LIST OF STANDARD METHODS FOR TESTING

Description	**Standard Procedure**
Size Distribution of Coals	JIS M 8811
Hardgrove Grindability Index (HGI)	ASTM D 409-93
Proximate Analysis of Coal and Coke	ASTM D 3173-92, 3174-93 and 3175-93
Elemental Analysis of Coal and Coke	ASTM D 3176 – 93
Total Sulphur in Coal and Coke	In LECO analyser by comparison with Internationally certified standards ASTM D 3177 – 93
SiO_2 in Coal and Coke Ash	ASTM D 2795 – 91
Other Ash Chemistry Components Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, ZnO, MnO, TiO_2	Plasma Spectrophotometry by comparison with Internationally certified standards
SO_3 in Coal and Coke Ash	In LECO analyser by comparison with Internationally certified standards
Analysis of Macerals in Coals	ASTM D 2799 – 94
Mean Max Reflectance of Coals	ASTM D 2798 – 91
Sole-Heated Contraction	ASTM D 2014 – 90
Gieseler Plastometer (Frico)	ASTM D 2639 – 90
Free Swelling Test (FSI) (CSN)	ASTM D 720 – 91
Dilatometer Audibert – Arnu	JIS M 8801
Size Distribution of Cokes	JIS M 8811 (ASTM D 293-93)
Drum Index (DI)	JIS K 2151
Coke Textures (Microscopy)	NBR 12636-92 and NBR 12637-92
Coke Strength after Reaction (CSR)	JIS K 2151 (NSC development)
Micum Slope (Extended ½ Micum)	USIMINAS / TEESSIDE Laboratories

FORECAST OF JELLINBAH'S CSR

1 INTRODUCTION

Forecast of Coke Strength after Reaction (CSR) from coal blends at USIMINAS is currently made through an equation in which one of the main variables is the Coke Reactivity Index (CRI) itself on cokes obtained from pilot oven carbonisation of the individual blend components. Coals of poor coking characteristics do not yield enough agglomerate to permit such CRI determination.

The objective of this study was to estimate the CRI of Jellinbah coal (JE) of poor agglomerating properties (FSI/CSN approximately 2), based on regression analysis derived from binary blends of JE and an MV Australian coking coal (MV).

2 EXPERIMENTAL

JE was introduced at an increasing percentage in binary blends of JE and MV whose samples were representatively collected under stopped-conveyor procedure at USIMINAS coal stock yard. Both JE and MV were duly crushed to the same level used at industrial oven batteries ie. 81.2% and 89.8% < 2.38 mm, respectively.

Carbonisation tests were carried out in the 30 kg pilot oven existing at USIMINAS R&D Centre under conditions which accurately simulate coking conditions for the gravity-charged, 4m high industrial ovens of Battery 1. The cokes thus produced were tested for strength (DI^{150}_{15}) and CRI/CSR. The results obtained for the binary blends and respective cokes are shown in Table 1 below.

Blends Coal/Coke Parameters	A	B	C	D	E
Mid Vol (%)	100	75	50	25	Nil
Jellinbah (%)	Nil	25	50	75	100
TOTAL	100	100	100	100	100
DI^{150}_{15} (%)	79.7	78.9	63.4	*	**
CRI (%)	17.8	24.9	31.4	38.5	**
CSR (%)	68.8	66.3	49.7	22.6	**

* Insufficient volume of coke for testing
** Blend did not form a coherent *lump coke*

3 CRI FORECAST

- The coke resulting from blend D (75% JE) showed low physical characteristics and did not yield enough volume to permit determination of drum tests.

- The blend having 100% JE blend did not yield a consistent lump coke.

CRI can be considered linearly additive for binary blends as widely known in literature and so it was for the blends JE/MV. Therefore, the extrapolation of CRI values through the respective regression equation can be accepted as fair and accurate as shown in Figure 9 below which does show a high correlation coefficient (r^2). Jellinbah's CRI calculated as described equals to 45.3%.

