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THE EFFECT OF SEVERAL CARBONIZATION VARIABLES ON THE QUALITY OF COKE PRODUCED IN THE 18-INCH MOVABLE-WALL COKE OVEN

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OCTOBER 1977

(Project 4.4.4.3.00 - Carbonization)

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 77-105 (TR)

ERP/ERL 77-105(TR)

THE EFFECT OF SEVERAL CARBONIZATION VARIABLES ON THE QUALITY OF COKE PRODUCED IN THE 18-INCH MOVABLE-WALL COKE OVEN

by

J.F. Gransden* and W.R. Leeder*

ABSTRACT

The 18-in. technical scale coke oven operated by the Coal Resource and Processing Laboratory (CRPL) was recently re-built. The heating walls, formerly constructed from silicon carbide tiles, were replaced with walls built from silica bricks similar to those used in industrial coke ovens. The effect of oven flue temperature, coal moisture content and the degree of coal pulverization on the quality of coke produced from a single coal blend, having a mean reflectance, Ro, of 1.12 and a maximum fluidity of 2448 dial divisions/minute, has been investigated. The results have been used to select standard operating conditions for the 18 in. coke oven that simulate industrial practice.

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1. INTRODUCTION

The Coal Resource and Processing Laboratory (formerly Canadian Metallurgical Fuel Research Laboratory) operates four technical-scale slot-type coke ovens(1). The largest is a movable-wall oven which has a coking chamber 18 in. wide, similar to the width of commercial coke ovens. The useful volume of the chamber is 13.5 cu ft and about 700 lb of coal is carbonized at a time. It is generally recognized that ovens of this size are required to produce coke similar in physical characteristics (e.g. strength, size distribution) to that produced in commercial equipment. Therefore, their use is essential in coking coal resource evaluation, in choosing blends of coals for industrial use and in research and development in the field of carbonization.

The 18-in. oven recently required refurbishing, and the opportunity was used to make a number of design changes. The most significant modification was the replacement of the silicon carbide bricks of the heating wall with silica bricks, similar to those used in industrial ovens.

The test program reported here was carried out to allow selection of a standard set of carbonization conditions for the oven. The conditions chosen simulate industrial practice. The program also gauges the sensitivity of the oven, to changes in the standard conditions either intentional or unintentional. The results also serve to illustrate how the properties of coke, made from a typical industrial blend of coals, vary with changes in the carbonization parameters.

2. 18-IN. OVEN OPERATION

The coal blend used in the test program was supplied by a member company of the Canadian Carbonization Research Association (C.C.R.A.) who sponsored the program. The blend consisted of three component coals identified as A, B and C in Table 1 where their chemical analyses are given. The blend was composed of 25 per cent coal A, 37.5 per cent coal B and 37.5 per cent coal C. The thermal rheological properties of the component coals and the blend are shown in Table 2.

The 18-in. technical-scale coke oven is electrically heated by twelve "Globar" resistance elements. Four temperature controllers each control three elements and maintain a constant flue temperature during the coking cycle. The crushed and weighed coal blend is charged at a predetermined moisture content, into the top of the oven. The charge is levelled in the oven by raking out excess coal through the levelling door. The oven bulk density is calculated from the amount of blend charged, the excess removed during charge levelling and the known volume of the oven. The coke is discharged from the oven by a pusher machine one half hour after the temperature at the centre of the charge has reached 1000°C. The coke is immediately quenched with water in a "quench" box and dropped 10 ft to a concrete floor to simulate coke handling in a commercial operation. It is then oven-dried and screened.

3. COKING VARIABLES

The coking variables investigated were the coal moisture content, the degree of coal pulverization and the oven flue temperature. Oven charges were carbonized at three nominal moisture levels (3, 5 and 7 per cent moisture), two degrees of coal pulverization (nominally 75 per cent and 90 per cent passing 1/8 in. sieve, Table 3) and at three different oven flue temperatures (1025, 1075 and 1150°C). These three independent variables are often discussed in terms of the two dependent variables, coking rate and dry-charge oven bulk density. The coking rate (defined here as the oven width in inches divided by the time, in hours, for the centre of the charge to reach a specified temperature) will depend on the moisture content and pulverization level of the coal and on the oven flue temperature. The oven bulk density will vary with the coal moisture and pulverization levels. The results from the 25 oven charges carbonized are given in Table 4.

3.1 Flue Temperature and Coking Rate

Figure 1 shows the relationship between the coking rate (or coking time) for a centre charge temperature of 900°C and the oven flue temperature. As expected, higher flue temperatures increase the coking rate (decrease the coking time). Two further trends in the data are apparent. Firstly, the higher the moisture content of the charge the faster the coking rate at constant flue temperature. Secondly, at constant flue temperature and moisture in the charge the coking rate of the coarser crushed coal is generally slower.

In Figure 2 the same relationship is shown except the coking rate is now defined as the time necesary for the centre-charge temperature to reach 1000°C. This temperature was not reached in all the tests run, especially those at the lower flue temperature which was only 25°C higher than 1000°C.

3.2 Effect of Coal Pulverization and Coal Moisture Content on Dry-charge Oven Bulk Density

The coal bulk density is affected by a number of factors related to the physical condition of the coal. Two of these factors are coal moisture content and pulverization level. Their effect on the bulk density of coal after charging into the oven and calculated on a dry basis is shown in Figure 3. Increases in the coal moisture content cause a decrease in the oven bulk density over the range used in this investigation. The finer grind has a bulk density about one pound per cubic foot less than the coarse ground coal at the 7 per cent moisture level. In industrial practice oil additions to the oven charges are often made. This increases the bulk density and minimizes the large effect variations in moisture can have on the bulk density(2).

3.3 Coking Rate and Oven Bulk Density

At each flue temperature a linear relationship between the coking time and the dry-charge oven bulk density was found. This is shown in Figure 4 where the coking time is defined as the time required for the centre-charge temperature to reach 900°C.

4. EFFECT OF CARBONIZATION VARIABLES ON COKE PROPERTIES

4.1 ASTM Coke Tumbler Test

This standard ASTM test(3) measures the coke stability which is an index commonly used to indicate the strength of coke. This measurement is regarded by coke-oven operators as the single most important index of coke quality. Briefly, the test consists of tumbling 22 lb of coke screened to 2 in. by 3 in. for 1400 revolutions at 24 1 rpm in a 3-ft diameter by 1.5 ft long cylindrical drum having two equispaced 2-in. lifters. The tumbled coke is screened over two square mesh sieves having hole diameters of 1 in. and 0.25 in.

respectively, and the percentages remaining on these screens are called the stability and hardness indices of the coke respectively.

The test data show that coke stability is influenced significantly by the pulverization level and the coal moisture content and to lesser extent by the oven flue temperature, Figure 5. In Figure 6, the coke stability is plotted against the dry-charge oven bulk density and the effect of coal pulverization on stability is more clearly seen. The stability increases as the bulk density is increased and is higher for the finer ground coal. Figure 7 shows the relationship between coke stability and the oven flue temperature. The effect of oven flue temperature is seen to be small. No clear trend is apparent for all the different moisture and pulverization levels, but the majority show minor decreases in stability as the flue temperature is raised from 1025°C to 1150°C.

The coke hardness is a measure of the abrasion resistance of coke. Figure 8 shows this coke property decreases with increase in moisture of the charge. The linear regression lines for the data collected at the three different flue temperatures further suggest the coke hardness is influenced by the flue temperature. At 7% moisture in the charge the coke hardness is increased by about three points as the flue temperature is increased from 1025 to 1150°C. The linear regression line for the coarse ground coal, in a plot of coke hardness versus moisture, differs by less than one point from the linear regression for the fine grind. The pulverization level therefore has little effect on coke hardness.

4.2 Coke Size Distribution

The coke particle size distribution is probably the second most important physical characteristic of coke after its strength. The optimum size-consist for the blast furnace is debatable, but it is generally agreed the size range should be narrow(4). The coke size consist can be altered by coke cutting and screening, but even so the natural size of ex-oven coke and the carbonization parameters which effect it are important with respect to the ultimate yield of furnace coke from the coke ovens.

The test results show that the amount of plus 2-in. screen coke produced decreases as the flue temperature is raised. In Figure 9, the percentage plus 2-in. coke is plotted against the flue temperature. The linear regression lines for the three different nominal charge moisture contents suggests the production of plus 2-in. coke increases with increasing charge moisture. The percentage of coke produced less than one-half inch in size, (coke breeze), was not found to correlate with flue temperature, moisture in the charge or the coke hardness.

