Correlations among some Physical Properties of Coke—a Statistical Study

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VARIOUS tests are employed in different countries for assessing the physical properties of coke. While the Shatter and the B.S. Abrasion tests are in general use in the United Kingdom, European practice is to employ the Micum test. In the U.S.A., the Haven test is employed in addition to a Shatter test similar to that of the U.K. The Indian steel plants carry out the Shatter, Micum and Haven tests. One of these plants uses a modified form of the original Breslau test in place of the standard Micum test[1].

In an earlier paper[2], a relationship has been established between the Micum and Breslau test results. The Micum test has lately been recommended by the International Organisation for Standardisation (ISO) for universal adoption. It is believed that this single test is capable of giving information obtainable from the other tests. The small amount of coke often obtained from small scale experiments does not permit all the recommended physical tests to be carried out. In laboratories not equipped with all the physical testing machines, it is often necessary to have an idea of the comparative results obtainable from the different tests.

A statistical study has, therefore, been made to ascertain the degree of correlation existing between the different physical test indices, and regression equations have been suggested for estimating some of them from known values of the others.

Relevant data were collected from various published and unpublished work of the Central Fuel Research Institute, Jealgora, and the Coal Blending and Coking Research Sub-Committee, Jamshedpur.

Discussion on the regression equations

Correlation between Shatter and Micum Indices: The following three relationships have been established applying the Method of Least Squares:

Formula No.

1. Shatter Index on 2″ (S_2) and Micum Index on 40 mm (M_{40}) (No. of data 231) — $S_2 = 35{\cdot}94 + 0{\cdot}61\,M_{40}$ ($r = +0{\cdot}75$)

2. Shatter Index on 1½″ ($S\,1\frac{1}{2}''$) and Micum Index on 40 mm (M_{40}) (No. of data 183) — $S\,1\frac{1}{2}'' = 53{\cdot}06 + 0{\cdot}50\,M_{40}$ ($r = +0{\cdot}87$)

3. Shatter Index through ½″ ($S\,\frac{1}{2}$) and Micum Index through 10 mm (m_{10}) (No. of data 159) — $S\,\frac{1}{2} = 0{\cdot}17 + 0{\cdot}24\,M\text{-}10$ ($r = 0{\cdot}50$)

The relationships are found to be statistically significant from analysis of variance given in the appendix.

The degree of relationship as measured by r (i.e. the coefficient of correlation) shown against each of the equations is observed to be fairly high in each case.

From the three formulae 1, 2 and 3, it may be seen that better prediction is possible of the values of the Shatter Index on 1½″ from known values

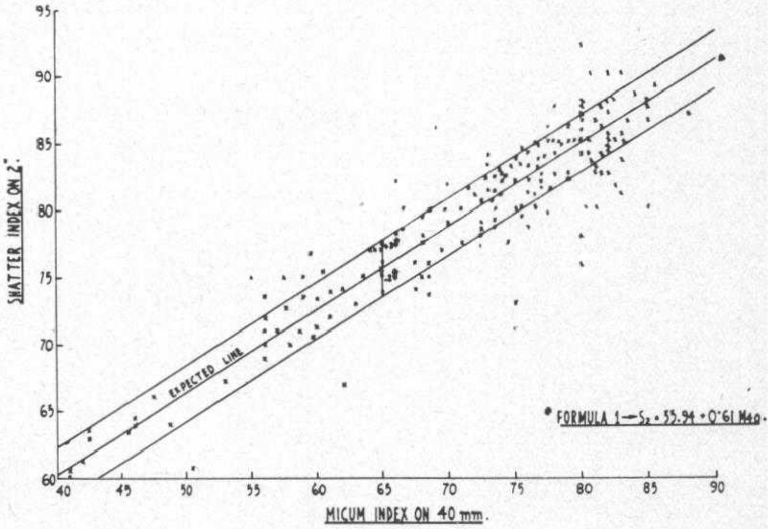

Fig. 1.

