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COMPARISON OF COMMERCIAL AND CANMET TEST OVEN COKE QUALITY - PART 3: COMPANY C

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by

J.T. Price*, J.F. Gransden*, and W.R. Leeder**

ABSTRACT

This is the third in a series of reports comparing coke made in CANMET test ovens to coke made in the oven batteries of the four Canadian steel companies. These companies use these comparisons to project commercial coke quality and hence to evaluate new coking coals and blends from carbonization tests made in CANMET test ovens.

The coal blend used at Company C and the coke produced were sampled and, after blending each to ensure homogeneity, were tested at the Ottawa, Edmonton and Company C laboratories. The coal samples were coked in four CANMET ovens and coke quality compared with the industrial sample.

The ASTM stability factor of Company C coke as measured at the two CANMET laboratories and the Company C research laboratory were in good agreement.

The coal blend of Company C coked in the 460-mm, the 310-mm, and the Koppers oven at their standard conditions gave cokes with similar coke stabilities to that produced industrially. The Carbolite oven operated under standard conditions produced cokes with stability factors 3.6 units higher than Company C coke but with similar ASTM hardness, and JIS tumbler indices. For the 460-mm oven, the values for the coke hardness factor, 60.2 and coke apparent specific gravity (ASG), 0.825 were considerably less than for the corresponding values of 66.6 and 0.913 for industrial coke. For all ovens, testing indicated the difference between a test coke and an industrial

*Research Scientists, Energy Research Laboratories, **Laboratory Manager, Western Regional Laboratory, CANMET, Energy, Mines and Resources Canada, Ottawa.

coke parameter could be minimized by optimizing coal bulk density and test oven flue temperature but no single set of conditions would make all parameters identical.

Overall however, coke produced in CANMET's four test ovens is very similar to coke produced industrially.

CONTENTS

TABLES

FIGURES

INTRODUCTION

The Canada Centre for Mineral and Energy Technology (CANMET) operates the only pilot coke ovens in Canada. Carbonization results from pilot scale ovens are required to reliably determine the coking properties of coals or blends, particularly when a coal has never been used commercially for the manufacture of metallurgical coke. CANMET ovens are relied upon by the Canadian mining companies, commercial coke makers and government for the evaluation of coking coal, research and development, and resource assessment.

Ideally coke made in any of the four CANMET test ovens would have identical properties to coke made commercially from the same coal. However, CANMET ovens do not make identical cokes because oven sizes and constructions differ. Variations in the properties of coke from different CANMET ovens are minimized by using different coking conditions for each test oven. Each Canadian coke manufacturer must adjust the coke quality test results from CANMET ovens to make them consistent with results that would be expected from their own operations. Such adjustments to test results are considered minor when compared with changes in coke quality associated with carbonizing different grades of coking coal. However, the western Canadian coal companies, who are marketing coal, are concerned that CANMET results may be conservative compared to test results from other organizations. This concern was reinforced when a preliminary comparison of industrial and CANMET coke quality results from the rebuilt Ottawa 460-mm oven showed larger differences than expected (1). A need to quantify and to identify the sources of differences between CANMET and each Canadian coke maker's results led to a proposal from the Canadian Carbonization Research Association (CCRA) to conduct a detailed correlation study of coke from (CANMET) ovens and the four major Canadian coke producers. Attention would be focussed on the Ottawa 460-mm oven. This report discusses the correlation of CANMET test results with those from coke carefully sampled from one coke oven battery of a steel plant, identified as Company C. Previous reports described the results of the program for Companies A and B (1,2).

EXPERIMENTAL METHOD

The test program was conducted so that all sources of differences in testing methods, operating results, etc. between CANMET and the company could be identified. To accomplish this, a representative sample of coal and its corresponding coke were taken at the company, the coal was carbonized in the CANMET test ovens and the resulting coke characterized and compared to the industrial coke sample. Where possible, sampling and testing procedures followed ASTM standards. Testing facilities were compared by testing repesentative samples of industrial coke at both CANMET and the company. Figure 1 shows schematic plan for this investigation and includes an approach, if necessary, for changing CANMET test oven conditions to produce coke with properties more similar to that of the industrial sample.

Sampling Procedures

Company C has three coal preparation plants that deliver coal to six oven batteries. Each preparation plant has conveyor belts supplying crushed and blended coal to holding bins above the coke oven batteries. For this study blended coal was sampled from one of these conveyor belts which delivered coal to two oven batteries. The conveyor handled about 240 tons of coal per hour. According to the ASTM standard (D2234) for the collection of a gross sample of coal, 22 incremental samples should be taken to obtain a sample representative for 8 h of production (3). However, only 14 increments of ~750 kg were taken (by stopping the belt) because of production and sampling difficulties and because a large gross sample of 10,500 kg was required.

The coke was sampled by stopping the belt and taking increments immediately after the wharf of the battery from which the sampled coal was carbonized. The ovens in this battery which are 450-mm wide were producing 16 h coke. Coke sampling began 28 h after the start of coal sampling because of production difficulties but still corresponded with the coal sampled because of an estimated 8-16 h holding time for coal in the storage bunkers. Every 30 minutes about 200 kg of wharf coke was sampled by stopping the belt for 10 minutes; this was done over a 6 h period. Two additional 75 kg samples of blast furnace coke were taken during this period from the company's normal sampling point.

The 10,500 kg gross sample of coal was blended at CANMET by mixing 1500 kg of coal at a time in a V blender to form 7 lots of mixed coal. Two hundred and fifteen kg of coal were then sampled from each of the 7 lots and the 1500 kg so obtained were again mixed in the V blender. This procedure was repeated until all coal had been cross-blended. The blended sample was then divided for carbonization testing in CANMET's Ottawa and Edmonton laboratories.

The gross coke sample was divided at CANMET into four representative samples using the alternate shovel method described in ASTM standard D346-78 (4). One coke sample was sent back to the company for testing, one was tested at each of the two CANMET laboratories (Ottawa and Edmonton) and the fourth sample was kept in reserve.

Blast furnace coke was sampled from the company's normal sampling station by taking four 35 kg grab samples. This coke had passed over several conveyor transfer points and down a conveying chute before being collected and tested.

RESULTS AND DISCUSSION

Coal Blend

The chemical rheological and petrographic properties of the coal blend from Company C are given in Appendix A. The coal size analysis showed discrepancies for the three different laboratories with an average of 80.1% minus 3.2 mm. This average size is the standard coal size used for CANMET ovens, about 80% minus 3 mm, and no further pulverization was done. Coal moisture was adjusted to determine coal bulk density in the ovens.

Comparison of coke - property determinations from different laboratories

The representative industrial coke samples described in the previous section were tested at Company C and at CANMET laboratories in Ottawa and Edmonton. A summary of findings appear in Table 1 and complete results are listed in Appendix B.

A t-test suggests the mean stability factors for the two CANMET laboratories and the company research laboratory were probably all equivalent but significantly different from results of the company quality control laboratory. This differnce is also reflected in the results for the blast furnace coke samples as tested in Ottawa, 58.5 and the company, 64.0. The ASTM hardness factors for the wharf coke were similar for the Ottawa, Edmonton and the company research laboratories.

The coke samples used for the ASTM tumbler tests at the Edmonton laboratory were bagged and shipped to Ottawa for screening to compare sieve sizes. A comparison of coke weights retained on 25.4 and 6.3 mm sieves is shown in Table 2. Edmonton results are (consistently) slightly higher than those from the Ottawa laboratory.

Properties of coke from technical-scale ovens

Carbonization data and the resulting coke properties for all oven tests appear in Appendix C.

Ottawa - 460-mm oven

Nine tests were carried out using three different flue temperatures (1125, 1175 and 1225°C) and three different coal bulk densities (740, 810 and 880 kg/m^3).

Using CANMET's standard practise for this oven with flue temperatures at 1125°C and dry coal bulk density in the oven of 740 kg/m^3 gave an ASTM coke stability factor of 55.5 units, only 1.4 units lower than that of the industrial wharf coke. The ASTM hardness factor, 60.2 and ASG, 0.825 were significantly lower than the figures for the industrial coke, 66.7 and 0.913 respectively. The amount of +51 mm coke, 80.1% and the reactivity, 32.3% according to the Nippon Steel Corporation method (4) were significantly higher than for the industrial coke of 74.0% and 23.8%. The JIS tumbler indices from thesea tests under standard condiitons, DI_{15}^{30} of 94.2 and DI_{15}^{150} of 83.1, were slightly smaller than the results for the industrial wharf coke, 94.5 And 83.8.

Eight additional tests were done in this oven at higher flue temperatures and bulk densities to try to minimize the differences in the coke quality parameters between industrial and test oven coke. Results plotted against bulk density are shown in Figure 2 (stability factor), Figure 3 (hardness factor), Figure 4 (Japanese drum indices), Figure 5 (coke ASG), Figure 6 (mean coke size), Figure 7 (coke reactivity) and Figure 8 (strength after reaction). Regression lines indicate the ASTM tumbler indices (stability and hardness), and the JIS DI_{15}^{150} tumbler index, are sensitive to changes in dry coal bulk density but relatively insensitive to changes in flue temperatures. However, the amount of +51 mm coke, mean coke size and coke reactivity are relatively insensitive to coal bulk density but are sensitive to oven flue temperature.

To make test oven coke with similar JIS tumbler and ASTM stabilities as the industrial coke, a coal bulk density of about 765-790 kg/m^3 is desired; while for ASTM hardness and ASG, a coal bulk density of about 870-890 kg/m^3 would be required in the test oven. For the test oven to duplicate the mean size, the strength after reaction and reactivity of the industrial wharf coke the figures suggest higher flue temperatures are needed for this test oven. However, these parameters warrant further investigation as they may be dependent on other factors such as final coke temperature, method of quench, and the degree of coke conditioning.

