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COKE STRENGTH - COMPARISONS OF DIFFERENT METHODS

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COKE STRENGTH - COMPARISONS OF DIFFERENT METHODS

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Abstract: - Coke tumbler test strength indices are perhaps the most important coke quality property that can be correlated with iron blast furnace performance. Unfortunately different standardized coke tumbler tests are used in various parts of the world. This paper reviews work that has related the results of the most common tumbler tests - namely, the American Society for Testing and Materials (ASTM), International Standards Organization (ISO) and Japanese Industrial Standards (JIS) methods. Comparisons indicate that correlations do exist between the coke strength indices of different methods but the correlations are generally not precise. Although the correlations can be used for estimating one test result, given another, testing of the coke using a specific method is required to assess reliably its strength for that method.

INTRODUCTION

The prime purpose of this paper is to discuss the most common coke tumbler strength indices used in the western world and to consider relationships between them. It has become increasingly important to be able to readily convert one coke quality index to another in support of increasing world trade in coke and coking coal and understanding publications and technical advances. For example, recent Japanese publications of importance to North American coke makers, coal producers and researchers have related coal petrographic reflectance and thermal rheological properties to Japanese, but not to North American, coke strength indices (1).

Coke quality is assessed from the chemical and physical properties of the coke sample. The chemical properties are determined in North

America using ASTM standards that include proximate analyses, ultimate analyses etc. (2). While other countries use different standards, generally their test results are similar. Coke physical properties include measurement of apparent specific gravity (ASG), size consist and strength parameters. ASG and size consist can generally be related even though different techniques are used in different parts of the world - such as sizing on round and square wire sieves. However this is not true of coke strength parameters.

Numerous test methods have been developed over the years to determine a measure of coke strength. Two general methods have been used: the drop shatter type and a variety of drum-type tests (3). Only the latter type will be considered in this paper as they are the most widely used today for metallurgical coke destined for the iron blast furnace. Coke strength is normally determined from an index calculated after tumbling a given weight of sized coke in a cylindrical drum at a specified speed of rotation for a given number of revolutions. The strength index is calculated using some measure of coke size reduction such as the cumulative weight of a tumbled sample remaining above a minimum size. Several standard forms of such tests are used in different parts of the world, all essentially following the same procedure. However, different specifications for drum size and speed of rotation, coke size, screen size and shape etc., are used and the strength indices derived from the different tests cannot be readily compared. Since no comprehensive theory exists to calculate or relate coke degradation observed with the different coke tumbler tests, only empirical comparisons between different test method results are possible. The principle methods to be discussed will be the most commonly used - the ASTM (4), JIS (5) and ISO Micum* and IRSID (6,7) standards for coke strength testing. This paper shall consider empirical relationships between the results of these test methods so that one coke strength index can be readily estimated from another.

Coke strength assessment has had a long history that has included sampling coke from blast furnaces and a variety of methods conducted at conditions that are more representative of the blast furnace environment - e.g. higher temperatures, use of CO_2, etc. (8,9,10,11,12). This report will not discuss the literature on high temperature assessment of coke quality. It is the authors' opinion that while high temperature tests may represent a particular environment in the blast furnace, generally such methods are probably also limited, like low temperature tests, in not giving a total picture of coke strength. As well, trends in standard room temperature tests have been found in some cases to correlate with high temperature strength results, both results have been correlated with blast furnace permeability (13,14,15) and low temperature standard test results have been correlated with blast furnace coke rates (16). Although high temperature testing has been conducted for over one hundred years and is most useful for research, owing to the large number of tests, time requirements, complexity of

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*Micum: Abbreviation of "Mission interalliée de control des usines et des mines" (Interallied Control Mission of Works and Mines).

methods and questions of interpretation, these tests have not found general acceptance as a control method for coke quality going to the blast furnace.

TEST METHODS

Most coke tumbler tests have a long history - for example the ASTM tumbler test for coke has remained essentially unchanged since 1928 and the present Micum test is based on the principle of the Breslau trommel test which originated in 1913 (4,6). The tests are relatively simple, a prerequisite to commercial operational usage, and have a long history of association with blast furnace performance.

