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COMPARISONS OF COKE PRODUCED IN DIFFERENT CANMET COKE OVENS: PART 1: 12- AND 18-INCH OVEN COKE STRENGTHS

W.R. Leeder and J.T. Price

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by

W.R. Leeder* and J.T. Price*

ABSTRACT

The Coal Resource and Processing Laboratory (CRPL), formerly known as the Canadian Metallurgical Fuels Research Laboratory (CMFRL), operates 12-inch, 18-inch and Koppers technical-scale movable-wall ovens. Each oven uses different standard conditions in order to produce coke of similar quality to that produced by industrial coke ovens. This report summarizes a number of tests carried out in more than one CRPL oven with the same coking coals or blends to determine how the quality of coke produced from one oven relates to that from the others. Regression analyses indicate that ASTM coke stabilities, ASTM coke hardnesses, and JIS DI^{30}_{15} coke tumbler test indices can be related linearly for any pair of ovens. Cokes produced from the same coal blend but carbonized in different ovens have similar ASTM stabilities. The ASTM hardness values are similar for cokes from the Koppers and 12-inch ovens but these values are consistently higher than hardnesses for cokes from the 18-inch oven.

*Research Scientists, Coal Resource and Processing Laboratory (formerly Canadian Metallurgical Fuels Research Laboratory), Energy Research Laboratories, CANMET, Department of Energy, Mines and Resources, Ottawa, Ontario.

COMPARAISONS ENTRE DU COKE PRODUIT DANS DIFFERENTS FOURS A COKE DE CANMET: 1ere PARTIE: RESISTANCE DU COKE DANS DES FOURS A COKE DE 12 ET 18 POUCES

par

W.R. Leeder* et J.T. Price*

SOMMAIRE

Au Laboratoire du traitement et des ressources en charbon (CRPL), anciennement le Laboratoire canadien de recherche sur les combustibles métallurgiques (CMFRL), on opère, à l'échelle industrielle, des fours à parois mobiles de 12 et 18 pouces et des fours de Koppers dans différentes conditions normales requises pour produire du coke d'une qualité analogue à celle du coke obtenu des fours à coke commerciaux. Ce rapport résume, donc, un certain nombre d'essais exécutés dans plus d'un four du CRPL utilisant le même charbon cokéfiant ou mélange, dans le but de connaître la relation qui existe entre la qualité du coke produit par un four et celle du coke des autres fours. Les auteurs ont établi un graphique afin de comparer la stabilité ASTM, la dureté ASTM et les résultats de l'essai JIS DI_{15}^{30} du coke dans un culbuteur pour tous les fours et ils ont soumis les résultats à une analyse de régression pour obtenir les équations linaires des moindres carrés.

*Chercheurs scientifiques, Laboratoire du traitement et des ressources en charbon (anciennement le Laboratoire canadien de recherche sur les combustibles métallurgiques), Laboratoires de recherche sur l'énergie, CANMET, Ministère de l'Energie, des Mines et des Ressources, Ottawa, Ontario.

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1. INTRODUCTION

The Coal Resource and Processing Laboratory (CRPL) operates four technical-scale coke ovens(1). It is generally recognized that ovens of this scale are required for a realistic interpretation of coking propensities of coals from new sources, particularly when there has been no prior history of their use for the manufacture of conventional coke. Several types of ovens are used at CRPL to carry out carbonization research in an effort to expand and conserve the Canadian coking resource, and are relied upon almost exclusively by Canadian mining companies, commercial cokemakers and governments in evaluating coking coals. Each type of oven has been run using different experimental conditions in an attempt to produce coke of similar strength to commercial coke, although other coke properties may change(2). Coke strength is used as the criterion for standardizing ovens since it is considered the most important coke quality parameter(3). The object of this study was to determine if CANMET ovens produce cokes of equivalent strength and to provide a basis for relating these experimental results. This is the first of several reports to consider the differences in the properties of cokes produced from these ovens so that all CRPL oven results can be compared and used with confidence. The conclusions from these reports should be useful to outside organizations wishing to interpret results obtained from CRPL or other technical-scale coke ovens.

The four technical-scale slot-type coke ovens operated by CRPL are an 18-in. movable-wall oven, two 12-in. movable-wall ovens, and a smaller 6-in. oven that respectively carbonize about 700, 500 and 30 lb of coal per batch. The 18-in. oven has the same width as commercial slot-type coke ovens, and simulates industrial practice. However, for historical and practical reasons, the 12- and 6-in. ovens are often used to assess coke quality. Early experimental results indicated that a coal carbonized in both the 12- and 18-in. ovens would produce cokes of different strength unless coal carbonizing conditions for the 12-in. oven were altered to compensate for this oven's smaller width. As a result, each coke oven is run at CRPL with its own unique set of operating conditions in an attempt to have all ovens yield the same strength coke from similar coal charges. For example, experience has shown that the 12-in. oven should have its coal charged to a dry oven bulk density of about 51 lb ft^{-3} to produce cokes of similar strength as that produced from the 18-in. oven which charges to a dry oven bulk density of about 46 lb ft^{-3}. However, such differences in carbonizing procedures were decided upon after only a limited number of coals were tested. Consequently some doubt has remained concerning the similarity of the different oven results. To clarify this situation and to gain more confidence in the different oven results, a study was undertaken whereby several different coking coals and coal blends were carbonized in two or more of the four ovens. Part of the study was concerned specifically with any differences in coke strength that might occur because the coal was coked in different ovens. Strengths were measured using ASTM and a modified JIS coke tumbler tests; the former is mainly of interest to Canadian steel producers and the latter to Canadian coke exporters. In this report coke strengths are compared graphically for all pairs of 18- and 12-in. ovens, and linear regression relationships are derived to determine if different ovens produced cokes of similar strength. Comparisons of the smaller 6-in. oven with the 12- or 18-in. ovens will appear in a future report.

2. EXPERIMENTAL

This section contains the following: a brief description of the 12- and 18-in. technical-scale coke ovens used by CRPL to prepare the coke for this study; details of ASTM and JIS coke tumbler test methods used at CRPL to assess coke strength; and statistical methods used to compare different coke oven coke strength results.

2.1 CRPL Coke Preparation

This section describes the 12- and 18-in. coke ovens and the operating procedures that have been used at CRPL.

Coke is produced in two 12-in. ovens; one in Ottawa which is electrically-heated, while the other is a Koppers gas-fired oven located in Edmonton. The electrically-heated 12-in. oven has a coking chamber about 12-in. wide, two end doors, "Globar" resistance elements that maintain desired oven flue temperatures, silicon carbide refractories and is discharged with a pusher machine. The oven is charged with approximately 500 lb of coal, whose moisture content has been adjusted to yield an oven dry charge bulk density of about 51 lb ft^{-3}. The flue temperature is preset at 900°C and it is increased to 1066°C at a rate of 19.44°C hr^{-1} after the coal is charged. This simulates the heating cycle found in a commercial-scale 18-in. slot-type coke oven using silica refractories. The gas-fired Koppers oven has a coking chamber about 12 inches wide, silica brick refractories and is equipped with a single end door from which the resultant coke is raked. This oven is charged with approximately 400 lb of coal whose moisture content has been adjusted to give an oven dry charge bulk density of about 51 lb ft^{-3}. The flue temperature is maintained at 1077°C during the entire coking period.

The electrically-heated 18-in. oven has a coking chamber about 18 in. wide, a horse-shoe shaped device that closes the side and top of the oven, "Globar" resistance elements that maintain desired oven flue temperatures and silicon carbide refractories. It is discharged with a pusher machine. The oven is charged with approximately 700 lb of coal whose moisture content had been adjusted to yield an oven dry bulk density of 51 lb ft^{-3} before, and 46 lb ft^{-3} after 1973. As is the case for the electrically-heated 12-in. oven, the flue temperature is preset at 900°C and after the coal is charged the temperature is increased to 1066°C at a rate of 12.22°C hr^{-1}.

The resultant coke from the 12- or 18-in. ovens is pushed out of the oven 0.5 hr after the centre temperature of the charge has reached 1010°C; it is cooled immediately with water in a "quench" box and dropped 10 ft to a concrete floor to simulate coke handling in a commercial plant. It is then dried and finally screened for testing.

2.2 CMFRL Tumbler Tests

Normally each technical-scale coke oven test provides sufficient coke to carry out both the ASTM and JIS coke tumbler tests. The coke used in these tests is hand-picked to remove door pieces. If sufficient coke of the size to be tested (2 by 3 in.) is not available, then more coke of the correct size is produced by cracking the larger pieces along existing fissures using the tip of a screwdriver. The methods used to carry out the tumbler tests at CRPL are summarized in Appendix A.

2.3 Data and Statistical Methods

The data which appear in Appendix B were obtained from oven correlation tests carried out over a period of years. They include the 1971-1973 tests already reported (4,5), as well as from 1974 and 1975. The 1973-1975 series was fairly extensive to gather sufficient information about performance of the Koppers gas-fired 12-in. oven. In this report the only data from Appendix B used to compare the oven strength results are from tests in which the 18-in. oven bulk densities were near 46 lb ft^{-3} and the Koppers and 12-in. oven bulk densities near 51 lb ft^{-3}. After eliminating results inconsistent because of oxidation, the correlations were calculated from the remaining data as obtained directly from the tumbler tests. No corrections were made for slight differences in oven bulk density or any other factor (e.g., tumbler wear) that might affect the results; any such errors are felt to be within the experimental errors of the test.

The data being compared were plotted and regressed using a Hewlett-Packard 9810A programmable calculator equipped with a 9862A plotter optional accessory. If more than one test were made with the same coal in the same oven, such results were averaged. Plotting allowed areas of deficient data, spreads in data, and slight differences in regression lines to be quickly and easily identified.

The linear regression model was chosen in all cases because there were not sufficient data to make it possible to choose between it and several other mathematical regression models. In a normal least squares regression, it is assumed that most of the error appears in the Y data(6,7). However, in this report it seems reasonable to assume that in comparing the coke tumbler test results of different ovens, the error in X and Y should be approximately equal. For such cases, Visman and Picard derived a modified least squares linear regression method, and it was used in this report for the oven comparison regressions(8). Details of the differences in the mathematical procedures of the normal and modified linear regression methods appear in Appendix C. It should be noted that in cases with a few well-spread points, that the modified method should give a better estimate of the true linear relationship.

