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NUMERICAL ANALYSIS APROACH OF SUPERPLASTIC DEFORMATION AND GASOSTATIC FORMING MODELING

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ABSTRACT: The classic approaches of the elastic-plastic large deformation, has been used the total Lagrangian formulation(TLF), where the initial undeformed configuration of the material is chosen to be the reference state, incremental TLF, and an alternative approach called updated Lagrangian formulation(ULF), which considered as reference state of deforming material the current configuration. The basis of the finite element analysis technique, using the variational approach, is to formulate a functional based on the specific constitutive relations. This functional is usually a statement of the potential energy of the deforming continuum.

1.INTRODUCTION

"Superplasticity is the name given to the ability of a material to sustain extremely large deformations at low flow stresses at a temperature around half the melting point expressed in Kelvin"(defined by *"Smithells Metals Reference Book", Seventh Edition, Edited by E.A. Brandes & G.B. Brook, Butterworth- Heineman, Oxford, 1998, page 36-1*).

In addition to this, superplastic materials are polycrystalline solids which have the ability to undergo large and uniform strains prior to failure. For deformation in tension, elongations to failure in excess of 200% are usually indicative of superplasticity, although several materials can attain extensions greater than 1000%, [6].

Fundamental to superplastic deformation is the dependence of the so-called flow stress on the rate of deformation.

In order to describe superplastic behavior of metals one use the following general constitutive equation:

$$\sigma = K\varepsilon^{n}\dot{\varepsilon}^{m} \qquad \textbf{(1)}$$

where *K* is the material consistency, ε is the true strain, *n* is the strain-hardening exponent (n take small values), $\dot{\varepsilon}$ is the strain rate and *m* is an exponent that evaluate the sensitivity of the flow stress σ to the strain rate.

Using a data base that consists by results of lot of experiments, has been obtained definitely values for deformation parameters *K* and *m*, it is propose here to find expressions of these parameters variation in order to facilitate the prevision the definitely values for these, which could be used later into different experiments or in superplastic deformation practice.

With this end in view, it will use interpolation with the Least Squares Method for an exponential function.

Let considering the next generally form of equation **(1)**:

$$\sigma_i = K_{jn} \cdot \dot{\varepsilon}_i^{m_{jn}} \qquad \textbf{(2)}$$

where:

i-(*takes values from* 1 to θ)- lots of experiments considering parameters K and m are constants;

j-(*takes values from* 1 to α)- lots of experiments considering grain size are invariable;

n-(*takes values from* 1 to β)- lots of experiments considering temperature are constant.

All the optimizations of these parameters have been obtained, until now, through three dimensions considerations, the cases in which m and K were functions of two variables: grain size L and strain rate $\dot{\varepsilon}$. Here it is supposed to consider that the two parameters depend on three variables: grain size L, strain rate $\dot{\varepsilon}$ and the deformation temperature, T. In this idea it can be write:

$$\begin{aligned} K_{jn} &= f_1(\dot{\varepsilon}, L_j, T_n) \\ m_{jn} &= f_2(\dot{\varepsilon}, L_j, T_n) \end{aligned} \qquad \textbf{(3)}$$

where:

L_j - represents the grain size;

T_n - represents the process temperature.

For a pair of value (L_j,T_n), it will establish the values K_{jn} and m_{jn}, by using The Least Squares Method defining thus an exponential with a minimum deviation beside values sets σ_i , $\dot{\varepsilon}_i$.

Mark the error expression with E:

$$E = \sum_{i=1}^{\theta} (\sigma_i - \sigma)^2 \qquad \textbf{(4)}$$

and replace relation **(1)** in **(4)**, the last relationship becomes:

$$E = \sum_{i=1}^{\theta} (\sigma_i - K_{jn} \cdot \dot{\varepsilon}_j^{m_{jn}})^2 \qquad \textbf{(5)}$$

For errors minimization let's write the first order derivatives of function relative at K_{jn} and m_{jn}:

$$\begin{cases} \dfrac{\partial E}{\partial K_{jn}} = -2\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{m_n} \cdot \sigma_i + 2\sum_{i=1}^{\theta} K_{jn} \cdot \dot{\varepsilon}_i^{2m_{jn}} \\ \dfrac{\partial E}{\partial m_{jn}} = -2\sum_{i=1}^{\theta} \sigma_i \cdot K_{jn} \cdot \dot{\varepsilon}_i^{m_{jn}} \cdot \ln \dot{\varepsilon}_i + 2\sum_{i=1}^{\theta} K_{jn}^2 \cdot \dot{\varepsilon}_i^{2m_{jn}} \cdot \ln \dot{\varepsilon}_i \end{cases} \qquad \textbf{(6)}$$

Conditions for local extreme are:

$$\begin{cases} -2\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{m_n} \cdot \sigma_i + 2\sum_{i=1}^{\theta} K_{jn} \cdot \dot{\varepsilon}_i^{2m_{jn}} = 0 \\ -2\sum_{i=1}^{\theta} \sigma_i \cdot K_{jn} \cdot \dot{\varepsilon}_i^{m_{jn}} \cdot \ln \dot{\varepsilon}_i + 2\sum_{i=1}^{\theta} K_{jn}^2 \cdot \dot{\varepsilon}_i^{2m_{jn}} \cdot \ln \dot{\varepsilon}_i = 0 \end{cases} \qquad \textbf{(7)}$$

Last system of two equations **(7)** is used to express found out K_{jn} (from first equation):

$$K_{jn} = \frac{\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{m_{jn}} \cdot \sigma_i}{\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{2m_{jn}}} \qquad \textbf{(8)}$$

and substitute relationship **(8)** in the second equation of system **(7)** we obtain an transcendental equation:

$$\left(\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{2m_{jn}}\right) \cdot \left(\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{m_{jn}} \cdot \sigma_i \cdot \ln \dot{\varepsilon}_i\right) - \left(\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{m_{jn}} \cdot \sigma_i\right) \cdot \left(\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{2m_{jn}} \cdot \ln \dot{\varepsilon}_i\right) = 0 \qquad \textbf{(9)}$$

which is used to obtain the numerical solution m_{jn}.