Details of the ASTM, JIS and ISO tumbler tests of coke quality appear in Table I. None of these tests will be described in detail as standards information is readily available (4,5,6,7). All the methods described are based on the principle that a weighed amount of sized coke is subjected to mechanical work in a tumbler drum equipped with lifters.

The ASTM test tends to be of long duration using a reasonably closely sized sample of coke. The JIS test uses roughly plus 2 in. coke and is conducted for a very short time - two and ten minutes. This particular method uses a large drum (1.5 m diam.) with a relatively small volume of coke as compared to the ASTM and ISO tests and is more of a shatter than an abrasion test. The ISO standards use intermediate tumbling times but with a larger volume of coke than in the other tests. For the JIS and ISO methods, the coke to be tested is obtained by retaining all coke above a minimum size. As a result the strength indices derived from the JIS and ISO tests tend to reflect the initial size of the coke used in the test, eg. top size, as well as the physical strength of the coke (17,18,19,20).

Concern about coke tumbler test methods resulted in reconvening of Sub Committee 3 (SC 3, Coke) of ISO/Technical Committee 27 (TC 27, Solid Mineral Fuels) in Paris, May, 1974, after a lapse of eight years, and again in Rome in 1976 and London in 1978. Documents emanating from this ISO sub committee are most useful in following changing patterns, developments and the latest thinking about coke strength testing (21). Consideration was given at the London meeting to simplifying test methods, comparing the different coke tumbler test indices, and considering the relative type of work conducted on a piece of coke in each respective test (22). A number of suggestions regarding modifying existing tumbler tests was made such as use of an optimal number of revolutions beyond which further testing was of no real benefit, use of more standard size of initial coke, etc. (22).

Efforts have been made to determine which coke tumbler test method appears to be the best, particularly in terms of sample representativeness and test reproducibility and sensitivity (3,23,24,25,26,27). Criticisms have been made of all test methods and include; Micum and IRSID lack sensitivity and are influenced by the top size of the coke used; JIS uses too small a sample weight and too short a tumbling time to yield sufficiently reproducible answers; Micum testing uses a sample

TABLE I

ASTM, JIS and ISO STANDARD COKE DRUM TESTS

Test	Designation	Test Method										Strength Indices	
		Coke			Drum Dimensions				Drum RPM	Test Duration (min)	Total Revs	Breakage	Abrasion
		Size	Weight	Moisture	Width	Diam	Lifters	Width					
ASTM	D 294-64	3x2 in.	22 lb	dry	18 in.	36 in.	2	2 in.	24±1	58	1400	%>1" Stability Factor	%>¼" Hardness Factor
JIS Drum Test	2151-72	+50mm	10 kg	dry	1.5 m	1.5 m	6	250mm	15	2	30	%>15mm=DI^{30}_{15}	
										10	150	%>15mm=DI^{150}_{15}	
Micum*	R 556	+60mm	50 kg	<5	1.0 m	1.0 m	4	100mm	25±1	4	100	%>40mm, M_{40}	%<10mm M_{10}
(Note half micum test uses half the weight and a drum 0.5 m in width)													
IRSID*	R 1881	+20mm	50 kg	<3	1.0 m	1.0 m	4	100mm	25±1	20	500	%>40,20mm I_{40},I_{20}	%<10mm I_{10}

*Round-hole sieves used - other tests use square-hole sieves that is too large in size; ASTM uses an unrepresentatively small coke weight for testing, too large a size of coke and tumbles for an unnecessarily long time; etc. None of the methods appears to be entirely satisfactory. Irrespective of the criticisms, all test indices continued to be extensively relied upon for coke quality control and the efficient operation of iron blast furnaces.

COMPARISON OF DIFFERENT TEST RESULTS AND DISCUSSION

Interest in comparing the strength-indices from various coke tumbler drum tests has existed for some years (20,23,24,25,26,27,28,29,30,31, 32,33,34,35,36,37,38,39,40,41,42,43). Many graphical and/or linear regression equation comparisons of the different test results have been made and a sample of results is reviewed in Fig. 1 to 4 and in Table II. This by no means represents a compendium of available relationships but includes many of the possible comparisons between ASTM Stability and Hardness, JIS DI^{30}_{15} and DI^{150}_{15}, ISO M_{40} and M_{10}, and ISO I_{40} and I_{10} indices. Some of the regression equations in Table II were rearranged, e.g. X and Y switched from the literature equations, to simplify presentation. Although this procedure is not statistically valid (a new regression relationship should be rendered after switching the variables), the errors in the original relationship are so great that rearranging should make little difference.

