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

- (1) K. Okushima: Trans. Japan Soc. Mech. Engrs., Vol. 21, No. 110(1955), p. 709.
- (2) E.H. Lee and B.W. Shaffer: Jour. Appl. Mech., Vol. 18, No. 4(1951), p. 405.

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

* Received 30th September, 1957.

** Superintendent, Takatori Workshop, Japanese National Railways, Suma-ku, Kobe.

body is applied, as has been done, to design of the foundation of hammer-forging machines. Design of the foundation of hammer-forging machines should be based on acting force.

For this purpose, the problem is to know the shape of deformation stress of article hammered. From the result of experiments, it is deemed proper to treat the shape of deformation stress as saw tooth waves for lead and as square waves for steel as seen in Fig. 2 and Fig. 3 respectively, though there are some deviations in both if strictly stated.

Detail of this impact stress is intended to be reported separately. Fig. 2 shows record of measurement of deformation stress when a steel test piece was forged by a steam hammer, and Fig. 3

Fig. 2

Fig. 3

Fig. 4 The instant when hammer head touches the article to be hammered

shows record of measurement of deformation stress in case of a lead test piece.

Consideration will first be made on the case of saw tooth waves.

2.3 Consideration on the case when the anvil is installed on an infinitely large foundation

In this case we can consider a mechanism as shown in Fig. 4. In favor of simplicity, we consider drop hammers only hereinafter. If we define

v_0 : velocity of hammer head at the instant when it touches the article to be hammered

w : hammer head weight

g : acceleration due to gravity

$F(t)$: deformation stress of the article hammered, we have the following equation

$$\frac{w}{g} \frac{d^2x}{dt^2} + F(t) = 0 \quad (1)$$

When we deal with $F(t)$ as saw tooth waves, it is given by

$$F(t) = \frac{F_a}{t_a} t \equiv ft \quad (\text{refer to Fig. 5})$$

So, solution of Eq. (1) is given by

$$x = v_0 t - \frac{gf}{6w} t^3 \quad (2)$$

Forging time or time till the velocity of hammer head becomes zero t_0 is obtained from $\frac{dx}{dt} = 0$ as follows ;

$$t_0 = \sqrt{\frac{2v_0 w}{gf}}$$

Displacement x_0 of hammer head during this t_0 equals forging amount ϵ_r .

Therefore

$$\epsilon_r = x_0 = x(t=t_0) = \frac{2}{3} v_0 \sqrt{\frac{2v_0 w}{gf}} \quad (3)$$

2.4 Consideration on the case when anvil is floating in space

In this case we consider a mechanism as shown in Fig. 6. v_0 and g will have the same definitions as in (2.3). Additional definitions are given as follows;

Fig. 5

Fig. 6

$w, u(t)$: hammer head weight, and displacement of hammer head after it touched the article hammered

$W, U(t)$: anvil weight, and displacement of anvil after hammer head touched the article hammered

As displacement of the hammer head is same as in case of (2.3)

$$\frac{w}{g} \frac{d^2 u}{dt^2} = -ft$$

$$\therefore u = v_0 t - \frac{gf}{6w} t^3 \quad (4)$$

Displacement of anvil is given by

$$\frac{W}{g} \frac{d^2 U}{dt^2} = ft \quad (5)$$

$$\therefore U = \frac{fg}{6W} t^3 \quad (6)$$

When forging action ends, $\frac{du}{dt} = \frac{dU}{dt}$, and if the time to this instant is defined t_1 ,

$$t_1 = \sqrt{\frac{2v_0 W w}{(W+w)gf}}$$

Displacement of anvil at the time of t_1 becomes

$$U_1 = U(t=t_1) = \frac{1}{3} \frac{v_0}{(1+\alpha)} \sqrt{\frac{\alpha}{1+\alpha}} \frac{2v_0 w}{gf} \quad (7)$$

where $\alpha = W/w \equiv$ anvil weight ratio.

