On the Mechanical Disintegration of Metal by a Stamp Mill

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On the Mechanical Disintegration of Metal by a Stamp Mill

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Synopsis

A disintegration experiment was made on some metals of different property by using a stamp mill, which was especially designed by one of the authors for the present work. The relationships between the work and the time, the mechanical property and the size of the material, and between the particle size distribution of the disintegrated product and the disintegrating time, were studied. The microscopic observation was also carried out on the all of the products during disintegration. On the basis of the experimental results the disintegration process and mechanism were considered.

I. Introduction

The present work was undertaken on the study of the disintegration mechanism of metals and alloys, and the properties of the powder produced by a stamp mill.

In general, the disintegration of metal is proceeded mainly by the following three actions; the shearing, the impact and the friction. Although, with a common mill, the collaboration of these three actions is responsible for the disintegration of the material; with a mill of the given type, the disintegration process is principally governed by a certain mechanism. On the basis of such concepts, the disintegration processes in a specified mill, in which a sole mechanism is predominating, has been studied in a series of our work. As already reported in our previous papers, such investigations have given us an available guidance in designing the most efficient mill for disintegration of various sorts of metals.

In the designing of a mill, we must seek a most profitable mechanism according to various mechanical properties of the material, and, moreover, it is necessary to have a sufficient knowledge about the relationship between the mechanical properties of the starting material and the disintegration process with the mill employed. In the present work, such relationship was studied on the various metals and alloys by using a stamp mill especially designed for the present work, in which the disintegration of the material can be carried out mainly with the impact shock of the stamp shoe.

II. Disintegration Mechanism of the Stamp Mill

The stamp mill used for the present work is illustrated in Fig. 1. The total weight of the cam, the stamp shoe and the shaft, is 22 kgrs, with which the materials charged in the pot are impacted. The stroke of the stamping motion is transmitted by a cam driven by an electrical induction motor through a pulley and a belt, which controls the turning speed of the cam.

In this work, the weight of the materials that are charged at one time was about 500 grs, the length of stroke, 90 mm, and the number of stamp per minute, 120. From such mechanism of the mill, it is unquetionable that the principal action of such a mill is the shock of stamp shoe. However, by observing the actual process of the disintegration in this mill, it could be found that the mechanism varied with every stage of the disintegration. In the earlier stage the impact energy of the stamp shoe is expended for the work of compacting the voluminous material and is rather consumed as a work of shearing and bending the metal chips used as the starting material. In the later stage, however, the produced powder is circulated in the pot by the reaction of stamping shock, and a portion of the supplied energy to the powder by stamp shoe is consumed by the circulating motion and the friction of the powder particles.(1) Moreover, in this stage the impact forces applied to the powder are buffed by the cushioning action of fine powder, and this prevents the force from concentrating to each particle. Accordingly, in this work, the process in the earlier stage of disintegration was particularly studied, where the impact force is effectively and directly acting on the materials.

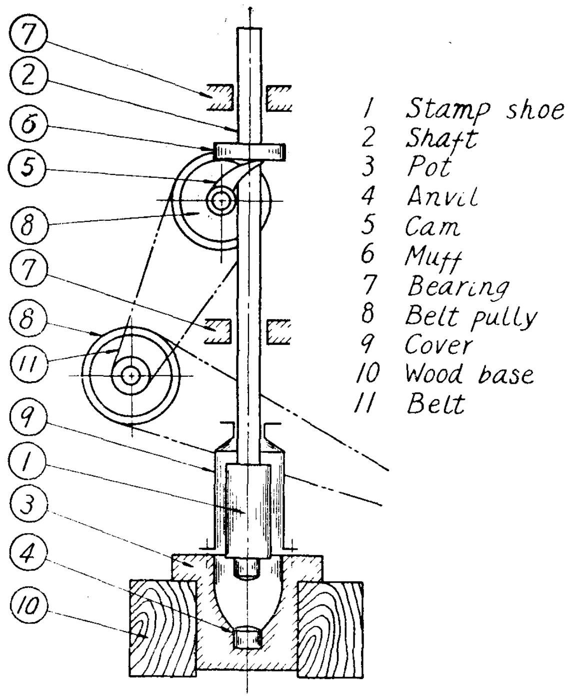

Fig. 1. Sample mill.

