Microscopic Kinematographs Applied to the Research of Metal Cutting.

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Abstract.

The main object of the present investigation is to study the deformation and flow of a metal under the action of a simple cutting tool, especially, to observe the manner of separation of the chip formed: and for this purpose microscopic kinematographs of chips in process of formation under different cutting conditions have been taken.

In order to make the observation as simple and direct as possible, the cut studied in the present investigation have all been made on the edge of revolving disk. The face of the disk has been polished and etched, in order to reveal the internal structure and the flow or deformation.

The materials used as stocks for the cutting experiments were mild steel, rolled brass, cast iron, and aluminium alloy.

The experimental cutting operations have been performed with ordinary carbon-steel parting tool and flattened edge tool, no lubricant being used.

The observation of the cutting edge of a tool and the deformation of chip has been made by means of the microscope supported on the tool rest of the lathe. The magnified images of the cutting edge and chips have been photographed by means of the "Ica universal kinamo."

The picture were taken from 15 to 20 magnifications for widening the field, but by projecting them for desired magnifications, the mechanism of the action of cutting tools might be clearly observed.

From these pictures it appears:—

(1) In a brittle metal, such as cast iron, the chip is crushed with little distortion, and the form is very irregular.

(2) In a ductile metal, such as an aluminium alloy or mild steel, the distortion of the chip is remarkable and a built-up edge is formed on the cutting edge of tool under a suitable speed and depth of cut, especially when a flattened edge tool is used a built-up edge is easily formed. In this case, the built-up edge is the actual cutting implement, the tool merely serving to support it.

INTRODUCTION

The action of a cutting tool upon a metal must, in some form or other, bring about rupture of the material, and, in a ductile metal, rupture can scarcely occur without accompanying plastic deformation. The study of the plastic deformation found close to the cut surface of metal, appears to offer an opportunity for interesting observation. The first attempt to cut sections through the cut surface of metal and the root of a chip, for the purpose of microscopic examination, was made by Mr. W. Rosenhain and afterward by Messrs. W. Rosenhain and A. C. Sturney(1) and also Dr. H. Klopstock,(2) and a related work was attempted by Mr. E. G. Herbert.(3)

The micrographs gave interesting indications of a flow of the material in the vicinity of the edge of cutting tool. The author succeeded in taking microscopic kinematographs of the manner of chip formation directly under the cutting conditions, and has published the part at the 143rd meeting of the Soc. of Mech. Eng. of Japan, May 25, 1928.

ARRANGEMENT

The general arrangement of the apparatus used in taking the microscopic kinematographs is shown in Figs. 1 and 2.

The sourse of light is the arc lamp (A) and the beam of light passes through the condenser (C) to the end of the microscope (M), which is Zeiss metallographic microscope for the factory use, fixed on the tool rest of the lathe. The magnifying power may be adjusted by changing oculars and objectives. The images of deformed part and cutting edge of tool are focused on the negative film in the camera (K) by adjusting the objective,

(1) Proc. I. Mech, E., 1925, P. 141.
(2) Trans. A. S. M. E., Vol. **47** (1925), P. 345.
(3) A. S. M. E. Vol. **49** (1927), P. 980.

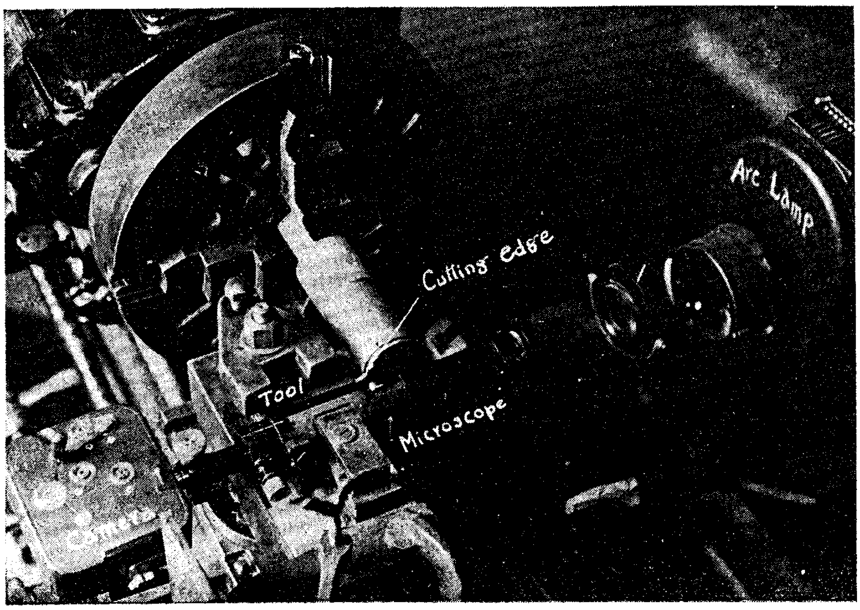

Fig. 1. General Arrangement.

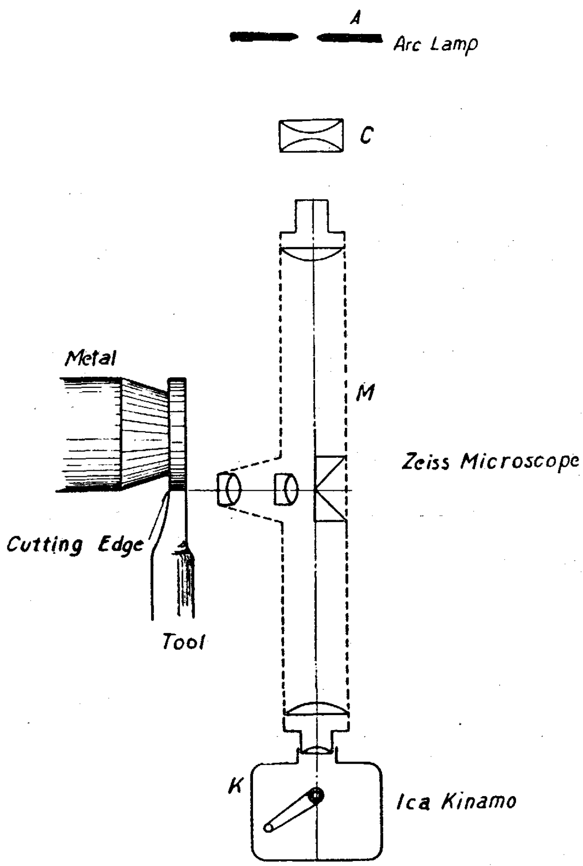

Fig. 2. Relative Positions of the Cutting Edge and Microscope.