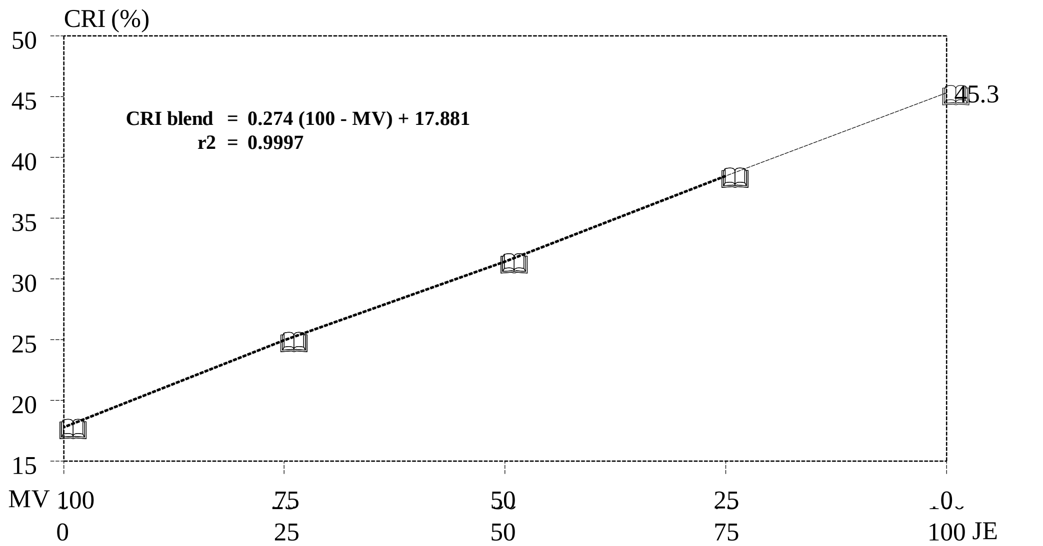

Figure 9. Behaviour of JE's CRI in binary blends with MV coal

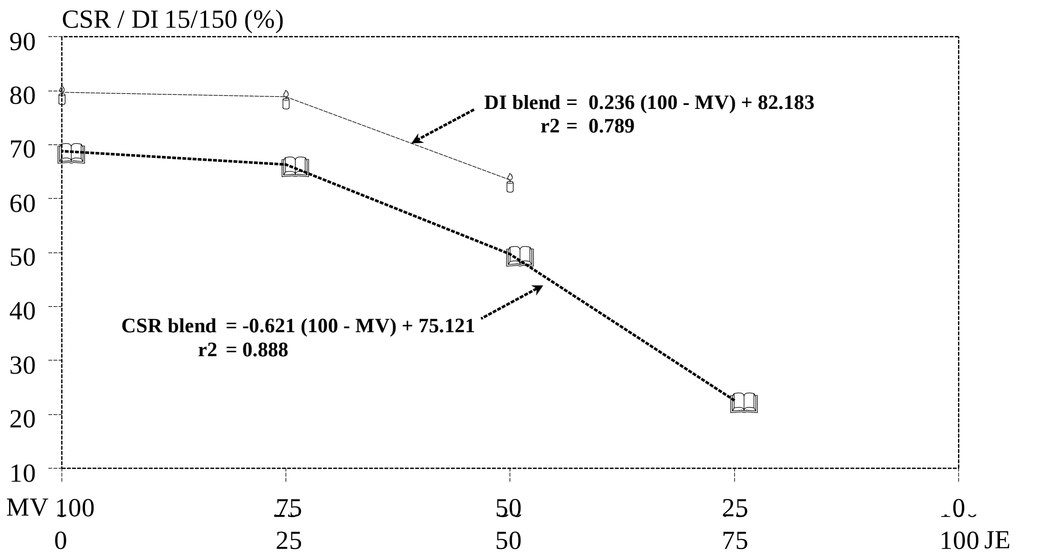

Figure 10. Behaviour of DI^{150}_{15} and CSR of binary blends with JE

In summary, it is not recommended to report a CSR number for JE and rather consider just the CSR forecast based on binary blend extrapolation (Figure 10).

However, if we can consider acceptable the well established correlation between CSR and CRI developed by ACIRL as given below,

$$CRI = 64.8288 - 0.6849 * CSR \qquad \text{for } n=463 \text{ and } r^2 = 0.87$$

Then CSR of JE would be 28.5%.

