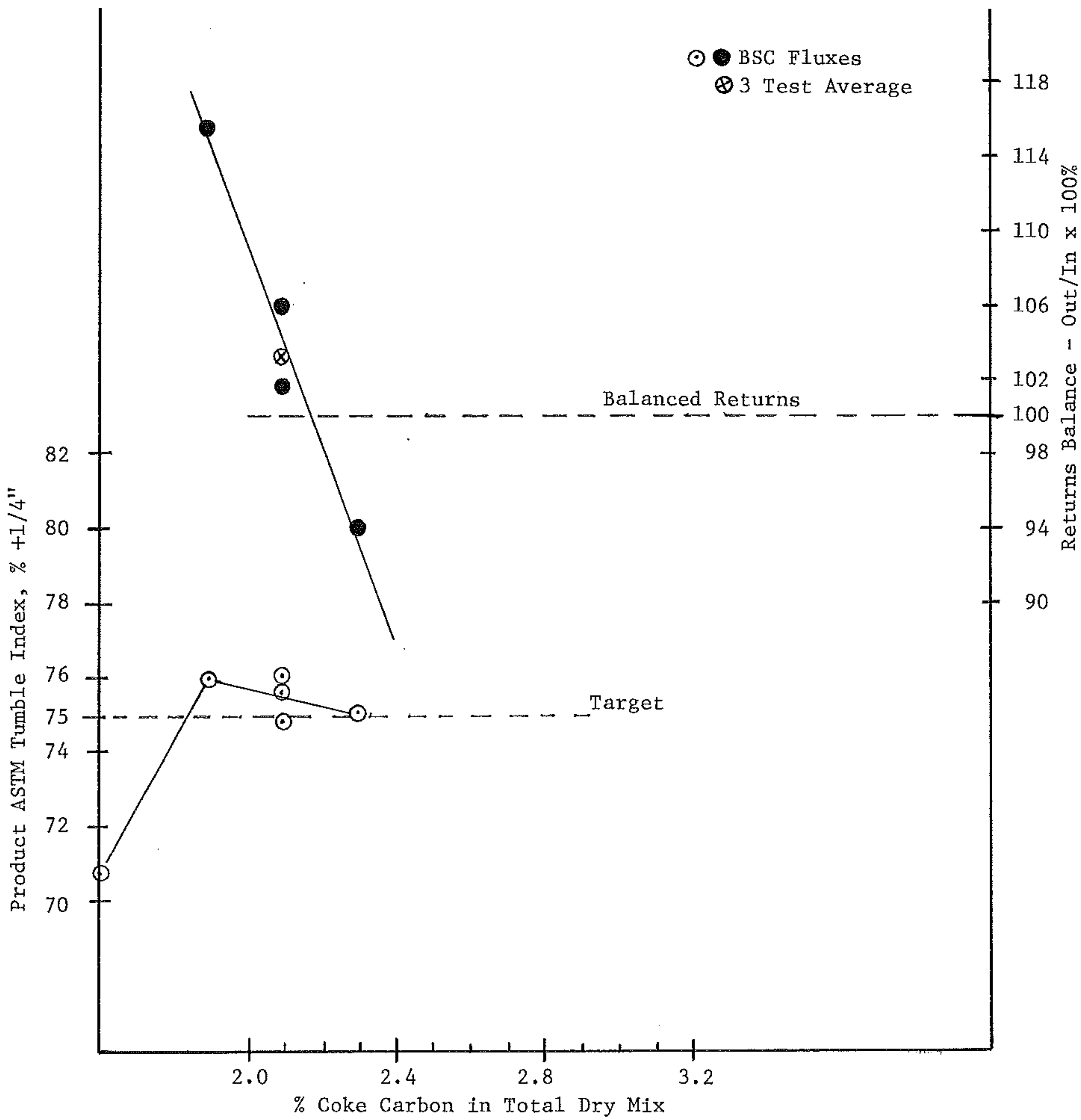

Figure 1

EFFECT OF SINTER MIX CARBON ON RETURNS AND PRODUCT TUMBLE INDEX

