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INVESTIGATION OF UPSETTING OF CYLINDER BY CONICAL DIES

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ABSTRACT

Process of upsetting of cylinder by two cone-concave dies has been analyzed theoretically and experimentally in order to determine the influence of die geometry on main process parameters. Theoretical Slab method has been used to obtain stress distribution over the die /workpiece contact surface and forming load. Beside, UBET prediction of load has been made. Experiments have been performed using specimens out of steel. Theoretical analysis and UBET give well agreeable results to experimental results.

1. INTRODUCTION

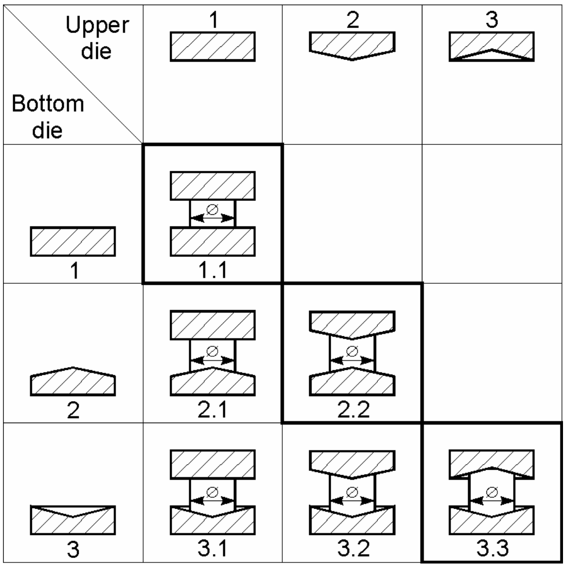
Free upsetting is a basic metal forming operation and it often occurs either as a separate process or in combination with other, more complex processes of bulk metal forming. In such cases free upsetting is usually the first phase of a multiphase operation. The most frequent form is upsetting of cylindrical or prizmatical billet by flat dies although the upsetting by cylindrical, spherical or tapered dies also take place.

Model of free upsetting is also used in the various theoretical investigation, e.g. in the material formability analysis, for the stress-strain curve determination etc.

Different variants of upsetting of prizmatical billet by cylindrical and flat dies has been analyzed in [1]. Deformation load and contact pressure has been evaluated.

In [2] deformation load and contact pressure in the process of upsetting by spherical dies has been investigated.

Tab. 1: Upsetting with conical dies



In [3] open die forming using semi-circular pressing tools has been presented. The effect of the die shape on metal flow and loading was investigated. This process is convenient for incremental progressively deformation over the entire length of the workpiece.

Authors in [4] used the process of compression of cylindrical samples with a cone shaped die in order to investigate cracks occurrence. The resulting cracks are classified according to their position and direction.

At the Institute for Production Engineering, University Novi Sad, wider investigation has been carried out in order to analyze the influence of die geometry on the process parameters in open die forging/ upsetting. Six different die combinations - models have been created (*Tab. 1*).

In this paper the processes of upsetting of cylinder by cone-concave dies (model 3.3, *Tab. 1*) has been investigated theoretically, using Slab method. UBET prediction has been also performed as well as the experimental verification of the theoretically obtained results.

2. THEORETICAL ANALYSIS

Theoretical analysis has been performed by using Slab method. In order to determine the stress state by upsetting of cylinder by cone - concave dies method, following assumptions have been made:

- Form of the cylinder does not change during deformation (no bulging).
- Flow stress is variable (not constant) in radial direction and it depends on effective deformation:

$$K = K_o + A \cdot \varphi_e^b \qquad (1)$$

K_o, A,b - material depended.