Correlation coefficients were used to consider the acceptability of the linear regression equation. If a correlation coefficient was greater than the table correlation coefficient for the degrees of freedom of the regression at the α=0.05 significance level, then the linear model was accepted. The averaging of the repeat runs removed the possibility of calculating the lack of fit and pure error of the regressions, which together would have indicated the adequacy of the linear regression model(7).

3. RESULTS AND DISCUSSION

The results of the studies to determine what, if any, differences occur in the quality of coke produced from the different CANMET technical-scale coke ovens appear in Appendix B. Coke ASTM stabilities and hardnesses factors, and the JIS DI_{15}^{30} indices were used as a measure of coke strength to compare differences in coke quality that may occur between the two 12-in. and 18-in. ovens. The oven results were compared in pairs as seen in Fig. 1 through 9. The linear relationships shown in these figures were derived using the Visman and Picard modified least squares regression method. A summary of the regressions appear in the table, details of which are found in Appendix C.

Stability regression results indicate that acceptable linear models relate this coke quality index for coke from the two 12- and 18-in. ovens. From these analyses it appears that cokes produced from a given coal or coal blend carbonized in either of the 12-in. or 18-in. ovens (using the standardized CRPL oven conditions) should have similar stabilities. This can be seen in Fig. 1, 2 and 3 where the regression lines fall close to the equivalence lines. The relationship derived between the stability of cokes produced in the 12-in. and 18-in. ovens is in agreement with previous studies that used more limited data(4,9), but unlike the previous studies the relationships derived in this work allow direct comparisons to be made of the stabilities obtained from the different CRPL ovens, without applying any correction factors.

Hardness regression results indicate that acceptable linear models can be used to relate this coke quality parameter for coke obtained from the Ottawa 12- and 18-in. and the Koppers gas-fired and Ottawa electrical 12-in. ovens, but little confidence can be placed in the relationship between the Koppers and 18-in. ovens. The 12-in. ovens gave similar hardnesses, seen in Fig. 5, where the regression line falls on top of the equivalence line. This might be expected since both oven coking chambers are 12 in. across and similar coking rates and charge bulk densities were used. However, the regression relationship between the Ottawa 12- and 18-in. ovens, while linear, does not fall near the equivalence line. Figure 4 indicates that the Ottawa 12-in. coke hardness values are greater than the corresponding 18-in. values. Although the linear relationship in Fig. 6 comparing the Koppers (12-in.) and 18-in. oven coke hardnesses is poor because of lack of data, all the Koppers coke hardnesses were also greater than the 18-in. values.

JIS DI_{15}^{30} regression results indicate that acceptable linear models can be used to relate the quality of coke, as defined by this parameter, obtained from the 12- and 18-in. ovens. Figures 7, 8 and 9 indicate a general lack and poor range of data. The regression line for the Ottawa 12- and 18-in. ovens comparison shown in Fig. 7 falls on the equivalence line with the data scattered around the two lines. However, in the electrical versus Koppers 12-in., and 18-in. versus Koppers comparisons (Fig. 8 and 9) the regression lines are unreasonably influenced by a single point, even though the remaining data are scattered around the equivalence line. Further data, particularly for the poorer quality cokes at DI_{15}^{30} values of less than 90, are necessary to define these relationships more clearly.

4. ACKNOWLEDGEMENTS

The authors would like to thank J.C. Botham, Manager, Coal Resource and Processing Laboratory for suggestions and continuing interest, and K.F. Hampel for gathering data and carrying out some of the calculations.

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TABLE 1

Summaries of the Linear Regression Results for Comparing Coke Tumbler Tests and Different CANMET Coke Ovens (Y = A + BX)

A. Stabilities Using the Visman and Picard Modified Regression Method

Fig.	Oven Results for[a] X	Y	N	A	B	R[b]	SE[c]
1	18	12	15	5.51	0.899	0.95 (0.51)	1.7
2	K	12	11	- 3.03	1.07	0.84 (0.60)	3.2
3	18	K	9	- 3.26	1.07	0.83 (0.67)	3.4

B. Hardnesses Using the Visman and Picard Modified Regression Method

Fig.	Oven Results for[a] X	Y	N	A	B	R[b]	SE[c]
4	18	12	15	3.91	1.05	0.82 (0.51)	1.36
5	K	12	10	3.66	0.94	0.7 (0.63)	1.5
6	18	K	8	- 34.3	1.72	0.6 (0.71)	2.8

C. JIS DI_{15}^{30} Using the Visman and Picard Modified Regression Method

Fig.	Oven Results for[a] X	Y	N	A	B	R[b]	SE[c]
7	18	12	13	- 1.60	1.02	0.85 (0.55)	0.89
8	K	12	10	14.8	0.84	0.90 (0.63)	0.70
9	18	K	7	- 38.8	1.42	0.92 (0.75)	1.03

a - K = Koppers gas-fired 12-in. oven
12 and 18 = electrical 12-in. and 18-in. ovens

b - R = correlation coefficient. The value in brackets is the minimum value for significance at the 0.05 level.

