Determination of the Workability of a Coal Face Underground by Measuring the Friability of Coal

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In this report, the results of an investigation of the friability-index of coal face underground, which would be the most useful index for prediction of face workability, at 141 working faces (62 coal mines) in Japan are described.

These results were classified separately for each district and working system, i. e., blasting, coal pick, coal cutter and Hobel mining, and then the friability-index measured at each coal face was compared with the working efficiency. Furthermore, from these results, we have proposed a method for designation of the workability of a coal face by the friability-index.

1. Foreword

Recently, for the purpose of improving the mining efficiency by mechanizing the mining operation at coal face underground, various types of continuous coal cutting machines, coal cutters, planers as well as drum cutters, are being successfully introduced into Japanese collieries, and expected to raise the efficiency of mining operations.

As a matter of fact, however, in adopting these coal cutting machines, the cuttability of the coal face must be precisely known in order to determine the type of machines to be used and their cutting conditions. If the cuttability can be measured, it is possible to determine the mining condition and the standard capacity of mining operation not only as to cutting machine mining, but also to a general mining system, and thus, we can expect that it would do much for the establishment of a mining plan and the improvement of efficiency.

The authors have carried out fundamental experiments on coal cutting practice these several years, and ascertained[1] that the friability-index, one of the mechanical properties of coal, denotes a remarkable relation to the cutting resistance of coal, because it is not only related to the hardness (or the original strength) of coal, but also to its cleat.

For homogeneous coal, cutting resistance is theoretically proportional to the strength of coal. Coal, however, is generally non-uniform, and has cleats or fissures, so a remarkable fluctuation appears in the value of its strength. Moreover the preparation of specimens for strength tests is very troublesome. But, in the measurement of the friability-index, fewer fluctuations appear because of the simultaneous testing of many samples of coal, their non-uniformities being averaged.

As for the friability test, we have two methods, the drop shutter test and the tumbler test. The drop shutter test requires no special testing apparatus and the preparation of samples takes less time than in the strength test, and can easily be carried out at any spot. So we consider it possible to predict the cuttability, or workability of a coal face by measuring the friability-index of coal, if the sampling of coal at the face and the testing method are standardized.

The authors established a standard for measuring the friability-index at the face of the coal mine. And in accordance with this standard, investigations of the friability-index have been carried out at 141 working faces in Japan by the Association of Coal Mining Engineering of Japan. The authors have obtained through these investigations results, which we are going to summarize and which enabled us to propose methods for the designation of face workability by means of the friability-index.

2. Relation between the Friability-Index and the Cutting Resistance of Coal in Fundamental Experiments

The authors carried out experiments on coal cutting, and found out the relation between friability-index measured by the drop shutter test and cutting resistance. Fig. 1 shows the experimental results[2] in the case of cutting coal block samples with a plane bit of 90 mm bit width and 35° rake angle. The cutting resistance of coal decreases hyperbolically in conformity with the increase of friability-index, for which we obtained the following relationship,

$$P \simeq \frac{180\, t^{0.5}}{F_D^{0.9}} \quad (\text{kg/cm}) . \qquad (1)$$

Where P is the maximum main cutting resistance per unit bit width, t is the depth of cut in mm and F_D is the friability-index measured by the drop shutter test.

For a pick bit with a 9 mm tip width and 40° rake angle, this relation is shown in Fig. 2 and expressed by the following formula[3],

$$P \simeq \frac{140\, t^{0.92}}{F_D^{0.75}} \quad (\text{kg}) . \qquad (2)$$

The relation between depth of cut t and maximum (or mean) cutting resistance $P(p)$ is generally given by the following formula,