Ottawa 310-mm oven

Three tests were carried out in this oven using its standard coal bulk density (800-830 kg/m^3) and flue temperature program. During the first test there was a short electrical outage so that tests were repeated in duplicate. The mean stability factor of the coke was 57.8 within one unit of the value obtained for the industrial wharf coke, 56.9. The mean hardness factor was 66.5 nearly identical to that of the industrial product while coke ASG, 0.893 and the amount of +51 mm coke, 59.6%, were lower than that obtained for the industrial cokes. Two additional tests were carried out in this oven under standard coking rates but at higher and lower bulk densities. Regression analysis of stability versus coal bulk density for all data show that coke stability factors similar to those of industrial coke occur at coal bulk densities of about 808 kg/m^3, near the lower limit of the standard test conditions used at CANMET. Similar analysis for ASTM hardness, JIS DI^{30}_{15}, and JIS DI^{150}_{15} factors show this 310-mm oven produces coke similar to the industrial coke parameter at coal bulk densities of 802, 725, and 740 kg/m^3 respectively. Coke ASG is also sensitive to changes in coal bulk density, however, the same ASG as industrial coke is not attained for this oven until the coal bulk density is about 860 kg/m^3. Coke size from this oven is much smaller than that from the industrial and 460-mm ovens and decreases very slightly with increased bulk density. The test run at a slower coking rate by starting the test at a lower flue temperature increased mean coke size quite markedly to 60.2 mm but still not to that of industrial coke, 65 mm. The coke reactivity measurements indicated the coke made in this oven was more reactive and had lower strength after reaction than the industrial coke.

Carbolite oven

This oven is newest of CANMET's test ovens. Preliminary sensitivity testing in this oven (5) with other coals indicated this oven should be operated at the standard conditions of: 800 kg/m^3 bulk density and a flue temperature program that increases from 875°C at the start of the test to 1130°C at a rate of 15°C/h. Coke made under standard conditions in this oven from the industrial blend had a coke stability factor of 60.8, 3.6 units higher; and an ASG of 0.900, about 0.015 units lower than the industrial coke (as measured in the same laboratory). However, the JIS tumbler indices, the ASTM hardness and mean coke size were similar to those for the industrial coke. Various methods of increasing coke rates in this oven were used in the remaining trials in an effort to make coke in this oven with properties similar to that of the industrial coke. Figure 2 includes a plot of stability versus bulk density for two tests at different bulk densities but at an initial flue temperature of 950°C and programmed to 1130°C at 10°C/h; interpolation shows industrial coke stability would occur from tests run at a coal bulk density of 800 kg/m^3. Coke ASTM hardness, JIS DI_{15}^{150} and ASG correspond to the industrial coke values at dry coal bulk densities of 816, 780 and 832 kg/m^3 respectively. Mean coke size from the test oven coke however, has decreased to about 60 mm, 5 mm smaller than the industrial coke.

Figure 9 shows the effects of changes in heating rates from 875 to 1130°C upon coking parameters. Although increasing the heating rate above 30°C/h did not affect coking times significantly; ASTM stability and mean coke size decreased while ASTM hardness increased with increased heating rates. A comparison of results with that of the industrial coke would suggest higher heating rates should be used in this oven to duplicate industrial coke stabilities but slower heating rates if coke hardness and size are to be similar to industrial coke.

Koppers oven

Seven tests were carried out in this oven at two different flue temperatures, 1075°C and 990°C using three different bulk densities. Coke quality results are plotted in Figures 2-9. Figure 2 shows that the ASTM stability factor for this oven is dependent on both coal bulk density and flue temperature. Using the standard flue temperatures of 1075°C it can be calculated from the linear regression: STAB = 68.07-.0241 FT +.0178 BD, R = .90 that the coal bulk density should be 840 kg/m^3 to obtain the same stability as the industrial coke.

The ASG and hardness factor for coke from this oven appear to be independent of flue temperature and become similar to that of industrial coke at a dry coal bulk density of 842 and 825 kg/m^3 respectively; the JIS tumbler indices become similar at 816 kg/m^3. Figure 6 shows mean coke size decreases with increasing flue temperature. The standard flue temperature of 1070°C for this oven produces coke that is smaller than from industrial ovens but the lower flue temperature (990°C) produces coke approaching the larger size of industrial coke.

Comparison of coking pressures

Figure 10 shows results of coke oven wall pressures plotted against dry coal bulk density for CANMET's four moveable-wall test ovens. The Ottawa 310-mm oven consistently gives higher pressures than the other test ovens but has the shortest coking time of all test ovens which may be responsible for higher pressures.

Results listed in appendix C for tests in the carbolite and 460-mm ovens suggest higher coking (heating) rates increase coking pressures. Figure 11 indicates coking wall pressures may depend on coal bulk density, and coking rate for the 310-mm and 460-mm ovens in Ottawa. This relationship did not hold however for tests in the Koppers and Carbolite oven. Further test work is in progress to relate the effects of heating rates and coal bulk density upon coke oven gas and wall pressures.

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4. "Standard method for collection and preparation of coke samples for laboratory analysis"; D 346-78; Annual Book of ASTM Standards; Philadelphia; American Society for Testing and Materials; 1978.

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Table 1 - Comparison of industrial wharf and blast furnace coke properties determined at different laboratories

Coke Property	Wharf Coke				Blast Furnace Coke	
	Ottawa	Edmonton	Company C Research	Company C Control Lab	Ottawa	Company C
ASTM stability factor	56.9	57.2	56.3	60.0	58.5	64.0
ASTM hardness factor	66.7	66.2	-	-	65.2	-
JIS DI $^{30}_{15}$	94.5	94.5	-	-	-	-
JIS DI$^{150}_{15}$	83.8	84.0	-	-	-	-
Apparent specific gravity	0.913	0.915	-	-	-	-
Plus 51 mm coke (%)	74.0	71.5	-	-	44.6	-

Table 2 - Comparison of amounts of ASTM tumbler coke retained on 25 and 6.3 mm sieves at Edmonton and Ottawa laboratories

Test A	Weight of +25 mm coke (kg)		Weight of +6.3 mm coke (kg)	
	Edmonton	Ottawa	Edmonton	Ottawa
840	5.75	5.58	6.54	6.41
841	5.72	5.57	6.69	6.51
842	5.58	5.53	6.73	6.71
843	5.74	5.75	6.67	6.64
844	5.76	5.65	6.64	6.60
845	5.78	5.69	6.70	6.67
846	5.76	5.77	6.67	6.68
847	5.74	5.71	6.71	6.67
848	5.71	5.67	6.56	6.62
849	5.68	5.68	6.70	6.56

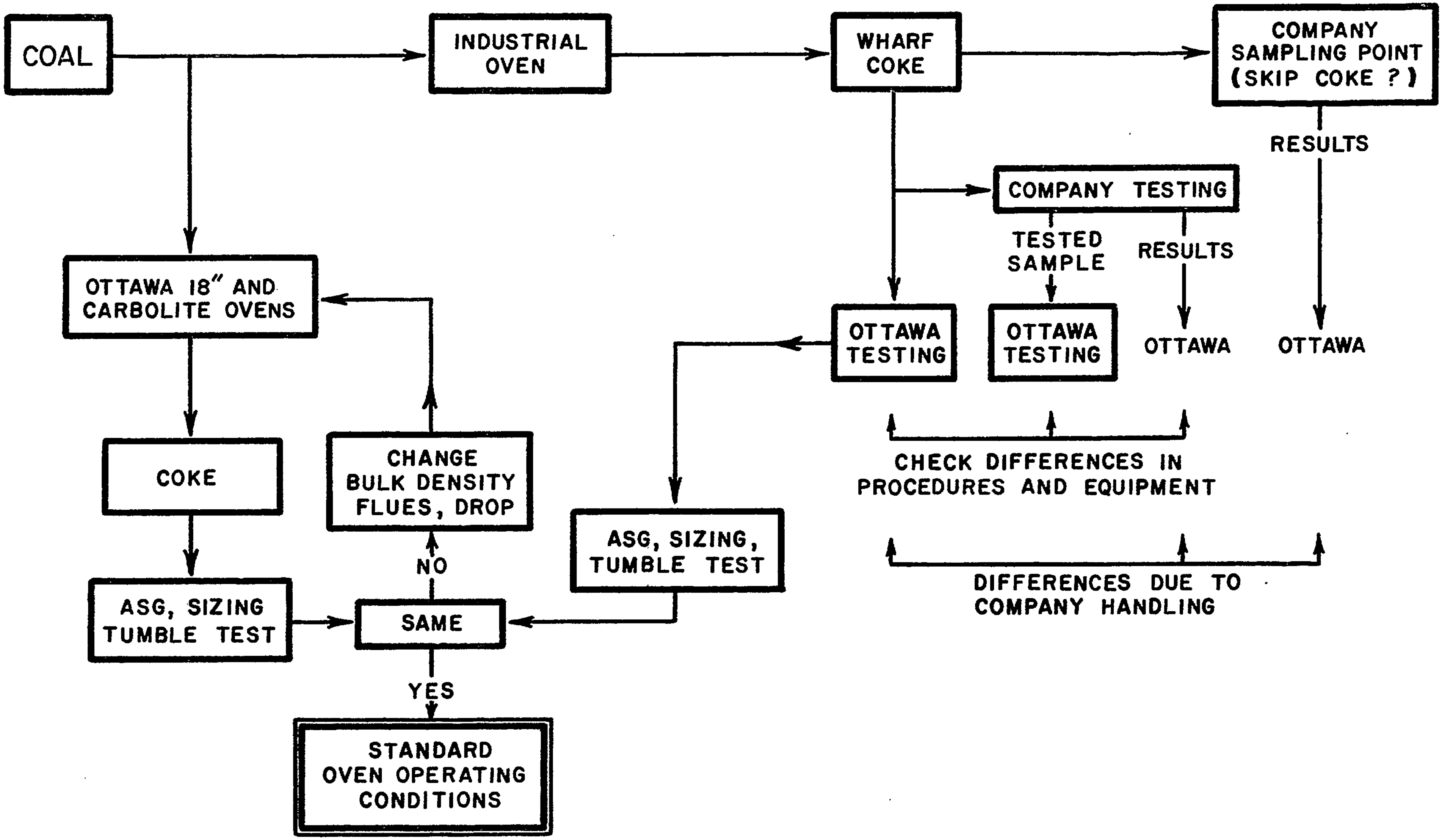

Fig. 1 Schematic work plan of sampling and testing.