The use of regression equations to relate two indices can lead to erroneous conclusions as precise predictions are not consistently possible through their use. Inspection of Fig. 1 and 2 points out the wide spread of experimental data and the resulting poor predictability that can be expected when utilizing the graphs or regression relationships. Although the graphs and equations are useful for estimating coke strength indices from a different test method result, testing of coke with a specific method still appears to be required to obtain reliable answers.

A number of studies have been undertaken to try to better understand tumbler tests. Investigations have been conducted to study the influence on the test results of: test procedures and equipment: characteristics of samples used; mechanism of internal degradation such as abrasion and shattering; method of expressing coke degradation strength; etc. Some of these studies have shed light on why good correlations might not be expected between test method results. A US Bureau of Mines study concluded that the main reason for variation between the ASTM and Micum methods was due to error deriving from the different types of screens used in the ASTM (square sieves) and ISO Micum (round hole) tests (35). Each test method uses different drum sizes, lifter widths, speed of rotation and volume of coke which leads to different net total work being conducted on the coke and also results in different relative contributions of abrasion and shatter mechanisms to the coke degradation in the drum (28,44). The M_{40} or I_{40} results of the JIS and ISO methods vary with varying top size of coke used, leading to a larger variation with the ASTM stability results (17,18,19,20). Commercially,