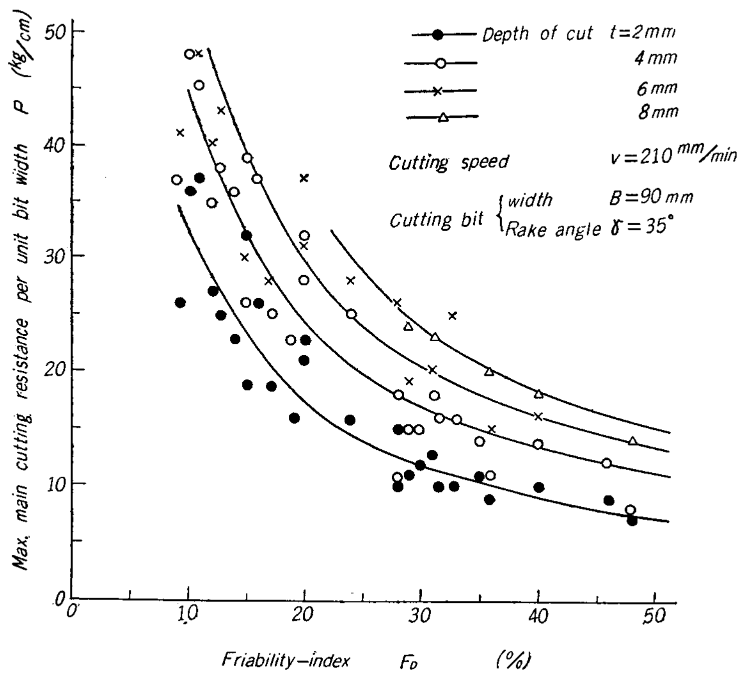

Fig. 1. Relation between friability-index and max. main cutting resistance per unit bit width of plane bit.

$$P = at^b \qquad (3)$$

where a is the coefficient of cutting resistance and b is the exponent of cutting resistance. The former is determined mainly by the properties of coal, particularly by friability-index, and the latter by the shape and size of the cutting bit.

Formula (3) is expressed by the following general formula in comparison with formulas (1) and (2),

$$P = \frac{a' t^b}{F_D^r} \frac{B}{10} \qquad (4)$$

where B is the bit width in mm. Formulas (1) and (2) have been obtained from experiments in cutting by bits with specially fixed bit

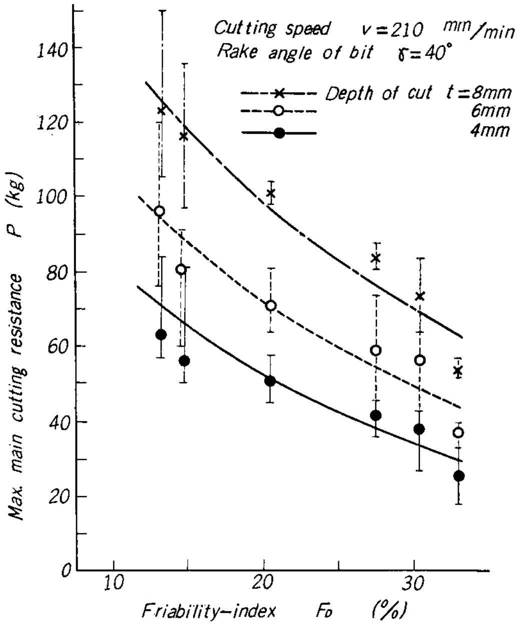

Fig. 2. Relation between friability-index and max. main cutting resistance (pick bit).

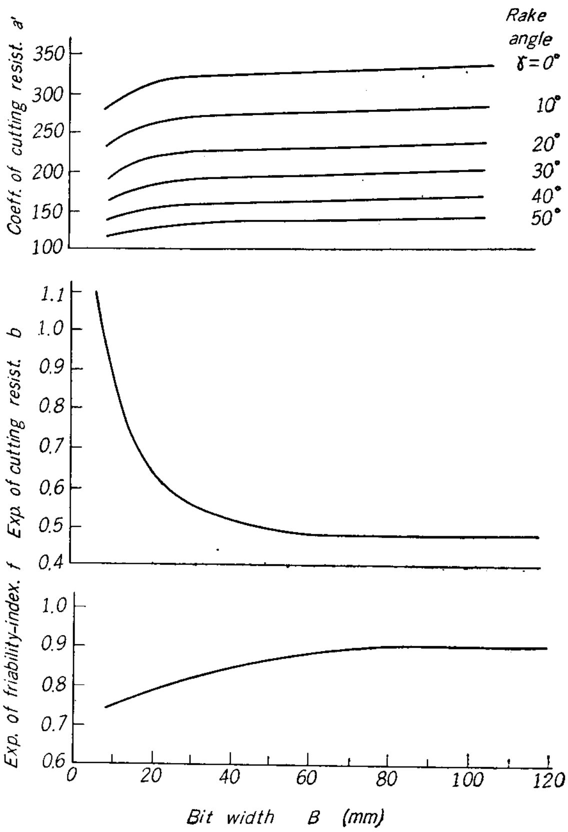

Fig. 3. Diagram of coefficient of cutting resistance, exponent of cutting resistance and exponent of friability-index.

