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# Experimental Study of Upsetting and Die Forging with Controlled Impact

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***Abstract*—**The results from experimental research of deformation by upsetting and die forging of lead specimens wit controlled impact are presented. Laboratory setup for conducting the investigations, which uses cold rocket engine operated with compressed air, is described. The results show that when using controlled impact is achieving greater plastic deformation and consumes less impact energy than at ordinary impact deformation process.

***Keywords*—**Rocket Engine, Forging Hammer, Sticking Impact, Plastic Deformation.

## I. INTRODUCTION

FOR impact plastic deformation at hot die forging, pneumatic and hydraulic hammers, with the mass of the falling parts from 0.5 to 40 tons are used [1], [2]. Due to the long period of use (over 150 years) these machines have reached the limit of its design and technology. One option for further development of machines and technologies for impact plastic deformation can be achieved by using a rocket engine propelled hammer – Fig. 1 (a). Fig. 1 (b) shows industrial rocket engine used at this hammer and die forged conical gear (low carbon alloyed steel) [3]. As can be seen from Fig. 1, the hammer design is very simple and as a result, it is more reliable in operation compared to other similar machines.

The die forging hammer shown on Fig. 1 has a falling part with mass of 220kg, but because of the possibility of deformation with greater speed than conventional hammers with it can produce forgings, which are made of ordinary hammers with 2 tons mass of the falling part. Depending on the amount of fuel (kerosene) supplied to the rocket engine and on the duration of the running time, it may be obtained an impact velocity from 6m/s up to 25m/s. Currently used pneumatic and hydraulic hammers work with an impact speed of 5m/s – 7.5m/s. This means that rocket propelled hammer can work with an impact velocity of both ordinary and high speed hammers.

Innovation from technological point of view is the ability to work with "controlled impact". Known impact machines work with "simple impact", in which there is always rebound after impact. This is due to interruption of the connection between the actuator (pneumatic or hydraulic cylinder) and the ram at the time of impact. When using a rocket engine propelled hammer the rocket engine can continue to work during the impact. Depending on the rocket engine force (thrust R) it can be adjusted the deformation force and the size of the rebound after impact, which we denote by the term "controlled impact". Under certain conditions [5], [6] it can be achieved impact without rebound, which we call "sticking impact".


(a) (b)

Fig. 1 (a) Front view of rocket engine propelled hammer (b) Rocket engine and die forged conical gear

This work presents the results of laboratory tests for controlled impact by upsetting and die-forging [4].

## II. LABORATORY SET-UP FOR CONTROLLED IMPACT

The laboratory setup is shown in Fig. 2 (a), [5]. Free fall down of falling part 3 is accelerated by cold rocket engine (part No 1 on Fig. 2 (b) attached to 3. The engine is started up at feeding to it of compressed air with a pressure of 35 bar. The engine force (trust R) at this pressure is 23 kg. From electronic control unit (part No 6 on Fig. 2 (a) can be set four regimes of operation of the engine – Fig. 3.

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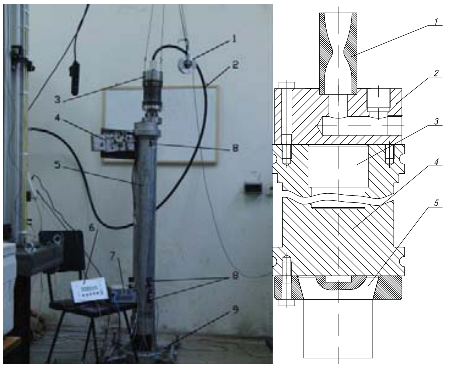


(a) (b)

Fig. 2 (a) Laboratory set-up: 1 – hose support roller; 2 – hose for pressure air feed; 3 – falling part; 4 – system for hold up of the falling part in upper position; 5 – tube body; 6 – electronic control unit; 7 – power supply of system 4; 8 – inductive sensors ; 9 – base (b) Falling part drawing: 1 – cold rocket engine; 2 – air inbody; 3 – additional weight; 4 – falling part body; 5 – punch