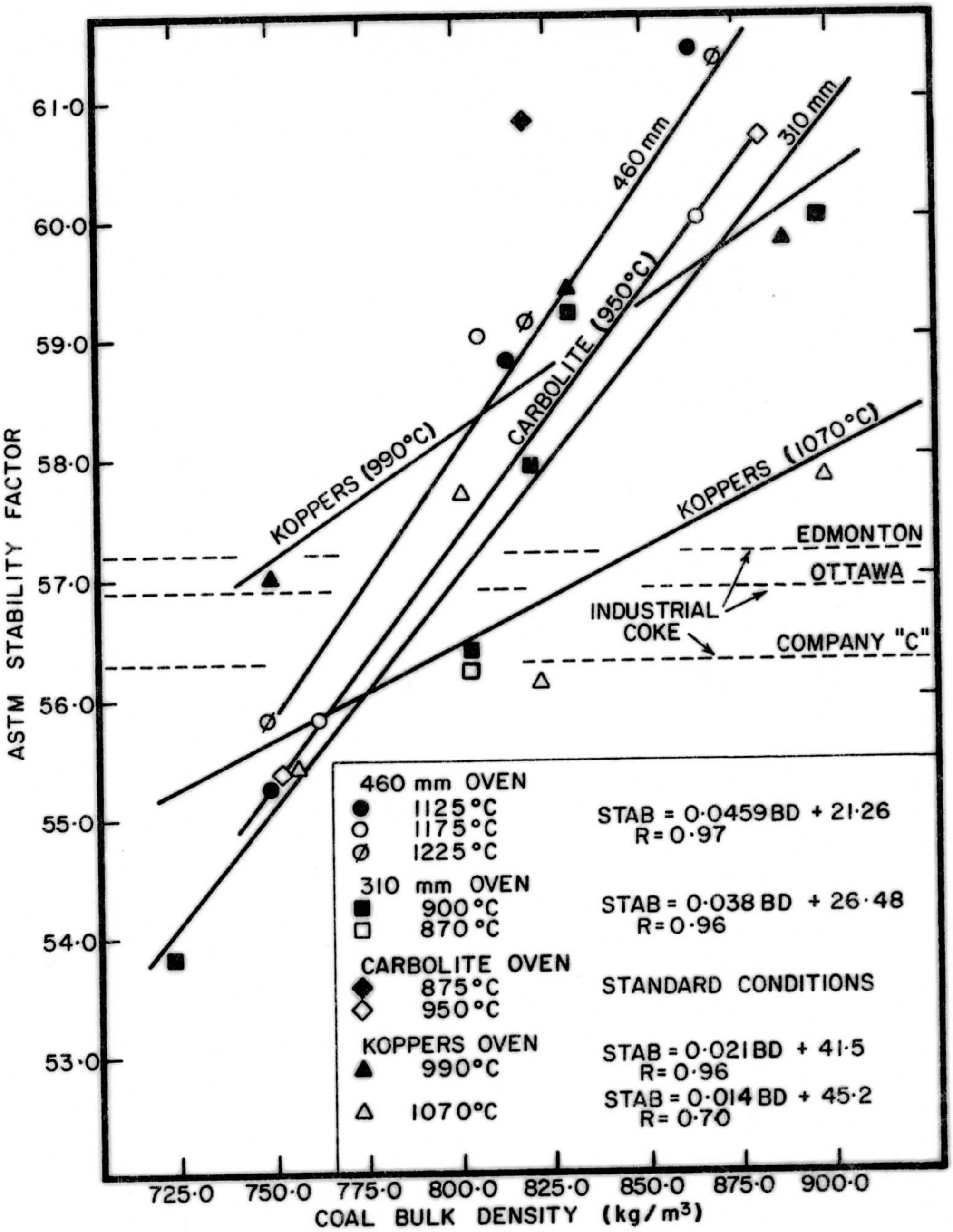

Fig. 2 ASTM stability factors for industrial and test oven cokes plotted as a function of coal bulk density in the oven.

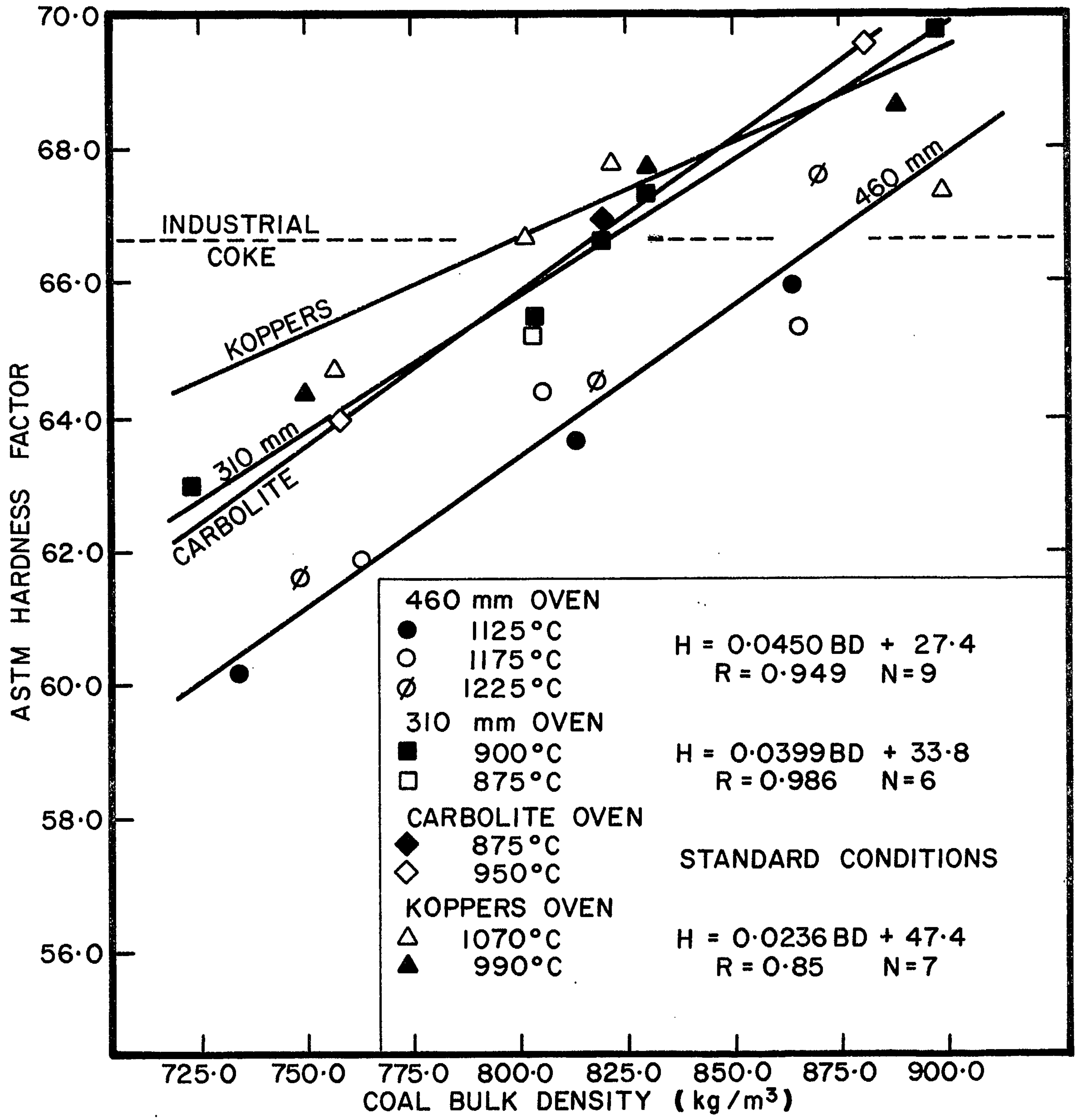

Fig. 3 ASTM hardness factors for industrial and test oven cokes plotted as a function of coal bulk density in the oven.

