On the Mechanical Pulverizing for Metals by a Specially Designed Eddy Mill

On the Mechanical Pulverizing for Metals by a Specially Designed Eddy Mill

Tosihiko OKAMURA, Kôji INAGAKI and Yosimichi MASUDA*

The Research Institute for Scientific Measurements

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Synopsis

A special eddy mill, in which metals are crushed chiefly by shearing due to mutual friction was designed and the crushing experiment for various metals and alloys was performed, and many important results on following subjects were obtained;

1. Relation between work amount for pulverizing and pulverizing time.
2. Relation between work amount for crushing and particle size of material.
3. Variation in the particle size distribution of mill product for the treating time.
4. Microphotographs of pulverized powders.
5. Oxidation of pulverized powder and temperature rise in pulverizing.

I. Introduction

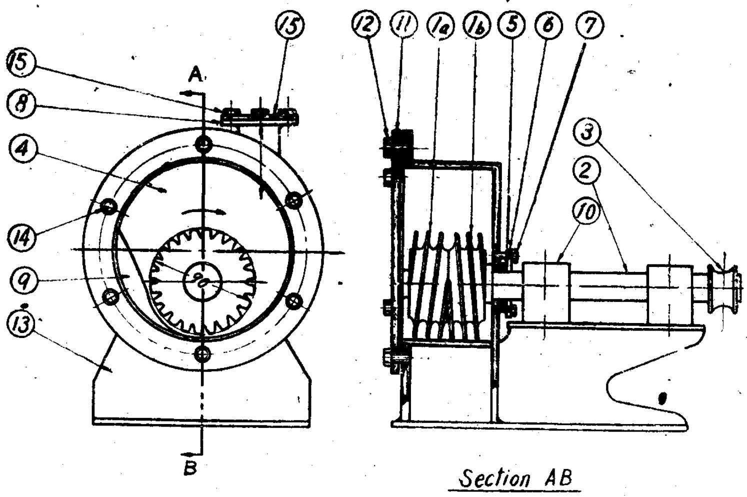
The present study aims to investigate on the pulverizing mechanism for metals and alloys and on the properties of the produced powder, by using various types of mills.

Shearing action by friction, impact action by stamping and exfoliating action by collision are regarded as the chief action for pulverizing. For common pulverizers, it is difficult to distinguish those three actions, hence the designer must invent to utilize them most effectively. Since there is no detail study on the pulverizing process of metals when one of them acts separately, it is very difficult to find the suitable pulverizing method, which should be adopted for various metals. To solve these problems, the pulverizing process of metals must be studied in a mill, in which pulverizing is mainly performed by one of the above mentioned three actions. For this purpose, a special eddy mill was constructed experimentally, in which metals were mainly pulverized by exfoliating action due to mutual particles collision, and its pulverizing process was studied.

II. Pulverizer and its action

The pulverizer is illustrated in Fig. 1; special screws (1a) and (1b), having 90 mm in outer diameter, rotate in the bottom of drum 4; the circular velocity of the screw is 16.7 m/sec and its velocity of holizontal displacement 0.66 m/sec; 500 grms of material are charged into the drum and the screw (1) is driven by 1 HP motor

* The Research Institute for Iron, Steel and Other Metals.



1a. Screw 1b. Screw 2. Shaft 3. V. Pully
4. Drum 5. Packing 6. Packing plate
7. Bolt 8. Charge hole 9. Liner 10. Bearing
11. Cover 12. Bolt 13. Bace
14. Cover fixed tap hole. 15. Charge hole cover

Fig. 1.

in variable speed. The action of this mill is shown in Fig. 2; two screws (1a) (1b) opposing each other are attached to the shaft and rotated with high speed along the arrow. The motion of material is shown by the arrows and the particles collide with each other at a, b and c. The notches cut on the thread of screws in order to stir up the powder more intensively are so dull that there scarcely occurs any cutting action. In short, in our mill, material particles are stirred up by the rotation of screws at high speed and pulverized mainly by exfoliating action owing to mutual collision of the particle.