BSC Mix - E-1 vs E-2 Strata Dolomite

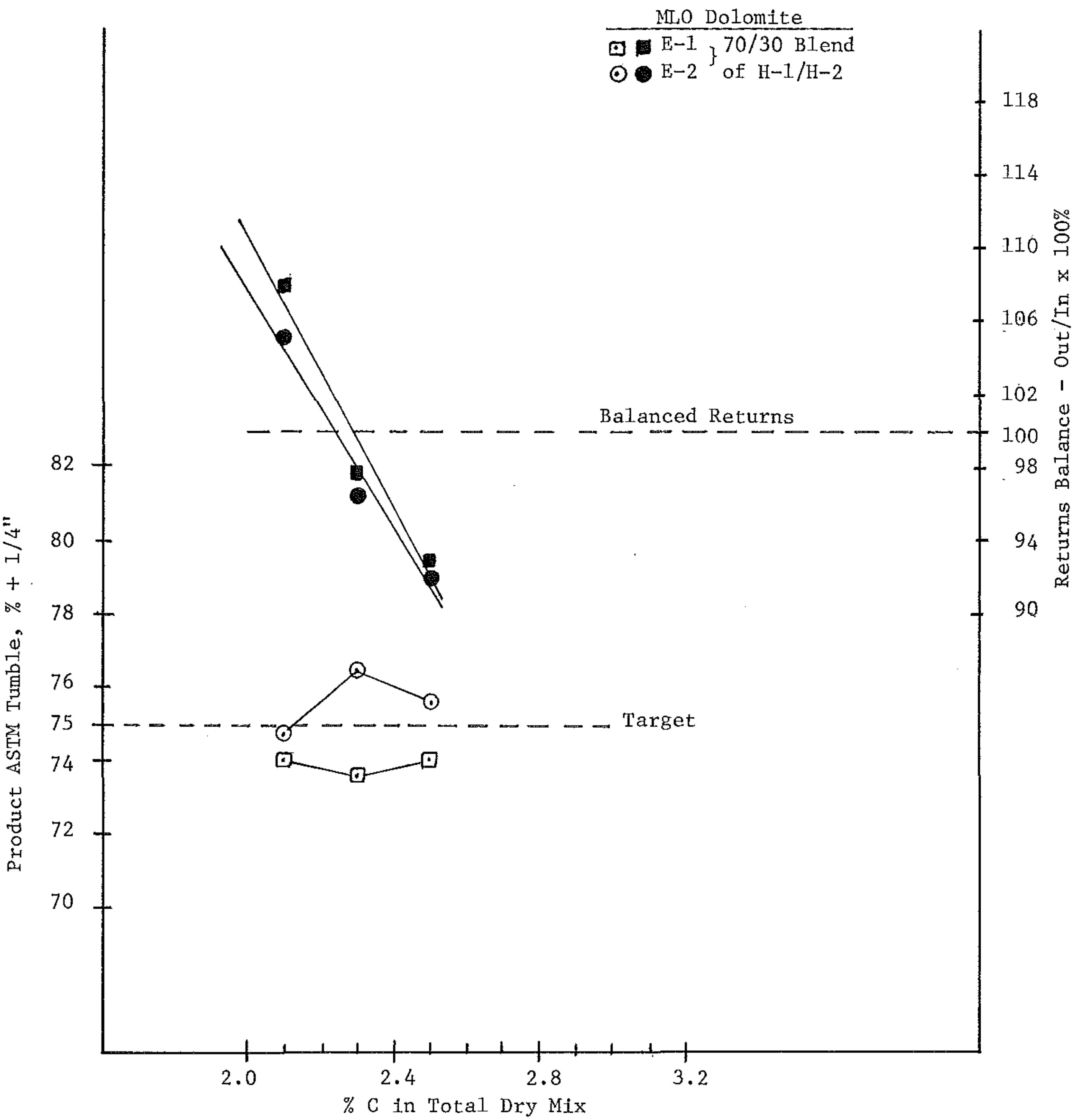

Figure 2

EFFECT OF SINTER MIX CARBON ON RETURNS AND PRODUCT TUMBLE INDEX

