PROC. OF JSCE,
No. 274, JUNE 1978

CHARACTERISTICS OF SHAPE VARIATION OF RIPPERTIP BY WEAR AND ABRASIVENESS OF ROCK

Tatsuro MURO*

1. INTRODUCTION

In recent years, almost all blasting operations for excavation of rock mass have been restricted in place of residence or urban district. On the other hand, ripping operations for mechanical excavation of rock mass have been increasingly adopted in a vast range. But, in the case of mechanical excavation of fairly hard rock mass, the wear of rippertip is shockingly severe. Therefore, the study of wear problems concerning with these rippertips becomes verv important, especially in the research of wear resistance of metal materials constituting these tips by means of today's deficiency of metal resources.

Here, first of all, paying attention to abrasiveness of rock surface, several laboratory tests have been executed concerning with the correlations between wear amount of metal material and depth of groove on surface of rock sample for various contact pressure. As the results, the surface of rock yields and the depth of groove starts to increase rapidly, when the contact pressure increases to take some value which is defined as abrasive strength of rock. Then, the relations between amount of wear of metal and contact pressure which varies in vast range containing the abrasive strength of several rock samples, are analysed.

Secondly, the characteristics of shape variation of rippertip by wear at ripping operations against two rock masses which are constituted representative of rock with high and low abrasive strength, are evaluated by simulation analyses.

2. ABRASIVENESS OF ROCK AND AMOUNT OF WEAR OF METAL

Express-method of the rock abrasiveness estimation by means of radioisotopic method was already developed by M. I. Smorodinov.[1] Here, for the purpose of testing the abrasiveness of rock sample by use of metal piece, relations between amount of wear of metal and contact pressure have been measured when a given metal specimen is pushed and slided on the surface of rock sample under various contact pressure and constant speed.

(1) Metal and Rock Specimens

As metal specimens, several test pieces with size $40 \times 5 \times 5$ mm have been made by means of cutting some rippertip (forging) under practical operation. The average tensile strength of the metal specimens is 156.5 kg/mm^2, the elongation is 6.2%, the contraction of area is 27.8%, the Charpy impact value is 5.9 kgm/cm^2, the Vicker's hardness is 402 ± 61.5, and the Shore hardness is about 55.1. And the metal specimen is constituted by specialized alloy steel with the chemical composition C; 0.27%, Si; 0.29%, Mn; 0.77%, Mo; 0.12%, P; 0.018%, S; 0.018%, Ni; 0.61%, Cr; 0.51%, and with a feathered structure of uniformly distributed fine carbide in a bainite modification[2] as shown in **Photo. 1**. From these material test results, the metal specimens is estimated as SNCM 21 (Ni-Cr-Mo alloy steel)[3].

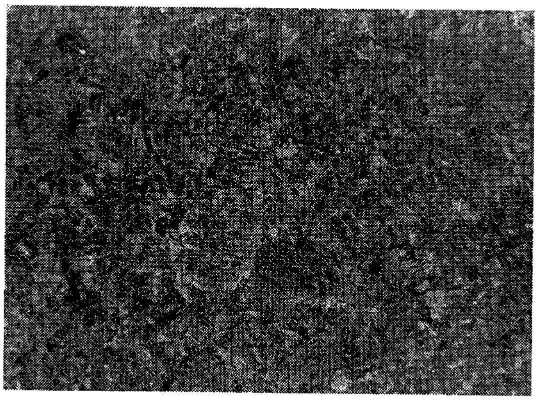


Photo. 1 Metallic texture of rippertip ($\times 300$).

* Dr. Eng., Associate Professor, Dept. of General Constructive Eng., Faculty of Eng., Fukui Univ.

Table 1 Physical Properties of Rock Sample.

Rock Sample	A	B	C	D	E	F
Name of Rock	Lapilli tuff	Lapilli tuff	Andesite	Coarse tuff	Lapilli tuff	Tuffaceous sandstope
Uniaxial Compressive Strength σ_c (kg/cm^2)	440	130	660	190	330	540
Elastic Wave Velocity V (m/sec)	2 540	2 100	3 960	2 340	1 960	3 180
Absorption W (%)	8.34	14.78	2.90	11.53	10.50	5.70
Apparent Specific Gravity G	2.35	1.86	2.40	2.24	2.13	2.30
Shore Hardness H_s	36.6	25.7	69.6	17.9	50.0	36.1
Amount of Los-Angeles U (%)	58.0	51.0	29.2	37.4	43.3	32.2
Mineral Composition						
Kinds of Quartz (%)	3.2	0	29.5	4.7	0	0
Kinds of Feldspar (%)	95.2	99.2	70.3	95.3	99.2	100.0
Colored Minerals (%)	1.6	0.8	0.2	0	0.8	0

Next, as rock specimens, 6 kinds of weak rock sampled from Echizen coast in Fukui Prefecture have been selected. These rock pieces are comparatively low compressive strength and show high rich abrasiveness.

Table 1 shows the physical properties and mineral composition analysed by means of heavy liquid tetrabromoethane[4]. The sample size was adjusted to be 25 × 25 × 5 cm and the surface of rock sample was finished to be ±0.05 mm average roughness.

(2) Experimental Test Apparatus and Performance

Fig. 1 shows the outline of wear test apparatus. The given rock sample is fixed on turn table of which diameter is 35 cm, and then the metal specimen slides on the surface of rock at 66 r.p.m. (sliding speed is 31.1 cm/sec) under various contact pressures. And, the test performance is shown in **Photo. 2**. This sliding speed 31.1 cm/sec (about 1.12 km/h) is selected as a standard running speed of tractor-mounted rippertip for operating at maximum tractive force 20 tons[5]. The contact pressure between metal specimen and rock sample is setted at 6.74, 10.00, 13.20, 16.40, 19.57, 22.78, 26.00 and 29.20 kg/cm^2 respectively. Those contact pressures selected here are representative pressures for a wide range of light wear zone (the coefficient of crack is comparatively high enough)

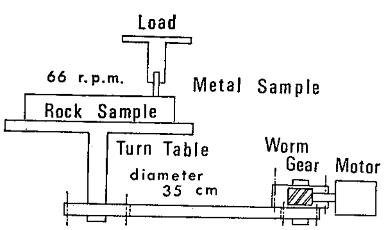


Fig. 1 General view of abrasive wear test apparatus.