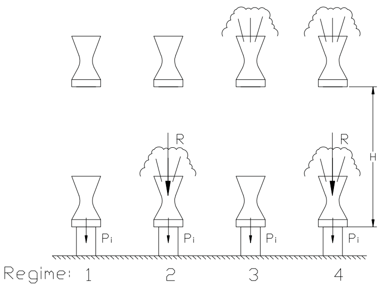


Fig. 3 Regimes of the experimental set-up: 1 – simple impact; 2 – simple impact + controlled impact; 3 – accelerated by rocket engine simple impact; 4 – accelerated impact + controlled impact; $P_i$ – impact force; R – rocket engine trust

## III. METHOD OF EXPERIMENT

### A. Upsetting Deformation

In these experiments, the mass of the falling part is $m_1$ = 32.97kg. Work in Regime 3, Regime 4 and H = 1m – Fig. 3. Lead specimens are used (99.99% Pb) with $D_0$ = 60mm, $H_0$ = 72mm, $H_0/D_0$ = 1.2 and 2.315kg mass. The ratio H / D = 1.2 is selected because at this ratio the effect of deformation with controlled impact is greatest [6]. Experiments are conducted with two specimens at each regime and the resulting data are averaged.

Since the deformation in one impact is small, several impacts are carried out to achieve a degree of deformation $\varepsilon_{max} = (H_0 - H_{min}/H_0)\ .100,\ \% \approx 35\%$, where $H_{min}$ is the specimen height at maximum deformation. After each i-th impact (i = 1, 2, …., n) the height $H_i$ is measured and following parameters are defined:

Relative deformation by each i-th impact

$$\varepsilon_i = \frac{H_0 - H_i}{H_0}.100,\% \qquad (1)$$

Total deformation after each i-th impact

$$\varepsilon_\Sigma = \sum_{i=1}^{n} \varepsilon_i,\% \qquad (2)$$

Impact energy by each i-th impact

$$E_i = \frac{mV_i^2}{2}, J \qquad (3)$$

Total energy after each i-th impact

$$E_\Sigma = \sum_{i=1}^{n} E_i, J \qquad (4)$$

Specific impact energy by each i-th impact

$$E_{s,i} = \frac{E_i}{\Theta}, J/sm^3 \qquad (5)$$

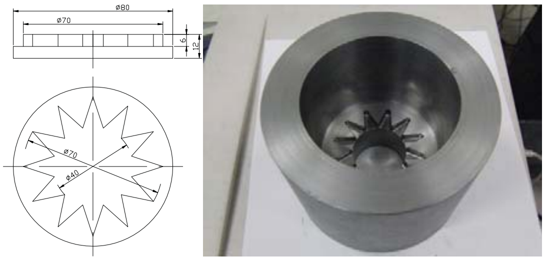
Total specific impact energy after each i-th impact

$$E_{s,\Sigma} = \sum_{i-1}^{n} E_{s,i}, J/sm^3 \qquad (6)$$

where $V_i$ is the impact velocity, m/s; Θ = 0.785. $D_0^2.H_0$, $sm^3$, is the workpiece volume (Θ = const.).

### B. Die Forging Deformation

In Fig. 4 (a) is shown a draw of "gear" type forging and in Fig. 4 (b) is shown the die for this forging. Lead billets with D = 36mm, H = 46mm (H / D = 1.27) and 530.70 gr. mass are used. The mass of the falling part is $m_2$ = 35.47kg. Experiments were conducted at a deformation Regime 3, Regime 4 and H = 1m. Successive blows on the billet are applied and after each blow the forging is took out and the degree of filling of the die is assessed. On finally filling of the die are counted the number of the blows and is determined the total energy consumed for each impact regime.