BSC SINTER MIX - H-1 VS H-2 SIZED DOLOMITE

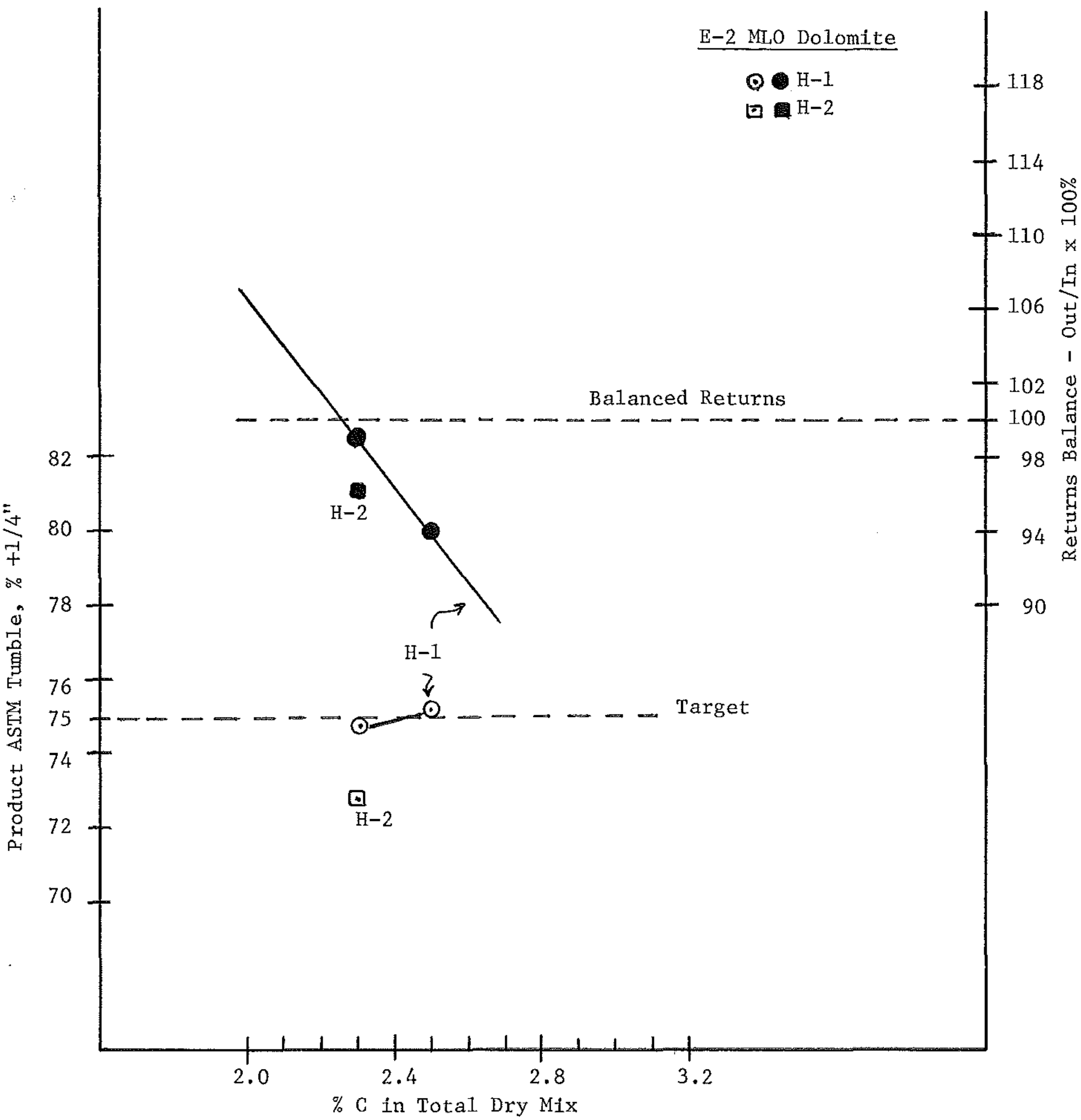

Figure 3