METHOD OF TAKING CUT AND PREPARING SPECIMENS.

In general the method of taking cuts was as follows :—

With the lathe running at a very slow cutting speed, i. e., .01 meter per min. some of the photographs were obtained at higher speed, i. e., 1.3 meter per min. to make the built up edge on the tool. The tool was driven in to the desired depth of cut, generally 0.2 mm. to 0.25 mm. deep.

The cutting tools used were an ordinary carbon-steel parting tools and flattened edge tool, and the cutting angles were tried one or more suitable angles for various materials.

The side of disk, which is kept at right angle to the cutting edge, was polished and etched for microscopic examination, and brought the side of tool at the plane.

The kinds of materials, hardness, cutting angles and cutting speeds for the experiment are shown in the following table I.

TABLE I.

Materials	Hardness Brinell No.	Dia. of Stock mm.	Cutting Angle	Cutting Speed m/min.	Depth of Cut mm.
Mild steel	128	50	60, 70	.01~1.4	0.2~0.4
Brass	140	60	70, 90	.01~.02	0.25~0.4
Cast iron	170	50	70	.01	0.25
Aluminium alloy	65	50	60, 70	.01~1.3	0.15~0.25
Lead		45	70	.02	0.25

THE BUILT-UP EDGE.

It is well known that a built-up edge is formed on the cutting edge when a ductile metal is cut. The mechanism of its formation may, however, be an interesting problem.

In a ductile metal, the chip is generally of the flow type, so called by Rosenhain and hence in case the cutting speed is low, the chip flows, being strained and changing the direction successively, but in case the cutting speed is high a built-up edge is formed, part of the chip being left on the cutting edge, as shown in Figs. 5, 12, 14, 15, 16.

As to the formation of the built-up edge various opinions have been proposed by the authorities. The author claims, however, that the causes are:—

a) Great pressure acting at the top of cutting edge, similar to the flow of a viscous fluid.

b) Great frictional resistance between the built-up edge and the upper surface of tool.

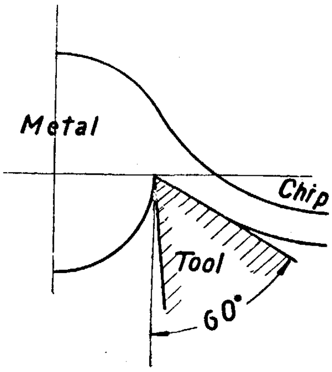

Fig. 3. No Built-up Edge.

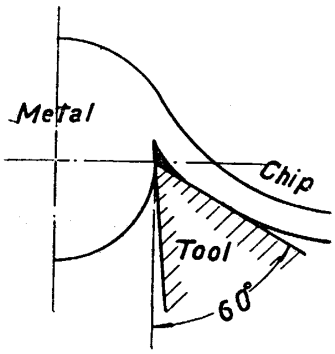

Fig. 4. Built-up Edge.

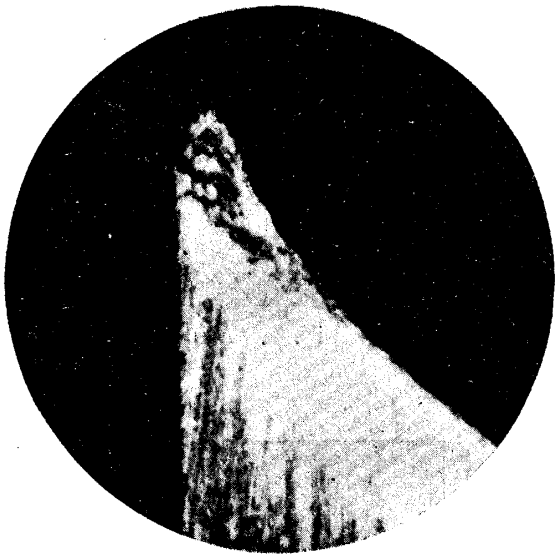

Fig. 5. The Built-up Edge remained on the Cutting Edge. ×60

In a ductile metal the friction is great, and thus an aluminium alloy forms readily a large built-up edge in a low cutting speed. It is clear that the friction on the upper surface of tool has an important connection with it, from the fact that the built-up edge is disappeared by using a lubricant, as shown in Fig. 8.

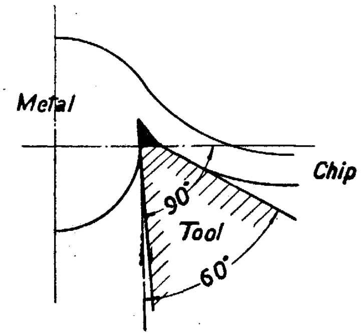

Fig. 6. The Built-up Edge on the Flattened Edge Tool.

The effect of the built-up edge is to change the actual cutting angle of tool, and to give an influence on the cutting force, which explains the variation of vertical force on tool with cutting speed, in the experiments conducted by Dr. Nicolson, T. E. Stanton and Hyde.

CUTTING EDGE OF ROUGHING TOOL.

The built-up edge is the actual cutting implement, the tool merely serving to support it. It is much harder than the metal to be cut. Dr. Klopstock has proposed to lesson the angle of incidence without unduly weakening the tool by forming a depression in the upper surface where the chip impinges. The depression must be done by means of a special attachment to a grinder.

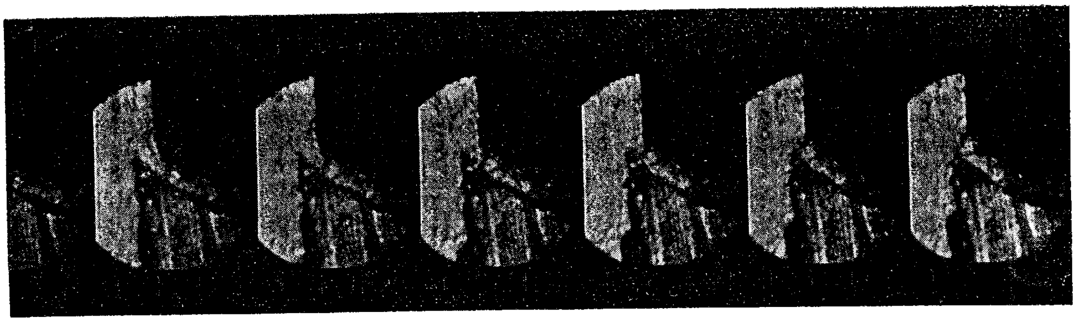

Fig. 7. Aluminium Cutting, No Lubricant, the Built-np Edge formed on the Flattened Edge.