width B (mm) and rake angle γ (degree), so in general formula (4), the influences of these items must be included. Thus we expressed in coefficient a' the influences of these non-proportional elements to the cutting resistance, but it is difficult to express these coefficients and exponents with a formula for wide variation of bit width, so we showed these relations in a diagram. Fig. 3, the results obtained from our experiments with these considerations, shows the coefficient of cutting resistance, the exponent of cutting resistance and the exponent of friability-index. Thus, the maximum main cutting resistance loaded on the cutting bit with any bit width and rake angle is calculated from formula (4) by measuring the friability-index of coal[4].

3. Standard for Measuring the Friability-Index

As mentioned above, the results of fundamental research show that the friability-index of coal will be a useful guide to the cuttability of coal, and moreover, the possibility of indicating quantitatively the workability of a coal face underground by the friability-index can be expected. For this purpose, we have standardized the procedure for the measurement of the friability-index.

The measuring method for the friability-index by the drop shutter test is provided[5] by the Standard of American Society for Testing Materials, but for simplification we have made some alterations which involve no essential differences[6].

(1) **Sampling positions.** As shown in Fig. 4, at the longwall working face, coal blocks sufficient for two tests must be taken as samples at roof side, middle

part and floor side at positions which are each 10 m distant from both ends of face and the divided positions. (These divisions differ according to the face length as shown in Table 1)

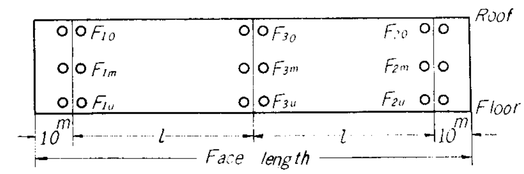

Fig. 4. Sampling positions at coal face.

Table 1. Relation between face length and sampling positions.

Face length	Section of sampling positions	
less than 100 m	F_1 F_3 F_2	3 sections
" 140 m	F_1 F_3 F_4 F_2	4 "
" 180 m	F_1 F_3 F_4 F_5 F_2	5 "
" 220 m	F_1 F_3 F_4 F_5 F_6 F_2	6 "

(2) **Sampling method.** If possible, 10~20cm size coal blocks must be taken by coal pick. These samples are brought up to the surface and carefully broken into 2~3 inch size with a hatchet. When it is difficult to obtain large coal blocks, a 2~3 inch size is permitted, although in this case, notice should be given.

Moreover, when the face is so soft as to make it impossible to get samples of 2~3 inch size, 1½~2 inch size is permitted, but in this case, adjustment of the measured value and notification are also required.

(3) **Method of experiment.** 4500±70 g of coal blocks in 2~3 inch size prepared according to the processes mentioned above are put in a box of 33×20×38 cm inner dimensions, whose bottom can be opened, and dropped together from a 6 ft. height on to a steel plate of ½ inch thickness. Then all the coal blocks on

Table 2. An example of a calculation of the friability-index F_D.

Retained on	Passing	Weight	Weight Percent (1)	Average of screen opening Inches (2)	Average of screen opening Factor (3)	Product of (1)×(3)
Sample						
2 in.	3 in.	4554 g	100.00	2.5	1.0	100.00
Dropped Coal						
2 in.	3 in.	2400 g	52.70	2.5	1.0	52.70
1½	2	802	17.61	1.75	0.70	12.23
1	1½	506	11.11	1.25	0.50	5.56
¾	1	204	4.48	0.875	0.35	1.57
½	¾	248	5.45	0.625	0.25	1.36
0	½	394	8.65	0.250	0.10	0.87
					Total......	74.39

Friability-Index $F_D = 100 - 74.39 \cong 25.6\%$

the plate are carefully returned to the box and dropped again.