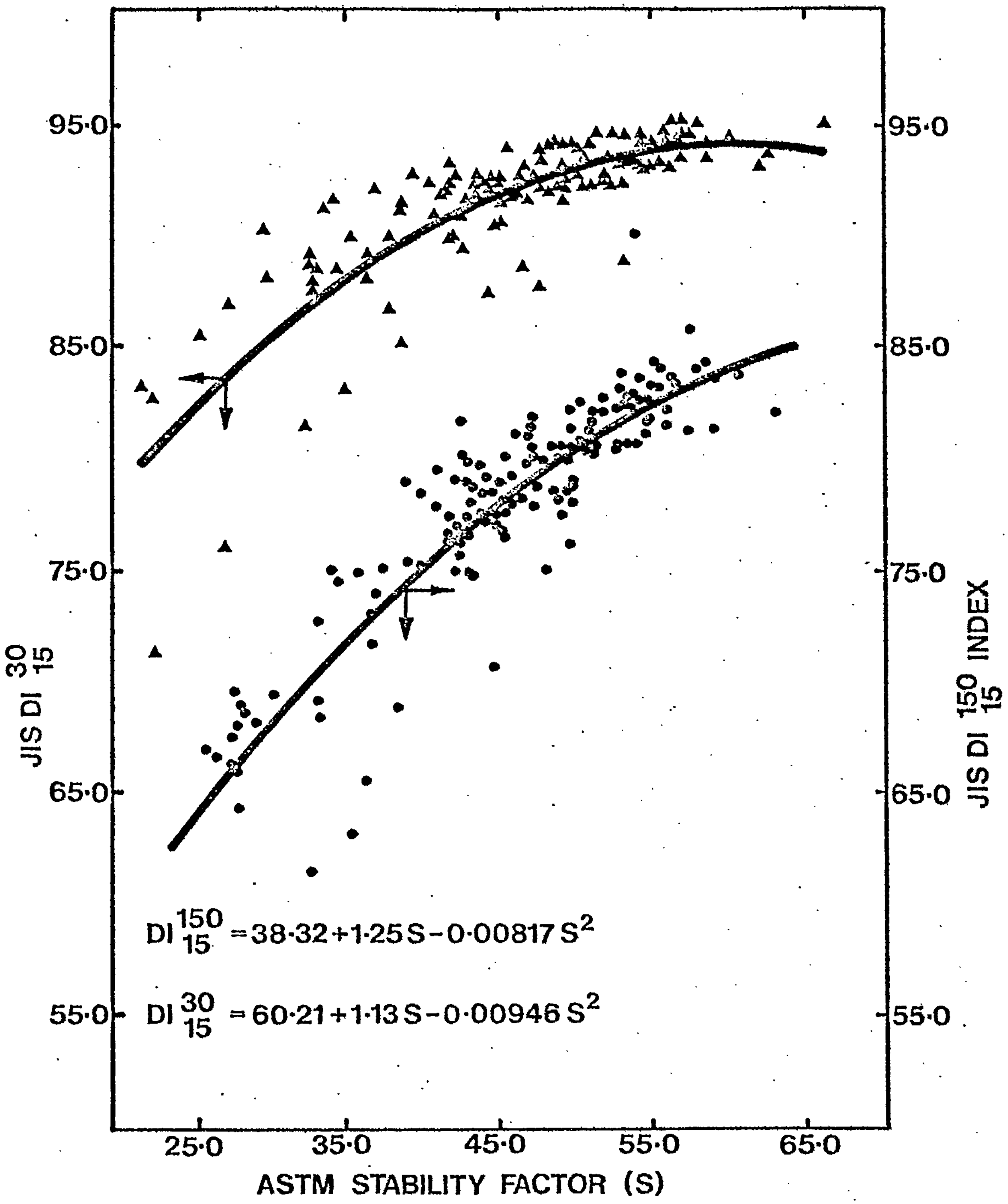

Figure 1. Comparison and Relationships Between ASTM Stability Factor(s) and JIS DI^{30}_{15} and DI^{150}_{15} indices (40).