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1 Das Gupta, N. N., Rao, V. V., and Sinha S. N.—"Physical Testing of Coke", F.R.I. News, Vol. 4, Dec., 1954, p. 7–15.

2 Ghosal, A., Sinha, B. K., Sinha, N. C, Ghosh, S. R., Das Gupta, N. N. and Lahiri, A.—"Statistical Study of Some Carbonization Tests Data," (Paper presented at the Symposium on Coal Carbonization, C.F.R.I., March 1957)

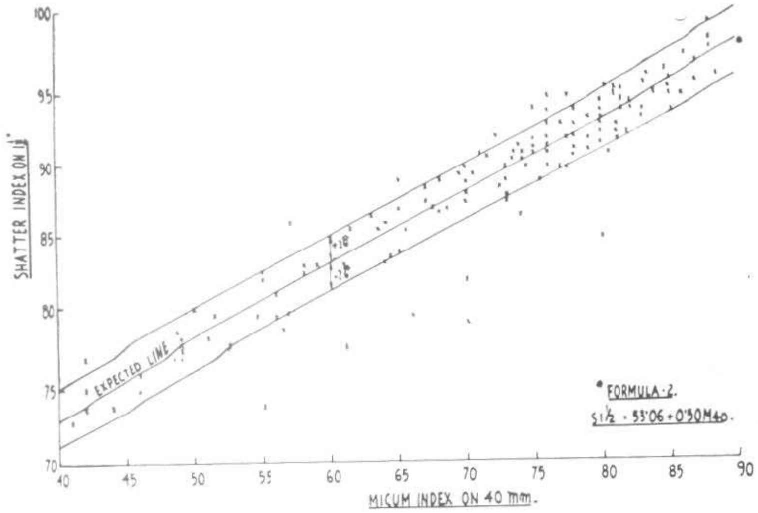

Fig. 2.

of Micum Index on 40 mm due to the higher degree of correlation between the variables. *This fact once again justifies the adoption of Shatter Index on 1½" as a measure of the Strength Index in preference to the Shatter Index on 2".*

On the other hand, the prediction of the values of Shatter Index through ½" from the Micum Index through 10 mm will not be very precise, although this correlation is also statistically significant. The small quantity of coke (50 lb) used in the Shatter test and the narrow range (about 2 to 4%) in which the results (*S* ½) generally lie limit the accuracy of the test results.

Tables I(*a*) and I(*b*) give some of the calculated and actually determined values of Shatter Indices against actually determined values of Micum Indices varying between 40 and 90.

It is observed from Table I(*a*) that in the case of the regression of *S* 1½ on M_{40} there is considerable difference between the experimental and expected values of *S* 1½ when the values of M_{40} are less than 65 but the agreement is better when the values of M_{40} are higher. With a view to fitting a better equation, for the Micum values less than 65, the original data along with a few more, were divided into two groups, namely, (I) those with M_{40} values of 65 and above and (II) those with M_{40} values less than 65. The new equation for the first group is found to yield almost identical figures for expected values of *S* 1½, as obtained from the original equation. The value of correlation coefficient is almost the same as observed for the overall data, being + 0·9 in the present case as against + 0·87 in the former. But the equation for the second group is an improvement over the original equation in predicting values of *S* 1½ from $M_{40} < 65$. Both the relationships are found to be statistically significant from the analysis of variance (tables given in the appendix). The scatter diagram with the expected regression line and its "tolerance range" is also shown in Fig. 4 for the second group. The expected *S* 1½, calculated by the equation for the two separate groups as also from the original equation are shown in Table I(*c*).