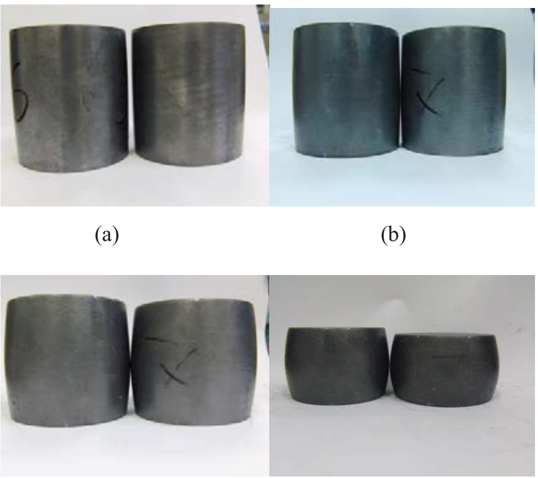
(a) (b)

Fig. 4 Gear type forging (a) draw of the "gear" type forging; (b) photo of the die

## IV. RESULTS OF THE EXPERIMENTS

### *A. Upsetting Experiments*

Fig. 5 shows the deformed samples and Table I shows the average data from the experiments. With the data of Table I are built in graphical form the relationships $N_i$ - $\varepsilon_{i,av}$ and $\Sigma E_{(s,i)av}$ - $\varepsilon_{i,av}$ – Figs. 6, 7.


(a) (b)

(c) (d)

Fig. 5 (a) unformed specimens; (b), (c), (d) change of the shape of the specimens after 3, 5 and 8 impacts

The right specimen in each photo is deformed with controlled impacts; Fig. 6 one is deformed with simple impacts.

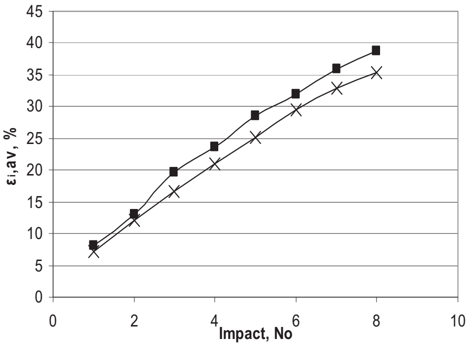


Fig. 6 Impact No - $\varepsilon_{i,av}$ function by upsetting; ■-controlled impact; x – simple impact

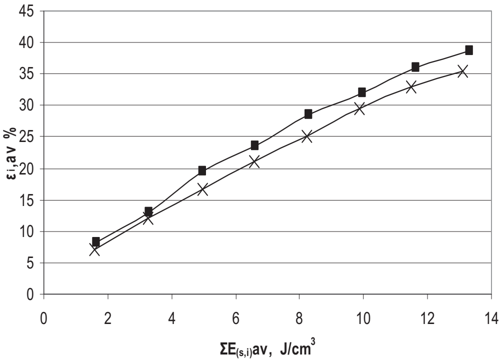


Fig. 7 $\Sigma E_{(s,i)av}$ - $\varepsilon_{i,av}$ function by upsetting; ■- controlled impact; x – simple impact

### *B. Die Forging Experiments*

Fig. 8 shows the obtained a "gear" type forgings and the Table II shows the average data of the experiments.

(a) (b)

Fig. 8 Filling of the tooth shape: (a) after 5 blows; (b) after 9 blows; forgings 3, 5 are received with combined impact; forgings 4,6 - with simple impact

## V. DISCUSSION OF THE RESULTS AND CONCLUSION

Table I shows that with increase in the number of strokes (increase the specific energy of impact ΣEs) increases the difference $\Delta\varepsilon = \varepsilon_{com} - \varepsilon_{sim}$, were $\varepsilon_{com}$ is the deformation by combined impact, $\varepsilon_{sim}$ is the deformation by simple impact. This increase is with a jump after the second impact, i.e. it has a minimum specific energy $(E_s)_{min}$, after which receives significant difference between $\varepsilon_{com}$ and $\varepsilon_{sim}$. From Table I and Fig. 7, it is seen that at an impact velocity $V_i$ = 4.5 m / s, $(E_s)_{min}$ = 4.95 J/sm$^3$. In [6 ] is shown that at $V_i$ = 7.2 m/s, $(E_s)_{min}$ = 3.5 J/sm3, i.e. $(E_s)_{min}$ depends on the speed of impact and on the thrust of a rocket engine R. Likely with increasing of R, $(E_s)_{min}$ will decrease and reach a certain value of R at which $(E_s)_{min} = 0$ .

