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EXPERIMENTS BASED ON NUMERICAL ANALISYS OF SUPERPLASTIC FORMING

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ABSTRACT

The superplastic forming operation occurs at an elevated temperature, where the flow stress of the sheet material is low. The sheet to be formed is placed in an appropriate SPF die, which can have a simple to complex geometry, representative of the final part to be produced. The sheet and tooling are heated and then a gas pressure is applied, which plastically deforms the sheet into the shape of the die cavity, [4].

In order to study the behavior of thin sheets of AL-7475 alloy, during the superplastic forming, there were made research on circular samples with 1.2 [mm] of thickness and 51 [mm] of diameters. The air pressure was 0.7 [MPa], forming temperature T_{def}=510[^{o}C] and strain rate $\dot{\varepsilon} = 0.1x10^{-3}[s^{-1}]$.

KEYWORDS: gasostatic forming, superplasticity, strain rate, strain stress, superplastic forming

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%, [4].

Based on practice and experiments, the superplasticity is the behavior of certain metals, alloys and some ceramics in the pre- established conditions, such as:

- Very low strain rate
- Low flow stresses;
- Temperature is constant and relatively high, during deformation;
- Microstructure with ultra fine grain(the size of grain is frequently lower than 10 µm);

Considering a data base, including the research results in superplastic deformation domain, and considering the difficulty to choose the optimal technological parameters in order to perform deformation of a material with superplastic behavior, we have considered necessary to draw up a simple and efficiently method for the determination technological parameters of deformation, in a certain situation.

Isothermal superplastic deformation is characterized through by the high temperature flow equation:

$$\sigma = K \cdot \dot{\varepsilon}^m \quad (1)$$

where:

σ -is the strain stress for plastic flow;
K -constant of proportionality;
$\dot{\varepsilon}$ -strain rate,
m -strain rate sensitivity (the sensitivity of stress strain 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):

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

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

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

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

First of all, this parameter is needed to setup the process technological parameters, 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).

Because the theoretical observations have to be verified and certified, or not, by experiments, I've realized, also at The Technical University of Cluj Napoca, Material Science and Engineering Faculty, Plastic Deformation Department, researches on superplastic aluminum commercial alloys: SUPRAL 100 (Aluminum 2004) and FORMALL (AL-7475)). These alloys are used to produce parts of plains wings and cockpit. Grain size of alloys are determining to develop the superplastic deformation of this materials. The grain size, measured on both axial and transverse directions, are $2[\mu m]$.

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

$$\dot{\varepsilon}_e = \left(\frac{2}{3}\dot{\varepsilon}_{ij}\dot{\varepsilon}_{ij}\right)^{\frac{1}{2}} \quad \textbf{(10)}$$

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].

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:

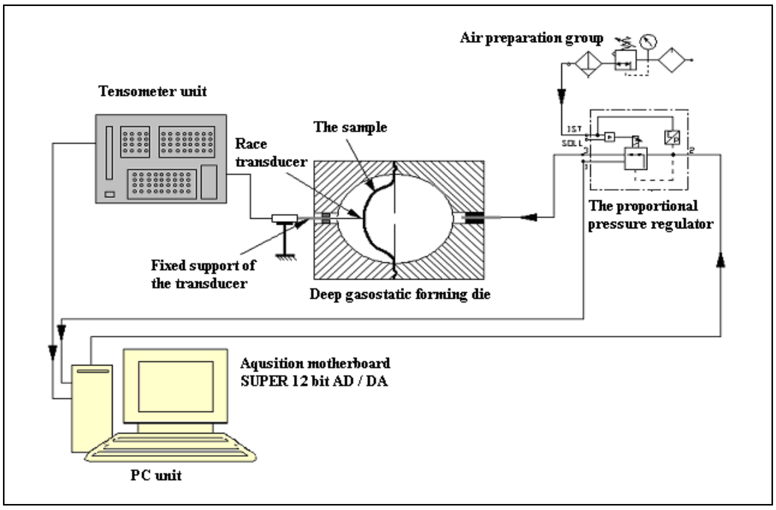

Fig. 3 – Integrated system scheme

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:

$$y = K_p \cdot (x_i - x_{i-1}) + K_d \cdot (x_i - x_{i-4}) - (x_i - x_{i-4})/t \qquad (11)$$

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.

