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A Sliding-Block Type Cutting Test Apparatus*

By Keiji OKUSHIMA**

This paper describes the specially-designed cutting test apparatus and some results obtained with it. Cutting test with general machine tools such as lathe, miller, etc. is usually apt to be accompanied by some unnecessary influences. Hence, an orthogonal cutting test apparatus, using a sliding-block, was designed in order to eliminate such unfavourable effects. The construction and use of this apparatus are dealt with in the first half and the test results for mild steel in the latter half.

1. Introduction

The cutting test aims at the measurement of cutting resistance, cutting power, machined surface roughness, cutting temperature, tool wear, and so on, in order to know machinability of the material and cutting efficiency of the tool; and as the cutting test apparatus for this purpose, the machine-tools such as lathe, milling machine, etc. are generally used. However, when these ordinary types of machine-tools are used in the test, they are apt to give peculiar effects of machine-tools upon the results. For example, when the cutting is performed on a lathe, vibration of the spindle and the tool inevitably gives an effect on the cutting state. Consequently, the data obtained thereby may not be applicable to general cases. Because of this, the cutting test apparatus specially designed to perform the most perfect cutting operation is necessary. The author designed and constructed a special cutting test apparatus for this purpose. The principle of it is as follows: the workpiece is set up on the sliding-block which slides down on the rails from an altitude, and is cut by the fixed tool installed at the lower part of the apparatus. Using this apparatus, the author believes that an almost perfect cutting test is made possible, though it cannot be called perfect. It is the purpose of this paper to describe the specially designed cutting test apparatus and some results obtained with it.

2. The construction of the cutting test apparatus

Fig. 1 shows the whole construction of the specially designed cutting test apparatus. The block

Fig. 1

Fig. 2

Fig. 3

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④ of about 300 kg holds the workpiece ⑤ in the middle of the upper plane, and is raised up to an arbitrary position on the sliding rail ⑥ by winding the rope ② on the motor-driven drum ①. The rope and the block are joined by the hook ③ as shown in Fig. 2, and this joint is released easily and instantaneously by applying small force in the arrow-direction. The block slides down freely along the two round rails ⑥ inclined at 45 deg. against the horizontal plane, the details of which are shown in Fig. 3. The block has a wheel on one side and two wheels on the other side. All wheels are fixed to the block and, consequently, they can not turn, but slides down along the rails. The purpose of this arrangement is to eliminate rotational vibration of wheels at the expense of a slight increase in frictional resistance.

The workpiece is shown also in Fig. 3. It is attached to the upper plane of the block by four bolts. The width of cut b is selected properly according to kinds of material. Tool is installed on the tool holder ③ which is supported by the tool-supporting frame ⑦. This construction is shown in detail in Fig. 4. The position of tool is adjusted by rotating the handle ④ and fixed by the lever ⑤. The position of tool is recorded by the dial gauge ⑥. The tool ④ is held by the wire-resistance type tool dynamometer⁽¹⁾ ③. In this case, measurements of two components of cutting resistance—principal and vertical—are sufficient. ⑨ is the brake apparatus which stops the block from sliding-down at a short distance after cutting. Cutting speed is changeable by selecting the height from which the block starts to slide down and is measured with the apparatus shown in Fig. 5. Brass pieces are inserted at equal intervals on the insulator which is set up on the upper plane of the block and are contacted with the metal brush which is held by the tool-holder. According to the electric circuit shown in the figure, the current flows whenever the metal-brush contacts the brass piece and it is recorded with an oscillograph. The cutting speed is calculated

from the wave-interval and the time-mark.

The above is a brief description of the construction of the cutting test apparatus. The author especially paid attention to give as high rigidity as possible to the whole construction so as to minimize its vibration. For this purpose, the tool holder is made as rigid as possible and it is reinforced with four stays as shown in the figure.

3. The operation of the cutting test apparatus

Firstly, the tool and workpiece are installed on the tool-holder and the block respectively. Putting the block under the tool-holder, the tool is fed until it comes into contact with the workpiece, then the block is raised up. Previous to the actual cutting, the approximate cutting velocity is predetermined by dropping the block from various positions of rail. Then raising the block up to the height where cutting speed of 100 m/min is obtained, and feeding the tool about 0.02 mm, the block is dropped. This initial operation is performed to make the surface of the workpiece flat and parallel to the cutting edge.