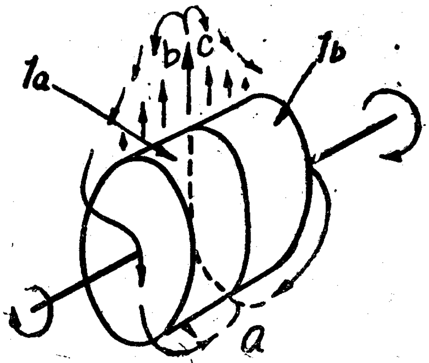


Fig. 2.

In the present experiment cast iron, imitation gold*, Cu, Ag, Cd, Sn and Pb were pulverized by this method; they were cast into a sand mould and cut by a metal saw to the size of 5 mm in width and 0.7 mm in thickness, and then charged into the drum; this procedure was followed, since chips cut by the metal saw have nearly the same shape for all metals, which are pliant or brittle, being independent of the hardness of the samples. The shape of the chips is shown in Fig. 9.

III. Definition of work for crushing

Rittinger's law states that the increase of work for crushing is proportional to the increase of the surface area of the treated matter. This law is adapted for the experiments. The surface area of sieved powder is calculated by assuming the cubical form of the particle, the edge length of which is equivalent to the mean length of the upper and lower screen mesh. Pulverized powder was classified into 10 size ranges from 10 to 300 mesh by sieving. So the surface area of the treated powder per gr. is given by,

$$A = 6\sum_{10}^{300}\frac{1}{l_a + l_b}\,\frac{1}{\rho}\,\frac{w}{W}\times 10^4\ \mathrm{cm}^2$$

where l_a : length of the upper screen mesh (mm)

* The composition of this cupper alloy is 4% Zn, 2.6% Al, 0.3% g, remains Cu.

l_b : length of the under screen mesh (mm)
ρ : true density of the powder,
w : total weight (gr),
$W.$: weight of the powder sieved by the two screens (gr).

IV. Crushing experiment

(a) Relation between work amount for pulverizing and pulverizing time. 500 grms of each metal were pulverized and the increases of total surface area of the pulverized powder were measured for every pulverizing time; the results are shown in Fig. 3. This method of calculation for the surface area as mentioned in

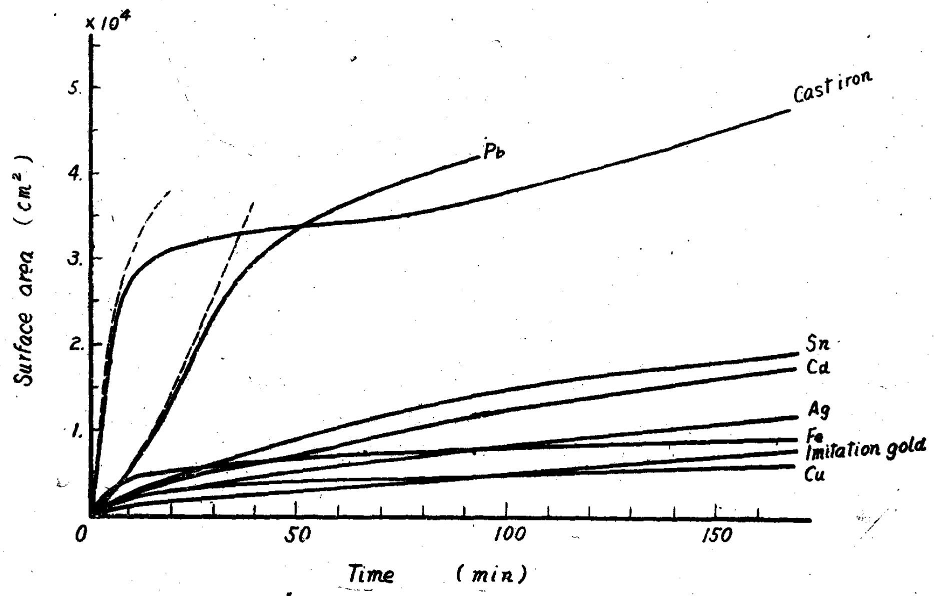


Fig. 3.

