with good efficiency, with rotor blades of same dimension.

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References

(1) W. H. Isay: *Ing.-Archiv*, Bd. 23(1955), S. 379.
(2) W. H. Isay: *Ing.-Archiv*, Bd. 24(1956), S. 148.
(3) M. Hirotsu: *Trans. Japan Soc. Mech. Engrs.*, Vol. 18, No. 69(1952), p. 65.

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On the Influences of the Finishing Condition of the Surface of Metallic Plate upon the Abrasion of Metals to the Fluid with Sand Particles*

By Sadaji YAMASITA**

In this report, the author refers to his study on the influences of the finishing conditions of metallic plate surfaces upon the abrasion of metals to the fluid with sand particles.

The working direction of file on the final finishing surface of metallic plate is set so that it has an angle of 90° to the flowing direction of the fluid with sand particles. And finishing conditions are : (1) the state of as-cast black sheet (2) bastered file finish (3) dead-smooth file finish (4) Emery paper 5 finish (5) Emery paper 3 finish (6) Emery paper 1 M finish (7) Emery paper 0/2 finish (8) Emery paper 0/4 finish (9) Emery paper 0/6 finish (10) Buff finish.

Surface conditions of metallic plate just before and after the experiment of abrasion were examined with a surface tester and surface roughness was measured.

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1. Introduction

The author has studied on the abrasion-mechanism of metals to fluid with sand particles.

The abrasion between solid bodies in general has been known to be variedly influenced according to finishing conditions of both of them(1)(2)(3)(4). In this report the author refers to his studies on the influences of the finishing conditions of metallic plate surface.

2. Experimental apparatus, kinds and methods

A. Experimental apparatus

In the whole apparatus as shown in Fig. 1, the circulatory system with a sand pump is employed.

In Fig. 2, test pieces as well as testing pipe is minutely shown, where the pipe, is divided in two parts longitudinally with a test piece inserted between them, and bound in the form of one pipe and fitted at the fixed position in the whole apparatus.

By a control screw of flapper, the flapper displacement h can be controlled so that the discharge, in other words, the velocity of fluid with sand particles flowing along both sides of the test piece in the testing pipe can be varied as desired.

Cartridge brass was chosen as the material of the test piece, and the traces of file (working direction) on each final finishing surfase were applied at 90° to the flow-direction of the fluid. And surface finish conditions were limited to the following 10 kinds :

The state of as-cast black sheet, bastered file finish, dead-smooth file finish, Emery paper 5 finish, Emery paper 3 finish, Emery paper 1 M finish, Emery paper 0/2 finish, Emery paper 0/4 finish, Emery paper 0/6 finish, and Buff finish.

The silica sand flown in the fluid of the present experiment was the sort of molding silica sand purchasable at the market, named Tokitsu

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4[5] (s.g.: 2.61, mean dia. of sand: 0.66 mm, shape-factor of particles: 1.47) (which is the silica sand with rather cubical form), and successively other kinds of sand (Tikuma-silica sand in nearly spherical form, shape factor 1.21 and Seto-silica sand in irregular form with acute edges, shape factor 1.87) were used for the experiment. In this experiment surface roughness was measured with Kosaka's surface-tester of needle-touch-style.

B. Kinds of experiment

(a) Abrasion test

(a′) The wear per unit area in unit time for each period of experimental time length of each test piece of ten finish conditions was measured and

(a″) the cumulative wear of each of ten finish conditions for each experimental time length was measured too.

(b) As a measure of surface roughness, and profiles, the maximum heights of surface roughness just before and after the abrasion test were determined.

(c) The relation between the maximum height of surface roughness and the wear was obtained.

C. Methods

(a) Abrasion test

Experimental conditions for (a′) and (a″):

The percentage of sand particles flown in the fluid for each test piece of 10 kinds of finish conditions was fixed in volumetric percentage of 10% (22.6% as gravimetric percentage) and the displacement of flapper in the apparatus mentioned above was fixed at 5 mm, and consequently the mean-velocity of the fluid with sand particles was measured 300 cm/sec[6]. And for each of 10 finish conditions abrasion test under the same condition was preformed 3 times with 30 test pieces all together. The value of wear is shown as the mean value obtained from these 3 tests of abrasion under the same condition.

