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UPSETTING OF BRASS BILLETS BY FLAT DIES

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ABSTRACT

Upsetting processes belong to the class of elemental bulk metal forming operations. Many multi stage forming processes include upsetting as one of the operations. Upsetting processes also can be used for determination of forming limit diagram.
Forming limit diagram (FLD) allows design and optimization of number of phases at forming process and also expresses possibility of material to be deformed in different stress-state condition. Present paper investigates formability of brass in cold upsetting processes. Four different tests (basic cylinder test, tapered test, collar cylinder test and Rastegajev test) were applied. The aim of investigation was to determine forming limit diagram for this material. Dies applied in experiment were flat plates. Strain path and history of deformation were determined experimentally for different types of billets. Forming limit diagram for brass was designed using experimental data.
Key words: *Formability, upsetting process, brass billets, flat dies*

1.0 INTRODUCTION

Formability is material capability to be plastically deformed without cracking or some other damaging form. Formability is not a unique material property since it is affected by both process and material variables. In bulk metal forming theoretical and empirical formability criteria are used.
Empirical criterions are based on experimental investigation of real forming processes and they are presented as Forming Limit Diagram (FLD) in two variants. First variant is strain based and it shows interrelation between components of strains of free surface at the moment of the crack appearance. Application of this FLD-type is shown in the papers [1, 2, 3].
Second variant of empirical formability criterion is stress based criterion. This criterion defines relationship between limit strain and stress indicator in the critical zone of the specimen.
In general, material formability (M_f) depends on type of material (H), its micro structure (S), process temperature (T), strain rate ($\dot{\varphi}$), stress state (T_σ), and, other factors [4]:

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$$M_f = F(H, S, T, \dot{\varphi}, T_\sigma ...) \tag{1}$$

Quantitative measure of limit formability is effective strain, (φ_e^l), i.e. strain in the moment of material structure damage or strain localization. For the given material, with defined initial microstructure and cold forming conditions by quasi static deformation, material formability is a function only on stress state in workpiece:

$$\varphi_e^l = F(T_\sigma) = F(\beta) \tag{2}$$

where is:

T_σ – stress tensor

β – triaxiality stress ratio at the critical point of specimen, i.e. at the point of structure damage.

In Fig. 1 graphical interpretation of the relationship (2) is given. This relationship represents the forming limit diagram. Forming limit diagram shows that in bulk metal forming processes in which compressive stresses prevail ($\beta < 0$) higher values of limit strains can be achieved compared to the processes in which tensile stresses are predominant ($\beta > 0$).

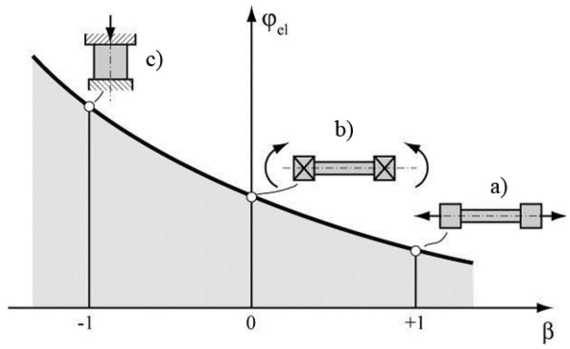


Fig.1 *- Forming limit diagram: a) uni-axial tension test, b) torsion test, c) uni-axial compression test*

Stress ratio is defined as:

$$\beta = \frac{\sigma_x + \sigma_y + \sigma_z}{\sigma_e} = \frac{\sigma_1 + \sigma_2 + \sigma_3}{\sigma_e} \tag{3}$$

where are:

$\sigma_x, \sigma_y, \sigma_z$ – normal stress components in orthogonal directions (*x, y, z)*

$\sigma_1, \sigma_2, \sigma_3$ – components of principal normal stress

σ_e – effective stress

Forming limit diagram is determined experimentally, by employing basic deformation models [4]:

- uni-axial tensile test, $\beta = +1$
- torsion test, $\beta = 0$
- uni-axial compression test, $\beta = -1$.