It is important to note that the results of simple replacement of MV Australian coal (the same used in the whole laboratory work) by Jellinbah in binary blends does repeat the good results found when JE replaced a coal of similar rank in normal blends of high/medium/low volatile coals which proves Joh's theory that blend characteristics (whether in the fluidity control or in the rank control region) plays a major role in any replacement.

1 SIZE DISTRIBUTION OF INDIVIDUAL COALS TO BE BLENDED (AFTER PULVERISATION)

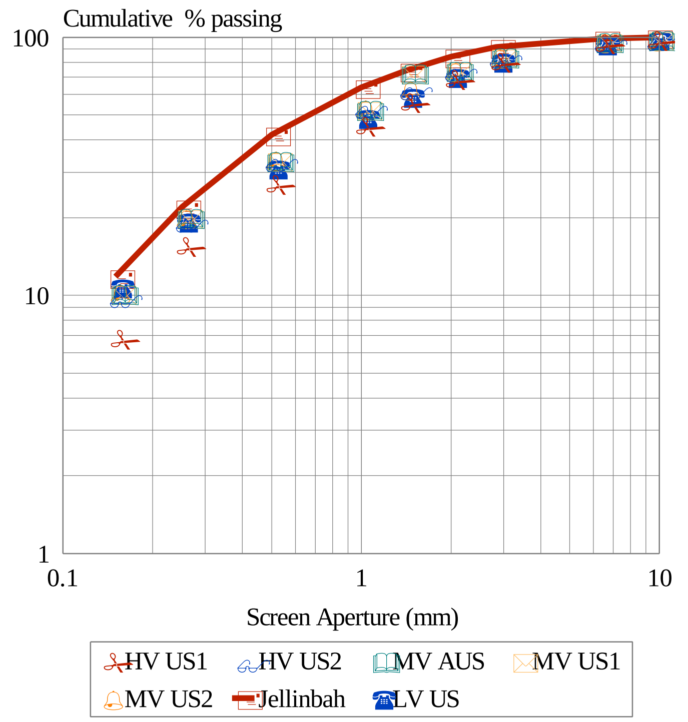

Figure 11. Pulverisation of Individual Coals

Pulverisation of the individual coals (% < 2.83 mm) was kept in the range 81 - 84%, with the exception of Jellinbah which could only be crushed to 91%.

2 PULVERISATION OF EACH BLENDING SERIES

Blend	**I**	**II**	**III**	**IV**
Charge	**Mass % < 2.83 mm**			
1	85.6	85.9	86.4	84.4
2	85.1	86.6	82.9	84.6
3	85.6	82.5	86.4	86.0
4	84.8	86.2	85.6	85.6
5	84.1	86.6	84.7	85.4
6	85.4	85.3	84.2	85.5
Average	85.1	85.5	85.0	85.2

Table 13 . Pulverisation of selected blends

PROCEDURE FOR ½ MICUM AND EXTENDED MICUM TEST

1 PROCEDURE

The ½ Micum Test is used to determine the so-called **"Micum Slope"** of a 25 kg standard coke sample whose size distribution is intended to represent the size distribution of the coke actually charged into blast furnaces. It is obtained through weighted average reconstitution (Test sample).

The test sample is charged into a drum of 1 m diameter and 500 mm width which rotates at 25 rpm. Tumbling is successively stopped at 100, 300, 500 and 800 revolutions so that size distribution and **Arithmetic Mean Size (AMS)** are determined for the specific instance.

The relationship between $\mathbf{10^4/(AMS)^2}$ and the number of rotations is a perfect linear fit whose slope times 100 gives the "Micum Slope" of the test sample.

Extrapolation of the linear fit to the y-intercept (zero rotations) gives the **Fissure-Free Size of Coke (D_{ff}** or **FFS)** thus meaning the size in which there would be no degradation due to abrasion but rather to volumetric breakage or fragmentation.

2 EVALUATION OF MICUM SLOPE

Micum Slope is a measure of abrasion resistance of coke particles under test ie.it just considers a fully stabilised coke since the initial reduction by fragmentation is not considered. European mills consider Micum Slope a better way to evaluate abradability than traditional M_{10}. They suggest that the latter does include some fragmentation effect.