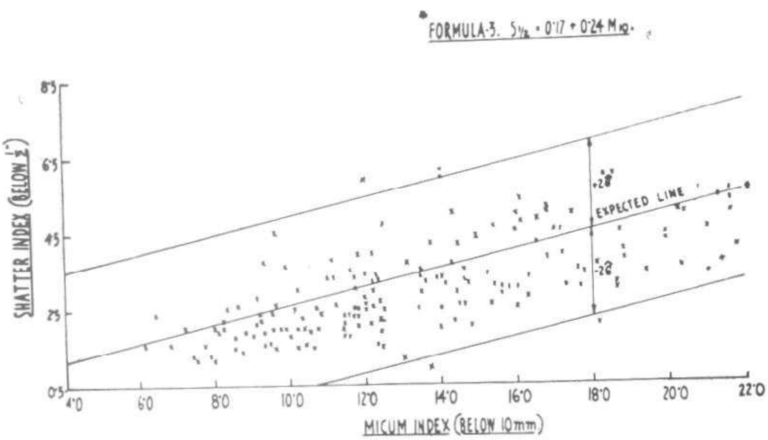

Fig. 3.

TABLE I(*a*)

Correlation of shatter and micum indices.

Formula :

(1) $S_2 = 35{\cdot}94 + 0{\cdot}61\ M_4O$

(2) $S\ 1\tfrac{1}{2} = 53{\cdot}06 + 0{\cdot}5\ \ M_4O$

Sl. No.	Micum on 40mm. (M_{40}, determined.)	SHATTER INDEX: On 2 in. (S 2) expected from equation (1)	On 2 in. (S 2) determined	On 1½ in. (S 1½) expected from equation 2	On 1¼ in. (S 1½) determined
1.	29.1	62.8	32.8	67.6	57.8
2.	39.5	60.0	68.9	72.8	68.1
3.	41.8	61.4	60.1	74.0	77.3
4.	46.3	64.2	64.4	76.2	74.9
5.	50.5	66.8	60.8	78.3	71.5
6.	56.4	70.3	73.0	81.3	74.0
7.	66.1	76.3	82.8	86.1	89.9
8.	68.4	77.7	60.1	87.3	93.2
9.	74.9	81.6	80.0	90.5	89.0
10.	76.1	82.4	86.8	91.1	93.0
11.	79.0	84.2	86.5	92.6	93.0
12.	79.8	84.6	78.0	92.9	92.5
13.	80.1	84.8	88.4	93.1	96.1
14.	82.9	86.5	87.9	94.5	94.1
15.	83.3	86.8	80.9	94.7	93.5
16.	84.6	93.2	87.6	95.4	95.4
17.	84.6	87.0	87.5	95.5	95.3
18.	85.4	88.0	88.4	95.8	94.8

(1) $S\ 1\tfrac{1}{2} = 53{\cdot}06 + 0{\cdot}5\ \ M_{40}$ (overall equation $r = +\ 0{\cdot}87$)

(2) $S\ 1\tfrac{1}{2} = 44{\cdot}1 + 0{\cdot}62\ M_{40}$ ($M_{40} = 65$ and above $r = +\ 0{\cdot}90$)

(3) $S\ 1\ \tfrac{1}{2} = 40{\cdot}4 + 0{\cdot}72\ M_{40}$ ($M_{40} < 65$; $r = 0{\cdot}81$) (Data = 50)

TABLE I(b)

Formula (3): $S\frac{1}{2} = 0{\cdot}17 + 0{\cdot}24\ M_{10}$ (*No. of data 134*)

Serial No.	Micum index through 10 mm (M_{10}) determined	Shatter index	
		Through $\frac{1}{2}$ in. ($S\frac{1}{2}$) Expected from Equation 3	Through $\frac{1}{2}$ in ($S\frac{1}{2}$) determined
1.	6·8	1·8	1·6
2.	7·5	2·0	1·2
3.	8·0	2·1	2·0
4.	9·9	2·6	3·1
5.	10·1	2·6	2·5
6.	11·7	3·0	3·0
7.	12·0	3·1	2·5
8.	15·6	3·9	2·9

TABLE I(c)

Formula:

(1) $S\ 1\frac{1}{2} = 53{\cdot}06 + 0{\cdot}50\ M_{40}$ (overall equation)
(2) $S\ 1\frac{1}{2} = 44{\cdot}1 + 0{\cdot}62\ M_{40}$ (for $M_{40} > 65$)
(3) $S\ 1\frac{1}{2} = 40{\cdot}4 + 0{\cdot}72\ M_{40}$ (for $M_{40} < 65$)