Table 1. Mechanical properties of some metals used as starting materials.

Metal	Tensile strength kg/mm^2	Brinell hardness H_B	Elongation %	Remark
Fe	57.65	99.7	6.8	0.1%C steel
Cast iron	20.00	146.0	—	
Cu	12.68	22.7	8.5	
Ag	8.76	26.7	12.5	
*Imitation gold	20.20	44.2	6.8	*Cu-Al-Ag-Zn-alloy
Cd	7.15	22.1	35.8	
Sn	1.30	8.0	61.0	
Pb	1.00	5.0	53.5	

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(1) K. Iwase, K. Ogawa and T. Nisijima; Journal of Applied Physics of Japan, **16** (1947) 34.

* The composition of this imitation gold is 4%Zn, 2.6% Al, 0.3% Ag, remains Cu.

III. The Metals used for the Disintegration Experiment

The disintegration experiment was carried out with various metals of different mechanical property as shown in Table 1.

The shape and form of the materials used are illustrated with the photographs in Fig. 7. As seen in the photographs, the chips machined from the ingot which was cast in the sand mould were used for the starting materials, because uniform chips can easily be obtained by sawing from any kind of metal brittle or ductile.

IV. Relation between the Work and Time for Disintegration

The total surface area in 500 grs of the disintegrated product, which could be approximately proportional to the work of disintegration, was determined after stamping for the given time.

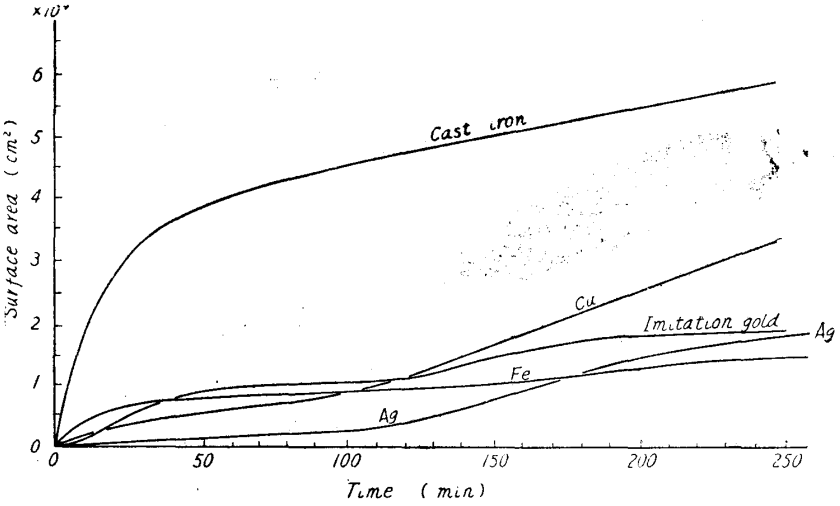

Fig. 2. Relation between disintegrating time and total surface area of various metals disintegrated in the case of stamp mill.

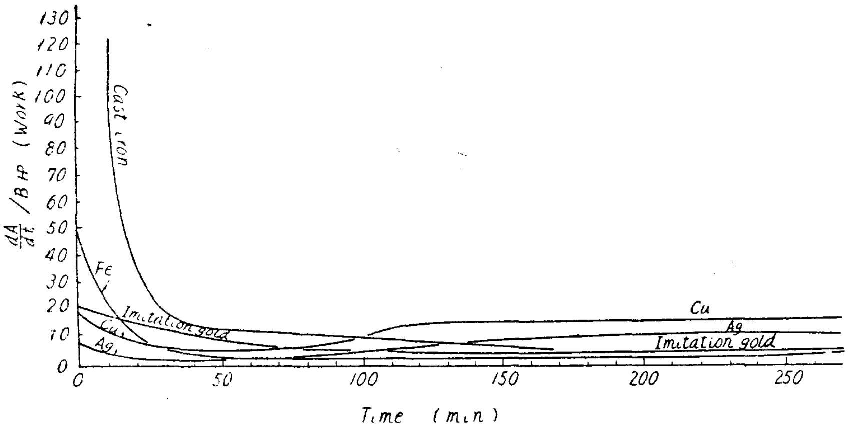

Fig. 3. Relation between the treating time and disintegrating works for various metals in the case of stamp mill.