Time intervals of abrasion test were set 10, 20, 30 minutes and 1, 2, 4, 8 hours, the same test piece being cumulatively tested for these 7 durations of time, and the wear for each test-time length was measured where in the case of (a′) the wear per unit area in unit time for each test time length was measured and simultaneously in the case of (a″) the cumulative wear for cumulative time lengths (for 10, 30 minutes and 1, 2, 4, 8, 16 hours) was measured.

In the case of the test piece in the state of as-cast black sheet finish condition, as the casting of a test piece with thickness of 1.6 mm is difficult while both the sides remain in the state of as-cast black sheet, only one side was left in the state of as-cast black sheet, the other side being ground with Emely paper 0/4, and finally from the wear of this test piece and that of Emery paper 0/4, the wear of the finished surface in the state of as-cast black sheet was obtained.

The discharge of the fluid with sand particles was measured for every 5 minutes with a 15 *l* capacity cylinder and simultaneously the quantity of settled sand particles as well as the percentage

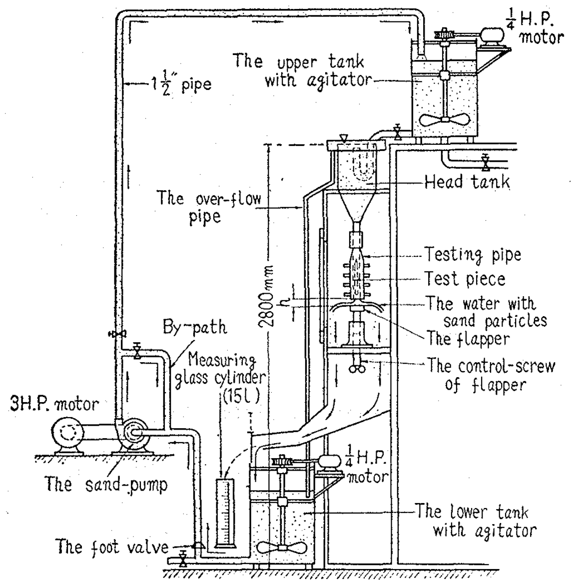

Fig. 1 Whole apparatus of the metallic plate to test the abrasion of metals to the fluid with sand particles

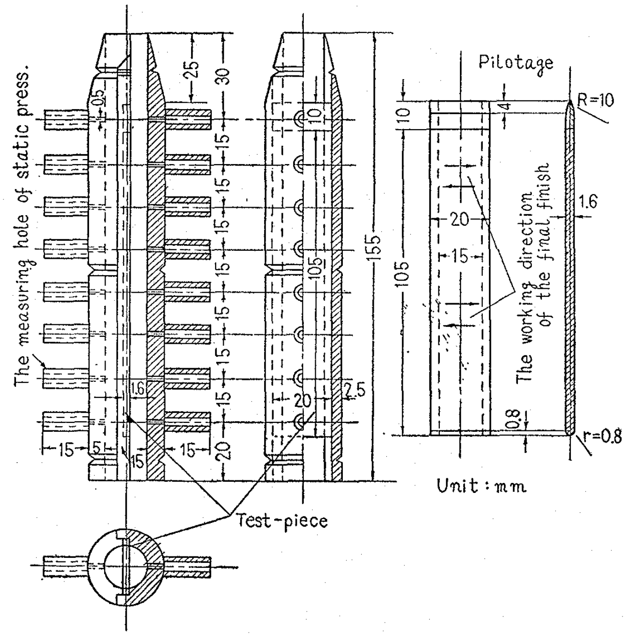

Fig. 2 Testing pipe and test piece; the pipe is divided in two parts with the test-piece between them

of sand particles flown in were determined, paying attention so that the mean velocity and the percentage of sand particles flown in might stay within the relative error of 0.5%.