c - SE = Standard error

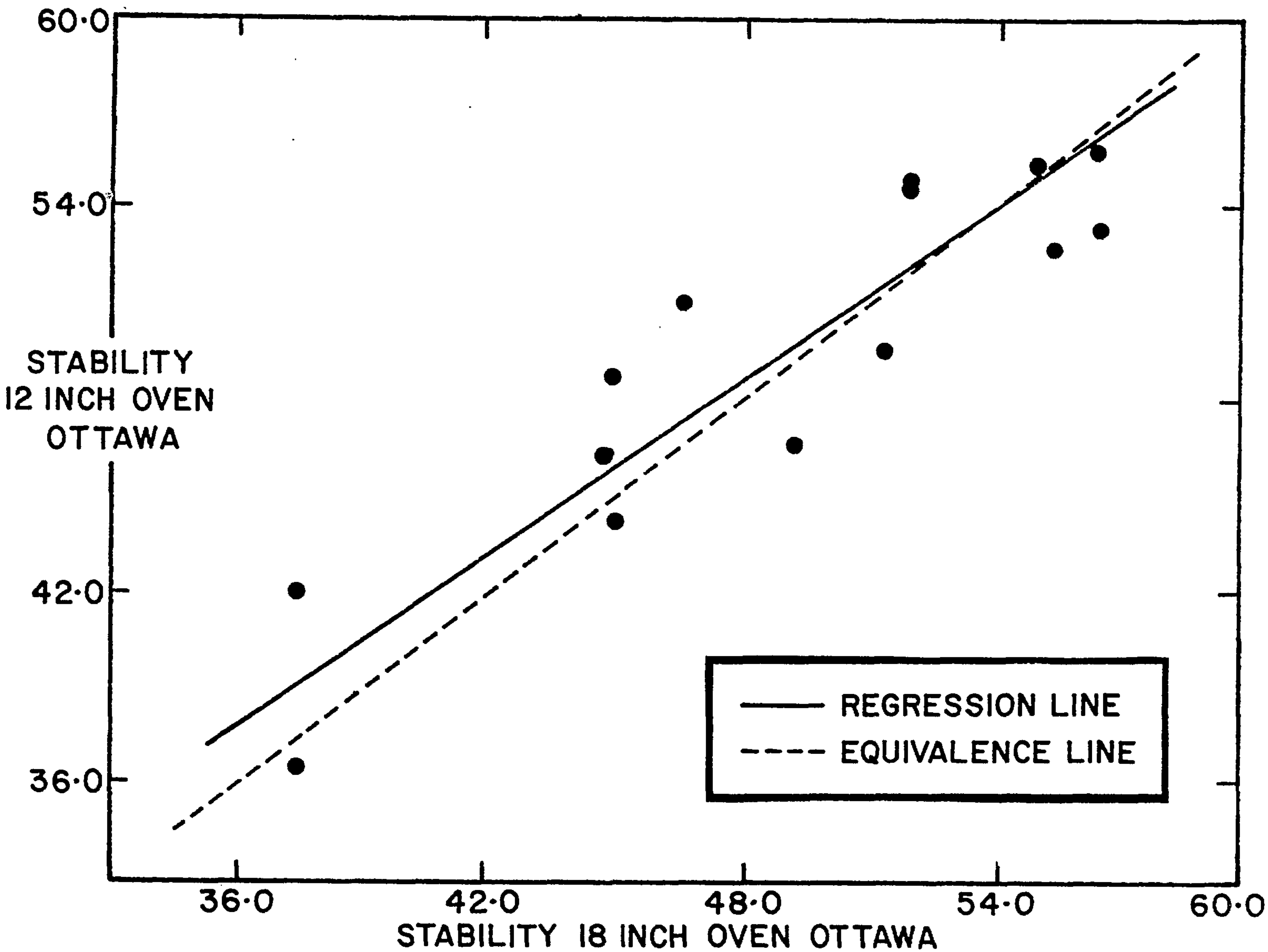

Fig. 1 Comparison of ASTM Stabilities - 12-in. versus 18-in. ovens

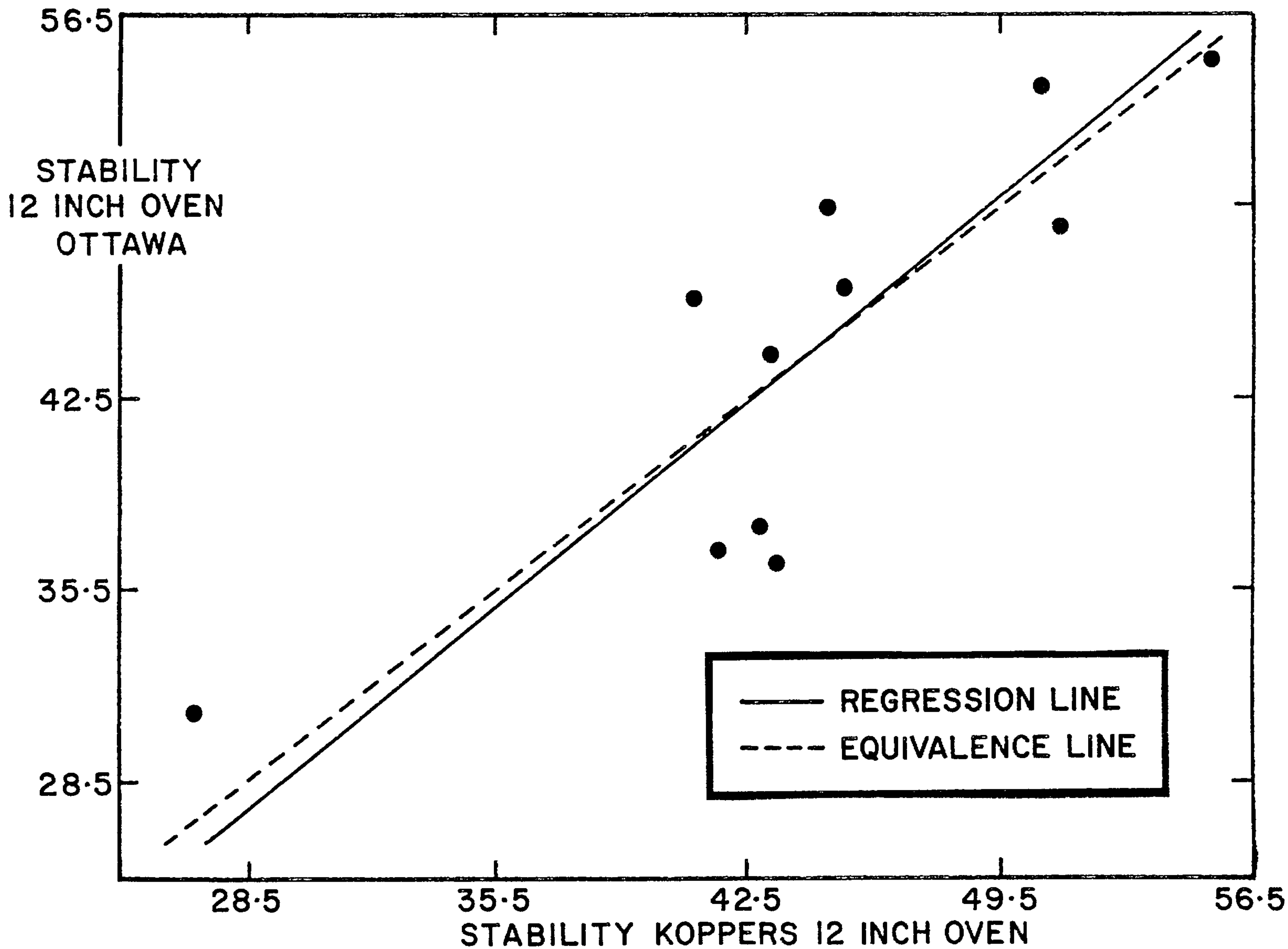

Fig. 2 Comparison of ASTM Stabilities - 12-in. versus Koppers ovens

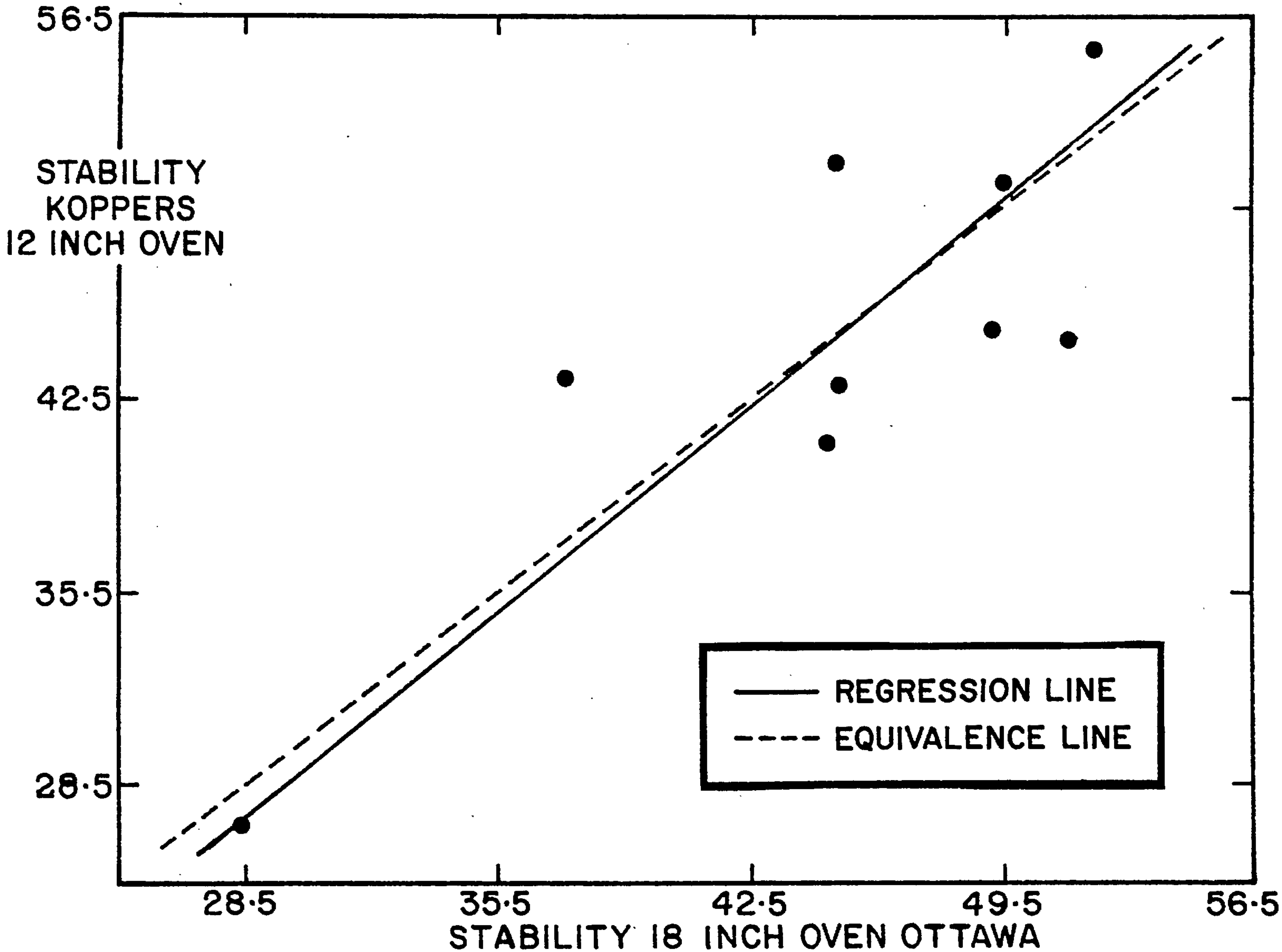

Fig. 3 Comparison of ASTM Stabilities - Koppers versus 18-in. ovens

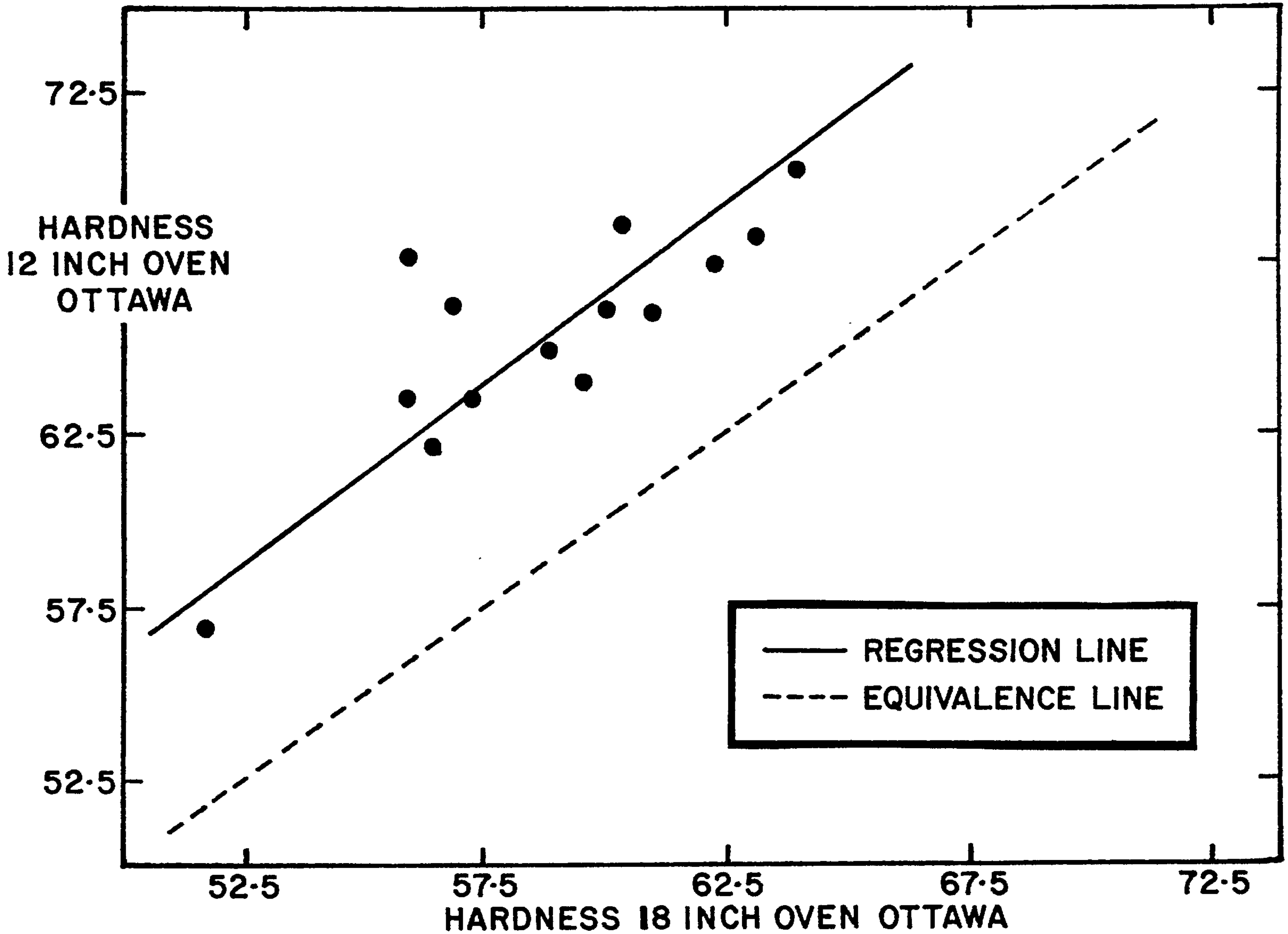

Fig. 4 Comparison of ASTM Hardnesses - 12-in. versus 18-in. ovens

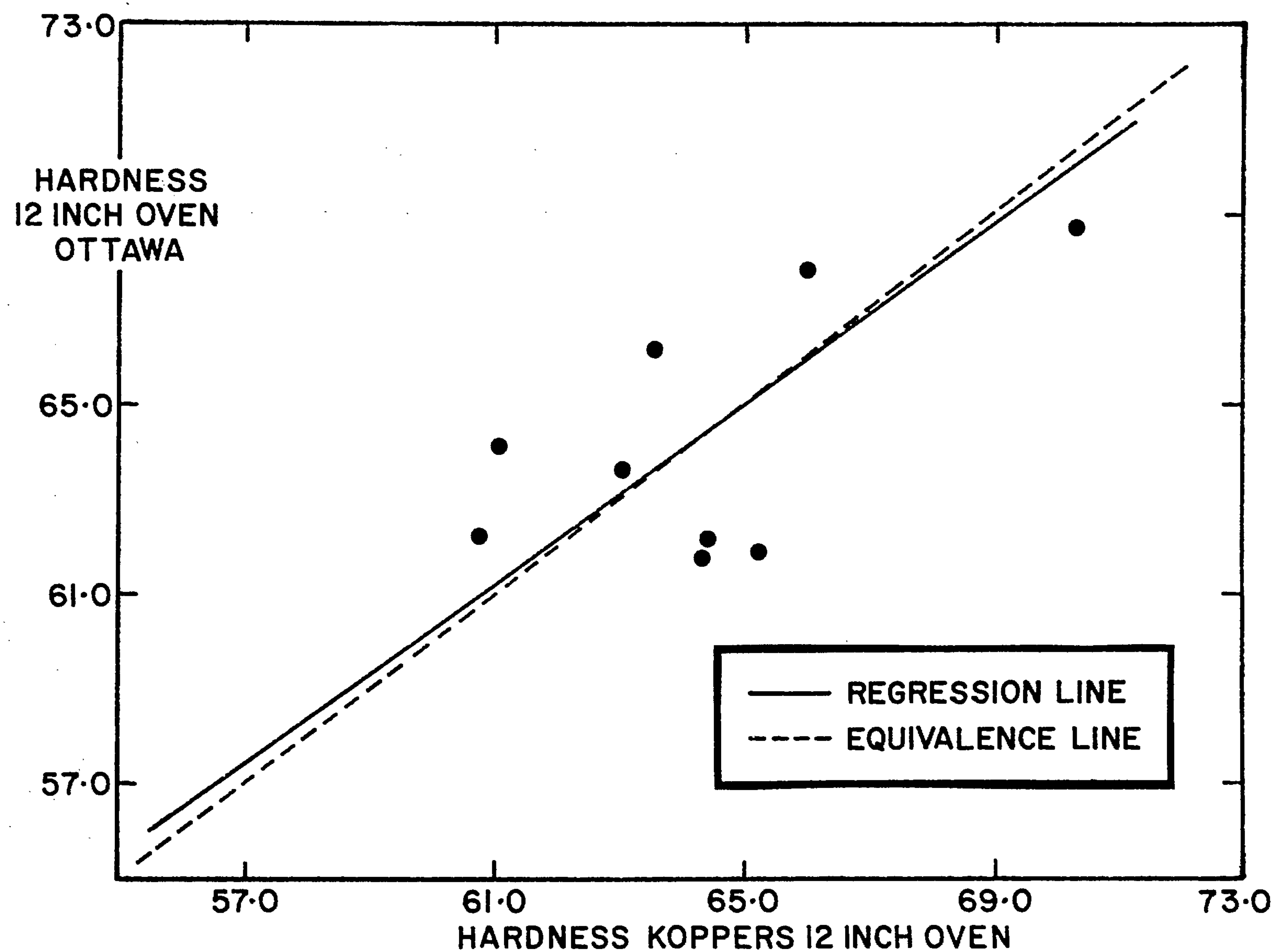

Fig. 5 Comparison of ASTM Hardnesses - 12-in. versus Koppers ovens