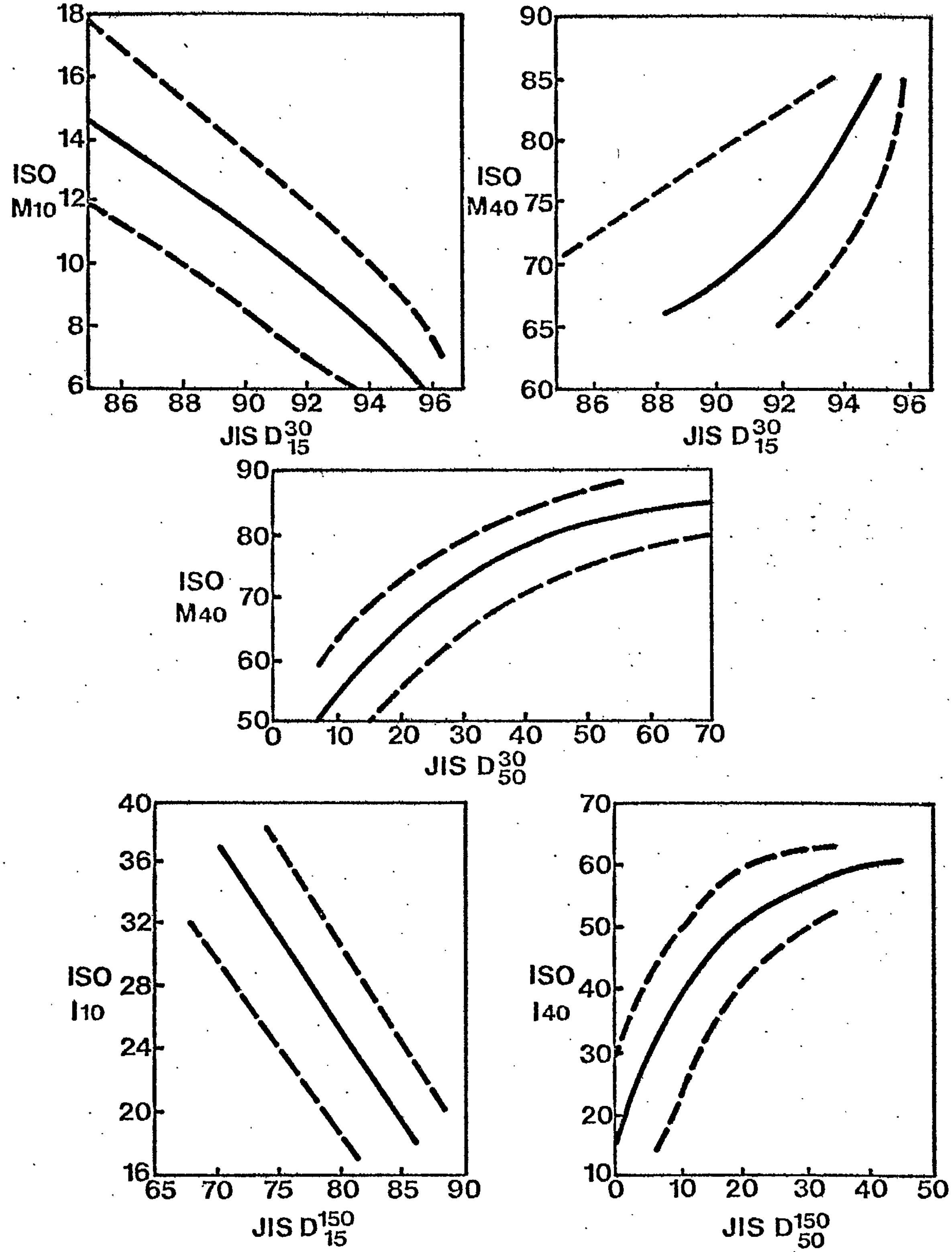

Figure 2. Relationships Between Various ISO and JIS coke tumbler test strength parameter (23). Dotted lines included 95% of about 300 data points.