The curves of the increase in the total surface area with the progress of the disintegration are indicated in Fig. 2. In this case the value of the total surface area in the product was calculated in the same way and under the same assumption as described in our previous paper.(2) As seen in the graphs, the work required for disintegration of such metals as 0.1 % carbon steel, cast iron and a imitation gold indicates an abrupt increase in the starting period, while it shows a stational increase for copper and silver. This fact becomes clearer, if the curve is differentiated with respect to the disintegrating time and studied the rate of increase in the work against the time, as shown in Fig. 3. From this graph, it can be seen that a larger work is required for disintegration of the brittle metal such as 0.1 % carbon steel, cast iron and the imitation gold in the beginning stage, and in the later it requires less work. This may be due to the favorable nature of the starting material for disintegration, which are given them occasionally during the production; this called "the initial effect" in our investigation.(3) The first favorable nature is the shape of the material, which should be flat and large in form. When such a voluminous material is charged in the pot, it will forcibly be moved and compacted by the stamping in the starting period. Such drastic motion of the material in the pot can occastionally give a favorable condition for disintegration. The second is the mechanical strength of the material produced during the maching process, which can be lowered by numerous notches and dislocations in the metal crystal. For these reasons, a larger portion of the supplied work can be used for disintegration of brittle metal than for tough metal, for which much of energy is consumed as a heat of friction and a deforming energy of the material. This can also be noted on the curves of the work for disintegration of any kind of metal. On the curves for copper or silver, a minimum appears in the earlier time, which means that, in this period, a large portion of the supplied energy is consumed because of deformations and crackings of materials.

From these result, it is supposed that the stamping method may be effective in disintegrating brittle metals. However, this method can not be available for very soft metals such as cadomium, lead and tin, because they easily make foil and a hard coagulation. In this case, therefore, it is necessary to use some lubricant to prevent the coagulation. Accordingly, in this work the experiment was not carried out on such metal.

V. Mechanical Property of the Material and the Work for Disintegration

In order to determine the most favourable device for disintegration of the respective metals, various metals of different mechanical property were disintegrated in the stamp mill, and the change in work used for the disintegration of such metal was studied with respect to the disintegration time and the mechanical property, such as tensile strength, hardness and elongation. The results are shown in Fig. 4, in which it can be seen that, in the earlier stage of the disintegration, a larger portion of the work is used for brittle metal of

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(2) T. Okamura, K. Inagaki and Y. Masuda; Sci. Rep. RITU, A-2 (1950), 361.

(3) T. Okamura, K. Inagaki and Y. Masuda; Sci. Rep. RITU, A-2 (1950), 364; 816.

high hardness and strength than for the ductile metal, as described above. From this fact, it may be supposed that the stamping can be the most efficient device for rough disintegration of a hard and brittle substance.