After this process the broken pieces are screened by 2, 1½, 1, ¾ and ½ inch size screens (50, 37.5, ⋯ 12.5 mm screens are permitted since 1 inch ≃ 25 mm).

In screening, care should be taken to prevent further breakage of the coal. The friability-index is calculated as shown in Table 2.

(4) **Disposition of measured value.**

(i) Two experiments for the samples taken from the same position are carried out, and then the mean values of F_{10}, F_{1m}, F_{1u}, F_{20}, F_{2m} and F_{2u} etc. are calculated.

(ii) Then the mean value of friability-index of the face is calculated by the following formula,

$$F_D = \frac{\Sigma F_0 + \Sigma F_m + \Sigma F_u}{\text{No. of sampling positions (9 or 12 etc.)}}. \qquad (5)$$

(5) **Sampling positions at face using coal cutting machine.** (Fig. 5) For the case of using a single jib cutter, coal samples must be taken at the cutting position of the jib by the same way as in article (1), then with the mean value of F_u obtained from experiment, the friability-index for the case of using a coal cutting machine should be designated.

When a double jib cutter is used, samples must be taken on the positions where the cutting is made by the upper and lower jibs, and with the mean value of F_m and F_u, the friability-index should be designated. As for planer (or Hobel), samples must be taken at the upper and lower parts where the cutting is made by the planer (or Hobel) bit, and with the mean value of F_m and F_u, the friability-index should be designated.

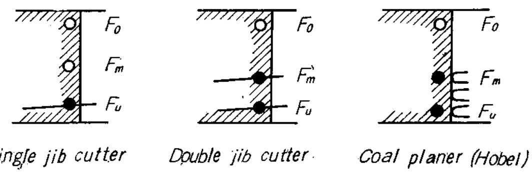

Fig. 5. Sampling positions at face of cutting machine mining.

(6) **Management of band.** In mining operation, when the influences of bands existing in the coal seam can not be neglected, by measuring the friability-index of the bands, their influence on the workability should be calculated using the following formula. (Fig. 6)

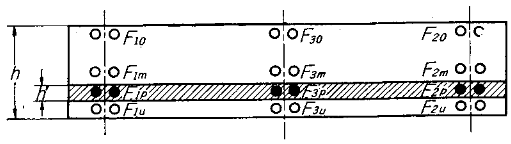

Fig. 6. Sampling of band.

Friability-index of coal seam $F_D = \frac{\Sigma F_0 + \Sigma F_m + \Sigma F_u}{9}\left(1 - \frac{h'}{h}\right) + \frac{\Sigma F_p}{3}\frac{h'}{h}$ (6)

where F_p is friability-index of band, h is height of seam and h' is total thickness of bands.

4. Results of an Investigation of the Friability-Index of Coal Face in Japan

According to the standard mentioned above, the investigations of friability-index of coal face of main coal mines in Japan were carried out[7]. Here follow the summarized results of their investigations.

(1) **Iuvestigated coal faces.** Investigations were carried out at the 141 coal faces shown in Table 3.

Table 3. Number of investigated coal faces in each district.

'District	Number of coal mines	Number of faces
Hokkaidō	19	49
Jōban	7	14
Ube	12	19
Kyūshū	24	59
Total	62	141

(2) **Results of investigation of friability-index classified separately for each district and working system.** Fig. 7 shows the frequency of measured value and the mean value of friability-index at 132 faces with the exception of the faces whose friablility-index could not be measured and those whose measuring conditions of friability-index showed remarkable deviations from the standard. Coal seams of Ube and Jōban district are generally hard and those in Kyūshū district are soft in comparison with the mean value of Japan, 28.9%. (No consideration was given to the bands existing in the coal seam for these valves.)

Table 4 shows the comparison of the friability-index of coal face classified separately for each mining system and district. Hobel mining face shows the largest value of all, and it takes smaller values in the order of pick, blast and cutter mining showing agreement with the recognized order. (Here, the friability-index of Hobel and cutter mining faces are those at the cutting positions shown in Fig. 5.) The mean friability-index of pick mining faces shows a small value, because the comparatively hard coal seams in Ube coal field are operated by coal pick mining. If the value measured at Ube district is excluded, the mean value is 35.6%.