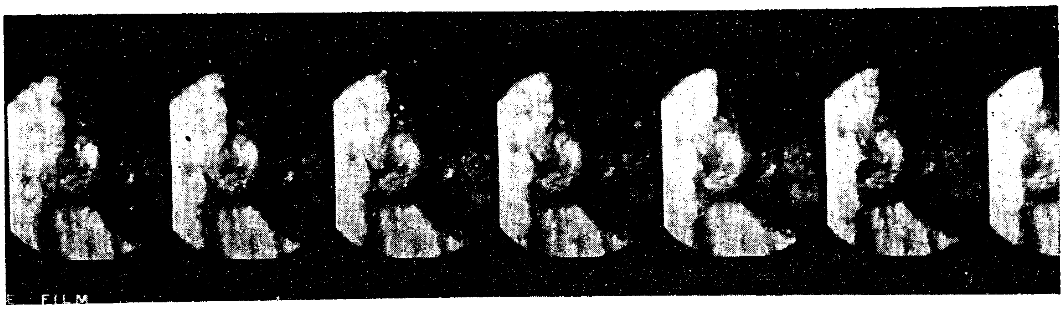

Fig. 8. Ditto, the Lubricant used in Same Condition.

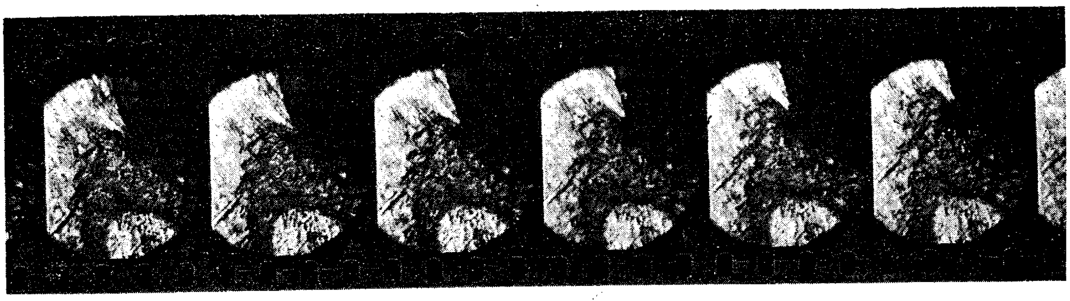

Fig. 9. Mild Steel, Built-up Edge on the Rounded Edge Tool (No Lubricant).

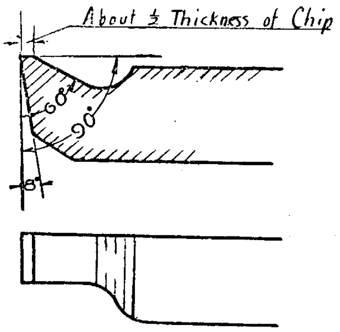

Fig. 10. Flattened Edge Tool used the Test.

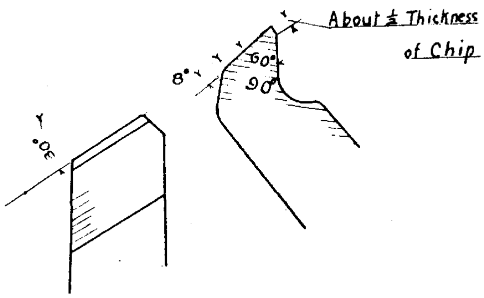

Fig. 11. Flattened Edge Tool for Rough Cutting.

The author found that by flattening the cutting edge of ordinary tool for the width less than the thickness of the chip, as shown in Figs. 10 and 11 a built up edge was easily formed and the durability of the tool was greatly increased. In such a flattened edge tool, the fact that a part of the chip forms a built-up edge on the flattened edge tool is the same in principle as the klopstock tool, but the former is the simplest form and obtained by grinding the edge of ordinary tool on an oil stone.

Fig. 12 show the built-up edges in cutting an aluminium alloy. Figs. 14, 15 and 16 show the built-up edge in mild steel in cutting with the flattened edge tool. The conditions are as follows:—

TABLE II.

	Cutting Speed m/min.	Cutting Angle	Depth of Cut. mm.
Fig. 12	0.05	60°	0.15
Fig. 13	0.01	70°	0.35
Fig. 14	1.9	60°	0.15
Fig. 15	0.018	60°	0.22
Fig. 16	1.38	60°	0.15

Fig. 12. Aluminium Alloy, the Built-up Edge formed, Slow Cutting Speed.

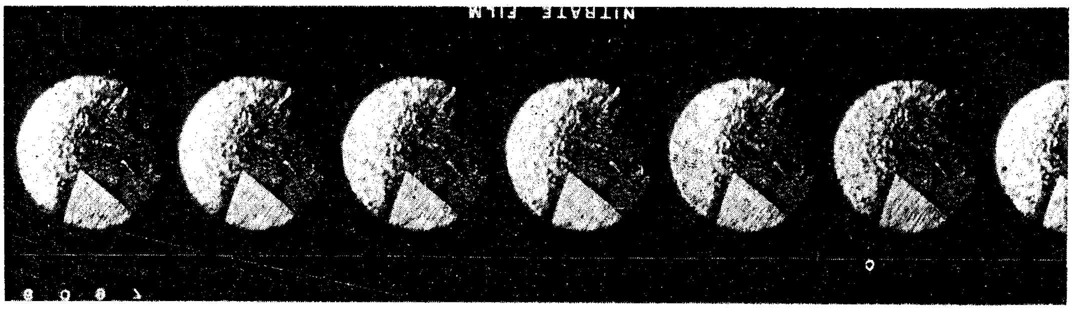

Fig. 16. Mild Steel, No Built-up Edge, Slow Cutting Speed.

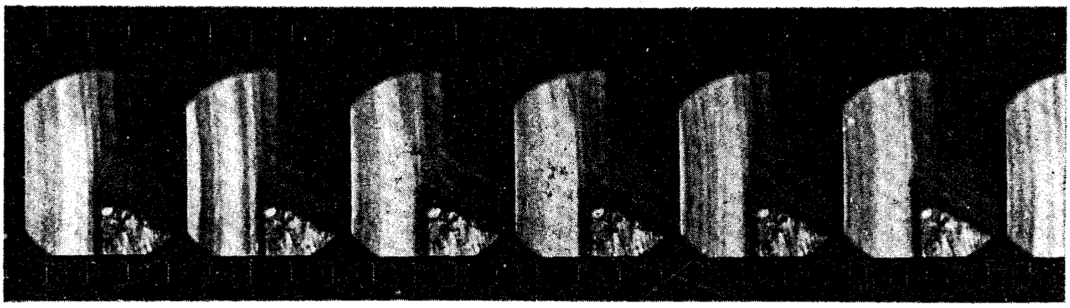

Fig. 14. Ditto, the Built-up Edge formed, Higher Cutting Speed.

