10th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2006, Barcelona-Lloret de Mar, Spain, 11-15 September, 2006

FORMABILITY LIMIT OF MATERIALS IN THE HYDROFORMING PROCESSES

Milan Jurković[1,2] **Edina Karabegović**[1] **Zoran Jurković**[2]

[1]**Tehnički fakultet Bihać**
Dr. Irfana Ljubijankića bb, Bihać
Bosna i Hercegovina

[2]**Strojarski fakultet Rijeka**
Vukovarska bb, Rijeka
Hrvatska

ABSTRACT

The knowledge of the metal formability limit during the process of cold deformation is very important from the standpoint of determination of the basic working process parameters, as well as from the aspect of optimal choice of technology and the use of the formability potential of the materials. This research carried out shows that by using an optimal scheme of principal stresses components the potential of metal materials formability substantially increases, which has an exceptional importance in projecting technology, tools and machining systems. Result of the investigation is identification stress strain state in the critical area of the work piece and location of a new hydroforming model in forming limit curve has been defined (FLC).

Keywords: formability, forming limit diagram, state of stress index, hydroforming

1.INTRODUCTION

The knowledge of the metal formability limit during the process of cold deformation is very important from the standpoint of determination of the basic working process parameters, as well as from the aspect of optimal choice of technology and the use of the formability potential of the materials [1,2,3,4,5,6]. The applicable importance of knowledge of formability limit of metals is the fact that for every forming process examined, we are able to foresee before its realization, with a great degree of probability, the size of allowed strain.

The formability criterion is the limiting degree of deformation who is determined of principal strain components in the cracks zone that is in the form of equivalent strain:

$$\varphi_e = \varphi_{e\,\mathrm{limiting}} = \frac{\sqrt{2}}{3}\sqrt{(\varphi_1-\varphi_2)^2+(\varphi_2-\varphi_3)^2+(\varphi_3-\varphi_1)^2}\,. \tag{1}$$

The limiting degree of deformation is used as a practical means in the determination of the formability limit of materials. The limiting degree of deformation (formability limit) of a metal depends on stress of state in the deformation zone, id est:

$$\varphi_{e\,\mathrm{lim}iting} = f(\sigma_{ij}) = f(\beta) = f\left(\frac{3\sigma_m}{\sigma_e}\right) = f\left(\frac{\sigma_1+\sigma_2+\sigma_3}{\sigma_e}\right) = f\left(\frac{I_1}{\sqrt{3J_2}}\right). \tag{2}$$

State of stress index *(β)* based on the first invariant of the stress tensor (I_1) and the second invariant of the deviatoric stress tensor (J_2) is according to [3,4,5] given in the form:

$$\beta = \frac{I_1}{\sqrt{3J_2}} = \frac{\sigma_1+\sigma_2+\sigma_3}{\sqrt{0.5\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]}} = \frac{3\sigma_m}{\sigma_e} \tag{3}$$

The first invariant of the stress tensor is defined with the expression:

$$I_1 = \sigma_1+\sigma_2+\sigma_3 = 3\sigma_m\,, \tag{4}$$

where σ_m is mean hydrostatic stress. The second invariant of the deviatoric stress tensor can be represented with the expression:

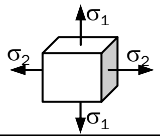
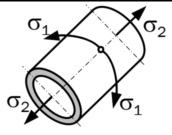
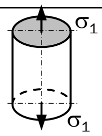
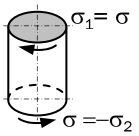
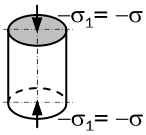
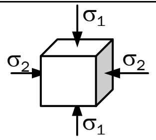
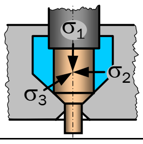
$$J_2 = \frac{1}{6}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right] = \frac{\sigma_e^2}{3}, \tag{5}$$

where σ_e is equivalent stress.

2. THE DEFORMATION MODELS

Typical of the deformation models and states of stresses index values are given in Table 1.

Table 1. Deformation models and state of stress index values for various states of stresses.