(b) In the measurement of the surface roughness, the surface roughnesses just before and after the abrasion test are profiled. In this case the surface roughness after the abrasion test is that which was obtained from the test piece tested for 30 cumulative minutes. In determination of the surface roughness from the profile, the author followed the JIS[7].

3. Results and consideration

Results obtained from each experiment performed by the methods with the apparatus mentioned above are :

(a) Results of the abrasion test

(a′) The wear per unit area in unit time for each period of each experimental time interval :

The relation between the wear and experimental time interval or running-distance is as shown in Fig. 3. For 0～10 minutes that is, for the running-distance of $0\sim1.8\times10^3$ m from the start of experiment, the wear has been found decreasing as the state of finish is improved from the state of as-cast black sheet to buff-finish.

So for as the surface situations are concerned, it may be stated that in general, where the finish is better, the upheaval will be smaller, but where the upheaval is smaller, the angle of upheaval will be larger, that is, nearly flat, while where the finish is rougher, the angle of upheaval will be more acute. Accordingly the abrasion-mechanism in this case being due to mechanical destruction of the upheaval of metal surface by sand particles in the fluid, it is presumably caused by the fact that when the finish is good, abrasion of upheavaltops by collision-contact of sand particles is more difficult than when the finish is rough.

And if the flowing of the fluid with sand particles is considered, it may be stated that where the finish is rougher, when the fluid with sand particles contacts with the rough finished surface, eddies conceivably occur more frequently and more violently. And since this kind of wear is greatly inclined to lose the existence of boundary layer working as protective film, the wear, where the finish is rougher will he larger, while where the finish is better, it will he smaller.

Then for the period of 10～30 minutes, that is, for the running-distance of $1.8\times10^3\sim5.4\times10^3$ m, though it appears quite irregularl, compared with the foregoing experiment for 0～10 minutes, that is, for the running-distance of $0\sim1.8\times10^3$ m, excepting the case of such extremely rough state of finish as the state of as-cast black sheet, there is observed the tendency that the state of finish which resulted in a large quantity of wear per unit area, in unit time length in the previous experiment resulted in a small quantity of wear in the succeeding experiment and the one with small wear in the previous experiment resulted in heavy wear in the succeeding experiment.

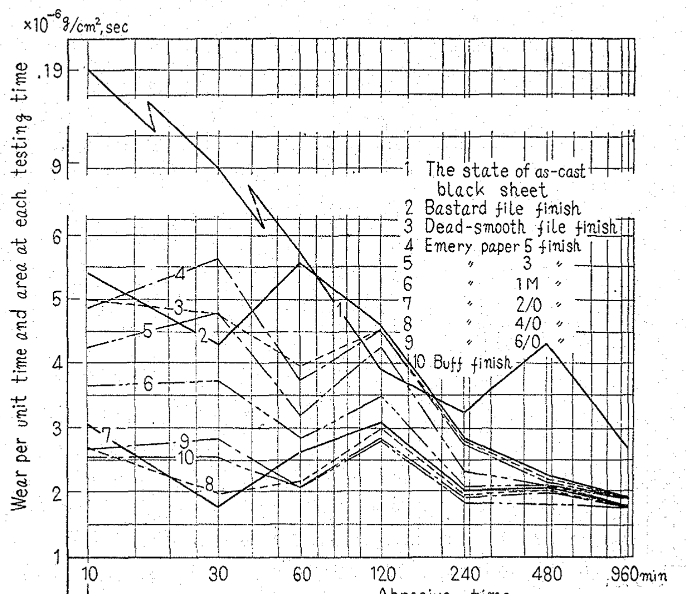

Fig. 3 The relation between the wear at each testing time and testing time of abrasion (or the running-distance)

This tendency was apparent not only in the 1st and 2nd experiment, but also in the 3rd experiment for 10～30 minutes, that is, for the running-distance of $1.8\times10^3\sim5.4\times10^3$ m and the subsequent experiments. In other words, the wear per unit area in unit time interval had a tendency to become smaller and smaller repeating the process of alternately becoming large or small, as the author continued his experiments. The better the finish was, the smaller the wear difference became.