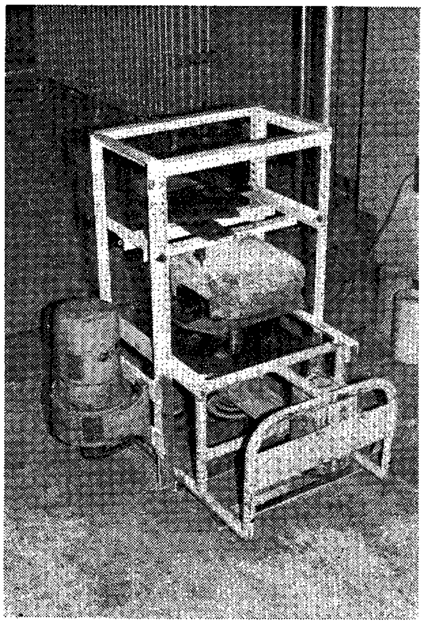


Photo. 2 Experimental apparatus.

[14]. The time required for wear test is 60 minutes at contact pressure from 6.74 to 16.40 kg/cm^2 and 30 minutes at contact pressure from 19.57 to 29.20 kg/cm^2. Then, both the amount of wear of metal specimen and the depth of groove on surface of rock sample were measured under each contact pressure after a constant time has passed. In this case, the amount of wear of metal specimen was measured as its weight loss by wear, using a chemical balance of maximum weighing 200 g, sensitivity 0.1 mg, and several points of depth of groove were measured and averaged by means of dial-gauge of 1/100 mm accuracy.

For the purpose of measuring more accurately the depth of groove on rock surface, the test specimens of metal was slided at the same circle groove on the rock surface until the depth of groove reached some measurable value. But, when the metal specimen was slided on the same circle groove at low contact pressure under the abrasive strength of rock, oxidized metal powder by wear was sometimes observed to adhere blackly on the rock surface. However, this problem was solvable by means of clearing the metal powder from rock surface using ethyl-alcohol.

(3) Test Results and Considerations

Fig. 2 shows the relations between amount of wear of metal specimen M and contact pressure p, as the test results from 6 kinds of rock sample. When these relations are replotted to logarithmic scale, it is evident that they are expressed by two folded lines as shown in **Fig. 3**. That is, the amount of wear M is expressed by exponential function of contact pressure p and is transformed into another exponential function when the contact pressure exceeds some pressure value.

Next, the measured depth of groove on rock surface occurred by the pass of metal piece has been converted into unit depth of groove d per single round pass of it. **Fig. 4** shows the relations between unit depth of groove d and contact pressure p. In the same way, replotting these relations to logarithmic scale, they are expressed by two folded lines as shown in **Fig. 5**. It is evident that the contact pressures corresponded to the folded points shown in **Fig. 5** agree well respectively to those of the another relations shown in **Fig. 3**. Then, from the analytical diagram **Fig. 3**, it is evident that the following experimental equations are completed as the relations between amount of wear of metal M (g/cm^2·cm) and contact pressure p (kg/cm^2) against 6 kinds of rock sample A, B, C, D, E and F respectively.

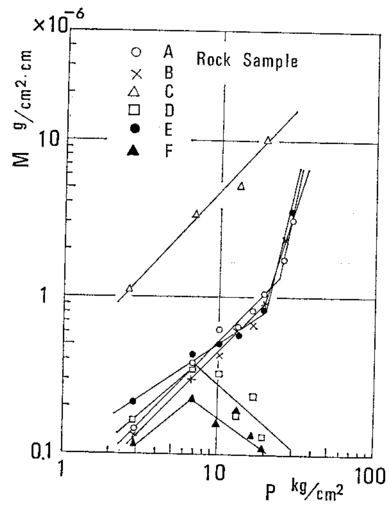


Fig. 3 Relations between M and P replotted in logarithmic scale.

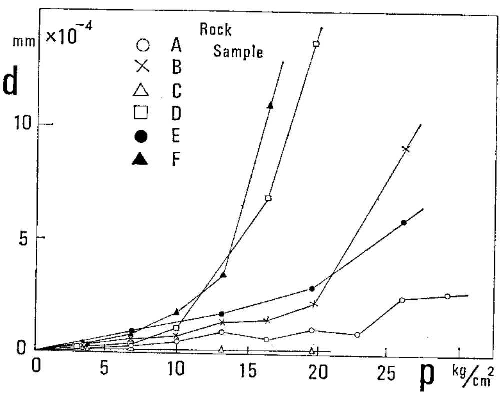


Fig. 4 Relations between unit depth of groove d per single round pass of test piece and contact pressure p.

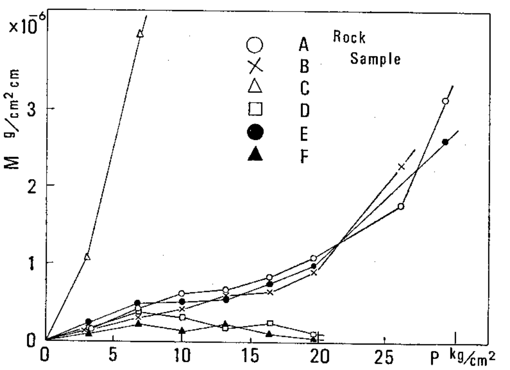


Fig. 2 Relations between amount of wear of metal specimen M and contact pressure P.