Deformed test pieces were sliced by an electrical method (no local melting zone admitted) for determining dimensions on transversal section. In the next images are emphasized results of measurements: pressure variation curve, strain variation and section dimensions (i.e. thickness). The analysis by MATLAB Programming Environment offered me an image of behavior of material during superplastic deep gasostatic forming. The interpolation and fitting procedure were interactive numerical methods used here to study the cross-section varied scene. All observation is made on pole zone and on corner radius zone, i.e. the most exposed zones of the test pieces. Following is presented a small part of experimental results:

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Timp_1 [se	Cursa_1 [r	Presiune_1 [bar]		Timp_2 [se	Cursa_2 [r	Presiune_2 [bar]		Timp_3 [se	Cursa_3 [r	Presiune_3 [bar]		Timp_4 [se	Cursa_4 [r	Presiune_4 [b
2	0	0.92	0		0	0.6	0		0	1.013	0		0	1.013	0
3	0.124	0.88	0.01		0.124	0.6	0.01		0.124	1	0		0.128	1	0
4	0.249	0.933	0.028		0.249	0.52	0.006		0.249	1.026	0.013		0.255	0.973	0.013
5	0.373	0.893	0.005		0.373	0.6	0.056		0.373	1.173	0.005		0.383	0.946	0.034
6	0.498	0.906	0.033		0.497	0.573	0.018		0.497	1.07	0		0.51	0.973	0.055
7	0.622	0.916	0.024		0.622	0.566	0.039		0.622	1.07	0		0.638	0.97	0.076
8	0.747	0.909	0.039		0.746	0.581	0.019		0.746	1.081	0		0.765	0.969	0.084
9	0.871	0.906	0.036		0.87	0.58	0.035		0.87	1.059	0.057		0.893	0.978	0.077
10	0.996	0.903	0.043		0.994	0.579	0.037		0.994	1.082	0.069		1.02	0.979	0.081
11	1.12	0.903	0.056		1.119	0.585	0.036		1.119	1.069	0.068		1.148	0.981	0.081
12	1.245	0.901	0.066		1.243	0.563	0.04		1.243	1.082	0.081		1.275	0.984	0.08
13	1.369	0.91	0.074		1.367	0.588	0.056		1.367	1.058	0.074		1.403	0.986	0.083
14	1.494	0.912	0.076		1.492	0.577	0.057		1.492	1.066	0.093		1.531	0.981	0.085
15	1.618	0.911	0.077		1.616	0.575	0.067		1.616	1.065	0.101		1.658	0.991	0.091
16	1.743	0.903	0.078		1.74	0.608	0.066		1.74	1.06	0.117		1.786	0.989	0.093
17	1.867	0.911	0.088		1.865	0.59	0.061		1.865	1.061	0.122		1.913	0.99	0.097
18	1.991	0.911	0.094		1.989	0.58	0.06		1.989	1.05	0.13		2.041	0.993	0.098
19	2.116	0.904	0.1		2.113	0.595	0.063		2.113	1.056	0.145		2.168	0.99	0.103
20	2.24	0.908	0.105		2.237	0.591	0.077		2.237	1.055	0.153		2.296	0.986	0.109
21	2.365	0.907	0.113		2.362	0.598	0.082		2.362	1.043	0.163		2.423	0.992	0.117
22	2.489	0.9	0.121		2.486	0.596	0.078		2.486	1.068	0.172		2.551	0.999	0.124
23	2.614	0.889	0.129		2.61	0.586	0.083		2.61	1.055	0.171		2.678	0.994	0.125
24	2.738	0.897	0.146		2.735	0.585	0.092		2.735	1.045	0.177		2.806	0.989	0.126
25	2.863	0.895	0.158		2.859	0.595	0.105		2.859	1.072	0.182		2.934	0.989	0.134
26	2.987	0.89	0.166		2.983	0.598	0.112		2.983	1.049	0.186		3.061	0.986	0.145
27	3.112	0.894	0.172		3.108	0.618	0.111		3.108	1.055	0.195		3.189	0.991	0.156
28	3.236	0.893	0.18		3.232	0.603	0.099		3.232	1.047	0.196		3.316	0.978	0.161
29	3.361	0.879	0.187		3.356	0.581	0.101		3.356	1.051	0.216		3.444	0.975	0.173
30	3.485	0.876	0.199		3.48	0.587	0.116		3.48	1.045	0.221		3.571	0.986	0.185
31	3.609	0.885	0.215		3.605	0.579	0.139		3.605	1.039	0.232		3.699	0.971	0.193
32	3.734	0.893	0.225		3.729	0.587	0.158		3.729	1.04	0.243		3.826	0.97	0.203
33	3.858	0.894	0.223		3.853	0.585	0.161		3.853	1.038	0.255		3.954	0.978	0.212
34	3.983	0.895	0.219		3.978	0.588	0.168		3.978	1.032	0.265		4.081	0.986	0.223

Chart1 / Chart2 / Chart3 / GAZ0082

CONCLUSION

On experiments basis we conclude:

- Superplastic properties of materials are determined by the grain microstructure. This is demonstrated by the uniform deformed section and the lack of thickness variation;
- Deformed parts are accurate in dimension, by copying internal cavity of the die;
- The grids are clearly deformed on the entire region. The original squares of the grid are finally rounded squares but equals deformed on the same meridian of the hemispherical shell and at the same ratio aspect on the opposite region.
- The influence of the friction during the gasostatic forming process is observed by variation of the thickness of the part in the pole of the hemispherical shell.

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