the preceeding section is not suitable for the metals especially for Pb and cast iron, which is pulverized to smaller size than −300 mesh. In the present paper, by this method, the average size of those particles below −300 meshes were assumed as −325 meshes. It is inferred from Fig. 3 that in general the total surface area of the powder increases with the progress of treating time as the smaller particles gradually increase. In particular, Pb pulverized for 20 minutes and cast iron for 70 minutes were pulverized nearly about below −300 mesh, as ascertained by microscopic observation. Hence, the inclination of these curves against the time axis shoued be increased considerably, as shown by the dotted line. The curves in Fig. 3 are differentiated with respect to the pulverizing time and the increasing rate of work amount (B. H. P.) for each metal is measured by prony dynamometer, and from both results the increasing rate of work amount per HP for every pulverizing time are obtained as shown in Fig. 4.

From these results it is realized for all metals and alloys except for Pb that the increasing rate of work amount for crushing decreases gradually with the increase of crushing time and approaches to an almost constant value for a while before the next increase.

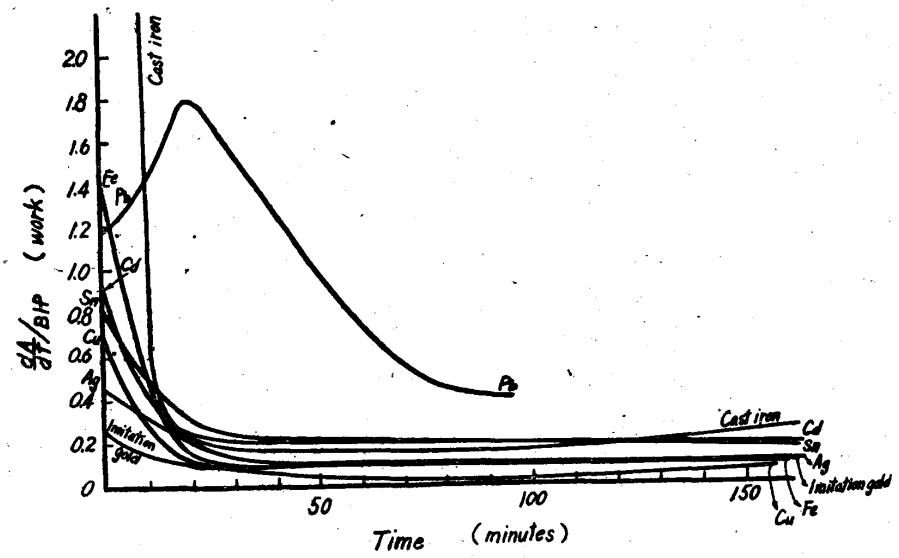


Fig. 4

The initial decline of the increasing rate may be due to brittle parts of crystal grain boundary and notches which arise in the metal chips during cutting.

Other reasons for the initial declination of the increasing rate, it is considered that the pulverization is facilitated by the concentrating of crushing stress on the larger chips; this will be called "intial effect" in the present paper. It is suggested that the comparatively horizontal part of the curve appears as the consequence of work hardening of metal particles caused by mutual collision of particles in this pericd and after a certain work hardening they are pulverlized by exfoliating action of collision. This will be called "contact effect" in the present paper. Cast iron chips, especially larger chips, are pulverized effectively by the mutual collision in the earlier stage of pulverizing, since they have less resistance to crushing. Then, they are pulverized directly by exfoliating without work hardening and there can be found a lot of very fine graphite particles in the crushed powders after the treatment for 160 min; this suggests that graphites in cast iron are pulverized especially after about 50 min of treatment. As for Pb, the rapid increase of work amount in the beginning of crushing is due to the spherodizing of the flat chips, and crushing is hardly performed in this period. After treatment for 15 min, the particles are pulverized by exfoliation of their surface layer due to mutual frictcn by collision. The pulverized powder contains many fine particles of 2~10 μ in diameter, so that the mean diameter of the particles in the powder below −130 mesh may be smaller than the one calculated above. Table 1 shows the ratio of the weight and surface area of the powder below −130 mesh to the total weight and surface

Table 1.