A satisfactory range for Micum Slope of BF cokes is 0.5 - 0.8, the lower the number the higher the abrasion resistance. Cokes produced from blends where HV coal participation is significant tend to exhibit higher figures for Micum Slope that is higher abradability. On the other hand, cokes produced from MV/LV rich blends tend to show the opposite trend.

As an example, average Micum Slope of British Steel's Scunthorpe coke batteries was 0.58 (Dawes Lane ovens) and 0.62 (Appleby) during the 1992/1993 period for an average rank of 1.26 $R_{o\ max}$ for the blend.

3 EVALUATION OF FISSURE-FREE SIZE

As said before, fissure-free size was developed to simulate a maximum obtainable size (theoretical) for stabilised cokes. The ESM believe Fissure-Free Size approximately represents the size of stabilised industrial cokes at BF stockline which is then considered a more suitable controlling parameter.

4 EVALUATION OF STABILISATION DEGREE

Quite low stability values (S < 50%) characterise a coke of low impact resistance thus detrimental to blast furnace permeability. European mills that pursue high coal injection rates in their BFs require Stability higher than 90%; internationally traded cokes, however, commonly have Stability lower than 80%, although a 70% minimum result could be accepted for an "all coke" BF operation.

5 ANALYSIS OF RESULTANT COKES (EXTENDED MICUM TEST)

A detailed analysis of the 4 cokes produced is given below in Tables 14, 15, 16 and 17. Figure 12 shows the best fit for Micum Slope. The slight displacement of Micum Slope to higher values (lower abrasion resistance) from cokes I to IV is not enough to confirm this statement and may be within the expected variation.

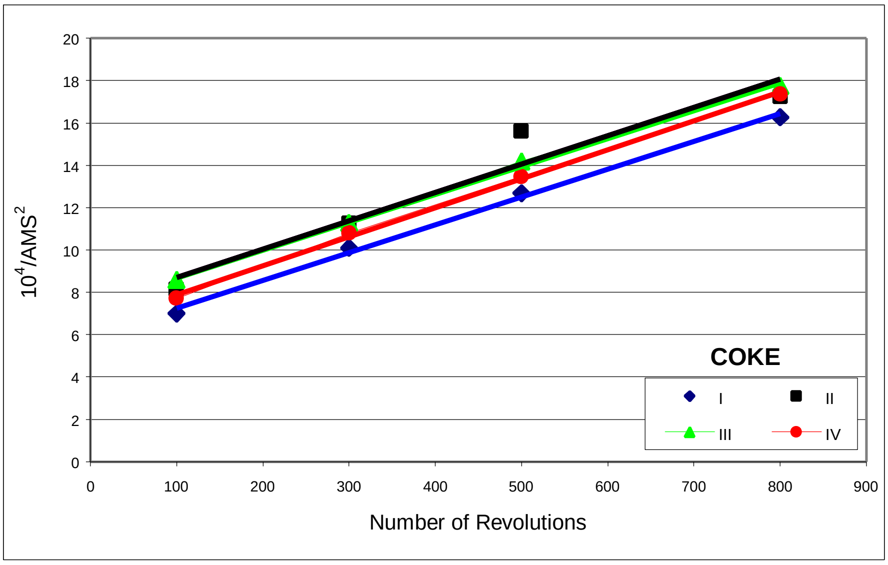

Figure 12. Best fit for micum slope of resultant cokes

5.1 Coke I (from Blend I – see p.14)

Coke Size Distribution		Reconstitution of Test Sample	
Screen Opening (mm)	**Cumulative (%)**	**Screen Opening (mm)**	**Weight (kg)**
80	6.1	80	1.6
60	26.4	60	5.4
40	76.2	40	13.2
30	88.4	30	3.3
20	94.1	20	1.5
10	95.8	10	25.0
0	100.0		

Size Distribution				
	100 revs.	**300 revs.**	**500 revs.**	**800 revs.**
Screen Opening (mm)	**% Retained, cumulative**			
80	0.6	0	0	0
60	4.7	2.6	2.1	1.3
40	**45.2**	**27.1**	**18.2**	**12.1**
20	89.5	80.1	73.6	65.7
10	92.9	85.1	79.6	72.4
0	100.0	100.0	100.0	100.0