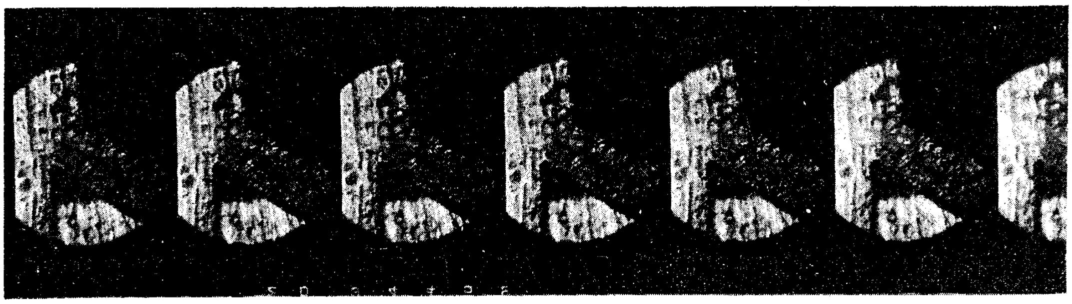

Fig. 15. Mild Steel, the Built-up Edge with the Flattened Edge Tol (No Etching).

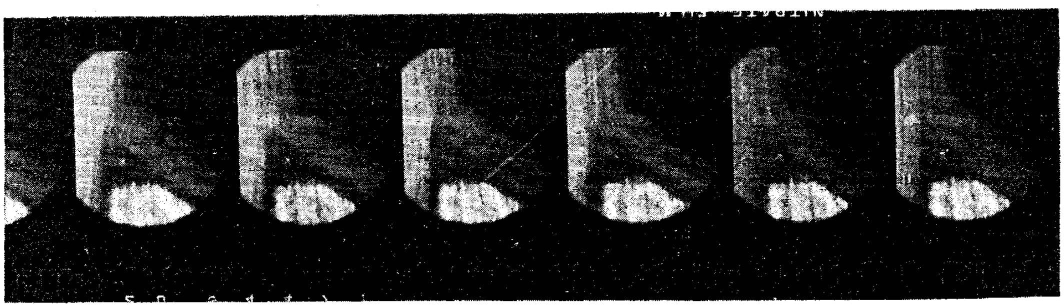

Fig. 16. Ditto, the Higher Cutting Speed.

VARIOUS SHAPES AND STRUCTURES OF CHIPS

Brass :—

The continuous pictures photographed in the present experiments are under the following conditions :—

Cutting angles=70°. 90°.

Cutting spead =.01 m. per min.

Depth of cut =.25 mm.

Rolled brass, Hardness 140 in Brinell number.

The advance of the tool causes a local crushing and incipient shearing of the metal in front of the tool face, at the boundary of this crushed and sheared region a crack, or tear, is formed, and this tear runs forward. As the tool progresses the metal above or outside this crack is progressivelly further sheared and crushed. A point, however, reached where the resistance to further tearing becomes too great owing to the increasing depth of the crack. At this point the chip sheares as shown in the Figs. 17 and 18. This shear may result in the complete separation of the chip or in a plastic displacement, in either case a fresh tear is started, and again runs forward and inward in advance of the tool.

It will be noticed that in this type of cutting, there is little or no real flow of the chip over the face of the tool or over any built-up front of the tool, although to a certain extent the chip in contact with the tool face slides upwards as shearing progresses. This motion is small, but the pressure large. This type is, of course, the result of combining a relatively large depth of cut with a large cutting angle.

Cast iron :—

Fig. 19 shows the part of the pictures taken in cutting cast iron. The cutting conditions are as follows :—

Cutting angle = 70

Cutting speed = .01 m. per min.

Depth of cut = 0.25 mm.

Brinell hardness number = 170.

In cutting, as soon as a crack is started in advance of the tool, the whole chip is crushed into entirely irregular forms, without plastic deformations, analogous to the lock excavation. In this case the chip is of the crush type. In such a brittle metal, a built-up edge is not to be considered, and consequently the cutting edge of tool is constantly impinged by the fresh chip.

Lead :—

In Fig. 20 is shown the part of the pictures in cutting lead under the same conditions as the above. In this case the chip is the flow type.

White wax :—

Fig. 21 shows the condition in which one end of a candle, 5 cm. in diameter, is cut. In this case the chip is sheared and forced out with an angle of 45° to the surface of tool.

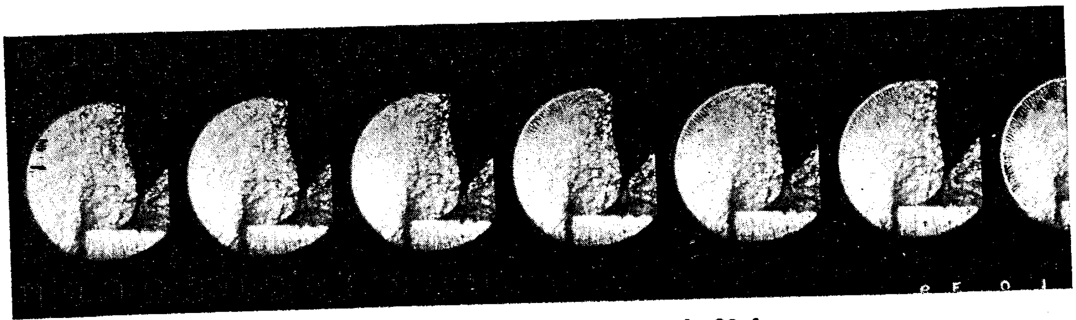

Fig. 17. Brass, the Cutting Angle 90 deg.

Fig. 18. Ditto, the Cutting Angle 70 deg.

Fig. 19. Cast Iron, the Chip of Crush type.

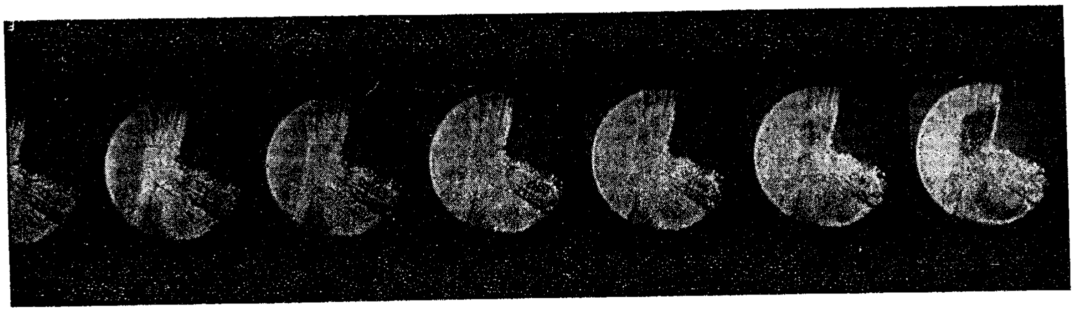

Fig. 20. Lead, the Chip of Flow type.