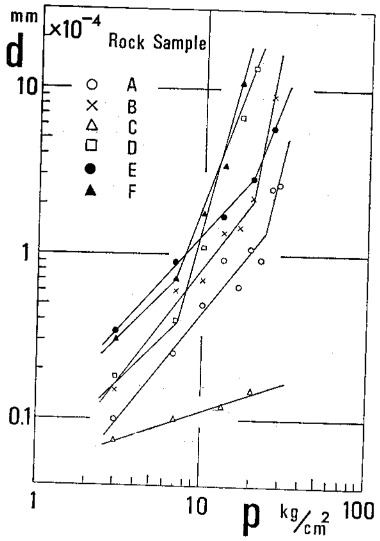


Fig. 5 Relations between d and p replotted in logarithmic scale.

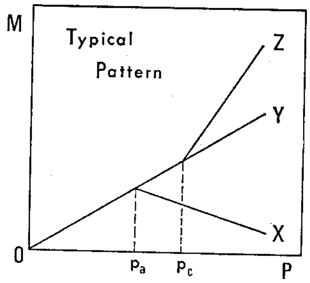


Fig. 6 Three typical relations between amount of wear of metal M and contact pressure p for rock material in logarithmic scale.

(A) $0 \leq p < 24.0\,\text{kg/cm}^2$ $M = 0.0513p^{1.03}$ …(1)
$24.0\,\text{kg/cm}^2 \leq p$ $M = 1.66 \times 10^{-6}p^{4.28}$ …(2)
(B) $0 \leq p < 19.6\,\text{kg/cm}^2$ $M = 0.0592p^{1.01}$ …(3)
$19.6\,\text{kg/cm}^2 \leq p$ $M = 4.66 \times 10^{-5}p^{3.32}$ …(4)
(C) $0\,\text{kg/cm}^2 \leq p$ $M = 0.3368p^{1.14}$ …………(5)
(D) $0 \leq p < 6.8\,\text{kg/cm}^2$ $M = 0.0708p^{0.84}$ ……(6)
$6.8\,\text{kg/cm}^2 \leq p$ $M = 1.8295p^{-0.84}$ ………(7)
(E) $0 \leq p < 19.6\,\text{kg/cm}^2$ $M = 0.1012p^{0.72}$ …(8)
$19.6\,\text{kg/cm}^2 \leq p$ $M = 2.72 \times 10^{-5}p^{3.48}$ …(9)
(F) $0 \leq p < 6.8\,\text{kg/cm}^2$ $M = 0.0447p^{0.84}$ ……(10)
$6.8\,\text{kg/cm}^2 \leq p$ $M = 0.8128p^{-0.67}$ ………(11)

From these experimental test results where metal materials slide on surface of rock specimens, the relation between amount of wear of metal M and contact pressure p is generally expressed by exponential function as follows;

$$M = ap^b \quad \cdots\cdots (12)$$

where M shows the amount of wear of metal material expressed by weight loss per unit contact area and unit sliding length, p is contact pressure between them, and coefficient "a" and index "b" are defined by several wear conditions, kinds of metal or rock material, contact pressure and so on. Here, the coefficient "a" is called "Coefficient of wear" and the index "b" is called "Index of wear".

Now, it is evident that the relations between amount of wear of metal material and contact pressure are divided into 3 different types according to kinds of rock material for a same metal material. That is, as shown in **Fig. 6**, the characteristics of these behaviours are classified into Type X, Y, and Z. For Type X, the amount of wear of metal specimen increases as the contact pressure increases at low contact pressure, but the amount of wear of metal decreases rapidly and at the same time the depth of groove on rock surface increases rapidly when the contact pressure exceeds some pressure P_a. Here, this contact pressure P_a corresponds with "Abrasive strength of rock P_{as}" which shows quantitatively the abrasiveness of rock material having a great influence upon the amount of wear of metal material. In previous experimental results, both rock sample D and F belong to this Type X, which have very rich abrasiveness. And the abrasive strength of rock p_{as} of rock sample D and F is exactly alike to be 6.8 kg/cm². Furthermore, almost all the energies generated from frictional work between metal and rock material are dissipated and exhausted by wear of metal material under low contact pressure within the abrasive strength of rock. On the other hand, the greater part of energies are exhausted by wear of rock material under high contact pressure over the abrasive strength of rock. The variation of energy consumption is also certified by the facts that the shear strain of rock material reaches to more deeper layer and the relative slide length between metal and rock specimen decreases due to adhesive action under high contact pressure beyond the abrasive strength of rock P_{as}. Therefore, it is considered that the depth of groove on rock surface increases and the amount of wear of metal decreases in spite of high contact pressure. Further, it should like to add that the index of wear 0.84 for both rock sample D and F under low contact pressure within the abrasive strength of rock agrees well with the index of wear for soil cement which showed at previous wear tests[6].

For Type Y, the amount of wear of metal increases monotonously as the contact pressure increases. Hence, it is not observed that the amount of wear of metal or the depth of groove of rock increases or decreases suddenly at some contact pressure. That is, it means that the wear condition of metal and rock material are not varied from the wide range of contact pressure, the metal material does not occur adhesive wear under high temperature appearing, and the abrasive strength of rock material is high enough. In previous experimental results, rock sample C belongs to this Type Y, where the relation between amount of wear of metal and contact pressure is given by exponential function having constant coefficient of wear and index of wear within contact pressure 19.6 kg/cm² under the experiment. Further, in this case, it is considered that the uniaxial compressive strength of rock is high enough, the depth of groove on rock surface is negligible small, and almost all the energies generated from frictional work are exhausted by wear of metal material only. But, when the contact pressure increases to more high value, it is estimated that the amount of wear of metal material increases rapidly by means of severe adhesive wear due to high frictional heating, and the hardness of rock surface falls down due to some thermal metamorphism action. And, it has been shown that the wear rate increases substantially when the contact pressure is larger than one third of the hardness of metal material, being equivalent to the Vicker's hardness in bulk. This point separates adhesive wear from machining abrasive wear[7]. Further, this kind of rock specimen, including rock sample C is found in the group of rock materials of which hardness are more larger than the hardness of metal material.