In the same way, displacement of hammer head at the same instant is indicated by

$$u_1 = u(t=t_1) = \frac{v_0}{3} \frac{3+2\alpha}{1+\alpha} \sqrt{\frac{\alpha}{1+\alpha}} \frac{2v_0 w}{gf} \quad (8)$$

Therefore, forging amount ε_f becomes

$$\varepsilon_f = u_1 - U_1 = \frac{2}{3} v_0 \sqrt{\frac{\alpha}{1+\alpha}} \frac{2v_0 w}{gf} = \varepsilon_r \sqrt{\frac{\alpha}{1+\alpha}} \quad (9)$$

2.5 Consideration on the case when anvil is supported by spring whose spring constant is K

In this case, we consider a mechanism as

Fig. 7

shown in Fig. 7. Actually, in addition to spring equivalent damper should be considered at the same time.

However, since such a mechanism can be considered as an intermediate between infinitely large foundation and spring-supporting foundation, it may be omitted for consideration of extreme condition.

We consider, therefore, anvil supported by spring only.

Definition of every symbol will be the same as before. Additional definitions are

$z(t), Z(t)$: displacements of hammer head and anvil respectively after hammer head touched the article hammered

Considering the motion of anvil

$$\frac{W}{g} \frac{d^2 Z}{dt^2} + KZ = ft \quad (10)$$

Solving this equation, displacement of anvil is given by

$$Z = \frac{fg}{W} \left(\frac{1}{K} \frac{W}{g} \right)^{3/2} \left(\sqrt{\frac{gK}{W}} t - \sin \sqrt{\frac{gK}{W}} t \right) \quad (11)$$

$$= \frac{fg}{W} \left(\frac{1}{K} \frac{W}{g} \right)^{3/2} \left\{ \frac{\left(\sqrt{\frac{gK}{W}} t \right)^3}{3!} - \frac{\left(\sqrt{\frac{gK}{W}} t \right)^5}{5!} + \dots \right\} \quad (12)$$

If we assume K is infinite, it becomes the case of (2.3). When K is determined within effective range, considering simultaneously numerical value of t , the second term and afterwards can be neglected. In such case

$$Z = \frac{fg}{6W} t^3 \quad (13)$$

From Eqs. (6) and (13), it is noticed that, when spring constant K is in such range as keeps balance with W , value of K has little influence on forging amount and the forging amount is similar to that of the case when anvil is floating in space.

2.6 Influence of anvil weight and spring constant on the forging effect

From (2.4) and (2.5), it is clear that it does not give influence on the forging effect even if spring constant considerably changes, and it is also clarified that even in case of spring-supporting anvil the forging effect may be considered same as that in case of anvil floating in space.

As regards influence of anvil weight, the relation as shown by Eq. (9) exists. Therefore, the relation between forging amount in case of floating anvil to that in case of infinitely large anvil ratio $\varepsilon_f/\varepsilon_r$ and the anvil weight ratio α becomes as shown by curve A in Fig. 8.

The foregoing concerns lead. As for steel, however, the shape of deformation stress of the article hammered is properly considered square

waves as previously described. For such square waves, we obtain the relation

$$\epsilon_{f0} = \epsilon_{r0} \frac{\alpha}{1+\alpha} \quad (14)$$

where ϵ_{r0} , ϵ_{f0} = considering shape of deformation stress to be square waves, forging amount in case of indefinitely large foundation and that in case of anvil floating in space respectively.

The relation given by Eq. (14) is as shown by curve B in Fig. 8.

Fig. 8

Table 1 Kind of experiments (unit mm, kg, kg/mm)

(a) Coil-spring-supporting (hammer head 75Kg)																		
Material of test piece	Size of test piece	Falling height of hammer head	Spring constant	Anvil weight and anvil weight ratio														
				375	525	675	825	900	1050	1200	1350	1500	1650	1950	2250			
Steel	80 ^t ×43 ^φ	2000	100	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			1060	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	35 ^t ×43 ^φ	2000	53300	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			106	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Lead	80 ^t ×43 ^φ	2000	100	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			170	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			243	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			475	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			1060	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			5000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	35 ^t ×43 ^φ	2000	53300	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			100	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			170	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			243	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			475	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			1060	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Lead	80 ^t ×43 ^φ	1000	50000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			53300	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			100	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			170	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			243	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			475	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	35 ^t ×43 ^φ	2000	1060	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			50000	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			53300	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			100	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			160	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			53300	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