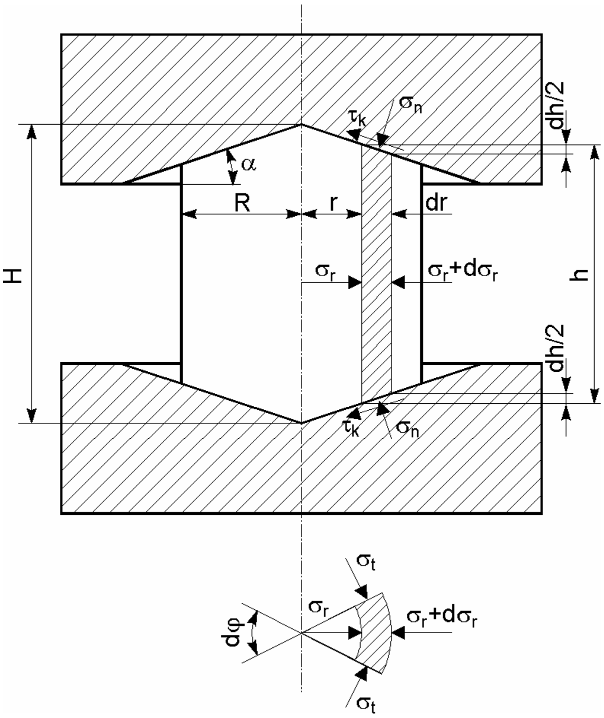


Fig.1: Stress components in the process of free upsetting by conical dies

- Tangential contact stress (τ_k) is proportional to the normal contact stress (σ_n) and coefficient of friction (μ).

$$\tau_k = \mu \cdot \sigma_n \qquad (2)$$

- Radial and tangential stresses are equal:

$$\sigma_r = \sigma_t \qquad (3)$$

Based upon the loading scheme (*Fig.1*) equilibrium equation in radial direction is:

$$\sigma_r \cdot h \cdot r \cdot d\varphi - (\sigma_r + d\sigma_r)(h + dh)(r + dr) \cdot d\varphi - 2\sigma_n \cdot \frac{dr}{\cos\alpha} \cdot \sin\alpha \cdot r \cdot d\varphi$$

$$-2\tau_k \cdot \frac{dr}{\cos\alpha} \cdot \cos\alpha \cdot r \cdot d\varphi + \sigma_t \cdot h \cdot dr \cdot \sin\frac{d\varphi}{2} = 0 \qquad (4)$$

By assuming $\sigma_r = \sigma_t$ and $\tau_k = \mu\sigma_n$, the above equation becomes:

$$\sigma_r \cdot \frac{dh}{dr} + \frac{d\sigma_r}{dr} \cdot h + 2\sigma_n(\mu + tg\alpha) = 0 \qquad (5)$$

Elimination of σ_n from (5) has been carried out by introducing the yield criterion:

$$\sigma_n - \sigma_r = K \quad \rightarrow \quad \sigma_n = K + \sigma_r \qquad (6)$$

which gives:

$$\frac{d\sigma_r}{dr}\cdot h+\sigma_r\cdot\frac{dh}{dr}+2\sigma_r\cdot tg\alpha+2K(\mu+tg\alpha)+2\mu\sigma_r=0 \qquad (7)$$

From the *Fig.1* can be seen: $\frac{dh}{dr}=-2tg\alpha$

Final form of the equation (7) is:

$$\frac{d\sigma_r}{dr}+\frac{2\mu\sigma_r}{h}+\frac{2K}{h}\cdot(\mu+tg\alpha)=0 \qquad (8)$$

In the above relation the value "h" can be obtained from the *Fig.1*:

$$h=H-2rtg\alpha \qquad (9)$$

Solution of the differential equation (8) for σ_r has been performed by numerical procedure (Runge-Kutha method). Boundary condition is:

$$r=R \qquad \sigma_r=0 \qquad (10)$$

Knowing the component σ_r (8) stress component σ_n can be determined by (6) e.g.:

$$\sigma_n=K+\sigma_r$$

Deformation load can be obtained by integration of contact stress along the contact surface:

$$F=\int_A(\sigma_n\cdot\cos\alpha-\tau_k\cdot\sin\alpha)dA=2\pi(1-\mu tg\alpha)\int_0^R\sigma_n\cdot r\cdot dr \qquad (11)$$