In Figure 10 the influence of the flue temperature on the distribution of coke in several size ranges is shown. The lines were obtained by linear regression from the results of all 25 oven tests. The minus 1-in. coke produced is unaffected by the flue temperature. However, the proportions of the 1.5 by 1-in. and 2 by 1.5-in. coke sizes increase at the expense of the larger sizes as the flue temperature is increased. Thus, higher oven flue temperatures narrow the size range of coke produced.

4.3 Apparent Specific Gravity

The apparent specific gravity of coke is measured by immersing a sample in water. The values obtained indicate the degree of porosity of the coke, and were found to depend on the oven bulk density, Figure 11. Changes in the oven flue temperature had no discernible effect on this coke parameter.

4.4 Japanese Coke Tumble Test, JIS DI^{30}_{15} Index

A Japanese coke tumble test has been routinely used by CRPL during the last 16 years. The cylindrical drum has a 1.5-m diameter and is 1.5-m long with six equi-spaced lifters, 0.25 m high. A 22 lb sample of 2 in. by 3 in. coke is tumbled for 30 revolutions at 15 revolutions per minute and then screened over square-mesh sieves having hole diameters of 50, 25 and 15 mm. The cumulative percentage remaining on the 15-mm sieve is known as the JIS DI^{30}_{15} index.

This index is plotted against the stability of the cokes made in the twenty-six oven tests of the present program in Figure 12. The regression line in Figure 12 was derived from the modified least squares linear regression method of Visman and Picard(5). This assumes the error in the two plotted parameters (X and Y) are approximately equal, whereas in the normal least squares regression it is assumed that most of the error appears in the Y data. The regression line gives the following relationship between the two indices

$$\text{JIS DI}^{30}_{15} = 87.03 + 0.134 \text{ x (Stability)}$$

4.5 Wall Pressure

The pressure on the coke oven walls during carbonization is measured by four load cells situated at the ends of four water-cooled tie-rods joining the four corners of the two walls. Unfortunately this measuring system gave erratic results during the first part of the program. The values recorded in Table 4 were obtained after the problems had been solved and the equipment satisfactorily calibrated.

Wall pressure measurements are an important function of the technical scale ovens. By carbonizing previously untried coal blends at this scale damage to the walls of industrial ovens can be avoided. It is generally agreed that coal blends that develop a wall pressure less than two pounds per square inch can be safely carbonized in commercial equipment(6).

The pressures developed by the coal blend used in the present work ranged from 0.31 to 0.56 pounds per inch when the oven bulk density was 48.6/ cu ft or below and 0.59 to 1.6 pounds per square inch at higher bulk densities.

4.6 Petrographic Prediction of Coke Stability

The petrographic analyses of the component coals and the calculated petrographic analysis of the blend is given in Table 5. The predicted stability indices appearing in this table have been calculated using a method similar to that described by Schapiro et al(7). The predicted stabilities apply to cokes produced in a 500 lb oven from coals crushed to 80 per cent minus 1/8 in. and carbonized at an oven bulk density of 55 lb/cu ft. When the stability and oven bulk density data for the coarse ground coal (Figure 6) is linearly regressed and the linear regression line extrapolated to an oven bulk density of 55 lb/cu ft, a stability index of 61.0 is obtained. This compares satisfactorily with the predicted stability of 61.2 for the coal blend.

SELECTION OF STANDARD OPERATING CONDITIONS

It is the intention of CRPL to operate the 18-in. oven with carbonization parameters close to those found in industry. The standard conditions were selected in conjunction with the four Canadain steel companies that operate coke-oven batteries. The average dry oven bulk densities of the industrial operations vary from 43 to 46.5/lb cu ft and the coal moisture from 6-8 per cent. The oven bulk density is only known accurately after the charge is in the technical-scale oven and is then not subject to adjustment. The standard operating conditions, therefore, specify the coal pulverization level and the coal moisture content which can be adjusted before charging. A coal pulverization level of 80 per cent minus 1/8 in. was selected together with a coal moisture level of 6 per cent. From Figure 3 these conditions will result in an oven bulk density of about 46.5 lb/cu ft.

It was further decided that the coking rate should be one inch per hour, when defined as the time necessary for the centre-charge to reach 1000°C, to simulate industrial conditions. With 6 per cent moisture in the charge, this requires a flue temperature of approximately 1125°C according to the data from the test program. The oven will be pushed one-half hour after the centre temperature has reached 1000°C.

6. CONCLUSIONS

The conclusions drawn from this study relate only to the coal blend used in it.

The coking rate increases the oven flue temperature. At constant flue temperature the coking rate increases with increasing coal moisture (decreasing oven bulk density). The strength of the coke produced, as measured by the stability index, increases with increasing oven bulk density and is higher for the finer ground coal. The size distribution of the coke is mainly influenced by the oven flue temperature and the distribution is narrowed by increasing the flue temperature.

To simulate industrial practice as far as possible, the following oven operating conditions have been chosen:

- flue temperature 1125°C
- coal moisture 6 per cent
- degree of coal pulverization 80 per cent passing 1/8 in. sieve.

These conditions result in a dry-charge oven bulk density of about 46.5 lb/cu ft and a coking rate of one inch per hour to a centre-charge temperature of 1000°C. The oven is pushed one-half hour after the centre-charge temperature reaches 1000°C.

7. ACKNOWLEDGEMENTS

The authors would like to thank Mr. A.W. Kay and other members of the Technical Committee of the CCRA for suggestions used in designing the experimental program. The coals used in the program were donated by a member company of CCRA. The Algoma Steel Corp. donated the silica bricks for the coke oven. The authors would also like to thank Mr. J.C. Botham, Manager, Coal Resource and Processing Laboratory, for suggestions and continuing interest, and Mr. J.G. Jorgensen, CRPL, for the petrographic analyses.

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TABLE 3

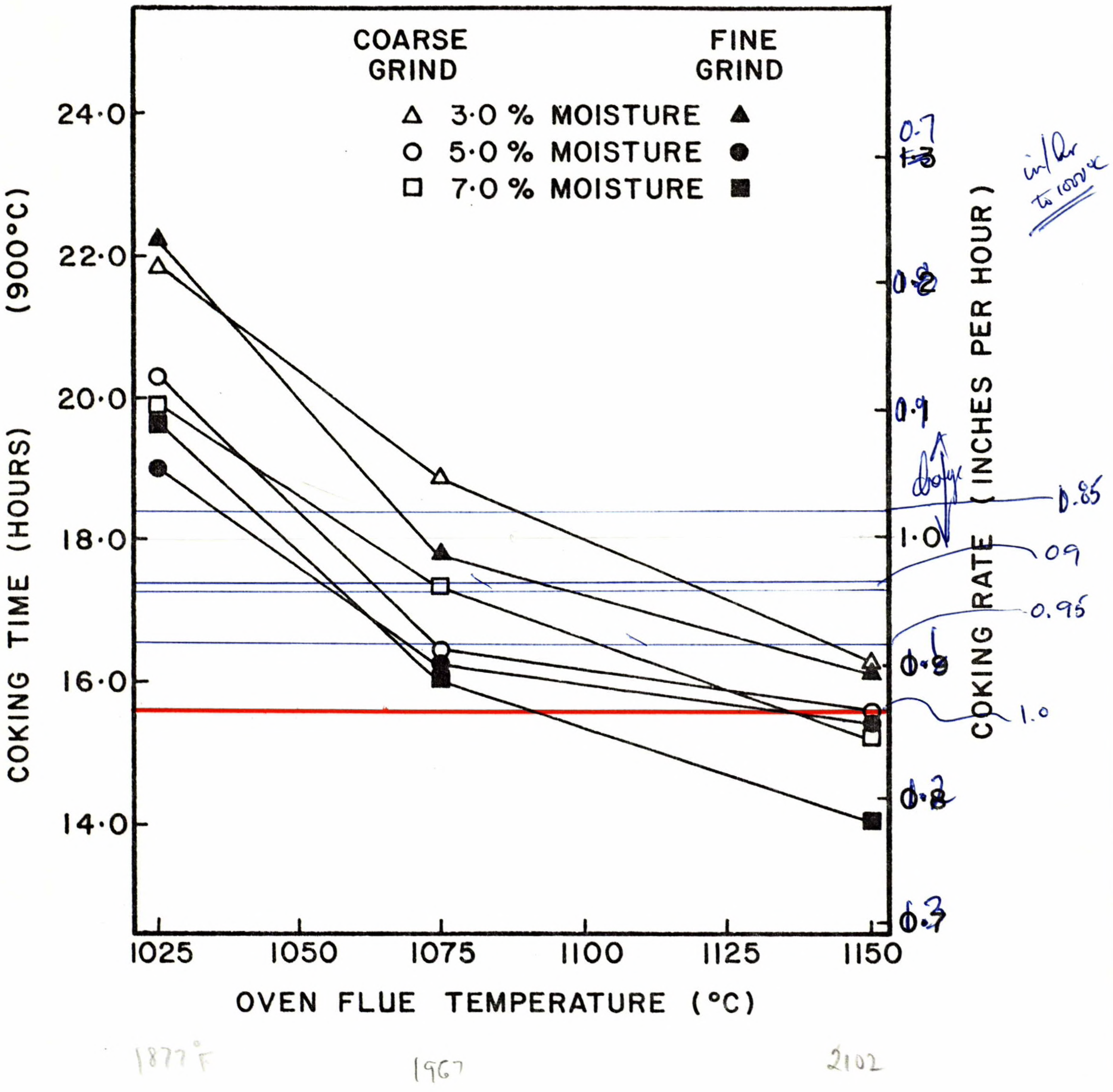
Sieve Analysis of Two Coke Oven Charges, Typical of the Coarse and Fine Grinds Used.