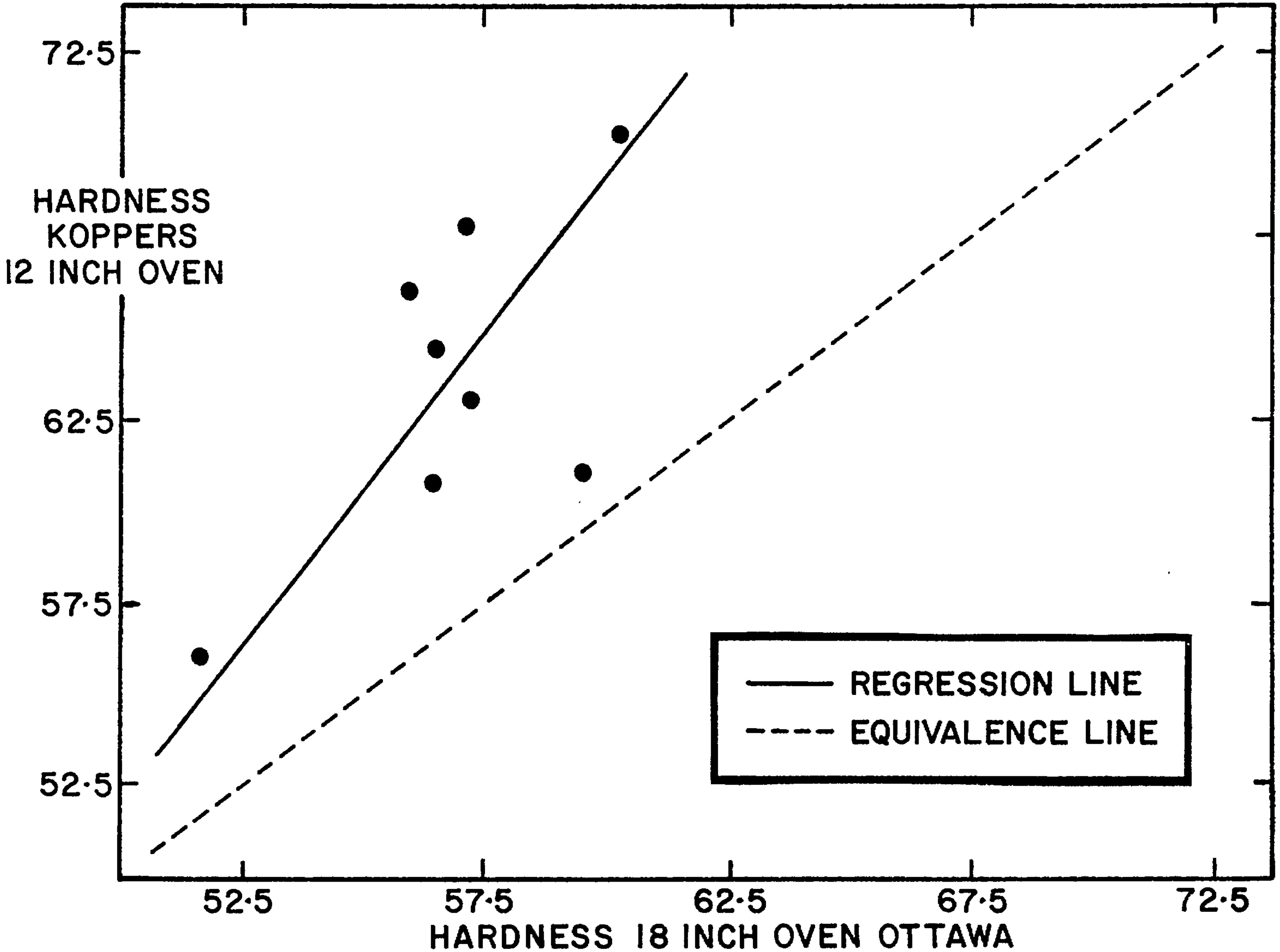

Fig. 6 Comparison of ASTM Hardnesses - Koppers versus 18-in. ovens

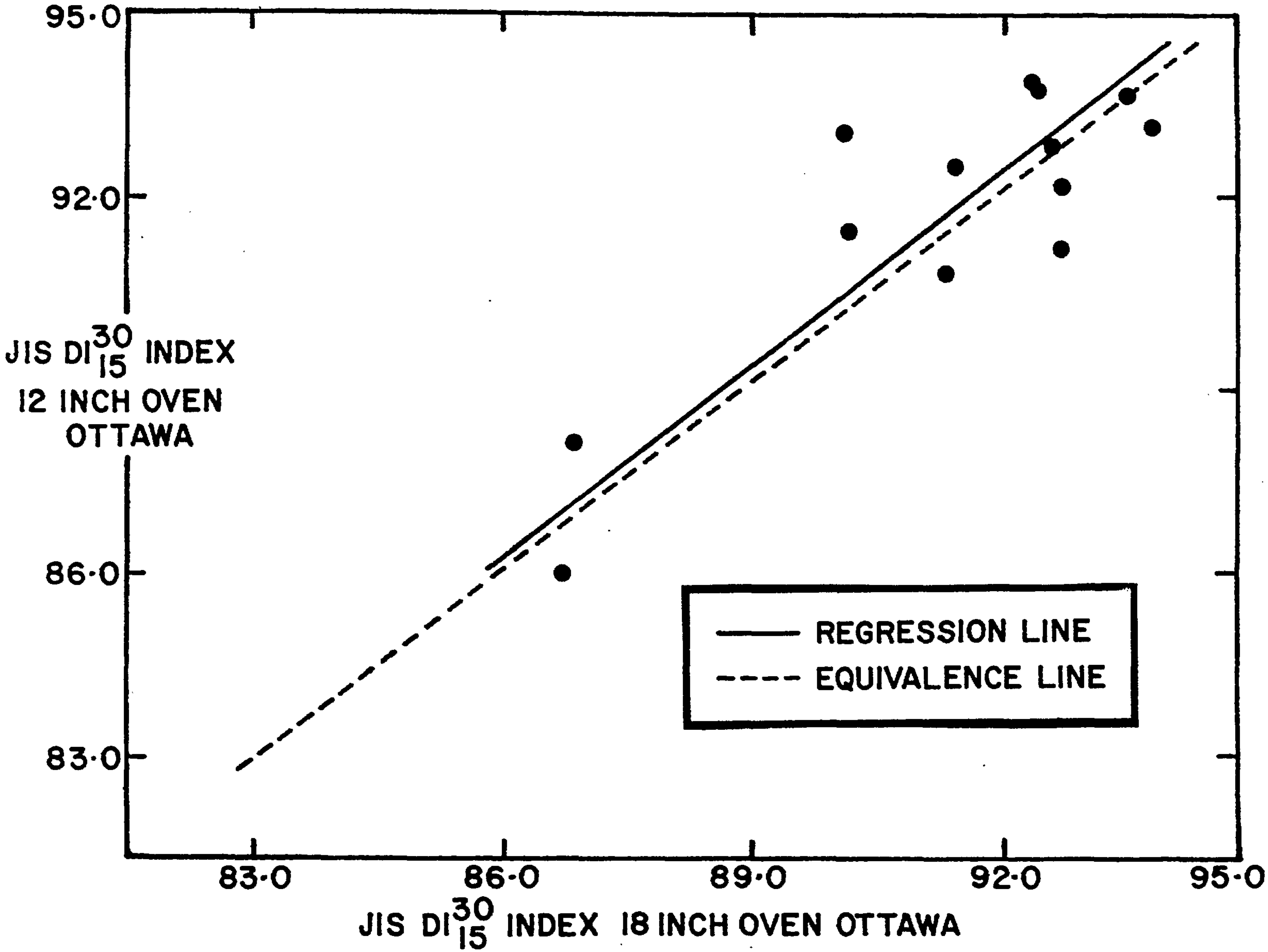

Fig. 7 Comparison of JIS DI_{15}^{30} Indices - 12-in. versus 18-in. ovens

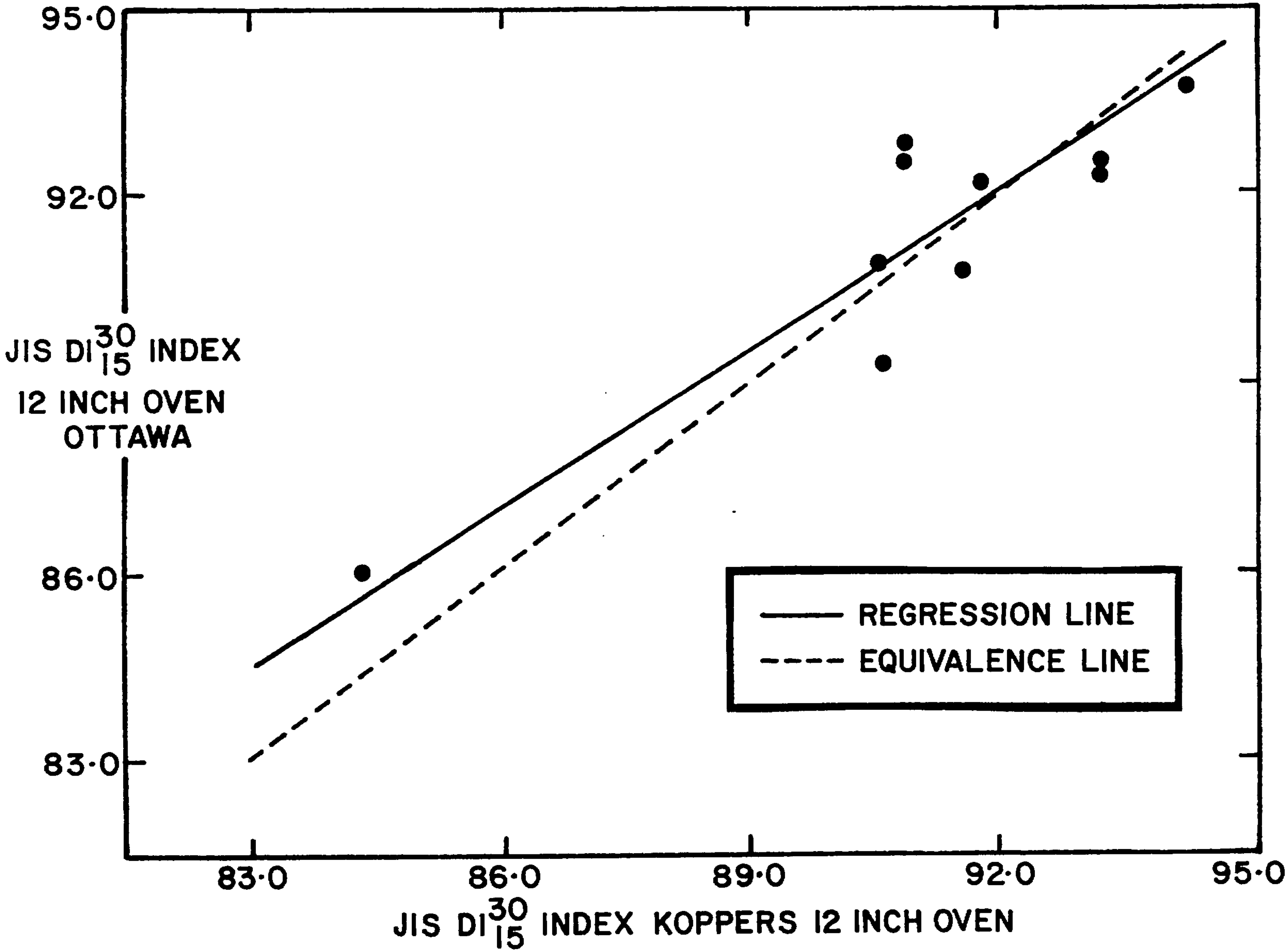

Fig. 8 Comparison of JIS DI^{30}_{15} Indices - 12-in. versus Koppers ovens

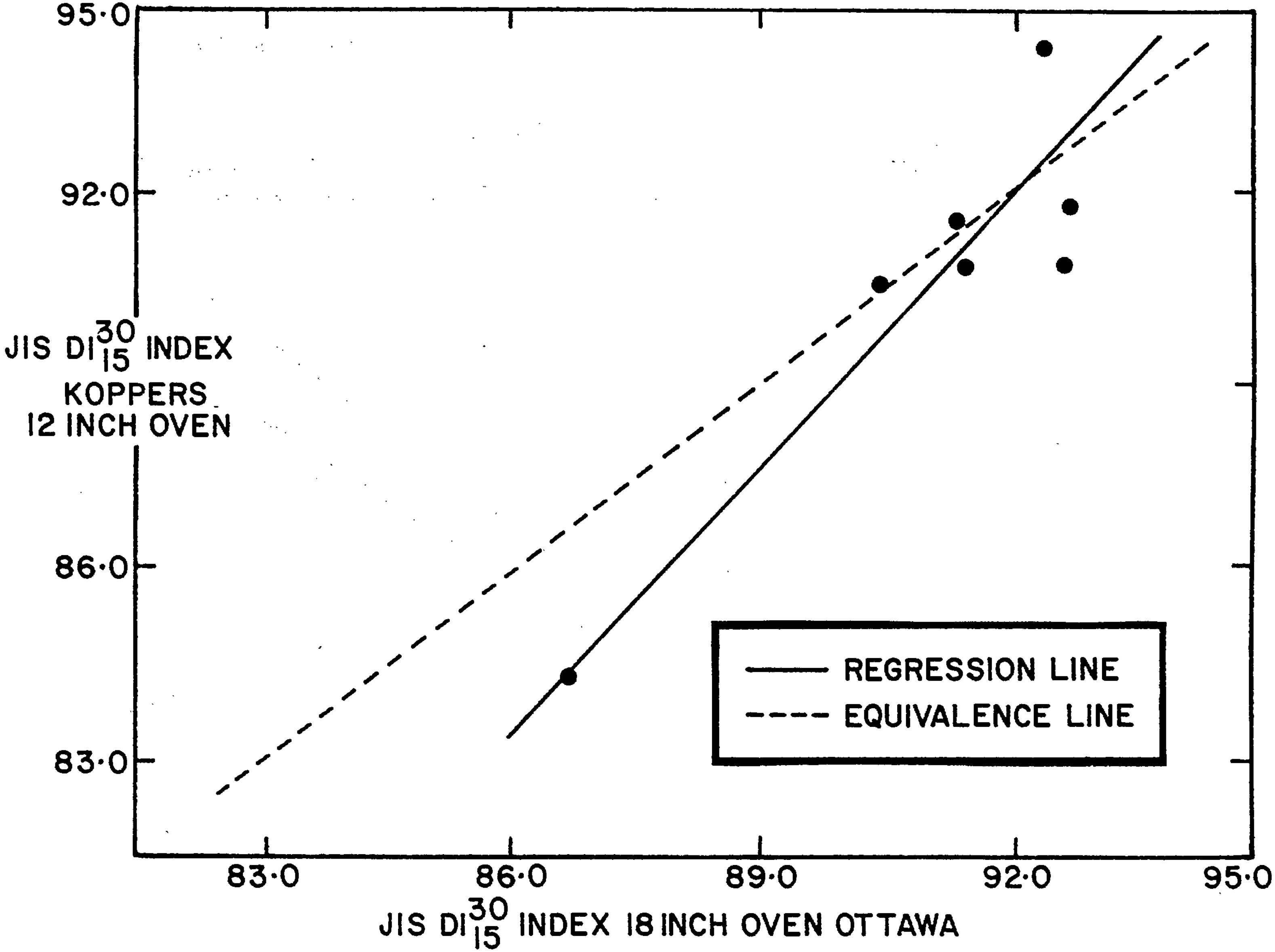

Fig. 9 Comparison of JIS DI^{30}_{15} Indices - Koppers versus 18-in. ovens

APPENDIX A

A SUMMARY OF THE ASTM, JIS AND CMFRL MODIFIED JIS COKE TUMBLER TESTS

The ASTM tumbler test for coke is carried out at CRPL according to the ASTM Standard[(a)]. That is, 22 lb of coke, screened to 2 in. by 30 in., is tumbled for 1400 revolutions at 24 ± 1 rpm in a 3-ft dia by 1.5-ft long cylindrical drum equipped with two equispaced 2-in. lifters set at 90 degrees to the drum wall. All the tumbled coke is screened over two square mesh sieves having hold diameters of 1 in. and 0.25 in. respectively and the percentages remaining on these screens are called the stability and hardness indices respectively.