Opening (mm)	120-100	100-80	80-60	60-40	40-20	20-10	10-0	AMS (mm)	$10^4/AMS^2$
Whole Coke	0	6.1	20.3	49.8	17.9	0	0	50.0	4.0
100 revs.	0	0.6	4.0	40.5	44.4	3.3	7.2	37.8	7.0
300 revs.	0	0	2.6	24.5	53.0	5.0	14.9	31.5	10.1
500 revs.	0	0	2.1	16.1	55.4	5.9	20.5	28.1	12.7
800 revs.	0	0	1.3	10.8	53.9	6.7	27.6	24.8	16.3

$y = 0.0131\ X + 5.9259\ \ (r^2 = 0.9962)$

FFS = 41.1 S = 82.2

Table 14. Size distribution, sample reconstitution and calculation of micum slope and stability of coke I

5.2 Coke II (from Blend II – see p.14)

Coke Size Distribution		**Reconstitution of Test Sample**	
Screen Opening (mm)	**Cumulative (%)**	**Screen Opening (mm)**	**Weight (kg)**
80	1.6	80	0.4
60	18.6	60	4.6
40	69.1	40	13.6
30	84.7	30	4.2
20	92.6	20	2.2
10	95.0	10	25.0
0	100.0		

Size Distribution				
	100 revs.	**300 revs.**	**500 revs.**	**800 revs.**
Screen Opening (mm)	**% Retained, cumulative**			
80	0.0	0	0	0
60	1.0	0.4	0.4	0.4
40	**35.8**	**21.1**	**11.1**	**8.9**
20	89.3	80.0	69.3	66.0
10	92.9	85.2	76.1	73.2
0	100.0	100.0	100.0	100.0

Opening (mm)	**120-100**	**100-80**	**80-60**	**60-40**	**40-20**	**20-10**	**10-0**	**AMS (mm)**	**$10^4/AMS^2$**
Whole Coke	0	1.6	17.0	50.4	23.6	0	0	45.7	4.8
100 revs.	0	0	1.0	34.7	53.6	3.5	7.1	35.0	8.1
300 revs.	0	0	0.4	20.6	58.9	5.3	14.8	29.8	11.3
500 revs.	0	0	0.4	10.7	58.2	6.8	23.9	25.3	15.6
800 revs.	0	0	0.4	8.5	57.1	7.2	26.8	24.1	17.2

$y = 0.0129 X + 7.0871$ ($r^2 = 0.9964$)

FFS = 37.6 S = 82.3

Table 15. Size distribution, sample reconstitution and calculation of micum slope and stability of coke II

5.3 Coke III (from Blend III – see p.14)

Coke Size Distribution		Reconstitution of Test Sample	
Screen Opening (mm)	**Cumulative (%)**	**Screen Opening (mm)**	**Weight (kg)**
80	5.8	80	1.5
60	23.5	60	4.8
40	72.9	40	13.3
30	86.1	30	3.6
20	92.9	20	1.8
10	95.2	10	25.0
0	100.0		

Size Distribution				
	100 revs.	**300 revs.**	**500 revs.**	**800 revs.**
Screen Opening (mm)	**% Retained, cumulative**			
80	0	0	0	0
60	2.4	0.6	0	0
40	**31.2**	**22.8**	**15.3**	**9.8**
20	88.2	78.1	71.5	64.1
10	91.7	83.6	77.6	71.5
0	100.0	100.0	100.0	100.0

Opening (mm)	120-100	100-80	80-60	60-40	40-20	20-10	10-0	AMS (mm)	$10^4/AMS^2$
Whole Coke	0	5.8	17.7	49.4	20.0	0	0	48.3	4.3
100 revs.	0	0	2.4	28.8	57.0	3.5	8.3	34.1	8.6
300 revs.	0	0	0.6	22.2	55.4	5.5	16.4	29.7	11.3
500 revs.	0	0	0	15.3	56.1	6.2	22.4	26.6	14.2
800 revs.	0	0	0	9.8	54.2	7.4	28.5	23.7	17.8