EFFECT OF SINTER MIX CARBON ON RETURNS AND PRODUCT TUMBLE INDEX

BSC MIX - MLO VS PI LIMESTONE

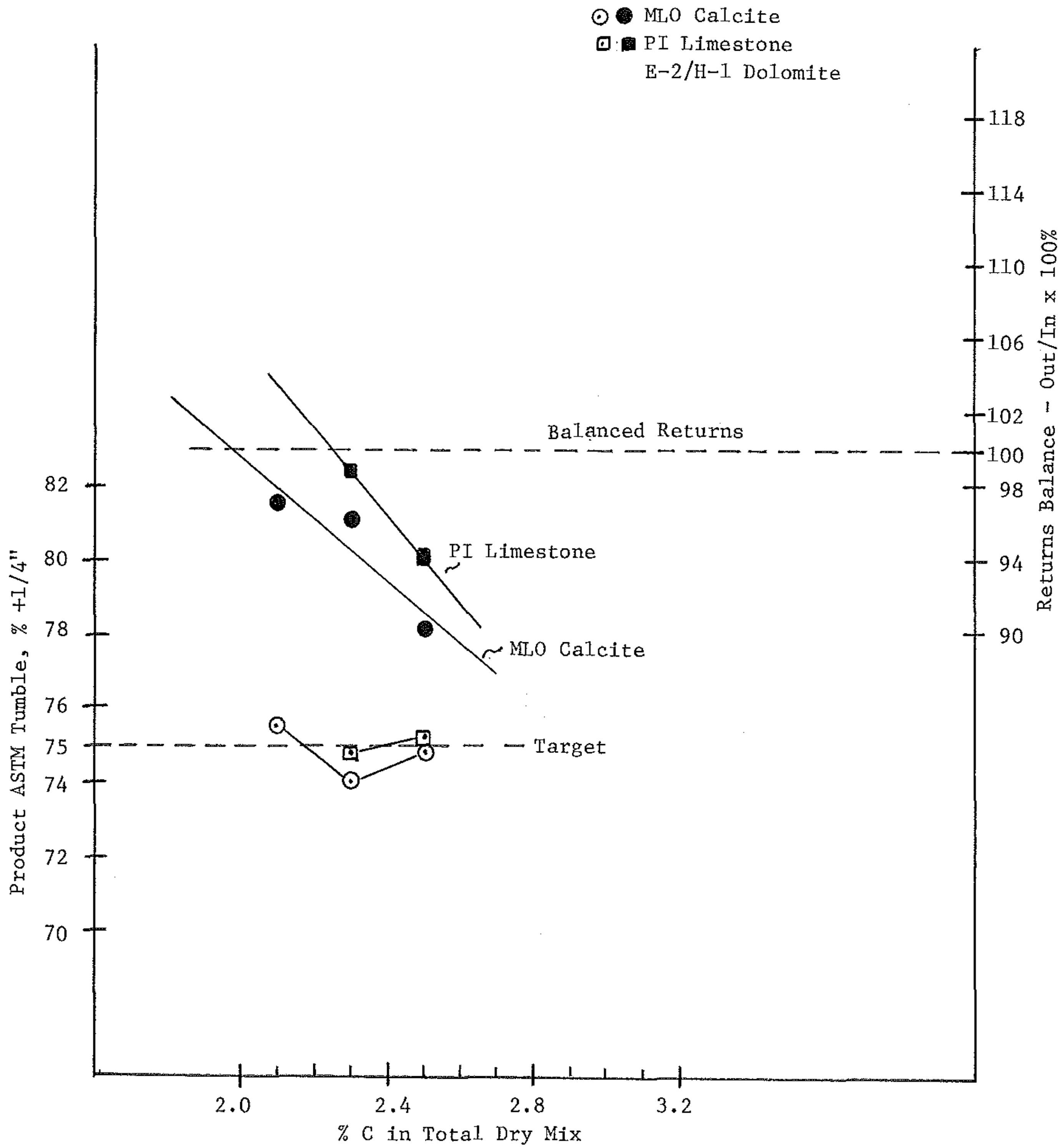

Figure 4