This result is considered to be caused by the following reason :

In general in the abrasion-phenomenon between solid bodies, their destruction is great at outset due to mutual crushing of upheavals of surfaces of solid bodies, but as their mutual crushing and scratching go on, their destruction becomes smaller and surfaces smoother[3], and on account of the mutual contact of smooth surfaces, the surfaces become rather rough[1]. And furthermore, after repetition of crushing and scratching between those rough surfaces, the layers directly under the surfaces receiving abrasion are gradually changed in quality under influences of hardening or others and there proceeds steady abrasion on the converted layers. However, the abrasion in the present experiment caused by the fluid with sand particles is apparently due to mechanical destruction caused by collision-contact of sand particles just like the abrasion between solid bodies[8]. And by means of X-ray diffraction the author confirmed existing layers of small metallic crystals as what are called Belby layers which became hard by splitting activity of those crystals. Therefore, in this case too, just as the case between solid bodies, the surface undergoes the action of becoming hard and smooth alternately in succession accompanying repeated change of wear becoming large and small alternately, and similarly in the present experiment, large and small wear resulted alternately. When the difference between large and small wear was great it was understood that the experiment was in the state of primary abrasion, and when it was small, it was in the stage of steady abrasion.

Four hours after the start of experiment, that is, where the running-distance is beyond 4.32×10^4 m,

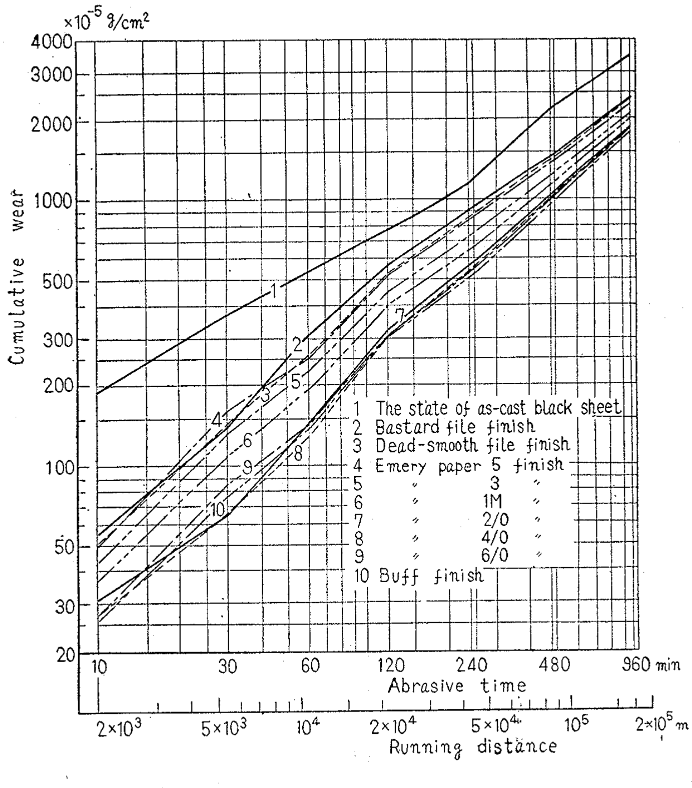

Fig. 4 The relation between the cumulative wear and testing time of abrasion (or the running-distance)

the wear of the metal with surface of better finish than that of Emery peper 1 M,—though there are increase and decrease, as each experiment goes on, per unit area in unit time length,—results in some approximately fixed value, while 16 hours after the start of experiment, that is, where the running-distance is 1.73×10^5 m, wear of buff finish is approximately (1.76×10^{-5} g/cm²sec) which is considered equal to that of steady abrasion a little after the primary abrasion.