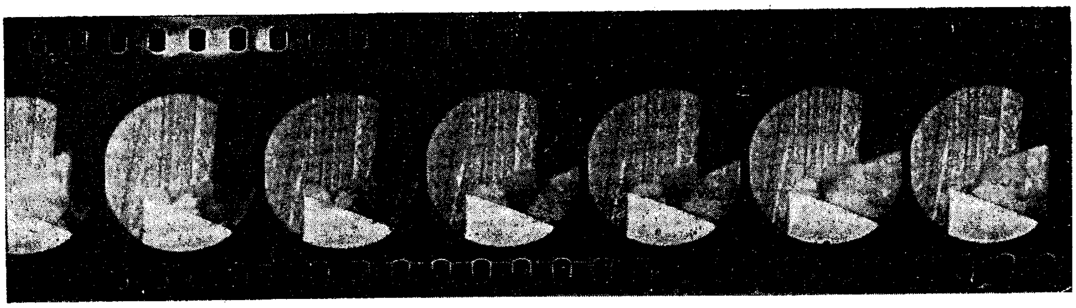

Fig. 21. White Wax, the Chip of Shear type.

SURFACES DEFORMED UNDER COMPRESSION.

It is aimed, in this preliminary test, to observe the propagation of strain caused by progressing the cutting edge of tool. The procedure is the same as the previous cutting, viz., the progress of the plastic deformation on the surface caused by pressing wedges or tools of various forms gradually from the direction parallel to the plane surface, which was polished and etched, was photographed.

Figs. 22–25 show the mild steel under compression, the magnification being 15.

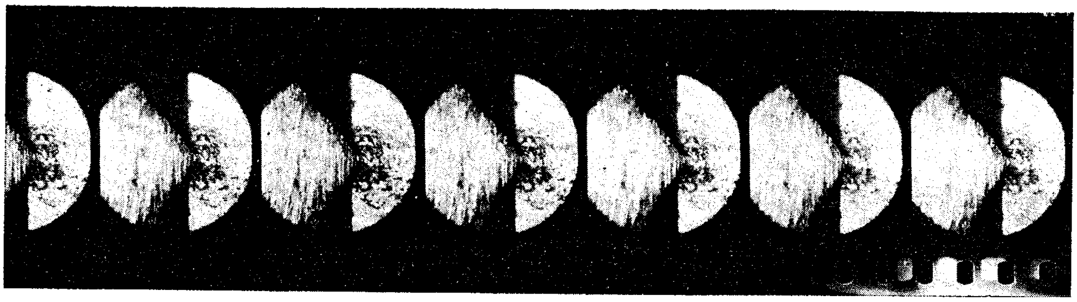

Fig. 22. Angle of Wedge 90 deg., the Deformation commenced.

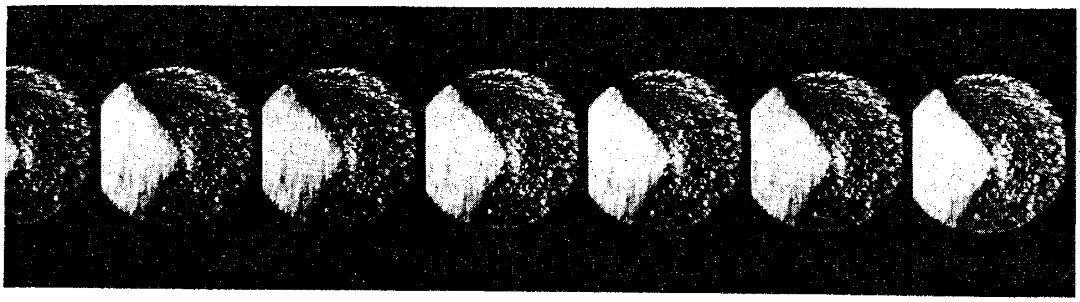

Fig. 23. Ditto, the Plastic Deformation progressed.

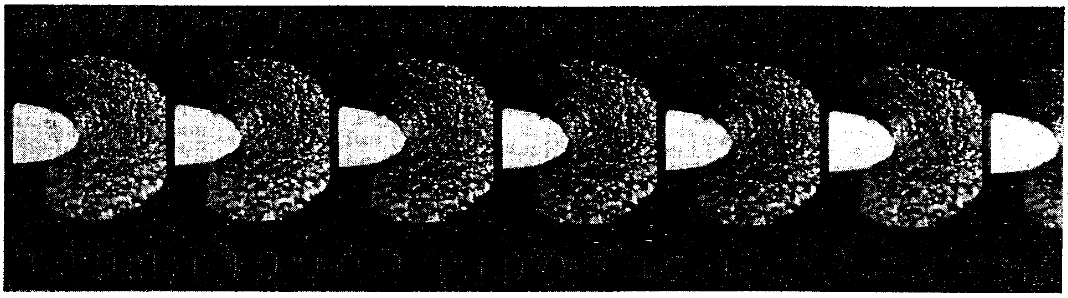

Fig. 24. The Deformed Zone by Curved Edge.

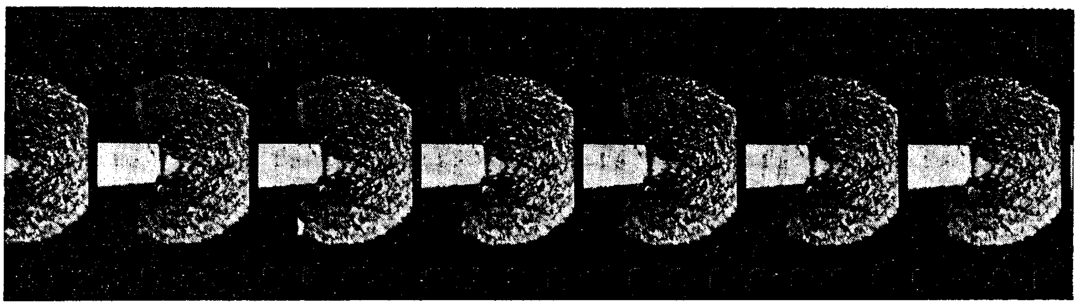

Fig. 25. The Deformed Zone by Rectangular Brook.