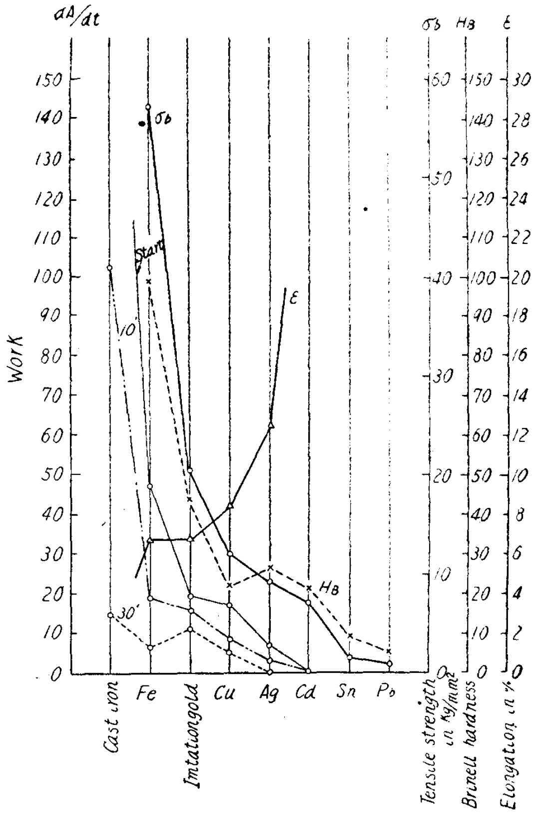

Fig. 4. Disintegrating work for various metals by stamp mill and their mechanical properties.

VI. Size of the Starting Material and the Work for Disintegration

Three sorts of the starting material different in size were used for this work, one of which was the chips machined by milling machine, 0.7×5×5 mm in dimension, and others are the product which were made previously by the stamp mill, 70 and 100 mesh in size respectively.

The disintegration was carried out with 500 grs of each material for 10 min., and after the treatment, the increase in total surface area of the product was measured by the procedure described previously. The results are shown in Fig. 5, in which it can be noted that the disintegrated product of copper from the starting material of 70 mesh contains a small surface area in the unit mass, while the increase in surface area of the product can be seen on the disintegration of silver. However, in the disintegration by using the starting material of 100 mesh, the appreciable increase in the surface area was observed in both metal products. Such a difference in the disintegration process of the both soft metals may be due to the characteristic nature of metal to the cold working. And it may be expected from this consideration that "the initial effect" on the disintegration can also play a considerable part in the process. In fact, when the mechanical property is scrutinized of the both metals of copper and silver cold rolled to the reduction of 50 pct., an appreciable difference can be noticed between the work-hardenabilities of those metals, as shown in Table 2. Silver indicates less strength and larger elongation than copper against a small degree of the reduction. These mechanical natures of silver give the

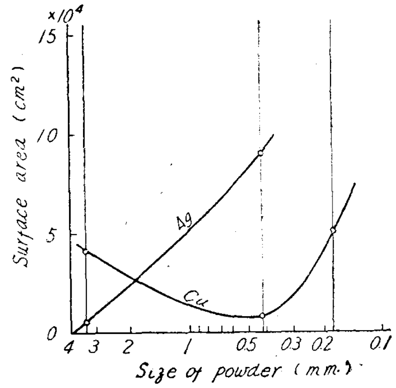

Fig. 5. Particle size of material and disintegrating works by stamp mill.

Table 2. Changing ratio of the mechanical properties of copper and silver with reduction by rolling.

Materials	Tensile strength $\frac{\text{Roll 50\%}}{\text{Cast}}$	Elongation $\frac{\text{Cast}}{\text{Roll 50\%}}$	Brinell hardness $\frac{\text{Roll 50\%}}{\text{Cast}}$
Cu	$\frac{25.83}{12.68}=2.02$	$\frac{11.00}{8.45}=1.30$	$\frac{43.2}{22.7}=1.90$
Ag	$\frac{28.60}{8.76}=3.26$	$\frac{19.9}{12.5}=1.77$	$\frac{71.4}{26.7}=2.67$

less "initial effect" to the material by the machining production, and the coarser powder of silver will not be disintegrated easily by stamping shock and will rather be deformed into a flat and thin frake. The finer powder than 70 mesh, however, which has suffered some degree of cold working and come to a fragile state, during the prior stamping operation, may be disintegrated easily by successive stamping. Therefore, in the finer powder, a less work of disintegration can reasonably be expected, and this is seen implicitly in the graph in Fig. 5.

On the other hand, the starting material of copper of 70 mesh, which has not suffered much cold working because it can be produced in a shorter time of stamping from a machined chips before the occurrence of work-hardening, may easily be worked by further stamping and a larger portion of the supplied energy will be consumed by this deformation work. This result appears in the graph in Fig. 5 as a large reduction in total surface area of the disintegrated product.