The Japanese coke tumble test standards specify that 22 lb of plus 2-in. coke be tumbled for 30 or 150 revolutions at 15 ± 5 revolutions per min in a 1.5-m diameter by 1.5-m long cylindrical drum equipped with six equi-spaced 0.25-m wide lifters set 90 degrees to the drum wall[(b)]. The coke, tumbled for 2 min (30 revolutions), is screened over square-mesh sieves having hole diameters of 50, 25 and 15 mm. The cumulative percentage remaining on the 15-mm sieve after 30 revolutions is known as the JIS DI^{30}_{15} index. In a recent test modification, the coke sample is reconstituted and tumbled for an additional 8 min for a total of 150 revolutions, after which it is screened again. The cumulative percentage retained on the 15-mm screen after 150 revolutions is known as the JIS DI^{150}_{15} index. However, this index is not considered in this report because of insufficient data.

A modified Japanese coke tumble test is used by CRPL to carry out the JIS coke tumbler test. The Japanese standard specifies that plus 2-in. coke be used in the tests. However, CRPL has used two different size consists in the JIS test during the last 15 years. From the JIS introduction at CRPL in 1961, and until 1972, the test was performed with plus 3-in.

(a) American Society for Testing and Materials Book of ASTM Standards; Part 26, D 294-64, pp 41-42; 1974.

(b) Japanese testing method for coke strength; Japanese Industrial Standard JIS K 2151-1972; Translation by Y. Okuyama, Nippon Kokan K.K., Technical Research Centre, Kawasaki, Japan.

coke. Coke size was changed in 1972 after discussions with the Japanese, and the test is now being run with minus 3-in. by plus 2-in. coke. The 2-in. by 3-in. coke was used in the JIS tests to achieve more consistent results from both the 12- and 18-in. ovens operated using the CRPL procedures. If this were not done, the regular plus 2-in. coke from the 12-in. oven would tend to give higher JIS DI_{15}^{30} indices than plus 2-in. coke from the 18-in. oven, because the 12-in. oven tends to produce smaller sized coke than the 18-in. oven[c]. Using this modification, consistent JIS results should be obtained from both the 12- and 18-in. ovens.

(c) Leeder, W.R. and Price, J.T.; Unpublished results; 1977.

APPENDIX B

CARBONIZATION DATA FROM TESTS TO COMPARE RESULTS FROM DIFFERENT CANMET TECHNICAL-SCALE COKE OVENS

Coal or Blend No.	Carbonization Conditions			Carbonization Results							
	Oven used[a]	Oven bulk density (lb/ft^3 db)[b]	Coking time (hr-min)	Coke yield[c] %	Apparent specific gravity[d]	Mean coke size (in.)	Coking pressure (psi)	ASTM tumbler test[e]		JIS tumbler test	
								stab.	hard	DI^{15}_{30}	DI^{15}_{150}
- 1972 Correlation Results											
1.	12	51.6	9-30	73.7		2.03	-	56.2	69.0	93.1	-
	12	51.4	9-40	71.7	0.869	2.05	-	57.7	67.8	93.9	
	12	51.8	9-15	73.9	0.890	2.11	-	56.1	68.5	92.2	
	18	46.0	16-45	67.7[c]	-	2.29	-	59.0	66.2	93.2	
	18	46.0	18-00	64.9[c]	0.894	2.27	-	60.3	67.8	93.6	
2.	12	50.3	8-50	66.7	0.820	2.05	-	40.2	63.5	88.9	
	12	49.8	8-50	65.9	0.822	2.02	-	40.3	63.4	88.6	
	18	50.9	17-50	58.7[c]	0.824	2.21	-	42.0	62.6	87.6	
3.	12	51.1	9-30	73.4	0.879	2.15	-	56.4	67.9	-	
	18	51.8	18-10	66.6[c]	0.890	2.23	-	58.3	67.1	93.6	
4.	12	49.3	9-50	75.7	0.856	2.03	-	60.9	70.4	95.3	
	18	51.7	18-00	68.4[c]	0.864	2.34	-	64.2	69.3	95.1	
	18	51.9	18-00	70.0[c]	-	2.43	-	64.1	69.2	94.8	
5.	12	50.8	8-46	71.6	0.835	1.99	-	50.6	64.2	92.2	
	18	52.5	17-45	65.0[c]	0.891	2.20	-	56.2	65.6	93.3	
6.	12	51.6	9-00	73.4	0.899	1.86	-	55.4	70.8	93.5	
	18	52.5	18-00	-	-	-	-	59.7	69.9	-	

NOTE: For Footnotes a, b, c, d, e, see page B8

(Table continued)

Coal or Blend No.	Carbonization Conditions			Carbonization Results							
	Oven used[a]	Oven bulk density (lb/ft^3 db)[b]	Coking time (hr-min)	Coke yield[c] %	Apparent specific gravity[d]	Mean coke size (in.)	Coking pressure (psi)	ASTM tumbler test[e]		JIS tumbler test	
								stab.	hard	DI^{15}_{30}	DI^{15}_{150}
7.	12	50.8	9-05	73.3	0.872	1.91	-	56.8	71.7	93.7	
	18	52.6	17-00	66.9[c]	0.779	2.27	-	62.9	69.8	94.0	
	18	52.4	18-00	67.8[c]	0.869	2.44	-	61.1	66.6	94.4	
- 1973 Correlation Results											
8.	12	51.0	9-05	68.7	0.826	2.04	0.4	42.0	64.9	88.0	
	12	51.0	8-57	68.8	0.826	1.99	0.4	42.0	65.0	88.2	
	18	51.5	17-15	63.5	0.837	2.33	0.4	40.2	63.2	86.4	
	18	51.4	17-15	62.9	0.829	2.37	0.4	40.7	63.0	86.3	
	18	49.4	17-15	63.0	0.834	2.44	0.4	41.2	64.1	87.1	
	18	49.6	17-15	63.3	0.822	2.37	0.3	40.8	64.1	86.7	
	18	46.1	17-50	63.9	0.681	2.45	0.2	37.4	58.8	86.9	
	30	50.1	2-20	69.7	-	1.55	-	37.0	53.3	-	
	30	50.0	2-18	69.7	-	1.54	-	37.0	55.3	-	
9.	12	50.7	8-50	70.2	0.83	1.91	0.29	51.4	66.3	90.7	
	12	50.8	9-00	70.9	0.83	1.97	0.27	50.8	65.9	92.2	
	18	51.1	17-45	64.0	0.83	2.55	0.31	53.0	66.0	91.5	
	18	51.1	17-40	63.6	0.84	2.49	0.31	52.7	65.9	91.9	
	18	49.0	17-15	61.0	0.81	2.29	0.31	51.6	63.4	91.3	
	18	48.9	17-10	61.4	0.82	2.31	0.60	49.8	62.9	91.1	
	18	45.4	17-00	62.8	0.80	2.31	0.18	46.3	60.3	90.4	
	18	45.4	17-00	63.8	0.80	2.29	0.18	47.0	61.5	90.0	

NOTE: For Footnotes a, b, c, d, e, see page B8

(Table continued)

Coal or Blend No.	Carbonization Conditions			Carbonization Results							
	Oven used[a]	Oven bulk density (lb/ft^3 db)[b]	Coking time (hr-min)	Coke yield[c] %	Apparent specific gravity[d]	Mean coke size (in.)	Coking pressure (psi)	ASTM tumbler test[e]		JIS tumbler test	
								stab.	hard	DI^{15}_{30}	DI^{15}_{150}
9.	30	49.9	2-16	68.4	-	1.48	-	44.2	62.3	-	
	30	50.9	2-20	70.5	-	1.48	-	45.8	61.2	-	
10.	12	51.2	9-15	71.5	0.85	2.00	0.62	52.6	67.4	93.1	
	12	51.1	9-30	71.8	0.86	1.98	0.70	53.0	67.7	93.0	
	18	51.6	17-45	69.9	0.87	2.41	0.71	59.0	67.0	94.0	
	18	51.5	17-45	68.2	0.87	2.35	0.52	59.3	68.4	93.1	
	18	49.0	17-15	67.9	0.86	2.47	0.56	57.3	66.3	89.5	
	18	48.9	17-15	67.3	0.83	2.39	0.57	57.3	65.8	91.1	
	18	46.3	16-55	64.8	0.80	2.35	0.19	56.4	62.6	90.3	
	18	46.2	16-50	64.1	0.80	2.31	0.19	54.5	61.8	90.0	
	30	49.5	2-15	75.5	-	-	-	50.6	60.6	-	
	30	49.7	2-15	73.1	-	-	-	50.6	65.0	-	
11.	12	50.4	10-30	72.9	0.89	2.17	1.20	56.8	67.7	93.7	
	12	50.6	9-30	73.0	0.90	2.01	1.60	54.8	68.9	93.6	
	18	51.3	18-00	70.1	0.91	2.40	1.17	59.6	68.6	94.5	
	18	51.2	18-00	70.2	0.91	2.55	1.62	60.7	67.3	94.8	
	18	49.6	17-20	67.4	0.88	2.40	0.56	58.7	65.8	94.4	
	18	49.8	17-30	65.6	0.86	2.66	1.07	58.2	65.1	94.5	
	18	46.4	16-15	67.9	0.83	2.40	0.52	56.9	63.2	93.8	
	18	46.3	16-05	67.7	0.83	2.42	0.52	56.0	63.0	93.4	
	30	51.0	2-22	76.1	-	1.51	-	46.8	64.9	-	
	30	51.4	2-18	75.4	-	1.54	-	49.3	66.0	-	

