EXPERIMENTAL RESEARCH DATA PROCESSING BY WAVELET FAMILIES TRANSFORMS

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Abstract: The paper consists on two very distinguished parts: one of them representing the superplastic forming process, using an original procedure, and other one is one non-conventional method of experimental data processing, using the toolbox provided by MATLAB environment. Data colected using by the first experimental procedure it is stocked on files of appropriate type to be processed on MATLAB environment, such as .mat or .m file. This data processed would be used for practical reason, in order to command the proportional regulator, or any other device.

Keywords: gasostatic forming, superplasticity, wavelet transform, residuals, statistics.

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%, [1].

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:

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

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),** given on [2]:

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

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:

$$K_{jn} = f_1(\dot{\varepsilon}, L_j, T_n) \qquad m_{jn} = f_2(\dot{\varepsilon}, L_j, T_n) \tag{3}$$

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:

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

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

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

Conditions for local extreme are:

$$\begin{cases} -2\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{m_n} \cdot \sigma_i + 2\sum_{i=1}^{\theta} K_{jn} \cdot \dot{\varepsilon}_i^{2m_{jn}} = 0 \\ -2\sum_{i=1}^{\theta} \begin{matrix} \sigma_i \cdot K_{jn} \cdot \dot{\varepsilon}_i^{m_{jn}} \cdot \ln\dot{\varepsilon}_i + \\ 2\sum_{i=1}^{\theta} K_{jn}^2 \cdot \dot{\varepsilon}_i^{2m_{jn}} \cdot \ln\dot{\varepsilon}_i \end{matrix} = 0 \end{cases} \tag{6}$$

Last system of two equations **(6)** is used to express found out K_{jn} (from first equation):

$$K_{jn} = \frac{\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{m_{jn}} \cdot \sigma_i}{\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{2m_{jn}}} \tag{7}$$

and substitute relationship **(7)** in the second equation of system **(6)** we obtain an transcendental equation:

$$\left(\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{2m_{jn}}\right) \cdot \left(\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{m_{jn}} \cdot \sigma_i \cdot \ln\dot{\varepsilon}_i\right) - \left(\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{m_{jn}} \cdot \sigma_i\right) \cdot \left(\sum_{i=1}^{\theta} \dot{\varepsilon}_i^{2m_{jn}} \cdot \ln\dot{\varepsilon}_i\right) = 0 \tag{8}$$

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 $2[\mu m]$.

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

<u>The pressure, [3]</u>:

$$p = \frac{4s_o \cdot h \cdot \sigma \cdot K_s}{r_o^2 \left(1 + \frac{h^2}{r_o^2}\right)^2} \tag{9}$$

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])

Given this data, the air pressure is calculated at: p=0.69585[N/mm^2] = 6.82404 [bar], so I used into my experiments p= $7 \pm 1\%$ [bar], considering the variations of pressure in the installation.

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

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

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].

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 samples

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

Fig. 2 – A sample formed part

a)-the sample
b)-deformed 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:

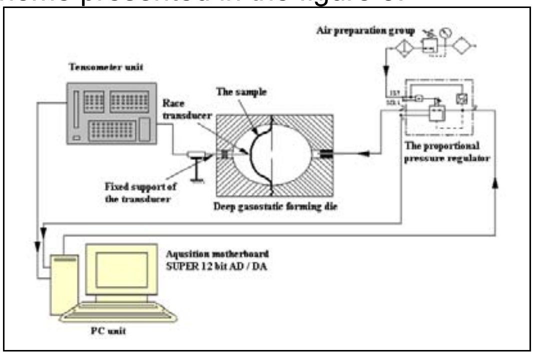

Fig. 3 – Integrated system

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 sygnal calculus is made by relationship:

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

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.

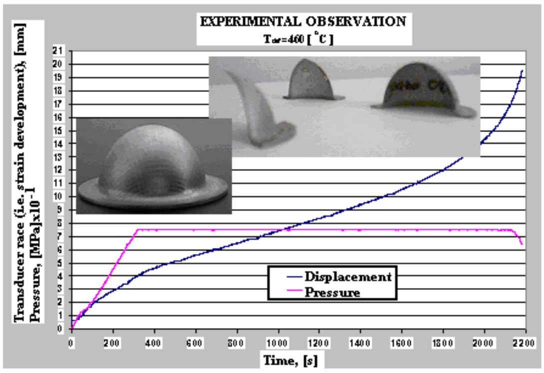

Fig. 4 – The pressure and strain variation, against the time ~starting thickness of 1.1 mm~