$y = 0.0132 X + 7.3657$ ($r^2 = 0.9982$)

FFS = 36.9 S = 76.3

Table 16. Size distribution, sample reconstitution and calculation of micum slope and stability of coke III

5.4 Coke IV (from Blend IV – see p.14)

Coke Size Distribution		Reconstitution of Test Sample	
Screen Opening (mm)	**Cumulative (%)**	**Screen Opening (mm)**	**Weight (kg)**
80	4.1	80	1.1
60	23.4	60	5.2
40	72.8	40	13.4
30	85.7	30	3.5
20	92.4	20	1.8
10	94.6	10	25.0
0	100.0		

Size Distribution				
	100 revs.	**300 revs.**	**500 revs.**	**800 revs.**
Screen Opening (mm)	**% Retained, cumulative**			
80	0.0	0	0	0
60	1.6	0	0	0
40	**41.5**	**26.6**	**18.1**	**11.3**
20	88.1	78.3	72.1	64.1
10	91.8	83.6	78.2	71.3
0	100.0	100.0	100.0	100.0

Opening (mm)	**120-100**	**100-80**	**80-60**	**60-40**	**40-20**	**20-10**	**10-0**	**AMS (mm)**	**10^4/AMS^2**
Whole Coke	0	4.1	19.3	49.4	19.6	0	0	47.8	4.38
100 revs.	0	0	1.6	39.9	46.6	3.7	8.2	36.0	7.71
300 revs.	0	0	0	26.6	51.7	5.4	16.4	30.4	10.8
500 revs.	0	0	0	18.1	54.0	6.1	21.8	27.3	13.5
800 revs.	0	0	0	11.3	52.8	7.1	28.8	24.0	17.4

$y = 0.0137\ X + 6.5195\ (r^2 = 0.9982)$

FFS = 39.2 S = 82.0

Table 17. Size distribution, sample reconstitution and calculation of micum slope and stability of coke IV

SIZE DISTRIBUTION AND SAMPLE RECONSTITUTION FOR DI $^{150}{}_{15}$

COKE SIZE DISTRIBUTION				
Screen Opening (mm)	**% Retained, cumulative**			
	Coke I	**Coke II**	**Coke III**	**Coke IV**
100	0	0	0	0
80	0	0	0	0
75	0	0	0	0
60	9.2	4.4	8.0	12.0
50	25.7	22.9	24.2	31.6
40	55.3	55.4	54.9	62.8
30	78.9	81.7	82.3	86.0
25	84.5	88.9	87.7	90.9
15	92.2	95.3	94.0	96.2
10	93.6	96.4	95.1	96.9
0	100.0	100.0	100.0	100.0
Reconstitution of Test Sample (kg)				
100	0	0	0	0
80	0	0	0	0
75	0	0	0	0
60	1.1	0.5	0.9	1.3
50	2.0	2.1	1.9	2.2
40	3.5	3.6	3.5	3.4
30	2.8	3.0	3.1	2.6
25	0.6	0.8	0.6	0.5
Total	10.0	10.0	10.0	10.0
DRUM INDEX ^{150}				
50 (DI $^{150}{}_{50}$)	0.0	0.0	0.5	0.0
25 (DI $^{150}{}_{25}$)	52.3	51.1	52.8	50.1
15 (DI $^{150}{}_{15}$)	**80.6**	**80.2**	**80.1**	**79.6**

Table18. Size distribution and sample reconstitution for DI $^{150}{}_{15}$

MICROTEXTURES OF COKED JELLINBAH

Photo Micrograph Number	Description
1	Inorganic Inclusion
2	Flow-type (indicates fusion; typical of LV coals); Anisotropic Inert
3	Anisotropic Inert
4	Anisotropic Inert and Flow-type
5	Anisotropic Inert and Basic Anisotropy (typical of high rank coals)
6	Anisotropic Inert and Isotropic (altered fusinite)
7	Isotropic (altered fusinite)
8	Basic Anisotropy
9	Anisotropic Inert and Flow Type
10	Isotropic (altered fusinite) and Flow-Type
11	Flow-Type
12	Flow-type and Anisotropic Inert
13	Flow-type
14	Flow-type