And with the metal with rougher finish than Emery paper 3, even 4 hours after the start of experiment, viz. where the running-distance was 4.32×10^3 m, the wear was great, but its decrease was great as each experiment gradually went on, and it approached to the value of (1.96×10^{-5} g/cm² sec) of the finish of Emery paper 3, 16 hours later, viz. at the running-distance of 1.73×10^3 m and after that it indicated the value of wear of the finish of Emery paper 3. Accordingly after passage of 16 hours, viz. at the running-distance of 1.73×10^5 m, it is supposed to reach steady abrasion. However, the metal in the state of as-cast black sheet represents a special case in which it would need more time to settle to steady abrasion.

(a'') Cumulative wear in each experimental period :

The relation between cumulative wear in each experimental period and its running-distance is shown in Fig. 4. As explained in (a'), within 4 hours of experiment, viz. within the running-distance of $0\sim4.32\times10^4$ m, some irregularity is seen in the relative curve. It testifies that the experiment is in the primary stage of abrasion. Beyond 4 hours, viz. beyond the running-distance of 4.32×10^4 m, no irregularity of the curve is seen, showing that the better the finish is, the less the cumulative wear.

Excepting the case of the state of as-cast black sheet, the results can be grouped into two classes by approximate similarity of cumulative wear :

(i) From bastered finish to Emery paper 5 finish and (ii) from buff finish to Emery paper 0/2 finish.

Among those belonging to the same class there is nothing but a very small difference from one another while the difference of each class from the other class is comparatively great. Therefore under the consideration of finish effect in regard to the abrasion of this case, it is assumed possible to classify the state of surfaces before abrasion into two classes :

(i) Comparatively coarse surface and (ii) comparatively polished surface with their boundary around the stage of Emery paper 3 finish and Emery paper 1 M finish.

Accordingly in regard to abrasion, the finish surface up to Emery paper 5 finish is considered influental as comparatively coarse surface, and on the other hand a good finish above Emery paper 0/2 finish is considered meaningless in consideration of this kind of abrasion. And this fact can be confirmed by observation of surface (roughness) measured by surface tester.

(b) Measurement of surface roughness

Surface profiles just before and after the abrasion experiment of 10 finish conditions are shown in Fig. 5. Figures entered therein indicate the maximum heights (micron) of surface roughness and wear ($\times 10^{-5}$ g/cm^2).

In general profiles before abrasion, compared with those after abrasion, are represented by finer upheavals sitting additionally on the indicating large upheavals. This is considered due to finer upheavals being easy to scratch off by collision-contact of sand particles. And generally the maximum height of surface roughness before abrasion is higher than that of surface ronghness after it. And also the order of the maximum heights of surface roughness after the abrasion is corresponding to that just before it.

The maximum heights of surface roughness becomes low on account of mechanical destruction of top of surface upheaval while at the mechanical destruction performed by some fixed quantity of sand particles, the destroyed part thus produced is considered to remain approximately in the same degree, so the metal with the maximum heights of surface roughness just before abrasion can be supposed to be with the maximum heights of surface roughness even after it.

However, while the maximum heights of roughness above Emery paper 0/2 finish is 0.5 micron and the maximum heights of surface roughness of buff finish which is of better finish than that of the above one before abrasion is 0.25 micron, the maximum heights of surface roughness of both of them after the abrasion is constantly 0.5 micron.

This fact reminds the author of his idea that the abrasion wear mentioned before can be classified into two groups : comparatively coarse surface and polished surface with the boundary around Emery paper 3 finish and Emery paper 1 M finish, and the idea turned out to be true. Furthermore this fact is interpreted to indicate that the maximum heights of surface roughness produced by collision-