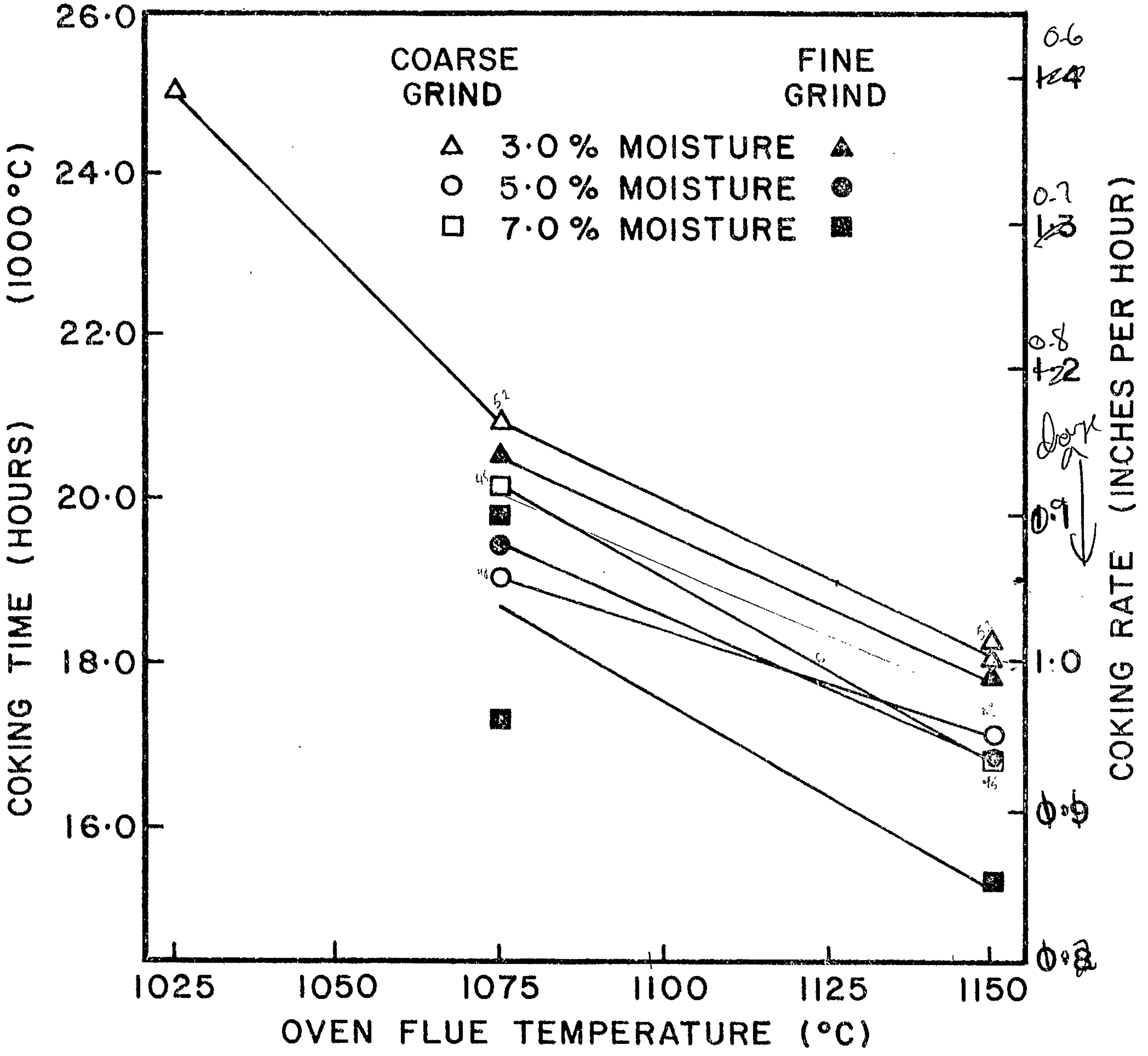
Size Range	Coarse Grind (%)	Fine Grind (%)
plus ¼ in.	5.4	0.2
¼-1/8 in.	18.3	7.7
1/8-1/16 in.	20.1	24.2
1/16-1/32 in.	18.7	24.5
minus 1/32 in.	37.5	43.4
Total minus 1/8 in.	76.3	92.1