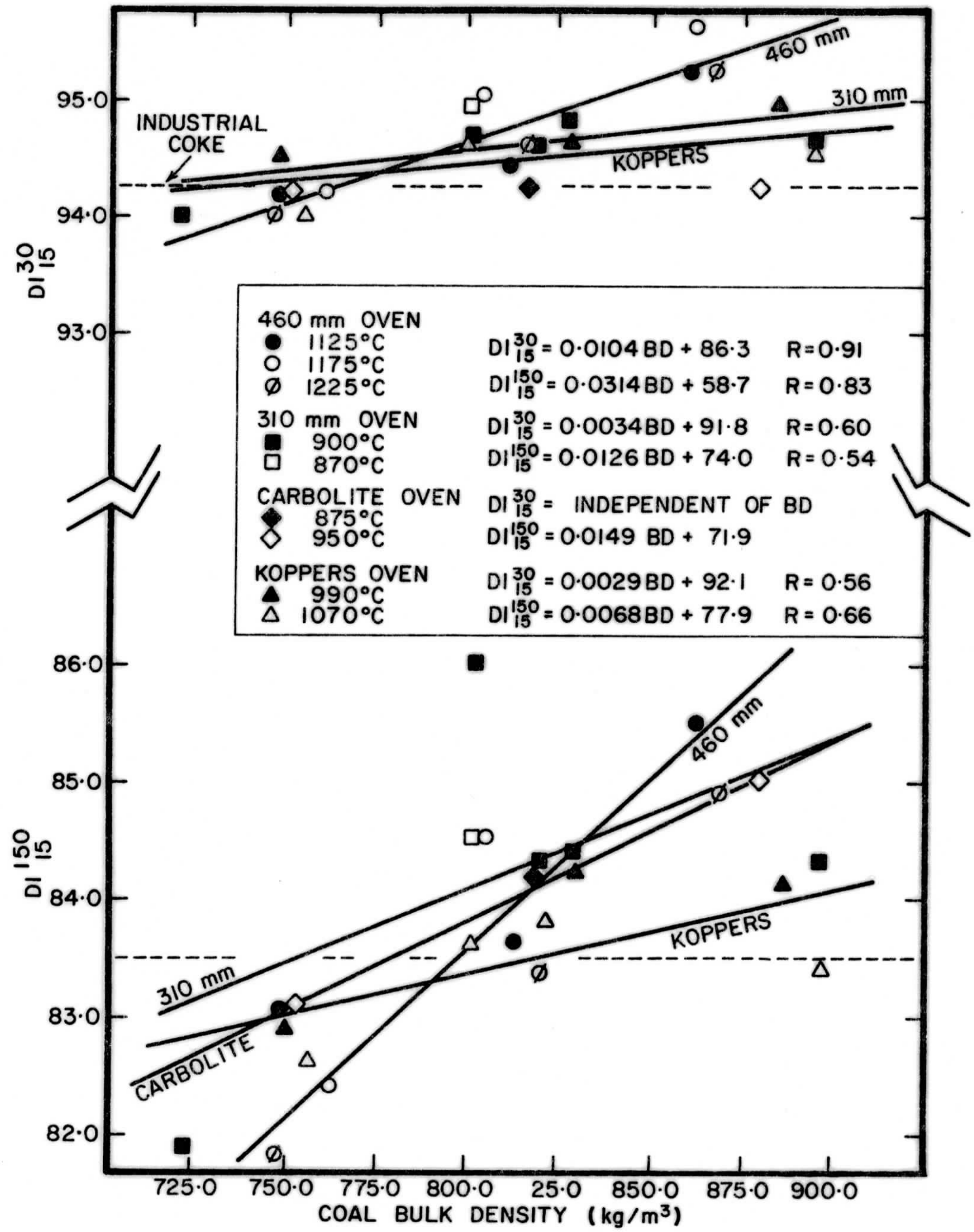

Fig. 4 JIS drum indices for industrial and test oven cokes plotted as a function of coal bulk density in the oven.

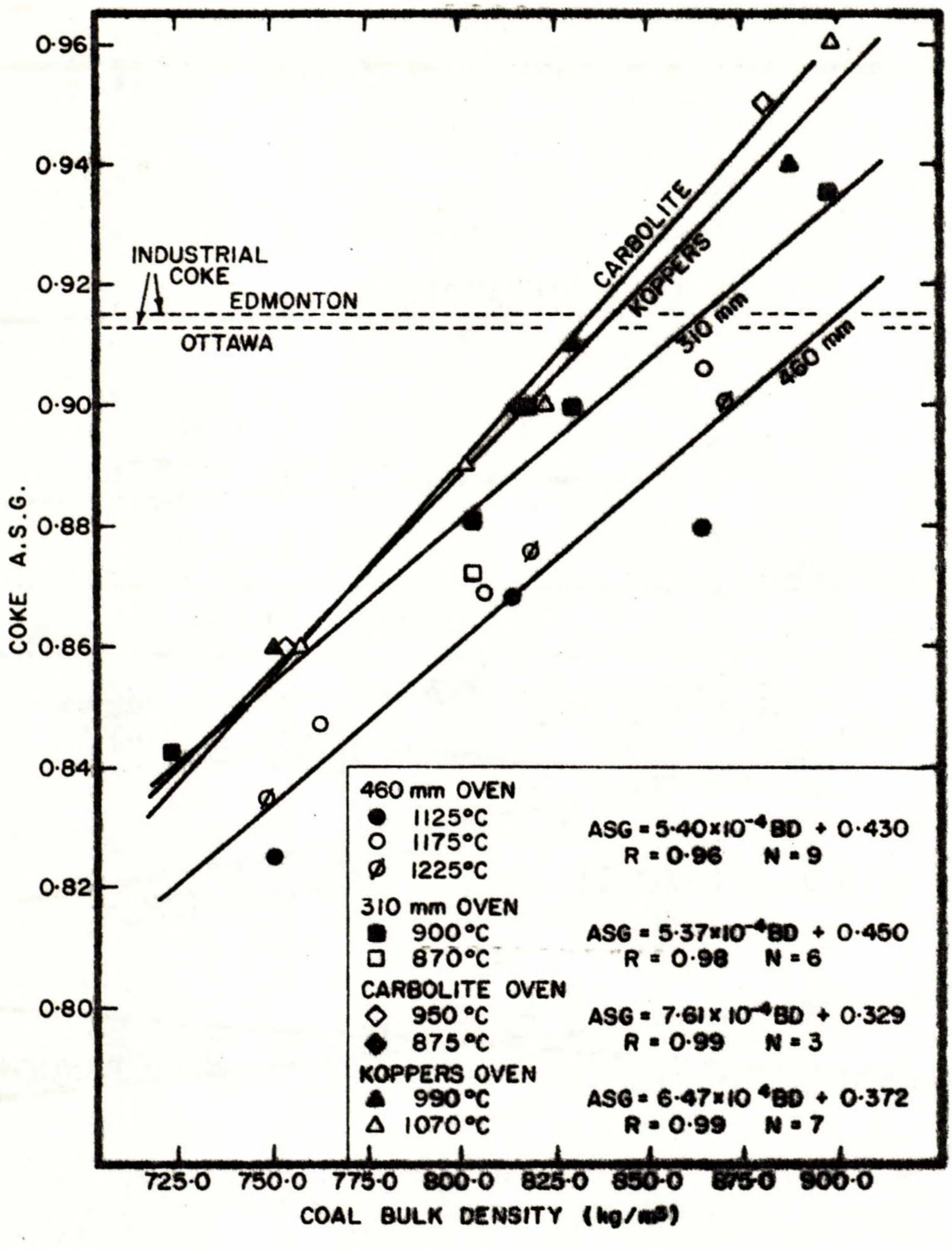

Fig. 5 Apparent specific gravity (ASG) of industrial and test oven cokes plotted as a function of the coal bulk density in the oven.

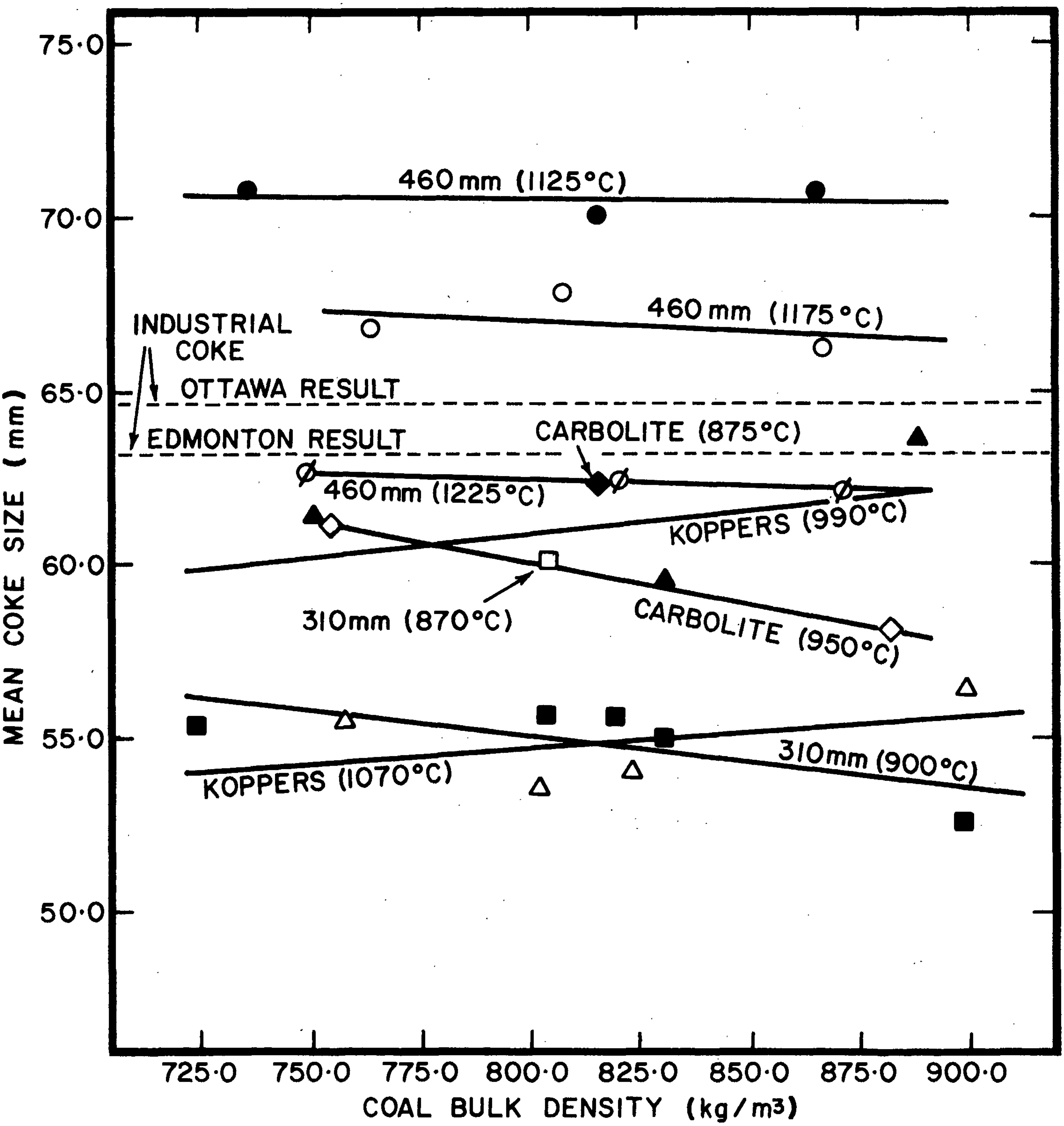

Fig. 6 Mean size of industrial and test oven cokes plotted as a function of the coal bulk density in the oven.