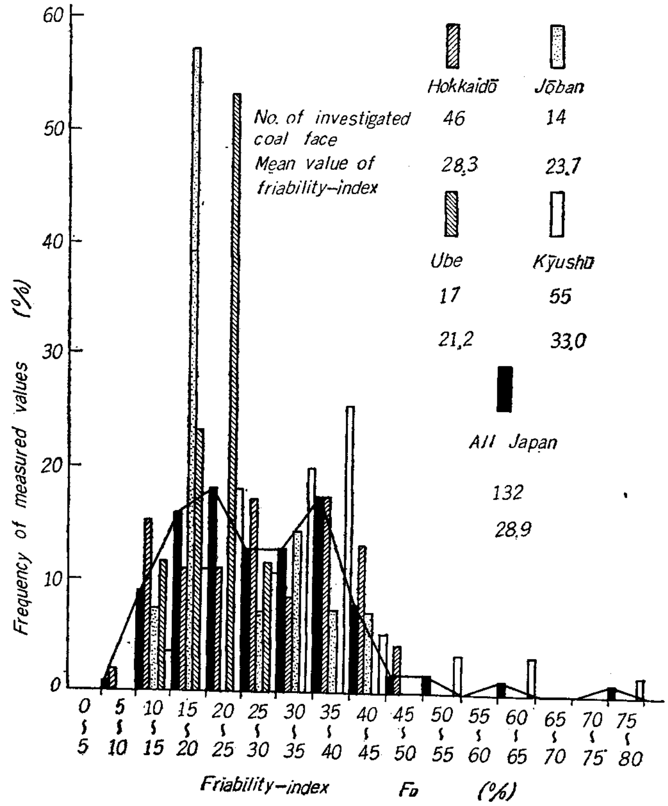

Fig. 7. Comparison of friability-index measured at individual districts in Japan.

Table 4. Comparison of the friability-index of coal face classified separately for each district and mining system.

District \ Mining system	Coal cutter	Coal pick	Blasting	Coal pick and Blasting	Hobel	Mean value
Hokkaidō	⑨ 21.5	⑳ 34.4 (34.1)	⑪ 23.7 (23.1)	① 33.0	② 21.9	28.3
Jōban	④ 26.1	⓪	⑦ 23.8	⓪	⓪	23.7
Ube	⓪	⑯ 21.3 (20.7)	① 20.3 (11.1)	⓪	⓪	21.2
Kyūshū	㉒ 28.9	③ 43.4	⑲ 32.0 (31.9)	③ 36.6	④ 49.4	33.0
Mean value	㉟ 26.7	㊴ 29.7 (29.3)	㊳ 27.8 (27.3)	④ 35.7	⑥ 40.3	28.9

(note: the numbers in the circle show the number of investigated faces)

Furthermore, values showed in the brackets in Table 4 include the value corrected by formula (6) considering influences of the bands.

(3) **Friability-index of band.** From the results of investigations of the friability-index of bands at 25 coal faces we calculated the mean value, 11.9%. The friability-index of coaly shales has a larger value, but it would be safe to suppose that the friability-index of hard sandy band is less than 10%.

(4) **Comparison of friability-index and working efficiency.** Working efficiency is not only related to the hardness of the coal face, but also to the natural conditions of the face, and the consumption of explosives may also differ according as the methods of drilling, the kinds of explosives and suitability of charge vary. Therefore, it may not be correct to compare the mining efficiency with the friability-index of the coal face, but we studied these comparisons.

Fig. 8 shows the relation between the friability-index of coal and the time required to mine 1 m^3 of coal seam with one coal pick. Large fluctuations appear in the measured value, but the time required to coal seam mining decreased in conformity with the increase of friability-index. Moreover, the influence of the height of the coal seam is also seen. From Fig. 9 which shows the relation between friability-index and out-put efficiency on the face of coal pick mining, it was also recognized that the efficiency increases in conformity with the increase of friability-index of coal seam. Here, on the coal faces where the influence of band was considered by formula (6), the friability-index shows the corrected values.