Furthermore, for rock Type Z, the amount of wear of metal increases gradually for increasing the contact pressure at low contact pressure range. After the contact pressure exceeds some contact pressure p_c, the amount of wear of metal increases more rapidly with the increasing contact pressure and is transformed into another exponential function. And, at the same time, the depth of groove increases suddenly after the contact pressure exceeds p_c, as shown in **Figs. 4** and **5**. In previous experimental results, rock sample A, B and E belong to this Type Z. As shown in **Fig. 5**, it is evident that each depth of groove on these rock surface at the contact pressure p_c is more larger than that of rock sample D and F at the contact pressure or the abrasive strength of rock p_a. And when the contact pressure which the depth of groove starts to increase suddenly is defined similarly as the abrasive strength of rock, the abrasive strength of rock p_{as} of rock sample A, B, and E is determined as 24.0, 19.6, and 19.6 kg/cm² respectively. At this contact pressure p_c ($\fallingdotseq p_{as}$), the wear condition of metal material varies and it is estimated that the amount of wear of metal is increased rapidly by overheating on metal surface and high temperature due to frictional work under high contact pressure.

From another experimental test results[8], it is estimated that the surface temperature is more than 900°C for the surface roughness of rock under the contact pressure p_c, and the wear surface of metal is softened by metallographic variation.

As mentioned above, the forms of wear of metal against rock material may be divided into three broad classes, and are determined fundamentally by the relative wear phenomena between metal and rock materials.

Then, determining that the abrasive strength of rock material is the contact pressure p_{as} at which the depth of groove on rock surface starts to increase rapidly, it becomes clear that, for rock Type X, the amount of wear of metal tends to decrease for increasing contact pressure of more than the abrasive strength of rock $p_{as} \fallingdotseq p_a$, while, for rock Type Z, it tends to increase more rapidly for increasing contact pressure of more than the high abrasive strength of rock $p_{as} \fallingdotseq p_c$. Therefore, it shall be confirmed that the abrasive strength of rock has an important influence on the amount of wear of metal material.

But, for the rock type Z, the fact is incidental that the contact pressure corresponding to abrasive strength of rock agrees well with the pressure occurring adhesive wear due to high temperature, and the causes and effects are not yet cleared.

Now, correlations between several properties of rock specimens are already reported in part[9]. Considering that the abrasive strength of rock depends principally on bonding force of rock-forming minerals, there are estimated to be high coefficient of correlations among the abrasive strength, compressive strength and Shore hardness of rock. And, the mutual correlations among coefficient of wear, index of wear of metal material and several properties of rock specimens are not evaluated because of scanty test data. However, it is estimated that the coefficient of wear under low contact pressure within the abrasive strength of rock is high correlated to Shore hardness and quartz or groundmass content. And the coefficient of wear under high contact pressure over the abrasive strength of rock are also estimated to increase with the increase of abrasive strength of rock.

3. RELATIONS BETWEEN ABRASIVE STRENGTH OF ROCK AND SHAPE VARIATION OF RIPPERTIP BY WEAR

As mentioned above, the results of abrasive wear test between metal and rock material cleared that the amount of wear of metal tends to decrease for rock Type X or increase for rock Type Z rapidly under high contact pressure of more than the abrasive strength of rock material. Rock Type X is the case where the hardness of metal material is more larger than that of rock material. When the contact pressure reaches to the abrasive strength of rock, almost all the energies are exhaused by abrasive wear of rock material due to yielding of the rock surface. On the other hand, rock Type Z is the case the hardness of metal material is slightly larger than that of rock material. The hardness of metal material is softened at the wear surface by frictional heat generated with the increase of contact pressure. And when the hardness of metal approaches to that of rock material under some contact pressure corresponding to the abrasive strength of rock, the surface of metal material is adhesively worn. Furthermore, as the contact pressure increases still more, the amount of wear of metal increases suddenly simultaneously with the rapid increase of depth of groove on rock material due to yielding of wear surface.

Now, in this section, the characteristics of shape variation of rippertip are theoretically considered from these laboratory wear test results in the case of mechanical excavation of 2 kinds of rock mass which are constituted representative of weak rock, rock Type X having comparatively small abrasive strength and middle hard rock, rock Type Z having comparatively large abrasive strength.

The initial shape and dimension of rippertip is shown in **Fig. 7**, which is selected as generally used tip in practical field. The total length is 375 mm, the width of pointed end is 88 mm, and the initial weight is about 15 kg. And the quality of tip is the same as previously mentioned in Section 2.1. When rigid material such as pointed end of tip penetrates into cracked rock mass, the distribution of contact pressure tends to concentrate on the edge part of pointed end of tip and decrease on the center according to elastic theory. For rock sample A, the average contact pressure for the wide range of shape variation due to wear is assumed to be shown as next quadratic equation (13-1). This assumption is very reasonable for the absolute value and shape of distribution of contact pressure against the compressive strength or coefficient of crack ($C_r=0.363$) of rock sample A. And, for rock sample D where the compressive strength is small and the coefficient of crack ($C_r=0.924$) is very high, the average contact pressure for the wide range of shape variation due to wear is assumed to be shown as next trigonometrical equation (13-2). This assumption is based on the remarkable decrease of contact pressure for edge part of pointed end of tip due to plastic yield of cracked rock fragments. The mean contact pressure q_1, which is calculated from excavating resistance acted on the pointed end $\overline{bc}$, is assumed in the next equations for original point o_1.