In order to predict deformation load and contact pressure by means of above equations it is necessary to determine effective deformation. This deformation is not constant in "r" direction, due to the die form. According to the *Fig. 2* it is:

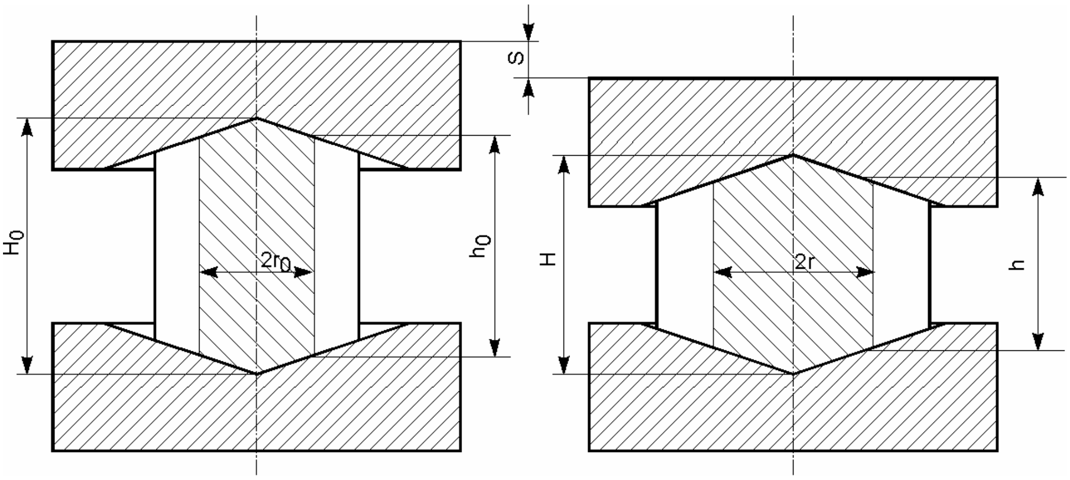


Fig.2: Geometry of the specimen

$$\varphi_e = \ln\frac{ho}{h}. \tag{12}$$

The value of "h" can be obtained from the volume constancy:

$$r_o^2 H_o - \frac{4}{3} r_o^3 \cdot tg\alpha - r^2 H + \frac{4}{3} r^3 \cdot tg\alpha = 0 \tag{13}$$

Analytical form of the stress-strain curve for the applied material (C 4732 – JUS; 42CrMo4 - DIN), obtained by Rastegaev test [1,2], is:

$$K = 714{,}44 + 1023 \cdot \varphi_e^{0{,}3547} \quad [MP] \tag{14}$$

For the UBET application linear form of the stress-strain curve is needed:

$$K = 10 \cdot (10{,}3 + 8{,}1 \cdot \varphi_e) \qquad [MP] \tag{15}$$

3. UBET SIMULATION

UBET (Upper Bound Elemental Technique) is a reliable theoretical approach which is able to produce a load prediction, contact pressure and material flow in axisymmetric forging/extrusion processes [5],[6]...The main input data to the program are the billet and die coordinates and required penetration. Other relevant parameters, such as friction factor, process type (hot, cold), material properties (stress-strain curve) and die velocity have also to be predefined.
The solution may be an approximate one, but the experimental verification carried out so far show that UBET has a great deal of potential for practical application and academic enhancement.
In current case load prediction performed by UBET is indicated in *Fig. 5* by dotted line. Assumed friction factor was m=0.2, die velocity 1mm/sec and stress-strain curve in its linear form (15).

4. EXPERIMENT

Two different cylindrical specimens of steel (C 4732 – JUS; 42CrMo4 - DIN), have been applied in the experiment:ϕ18x26mm, $\alpha = 10^o$ and ϕ18x40mm, $\alpha=20^o$. Upsetting was performed on hydraulic press Sack&Kiesselbach of 6,3 MN, using the tooling shown in ***Fig.3***.