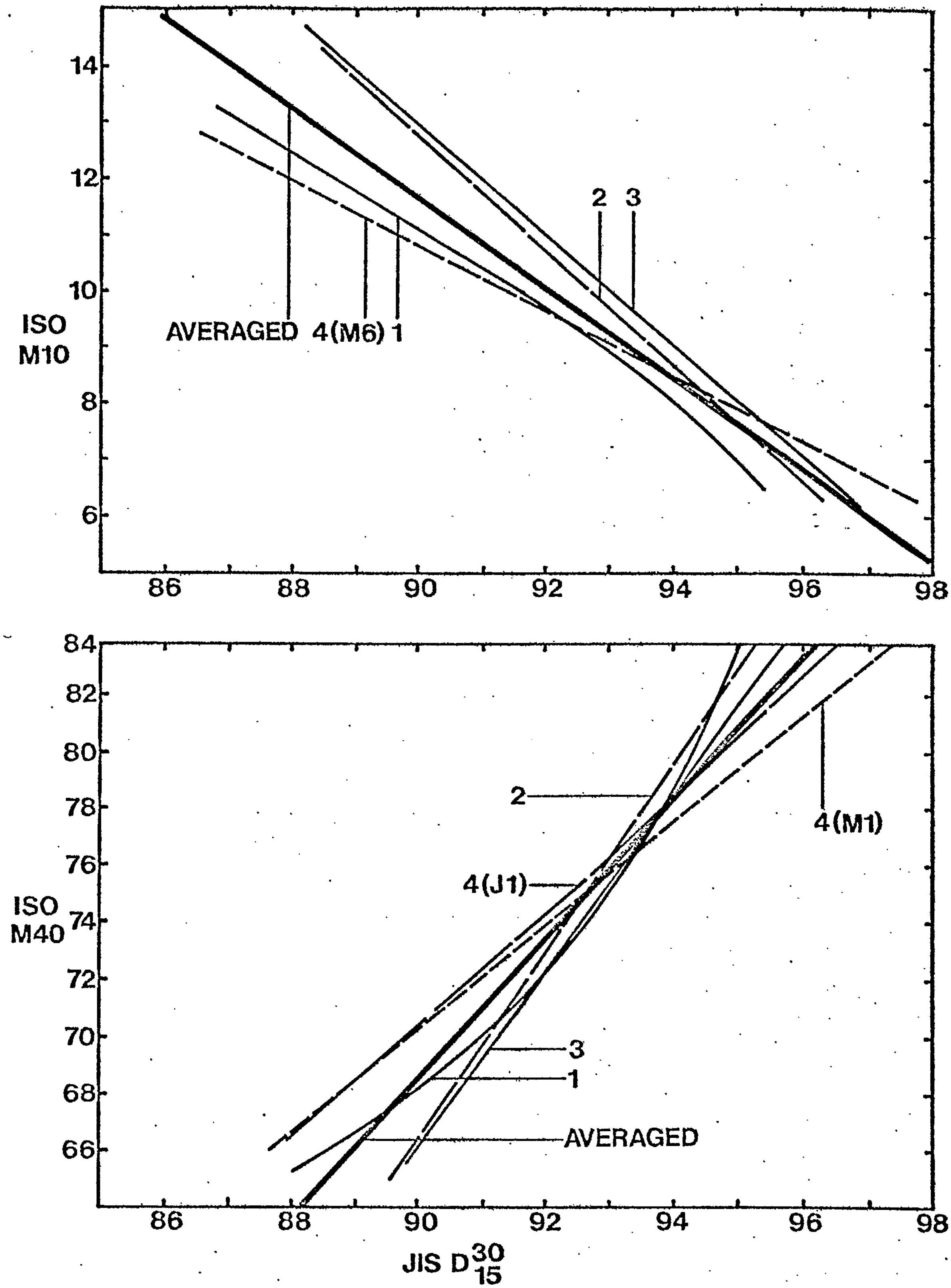

Figure 3. Various Regression Relationships between ISO M_{40} and M_{10} with JIS DI_{15}^{30} indices (1=ref.23; 2=ref.33; 3=ref.32; 4=ref.43).