State of Stress	Deformation models	Applied Stress σ_1	Mean Stress σ_m	Effective Stress σ_e	State of Stress Index β
Equibiaxial Tension		$\sigma_1 = \sigma_2 = \sigma$ $\sigma_3 = 0$	$\sigma_m = \frac{\sigma_1 + \sigma_2}{3} =$ $= \frac{2\sigma_e}{3}$	$\sigma_e = \sigma_1 = \sigma_2$	$\beta = \frac{2\sigma_e}{\sigma_e}$ $\beta = +2$
Thin Wall Tube Under Internal Pressure		$\sigma_1 = \sigma$ $\sigma_2 = \frac{\sigma_1}{2} = \frac{\sigma}{2}$ $\sigma_3 = 0$	$\sigma_m = \frac{1{,}5\sigma}{3} = \frac{\sigma}{2}$	$\sigma_e = \frac{\sigma}{2}\sqrt{3}$	$\beta = \frac{1{,}5\sigma}{\frac{\sigma}{2}\sqrt{3}} =$ $= +1{,}73$
Simple Tension		$\sigma_1 = \sigma$ $\sigma_2 = \sigma_3 = 0$	$\sigma_m = \frac{\sigma_1}{2} = \frac{\sigma}{2}$	$\sigma_e = \sigma_1 = \sigma$	$\beta = \frac{\sigma_1}{\sigma_e} = +1$
Pure Shear		$\sigma_1 = \sigma$ $\sigma_2 = -\sigma$ $\sigma_3 = 0$	$\sigma_m = 0$	$\sigma_e = \sigma_1\sqrt{3} = \sigma\sqrt{3}$	$\beta = 0$
Simple Compression		$-\sigma_1 = -\sigma$ $\sigma_2 = \sigma_3 = 0$	$\sigma_m = -\frac{\sigma_1}{3} =$ $= -\frac{\sigma}{3}$	$\sigma_e = \lvert\sigma_1\rvert = \lvert\sigma\rvert$	$\beta = -\frac{\sigma_1}{\sigma_e} = -1$
Equibiaxial Compression		$-\sigma_1 = -\sigma_2 = -\sigma$ $\sigma_3 = 0$	$\sigma_m = -\frac{2\sigma}{3}$	$\sigma_e = \lvert\sigma\rvert = \lvert\sigma_1\rvert =$ $= \lvert\sigma_2\rvert$	$\beta = -\frac{2\sigma}{\sigma_e} = -2$
Hydrostatic Extrusion		$-\sigma_1 = -2\sigma$ $-\sigma_2 = -\sigma_3 = -\sigma$	$\sigma_m = -\frac{4\sigma}{3}$	$\sigma_e = \lvert\sigma\rvert$	$\beta = -\frac{4\sigma}{\sigma_e} = -4$

3. FORMABILITY LIMIT AND HYDROSTATIC PRESSURE

The hydrostatic pressure to increase of formability materials in the hydroforming processes (Fig 1).

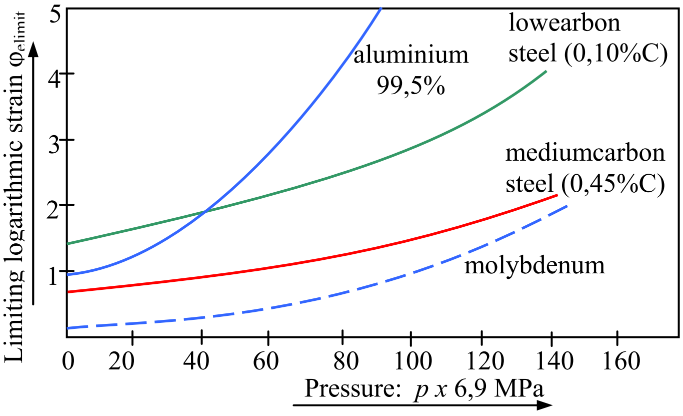


Figure 1. Limiting strain of metals is dependenton the hydrostatic pressure $\varphi_{elimit}=f(p)$

4. FORMABILITY OF MATERIALS IN THE HYDROFORMING PROCESSES

4.1. Formability of thin wall tube of load internal pressure

Fig.2 shows the process of tube compressive load by using internal pressure.