The fact mentioned above was verified by the further microscopic observation of the starting material and the disintegrated product. A marked difference in shape of particle was recognized between the 70 mesh powders of copper and silver as seen in the photographs in Fig. 7. The silver powder contains many round-edged, thick and flat particles, while the copper contains many thin and cracked particles. However, while observing the 100 mesh powder of copper, it was seen that the particles were severely flatened and cracked, and they were kept in such a condition as to be easily disintegrated by the impact shock of stamping. For such a powder, therefore, a large portion of the supplied work must be used for disintegration; in fact it was also the case with the present experimental result. Thus, for a better understanding of the disintegrating mechanisms and processes of metal, an abundant knowledge is required on the correlating effects between various mechanical properties of metal.

VII. Change in Particle Size Distribution of Product with Disintegration Time

Throughout all processes of disintegration, the product was classified into 10 grades by sieving at every end of the treatment for a given period of time. The curves of particle size distribution at respective stages of the disintegration process were obtained as shown in Fig. 6. From these curves, it can be seen that the particle size of the produced powder tends to a certain value and on the curve a maximum appears at a certain particle size. This means that, in this mill, the disintegration of the material can easily be carried out up to certain particle size, which was 70 mesh in this case. At the same time, it also suggests that the simple division of the produced grain can effectively be promoted by impact shock of stamping up to the particle size of 70 mesh. When the ordinal material except such metal as cast iron is stamped, the size distribution could scarecely be changed in a short time with successive stamping. After a long time stamping, however, the portion of the powder finer than 300 mesh indicated a gradual increase. Such a finer powder may be produced by the mutual polishing of the particles, which are forcibly moved and circulated by impact shock in the pot. The particles are polished one another and the surfaces are exfoliated by the severe shearing stress. We call this the "frictional effect."

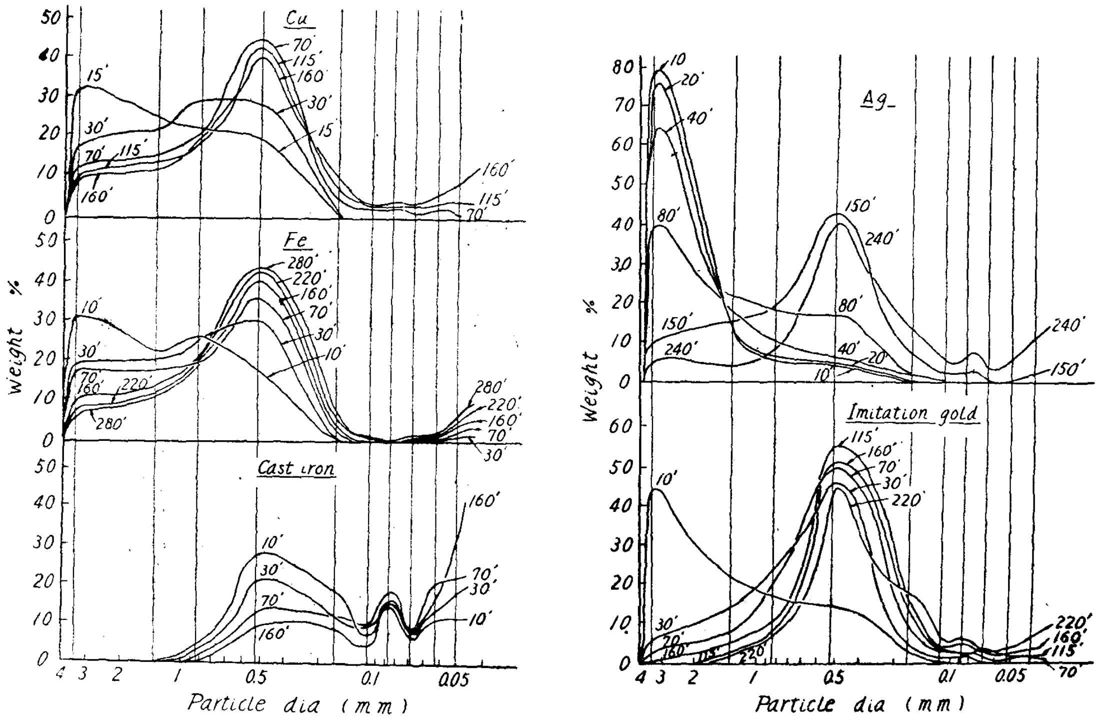

Fig. 6. Variation in particle size distribution of various powders produced with the change of disintegrating time in stamp mill.