Sl. No	M_{40}	S 1½ experimental	EXPECTED VALUES OF S 1½		
			By Equa. I.	By Equa. II. for $M_{40}>65$	By Equa. III for ($M_{40}<65$)
1.	23.1	57.8	64.6	-	57.0
2.	29.1	57.8	67.6	-	61.4
3.	33.9	66.8	70.1	-	64.8
4.	39.5	68.1	72.8	-	68.8
5.	41.8	77.3	74.0	-	70.5
6.	44.1	70.0	75.1	-	73.3
7.	46.3	74.9	75.2	-	73.3
8.	50.5	79.0	78.3	-	76.8
9.	56.4	74.0	81.3	-	81.0
10.	60.8	88.4	83.5	-	84.2
11.	66.1	89.9	86.1	85.1	-
12.	68.4	93.2	87.3	86.5	-
13.	70.0	90.4	88.1	87.5	-
14.	74.9	89.0	90.5	90.5	-
15.	76.1	93.0	91.1	91.3	-
16.	76.8	92.0	91.5	91.7	-
17.	79.0	93.0	92.6	93.1	-
18.	80.1	96.1	93.1	93.8	-
19.	82.9	94.1	94.5	95.5	-
20.	84.6	95.4	95.4	96.6	-

The Tables (I, II, III, IV and V) showing the analysis of variance for these formulae are given in the appendix and the tolerance range for 95% probability level for each of the equation is shown in the Figs. 1, 2, 3 and 4.

Correlation between Haven, B.S. Abrasion and Micum indices

The statistical relationship between (*i*) Haven stability factor on 1″ and B.S. Abrasion Index on 1″ (*ii*) B.S. Abrasion Index on 1/8″ and Micum Index through 10 mm and (*iii*) Haven hardness factor on ¼″ and Shatter Index through ½″ is given by the following three formulae:

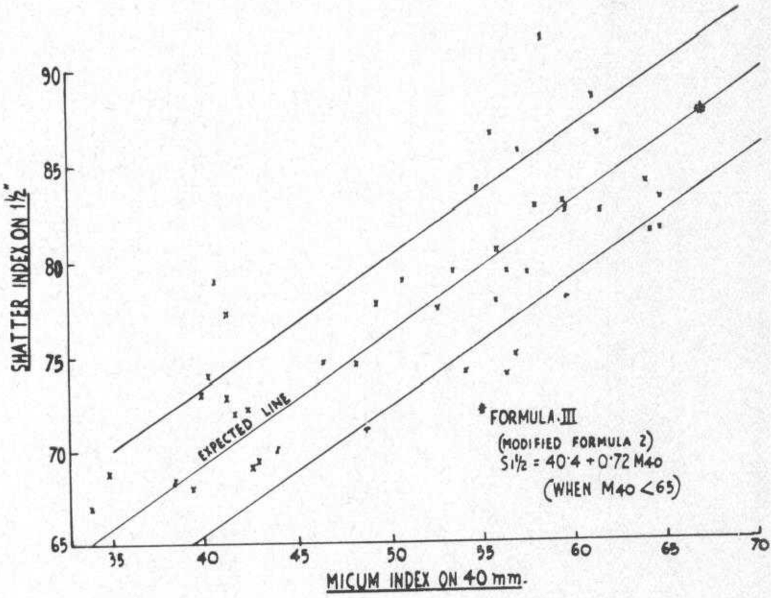

Fig. 4.

Formula No.