Limit strain at $\beta = +1$ experimentally is performed by tension test in stage of uniform deformation. Criterion of uniform deformation as a limit value by $\beta = +1$ is based upon the fact that in the tension test uni-axial stress state exists only in the phase of homogeneous deformation, i.e. untill the moment of maximum load. In localized deformation three-axial tensile stress state occurs ($\beta > +1$), which accelerates voids initiation in the micro structure of the material, their growth, voids linking and finally, crack of the specimen [5].
Instead of uni-axial compression experiment, cylinder upsetting by flat dies in real friction conditions is often used.
For more detailed construction of FLD application of more sophisticated methods is needed. In the case of non-monotonous processes [6] stress indicator (β) changes during deformation and its average value is inserted in the FLD diagram. Average value of stress indicator is defined as:

$$\beta_{av} = \frac{1}{\varphi_e^l} \int_0^{\varphi_e^l} \beta(\varphi_e) d\varphi_e \tag{4}$$

where is:

$\beta(\varphi_e)$ – history of stress ratio.

By determination of stress indicator (β), for the case that material damage occurs at free surface of the specimen, two methodologies, based upon deformation theory i.e. flow theory, are applied.
In the paper [7] determination of stress components at free surface of cylinder (equatorial surface) was conducted by employing deformation theory, i.e. by using following relations:

a) Stress- strain relationship:

$$\frac{d\varphi_\theta}{\sigma_\theta - \sigma_m} = \frac{d\varphi_z}{\sigma_z - \sigma_m} \tag{5}$$

b) Hydrostatic stress:

$$\sigma_m = \frac{\sigma_r + \sigma_\theta + \sigma_z}{3} = \frac{\sigma_\theta + \sigma_z}{3} \tag{6}$$

c) Misses yield criterion:

$$\sigma_\theta^2 + \sigma_z^2 - \sigma_\theta \cdot \sigma_z = \sigma_e^2 \tag{7}$$

By combining of above equations stress components σ_z, σ_θ stress indicator β at the free surface of the cylinder can be obtained:

$$\sigma_z = \pm\sigma_e\left[1-\frac{1+2\alpha}{2+\alpha}+\left(\frac{1+2\alpha}{2+\alpha}\right)^2\right]^{-1/2} \quad (8)$$

$$\sigma_\theta = \sigma_z \cdot \left(\frac{1+2\alpha}{2+\alpha}\right) \quad (9)$$

$$\beta = \frac{\sigma_x+\sigma_y+\sigma_z}{\sigma_e} = -\frac{1+\frac{1+2\alpha}{2+\alpha}}{\sqrt{1-\frac{1+2\alpha}{2+\alpha}+\left(\frac{1+2\alpha}{2+\alpha}\right)^2}} \quad (10)$$

where are:

σ_x , σ_θ , σ_z , – stress components in the directions of corresponding axis (*r, θ, z*),

σ_r =0; σ_m – hydrostatic stress; σ_e – effective stress.

In the equations (8, 9, 10) “α ” is a strain ratio defined as:

$$\alpha = \frac{d\varphi_\theta}{d\varphi_z} \quad (11)$$

Prior to that, strain path is defined as:

$$\varphi_\theta = f(\varphi_z) = A\varphi_z + B\varphi_z^2 \quad (12)$$

where *A* and *B* are coefficients of regressive curve.

In the paper [8], average value of stress indicator was determined by flow theory:

$$\beta_{av} = \frac{2}{\varphi_e^l}(\varphi_1^l + \varphi_2^l) \quad (13)$$

where:

φ_1^l and φ_2^l - components of main strains in fracture zone

φ_e^l - effective strain in the moment of specimen fracture:

$$\varphi_e^l = \frac{2}{\sqrt{3}}\int_0^{\varphi_e^l}\sqrt{(A+2B\varphi_z)^2 + A + 2B\varphi_z + 1d\varphi_z} \quad (14)$$

The present paper describes an experimental study on formability of brass. Four basic tests were completed. Using experimental data, forming limit diagram was designed.

2.0 DETERMINATION OF FORMING LIMIT DIAGRAM FOR BRASS

Experimental part was conducted in Laboratory for Technology of Plasticity, University of Novi Sad. For upsetting, Sack&Kiesselbach hydraulic press with 6.3MN rated force was used. Four tests were applied for determination of forming limit diagram (table 1). Lubrication was performed with mineral oil.