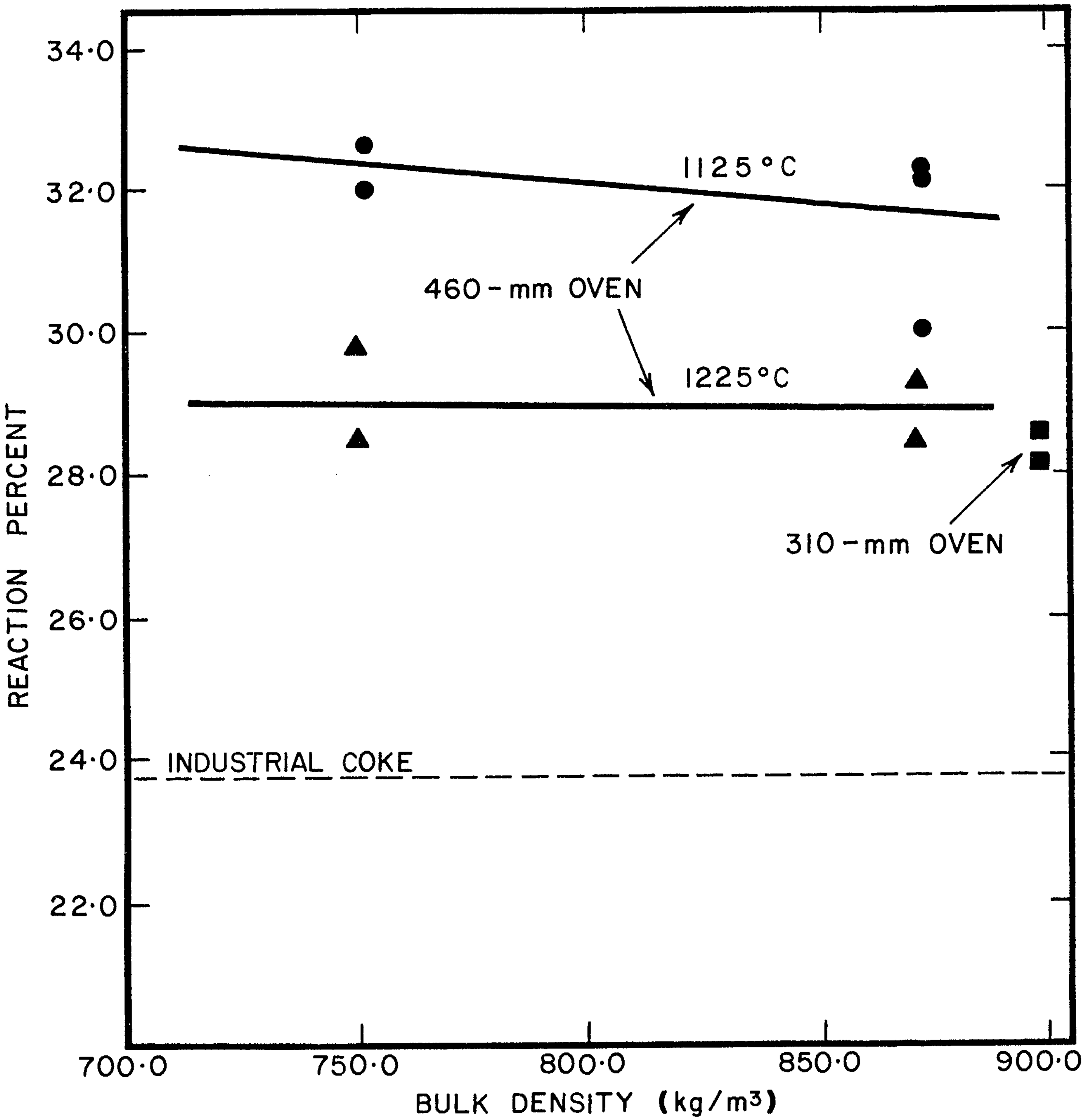

Fig. 7 Percent of coke reacted with CO_2 plotted as a function of the coal bulk density in the oven in which the coke was prepared.

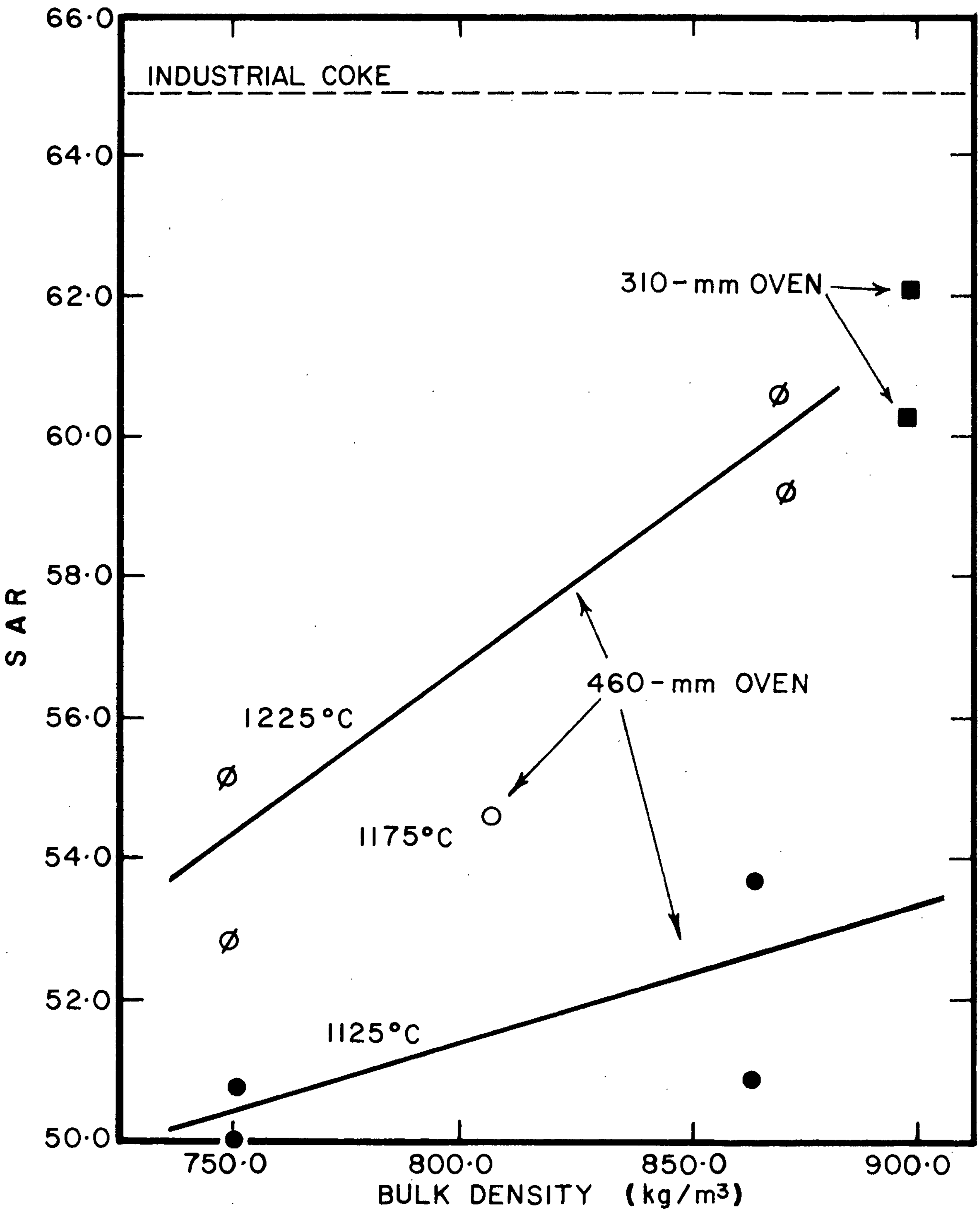

Fig. 8 Strength of coke after reaction with CO_2 plotted as a function of the coal bulk density in the oven in which the coke was prepared.