NOTE: For Footnotes a, b, c, d, e, see page B8 (Table continued)

Coal or Blend No.	Carbonization Conditions			Carbonization Results							
	Oven used[a]	Oven bulk density (lb/ft^3 db)[b]	Coking time (hr-min)	Coke yield[c] %	Apparent specific gravity[d]	Mean coke size (in.)	Coking pressure (psi)	ASTM tumbler test[e]		JIS tumbler test	
								stab.	hard	DI^{15}_{30}	DI^{15}_{150}
- 1974 Correlation Program											
12.	12	50.1	9-35	67.8	0.86	2.07	0.20	31.4	56.6	87.2	
	12	50.0	9-35	67.8	0.87	2.04	0.28	30.4	57.0	84.1	
	12	50.2	9-35	68.1	0.86	1.98	0.25	31.5	57.5	86.6	
	18	46.4	18-00	69.3	0.82	2.35	0.31	29.5	52.3	85.9	
	18	46.6	18-00	69.4	0.82	2.29	0.31	27.2	51.0	87.6	
	30	51.3	2-50	69.6	-	1.69	-	38.6	50.2	-	
	30	51.2	2-45	69.3	-	1.73	-	39.5	50.9	-	
	30	51.2	2-47	69.4	-	1.74	-	38.6	51.1	-	
	k	51.1	8-42	67.2	-		0.38	28.1	60.5	86.9	68.5
	k	50.9	8-22	66.8	-		0.30	27.3	59.8	85.6	66.1
	k	51.2	8-45	66.1	-		0.12	28.7	61.4	85.8	68.0
	k	49.1	8-30	66.4	-		0.56	27.7	58.4	85.6	67.9
	k	48.5	8-23	66.5	-		0.10	27.7	57.8	84.1	64.3
	k	48.5	8-02	66.3	-		0.65	27.9	58.4	85.6	68.8
	k	47.5	8-13	66.3	-		0.34	27.4	56.1	85.1	67.4
	k	46.9	8-05	66.2	-		0.42	27.6	55.1	83.6	65.9
	k	46.9	8-12	66.3	-		0.47	26.2	56.9	84.4	66.5
13.	18	47.0	18-00	65.9	0.81	2.49	0.23	44.7	56.4	91.5	76.1
	k	51.9	8-54	68.7	0.85	2.09	1.12	42.1	61.4	91.3	76.9
	k	50.8	8-23	69.2	0.84	2.07	0.93	39.8	60.1	90.5	75.1
	12	50.8	9-20	71.2	0.86	2.18	0.71	46.3	62.2	92.5	-

NOTE: For Footnotes a, b, c, d, e, see page B8 (Table continued)

Coal or Blend No.	Carbonization Conditions			Carbonization Results							
	Oven used[a]	Oven bulk density (lb/ft^3 db)[b]	Coking time (hr-min)	Coke yield[c] %	Apparent specific gravity[d]	Mean coke size (in.)	Coking pressure (psi)	ASTM tumbler test[e]		JIS tumbler test	
								stab.	hard	DI^{15}_{30}	DI^{15}_{150}
14.	12	50.7	9-40	73.4	0.89	2.22	1.25	46.8	64.1	91.7	75.3
	12	50.8	9-45	73.2	0.89	2.22	1.25	46.9	63.4	92.3	78.5
	12	50.2	9-47	73.2	0.87	2.23	0.79	46.4	63.4	92.5	79.1
	18	46.7	18-00	73.9	0.81	2.86	0.46	49.8	57.1	93.4	-
	18	47.0	16-50	73.7	0.82	2.80	0.59	48.6	57.2	92.2	77.1
	30	52.0	2-40	74.7	-	-	-	54.2	61.6	-	-
	30	52.0	2-40	73.3	-	1.73	-	54.5	63.3	-	-
	k	51.8	9-09	70	0.88	2.12	1.16	45.0	63.5	92.0	78.9
	k	51.7	8-45	69.8	0.88	2.09	1.43	43.1	62.5	91.7	77.9
15.	12	50.2	9-30	74.6	0.87	2.30	1.12	49.5	64.5	92.9	-
	12	50.2	9-45	74.8	0.87	2.26	1.16	49.6	64.0	93.3	-
	12	50.2	10-00	74.4	0.85	2.25	1.15	49.6	63.8	92.2	-
	18	46.6	18-00	73.2	0.85	2.84	0.46	50.8	58.8	93.0	-
	18	46.6	18-00	73.1	0.86	2.86	0.55	51.9	60.2	92.4	-
	30	52.4	2-50	74.4	-	1.75	-	48.2	60.2	-	-
	30	52.4	3-00	74.9	-	1.86	-	53.0	61.1	-	-
	30	52.2	3-00	75.4	-	1.75	-	51.0	60.6	-	-
	k	51.8	9-32	73.0	-		0.93	47.8	63.4	92.3	79.8
	k	52.1	9-53	67.4	-		1.11	48.5	63.3	92.5	80.5
	k	51.3	9-23	71.9	-		1.45	47.1	63.7	92.7	80.4
	k	48.0	8-25	73.3	-	-	0.67	47.2	61.6	92.3	81.7
	k	48.9	9-15	72.4	-	-	0.85	46.9	60.4	91.1	80.9
	k	48.8	8-40	73.1	0.89	2.29	1.1	46.4	62.6	92.1	78.6

NOTE: For Footnotes a, b, c, d, e, see page B8 (Table continued)

Coal or Blend No.	Carbonization Conditions: Oven used[a]	Oven bulk density (lb/ft^3 db)[b]	Coking time (hr-min)	Carbonization Results: Coke yield[c] %	Apparent specific gravity[d]	Mean coke size (in.)	Coking pressure (psi)	ASTM tumbler test[e]: stab.	ASTM tumbler test[e]: hard	JIS tumbler test: DI^{15}_{30}	JIS tumbler test: DI^{15}_{150}
15.	k	46.1	8–25	72.6	–	–	0.70	43.6	61.8	90.8	79.6
	k	45.7	8–31	70.8	0.84	2.17	0.92	45.8	60.3	91.1	78.0
16.	12	50.5	9–15	76.0	0.85	2.60	–	–	63.6	90.8	–
	18	46.5	18–00	70.5	0.81	2.83	–	44.7	54.7	91.6	–
	18	46.5	18–00	71.6	0.84	3.01	–	44.7	57.0	91.2	–
	k	51.8	9–23	72.4	0.88	2.32	2.4	45.5	63.6	92.7	80.0
	k	51.8	9–31	72.6	0.89	2.42	2.4	45.8	62.5	92.3	79.1
	k	48.0	8–40	73.5	0.87	2.38	1.50	42.2	62.5	90.8	79.0
	k	48.0	8–34	72.3	0.87	2.37	1.60	42.8	62.4	92.2	78.6
	k	45.8	8–23	70.2	0.83	2.34	0.96	43.3	59.7	91.3	78.1
	k	45.8	8–30	72.4	0.85	2.38	1.08	41.6	61.1	91.7	77.4
	k	45.7	8–51	73.0	0.86	2.50	0.80	42.8	60.7	91.3	77.3
	k	46.1	8–58	72.4	0.86	–	0.58	44.6	61.8	91.7	
17.	12	51.0	9–35	81.1	0.997	2.19	0.5	58.0	70.3	95.1	
	k	51.1	8–49	77.6	0.97	2.25	0.8	53.8	68.3	94.7	84.2
18.	12	50.9	9–45	80.1	0.94	–	3.59	53.9	66.1	92.3	–
	18	47.2	18–00	71.4	0.92	1.98	–	38.5	45.6	–	–
	18	47.1	16–80	66.4	0.93	1.93	0.34	35.5	43.1	–	–
	30	52.0	2–30	82.7		1.50	–	52.8	62.2	–	–
	k	51.0	9–40	77.6	0.94	2.45	2.26	51.0	63.7	93.8	81.1
	k	51.0	9–26	79.4	0.94	2.49	2.96	50.4	63.4	92.8	80.3
19.	12	49.1	9–20	76.6	0.97	1.99	0.46	52.6	70.5	91.3	81.5
	18	47.4	18–00	74.1	0.94	2.22	1.11	49.5	57.1	–	83.5
	30	49.3	–	78.0		1.72	–	55.2	62.7	–	–
	k	50.5	9–31	74.1	0.94	2.14	0.48	49.7	67.6	92.1	78.0
	k	51.1	9–33	75.4	0.99	2.14	0.30	51.2	67.9	92.9	80.4

NOTE: For Footnotes a, b, c, d, e, see page B8 (Table continued)