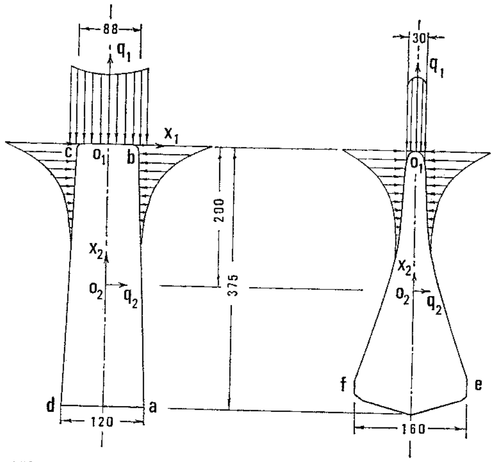


Fig. 7 Dimension and shape of rippertip, and distribution of contact pressure for rock type *Z*.

For rock Type Z (Rock sample A)

$$q_1=0.0129132x_1^2+225.0 \qquad \text{(13-1)}$$

For rock Type X (Rock sample D)

$$q_1=5.0\cos\left(\frac{\pi}{55}x_1\right)+10.845 \qquad \text{(13-2)}$$

And the mean contact pressure q_2 acted on the tip side $\overline{ab}$ or $\overline{cd}$, front part $\overline{o_1e}$, and rear part $\overline{o_1f}$ is assumed in the next equations for original point o_2.

For rock Type Z (Rock sample A)

$$q_2=\frac{1\,575.0}{210.0-x_2}+92.5 \quad\cdots\cdots\cdots\cdots(14\text{-}1)$$

For rock Type X (Rock sample D)

$$q_2=-2.5\cos\left(\frac{\pi}{200}x_2\right)+4.30\quad\cdots\cdots\cdots\cdots(14\text{-}2)$$

Here, x_1, x_2 and q_1, q_2 is expressed by mm and kg/cm^2 unit, respectively.

The total absolute values of excavating resistance acted on rippertips are roughly estimated at about 80% of maximum traction force of bulldozer 20 tons, for ripping operation by use of 2 tips against middle hard rock mass (Type Z), and at about 10% of the maximum traction force for ripping operation by use of 3 tips against weak rock mass (Type X). The distribution of contact pressure acted on the surface of tip should be varied according with the shape variation of tip due to wear. But, in this simulation, the average distribution of contact pressure for various shape of tip has been assumed. As the practical distribution of contact pressure in the field has remarkably changed, such an assumption is considered to be inevitable and beyond any control. This assumption of distribution of contact pressure has been well examined for soil and rock mechanics. It is shown that the results of simulation shown in

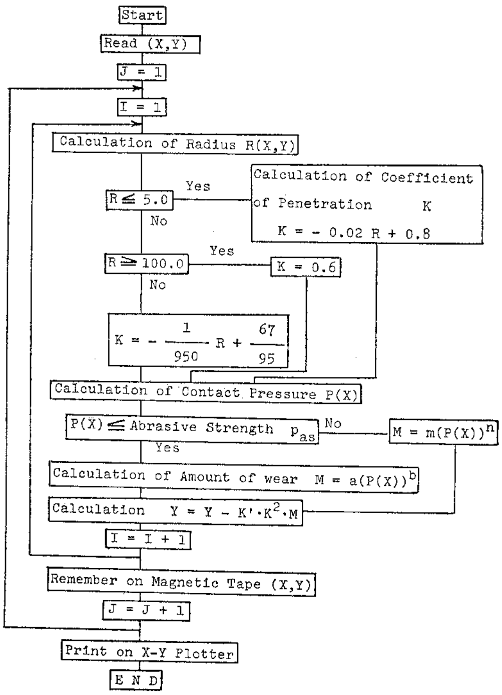


Fig. 8 Flow chart.

Fig. 9 and **Fig. 10** are well agreed with the field test data[13].

Now, the shape variation of rippertip due to abrasive wear can be simulated from the equation of amount of wear given by the function of contact pressure, considering the wear characteristics of edge part of tip[10)11)]. In this case, furthermore, considering the abrasive strength of rock, the simulation is expressed as a flow chart shown in **Fig. 8** or a program example shown in **Appendix I.**

In this flow chart, the coefficient of penetration K is defined as ratio of depth of penetration of running particle against metal body to depth of penetration at static state[10] and is varied with the radius of curvature R of the surface of rippertip. The calculations of contact pressure $P(X)$ acted on the pointed end of tip and the tip side depend on Eq. (13) and Eq. (14) respectively. If the contact pressure $P(X)$ is smaller than the abrasive strength of rock p_{as}, the amount of wear M can be calculated by use of Eq. (12) as follows: $M=a(P(X))^b$. Otherwise, the amount of wear M can be calculated by use of another exponential function as follows: $M=m(P(X))^n$. Here, the calculated amount of wear M should be modified for the radius of curvature of tip surface, sliding speed v and number of sliding particle per unit distance of broken rock particles on tip surface m_i, and shape of rock particle etc. And the hardness of metal and the sliding speed of broken rock particles are constant for this experimental condition.

Previously mentioned, the amount of wear of metal M_0 (g/cm^2·cm) is formulated in the equation by use of α_i (depth of penetration of particle to metal surface), considered that the scratch groove is scratched by larger rock particle.

$$M_0=K_0\rho\tan(\theta'/2)\left(m_1\alpha_1^2+\frac{3}{8}\sum_{i=2} m_i\alpha_i^2\frac{\alpha_i}{\alpha_1}\right)\quad\cdots\cdots\cdots\cdots(15)$$

Here, α_1 is the depth of penetration of a particle of the largest grain-size, ρ is the density of metal, θ' is average vertical angle of streaks. K_0 is a constant which is decided by the rate of partial charge of load, by the interruption of streaks with crushing of particles at moving state etc.

And,

$$m_i\alpha_i^2=K^2\frac{\sin(\theta/2)}{4H_V\tan^2(\theta/2)}m_iN_i(X)$$
$$=K^2\frac{\sin(\theta/2)}{4H_V\tan^2(\theta/2)}P(X)\quad\cdots\cdots\cdots(16)$$

K is the coefficient of penetration, H_v is Vicker's hardness of metal and $N_i(X)$ is normal load acted on each particle.