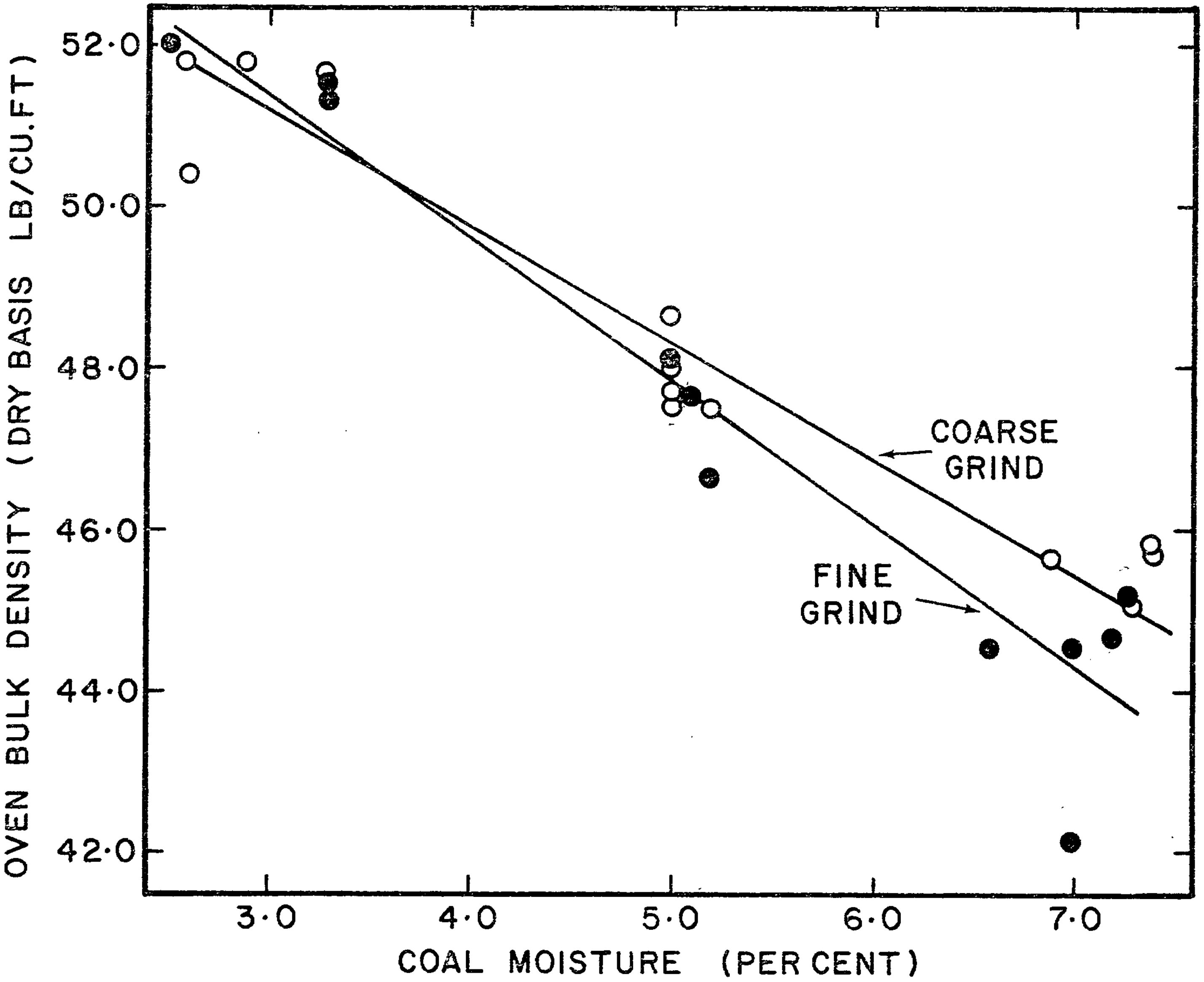
TABLE 4

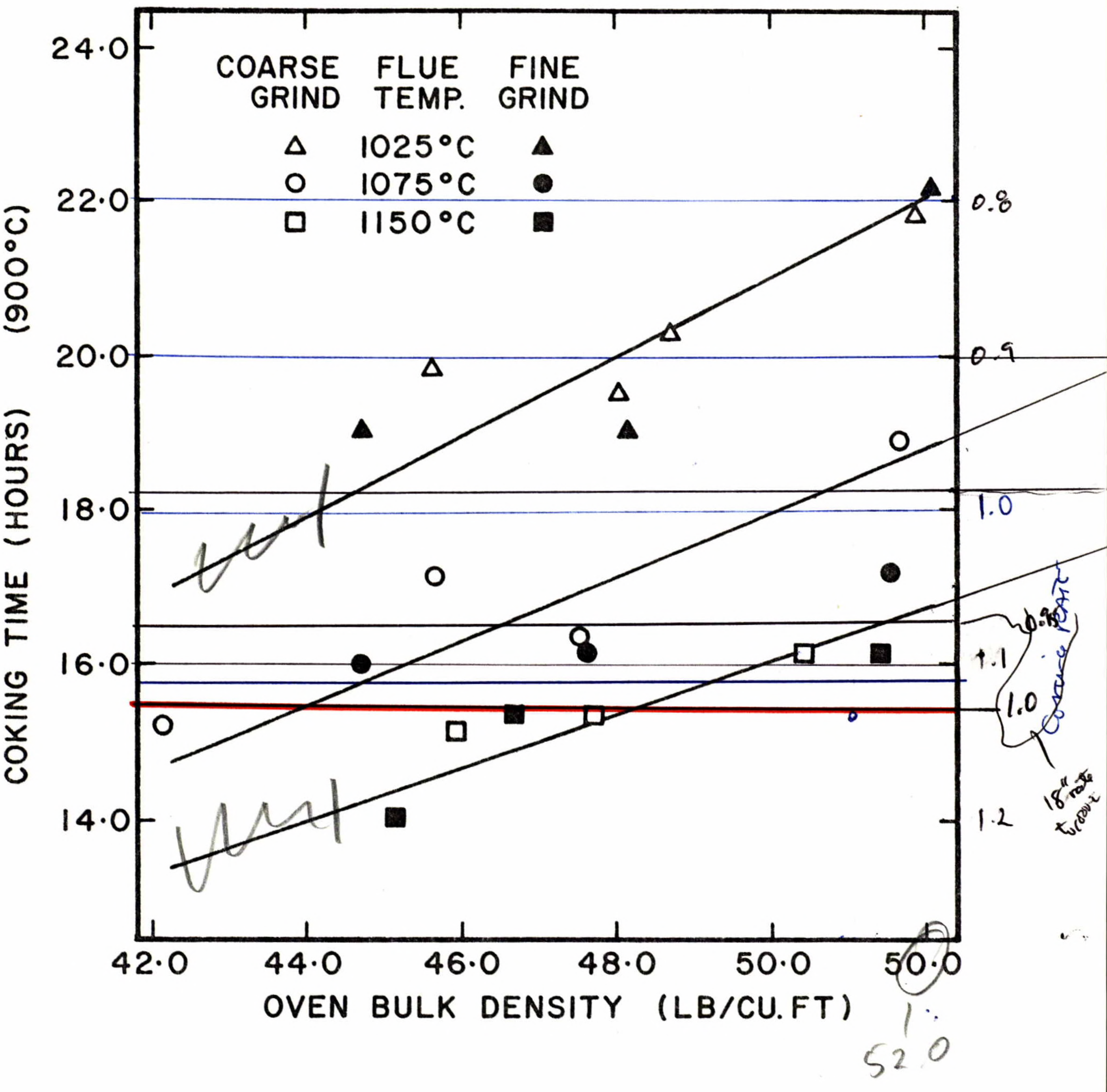
Carbonization Data

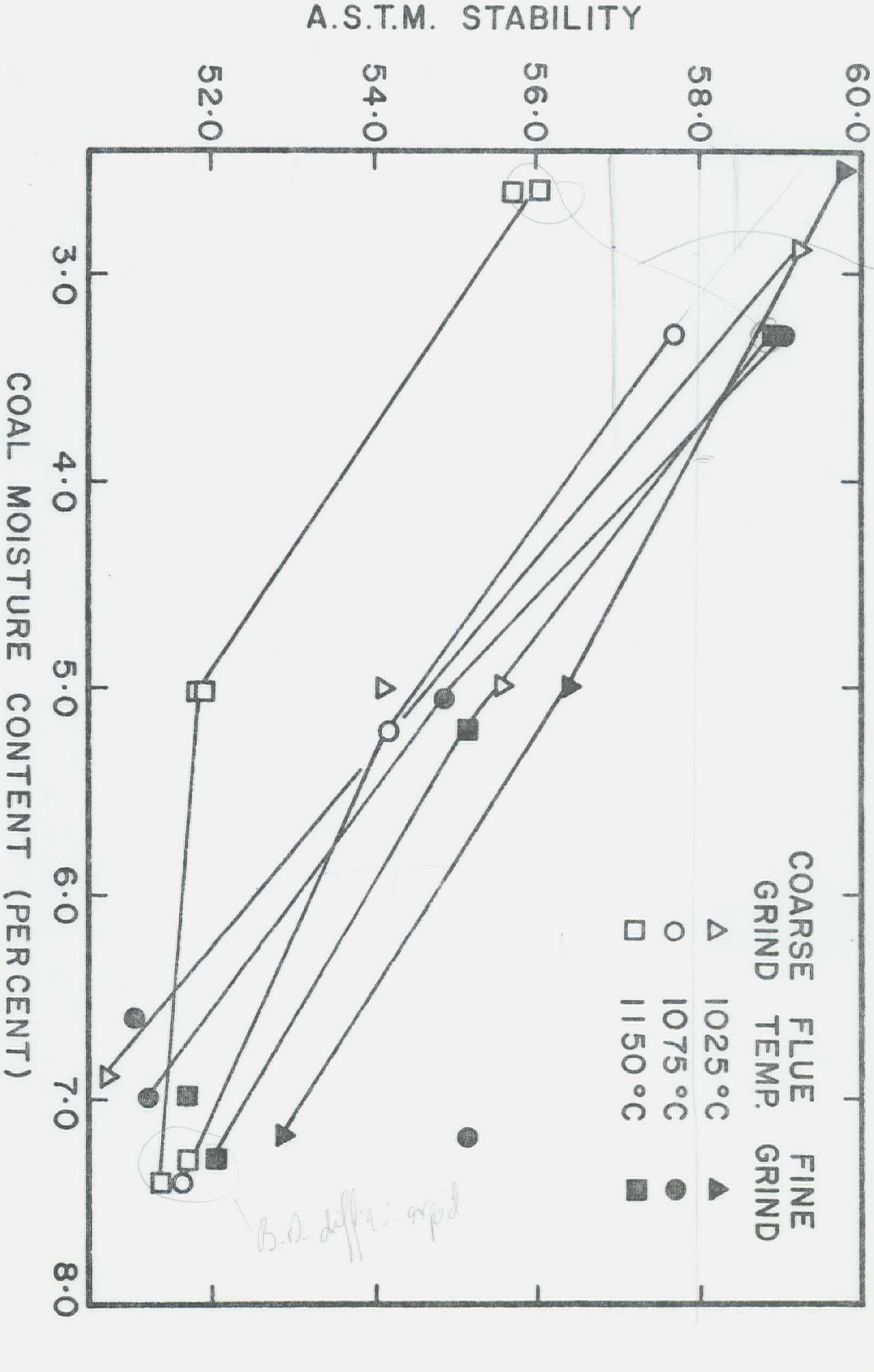
TEST NO.	OVEN FLUE TEMP. °C	COAL MOISTURE %	GRIND FINE/ COARSE	OVEN BULK DENSITY lb/cu ft	WALL PRESSURE lb/sq in.	ASTM STABILITY	ASTM HARDNESS	JIS $DI\frac{15}{30}$	SIZE DISTRIBUTION (inches)							APPARENT SPECIFIC GRAVITY	COKING TIME HOURS	
									+4	+3	+2	+1½	+1	+¾	+½		900°C	1000°C
195	1075	5.1	F	47.6		54.8	59.9	94.0	7.3	28.5	71.6	88.0	94.9	95.7	96.4	-	16.2	-
198	1075	3.3	F	51.5		59.0	65.0	95.2	5.2	23.9	68.4	87.3	94.1	94.7	95.5	0.876	17.2	20.5
199	1075	7.2	F	44.7		55.1	60.6	94.5	7.1	30.3	72.9	87.9	95.6	96.6	97.2	0.835	16.0	17.3
201	1025	5.0	F	48.1		56.4	60.3	94.4	13.2	39.4	75.6	89.0	95.8	96.5	97.2	0.821	19.0	-
202	1025	7.2	F	44.7		52.9	57.1	94.1	11.3	35.7	76.2	89.5	95.0	95.8	96.8	0.824	19.6	-
203	1025	2.5	F	52.0		59.8	64.8	94.7	16.7	39.4	77.2	90.5	94.9	95.8	96.7	0.882	22.2	-
205	1150	3.3	F	51.3		58.9	66.9	94.8	3.2	24.4	63.9	85.1	94.4	95.1	95.8	0.905	16.1	17.9
206	1150	5.2	F	46.7		55.1	62.1	94.1	4.3	23.5	65.0	84.1	95.2	96.0	96.7	0.844	15.4	16.8
207	1150	7.3	F	45.1		52.0	60.0	94.5	4.7	24.1	64.6	87.4	95.0	96.0	96.7	0.828	14.0	15.3
208	1150	2.6	C	50.4		56.0	65.2	95.3	5.1	23.3	62.4	84.2	95.9	96.8	97.6	0.902	16.2	18.0
209	1150	5.0	C	47.7		51.9	60.1	93.7	7.5	26.0	67.8	86.8	94.9	95.8	96.6	0.822	15.4	17.2
210	1150	7.4	C	45.8		51.4	59.8	92.8	3.9	23.5	66.3	87.2	94.3	95.4	96.3	0.811	15.3	16.8
211	1075	7.4	C	45.7		51.6	57.9	93.1	5.1	34.7	74.0	88.3	95.1	95.9	96.8	0.848	17.2	20.2
212	1075	5.2	C	47.5		54.1	62.2	94.2	6.2	28.1	69.9	87.9	95.1	95.9	96.5	0.857	16.4	19.0
213	1075	3.3	C	51.6	1.6	57.7	65.7	94.4	14.9	31.3	71.0	88.8	95.3	96.1	97.1	0.921	18.9	21.0