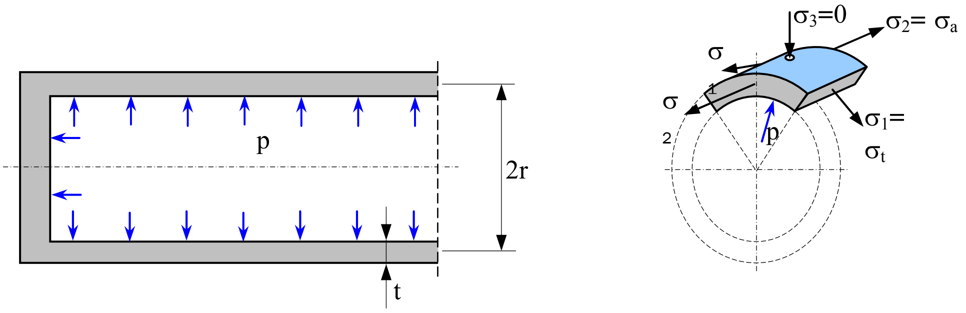


Figure 2. Schematic outline of tooling in hydroforming of a tube and state of stress

Stress are: $\sigma_t = \sigma_1 = \frac{p \cdot r}{t}$ and $\sigma_a = \sigma_2 = \frac{p \cdot r}{2t}$ or $\sigma_2 = \sigma_1/2$. (6)

Equivalent stress: $\sigma_e = \frac{\sqrt{3}}{2} \quad \sigma_1 = \frac{p \cdot r \cdot \sqrt{3}}{2t}$. (7)

Axial strain $\varphi_3 = 0$, that is state of stress index:

$$\beta = \frac{\sigma_1 + \sigma_2 + \sigma_3}{\sigma_e} = \frac{\frac{\mathrm{p \cdot r}}{\mathrm{t}} + \frac{p \cdot r}{2t} + 0}{\frac{p \cdot r \cdot \sqrt{3}}{2t}} = 1{,}73 \tag{8}$$

where are: r-radius of tube, d_0 – initial tube diameter and d_1 –finite tube diameter, t- tube wall thickness.

4.2. Formability of tube hydroforming by using beneficial expansion

Fig.3. shows the process of tube hydroforming by using beneficial expansion.

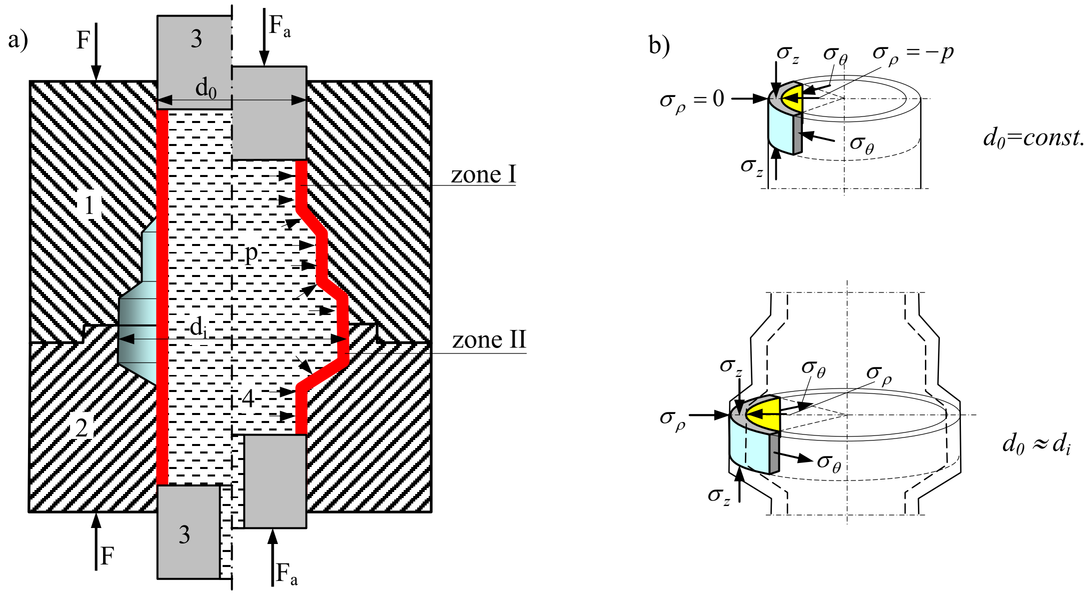


Figure 3. Tube hydroforming (a) and schema state of stress (b)

Forming guided zone 1:

- For $|\sigma_z| > |\sigma_\theta| > |\sigma_\rho|$ and $\sigma_\rho = p$ is state of stress index:

$$\beta = \frac{-\sigma_z - \sigma_\theta - \sigma_\rho}{\sigma_e} = -1{,}5 - \frac{3p}{k_f}$$

Forming expansion zone 2:

-The state of stress index for $d_0 < d < d_i$ and $|\sigma_\theta| > |\sigma_z|$ or $\sigma_\theta > \sigma_z$, that is $\sigma_\rho = \sigma_n = 0$, in general form is:

$$\beta = \frac{\sigma_\theta + \sigma_y}{\sigma_e} = \frac{2p}{k_f}$$

-The state of stress index for $d_0 \approx d_i$ and $|\sigma_\rho| > |\sigma_z| > |\sigma_\theta|$ and $\sigma_\rho = p$, in general form is:

$$\beta = \frac{\sigma_z - \sigma_\rho + \sigma_\theta}{\sigma_e} = 1{,}5 - \frac{p}{k_f}$$

5. FORMING LIMIT DIAGRAM (FLD) BY HYDROFORMING PROCESSES

The Forming limit diagram gives information about the formability potentional of the materials depending of the state stress $\varphi_{elimiting}=f(\beta)$ for practical range of applications $-5 \leq \beta \leq 2$.

The graphical interpretation of FLD is shown in Fig.4.

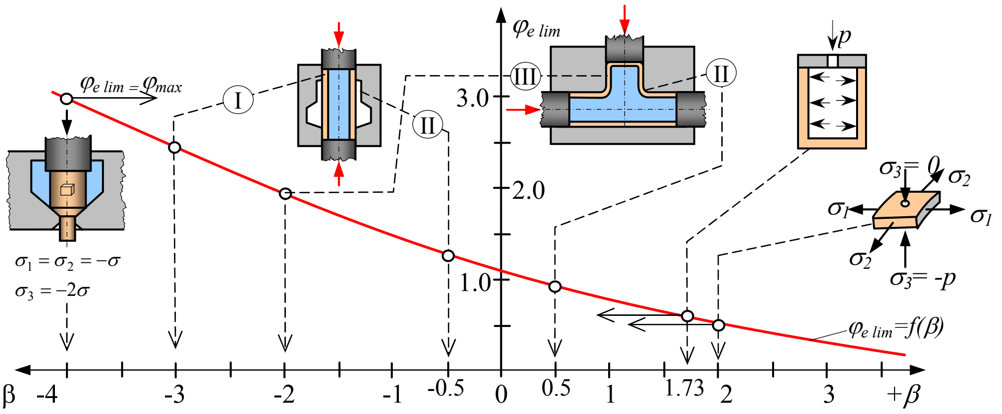


Figure 4. FLD for hydroforming processes $\varphi_{elimiting}=f(\beta)$

6. CONCLUSIONS

On the basic of the analysis it can be concluded that the focus of an optimal hydroforming processes is directed to the values $\beta > 0$ so that is they attain greater permissible degree of deformation. The methodology applied in this work $\beta=f(\sigma_{ij})$ and $\varphi_{elimiting}=f(\beta)$ is based on the theoretical-experimental method, where a state of stress index β is based on the theory of plasticity as values of invariant stress-strain of state, with its equivalent strain φ_e for hydroforming processes determined in the crack zone $\varphi_e = \varphi_{elimiting}$, as limiting of deformation.

7. REFERENCES

[1] Jurković M.: Deformation of the Formability Limit of Metals in Processes of Plastic Forming, Engineering Review 15(1995)9-22, 1995.
[2] Jurković M., Jurković Z., Karabegović E.: Modelling of Metal Formability in Forming Processes (Forming Limit Curves-FLC), Proc. TMT 2003, Barcelona, 2003, p.165-168.
[3] Jurković M.: Determination of the Limiting Formability of Metal in Fuctin of the State of stress, Proc. 22nd conf.65-74, Skopje, 1989.
[4] Karabegović E.: Theoretical Analysis and Numerical Simulation of Hydroforming Thin Wale Elements, Master thesis, (in Bosnian), Technical Faculty, University of Bihać, 2005.
[5] Jurković M., Karabegović E., Đukić H., «Friction Influence on the Stress Stand at the Hydroforming of tubes», MECHANIKA 2006, ISSN 1822-2951, p.124-128, Kaunas, Lithuania, 2006.
[6] Jurković M., Mamuzić I., Karabegović E.: The Sheet Metal Forming with Hydraulic Fluid Pressure, Metallurgy 43(2004)4, p.315-322.
[7] Karabegović E., Rošić H., Mahmić M., Comparison and supstitution of conventional processes of plastic forming applying hydroforming, Journal MECHANIKA Nr.1(57), ISSN 1392-1207, p.66-72, Kaunas, Lithuania, 2006.
[8] Gelin J.C., Ghouati O., Labergere C.: Identificatin and Optimisation in Tube Hydroforming, Proc. TPR 2000, Cluj-Napoca, p.15-20.