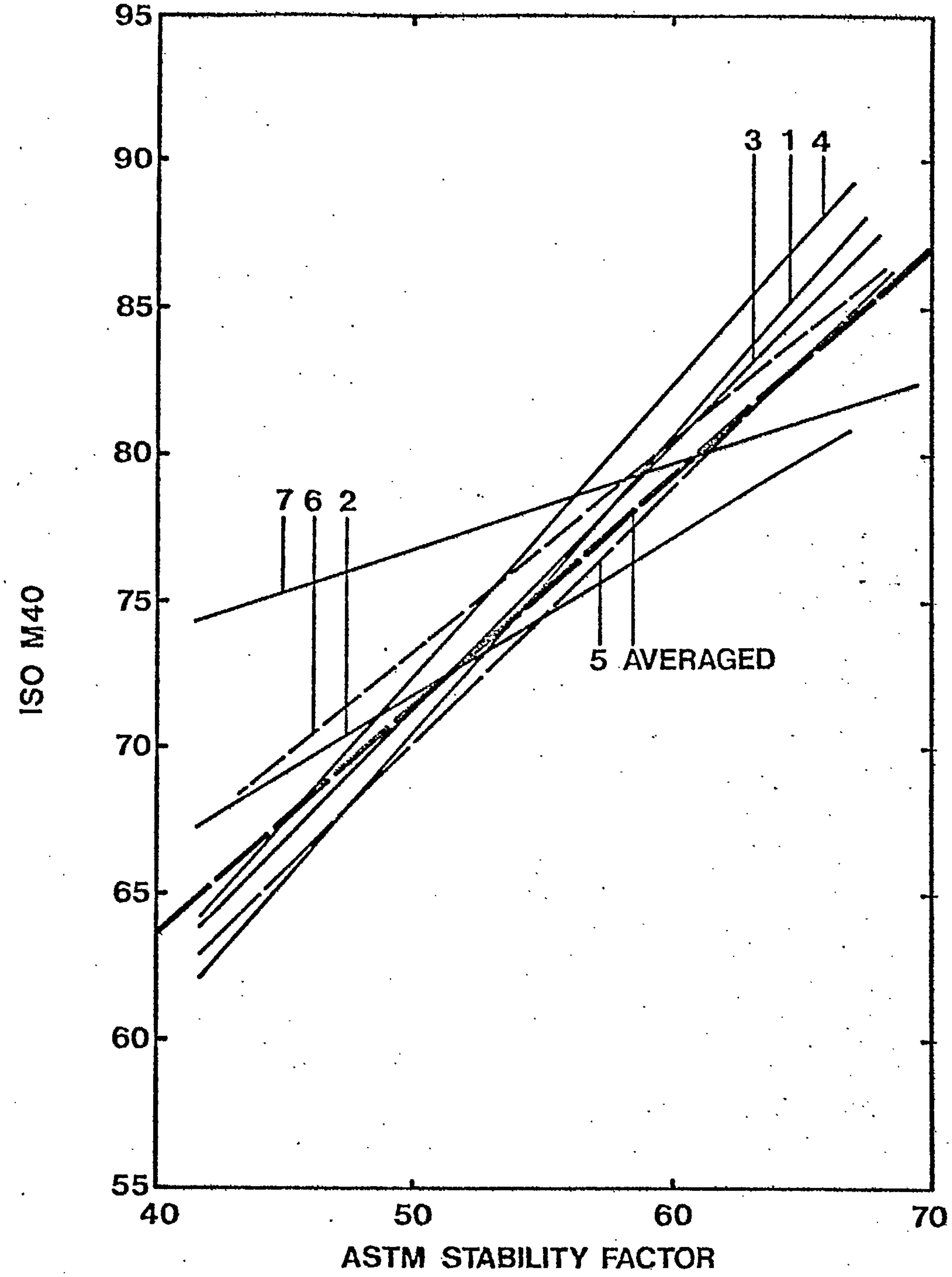

Figure 4. Various Regression Relationships between ISO M_{40} index and ASTM stability factor (31). (1=ref.36, 2=ref.41, 3=ref.31, 4=ref.42, 5=ref.35, 6=ref.35, 7=ref.25, Averaged=ref.34).

TABLE II

LEAST SQUARES REGRESSION EQUATIONS RELATIVE DIFFERENT COKE TUMBLER DRUM TEST STRENGTH INDICES *

No.	Y	X_1	X_2	Relationship	Ref	Comments
1.	S	DI^{30}_{15}	–	$Y=59.7-\frac{(3.55-0.03784X_1)^{1/2}}{0.01892}$	40	r = 0.94; n = 182
		DI^{150}_{15}	–	$Y=76.5-\frac{(2.81-0.03268X_1)^{1/2}}{0.01634}$	40	r = 0.90; n = 182
		DI^{30}_{15}		$Y=\frac{X_1^{2.56}}{1,442}-20.1$	38	rearranged equations of M_{40}, S and DI^{30}_{15}
2.	S	M_{40}	–	$Y=X_1-20.1$	36	n ≃30
				$Y=1.58X_1-64.3$	35	r = 0.65; n = 18
				$Y=1.32X_1-43.9$	34	calculated from averaging of relationships in ref.25
				$Y=1.88X_1-84.6$	41	95% limits ±5.5
				$Y=1.1X_1-28.8$	31	
				$Y=0.91X_1-13.9$	42	
				$Y=1.13X_1-29.4$	35	r = 0.898; n = 16
				$Y=3.2X_1-198.9$	25	
3.	S	M_{10}	–	$Y=-2.62X_1+73.9$	36	n ≃30
4.	H	M_{10}		$Y=(-)0.287X_1+68.6$	36	
				$Y=(-)7.41X_1+$ 127.1	35	r = 0.68; n = 18
				$Y=(-)3.45X_1+$ 94.1	35	r = 0.68; n = 16
				$Y=-0.549X_1+74.4$	31	
				$Y=-1.41X_1+79$	-	AVG. OF 3 PREVIOUS RELATIONSHIPS
5.	DI^{30}_{15}	M_{40}	–	$Y=17.14X_1^{0.39}$	36	
				$Y=0.317X_1+69$	38	
				$Y=0.30X_1+70.07$	33	r = 0.81; n = 90
6.	DI^{150}_{15}	M_{40}		$Y=0.68X_1+26.07$	33	r = 0.90; n = 29
7.	DI^{30}_{15}	M_{10}		$Y=-1.54X_1+103$	36	n ≃30
				$Y=-1.01X_1+103$	38	
				$Y=-0.97X_1+102.4$	33	r = 0.68; n = 90
8.	DI^{150}_{15}	M_{10}		$Y=-2.37X_1+102.2$	33	r = 0.64; n = 29

(cont'd)

TABLE II (cont'd)