214	1025	2.9	C	51.8	1.13	59.3	67.0	95.2	20.3	47.4	80.4	91.6	95.9	96.7	97.4	0.931	21.9	25.0
215	1025	5.0	C	48.6	0.34	55.5	62.3	94.0	16.3	39.2	78.9	90.0	95.3	96.1	96.9	0.860	20.3	-
216	1025	6.9	C	45.6	0.31	50.6	56.8	93.7	20.6	42.1	79.4	90.3	94.3	95.2	96.2	0.815	19.9	-
217	1025	5.0	C	48.0	0.56	54.1	60.5	94.9	15.6	38.2	77.9	90.5	95.3	96.1	97.0	0.849	19.5	-
218	1075	7.0	F	42.1	0.56	51.2	56.2	94.3	4.9	23.7	70.0	87.3	94.3	95.3	96.2	0.809	15.3	19.8
219	1150	5.0	C	47.5	0.49	51.8	61.1	94.1	2.9	25.1	64.7	85.3	94.8	95.9	96.9	-	-	-
220	1150	7.3	C	45.5		51.7	62.1	94.4	3.7	23.8	64.9	86.1	94.8	95.9	96.7	0.813	-	-
221	1150	7.0	F	44.5		51.7	57.8	94.3	6.6	26.3	71.1	87.7	94.9	95.6	96.4	-	-	-
222	1075	6.6	F	44.5		51.0	56.6	94.2	12.2	30.5	71.9	84.7	94.6	95.5	96.3	0.820	-	-
223	1150	2.6	C	51.8	0.59	55.7	67.3	95.0	3.2	17.1	58.7	84.0	95.4	96.6	97.3	-	-	18.25


COARSE GRIND
FINE GRIND
△ 3·0 % MOISTURE ▲
○ 5·0 % MOISTURE ●
□ 7·0 % MOISTURE ■
COKING TIME (HOURS) (900°C)
24·0
22·0
20·0
18·0
16·0
14·0
COKING RATE (INCHES PER HOUR)
~~1·3~~ 0·7
~~1·2~~ 0·8
~~1·1~~ 0·9
1·0
~~0·9~~ 1·1
~~0·8~~ 1·2
~~0·7~~ 1·3
in/hr to 1000°C
0.85
0.9
0.95
1.0
1025
1050
1075
1100
1125
1150
OVEN FLUE TEMPERATURE (°C)
1877°F
1967
2102


COARSE GRIND
FINE GRIND
△ 3·0 % MOISTURE ▲
○ 5·0 % MOISTURE ●
□ 7·0 % MOISTURE ■
COKING TIME (HOURS) (1000°C)
26·0
24·0
22·0
20·0
18·0
16·0
COKING RATE (INCHES PER HOUR)
0.6
~~1·4~~
0.7
~~1·3~~
0.8
~~1·2~~
0·9
1·0
0·9
0·8
Dory
52
45
48
1025
1050
1075
1100
1125
1150
OVEN FLUE TEMPERATURE (°C)

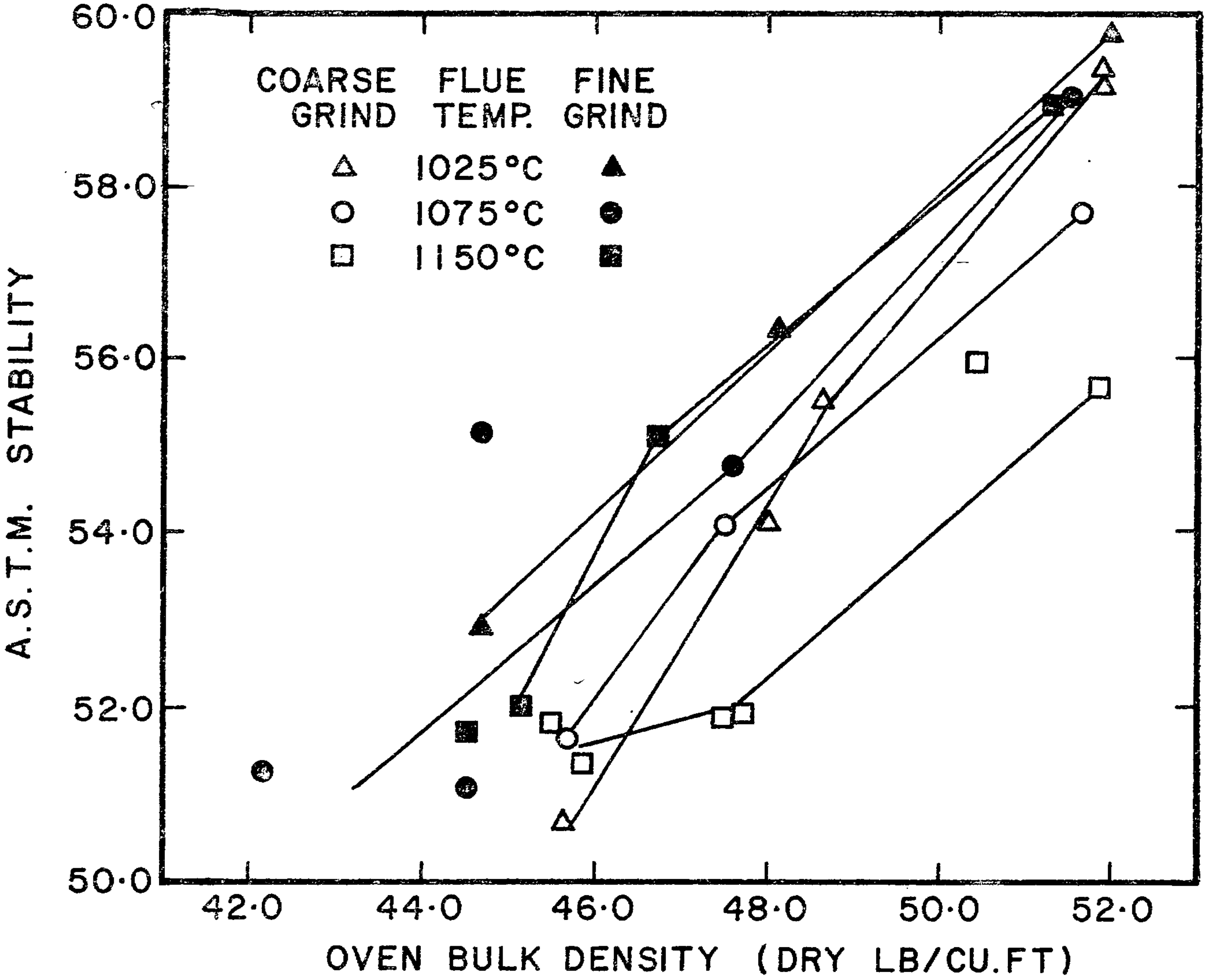

52·0
50·0
48·0
46·0
44·0
42·0
OVEN BULK DENSITY (DRY BASIS LB/CU.FT)
3·0
4·0
5·0
6·0
7·0
COAL MOISTURE (PER CENT)
COARSE GRIND
FINE GRIND