First of all, this parameter, is needed to setup like technological parameters of the process, such as pressure of gas used for forming parts (air or argon for superplastic materials which are low resistant at chemical corrosion during the thermal process), strain rate (it is necessary to underline the difference between the strain rate of deformation and the speed of deformation). There is no one best method to determine the strain rate sensitivity coefficient, "*m*", (which is defined by the sensitivity of stress strain to the strain rate of deformation).

Technological parameters of superplastic forming are determined on theoretical basis above described, and are:

The pressure:

$$\mathbf{p} = \frac{\mathbf{4s_o \cdot h \cdot \sigma \cdot K_s}}{\mathbf{r_o^2\left(1+\frac{h^2}{r_o^2}\right)^2}} \qquad \textbf{(10)}$$

where

- s_o-sample thickness (s_o=1,2 [mm]);
- h-hemispherical shell height (h=24[mm]);
- σ-flow stress, at deforming temperature ($\sigma_{FORMALL} = 32[MPa]$);
- K_s-transversal variations of thickness coefficient, corresponding at m=0,5 (K_s=0,7);
- r_o- hemispherical shell radius (r_o=16[mm])

Strain rate, as determining element of the pressure adjustment procedure, realized by one proportional regulator it is analytical determined by relation:

$$\dot{\varepsilon}_e = \left(\frac{2}{3}\dot{\varepsilon}_{ij}\dot{\varepsilon}_{ij}\right)^{\frac{1}{2}} \qquad \textbf{(11)}$$

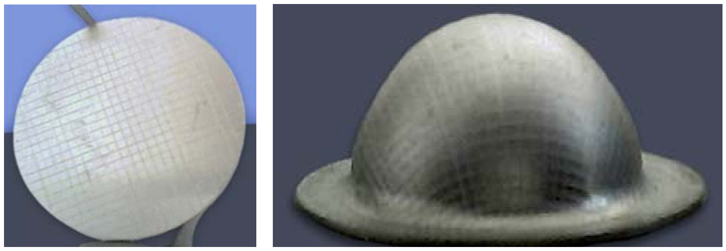
Although, from experiments I adopted the strain rate value of $\dot{\varepsilon} = 0.0001[s^{-1}]$ for FORMALL alloy and using this, I found the true strain rate as v_{12}=0.0012[mm/s].

2.THE METHOD

- There was realized experiments on a number of 11 samples of FORMALL alloy, with 51[mm], in diameter, thickness 1,2[mm], at forming temperature T_{def}=510[^{o}C] and strain rate value $\dot{\varepsilon} = 0.1x10^{-3}[s^{-1}]$;

Fig. 1 – Gasostatic deep drawing tool

- Two samples was prepared especially, by drawing a rectangular grid spaced at one millimeter distance;



a)-the sample *b)-deformed part*
Fig. 2 – A sample and the formed part

- Using the Coordinates Measuring Machine of type MC 1200, with radius of the tool of 0.2332 [mm], was realized measurements and the results was stocked into a Delphi data file. Using this data the actual profile was realized also helped on AutoCAD facilities. On each section was realized graphical representation of the variation of transversal section;

3.EXPERIMENTS AND RESULTS

In order to set up a good procedure of experiments analysis, there were designed an integrated control system with a general scheme presented in the figure 3:

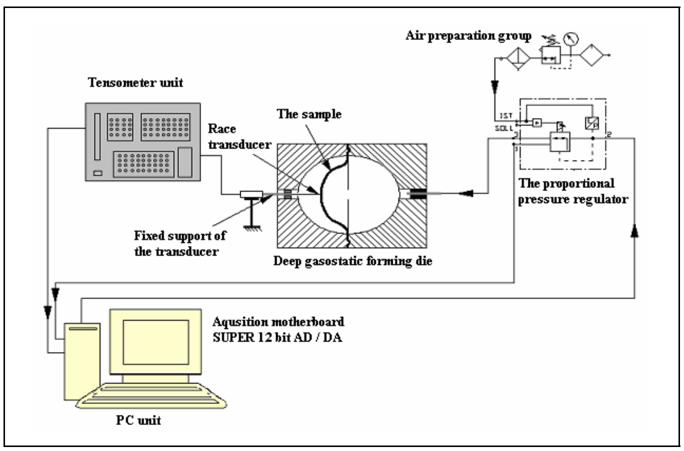


Fig. 3 – Integrated system diagram

The control system is composed by the proportional-pressure regulator and the additional software special designed to adjust and control the air pressure in the process, and strain rate respectively. The role of the control system consists in the adjustment procedure which is of proportional-derivative (PD) type. The output voltage signal calculus is made by relationship:

$$y = K_p \cdot (x_i - x_{i-1}) + K_d \cdot (x_i - x_{i-4}) - (x_i - x_{i-4})/t \qquad \textbf{(12)}$$

where:

- y is the calculated value;
- x_i is the observed value

and coefficients are: K_p = 0.0001 and K_d = 0.3, which are experimental data.

Experiments were realized following the procedure above stated with respect of theoretical observation and technological parameters calculated here.