	Weight % −300 mesh	Total surface area (cm^2)
Pb	65.8	91.8
Sn	8.3	42.3
Cd	10.7	48.2
Cast iron	12.9	28.4
Fe	3.7	33.0
Imitation gold	3.3	31.3
Ag	7.9	37.8
Cu	2.1	25.2

area of the obtained powder. The percentage of surface area amounts to about 40% in soft metal and over 90% in the case of Pb. As above mentioned, there are many fine particles in the Pb powders, whose diameter can not be measured by the optical microscope. The cast iron powder contains similar fine particles of graphite. Therefore, the true total surface area of these powders must be considerably larger than the calculated one. It may be concluded from the above results, that the total contact area between particles which are more finely pulverized with the increasing of pulverizing time, is augmented, so that the exfoliation caused by mutual friction acts effectively owing to the mutual collision of the particles.

(b) Relation between work amount for crushing and particle size of material.

In our mill, 400 grms of uniform powders of Cu, Ag and cast iron were crushed for 10 min, and the increases of total surface areas measured for each powder were classified previously to have a uniform particle size of 10, 65 and 100 mesh respectively. The obtained results are illustrated in Fig. 5. The curves show that the work amount for 65 mesh powder is the minimum and that there is an increase gradually with the decrease of the particle size. This may be attributed to the decrease of the "initial effect"; the work amount first decreases with a decrease of particle size, until the metals are crushed to 65 mesh. On the other hand the "collision effect" may give rise to the increase of work amount for the pulverizing of −100 mesh powder which is caused by the

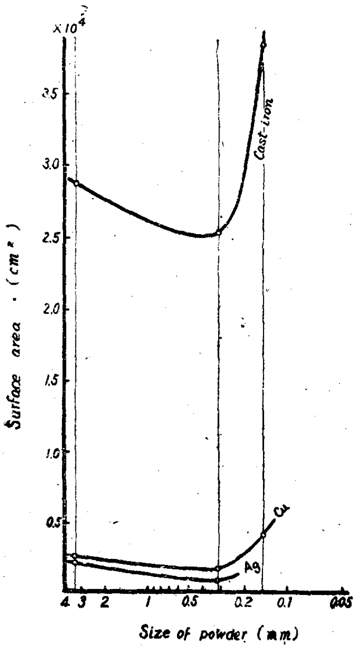


Fig. 5.

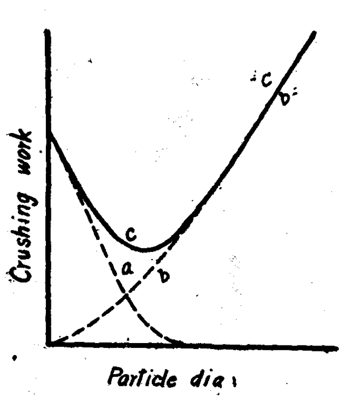


Fig. 6.

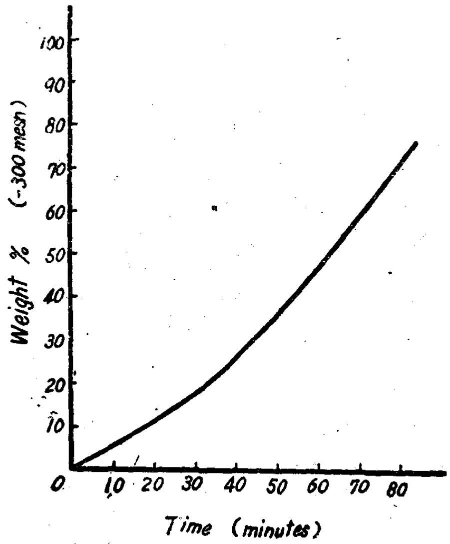


Fig 7.

"collision effect". Both effects are shown analytically in Fig. 6; a is "initial effect" and b "collision effect". The curve b can be obtained experimentally in the case of the pulverizing for Pb, which can be pulverized mostly "collision effect". Fig. 7 was obtained from the result of measurements of weight percentage of −300 mesh Pb powder for each pulverizing time. The treating time in the abscissa of the figure is obviously inversely proportional to the particle size. Therefore, the work amount versus particle size curve can be generally illustrated by the curve C, which is resultant of a and b. Then, it is concluded that the crushing process of metals and alloys proceeds in obeying the curve a, b or the resultant curve C.