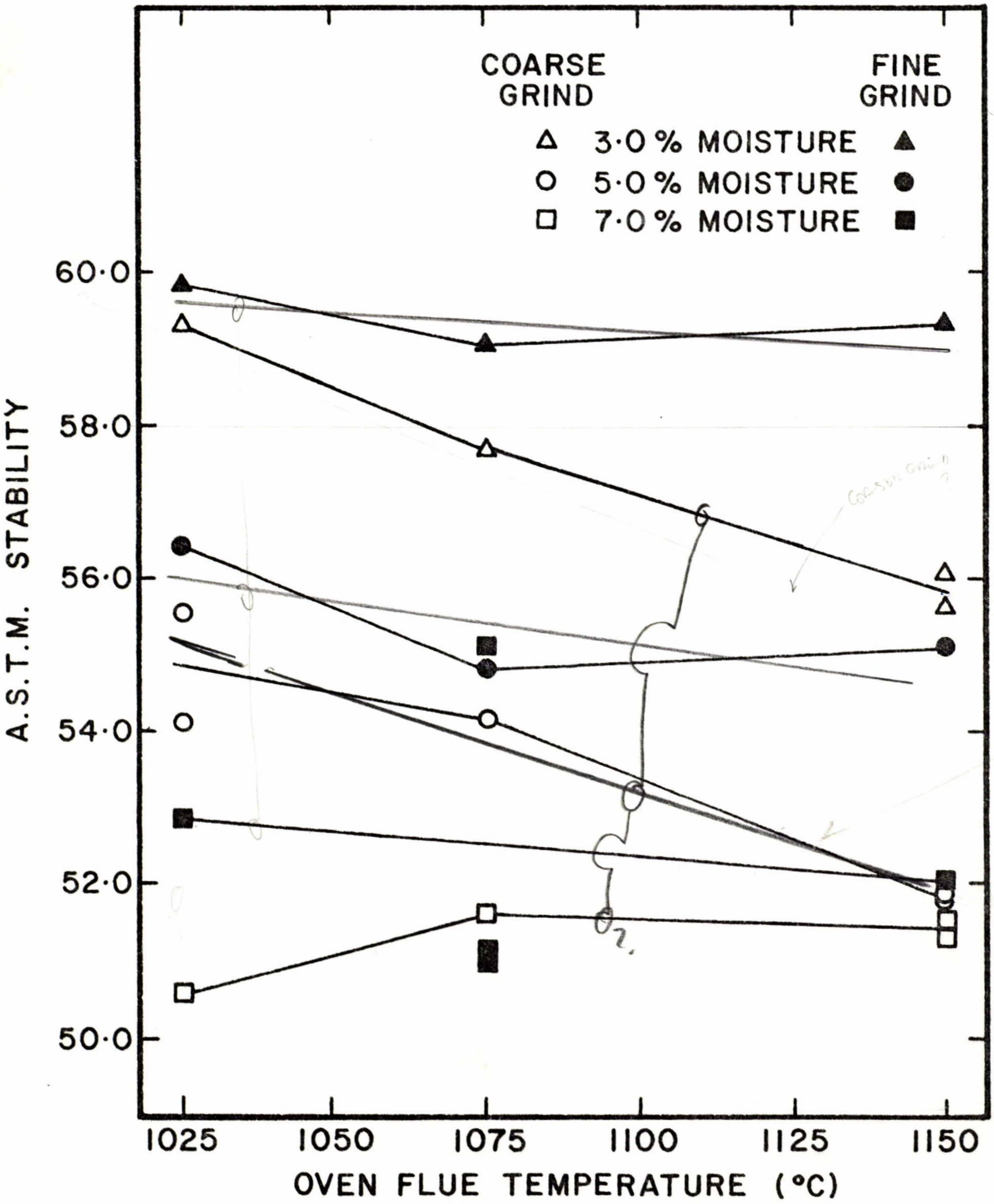

COARSE GRIND
FLUE TEMP.
FINE GRIND
△ 1025°C ▲
○ 1075°C ●
□ 1150°C ■
COKING TIME (HOURS) (900°C)
24·0
22·0
20·0
18·0
16·0
14·0
42·0
44·0
46·0
48·0
50·0
50·0
OVEN BULK DENSITY (LB/CU.FT)
0.8
0.9
1.0
0.95
1.1
1.0
1.2
Coking Rate
18" rate turnover
52.0



not B.D.
i- content of particle

B.D. diff'n i. expd

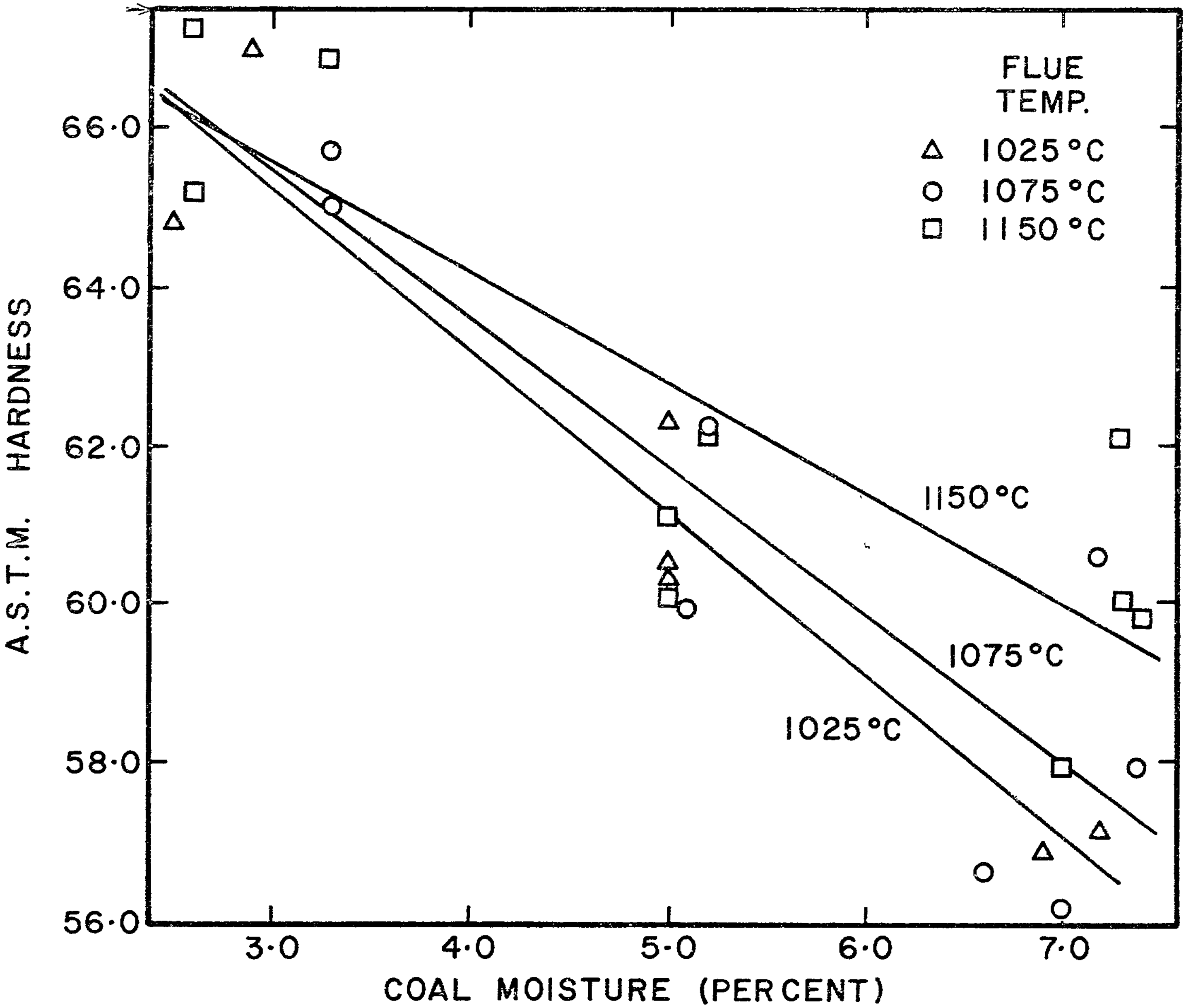

60·0
58·0
56·0
54·0
52·0
50·0
A.S.T.M. STABILITY
COARSE GRIND
FLUE TEMP.
FINE GRIND
△ 1025°C ▲
○ 1075°C ●
□ 1150°C ■
42·0
44·0
46·0
48·0
50·0
52·0
OVEN BULK DENSITY (DRY LB/CU.FT)