Then the main test is performed. The following method is adopted to measure the depth of cut precisely. As shown in Fig. 6, a standard surface is fixed on the block, and the difference of heights of the work surface and of the standard surface before cut is measured with the dial gauge installed on the reverse side of the tool-holder. Then the block is raised and stopped at a position where the desired cutting speed is obtained. The tool is fed to the position of desired depth of cut and the amount of this feed is also determined by the dial gauge.

Thus the whole preparation is ready. The tool dynamometer and the cutting speed measuring

Fig. 4

Fig. 5

Fig. 6

apparatus are put in the operation state. Then, as the joint between the hook of the block and the rope is released, the block slides down and the cutting is performed. After raising the block back to underneath the tool-holder, the difference between the heights of the newly machined surface and the standard surface is measured and, by comparing this value with the pre-measured value before cutting, the practical depth of cut is determined. Strictly speaking, the feed of tool should be equal to the depth of cut; however, they do not coincide at times owing to various causes and the above procedure of measurement is taken for the sake of assurance. Fig. 7 shows an example of the oscillograph obtained with the above procedure. The cutting conditions for this case are as follows:

Tool: high speed steel; rake angle 10° ; relief angle 8° ; dimension of shank $19 \times 19 \text{ mm}^2$

Workpiece: 0.17% carbon steel (ultimate strength 46 kg/mm^2)

Cutting velocity: 170 m/min

Depth of cut: 0.14 mm

Fig. 7

4. The cutting test for mild steel

The compositions and mechanical properties of mild steel used in the cutting test are shown in Table 1. The width of cut is 3 mm. The tool is such as mentioned above, lapped by oil stone after grinding by WA-80-K wheel, and its roughness of cutting edge is under 1μ .

a) The cutting resistance

Measuring the cutting force varying the depth of cut within the range of $0.03 \sim 0.2 \text{ mm}$ which corresponds to the feed in the three-dimensional cutting and the cutting velocity to 140, 170, 200, and 250 m/min, the specific cutting force is calculated and plotted with respect to the depth of cut as shown in Fig. 8. The effect of cutting velocity seems to be negligibly small in the range of cutting velocity used in the experiment. The approximate equation between the depth of cut and the specific cutting force is determined by the method of least squares as follows:

$$p_1 = 135 \cdot s^{-1/4} \text{ kg/mm}^2$$

for principal cutting force

and

$$p_2 = 55 \cdot s^{-1/3} \text{ kg/mm}^2$$

for vertical cutting force

.....(1)

where s is the depth of cut in mm. The fact that the index numbers for principal and vertical cutting forces are different means that the direction of the resultant cutting force varies with depth of cut.

(a) Principal cutting force

(b) Vertical cutting force

Fig. 8

Table 1

Chemical compositions %								Mechanical properties	
C	Si	Mn	Cu	Cr	P	S	Fe	Tensile strength	Rockwell hardness (B Scale)
0.17	0.25	0.46	0.14	0.09	0.36	0.025	Remains	46.2 kg/mm ²	70

b) The roughness of machined surface

The surface roughness is almost constant (about 3μ) in a wide range of cutting conditions used in the experiment. By the microphotography of the machined surface, the existence of tear owing to built-up edge is observed even at the high cutting velocity of 250 m/min.

c) The shear angle

In the case of the flow type chip, the direction of the slip plane, i.e. the shear angle ϕ shown in Fig. 9, is calculated from the following equation when the cutting ratio $r (=s/s_1)$ is known:

$$\phi = \frac{r \cdot \cos \alpha}{1 - r \cdot \sin \alpha} \quad (2)$$

where α is the rake angle. The cutting ratio means the ratio between depth of cut and thickness of chip, therefore, it is determined by measuring the thickness of chip with the dial gauge. How-