As for the disintegration process of cast iron, the situation becomes quite different from other soft metals. Because of the brittleness, the material can be divided into finer grade than 70 mesh by sole impact shock of the stamping and the disintegration of this type can proceed easily to the degree of 200 mesh. The curve of size distribution for cast iron shows three maxima at the particle sizes of 70, 200 and 300 meshes, and with further duration of disintegration these maxima are displaced toward finer size. A typical example of this type can be seen in the process of disintegration of a mixture from tungsten carbide and cobalt, carried out by O. Meyer and W. Eilender with a ball mill,(4) and their experimental data directly indicates the fact mentioned above, that the maximum point appeared on the curve of size distribution is displaced toward finer size with the progress of disintegration time. In this case as well as in other cases of Eddy mill or Cutting mill, it must be considered from these evidences that there are two different stages in the disintegration process of metals; the first stage is a rough disintegration by simple dividing and the second a rerfining stage by frictional polishing. Thus, in order to make a most efficient disintegration with metal, it is necessary to design the mechanism of mill as to conduct effectively these two types of disintegrating action, according to the physical properties of the metal. This conclusion has been drawn also from the experimental results of disintegration of metals by Eddy mill or by Cutting mill, on which we reported in our previous papers.(5)

VIII. Microscopic Observation of the Disintegrated Product

The microphotographs of the disintegrated products are shown in Fig. 7. All of the powders shown in this figure were produced by the longer disintegration, and consequently their surfaces are polished to some degree by mutual friction between the particles. The times of disintegration were 160 min. for copper and cast iron, 240min. for silver, 220min. for the imitation gold and 280 min. for 0.1 % carbon steel respectively. As seen in these photographs, the particle of copper product of 70 mesh shows a flat and thin form and it has many large cracks in the matrix of the particle, while this can not be seen in the product of other metals. On the other hand, it is interesting that these products such as copper or imitation gold contain less amount of finer particle than those of other metals, though this seems to be due to various physical properties of the metals. However, it can not be explained from a simple consideration and it may require more experimental verification in this field.

In the products of 0.1 % carbon steel and cast iron, it can particularly be noticeable that coarser particles than 300 mesh have the round-edged and similar form, while the particles finer than that mesh have the irregular and angular form. The same tendency in form of the product was recognized in other metals, except silver. As already mentioned in the last section, such difference in the form of the finer and the coarser product is unquetionably due to the producing mechanism. Therefore, in conclusion, we must propose the two different mechanisms, the rough and fine, in general disintegration of ordinary metals.

IX. Summary and Conclusion

From the results of the experimental work described in this paper, it was found that in the disintegration of ordinary metals two different types of the

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(4) F. Skaupy, "*Metallkeramik*" (1943), 32.

(5) T. Okamura K. Inagaki and Y. Masuda ; Sci. Rep. RITU, A-2, **2**, (1950) ; A-2, **5**, (1950).