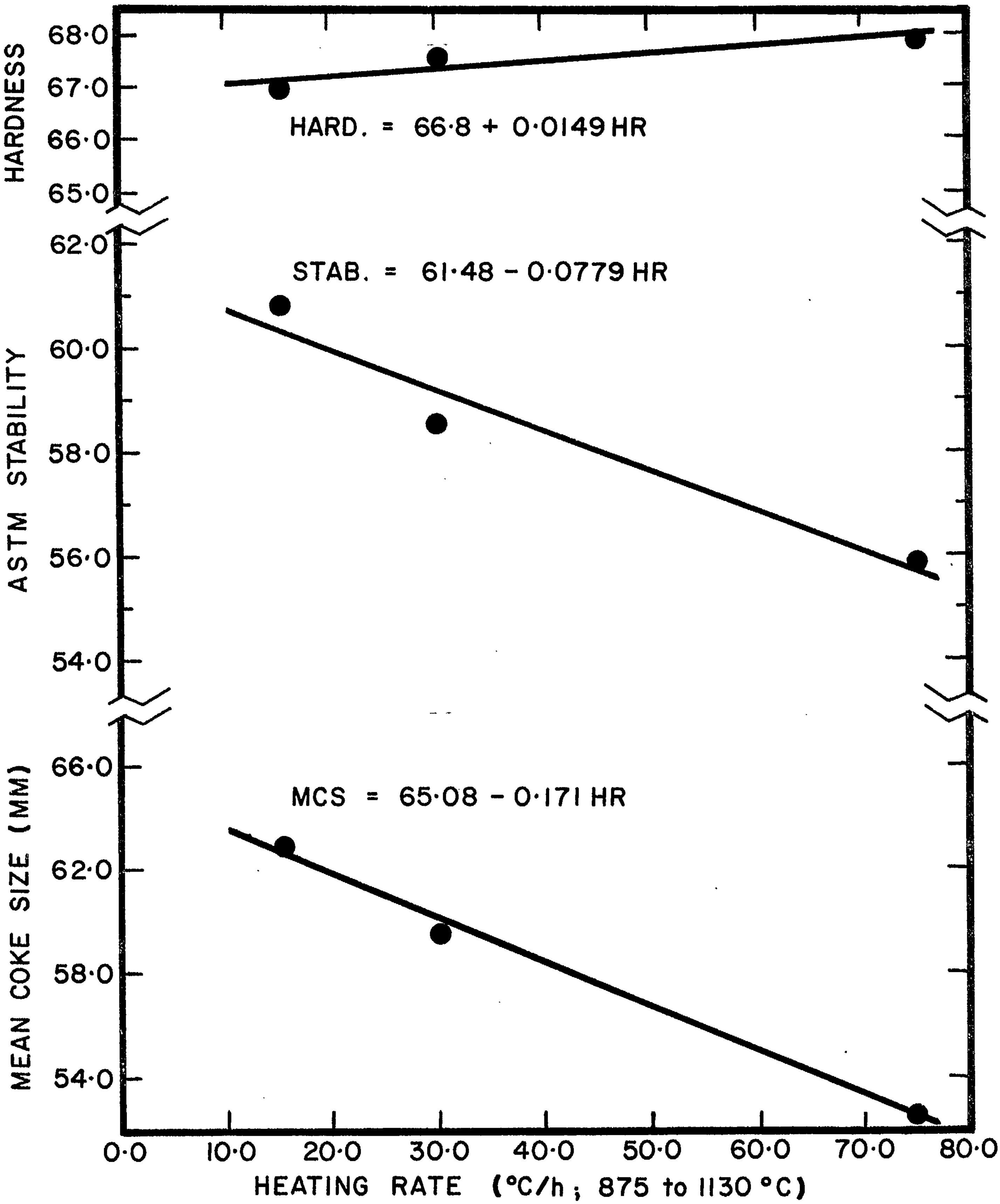

Fig. 9 Effects of rate of heating from 875 to 1130 ^{o}C on mean size, ASTM hardness, and stability of coke from Carbolite test oven.

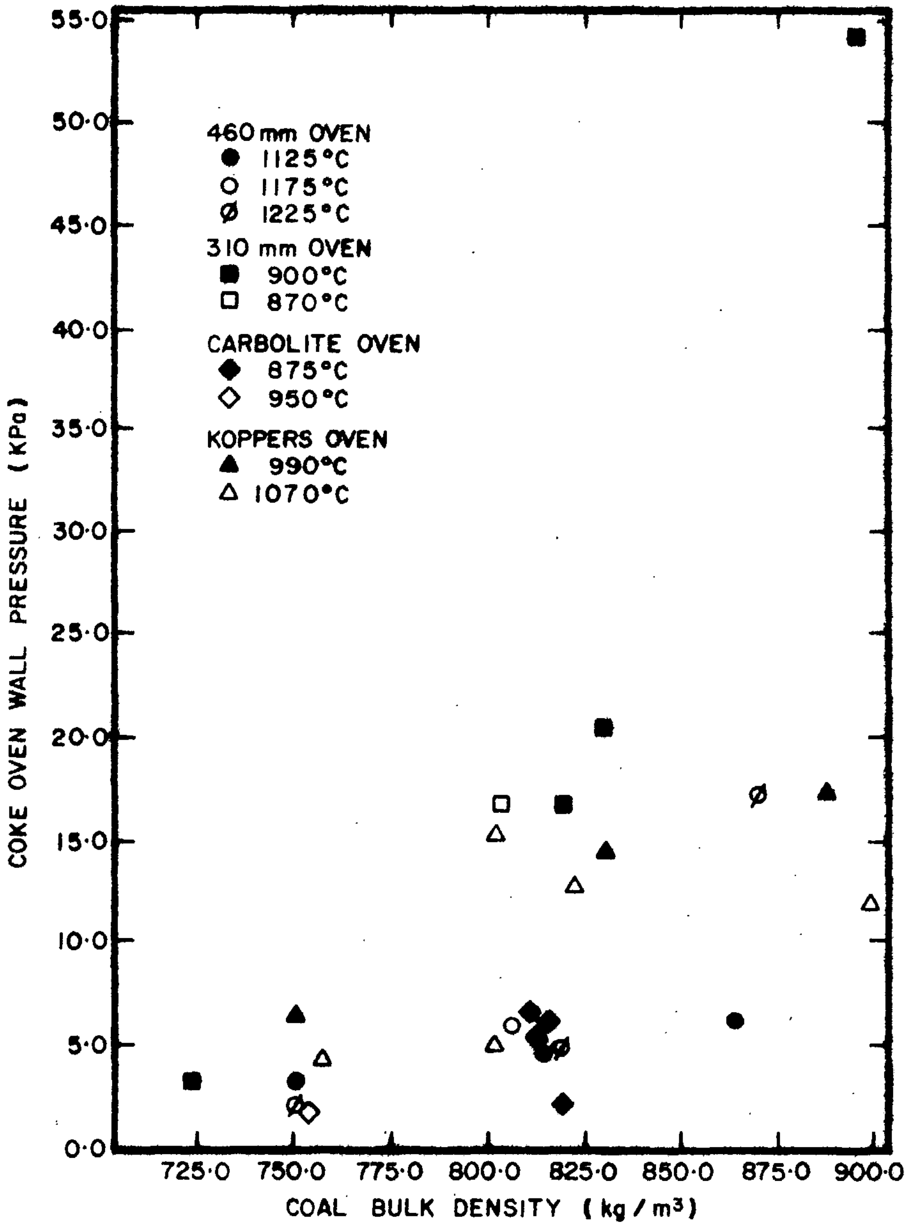

Fig. 10. Wall pressures obtained for blend C at several bulk densities in different CANMET test ovens.

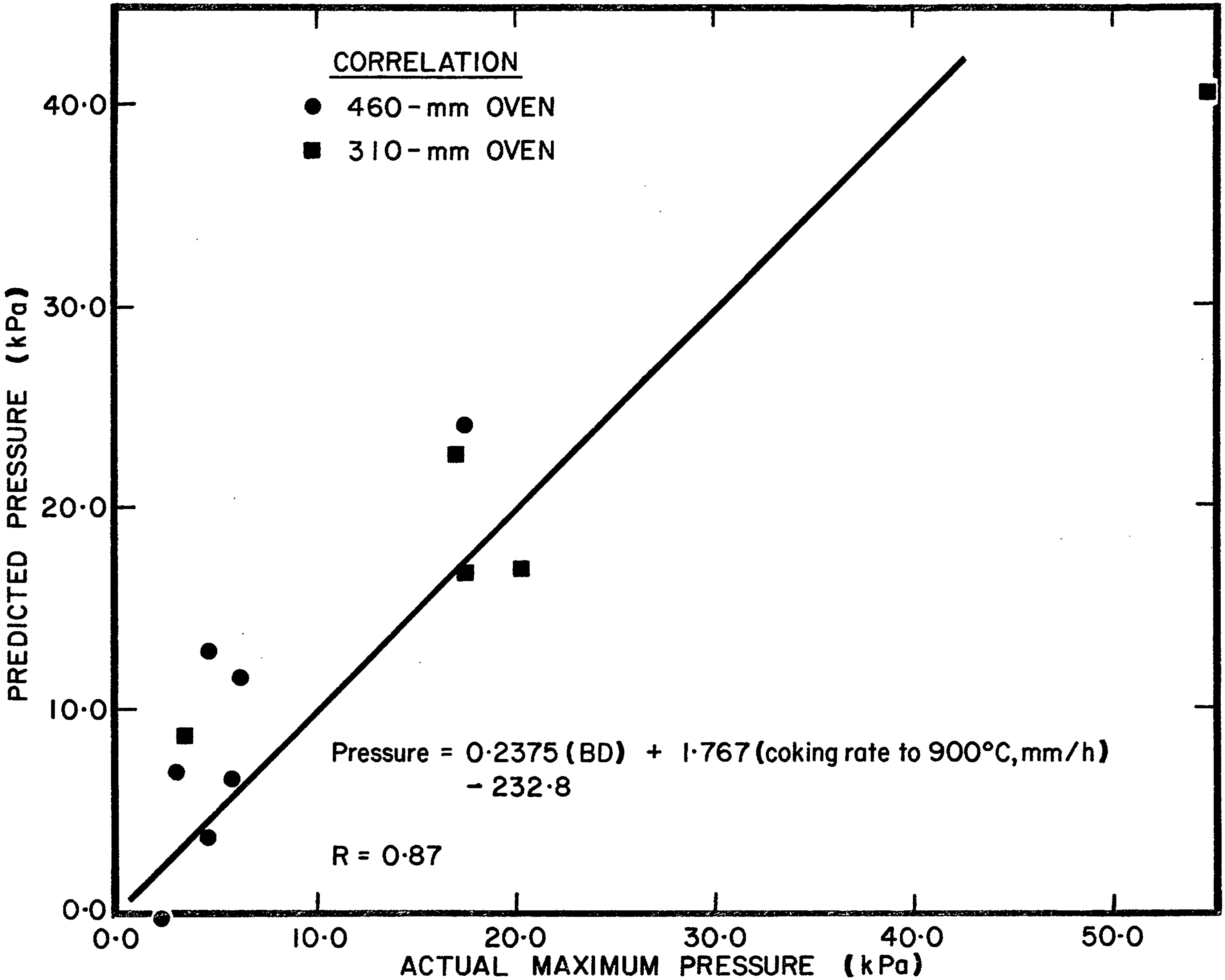

Fig. 11 Comparison of actual and predicted wall pressures from coal bulk densities and heating rates in 460-mm and 310-mm test ovens.