Coal or Blend No.	Oven used[a]	Oven bulk density (lb/ft^3 db)[b]	Coking time (hr-min)	Coke yield[c] %	Apparent specific gravity[d]	Mean coke size (in.)	Coking pressure (psi)	ASTM tumbler test[e] stab.	ASTM tumbler test[e] hard	JIS tumbler test DI^{15}_{30}	JIS tumbler test DI^{15}_{150}
20.	12	50.1	9-00	78.7	0.95	2.27	0.42	54.9	68.7	93.7	-
	18	47.2	18-00	74.7	0.93	2.75	0.34	52.0	60.2	92.5	-
	k	51.5	9-13	76.5	0.97	2.36	0.90	55.5	70.4	94.3	84.0
	k	51.5	9-32	77.3	0.98	2.32	0.88	55.1	70.2	94.4	84.2
21.	12	51.3	10-15	75.7	1.00	1.92	0.81	48.8	67.8	92.5	-
	18	46.8	15-30	72.8	0.93	2.16	0.28	44.9	55.9	-	-
	30	52.2	2-25	80.8	-	1.43	-	53.1	65.6	-	-
	k	51.0	9-24	73.1	0.94	2.17	0.52	51.1	67.5	93.4	81.5
	k	50.7	9-30	73.2	0.92	2.07	0.52	51.1	64.5	93.2	80.2
22.	12	51.2	9-30	70.0	-	2.11	0.41	36.5	62.1	-	-
	18	47.9	18-00	70.1	-	2.36	0.31	37.4	56.5	90.5	-
	30	52.2	2-32	72.9	-	1.52	-	44.4	58.8	-	-
	k	52.0	9-30	71.8	0.91	2.10	0.55	42.9	64.5	90.2	76.4
	k	51.6	9-14	69.8	0.92	2.08	0.30	43.7	64.3	91.0	77.4
23.	12	50.5	9-25	72.5	0.88	2.48	0.56	54.7	66.3	91.2	-
	18	47.2	18-00	67.7	0.82	2.79	-	47.7	53.8	91.8	-
	18	46.5	18-00	72.5	0.84	3.07	0.31	54.2	58.5	93.5	-
	18	47.6	16-00	70.2	0.85	2.97	-	53.9	58.1	93.2	-
24.	12	50.6	9-35	70.9	-	1.89	0.89	53.4	70.2	93.1	-
	18	47.6	16-00	71.0	0.83	2.35	-	56.8	63.9	94.2	-
	18	46.6	16-00	71.0	0.86	2.47	-	56.3	63.8	93.6	-
25.	12	47.6	8-45	71.6	0.90	2.38	0.52	57.9	67.0	94.1	-
	18	47.5	18-00	69.0	0.83	2.80	-	54.6	59.9	91.2	-
26.	12	46.8	9-10	73.0	0.84	2.07	0.44	53.6	66.5	93.8	-
	18	47.3	16-00	72.7	0.86	2.19	0.40	54.8	65.0	93.2	-

NOTE: For Footnotes a, b, c, d, e, see page B8

(Table continued)

Coal or Blend No.	Carbonization Conditions: Oven used[a]	Oven bulk density (lb/ft^3 db)[b]	Coking time (hr-min)	Carbonization Results: Coke yield[c] %	Apparent specific gravity[d]	Mean coke size (in.)	Coking pressure (psi)	ASTM tumbler test[e]: stab.	hard	JIS tumbler test: DI_{30}^{15}	DI_{150}^{15}
27.	12	50.1	9-30	70.9	-	2.39	0.69	55.4	66.2	93.8	-
	18	46.7	16-00	68.6	0.81	2.70	-	55.0	60.0	92.4	-
28.	12	51.4	9-30	70.9	-	2.17	0.39	37.8	61.7	90.9	-
	k	51.4	8-38	71.1	0.87	2.03	0.3	42.6	64.4	91.6	76.2
	k	51.2	8-44	71.7	0.88	2.01	0.44	43.0	64.3	90.1	74.8
29.	k	51.8	9-07	71.3	0.87	1.98	0.23	41.6	65.3	90.6	76.4
	k	51.5	9-15	72.4	0.87	2.01	0.3	41.6	65.1	90.7	76.2
	12	50.7	9-20	69.9	-	2.13	0.33	36.9	61.8	89.3	-
30.	12	51.0	9-30	72.1	0.92	2.22	0.56	39.4	61.1	88.2	-
	18	47.2	15-15	70.1	0.86	2.42	0.52	35.5	43.1	-	-
	30	52.3	2-29	73.7	-	1.47	-	47.5	60.2		

a - 12 = Ottawa 12-in. oven; 18 = Ottawa 18-in. oven; 30 = Ottawa 6-in. (30 lb) oven; k = Edmonton 12-in. oven.

b - Oven bulk density, dry basis (db).

c - Low coke yields caused by burning in oven.

d - Coke apparent specific gravity.

e - stab. = ASTM stability factor
hard. = ASTM hardness factor.

DETAILS OF LEAST SQUARES LINEAR REGRESSION ANALYSES FOR COMPARING COKE TUMBLER TEST RESULTS FROM DIFFERENT CANMET TECHNICAL-SCALE COKE OVENS

The least squares linear regression equation is defined as:

$$Y = A + BX$$

A and B are constants defined as:

$$B = \frac{\Sigma xy}{\Sigma x^2} \qquad A = \bar{Y} - B\bar{X}$$

where, for the experimental values (X_i, Y_i),

$$x = X_i - \bar{X}$$

$$y = Y_i - \bar{Y}$$

$$\bar{X} = \frac{\Sigma X_i}{n}$$

$$\bar{Y} = \frac{\Sigma Y_i}{n}$$

Analysis of variance of the regression uses the following equations:

Regression sums of squares = RSS = $\frac{(\Sigma xy)^2}{\Sigma x^2}$

Total sums of squares = TSS = Σy^2

Residual sums of squares = ReSS = TSS − RSS

Residual mean square = $\frac{\text{ReSS}}{\text{Residual degrees of freedom}}$ = RMS

Standard error = S_E = $\text{RMS}^{\frac{1}{2}}$

R = correlation coefficient

$= \Sigma xy / (\Sigma x^2 \Sigma y^2)^{\frac{1}{2}}$

The regression analyses used to compare the coke tumbler test results obtained from different CANMET technical-scale coke ovens make use of the modified regression equations of Visman and Picard*. This method is reviewed and compared with a normal regression below. All the calculations in this report use the Visman and Picard modification.

TABLE C1 Summary of Regression Methods

Details	Normal Regression	Visman and Picard Modified
Consideration of errors	Assume all errors are in Y	Assumes both X and Y have errors
Equation regressed	$Y = A + BX$ where $B = \frac{\Sigma xy}{\Sigma x^2}$ and $A = \overline{Y} - B\overline{X}$	$Y = A + BX$ where $B = \frac{k\frac{\Sigma xy}{\Sigma x^2} + j\frac{\Sigma y^2}{\Sigma xy}}{k + j}$ and $A = \overline{Y} - B\overline{X}$ where $k = s_y/\overline{Y}$ = variation coefficient of Y; $j = s_x/\overline{X}$ = variation coefficient of X
Comment	Regression X onto Y	Averages the result of regressing X onto Y and Y onto X.

*Visman, J. and Picard, J.L. Guide to engineering statistics; Mines Branch Information Circular IC 233, Department of Energy, Mines and Resources, Ottawa, Canada; 1970.

TABLE C2 Detailed Statistical Results from Stability Data

Y oven vs X oven	12-in. vs 18-in.				12-in. vs Koppers				Koppers vs 18-in.			
Figure No.	1				2				3			
	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X
Data	42.0	37.40	54.90	52.00	31.10	27.06	37.80	42.80	27.06	28.35		
	51.10	46.65	48.80	44.90	46.30	40.95	36.90	41.60	40.95	44.70		
	52.80	55.45	36.50	37.40	46.70	45.15			45.15	49.20		
	55.80	56.45	54.70	51.93	49.57	44.70			44.70	51.35		
	31.10	28.35	53.40	56.54	44.20	43.08			43.08	45.00		
	46.30	44.70	55.40	55.00	53.90	50.70			50.45	49.50		
	46.70	49.20			54.90	55.30			55.30	52.00		
	49.57	51.35			48.80	51.10			51.10	44.90		
	44.20	45.00			36.50	43.30			43.30	37.40		
$\bar{X}$	47.49				44.16				44.71			
$\bar{Y}$	48.22				44.24				44.56			
N	15				11				9			
A	5.51				- 3.03				- 3.26			
B	0.899				1.07				1.07			
R	0.945				0.840				0.832			
SE	1.70				3.16				3.41			
UCL B*	1.02				1.38				1.45			
LCL B	0.778				0.760				0.694			

* UCL = 95 per cent upper confidence limit on B; LCL = 95 per cent lower confidence limit on B.

TABLE C3 Detailed Statistical Results from Hardness Data

Y oven vs X oven	12-in. vs 18-in.				12-in. vs Koppers				Koppers vs 18-in.			
Figure No.	4				5				6			
	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X
Data	64.95	58.80	68.70	60.20	57.00	56.0	61.70	64.35	56.0	51.65		
	66.10	60.90	67.80	55.90	62.20	60.75	61.80	65.20	60.75	56.40		
	67.55	62.20	62.10	56.50	63.60	63.00			63.00	57.20		
	68.30	63.10	66.30	56.80	64.10	61.05			61.05	59.50		
	57.00	51.65	70.20	63.85	66.10	63.55			67.75	57.10		
	62.20	56.40	66.20	60.00	68.70	70.30			70.30	60.20		
	63.60	57.20			67.80	66.00			66.00	55.90		
	64.10	59.50			62.10	64.40			64.40	56.50		
	63.60	55.85										
$\overline{X}$	58.59				63.46				56.80			
$\overline{Y}$	65.25				63.51				63.66			
N	15				10				8			
A	3.91				3.66				- 34.3			
B	1.05				0.943				1.72			
R	0.82				0.792				0.675			
SE	1.36				1.52				2.79			
UCL B	1.29				1.25				2.72			
LCL B	0.806				0.632				0.724			

TABLE C4 Detailed Statistical Results from Hardness Data

Y oven vs X oven	12-in. vs 18-in.				12-in. vs Koppers				Koppers vs 18-in.			
Figure No.	7				8				9			
	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X
Data	88.10	86.90	93.70	92.50	85.97	84.37	89.30	90.65	84.37	86.75		
	91.45	90.20	91.20	92.80	92.50	92.90			90.90	91.50		
	93.05	90.15	93.10	93.90	92.17	91.85			91.85	92.80		
	93.65	93.60	93.80	92.40	92.80	90.95			90.95	92.70		
	85.97	86.75			90.80	91.63			91.63	91.40		
	92.50	91.50			92.30	93.30			94.35	92.50		
	92.17	92.80			93.70	94.35			90.60	90.50		
	92.80	92.70			92.50	93.30						
	90.80	91.40										
$\overline{X}$	91.35				91.10				91.16			
$\overline{Y}$	91.71				91.29				90.66			
N	13				10				7			
A	- 1.60				14.86				- 38.85			
B	1.02				0.838				1.42			
R	0.855				0.898				0.915			
SE	0.890				0.702				1.03			
UCL B	1.27				1.036				1.93			
LCL B	0.776				0.640				0.909			

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