9.	DI^{30}_{15}	M_{40}	M_{10}	$Y=0.243X_1-0.481X_2+78.8$	33	r = 0.87; n = 90
10.	DI^{150}_{15}	M_{40}	M_{10}	$Y=0.605X_1-0.666X_2+39.1$	33	r = 0.92; n = 29
11.	DI^{30}_{15}	S	–	$Y=56S^{0.14}$	31	
12.	M_{40}	DI^{30}_{15}		$Y=2.4X_1-147$	–	Averaged from Fig.5
13.	M_{10}	DI^{30}_{15}		$Y=-0.84X_1+87.3$	–	Averaged from Fig.5

*S = ASTM Stability Factor; H = ASTM Hardness Factor

n = number of samples studied; r = regression correlation coefficient the sampling point for the coke may also lead to different correlations as skip coke is smaller and has been stabilized (20). Coke oven operating conditions may also influence the comparative results. Increases in the bulk density of the coke oven charge in pilot scale tests lead to an increase in the resulting coke ASTM stability factor (3) but may either increase or decrease the resulting coke M_{40} index (45). Different levels of sensitivity can also lead to poor correlations. Studies at CANMET suggested that the JIS DI^{30}_{15} index is a less sensitive coke strength parameter than the ASTM stability factor (3,26). Repeatability of tests has also been considered and opposing opinions exist (3,23, 24,26). The JIS repeatability is felt to be poorer than for the ASTM or ISO methods (23). However, efforts have been made in Japan to determine the most reproducible tests between the laboratories by calculating a signal to noise ratio (S/N) (24,32). This ratio reflects both the repeatability and sensitivity of the test. All the tumbler tests had approximately the same S/N ratio, but the JIS test had the best repeatability and the ASTM test had the lowest repeatability between samples (32).

The authors assume the overall relevance of coke tumbler tests and other coke quality parameters to the blast furnace will be covered in other papers. However, some points are worth considering with respect to ambient temperature tumbler testing of coke as it relates to coke performance in the blast furnace. The amount of work necessary to reduce skip coke to tuyere sized coke has been considered by several authors (46,47,48). In terms of tumbler drum revolutions, no matter what coke tumbler test was used, the numbers vary between 30 - 600 revolutions with most estimates averaging about 200 - 500 revolutions. Interestingly, it has been shown that the coke being tested in such tumbler tests undergoes an initial fast rate of size reduction which then decreases in a linear fashion (46,47,49). The initial size reduction takes about 25 - 100 revolutions (46,49). This suggests that a tumbler test should be about 200 - 500 revolutions in duration both to simulate coke degradation between the skip and tuyeres and to permit the initial rate of size reduction to stabilize. This corresponds to the revised JIS DI^{150}_{15} and ISO IRSID indices, but is far less work on the coke than is conducted in the ASTM (1400 revolutions) and more than in the Micum (100 revs) or JIS DI^{30}_{15} (30 revs) methods. Interestingly, the Coke Evaluation Project sponsored by the American Iron and Steel Institute and American Coke and Coal Chemicals Institute in 1952, concluded that only 400 revolutions were necessary to obtain the same test sensitivity (50) and serious consideration is being given to com bining the ISO Micum and IRSID standards (22). *

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ABSTRACT

Coke quality is assessed from its chemical composition, including ash, sulphur, etc, and its physical properties, usually size and strength. For metallurgical coke destined for the iron blast furnace, coke strength is measured by an index derived from standard tumbler degradation tests on coke. Such indices are perhaps the most useful of the coke quality parameters as they correlate with blast furnace performance. For most countries, methods of analysis for coke chemical composition and sizing give similar results, but standard methods of determining coke strength indices are quite different and tend to yield dissimilar values. Knowing how the indices from different standard tests are related is important because of increasing international trade in coke and increasing global developments in technology that influence, or are affected by, coke strength. This paper reviews work that relates coke strength indices obtained from some of the most common international tumbler strength tests - namely the North American ASTM, European ISO and Japanese JIS methods. Comparisons indicate that correlations do exist between the different methods but they are generally not precise. Although the correlations can be used for converting a test result from one method to another, testing with a specific method still appears to be required to assess reliably the strength of a given coke sample for the specified method.

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