(b) Coil-spring-supporting (hammer head 10Kg)																				
Spring constant	Falling height of hammer head	Anvil weight	Anvil weight ratio	Test piece																
				48.4 ^t ×26 ^φ	21 ^t ×23 ^φ	Steel	Lead	Steel	Lead	Steel	Lead	Steel	Lead	Steel	Lead	Steel	Lead			
115	1120	18.3	1.83	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
115	1120	150.0	15.0	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
(c) Laminated-spring-supporting (hammer head 75Kg)																				
Spring constant		770	1030	1280	1540	1800	2180													
Spring condition		Oiling	No Oiling	Oiling	No Oiling	Oiling	No Oiling	Oiling	No Oiling	Oiling	No Oiling	Oiling	No Oiling	Oiling	No Oiling	Oiling	No Oiling			
Falling height of hammer head		2000																		
Anvil weight		630 (Anvil weight ratio 8.4)																		
Test piece		Lead 80 ^t ×43 ^φ																		
(d) Direct installation on earth (hammer head 20Kg)																				
Falling height of hammer head	Test piece	Shape of anvil and supporting method		Under ground depth	Experiment															
		Size	Weight																	
1120	48.4 ^t ×26 ^φ	Lead	19.3	400	○															

Table 2

Steel

are as shown in Table 2. Size of test piece employed in each experiment is seen in Table 1.

3.3 Apparatus for experiments

For experiments of Table 1 (a) and (c), an apparatus as shown in Fig. 9 was used. In this

apparatus, anvil weight is adjustable between 375 kg and 2 250 kg; two kinds of falling height, 1 m and 2 m, are available; and both coil springs and laminated springs can be used. For experiments of Table 1 (b), an apparatus as shown in Fig. 10 was used,

Hammer head weight 75 kg
Anvil weight 375~2 250 kg
Falling height 1 000~2 000 mm

Fig. 9

Hammer head weight 10 kg
Anvil weight 150 kg
Falling height 1 120 mm

Fig. 10

Hammer head weight 20 kg
Anvil weight 152~213 kg
Falling height 1 120 mm

Fig. 11

Table 3 Temperature of test piece

(a) Coil-spring-supporting (hammer head 75 kg)

Material of test piece	Size of test piece	Falling height of hammer head	Spring Constant	Anvil weight and anvil weight ratio											
				375	225	675	825	900	1050	1200	1350	1500	1650	1950	2250
				5	7	9	11	12	14	16	18	20	22	26	30
Steel	80 l × 43 φ	2 000	100	900°C 900	920 950	950 960	920 950	900 950	950 900	920 900	920 940	900 900	940 940	950 950	900 900
			1 060	940 920	960 940	960 950	920 930	900 910	900 900	900 900	900 900	910 950	950 930	910 910	900 900
			53 300	950 940	940 950	940 950	950 —	930 900	950 940	900 900	900 900	930 950	900 910	900 900	950 940
	35 l × 42 φ	2 000	106												900 —

(b) Coil-spring-supporting (hammer head 10 kg)

Spring constant	Falling height of hammer head	Anvil weight	Anvil weight ratio	Test Piece	
				48.4 l × 26 φ	21 l × 23 φ
				Steel	Steel
115	1 120	18.3	1.83	835	
		31.0	3.10	840	
		41.1	4.11	850	
		51.1	5.11	840	
		60.9	6.09	850	
		118.0	11.8	855	845
	560	150.0	15.0	850	850
	1 120			845	835
	560			840	840

Fig. 12 Result of experiments

and for experiments of Table 1 (d), one as shown in Fig. 11.

3.4 Other conditions for experiment

(a) Kind of forging—The experiment was done in form of free forging, dropping the hammer head on test piece placed on anvil. (b) End condition of test piece—Upper face of anvil and lower face of hammer head were very smoothly finished by lapping. However, end faces of test piece to be placed on anvil were machine-finished (degree 12-S) for both lead and steel, and for steel test piece descaling was done after heating. No lubricant (such as oil) was used either between upper face of anvil and test piece or between lower face of hammer head and test piece. (c) Temperature of test piece—Temperature of steel test piece on anvil was measured by means of radiation pyrometer, descaling it right before hammering. Although the best effort was made to make the temperature constant, actual result of measurement is as seen in Table 3. As for lead, test pieces of room temperature were used.