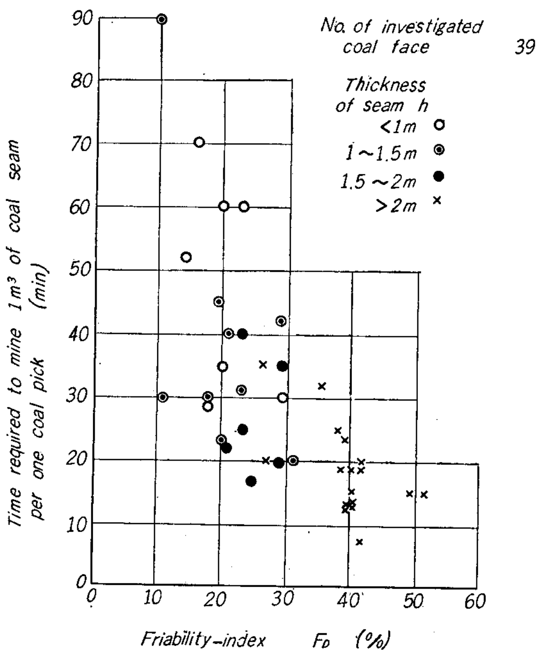

Fig. 8. Relation between friability-index and time required to mine.

Then the authors studied the relation between friability-index and out-put efficiency, consumption of explosives on the face of blast or cutter mining, although we could not find any clear relation for the reasons mentioned above. These relations on the face of cutter mining, as an example, are shown in Fig. 10.

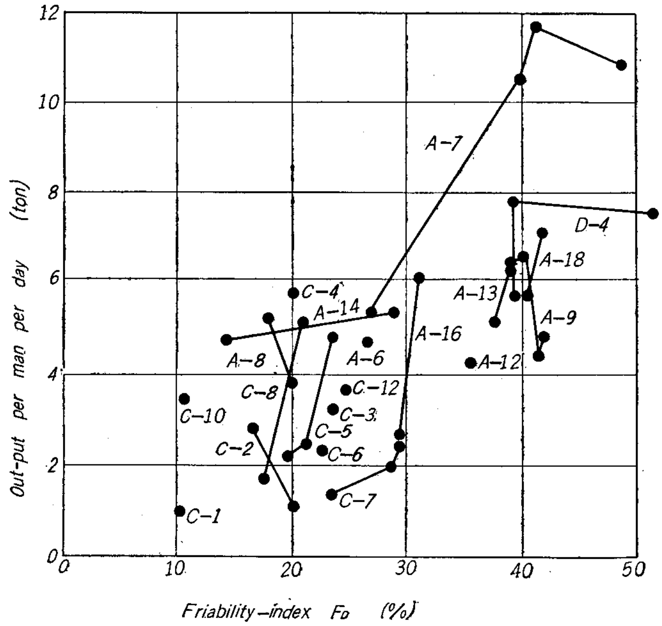

Fig. 9. Relation between friability-index and out-put efficiency on face of coal pick mining.

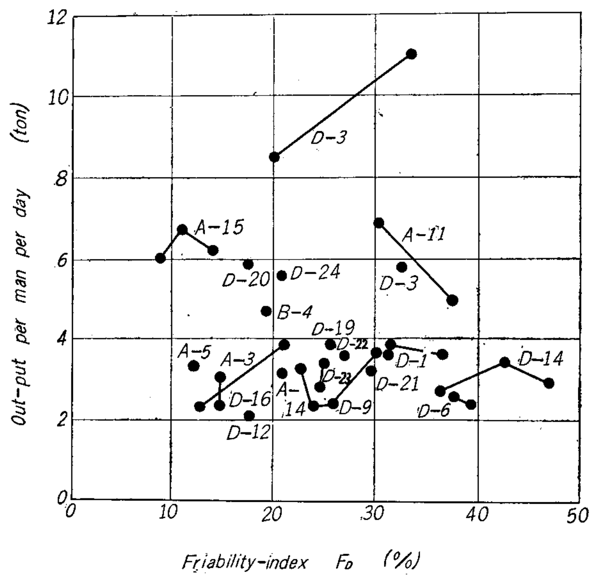

Fig. 10. Relation between friability-index and out-put efficiency on face of coal cutter mining.