APPENDIX A - Chemical, rheological, petrographic, and size analyses of coal blend C

	Ottawa Results	Edmonton Results	Company C
Proximate Analysis (db)			
Ash	5.7	-	5.4
Volatile Matter	26.4		26.7
Fixed Carbon	67.9		67.9
Ultimate Analysis (db)			
Carbon	83.5		
Hydrogen	5.1		
Sulphur	0.75		0.80
Nitrogen	1.5		
Ash	5.7		
Oxygen (by difference)	3.4		
Gieseler Plasticity			
Start temperature °C	412		
Fusion temperature	425		
Maximum fluid temperature	455		
Final fluid temperature	492		
Solidification temperature	495		
Melting range	80		
Maximum fluidity (ddpm)	1642		
Dilatation			
Softening temperature °C	375		
Maximum contraction temp.	421		
Maximum dilatation temp.	466		
Contraction %	25		
Dilatation %	109		
Free Swelling Index	8		
Grindability Index			
Hardgrove index	82		
Blend Pulverization			
+12.7 mm	3.1		
12.7 x 6.3 mm	9.5	3.1	6.9
6.3 x 3.2 mm	9.7	8.0	
3.2 x 1.6 mm	13.6	16.1	
1.6 x 0.84 mm	17.6	17.5	
% passing 0.84 mm	46.5	55.3	
% passing 3.2 mm	77.7	88.9	73.9

APPENDIX A - Cont'd

Petrographic Analysis	
Distribution of V types	
V7	-
V8	-
V9	16.2
V10	25.1
V11	9.6
V12	5.2
V13	-
V14	2.2
V15	4.4
V16	9.6
V17	1.5
Reactive Components	
Total vitrinite	64.2
Reactive semi-fusinite	4.5
Exinite	5.1
Total	73.8
Inert Components	
Inert semi-fusinite	9.1
Micrinite/coke	7.7/1.2
Fusinite	4.9
Mineral matter	3.3
Total	26.2
Petrographic Indices	
Mean reflectance	1.19
Balance index	1.09
Strength index	4.76
Stability index	61.8

APPENDIX B - Properties of Company C coke

Table B-1 - Coke tumble tests and apparent specific gravity of industrial wharf coke

	Testing Laboratory			
	Ottawa	Edmonton	Company C	
ASTM stability factor			Research	Control Lab
	58.3 56.8	57.6 57.2	56.3 56.0	59.5 62.9
	57.5 55.8	55.8 57.4	55.7 56.4	62.3 62.0
	57.5 57.4	57.6 57.8	55.6	61.7
	55.8 56.6	57.6 57.4	57.8	62.9
	57.0 56.8	57.1 56.8		
Mean	56.9	57.2	56.3	61.9
Standard deviation	0.78	0.58	0.80	1.26
ASTM hardness factor	67.0 67.4	65.4 67.3		
	66.9 67.8	66.9 66.8		
	67.0 66.6	66.4 67.0		
	66.2 67.4	66.7 67.1		
	65.0 65.4	65.6 67.0		
Mean	66.7	66.6		
Standard deviation	0.90	0.64		
Modified JIS tumbler				
DI^{30}_{15}	94.5 95.1	94.6 94.8		
	95.0 94.6	94.7 94.5		
	94.3 95.1	94.1 94.5		
	93.5 94.1	94.3 94.6		
	95.0 93.9	94.6 94.3		
Mean	94.5	94.5		
Standard deviation	0.56	0.21		
JIS DI^{150}_{15}	84.1 84.4	84.7 85.2		
	84.2 83.9	83.5 83.8		
	83.2 84.4	83.5 83.6		
	82.4 83.0	84.1 83.4		
	84.4 84.3	84.3 83.8		
Mean	83.8	84.0		
Standard deviation	0.71	0.59		

APPENDIX B - Cont'd

	Ottawa	Edmonton	Company C Research	Control Lab
Half micum test				
M_{40}		71.3		
		72.4		
		72.0		
Mean		71.9		
Range		1.1		
M_{10}		6.9		
		6.9		
		6.8		
Mean		6.9		
Range		0.1		
Half Irsid Test				
I_{40}		47.9		
		46.4		
		50.4		
Mean		48.2		
Range		4.0		
I_{20}		75.8		
		72.5		
		76.1		
Mean		74.8		
Range		3.6		
I_{10}		21.4		
		20.9		
		20.3		
Mean		20.9		
Range		1.1		

APPENDIX B - Cont'd

	Ottawa		Edmonton			Company C	
Apparent specific gravity	0.921	0.909	0.903	0.907	0.919	-	-
	0.916	0.906	0.914	0.929	0.915	-	-
	0.902	0.931	0.912	0.910		-	-
	0.894	0.911	0.924	0.924		-	-
	0.914	0.923	0.902	0.923		-	-
Mean	0.913		0.915				
Standard deviation	0.011		0.009				
Strength After Reaction Test							
Reaction percent	23.5		-			-	-
	24.0		-			-	-
SAR	65.9		-			-	-
	63.9						

Table B-2 - ASTM tumbler results for the industrial blast furnace coke

	Testing Laboratory	
	Ottawa	Company C
ASTM STability Factor		
	58.64	
	58.23	
	58.50	
Mean	58.5	64.0
σ	0.21	

Table B-3 - Size analysis of industrial cokes

Size (mm)	Ottawa	Edmonton	Company C
	WHARF COKE		
	Testing Laboraotry Results (cumulative %)		
+102	4.2	-	
+ 89	-	-	
+ 76	28.7	26.9	
+ 51	74.0	71.5	
+ 38	89.0	88.5	
+ 25	96.2	94.8	
+ 19	97.0	96.1	
+ 12.7	97.5	96.8	
- 12.7	2.5	3.2	
	BLAST FURNACE COKE		
+102	1.3	-	
+ 89	-		
+ 76	9.6		
+ 51	44.6		
+ 38	69.8		
+ 25	85.8		
+ 19	88.0		
+ 12.7	89.7		
- 12.7	10.3	-	

APPENDIX C - Carbonization test results from coal blend C

Test Identification Number	18-504	18-514	18-505	18-508	18-512	18-509
Date of Test						
Laboratory Number						
Description	Ottawa 460-mm oven					
CARBONIZATION CONDITIONS						
Net Weight of Charge (wet) .... lb						
Moisture in Charge .... %	5.9	4.2	3.1	5.9	4.2	3.6
ASTM Bulk Density (wet) .. kg/m^3 lb/ft^3	665.6	730	778	669	734	797
Calc. Charge Bulk Den . in Oven (db) kg/m^3	750	814	864	763	806	867
Flue Temp. Control .... °C	1125°C	1125°C	1125°C	1175°C	1175°C	1175°C
CARBONIZATION RESULTS						
Gross Coking Time .... hr:min	20:05	20:35	21:00	21:00	19:40	21:45
Final Centre Temperature .... °C	975°C	950°C	950°C	1004°C	993°C	1015°C
Coking Time to Centre Temp .... 900°C	17:45	19:00	19:20	16:40	15:55	17:15
Coking Time to Centre Temp .... 1000°C	-	-	-	-	-	-
Maximum Wall Pressure .... kPa	3.17	4.69	6.06	-	5.93	0.86
Coke Yield Actual .... %	74.1	74.5	75.0	73.2	-	-
Mean Coke Size .... mm	70.9	70.1	70.9	66.8	67.8	66.3
Apparent Specific Gravity	0.825	.868	0.88	0.847	0.869	0.907
Screen Analysis of Coke						
(cumulative percentage retained on)						
3 inch sieve 76 mm	37.0	37.4	39.3	32.2	35.3	30.8
2 inch sieve 51 mm	80.1	79.5	80.4	75.3	75.5	73.3
1 1/2 inch sieve 38 mm	91.6	91.6	91.7	90.3	89.3	90.2
1 inch sieve 25 mm	96.0	96.2	95.9	95.8	95.6	96.0
3/4 inch sieve 19 mm	96.9	96.9	96.7	96.5	96.5	96.8
1/2 inch sieve 12.7 mm	97.5	97.6	97.2	97.2	97.2	97.5
Percentage -12.7 mm (breeze)	2.5	2.4	2.8	2.8	2.8	2.5
Tumbler Test (ASTM)						
Stability Factor	55.5	58.8	61.4	55.8	59.0	60.0
Hardness Factor	60.2	63.6	65.9	61.9	64.4	65.3
Japanese Drum Test (JIS)						
(cumulative percentage retained on)	* **	* **	* **	* **	* **	* **
15 mm Sieve	94.2 83.1	94.4 83.6	95.2 85.5	94.2 82.4	95.0 84.5	95.6 87.9