4. Haven Stability Factor on 1″ (H_1) and B.S. Abrasion Index on 1″ (Ab_1) (No. of observations = 100) — $H_1 = 1{\cdot}25\ Ab_1 - 31{\cdot}19$ ($r = +0{\cdot}81$)

5. B.S. Abrasion Index on 1/8″ ($Ab1/8$) and Micum Index through 10 mm (M_{10}) No. of observations = 100) — $Ab\ 1/8 = 93{\cdot}00 - 1{\cdot}74\ M_{10}$, ($r = -0{\cdot}85$)

6. Haven Hardness Factor on $\frac{1}{4}$″ ($H\frac{1}{4}$) and Shatter Index thro. ½″ ($S\frac{1}{2}$) (No. of observations = 134) — $H\frac{1}{4} = 68{\cdot}40 - 2{\cdot}75\ S\frac{1}{2}$, ($r = -0{\cdot}58$)

The degree of relationship as shown by r is again found to be statistically significant in each case and quite satisfactory though it is comparatively poor in the case of Formula 6 correlating the Hardness Factor from Haven test with the Shatter Index through ½″. From the nature of scatter of the points in Fig. 6 it is seen that a parabolic equation might be a better fit to the given data.

The Tables (VI, VII and VIII) showing the analysis of variance for these formulae are given in the Appendix and the "tolerance range" for 95% probability level for each of the equations is shown in Figs. 5, 6 and 7.

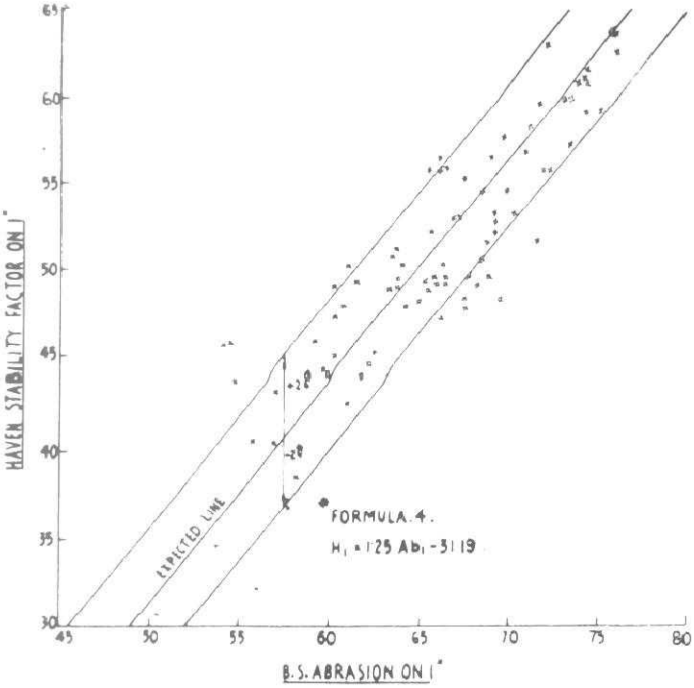

Fig. 5.

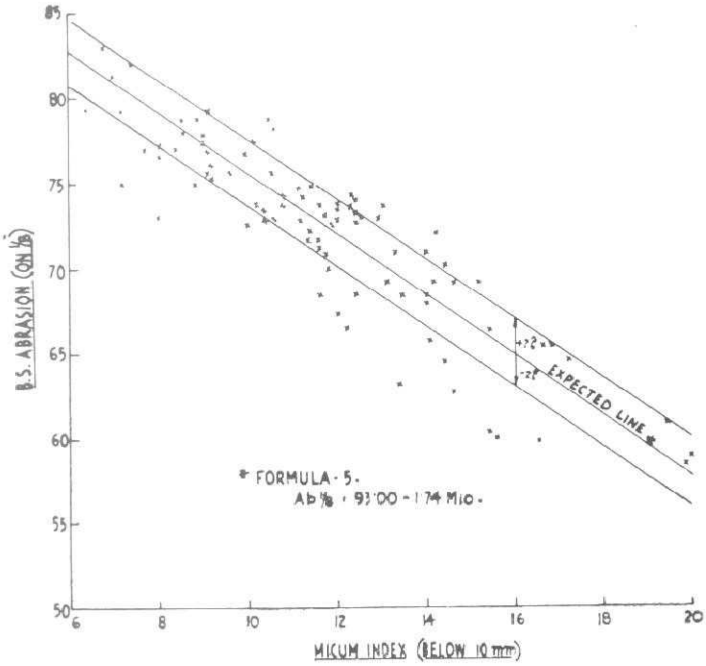

Fig. 6.