TABLE I
AVERAGE DATA OF UPSETTING EXPERIMENTS

REGIME 3: SIMPLE IMPACT

| $N_i$ | $V_{imp,av}$, m/s | $H_{i,av}$, mm | $\Delta H_{i,av}$, mm | $\varepsilon_{i,av}$, % | $E_{(imp,i)a}$ J | $E_{(s,i)av}$, J/sm$^3$ | $\Sigma E_{(s,i)av}$, J/sm$^3$ |
|---|---|---|---|---|---|---|---|
| 1 | 4.445 | 66.65 | 5.35 | 7.43 | 352.70 | 1.600 | 1.600 |
| 2 | 4.540 | 63.35 | 8.65 | 12.01 | 339.81 | 1.669 | 3.269 |
| 3 | 4.565 | 60.00 | 12.00 | 16.66 | 343.53 | 1.687 | 4.956 |
| 4 | 4.490 | 56.90 | 15.10 | 20.97 | 332.36 | 1.632 | 6.588 |
| 5 | 4.505 | 53.90 | 18.10 | 25.14 | 334.56 | 1.641 | 8.229 |
| 6 | 4.490 | 51.19 | 20.81 | 28.90 | 332.34 | 1.632 | 9.861 |
| 7 | 4.495 | 48.30 | 23.70 | 32.95 | 333.08 | 1.636 | 11.49 |
| 8 | 4 485 | 46.50 | 25.50 | 35.42 | 330.12 | 1.611 | 13.11 |
| REGIME 4: COMBINED IMPACT | | | | | | | |
| 1 | 4.505 | 66.05 | 5.85 | 8.14 | 334.59 | 1.645 | 1.645 |
| 2 | 4.515 | 62.45 | 9.35 | 13.00 | 336.05 | 1.653 | 3.298 |
| 3 | 4.545 | 57.80 | 14.10 | 19.61 | 338.28 | 1.660 | 4.958 |
| 4 | 4.525 | 54.80 | 17.00 | 23.64 | 337.54 | 1.660 | 6.618 |
| 5 | 4.540 | 51.40 | 20.50 | 28.51 | 339.78 | 1.675 | 8.293 |
| 6 | 4.545 | 48.95 | 22.95 | 31.91 | 340.53 | 1.675 | 9.968 |
| 7 | 4.550 | 46.05 | 25.85 | 35.95 | 341.28 | 1.679 | 11.65 |
| 8 | 4.525 | 44.05 | 27.85 | 38.73 | 337.56 | 1.660 | 13.31 |

From the upsetting experiments [7] conducted with lead specimens at $H_0/D_0 = 1.2$ was found that the average difference in the relative degree of deformation $\Delta\varepsilon_{,avg} = 3.59\%$ (Table I). This difference means that the average deformation by combined impact upsetting is 10.13% more than upsetting by simple impact.

Table II shows that the total energy $\Sigma E_{s,i}$ , to obtain quality forging with a simple impact is $\Sigma E_{i,i} = 4077.34$ J (12 impacts), and with a combined impact $\Sigma E_{i,i} = 3025.19$ J (9 impacts). The difference $\Delta\Sigma E_{i,i} = 1052.15$ J is 25.8% , i.e. the energy consumption by combined impact die forging is with 25.8% less than by die forging with simple impact. In practice this means that in hot die forging wit combined impact can be used hammer which impact energy is 25.8% less than the impact energy of the simple impact working hammer.

For example, if use simple blow hammer with mass of falling part (ram) $m_s = 2$ tons and impact velocity $V_i = 4.5$ m / s, the impact energy will be

$$E_s = \frac{2000 \times (4.5)^2}{2} = 20250, J. \tag{7}$$

If energy reducing with 25.8% at rocket engine propelled hammer, it would be 15025.5 J, and the mass $m_c$ of the ram is

$$15025.5 = \frac{m_c.20,25}{2} \rightarrow m_c = 1484, \text{kg} = 1.484, \text{ton}. \tag{8}$$

It follows from (8) that in combined impact die forging with the same impact speed (4.5 m/s) can be used a hammer with ram mass 1.484 ton, i.e. to work with smaller standard hammer for hot die forging with ram mass of 1.5 ton. This result is unaffected from the impact velocity [8].