*30 revolutions; **150 revolutions

Test Identification Number	18-510	18-515	18-511	12-819	12-818	12-820	12-831	12-832	12-835
Data of Test									
Laboratory Number									
Description	Ottawa 460-mm oven			Ottawa 310-mm oven					
CARBONIZATION CONDITIONS									
Net Weight of Charge (wet) .... lb									
Moisture in Charge .... %	6.0	4.1	3.0	0.8	3.1	5.9	3.5	3.0	3.0
ASTM Bulk Density (wet) .... kg/m^3	672	730	784	872	778	669	776	792	792
Calc. Charge Bulk Den . in Oven (db) kg/m^3	748	819	870	898	803	723	803	819	830
Flue Temp. Control .... °C	1225°C	1225°C	1225°C	900°C	900°C	900°C	871°C	900°C	900°C
				+19°C/h	+19°C/h	+19°C/h	+19°C/h	+19°C/h	+19°C/h
CARBONIZATION RESULTS									
Gross Coking Time .... hr:min	18:40	18:50	21:40	10:05	9:40	9:00	10:25	10:20	9:45
Final Centre Temperature .... °C	1040°C	1032°C	1065°C	1071°C	1060°C	1071°C	1060°C	1080°C	1060°C
Coking Time to Centre Temp .... 900°C	14:55	15:40	16:10	9:00	-	7:45	9:10	8:50	8:45
Coking Time to Centre Temp .... 1000°C	-	-	-	-	-	-	-	-	-
Maximum Wall Pressure .... kPa	2.14	4.82	17.4	54.7	-	3.4	17.2	17.2	20.6
Coke Yield Actual .... %	74.5	74.2	73.8	75.7	75.7	76.1	75.1	75.7	75.9
Mean Coke Size .... mm	62.7	62.5	62.2	52.8	55.9	55.4	60.2	55.9	55.1
Apparent Specific Gravity	.835	.876	0.90	0.935	0.881	0.843	0.873	0.900	0.897
Screen Analysis of Coke									
(cumulative percentage retained on)									
3 inch sieve 76 mm	24.1	23.3	24.3	6.2	10.5	10.7	17.2	10.3	9.0
2 inch sieve 51 mm	70.2	70.4	68.5	52.1	60.4	58.8	69.0	60.0	58.5
1 1/2 inch sieve 38 mm	88.3	88.7	88.1	81.3	85.3	82.6	87.7	85.3	84.6
1 inch sieve 25 mm	95.3	96.2	95.8	95.6	94.9	95.0	95.9	95.5	95.4
3/4 inch sieve 19 mm	96.4	97.0	96.7	97.1	96.3	96.2	96.8	96.7	96.5
1/2 inch sieve 12.7 mm	97.2	97.7	97.4	97.6	97.1	97.1	97.5	97.5	97.4
Percentage -12.7 mm (breeze)	2.8	2.3	2.6	2.4	2.9	2.9	2.5	2.6	2.6
Tumbler Test (ASTM)									
Stability Factor	55.8	59.1	61.3	60.1	56.4	53.8	56.2	57.9	59.2
Hardness Factor	61.6	64.5	67.6	69.8	65.5	63.0	65.3	66.6	67.3
Japanese Drum Test (JIS)									
(cumulative percentage retained on)	* **	* **	* **	* **	* **	* **	* **	* **	* **
15 mm Sieve	94.0 81.8	94.6 83.3	95.2 84.9	94.6 84.3	94.7 86.0	94.0 81.9	94.4 84.5	94.6 84.3	94.8 84.4

*30 revolutions; **150 revolutions

Test Identification Number	C-75	C-77	C-78	C-79	C-80	C81	C-83	C-91
Date of Test	Dec. 11/81	Jan. 22/81	Jan. 27/81	Feb. 3/81	Feb. 10/81	Feb. 17/81	Feb. 26/81	Mar. 26/81
Laboratory Number								
Description	Carbolite Test Oven							
CARBONIZATION CONDITIONS								
Net Weight of Charge (wet) .... kg	298.6	316.5	278.6	297.2	296.1	297.3	297.1	295.3
Moisture in Charge .... %	3.3	1.9	4.7	3.5	3.5	3.3	3.6	3.2
ASTM Bulk Density (wet) .. kg/m^3 lb/ft^3	774	856	704	781	792	795	785	787
Calc. Charge Bulk Den . in Oven (db) kg/m^3	819	882	754	814	811	816	813	811
Flue Temp. Control .... °C	975+15°/h to 1130°C	950+10.5°/h to 1130°C	950+10.5°/h to 1130°C	900+17°/h to 1206°C	875+75°/h to 1130°C	875+15°/h to 905+75°/h to 1130°C	875+30°/h to 1130°C	950+30°/h to 1130°C
Charge Push (Centre temp + soak time) °C-hr	950 + 3	950 + 3	950 + 3	950 + 3	950 + 3	950 + 3	950 + 3	950 + 3
Conditioning Drop After Push .... ft	10	10	10	10	10	10	10	10
CARBONIZATION RESULTS								
Gross Coking Time .... hr:min	19:07	18:05	17:21	17:28	15:51	16:40	16:59	15:49
Final Centre Temperature .... °C	1031	1045	1047	1091	1064	1055	1044	1063
Coking Time to Centre Temp .... 900°C	15:20	14:39	14:02	14:12	12:27	12:54	13:37	12:32
Coking Time to Centre Temp .... 1000°C	17:17	15:59	15:14	14:58	13:29	13:57	14:41	13:21
Maximum Wall Pressure .... kPa	2.20		1.93	5.37	6.75	6.13	5.51	6.3
Coke Yield Actual .... %	72.6	74.0	74.7	74.9	74.7	74.3	74.6	74.1
Mean Coke Size .... mm	62.7	58.4	61.2	61.2	52.3	55.6	59.7	58.4
Apparent Specific Gravity	0.90	0.95	0.86	0.93	0.90	0.91	0.91	0.90
Screen Analysis of Coke (cum % retained on)								
4 inch sieve .... 100 mm	2.1	2.4	3.0	2.9	0.6	1.4	0.3	2.0
3 inch sieve .... 75 mm	21.9	15.4	19.3	16.7	4.9	7.6	14.1	13.2
2 inch sieve .... 51 mm	75.6	63.1	70.2	71.6	47.9	60.3	71.1	66.9
1 1/2 inch sieve .... 38 mm	90.3	87.3	89.3	90.7	84.6	86.1	91.2	86.9
1 inch sieve .... 25 mm	95.3	94.8	95.4	46.1	95.0	95.4	96.1	95.3
3/4 inch sieve .... 19 mm	96.4	96.3	96.3	96.9	96.6	96.8	96.9	96.6
1/2 inch sieve .... 12.7 mm	97.1	97.1	97.0	97.5	97.4	97.6	97.5	97.4
Percentage - 1/2 inch (breeze) ... -12.7 mm	2.9	2.9	3.0	2.5	2.6	2.4	2.5	2.6
Tumbler Test (ASTM)								
Stability Factor	60.8	60.7	55.4	59.2	55.8	56.7	58.5	55.6
Hardness Factor	66.9	69.5	63.8	68.3	67.9	68.1	67.5	68.2
Japanese Drum Test (JIS)								
(cumulative percentage retained on)	* **	* **	* **	* **	* **	* **	* **	* **
15 mm Sieve	94.2 84.2	94.2 85.0	94.2 83.1	94.4 83.7	94.3 84.0	94.2 83.4	94.3 83.8	94.2 84.1

*20 revolutions; **150 revolutions

Test Identification Number	K-455	K-450	K-452	K-453	K-454	K-458	K-459
Date of Test	Jan. 27/81	Dec. 16/81	Jan. 14/81	Jan. 20/81	Jan. 22/81	Feb. 12/81	Feb. 19/81
Laboratory Number							
Description				Koppers Test Oven			
CARBONIZATION CONDITIONS							
Net Weight of Charge (wet) kg	169.6	178.0	194.0	168.6	195.6	181.9	184.0
Moisture in Charge %	4.3	3.5	2.0	4.7	1.5	3.2	3.3
ASTM Bulk Density (wet) kg/m^3	722	786	851	712	872	800	800
Calc. Charge Bulk Den . in Oven (db) kg/m^3	757	802	888	750	899	822	830
Flue Temp. Control °C	1072°C	1073°C	990°C	993°C	1081°C	1071°C	989°C
Charge Push (Centre temp + soal time) °C-hr	1010 + 1/2	1010 + 1/2	1010 + 1/2	1010 + 1/2	1010 + 1/2	1010 + 1/2	1010 + 1/2
Coke Conditioning Drop After Push ft	10	10	10	10	10	10	10
CARBONIZATION RESULTS							
Gross Coking Time hr:min	9:29	9:56	12:31	11:26	10:01	9:51	11:35
Final Centre Temperature °C	1043°C	1010+	1023°C	1021°C	1040°C	1052°C	-
Coking Time to Centre Temp 900°C	8:10	8:05	10:24	9:16	8:40	8:41	9:57
Coking Time to Centre Temp 1000°C	8:51	9:20	11:43	10:38	9:25	9:13	10:54
Maximum Wall Pressure kPa	4.27	4.82	17.7	6.55	11.7	12.8	14.4
Coke Yield Actual %	73.8	73.2	73.7	74.1	74.2	73.5	73.6
Mean Coke Size mm	55.6	53.8	63.8	61.5	56.6	54.1	58.7
Apparent Specific Gravity	0.86	0.89	0.94	0.86	0.96	0.90	0.91
Screen Analysis of Coke (cumulative percentage retained on)							
4 inch sieve 100 mm	1.0	0.0	6.8	5.2	0.7	0.8	1.9
3 inch sieve 76 mm	12.8	8.8	25.6	20.6	12.4	6.6	16.5
2 inch sieve 51 mm	57.0	55.2	70.1	69.2	59.1	50.8	64.3
1 1/2 inch sieve 38 mm	82.8	83.0	87.9	86.6	87.5	84.3	85.1
1 inch sieve 25 mm	94.3	94.2	95.5	94.6	95.4	94.9	95.4
3/4 inch sieve 19 mm	96.1	96.1	96.9	96.0	96.8	96.2	96.7
1/2 inch sieve 12.7 mm	97.0	97.0	97.5	96.9	97.6	97.0	97.5
Percentage -12.7 mm (breeze)	3.0	30.	2.5	3.1	2.4	3.0	2.5
Tumbler Test (ASTM)							
Stability Factor	55.4	57.7	59.8	57.0	57.8	56.1	59.4
Hardness Factor	64.7	66.7	63.6	64.4	67.3	67.8	67.7
Japanese Drum Test (JIS) (cumulative percentage retained on)	* **	* **	* **	* **	* **	* **	* **
15 mm Sieve	94.0 82.5	94.6 83.6	94.9 84.1	94.5 82.9	94.5 83.4	94.2 83.8	94.6 84.2

*30 revolutions; **150 revolutions