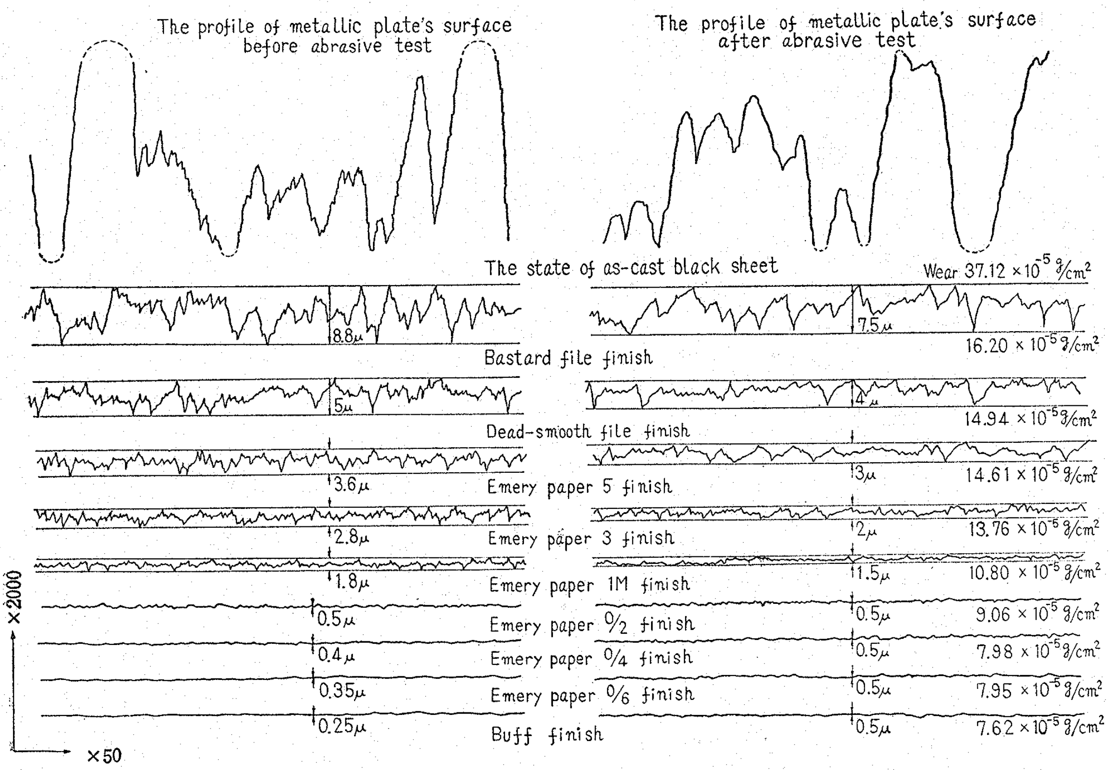

Fig. 5 The profile of metallic plate's surface before and after abrasive test and their max. height of surface roughness and wear

contact of Tokitsu silica sand 4 under the present experimental condition of abrasion with cartridge brass plate is 0.5 micron.

(c) Relation between the maximum height of surface roughness and abrasion wear

Calculating from the measured results of abrasion in Experiment (a) and of the maximum height of surface roughness before the abrasion, the relation between the maximum heights of surface roughness and the abrasion wear was obtained as shown in Fig. 6.

This relation is of linear relationship indicated in logarithmic rectangular coordinate. And from the experimental result obtained by testing on other kinds of silica sand, each of them indicates a nearly parallel relation to one another.

Thus the following formula can be established:

$$\log\frac{W}{A}=n\log H+k, \qquad \therefore\quad W=K\cdot A\cdot H^{n}$$

where W/A ($\times10^{-5}$ g/cm^2) represents the wear per unit area, H (micron) represents the maximum heights of surface roughness before the abrasion.

From the results thus obtained it can be concluded that the abrasion wear by all silica sands employed in the present experiment is in proportion with 0.228～0.218 (in average 0.22) powers of the maximum heights of surface roughness.

4. Conclusion

1) When the surface finish of the test piece is better than that above Emery paper 0/2 finish (the maximum heights of surface roughness is 0.5 micron), that plate can be treated as comparatively polished surface, but when it is coarser than that above Emery paper 5 finish (the maximum heights of surface roughness is 3.6 micron), it can be deemed as comparatively coarse surface, while the finish-surface which is better than that of Emery paper 0/2 finish (the maximum heights of surface roughness is 0.5 micron) is observed turning into coarse surface by abrasion accordingly regarded meaningless for practical working.