The results of theoretical calculation have been shown that the relation between amount of wear and contact pressure have an exponential function as well as the experimental results[12].

In general, as the radius of curvature of tip surface is considered, the relation between depth of wear on tip surface M_1 and contact pressure $P(X)$ can be written as follows:

$$\begin{aligned} M_1 &= \frac{1}{\rho} M_0 v \Delta t \quad (\Delta t \text{ is time}) \\ &= K_1 \cdot K^2 \cdot a(P(X))^b \cdot v \Delta t \\ &= K' \cdot K^2 \cdot M \ (\text{mm}) \quad \cdots\cdots\cdots(17) \end{aligned}$$

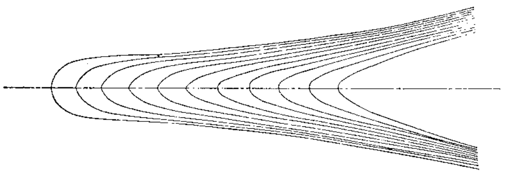
The coefficient K' can be decided for any K_0 value, number of sliding particle, shape and grain-size of particle, shape of scratch groove, sliding velocity and sliding period etc.

On the other hand, the program example shown in **Appendix I** is a simulation program to calculate the shape variation of side part of tip $\overline{ab}$ (the co-ordinate system $x_2q_2(o_2)$ in plan of **Fig. 7**) due to abrasive wear for rock sample A. It is a matter of course that the shape variation of end point of tip $\overline{bc}$ (the co-ordinate system $x_1q_1(o_2)$ in plan of **Fig. 7**) and front $\overline{o_1e}$ or rear part o_1f of tip (the co-ordinate system $x_2q_2(o_2)$ in elevation of **Fig. 7**) have been simulated for each distribution of contact pressure.

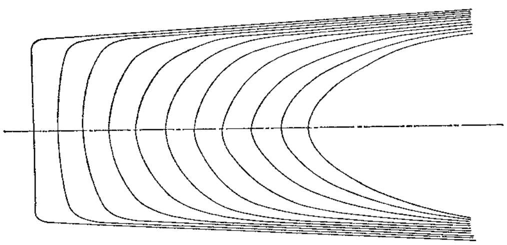
For middle hard rock mass represented by rock sample A and weak rock mass represented by rock sample D, the shape variations of tip are shown in **Figs. 9**(a)(b) and **Fig. 10**(a)(b) respectively as the results of summarized these 3 simulation curves.

For excavating of middle hard rock mass having comparatively high abrasive strength of rock, the shape variation of rippertip with time for ripping operation by 2 tips against rock mass constituted representative of rock sample A is shown in **Fig. 9**(a)(b). In this simulation program, the coefficient K' is decided assuming that the coefficient of crack of this rock mass is 0.363 and the index of rock mass strength for wear is calculated to be 41.1[13)14)]. As the wear life is calculated to be 120 hours for wear length of pointed end of tip 160 mm, the isochrone in this figure shows the shape variation of tip for each 10 hours of ripping operation time.

For excavation of weak rock mass having low abrasive strength of rock, the shape variation of rippertip with time for ripping operation by 3 tips against rock mass constituted representative of rock sample D is shown in **Fig. 10**(a)(b). In this case, assuming that the coefficient of crack of rock mass is 0.924, the index of rock mass strength for wear is calculated to be 2.12, and the isochrone in this figure shows the shape variation

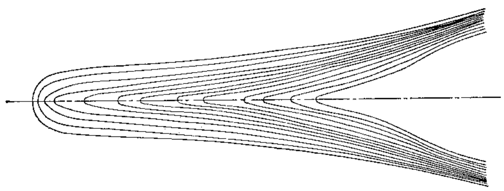


(a) Elevation

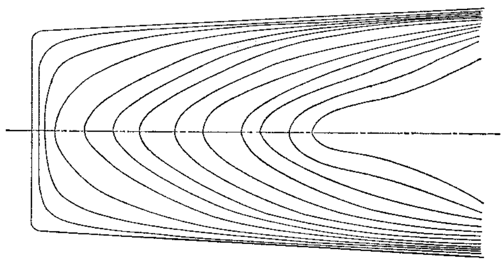


(b) Plan

Fig. 9 Simulation results for shape variation of rippertip with time by wear against rock mass constituted of rock sample A (The interval of isochrone shows 10 hours of ripping operation time).



(a) Elevation



(b) Plan

Fig. 10 Simulation results for shape variation of rippertip with time by wear against rock mass constituted of rock sample D (The interval of isochrone shows 20 hours of ripping operation time).

of tip for each 20 hours of ripping operation time.

From these simulation results, it is cleared that the characteristics of shape variation of rippertip is considerably varied by the properties of rock mass. That is, for the rock mass constituted of rocks having comparatively high abrasive strength, the end point of tip is worn roundly by abrasive wear action accompanying with impact load and the ability of excavation tends to decrease with the progress of wear. It may be explained that the wear of end point of tip progresses more remarkably than that of another parts, since the contact pressure concentrated on the end point of tip exceeds far away the abrasive strength of rock, and the wear of metal material increases rapidly due to softening of metal under high frictional temperature accompanying with the increase of wear of rock material under high contact pressure as shown in previous **Figs.** 3 and 4.

On the other hand, for the rock mass constituted of rocks having low abrasive strength, the wear of side parts of tip progresses more rapidly rather than that of pointed end of tip. And, it is characterized that, as a whole, the shape of pointed end of tip becomes gradually to be sharp and slender. This characteristic of shape variation may be explained to be reduced to 2 causes; the amount of wear of metal material decreases because almost all the energies i.e. frictional works are exhausted by wear of rock material as shown in previous **Figs. 3** and **4** even if the contact pressure concentrated on the end point of tip exceeds the abrasive strength of rock, and the amount of wear of side parts of tip increase relatively in rapid speed rather than that of end point of tip because the contact pressure acted on the side parts of tip are generally small within the abrasive strength of rock and also the wear resistance of metal material against abrasive action is small enough than that of rock material within the abrasive strength of rock[15)16)].