TABLE II
DATA OBTAINED FROM DIE FORGING EXPERIMENTS

| Regime | $N_i$ | $V_{i,i}$, m/s | $E_{i,i}$, J | $\Sigma E_{i,i}$, J/sm$^3$ | $E_{s,i}$, J/sm$^3$ | $\Sigma E_{s,i}$, J/sm$^3$ |
|---|---|---|---|---|---|---|
| Simple Impact (Regime 3) | 1 | 4.27 | 325.00 | 325.00 | 6.94 | 6.94 |
| | 2 | 4.32 | 332.66 | 657.66 | 7.10 | 14.05 |
| | 3 | 4.36 | 338.85 | 996.50 | 7.42 | 21.28 |
| | 4 | 4.39 | 343.53 | 1340.03 | 7.34 | 28.62 |
| | 5 | 4.37 | 340.40 | 1680.43 | 7.27 | 35.89 |
| | 6 | 4.39 | 242.53 | 2023.96 | 7.34 | 43.23 |
| | 7 | 4.39 | 343.53 | 2367.48 | 7.34 | 50.56 |
| | 8 | 4.35 | 337.29 | 2704.44 | 7.20 | 57.77 |
| | 9 | 4.41 | 346.66 | 3051.44 | 7.40 | 65.17 |
| | 10 | 4.40 | 345.09 | 3396.53 | 7.37 | 72.54 |
| | 11 | 4.37 | 340.40 | 3736.93 | 7.27 | 79.81 |
| | 12 | 4.37 | 340.40 | 4077.34 | 7.27 | 87.08 |
| Controlled impact (Regime 4) | 1 | 4.26 | 323.48 | 323.48 | 6.91 | 6.91 |
| | 2 | 4.36 | 338.85 | 662.33 | 7.24 | 14.15 |
| | 3 | 4.44 | 351.39 | 1013.72 | 7.50 | 21.65 |
| | 4 | 4.34 | 335.74 | 1349.47 | 7.17 | 28.82 |
| | 5 | 4.28 | 326.53 | 1675.99 | 6.97 | 35.79 |
| | 6 | 4.33 | 334.20 | 2010.19 | 7.14 | 42.93 |
| | 7 | 4.37 | 340.40 | 2350.59 | 7.27 | 50.20 |
| | 8 | 4.33 | 324.20 | 2684.79 | 7.14 | 57.34 |
| | 9 | 4.37 | 340.40 | 3025.19 | 7.27 | 64.61 |

The following conclusions can be drawn:

- By upsetting of lead specimens with diameter 60mm, H/D = 1.2, R = 23 kg, $V_i \approx 4.5$ m/s and eight consecutive impacts the obtained relative deformation $\varepsilon_c$ by controlled impact is 10.13% higher than the relative deformation $\varepsilon_s$ obtained by simple impact.
- By upsetting with a few impacts, significant difference between the relative degree of deformation ε in simple and combined impact is obtained after reaching the specific impact energy $E_s$ of a certain value, denoted by us as $(E_s)$ min. The minimum specific energy $(E_s)_{min}$ depends on the impact speed and on the rocket engine trust R.
- In die forging of a "gear" type forgings with the application of successive blows is found that deformation with combined impact consumes 25.8% less energy than deformation with simple impact. This means that in die forging production practice can be used rocket engine propelled hammers with smaller ram mass, compared with hammers working with simple impact. This difference will be greater, as greater is the rocket engine thrust R.
- From the results of the conducted experiments it follows that the obtained degree of deformation by combined impact is greater than the degree of deformation obtained by simple impact. Magnitude of this difference depends on many factors, the most important of which is the rocket engine trust R.

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