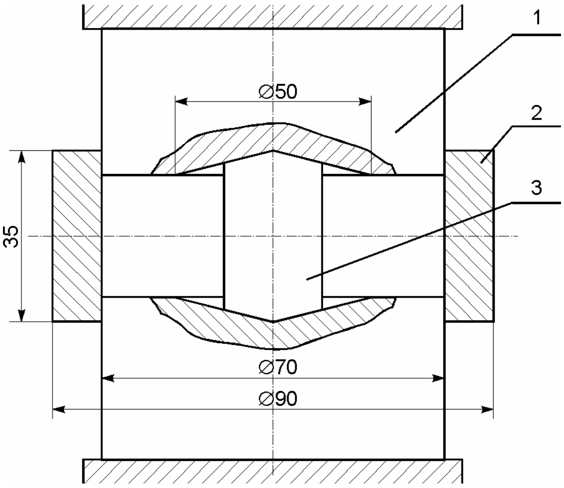


Fig.3: Tooling for upsetting
die; 2 – ring; 3 – specimen

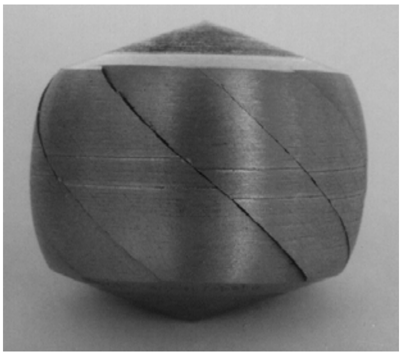


Fig. 4**:** Specimen ϕ18x40mm, α=20°

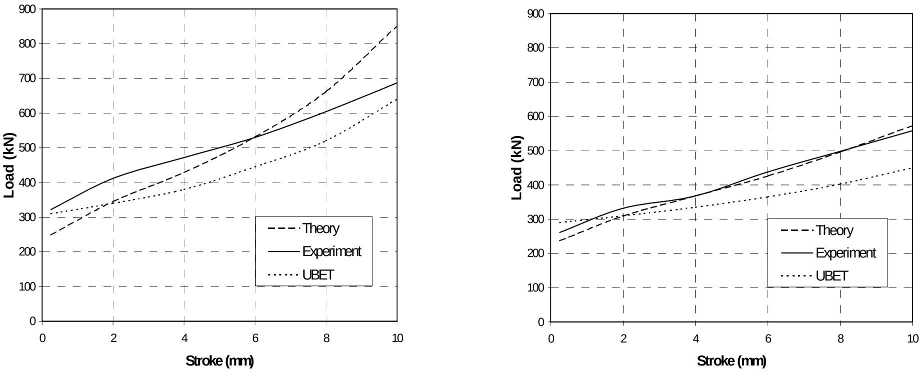
During the process load - stroke curve has been recorded. In *Fig. 4* photograf of deformed specimen ϕ18x40mm, α=20° is given.

5. RESULTS

In *Fig.* ***5*** the load - stroke characteristics, predicted by Slab method (dashed line), UBET (dotted line) and experimentally obtained (solid line) for two different die inclination angle ($\alpha = 10^0$ and $\alpha = 20^0$) are given.

As it can be seen, experimental load and load calculated by Slab method are in a relatively close agreement whereas load predicted by UBET is lower during whole process. This difference can be attributed to the fact that the real stress-strain curve for the given material ($K = 714{,}44 + 1023 \cdot \varphi_e^{0{,}3547}$ $[\mathrm{MP}]$), obtained in Rastegaev test, was transformed for the need of UBET application into the linear form: $K = 10 \cdot (10{,}3 + 8{,}1 \cdot \varphi_e)$ $[\mathrm{MP}]$. These two forms differ (for lower strains linear form gives higher values of stress and for higher strains it gives lower stress values) . Direct implication of this is UBET underestimation of load. Thus, a linear form of stress-strain curve, used by UBET does not describe material behavior during plastic deformation in accurate way.