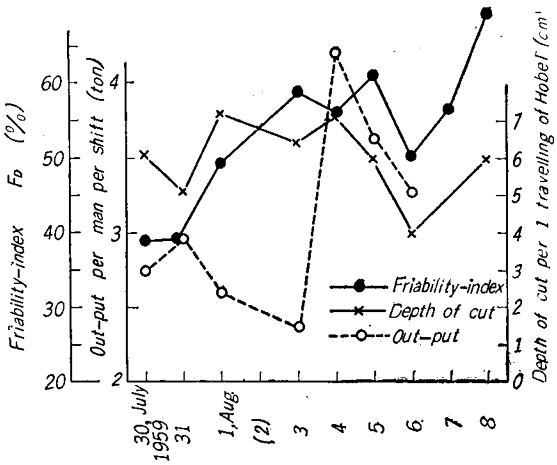

Fig. 11. Results of serial measurements of friability-index at face of Hobel mining in D-14 mine (note: 2, Aug. was holiday, so we have no data).

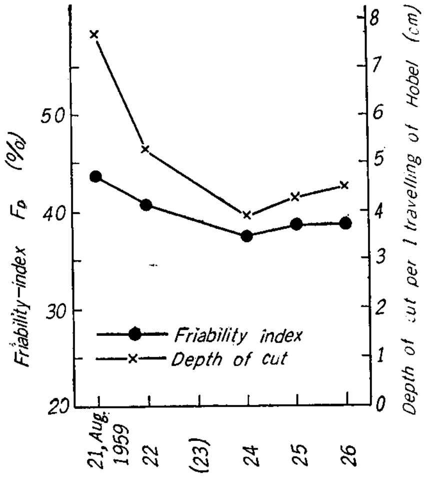

Fig. 12. Results of serial measurements of friability-index at face of Hobel mining in D-4 mine (note: 23, Aug. was holiday).

For the face of Hobel mining, we carried out serial measurements of the friability-index, and then these results were compared with the depth of cut per one travelling of Hobel and the out-put efficiency. From Fig. 11 and 12, only a slight relationship between friability-index and out-put efficiency was recognized due to the influences of other conditions, but it was ascertained that the friability-index had some relation to the depth of cut per one travelling of Hobel, and so it would be recognized that this is a useful guide to the determination of the cuttability of a coal seam.

5. Fluctuations of the Measured Value of Friability-Index

Friability-index of coal seam described above shows the mean value of friability-index measured at different measuring points. Furthermore we investigated the fluctuations of friability-index due to the influences of the non-uniformity of coal seam.

(1) Fluctuations of friability-index in vertical direction of coal face.

The results of tests for the friability-index of the coal samples taken at three points of the coal face, roof side, middle part and floor side, are denoted by F_0, F_m and F_u respectively. From these values we got the ratio of fluctuation, which is shown in Table 5. Here, the ratio of fluctuation is the ratio of the standard deviation of each measured value to the mean value.

Some differences are seen in the values classified separately for different

Table 5. Ratio of variation of measured value of friability-index (F_0, F_m and F_u) in vertical direction.

district	Min.	Max.	Mean
Hokkaidō	0.6%	43.4%	11.0%
Jōban	1.0	38.6	14.6
Ube	1.7	42.8	17.8
Kyūshū	0.4	31.7	11.9
Japan	0.4	43.4	12.5

Table 6. Ratio of variation of measured value of friability-index (F_1, F_2 and F_3 ...) in horizontal direction.

district	Min.	Max.	Mean
Hokkaidō	0.8%	27.6%	11.0%
Jōban	2.2	24.1	11.0
Ube	2.1	33.5	12.4
Kyūshū	0	25.3	9.6
Japan	0	33.5	10.6

districts and the mean value of all is 12.5%.

(2) Fluctuations of friability-index in horizontal direction.

The coal samples are taken at two positions, 10 m from the two ends of face (F_1 and F_2) and in the middle of face (F_3, F_4 ...). The ratio of fluctuation measured with these samples is shown in Table 6. The mean value of all in this direction is 10.6%.

Furthermore, the differences between the two ends and the middle of the face are shown in Fig. 13. This shows the frequency of ratio of the mean value of friability-index measured at the two ends of face (F_1 and F_2) and at the middle. The hatched parts show that the friability-index measured at the middle part is smaller, in other words, the coal at the middle is harder than at the two ends. It is recognized that most of the investigated values are 0.8~1.2, and the mean value of all is 1.00, there being little difference between the two ends and the middle of face.