Table 1 - Types of billets with initial dimensions used in experiment

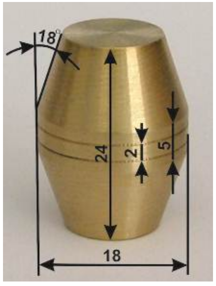
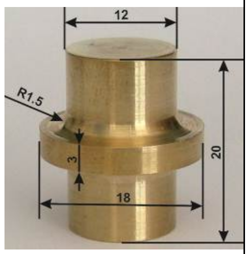
			
Basic cylinder test billet (BC)	Tapered test billet (TP)	Rastegajev test billet (RT)	collar cylinder test billet (CC)

Table 2 - Values of strains

BC		TP		RT		CC	
φ_z	φ_θ	φ_z	φ_θ	φ_z	φ_θ	φ_z	φ_θ
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-0.09	0.04	-0.07	0.05	-0.06	0.03	-0.02	0.01
-0.19	0.09	-0.21	0.10	-0.08	0.03	-0.03	0.02
-0.29	0.13	-0.32	0.16	-0.10	0.06	-0.04	0.04
-0.37	0.18	-0.43	0.21	-0.13	0.08	-0.05	0.06
-0.52	0.23	-0.55	0.28	-0.15	0.10	-0.07	0.07
-0.57	0.28	-0.56	0.32	-0.19	0.15	-0.08	0.10
				-0.19	0.19	-0.09	0.11
				-0.25	0.26		

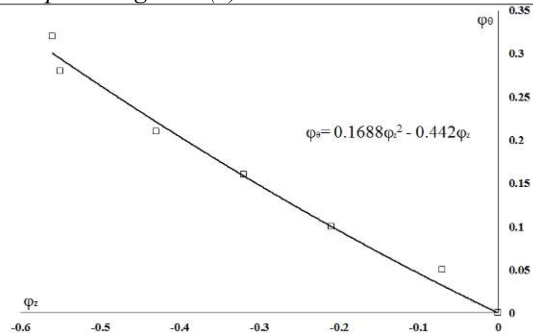
For local strain determination, marked zone around equatorial plane of each billet was used. Initial height of marked zone is shown in (table 1). After every deformation phase, marked zone and billet diameter were measured and local strains were calculated according to equation (15):

$$\varphi_z = \ln\frac{Z}{Z_0} \quad \text{and} \quad \varphi_\theta = \ln\frac{D}{D_0} \tag{15}$$

Values of strains for each billet and deformation phase are presented in table 2. In all four tests crack appeared at free lateral surface of the billets (table 3a). Strain path curves shown in table 3b were drawn based upon data from table 2. Relationship between deformations in two orthogonal directions is approximated by expression (12).

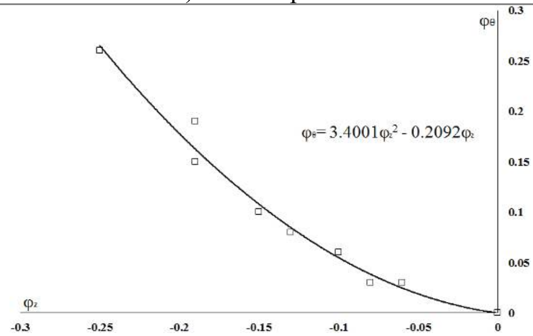
Table 3 - Billets after deformation (a) and strain path diagrams (b)