(c) Variation in the particle size distribution of mill product for the treating time.

The variations in the size distribution of mill products with pulverizing time, were obtained by sieving in 10 size ranges from 10 to 300 mesh for all obtained products after pulverizing for a certain period of time, namely, 10, 30, 75 and 160 min. The results are shown in Fig. 8. From the graphs it may be seen that in usual metals except for Pb the particle size of mill product tends to a certain given size range with increasing of crushing time, which is at 150 mesh for cast iron and about 65 mesh for other metals. This phenomena will be caused by the "initial effect" of crushing, which is mentioned in the interpretation of the curve (a) in the preceeding section.

In the earlier stage of crushing process, the "initial effect" of crushing acts on the crushing function effectively by forced string of the mass of powdered material and the disintegration proceeds easily to the 65 mesh or about the 150 mesh. On the other hand, this phenomena does not conspicuously appear in the graphs for such a metal as Pb, which is disintegrated only by mutual collision of particles. From this fact it may be said, that no "initial effect" occurs in the powder, which reaches a certain particle size by disintegration, and in this case the fine disintegration proceeds by exfoliation owing to simple mutual collision of powder paritcles. Accordingly the fine disintegration by simple collision effect should be taken into account in the stage after the foregoing condition.

Such consideration on the pulverizing process will be ascertained by further examination of microphotographs for the powders of each size ranges as shown in the next section.

(d) Microphotographs of pulverized powders.

Fig. 9 shows the microphotographs for the starting material and the pulverized powders of each size ranges of 10∼−300 mesh, for which the pulverizing time is 160 minutes, expect for Pb, which was pulverized for 75 minutes. Accordingly, in this case the "initial effect" of crushing decreases to a certain degree and the collision effect mainly governs the pulverizing action.

As shown in these photographs, the particle shapes of the powders, as Pb, Sn and Cd, are nearly spherical in all described size range, while the other metals