THE STATICAL CUTTING PRESSURE IN CHIP FORMATION.

For measuring the cutting pressure exerted on the tool very exactly, the author used the hardness tester "Monotron", the cutting tool being fixed on the machine instead of the impressing ball. The web of specimen 1 mm. thick was put on the table, vertically and under the cutting edge.

The cutting pressure and depth of impression of the tool were measured by the dials fixed on the machine, under the very slow cutting speed, the arrangement and the Chip-Pressure curves are shown in Figs. 26, 27 and 34. The specimen are the same materials as in the previous cutting.

The stage of chip formations corresponding to the Chip-Pressure curves are photographed by means of the microscopic kinematographs, a part of films being shown in Figs. 28—33.

In the pictures, the test pieces are shown on the upper half and two dials in the lower, the large dial indicates the pressure and the other the impression. They were photographed by two cameras separately under a single control during the experiment, and printed together in the convenience of illustration.

The relation between cutting area and maximum cutting pressure is shown in Fig. 35. In the figure, the points marked by "○" are plotted in the experiments with knife edge of cutting angle of 70°, and "●" being with the flattened tool, the flattened width being 0.26 mm.

In cases of Aluminium alloy, Cast iron and Brass, difference in pressure can not be recognized with either tools, but in the case of mild steel their cutting pressure increased with the flattened tool.

In these cases, no built-up edge formed with slow cutting speed. The cutting pressure will, however, be decreased with the suitable cutting speed by which a built-up edge appears.

Experiments with various cutting angles are now in proceeding.

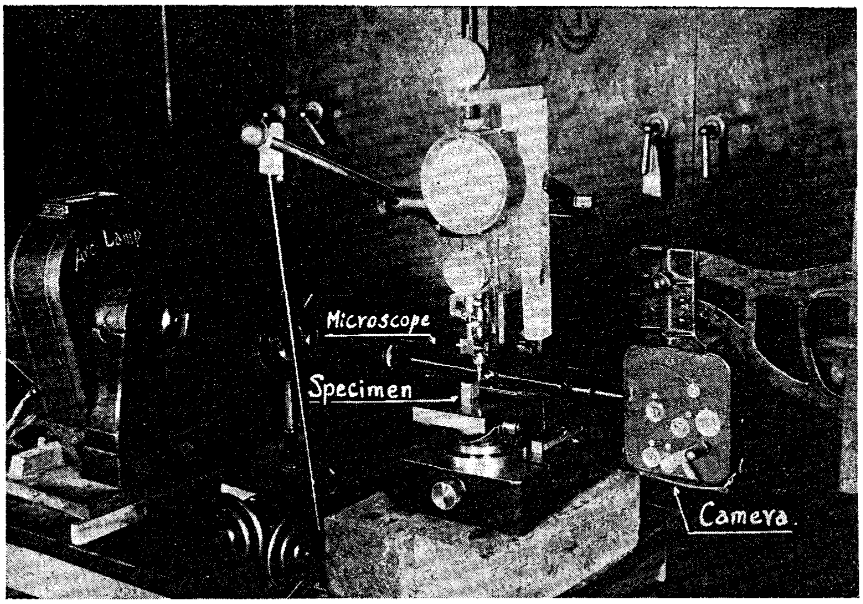

Fig. 26.

Arrangement for Cutting Pressure Measurement in Chip Formation.

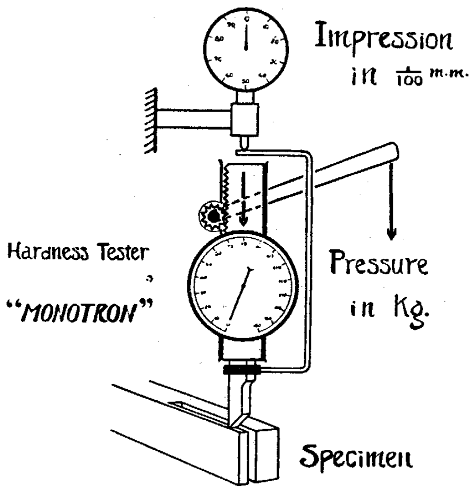

Fig. 27.

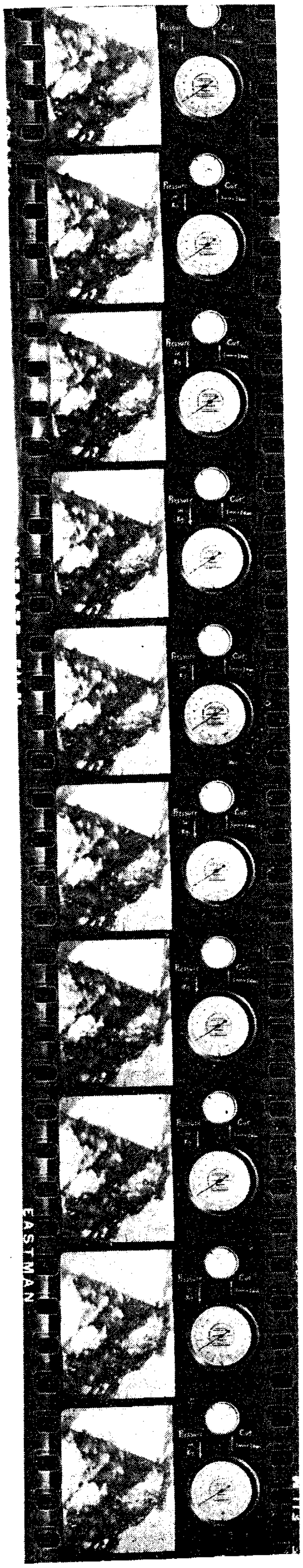

Fig. 28. Cast Iron. The Chip crushed with Cutting Angle of 70 deg.