Fig. 9

Fig. 10

Fig. 11

ever, the measurement of chip thickness is generally difficult owing to the serrated back side of chip, and the shear angle calculated from the cutting ratio obtained thereby tends to show a smaller value than the accurate value. For this reason, the author has determined the cutting ratio with the length of cut l and the length of chip l_1 from the following expression:

$$r = l_1/l \quad (3)$$

The cutting ratio r thus obtained is substituted into Eq. (2) and the shear angle is calculated, and it is shown in Fig. 10 in relation to the depth of cut. As in the case of specific cutting force, no effect of cutting velocity appears in this case also within the range of cutting velocity used in this experiment. The relation between the shear angle and the feed is expressed as follows:

$$\phi = 28 \cdot s^{1/2} \quad (4)$$

d) The relation between the friction coefficient and the shear angle

Using the experimental equation of cutting resistance (1) mentioned above, the friction coefficient between the tool face and chip is determined as follows. By Merchant's equation,

$$\mu (\equiv \tan \beta) = \frac{P_2 + P_1 \cdot \tan \alpha}{P_1 - P_2 \cdot \tan \alpha} \quad (5)$$

Then the relation between the friction angle β and the shear angle ϕ is plotted in Fig. 11 by combining Eqs. (4) and (5). This relation is almost linear and expressed as follows:

$$\phi = 59.5^\circ - \beta \quad (6)$$

It is a noteworthy fact that the above equation shows fairly good approximation with the theoretical equation given by Lee-Shaffer⁽²⁾:

$$\phi = \frac{\pi}{4} - \beta + \alpha \quad (7)$$

where $\alpha = 10^\circ$.

5. Conclusions

The above describes the specially designed cutting test apparatus and some results for mild steel obtained with it. The author believes that he has satisfactorily accomplished his aim in designing and constructing an apparatus to be used in performing a cutting test which is free from undesirable effects of machine-tools, although this apparatus, at this stage, it has yet a room for improvements.

The test results on mild steel by this cutting test apparatus are summed up as follows:

i) The cutting force is not affected by the cutting velocity in the range of 140~250 m/min.

ii) The specific cutting force decreases with an increase of depth of cut, but the rate of decrease

differs between the principal and vertical cutting forces.

iii) The shear angle is affected by the depth of cut.

iv) The relation between the shear angle and the friction coefficient is expressed approximately as $\phi = \frac{\pi}{4} - \beta + \alpha$.

v) The roughness of machined surface is

affected neither by depth of cut nor by cutting velocity within the range of cutting conditions used in the experiment.

References

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On the Influence of Anvil Weight and Rigidity of Supporting Material (Represented in the Form of Equivalent Spring) on Hammer-Forging Effect*

By Sakuo OMODAKA**

In case of hammer-forging, it has heretofore been said that the forging effect is greatly influenced by anvil weight and rigidity of supporting material (represented in the form of equivalent spring) or, in other words, anvil weight ratio (anvil weight over hammer head weight) and rigidity of spring. However, the writer has found that, in case of free forging, as far as anvil weight ratio is larger than a certain value which is far smaller than that having been said to be the limit, there exists little influence of anvil weight ratio and rigidity of spring on hammer-forging effect. Result of experiments conducted and theoretical explanation therefor are given here.

1. Introduction

Among various factors to be considered in designing and installation of hammer-forging machines, determination of anvil weight and spring constant of supporting material (represented in the form of equivalent spring) is very important. It will be convenient for designing the foundation of hammer-forging machine, if we can determine freely anvil weight and spring constant only from the view points of machine strength and vibration prevention.

Although it has heretofore been said that they have great influence on various aspects of hammer-forging, and especially the forging effect is greatly influenced by anvil weight ratio, namely, anvil weight to hammer head weight ratio, the writer has found both theoretically and experimentally that,

in case of free forging, anvil weight ratio (which is larger than a certain small limit) and spring constant do not have so great influence on the forging effect and they may be determined freely to a considerable extent in design of the equipment.

2. Theoretical study

2.1 Forging effect

Forging effect defined in strength of materials or theory of plasticity considers absorbing energy, and it must be dealt with very strictly. However,

Fig. 1

simplifying for industrial purpose, here, we consider only deformation by forging. For example, in case l_1 becomes l_2 as shown in Fig. 1, we put as follows;

$$l_1 - l_2 = \text{forging amount}$$

$$(l_1 - l_2) / l_1 \% = \text{forging effect}$$

2.2 Deformation stress of article hammered in hammer-forging

It is not proper that percussion theory of rigid

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