In further work investigation will be focused on the formability potential of material in connection with different die shapes.



a) *b)*

Fig. 5: Load-stroke diagrams: a) ϕ 18x26 mm, $\alpha=10^o$; b) ϕ18x40 mm, $\alpha=20^o$

6. LITERATURE

[1] Vilotic D., Shabaik A.: Analysis of upsetting with profiling dies, Journal of Engineering Materials and Technology, Vol.107,pp261-264. Oct.1985.

[2] Vilotic D, Plancak M., Vujovic V., Milutinovic M., Gelei A.: Some Aspects of upsetting of cylinder by spherical dies, International Conference of Industrial Tools, ICIT'97, Proceedings ,pp 65-69, Maribor-Slovenia, 1997.

[3] Fereira J., Osman F.H.: Investigation into bar profiling using semi-circular tools, Advances in Material and Processing Technologies 97, pp.855-860.

[4] Matilde S., Pertence A., de Aquilar M.,Celtin P.: Formacao de trincal do tipo β no ensais de cone truncado, II Conferencia International de forjamento/ Porto Alegre, Brasil, 1998, pp. 98-112.

[5] Bramley A.: Computed Eided Forging Design, Analysis of the CIRP Vol. 36/1/1987

[6] Osman F.H.: Computerized simulation of forging processes, PhD Thesis, University Leeds, 1981

SABIJANJE CILINDRA POMOĆU KONIČNIH ALATA

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REZIME

Slobodno sabijanje u svojim različitim varijantama često se pojavljuje u obradi deformisanjem, ili kao posebna operacija ili kao sastavni deo kompleksnih operacija. Kod složenih postupaka slobodno sabijanje je obično prva faza procesa.

Ova tehnološka metoda često je teoretski analizirana i to pomoću različitih metoda i u različitim ciljevima, npr. u analizi obradivosti, određivanje krive deformacionog otpora itd.

Na Institutu za Proizvodno mašinstvo u Novom Sadu izvršena su šira istraživanja procesa sabijanja sa ciljem da se analizira istraživanje procesa sabijanja sa ciljem da se analizira uticaj geometrije alata na procesne parametre. Korišćena je metoda preseka i UBET simulacija, uz eksperimetalnu verifikaciju dobijenih rezultata. U analizi je korišćen cilindrični pripremak ϕ18*40, materijal Č.4732, a alat je bio koničan.

Tok deformacione sile određen je pomoću 3 metode (metoda preseka, UBET i eksperiment). Metoda preseka daje rezultate koji su u dobroj korelaciji sa eksperimentalnim rezultatima, dok UBET daje nešto više vrednosti sile. To se može objasniti činjenicom da je k-φ kriva oblika:

$$K = 714 + 103\varphi_e^{0.3547} \quad [\mathrm{MPa}]$$

dobijena u Rastegajev testu, za potrebe UBET simulacije morala biti transformisana u linearan oblik:

$$K = 10(10.3 + 8.1\varphi_e) \quad [\mathrm{MPa}]$$

Dalja istraživanja na ovom planu biće fokusirana na problem obradivosti i uticaj geometrije alata i geometrije pripremka na obradivost.

U UBET simulaciji korišćen je faktor trenja m=0,2 a brzina alata 1 mm/s.

U metodi preseka usvojene su sledeće pretpostavke:

- oblik pripremka ostaje za svo vreme deformisanja cilindričan
- efektivni napon nije konstantan u radijalnom pravcu nego zavisi od efektivne deformacije
- tangencijalni napon usled trenja je $\tau = \mu \cdot \sigma_n$
- radijalni i tangencijalni naponi su isti; $\sigma_r = \sigma_t$