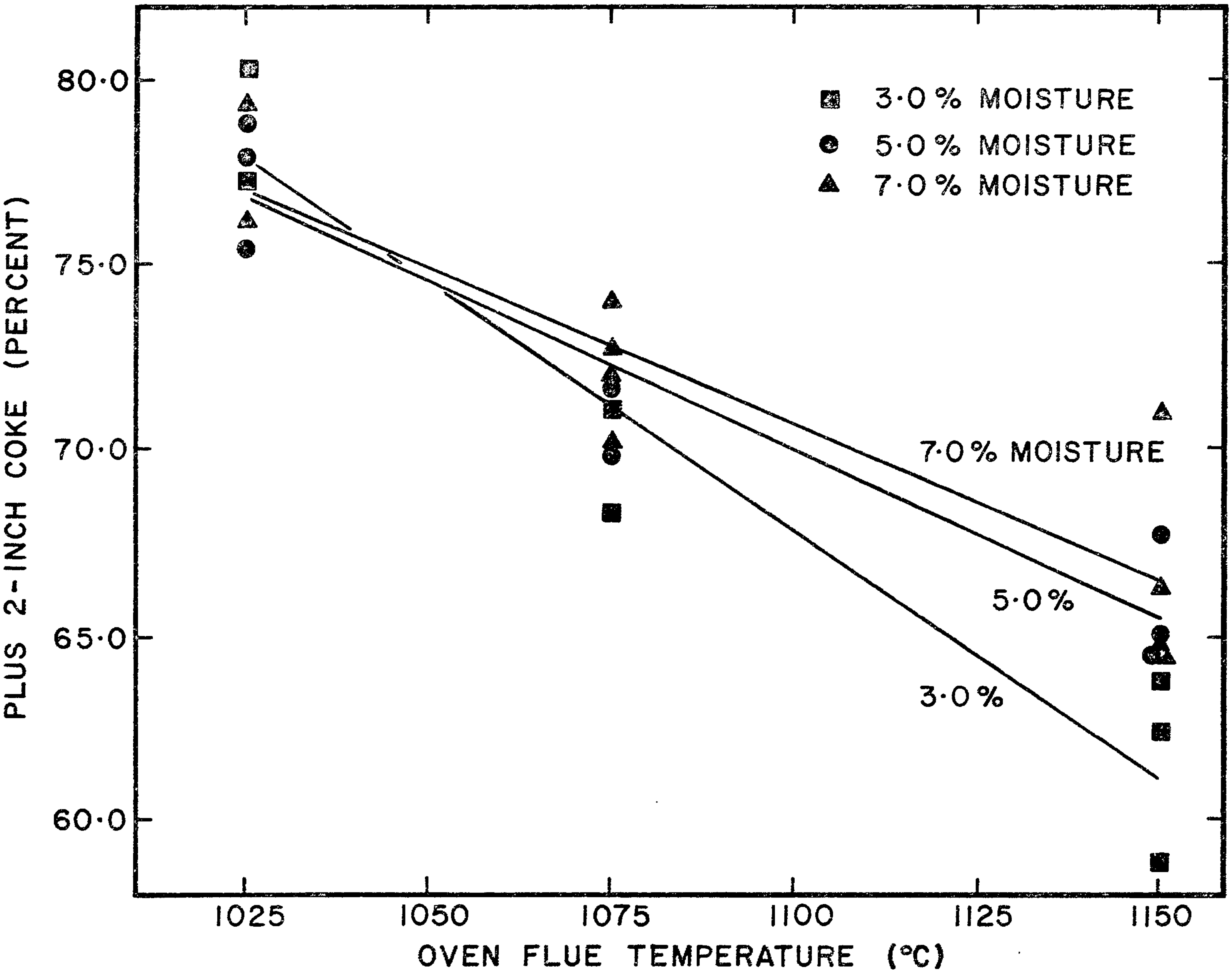


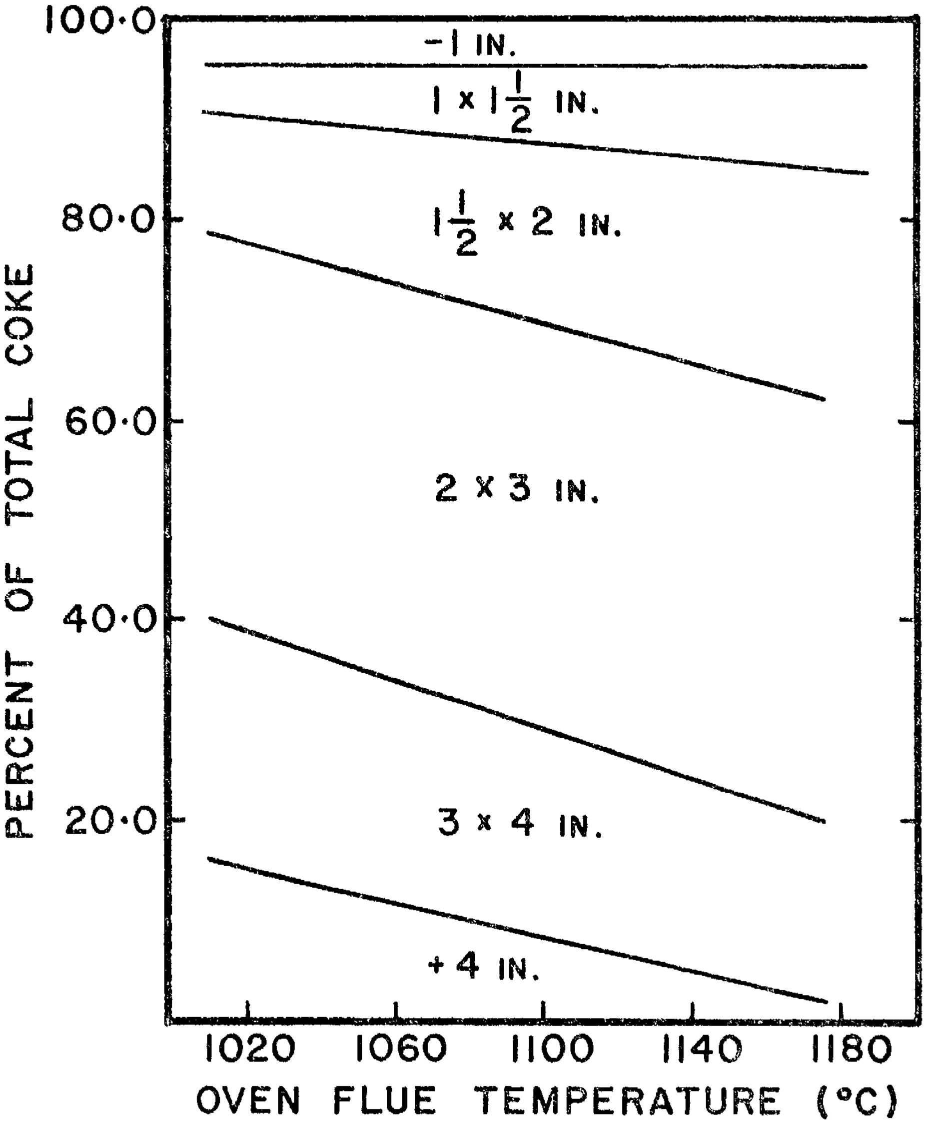
Coarser grind ?