Furthermore, these simulation results are found to correspond well with the field test results reported in another paper[13)].

Therefore, as an effective means to raise the wear resistance of rippertip, it is necessary to consider the relationship between the characteristics of shape variation of rippertip and various kinds of rock mass, especially the abrasiveness of rock material. And it is important as metal material of tip to select several adequate steel materials having high wear resistance and to develop new method of heat treatment of them, corresponding with these field conditions.

4. CONCLUSION

For studying the characteristics of shape variation of rippertip due to abrasive wear in the field of ripping operation, or mechanical excavation of various rock masses, it is important to consider the abrasive wear characteristics between rock material and metal material of which the tip is constituted. Here, the influence of abrasiveness of rock material on the characteristics of shape variation of tip has been considered by means of simulation analysis, based on several abrasive wear test results in laboratory.

These laboratory test results and some simulation results are summarized as follows;

(A) From several abrasive wear test results between wear resisting steel and rock material used in the laboratory, the wear characteristics between them are classified into 3 groups (1) (2) and (3).

(1) The amount of wear of metal material increases as the contact pressure increases at low contact pressure, but the amount of wear of metal decreases rapidly and at the same time the depth of groove on rock specimen increases rapidly when the contact pressure exceeds some pressure, which is called "Abrasive strength of rock". For this type, almost all the energies generated from frictional work between them are dissipated and exhausted by wear of metal material under low contact pressure within the abrasive strength of rock. On the other hand, greater part of energies are exhausted by wear of rock material under high contact pressure over the abrasive strength of rock. Therefore, it is considered that the depth of groove on rock surface increases and the amount of wear of metal decreases in spite of high contact pressure.

(2) The amount of wear of metal increases monotonously as the contact pressure increases. Hence, it is not observed that the amount of wear of metal or the depth of groove of rock increases or decreases suddenly at some contact pressure. It means that the wear condition of metal and rock material are not varied from the wide range of contact pressure, the metal material does not occur adhesive wear under high temperature, and the abrasive strength of rock material is high enough.

(3) The amount of wear of metal increases gradually for increasing the contact pressure at low contact pressure, but it increases more rapidly with the increasing contact pressure by adhesive wear due to high frictional temperature and is transformed into another exponential function

after the contact pressure exceeds some contact pressure which is called abrasive strength of rock. And, at the same time, the depth of groove increases suddenly after the contact pressure exceeds the abrasive strength of rock.

(B) The characteristics of shape variation of rippertip has been cleared by simulation analysis for several rock masses from these laboratory abrasive wear tests. That is, for the rock mass constituted of rocks having comparatively high abrasive strength, the end point of tip is worn roundly by abrasive wear action accompanying with impact load and the ability of excavation tends to decrease with the progress of wear. On the other hand, for the rock mass constituted of rocks having low abrasive strength, the wear of side parts of tip progresses more rapidly rather than that of pointed end of tip.

Hence, the influence of abrasiveness of rock material on the shape variation of rippertip has been considered, and successful use of these conclusions will be evaluated to make them more meaningful at several wear problems. It must be very much hopeful of success to evaluate the wear resistance of tip and to elongate the wear life of tip.

The author wishes to express his sincere thanks to Prof. S. Hata, Kyōto University and Prof. T. Irie, Fukui University for their encouragements and valuable discussions.

References

1) M. I. Smorodinov: Express-method of the rock abrasiveness estimation, Proc. of the First Congress of the International Society of Rock Mechanics, Lisboa, 1966, pp. 111–113.
2) R. Hashiguchi: Metallography Handbook, Asakura-Shoten, 1970, pp. 602–622. (In Japanese)
3) JIS Handbook, Iron and Steel, Japanese Standards Association, 1972, pp. 839–842. (In Japanese)
4) S. Matsuo, K. Nishida: Physical and Chemical Properties of Decomposed granite soil grains, Soils and Foundations, Vol. 8, No. 4, 1968, pp. 10–20.
5) T. Morita, K. Satsumabayashi: Bulldozer, Sangyō-Tosho, 1970, pp. 199–236. (In Japanese)
6) S. Hata, T. Muro: Friction and wear of a steel plate against sandy soil, Trans. of the JSCE, No. 157, 1968, pp. 42–53. (In Japanese)
7) M. C. Shaw: Fundamental of wear, Ann. C.I.R.P., 19, 1971, pp. 533–540.
8) S. Hata, T. Muro: Wear of metal by gravelly soil at several states of water content, Proc. of the JSCE, No. 206, 1972, pp. 95–110. (In Japanese)
9) T. Muro: Correlations between several properties of rock specimens, Memoirs of the Faculty of Engineering, Fukui University, Vol. 24, No. 1, 1976, pp. 1–18.
10) S. Hata, T. Muro; Wear mechanism of Edge Part of Tools by Sandy Soil, Proc. of JSCE, No. 199, 1972, pp. 97–107. (In Japanese)
11) S. Hata, T. Muro: Wear characteristics of the edge of blade by sandy soil, Proc. of JSCE, No. 202, 1972, pp. 91–101. (In Japanese)
12) S. Hata, T. Muro: Mechanism of Friction and Wear of Steel Plate against Solidified Sandy Soil, Memoirs of the Faculty of Eng., Kyoto University, Vol. 31, Part 4, 1969, pp. 456–489.
13) T. Muro: Characteristics of shape variation of rippertip—from field test—, Memoirs of the Faculty of Engineering, Fukui University, Vol. 25, No. 1, 1977, pp. 1–12.
14) S. Hata, T. Muro and Y. Kaneko; Estimation of Life of Rippertip due to Wear, Proc. of the JSCE, No. 268, 1977, pp. 119–127.
15) S. Hata, T. Muro and M. Kaneuji: Characteristics of shape variation of rippertip, 29th Conf. JSCE, No. 3, 1974, pp. 324–325. (In Japanese)
16) T. Muro, T. Nakamura: Influence of rock properties on wear of rippertip, 30th Conf. JSCE, No. 3, 1975, pp. 518–519. (In Japanese)