Table II shows some calculated and actually determined values of the properties under study.

It is worthwhile to mention here that no well-defined relationship could however be detected between Haven on 1″ and Shatter on 1½″ or between Micum on 40 mm and Haven on 1″.

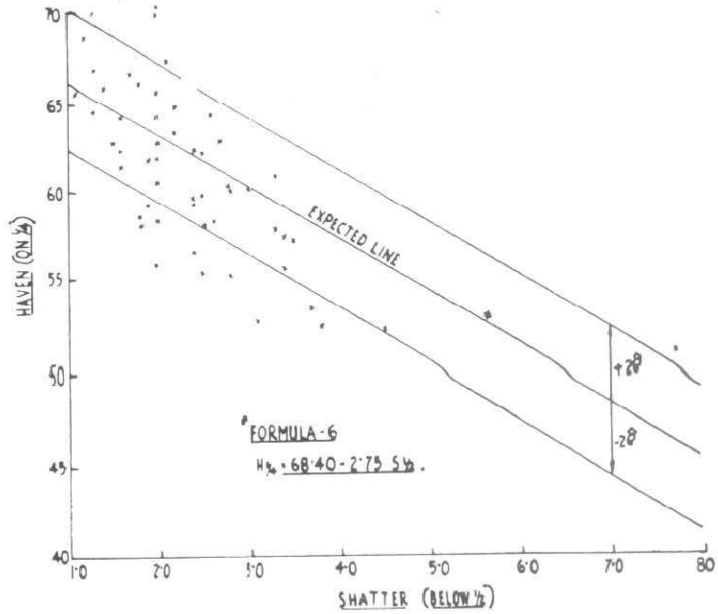

Fig. 7.

TABLE II

Correlation of Haven, B. S. Abrasion and Micum Indices

Formula : (4) $H_1 = 1{\cdot}25 \ Ab_1 - 31{\cdot}19$

(5) $Ab\ 1/8 = 93{\cdot}00 - 1{\cdot}74\ M_{10}$

(6) $H1/4 = 68{\cdot}40 - 2{\cdot}75\ S1/2$

Sl. No.	B. S. Abrasion on 1″ (Ab_1)	Haven on 1″ (H 1)		M_{10} (Determined)	B. S. Abrasion on 1/8″ (Ab 1/8″)		Shatter Index thro. 1/2″ (S 1/2 determined)	Haven on 1/4″ (H 1/4)	
		Determined	Calculated from Equa. 4		Determined	Calculated from Equa. 5		Determined	Calculated from Equa. 6
1.	37.8	17.9	16.1	6.8	83.0	81.2	1.6	70.7	64.4
2.	40.4	30.7	29.3	8.0	73.0	79.1	1.9	65.5	63.2
3.	50.4	30.1	31.8	10.4	72.9	74.9	2.3	45.4	62.1
4.	60.8	47.7	44.8	11.4	74.8	73.2	2.4	59.1	61.8
5.	61.0	42.6	44.1	11.8	68.3	72.5	2.5	55.1	61.5
6.	65.8	49.1	51.1	12.0	57.4	72.1	2.8	55.1	60.7
7.	66.1	55.6	51.4	13.5	59.7	69.5	3.0	47.8	60.1
8.	68.4	54.6	54.3	14.1	69.9	68.5	3.1	52.6	59.9
9.	69.9	57.7	56.2	14.2	67.9	68.6	3.5	57.3	58.8
10.	70.9	56.8	57.4	15.4	66.4	67.2	3.7	53.7	58.2
11.	71.2	58.1	57.8	16.5	60.0	64.3	4.0	49.5	57.4
12.	73.7	60.8	60.9	20.3	58.9	57.7	4.3	60.0	56.6
13.	74.1	59.0	61.4	24.0	50.8	51.2	7.7	50.9	47.2
14.	75.3	59.4	62.9	26.8	58.6	46.4	8.7	45.2	44.2
15.	76.0	74.6	63.8	26.7	57.1	46.5	10.8	45.7	38.7

Conclusion

The suggested regression equations show that it is possible to calculate fairly accurately the Shatter Indices of cokes from a knowledge of their Micum Indices.