2) Comparatively polished surface is likely to immediately undergo steady abrasion, while comparatively coarse surface is just the contrary.

3) In each state of finish, the abrasion wear per unit area in unit time length repeats the cycle of alternate increase and decrease in the period of primary abrasion, gradually proceeding to steady abrasion in the process.

4) The better the state of finish is, the smaller the abrasion wear for each running-distance.

5) The abrasion wear is in proportion with 0.228～0.218 (in average 0.22) powers of the maximum height of surface roughness.

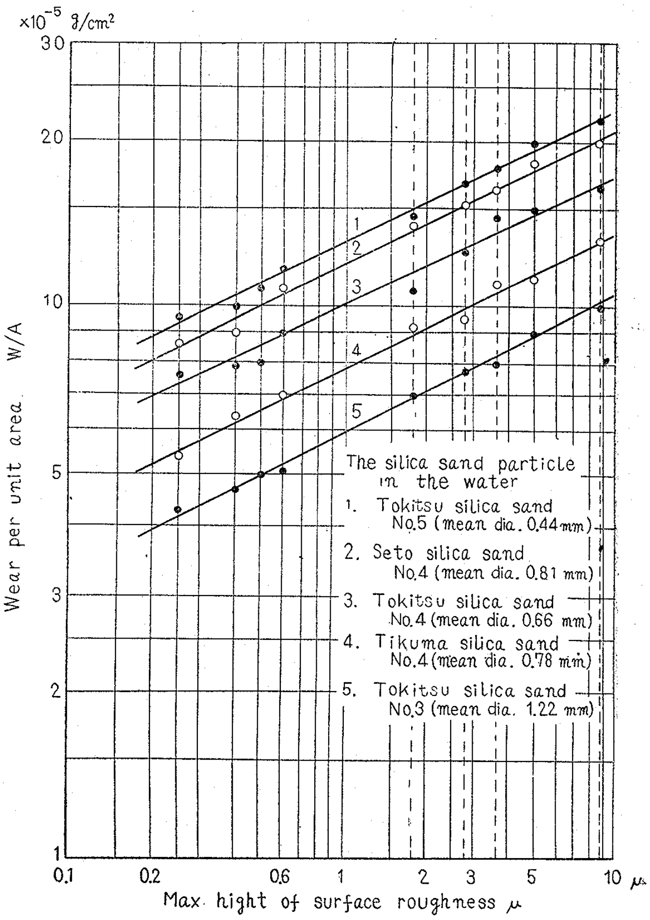

Fig. 6 The relation between the wear per unit area and the max. height of surface roughness with different sorts of the silica sands

Table 1

Silica sand / Symbol	Tokitsu 5	Seto 4	Tokitsu 4	Tikuma 4	Tokitsu 3
n	0.225	0.228	0.218	0.221	0.228
k	1.127	1.086	1.009	0.903	0.783
K	13.393	12.195	10.202	7.998	6.064
Error $\times10^{-5}$ g/cm^2	0.35	0.36	0.24	0.24	0.11
Abs. error %	2.41	2.82	3.52	2.84	1.76

References

(1) S. Majima: *Trans. Japan Soc. Mech. Engrs.*, Vol. 5, No. 21, I(1939), p. 97.
(2) F.P. Bowden and K.E.M. Hidler: *Proc. Roy. Soc.*, 1(1936), p. 640.
(3) M. Ogosi: *Trans. Japan Soc. Mech. Engrs.*, Vol. 5, No. 21, I(1939), p. 105.
(4) S. Majima: *Trans. Japan Soc. Mech. Engrs.*, Vol. 6, No. 25, I(1940), p. 27.
(5) S. Yamasita: *Trans. Japan Soc. Mech. Engrs.*, Vol. 23, No. 134(1957), p. 737.
(6) S. Yamasita: *Trans. Japan Soc. Mech. Engrs.*, Vol. 23, No. 133(1957), p. 646.
(7) JIS B 0601—1955.
(8) K. Asakura: KINZOKU NO MAMŌ, *Abrasion of Metal* (1945 Maruzen), p. 20.