Appendix I An Example of Simulation Program

```
C         SHAPE VARIATION OF RIPPERTIP DUE TO ABRASIVE WEAR (ROCK SAM-
          PLE A)
          COMMON X(110), Y(110), R(100), AK(110), Z(110), YY(110), P(110), PP(110), Q(110),
         1Y1(110), YY1(110), YY2(110)  A(110), B(110), D(110)
          DOUBLE PRECISION X, Y, R, AK, Z, YY, P, PP, Q, Y1, YY1, YY2, D, E, AMIN
          READ(5,100) (Y(K), K=1,101)
  100     FORMAT(5F12.0)
          WRITE(6,101)(Y(K), K=1,101)
  101     FORMAT(1H1, 5H DATA/ /21(1H0, 5D15.5/) )
          X(1)=0.0
          DO 10 I=1,100
   10     X(I+1)=X(I)+2.000
          REWIND 81
          WRITE(81,103) (X(K), K=1,101), (Y(K), K=1,101)
  103     FORMAT(16E16.5)
          DO 20 J=1,10
          DO 30 K=2,100
          IF(DABS((Y(K)-Y(K-1))*(X(K+1)-X(K))-(Y(K+1)-Y(K))*(X(K)-X(K-1))).
         1L T.0.000001) GO TO 21
          R(K)=DSQRT((X(K)-((Y(K)-Y(K+1))*(Y(K-1)-Y(K))*(Y(K-1)-Y(K+1))+
         1(Y(K)-Y(K+1))*((X(K-1))**2-(X(K))**2)+(Y(K)-Y(K-1))*((X(K))**2-(X(K
         2+1))**2))/((X(K)-X(K-1))*(Y(K+1)-Y(K))-(X(K+1)-X(K))*(Y(K)-Y(K-1)))
         3/2.0)**2+(Y(K)-((X(K)-X(K+1))*(X(K-1)-X(K))*(X(K-1)-X(K+1))+((Y(K
         4-1))**2-(Y(K))**2)*(X(K)-X(K+1))+((Y(K))**2-(Y(K+1))**2)*(X(K)-X(K-
         51)))/((Y(K)-Y(K-1))*(X(K+1)-X(K))-(Y(K+1)-Y(K))*(X(K)-X(K-1)))/2.0)*
         6*2)
          IF(R(K).LE.5.0)GO TO 11
          IF(R(K).GE.100.0) GO TO 21
          AK(K)=-0.001052632*R(K)+0.7052631579
          GO TO 31
   11     AK(K)=-0.020000000*R(K)+0.8000000000
          GO TO 31
   21     R(K)=9.9999
          AK(K)=0.600
   31     AK(1)=0.600
          AK(K)=(AK(K-1)+AK(K) )/2.0
          D(1)=0.0
          E=X(K)+D(J)
          IF(E.GT.200.0) GO TO 34
          YY(K)=1575.0/(210.0-E)+92.5
          IF(YY(K).LE.24.0) GO TO 32
          IF(YY(K).GT.24.0) GO TO 33
   32     P(K)=1.03*DLOG(YY(K))
          PP(K)=0.0513*DEXP(P(K))
          Q(K)=Y(K)-(AK(K))**2*PP(K)/250.0
          GO TO 30
   33     P(K)=4.28*DLOG(YY(K))
          PP(K)=0.00000166*DEXP(P(K))
          Q(K)=Y(K)-(AK(K))**2*PP(K)/250.0
          GO TO 30
   34     Q(K)=-10.0
   30     CONTINUE
          DO 40 L=2,100
```

```
   40 Y(L)=Q(L)
      Y(1)=2.0*Y(2)-Y(3)
      Y(101)=2.0*Y(100)-Y(99)+1.4142*(Y(100)-Y(99))
      AMIN=100.0
      DO 81 L=1,101
      IF(DABS(Y(L)).LE.AMIN) GO TO 82
      GO TO 81
   82 AMIN=Y(L)
      C=L-1
      D(J+1)=200.0-2.0*C
   81 CONTINUE
      DO 42 L=1,101
      IF(Y(L).GE.-10.0) GO TO 42
      Y(L)=-10.0
   42 CONTINUE
      WRITE (81,102) (X(K), K=1,101), (Y(K), K=1,101)
  102 FORMAT (16E16.5)
   20 CONTINUE
      END FILE 81
      DO 1000 K=1,101
      A(K)=0.0
 1000 B(K)=0.0
      A(1)=0.0
      B(1)=-20.0
      A(2)=200.0
      B(2)=60.0
      CALL SET
      CALL SCALE(A, 200.0, 101, 1)
      CALL SCALE(B, 80.0, 101, 1)
      CALL AXIS (0.0, 0.0, 2HMM, -2, 200.0, 0.0, 0.0, 1.0, 20.0)
      CALL AXIS (0.0, -20.0, 2HMM, 2, 80.0, 90.0, -20.0, 1.0, 20.0)
      REWIND 81
      DO 2000 J=1, 11
      READ (81, 200) (X(K), K=1,101), (Y(K), K=1,101)
  200 FORMAT (16E16.5)
      DO 3000 K=1,101
      A(K)=X(K)
 3000 B(K)=Y(K)
      CALL LINE (A, B, 101, 1, 0, 42)
      CALL PLOT (0.0, 0.0, -3)
 2000 CONTINUE
      REWIND 81
      STOP
      END
```

NOTATIONS

X(K), Y(K)	:	Co-ordinates of curve
R(K)	:	Radius of curvature
AK(K)	:	Coefficient of penetration
YY(K)	:	Normal stress
PP(K)	:	Amount of wear

(*Received November 24, 1976*)