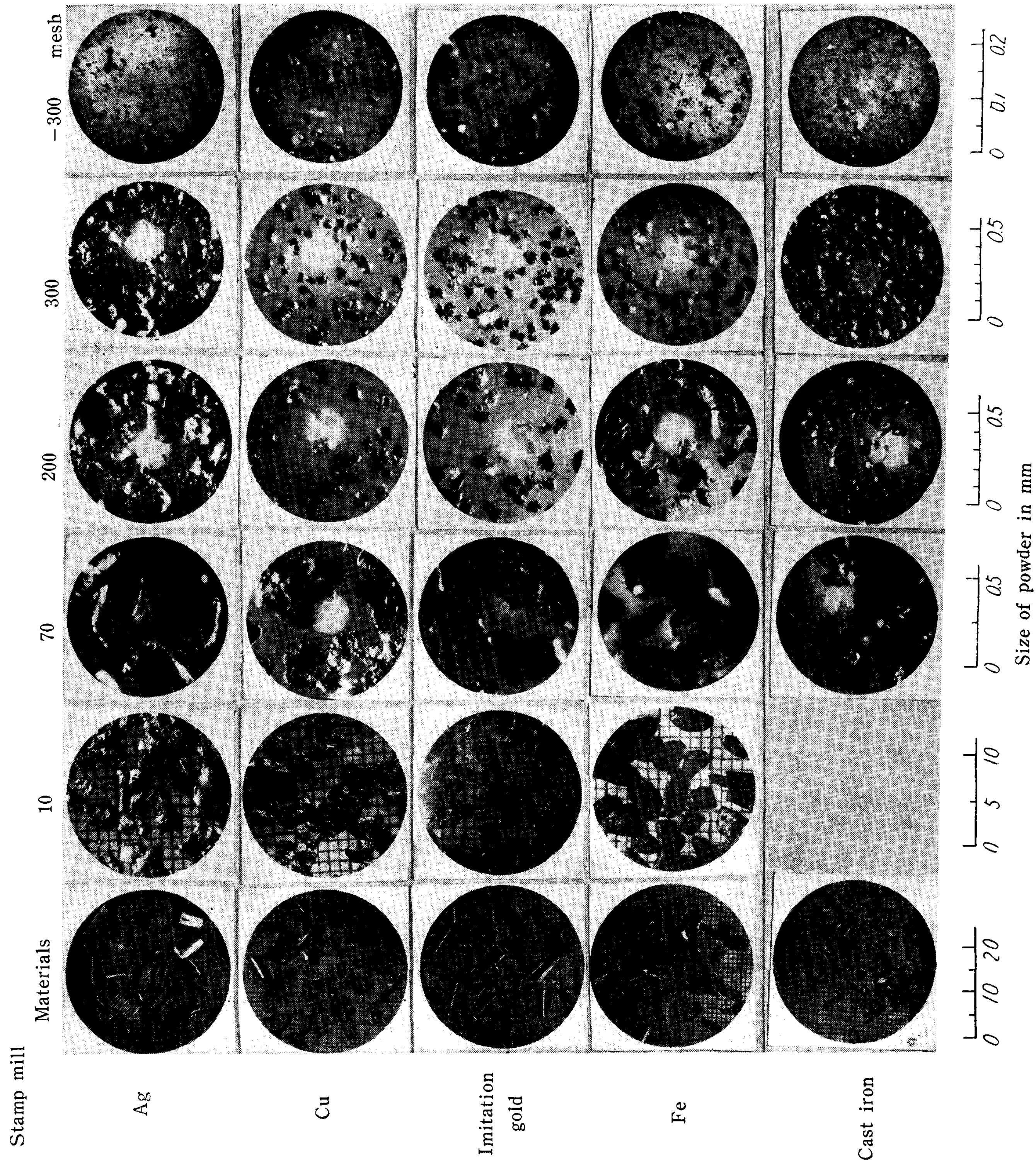

Fig. 7. Photographs of various metal powders disintegrated by stamp mill.

mechanism, the rough and the fine are generally involved. The rough disintegration process is intensively influenced by the mechanical nature of the metal to be pulverized; we call the phenomenon "the initial effect" of disintegration. On the other hand, in the fine disintegration process the finer powder is produced as a consequence of mutual polishing of the coarse grain, which is produced during the prior rough-disintegration process. The same fact was also recognized in the case of disintegration of metal by the Eddy and the Cutter mill, the results of which were reported in our previous papers. Accordingly, it is concluded that in the disintegration process of ordinary metal, there are at least two possible mechanisms, the rough and the fine disintegration which can be a general tendency independent of the disintegration method, though it is unquetionable which mechanism rough or fine, is most predominant in the disintegration process, is determined according to the method of disintegration and the physical property of the material used in the case. The authors wish to thank Miss. E. Togashi for her assistance during the preparation of microphotograph and other experimental course. A part of the expenditure of this work was aided by the Grant in Aid for Fundamental Scientific Research from the Ministry of Education.