3.5 Result of experiments

From these experiments, the relation between anvil weight ratio α which is larger than a certain value and forging effect, and that between spring constant K and forging effect are as shown in

Fig. 12.

As is clear from Fig. 12, the forging effect is not specially influenced either by anvil weight ratio α or by spring constant K . When we apply the conditions under [2] to the result of experiment of Table 1 (b) and make plotting, we obtain $\times$ marks for lead test piece and $\circ$ marks for steel test piece, both in Fig. 8.

Deviation of the results of experiment for steel from the theoretical curve, while the results of experiment for lead coincides with theoretical curve, is considered largely due to unevenness of temperature of the test piece when it is hammered.

When anvil weight ratio is smaller than a certain value (which is far smaller than the value having been said limit), the forging effect is apparently influenced by anvil weight ratio α , and it is clear from this figure that the influence in this case accords with the theory under [2].

4. Conclusion

In case of free forging, the following matters are confirmed from the result of experiments using model hammers;

(1) Theoretical consideration stated in [2] coincides with the result of experiments.

(2) Therefore, anvil weight ratio, as expressed

in Fig. 8, may be determined such as is far smaller than what has hitherto been said limit, and when anvil weight ratio is larger than such value, it does not influence much on the forging effect.

(3) Spring constant of anvil-supporting material (equivalent spring) also does not have so great influence on the forging effect.

(4) In design of hammer-forging machines, it is not necessary therefore, to have large anvil in such meaning as has been said.

(5) In case of installation of hammer-forging machines, no special consideration has to be made on influence of anvil weight and stiffness of anvil-

supporting material on the forging effect, and the anvil weight and the stiffness of anvil-supporting material may be considerably freely determined from the viewpoints of strength of foundation and vibration prevention.

Although as previously stated the above conclusion is witnessed by experiments using model hammer, the writer intends to make further confirmation with actual working hammers.

The writer wishes to express his sincere thanks to Prof. H. Yamanouchi and Prof. T. Takahashi of Waseda University for their valuable advices.

On the Impact Stress in Hammer Forging*

By Sakuo OMODAKA**

In order to solve various problems in relation to hammer forging equipment, it is essential to clarify impact stress in hammer forging. However, due to difficulty of making this sort of experiments, there have been few reports of experiments which give us practical figures.

Making experiments with model hammers and steam hammers for actual use, the writer has measured by means of Braun tube oscillograph various values of impact force and various relative conditions which are necessary for theoretical design of mount and foundation of forging hammers.

From the result of these measurements, practical conditions and figures have been obtained.

The writer has also found that shape of the stress greatly varies with material of the article hammered, and that close attention must be paid to the method of measurement for experiments of this kind.

1. Introduction

In order to solve various problems in relation to hammer forging work or installation of hammers, it is essential to clarify impact stress in hammer forging. Especially for theory of design of foundation of steam hammer or air hammer, as presented by the writer in his relative treatise, shape and absolute value of the stress have to be known. However, due to difficulty of making experiments, though theoretical solution on assumptions is easy, there have been few reports of experiments which give us practical figures.

This study was done to obtain various values

of impact force and various relative conditions which can be used for industrial purpose, as necessary factors for theoretical design of foundation and mount of forging hammer. Luckily, impact stress in hammer forging could be experimentally measured with great success by means of Braun tube oscillograph. At the same time, by making clear the proper way of dealing with those measured values, figures which can be used for design of mount and foundation of hammer forging machines could be obtained.

It has also become clear from experimental photographs that the shape of the stress greatly varies with material of article hammered. This may have an important meaning for any theoretical consideration relating to percussion. It has further been found that the measuring method in

* Received 21st January, 1958.

** Superintendent, Takatori Work Shop, Japanese National Railways, Suma-ku, Kobe.