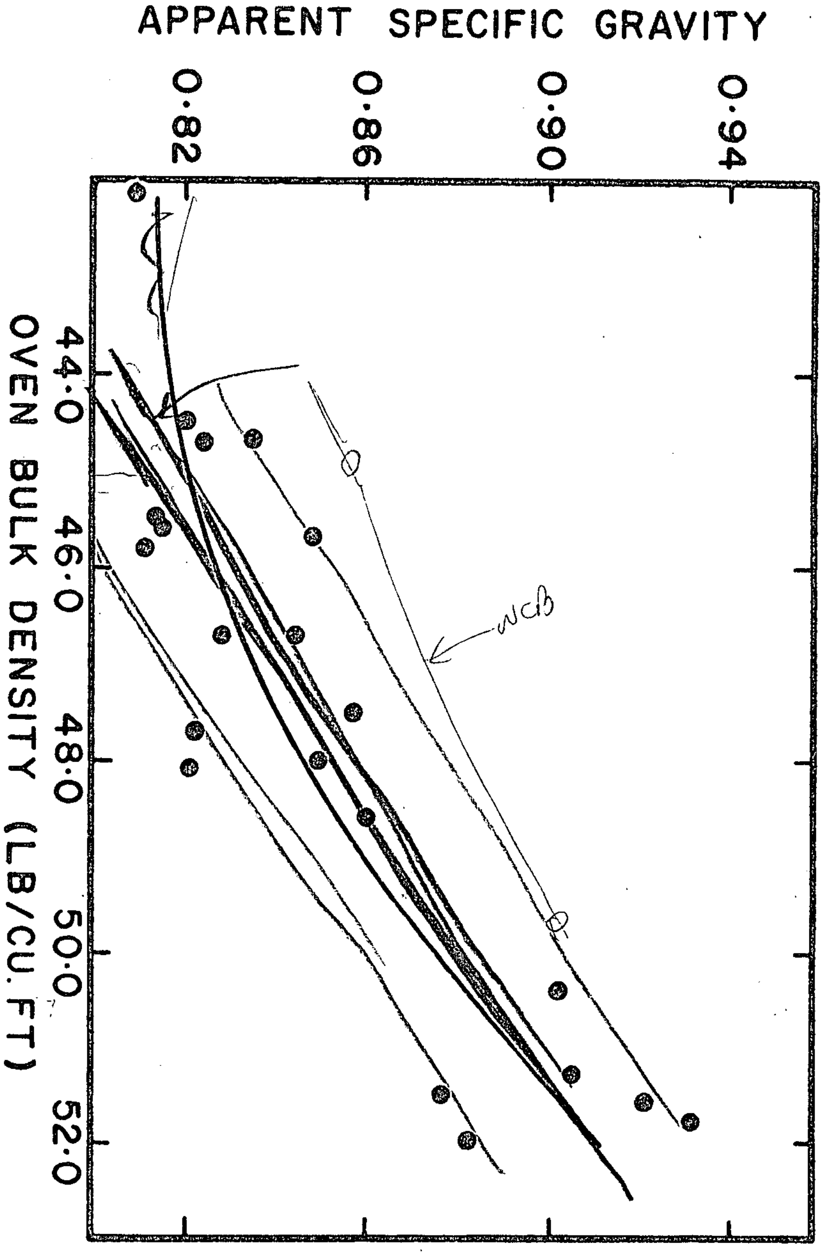
O_2

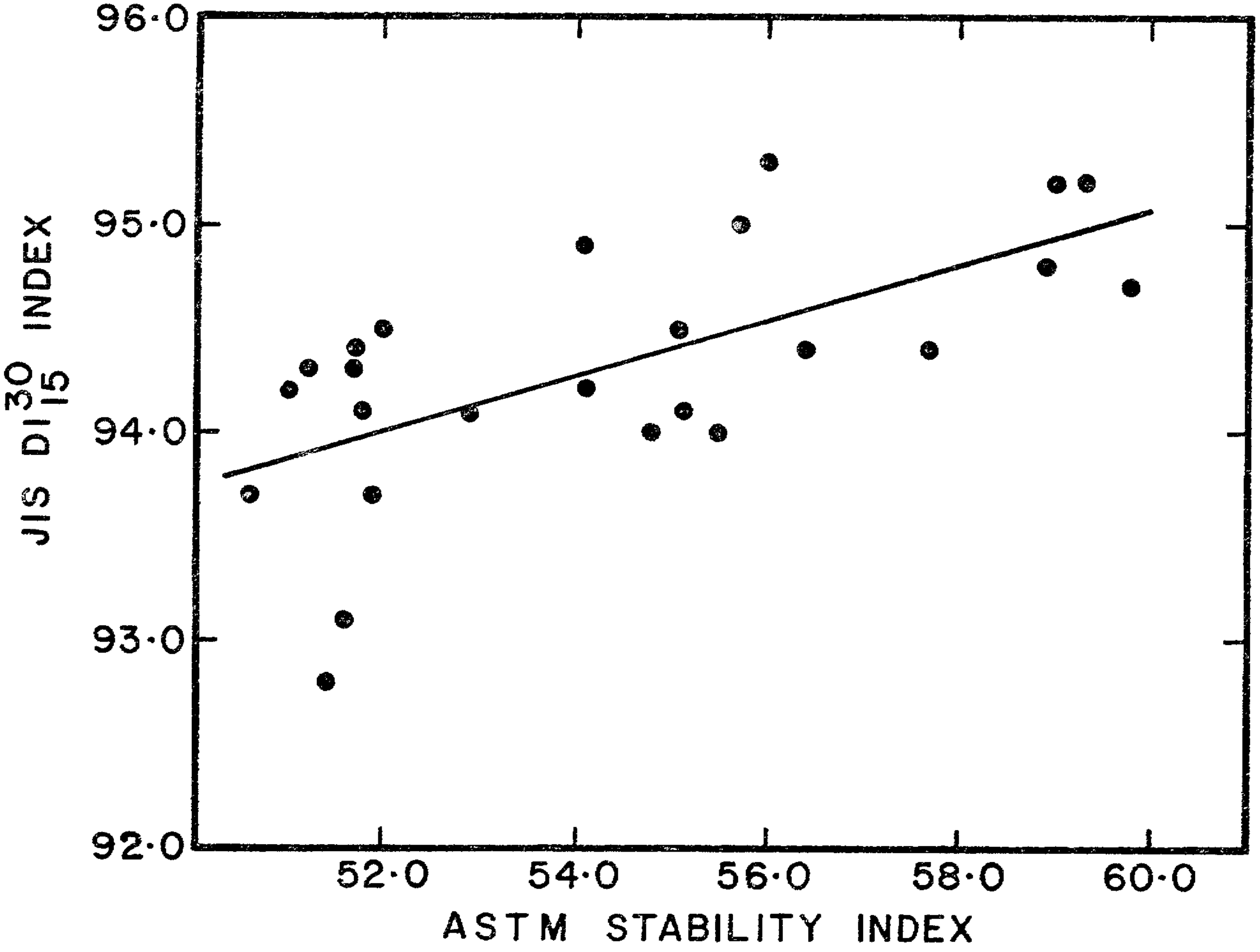
std conditions


FLUE TEMP.
△ 1025 °C
○ 1075 °C
□ 1150 °C
1150 °C
1075 °C
1025 °C
A.S.T.M. HARDNESS
66·0
64·0
62·0
60·0
58·0
56·0
3·0
4·0
5·0
6·0
7·0
COAL MOISTURE (PERCENT)


PLUS 2-INCH COKE (PERCENT)
80·0
75·0
70·0
65·0
60·0
1025
1050
1075
1100
1125
1150
OVEN FLUE TEMPERATURE (°C)
■ 3·0% MOISTURE
● 5·0% MOISTURE
▲ 7·0% MOISTURE
7·0% MOISTURE
5·0%
3·0%


100·0
80·0
60·0
40·0
20·0
PERCENT OF TOTAL COKE
−1 IN.
$1 \times 1\frac{1}{2}$ IN.
$1\frac{1}{2} \times 2$ IN.
2 × 3 IN.
3 × 4 IN.
+4 IN.
1020
1060
1100
1140
1180
OVEN FLUE TEMPERATURE (°C)


APPARENT SPECIFIC GRAVITY
0·82
0·86
0·90
0·94
OVEN BULK DENSITY (LB/CU.FT)
44·0
46·0
48·0
50·0
52·0
WCB


96·0
95·0
94·0
93·0
92·0
52·0
54·0
56·0
58·0
60·0
ASTM STABILITY INDEX
JIS DI_{15}^{30} INDEX