a) BC after deformation



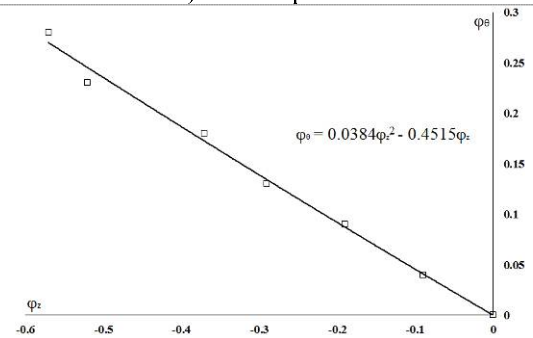
b) Strain path for BC

a) TP after deformation



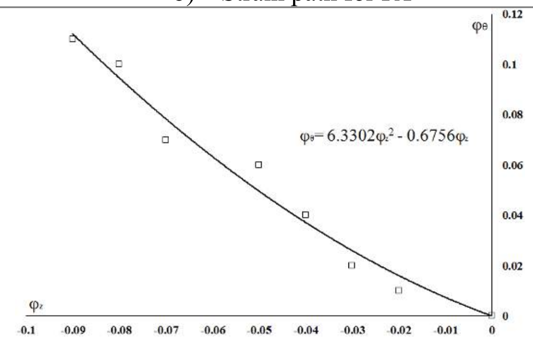
b) Strain path for TP

a) RT after deformation



b) Strain path for RT

a) CC after deformation



b) Strain path for CC

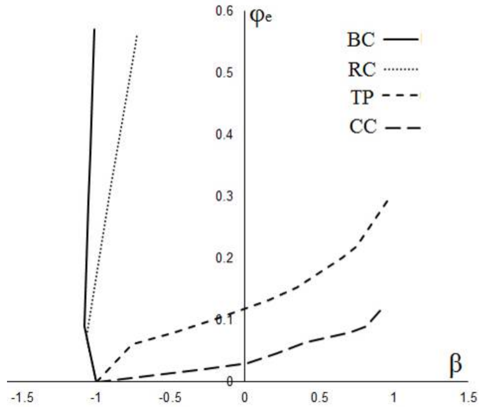


Fig.*3 - History of deformation for all types of billets*

Based on this data, change of stress ratio during upsetting process of each particular test is shown in Fig. 3. Average value of stress index (β) was calculated by expression (4). Obtained data, together with the values of effective limit strains, were superimposed into forming limit diagram, Fig. 4.

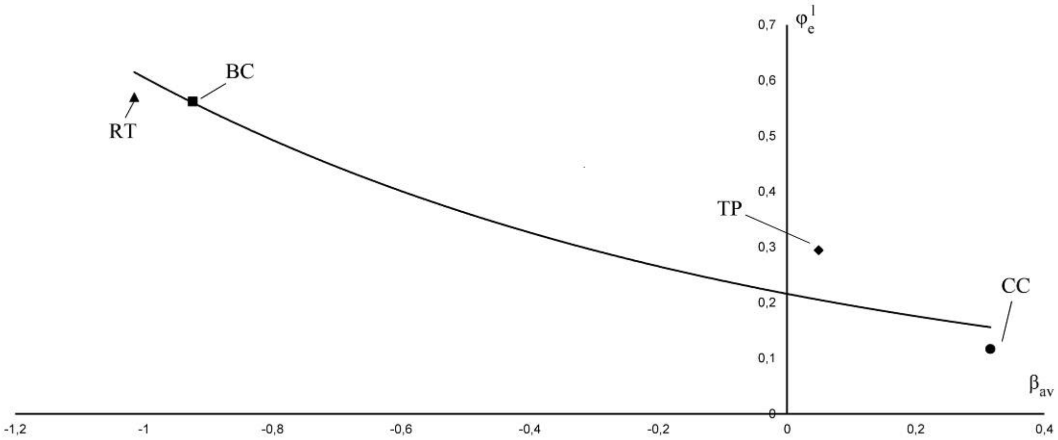


Fig.4 *- FLD for brass*

3.0 CONCLUSION

For FLD determination, generally, three basic tests (upsetting of cylinder, torsion and uniaxial tension test) are applied.

Procedure for FLD determination for brass using different upsetting tests is presented in this paper. Strain path diagrams presented in table 3 (b) shows that there is difference in forming conditions between used upsetting tests. In case of Rastegajev test it can be seen that deformation is homogeneous. Non homogeneous deformation appears in other three tests.

Fig. 3 shows that triaxiality ratio β stays constant during deformation only in case of Rastegajev test, which means that monotonic process occurs.
Forming limit diagram show that compressive stress state appears in upsetting of basic cylinder and Rastegajev billets. Given to that, best forming conditions exist in BC and RT. Tensile stress state occurs in case of CC and TP.

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SABIJANJE MESINGANIH UZORAKA RAVNIM ALATIMA

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REZIME

Dijagram granične deformabilnosti prikazuje sposobnost materijala da se plastično deformiše u različitim naponsko-deformacionim uslovima. Ovaj dijagram omogućuje optimizaciju broja faza deformisanja pri obradi u hladnom stanju.
U ovom radu dat je prikaz rezultata eksperimentalnog određivanja dijagrama granične deformabilnosti za mesing CW603N. Cilj istraživanja je bio određivanje dijagrama granične deformabilnosti za ovaj materijal sabijanjem četiri tipa uzoraka: cilindrični uzorka, konusni uzorak, Rastegajev uzorak i cilindrični uzorak sa prstenom. Alati koji su korišćeni u eksperimentu su ravne ploče. Put deformacije kao i istorija deformisanja su određeni eksperimentalno za primenjene tipove uzoraka. Dijagram granične deformabilnosti za korišteni materijal predstavlja vezu između granične deformacije i srednje vrednosti pokazatelja naponskog stanja.
***Ključne reči**: Deformabilnost, slobodno sabijanje, mesingani uzorci, ravni alati*