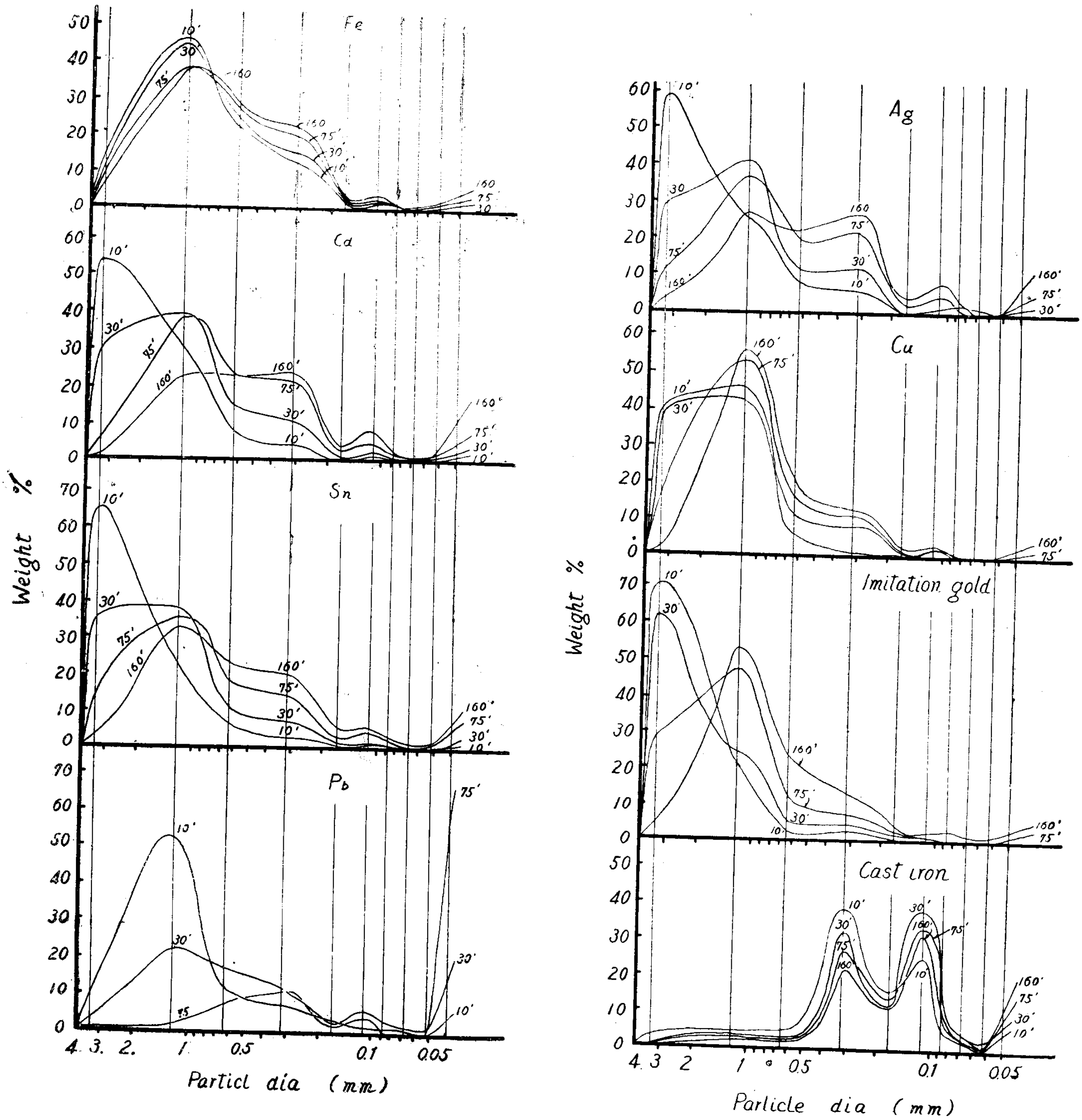
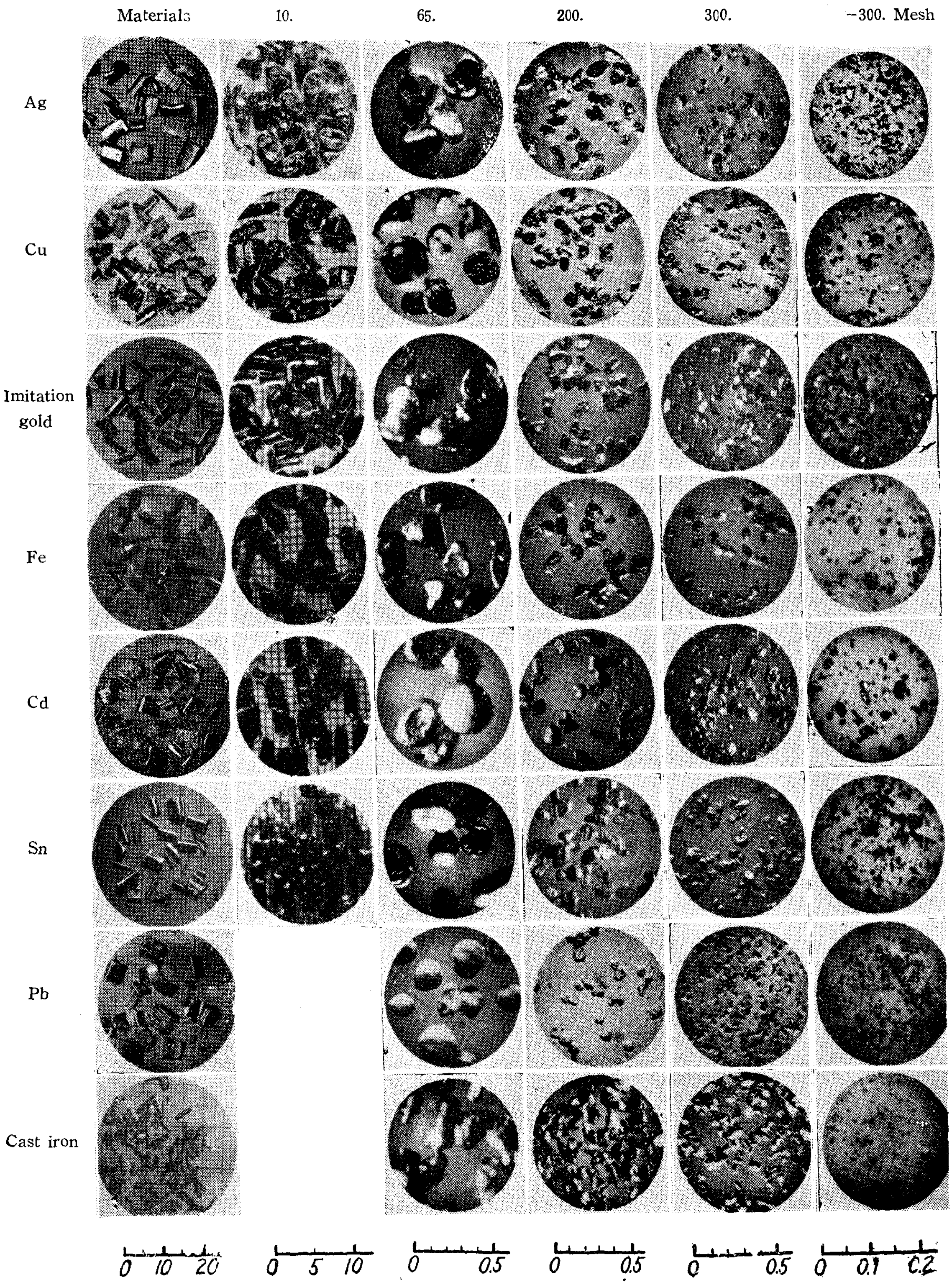