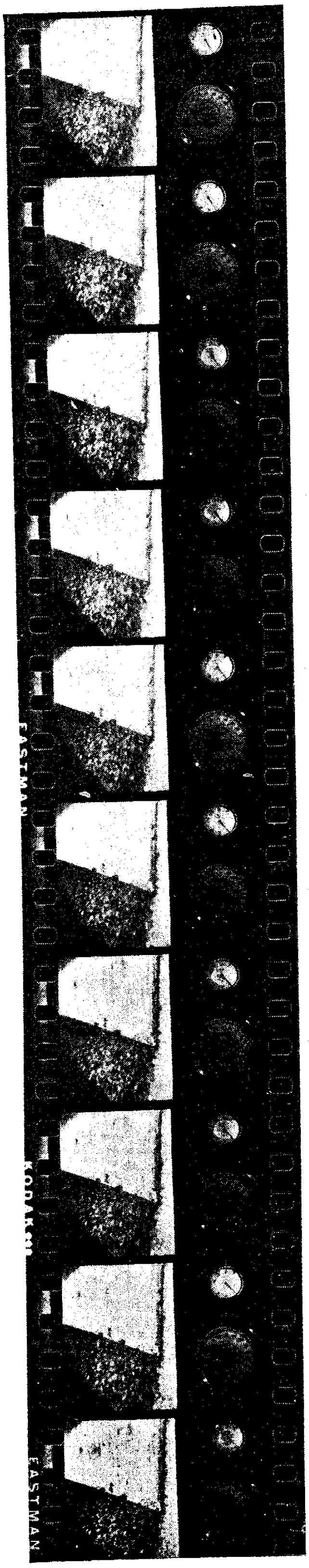

Fig. 29. Mild Steel No Built-up Edge.

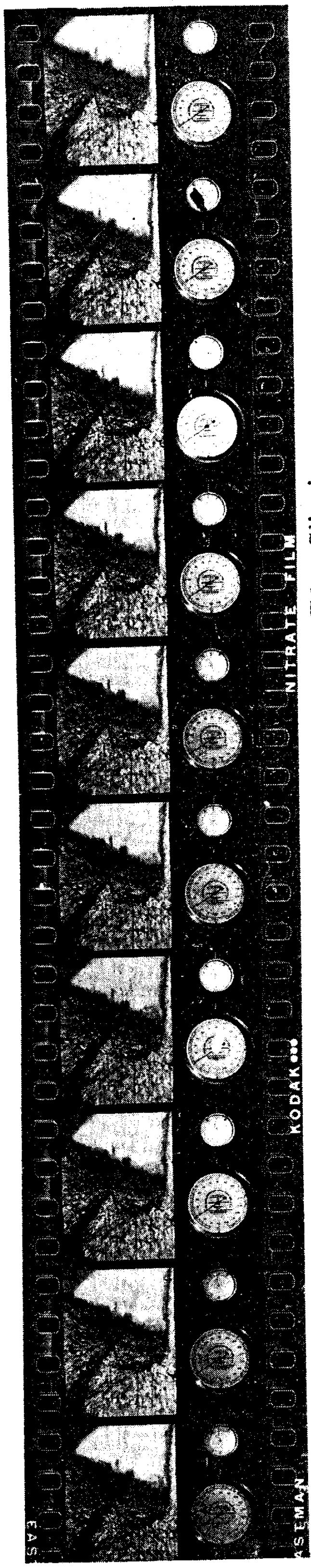

Fig. 30. Aluminium Alloy. The Built-up Edge Slipping.

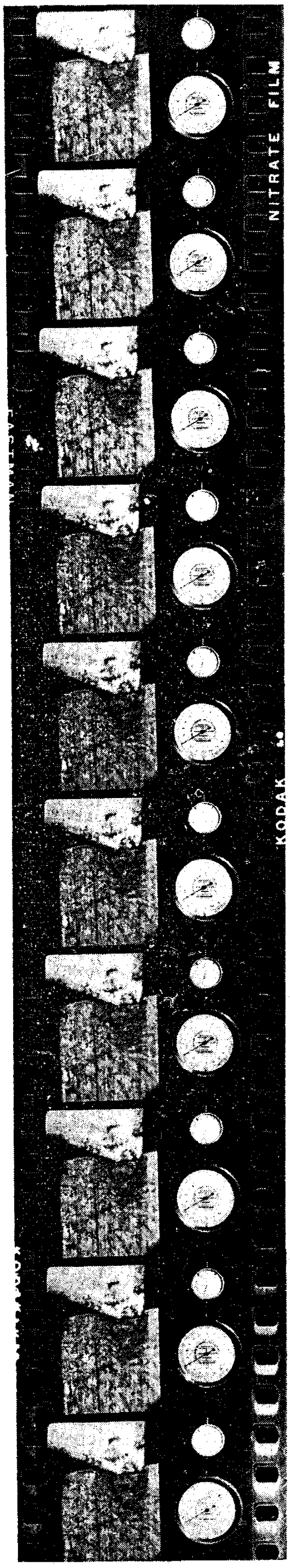

Fig. 31. Aluminium alloy. Built-up Edge commenced with Flattened Edge.

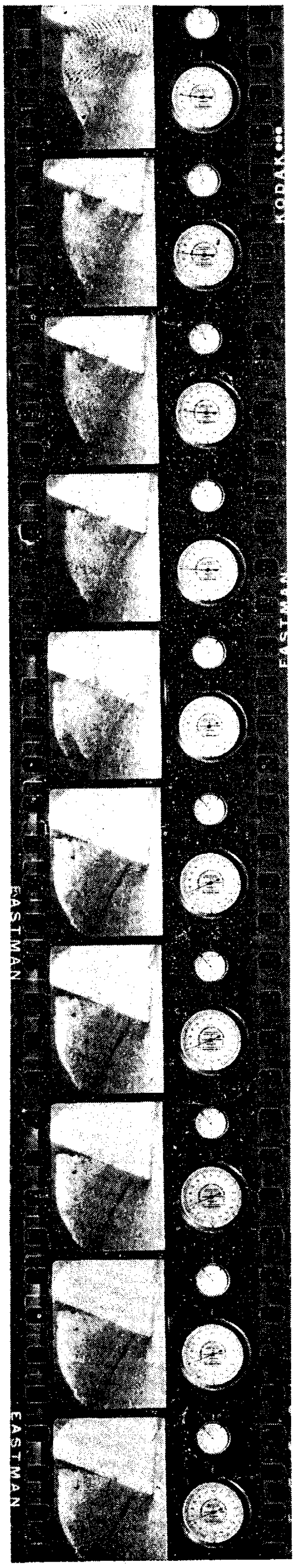

Fig. 32. Brass. The Crack and Shear occurred at the Max. Pressure of 40 Kg. (70 Kg. per mm.^{2}).