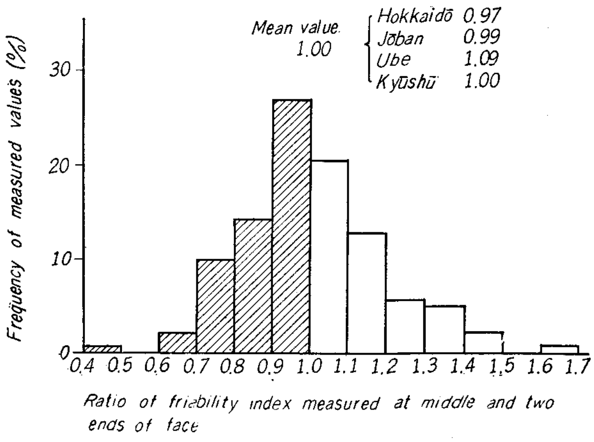

Fig. 13. Ratio of friability-index measured at middle and two ends of face.

6. Classification of "Hardness" (Workability) of Coal Face by Measuring the Friability-Index of Coal

As the friability-index is considered to be the most useful index of expressing the "hardness" (workability) of a coal face, the classification of these values should be very effective. From the results of investigation described above, the mean value of the friability-index in Japan is about 28%, so it will be suitable to choose this value as medium hardness.

The classification shown in Table 7 is our proposal of the grades of "hardness" and their designations. If these methods of designation could be generalized, we believe that a quantitative concept will be established for expressing the "hardness" of the coal face, and that these classifications will be a unified standard in comparison with the conventional subjective expressions of the workability of the coal faces at every coal mine.

Table 7. Classification of hardness of coal face.

Classification of friability-index F_D	<10	10～15	15～25	25～35	35～45	range 45～sampling possible	range sampling impossible
Designation of hardness	ultra hard	very hard	hard	medium	soft	very soft	ultra soft
Symbol	3H	2H	H	M	S	2S	3S
	1, 2	3	4, 5	6, 7	8, 9	10, 11, 12 ·················· 20	

Futhermore, though the friability-index of coal was mainly considered for coal cutting operations, this method can be safely applied to general mining systems, because the friability-index denotes the resistance characteristics for the impact breakage of coal. From that standpoint, the authors studied these problems with the consideration that it will be possible to apply these classifications to general mining systems, and determined the range of friability-index of coal seam effective and desirable for every coal mining system as follows,

for blast mining: hard, very hard and ultra hand (H, 2H, 3H)
for cutter mining: hard, medium and soft (H, M, S)
for drum cutter mining: medium and soft (M, S)
for coal pick mining: medium, soft, very soft and ultra soft (M, S, 2S, 3S)
for Hobel mining: soft, very soft and ultra soft (S, 2S, 3S)
for Hobel (for hard seam) mining: medium (M)
for scraper mining: very soft and ultra soft (2S, 3S)

If these ranges of classifications would be too extensive, another classifying system may be applied. That is, the range of $0 < F_D < 5$ is designated with symbol 1 and $5 \leq F_D < 10$ is designated with 2 as is shown in Table 7.

Although more precise studies on these problems are to be done in the future, the authors believe this method would be a useful guide for the designation of "hardness" of coal face and for the determination of mining operation systems.

7. Conclusion

The results of investigation of the friability-index which seems to be a useful guide to the workability of a coal face underground have been described in this paper. Although the friability-index can not be said to be perfect or complete for the estimation of coal face workability, its measurement is much easier as compared with those methods which require special experimental equipment or tools, and which have hitherto been adopted in Western countries[8),9)].

We find it interesting that, in a recent report, Dr. I. Jones noted[10)] that "Impact Strength Index" (which seems to be of the same nature as the friability-index) would be a useful guide to the workability of a coal face.

Our classification of friability-index is not a final proposal but a first attempt. We will try to give greater generality to this classification by precies studies in the future. Especially, the influences of bands and silicified woods existing in the coal seam must be thoroughly considered.

But even the present classification has a reasonable utility value.

Acknowledgement

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