The Stability Factor of coke as normally assessed by the percentage of material remaining on 1″ from the Haven tests can be expressed equally well by the percentage of material remaining on 1″ from the B.S. Abrasion test. The Micum Index through 10 mm and B.S. Abrasion Index on 1/8″ are closely related to each other.

These regression equations are, however, by no means meant for replacement of the standard laboratory tests. These are added aids to any investigation for checking the experimental results and would prove useful for an approximate assessment of the coke properties when the recommended testing machines are not readily available.

Acknowledgement

Thanks are due to Mr. A. Ghosal, Statistical Officer, for helpful suggestions and the workers of the Carbonisation Division—specially to Messrs T. C. Tarafder and S. N. Sinha—for help in collating the mass of data required in preparing this paper and also to the Coal Blending and Coking Research Sub-Committee, Jamshedpur, whose published and unpublished reports were freely drawn upon.

APPENDIX

Analysis of Variance

TABLE I

Shatter Index on 2 in. and Micum Index on 40 mm.

Source	D.F.	S.S.	M.S.	F.	Remarks
Due to regression	1	348·5	348·50	290·4	Highly significant at 1% level for 1,229 d.f.s.
Deviation from regression	229	268·4	1·20	290·4	
Total	230	616·9	—	—	

TABLE II

Shatter Index on 1½ in. and Micum Index on 40 mm.

Source	D.F.	S.S.	M.S.	F.	Remarks
Due to regression	1	593·3	593·3	525·0	Highly significant at 1% level for 1,181 d.f.s.
Deviation from regression	181	204·1	1·13		
Total	182	797·4	—	—	

Shatter Index (1½″) on Micum 40 mm.

TABLE III

Analysis of variance (for M_{40}—65 and above)

Source	D.F.	S.S.	M.S.	F.	Remarks
Due to regression	1	255·09	255·09	307·3	Highly significant at 1% F 1,178 d.f.s.
Deviation from regression	178	147·04	0·83		
Total	179	402·13	—	—	

Shatter Index (1½″) on Micum 40 mm.

TABLE IV

Analysis of Variance (for M_{40}<65)

Source	D.F.	S.S	M.S.	F.	Remarks
Due to regression	1	335·4	335·4	93·9	Highly significant at 1% F1, 49
Deviation for regression	48	172·4	3·6		
Total	49	507·8			

TABLE V

Shatter Index through ½″ and Micum Index through 10 mm.

Source	D.F.	S.S.	M.S.	F.	Remarks
Due to regression	1	58·4	58·4	44·9	Highly significant at 1% for 1, 157 d.f.s.
Deviation from regression	157	204·7	1·3		
Total	158	263·1	—		

TABLE VI

Stability factor on 1″ and B.S. Abrasion Index on 1″

Source	D.F.	S.S.	M.S.	F.	Remarks
Due to regression	1	445	445	186·97	Regression is highly significant at 1% level for 1, 98 d.f.s.
Deviation from regression.	98	233	2·38		
Total	99	678	—	—	

TABLE VII

B. S. Abrasion Index on 1/8 in. and Micum Index through 10 mm.

Source	D.F.	S.S.	M.S.	F.	Remarks
Due to regression.	1	226	226	292·3	Regression highly significant at 1% level for 1, 38 d.f.s.
Deviation from regression	98	89	0·90		
Total	99	315	—	—	

TABLE VIII

Hardness factor on ½ in. and Shatter Index through ½ in.

Source	D.F.	S.S.	M.S.	F.	Remarks.
Due to regression	1	229	229	59·48	Regression highly significant at 1% level for 1, 132 d.f.s.
Deviation from regression.	132	508	3·85		
Total	133	737	—	—