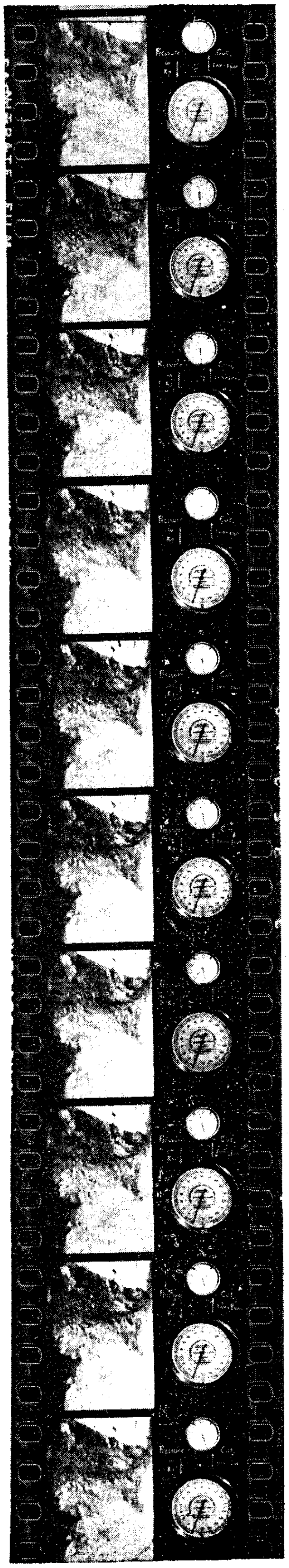

Fig. 33. Lead. The Deformed Zone Slipping.

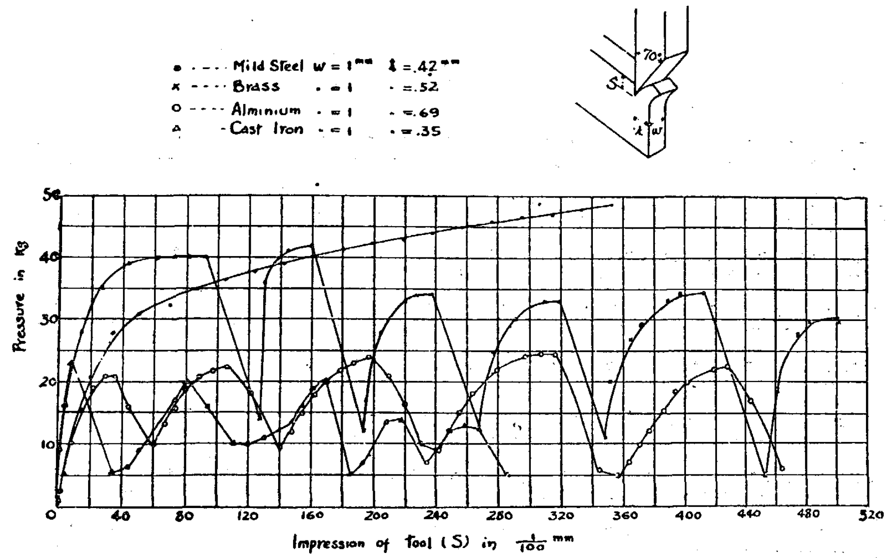

Fig. 34. Chip-Pressure Curves Corresponding to the Films.

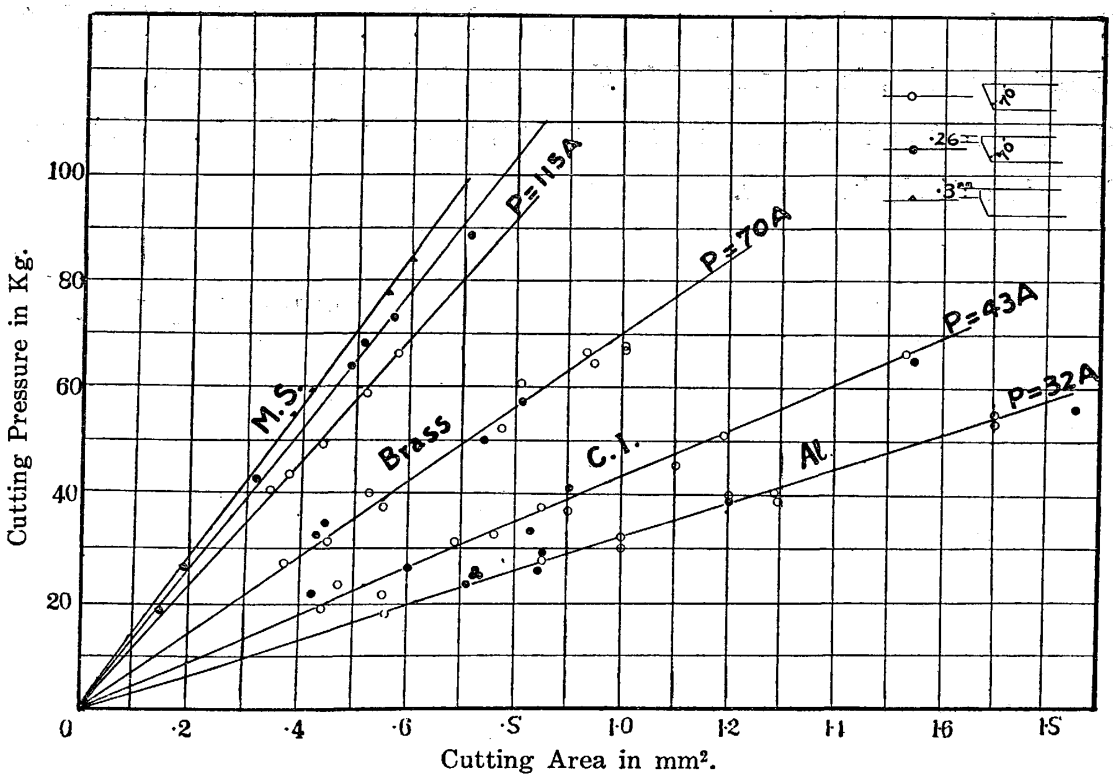

Fig. 35. Effect of the Cutting Edge.

CONCLUSION.

The study of the metal cuttings which is described in the present report is essentially of a preliminary and tentative nature.

1) The method of study, namely, the microscopic kinematographs of metal cutting, leads to a series of interesting observations which seem to afford a new insight into the mechanism of cutting tool action.

2) In a ductile metal, such as an aluminium alloy or mild steel, a built-up edge is formed on the cutting edge of tool under a suitable speed and depth of cut, especialy when a flattened edge tool is used a built-up edge is easily formed, which improve the durability of the tool.

If the frictional resistance between the built-up edge and the top surface of tool is small, as in using a lubricant, the built-up edge flows without consisting.

3) The increase of cutting pressure caused by the use of tool slightly flattened at the cutting edge, is very small in the case of slow cutting.

4) In a brittle metal, such as cast iron, the chip is of the crush type, and the form is entirely irregular.

Tokyo, May 1929.