Fe
Cd
Sn
Pb
Weight %
Particl dia (mm)
Ag
Cu
Imitation gold
Cast iron
Weight %
Particle dia (mm)

Fig. 8.



Size of powder in mm.

Fig. 9.

are disintegrated similarly into ellipsoidal shape in 10～−300 mesh. No tendency to similar disintegration have been recognized and the particle shapes are very irregular. As above mentioned, the disintegration proceeds by only mutual collision of particles in the powder, which is disintegrated to a certain size range by "initial effect" of crushing. In such condition of crushing, there is no chance of dividing the particle into two or three fragments by any forced stiring, and the particles come to point-to-point contact in which the fine fragments are exfoliated from the surface of the particles by frictional shearing. In this consequence, the produced powder has the particle size of −300 mesh and an irregular particle shape, as shown in the photographs.

Although few experiments were made for the spherodization of this irregular shaped particles by long stirring(1), they will be omitted in this paper since only the mechanism and process of the producting of fine powder are considered.

The pulverizing process to reach the particle size of 300 mesh is a type of similar dividing disintegration, in which the powder having the particle size of +300 mesh come to frictional contact and the fine fragments fall off from the surface of particles. In consequence, the particles become smaller and of similer shape as the original particle with the progression of pulverizing process. From these evidences, in the pulverizing process there is a sharp distinction between both types of mechanism for producing of coarse and fine powder.

(e) Oxidation of pulverized powder and temperature rise in pulverizing.

The pulverized powder by the eddy mill is less oxidized than that obtained from the other mill and keeps its luster for a comparatively long time. Among various reasons the main one is as follows: in the case of eddy mill, the powder has an amorphous surface, owing to the collision with each other, while the powder in the stamp mill and cutting mill are always exposed to fresh air in crushing treatment and thus suffer heavier oxidation.

The maximum temperature rise in this mill after treating for 160 min. is 40° for Fe and the minimum is 15° for Pb. The temperature rise depends on the coefficient of mutual kinetic friction, specific gravity, specific heat, stored energy in work-hardening and other physical properties of the treated metal. Therefore, conclusive remarks for these phenomena require more experimental results.

Summary

A special eddy mill, in which metal is crushed chiefly by shearing due to mutual friction was desinged and the crushing experiments for Cu, Ag, cast iron, Fe, imitation gold, Pb, Sn and Cd were performed to analize the crushing process of these metals, and the relations of the work amont to crushing time and particle size, etc. were measured.

In conclusion, the present writters express their best thanks to Assist. Prof. H. Kojima for his valuable discusions during the course of this investigation.

(1) T. Nisijima Y. Yamamoto and K. Ogawa, Science of Powder, 2 (1945) 156.