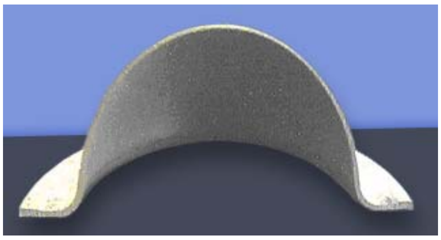

Fig. 5 – Deformed hemispherical shell

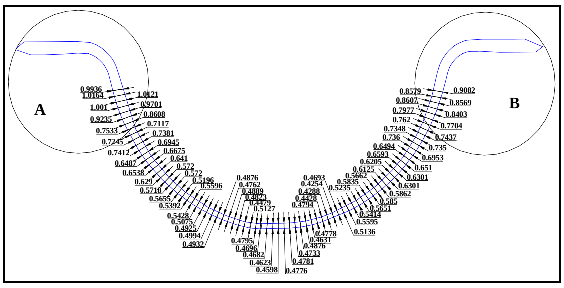

Fig. 6 – Dispersion of measurements points on axial section

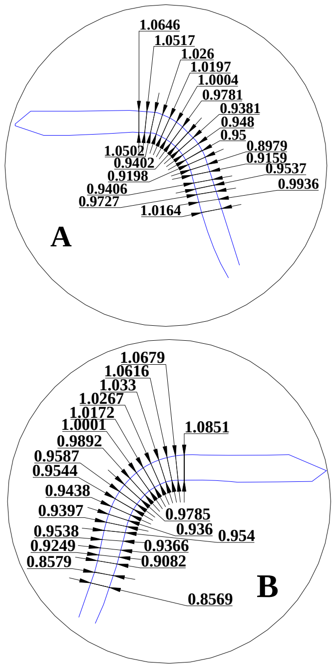

Fig. 7 – Dispersion of measurements points on the corner radius

4. WAVELETS FAMILIES TRANSFORMS

Wavelets families transforms are:

- Haar
- Daubechies
- Biorthogonal
- Coiflets
- Symlets
- Morlet
- Mexican Hat
- Meyer
- Other Real Wavelets
- Complex Wavelets

In order to ilustrate the advantages of wavelets families transforms using, to corect and setup work parameters, the “sygnal” saved on file “Presiune.mat”, containing experimental data were processed by two Wavelet families (Daubechies (db7 of level 5) and Biorthogonal family(bior3.7 of level 5)). The reason of choosing this two methods (families of Wavelets transforms) consists on classical properties of first one, and the appropriateness of the second one.

Using the most common Graphical User Interface developed on study of Wavelets transforms procedures, *wavemenu*, The Wavelet Toolbox Main Menu on MATLAB technical computing environement, one may develop a study of experimental data obtained by a common method, such as using Hardware Acquisition Environment.

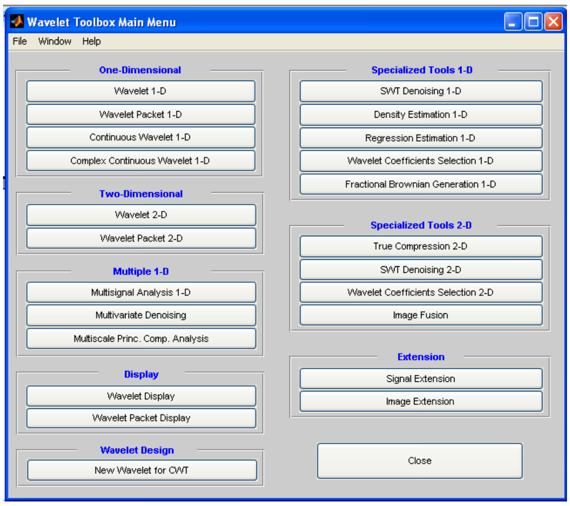

Fig. 8- Wavelet Toolbox Main Menu

The "sygnal" represented on file "Presiune.mat", had been processed, following the Wavelet Transforms families procedure:

A) Daubechies Wavelets Family

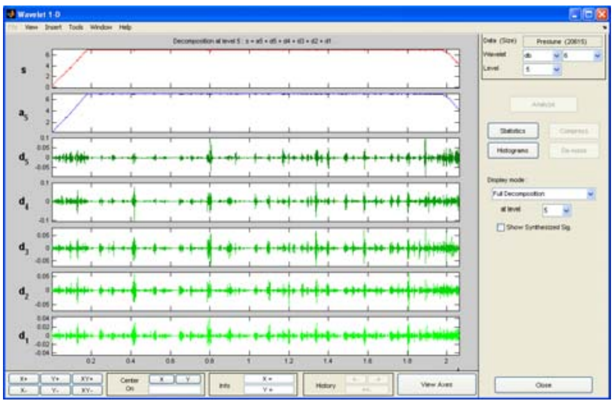

Fig. 9- Analysis of the "sygnal"

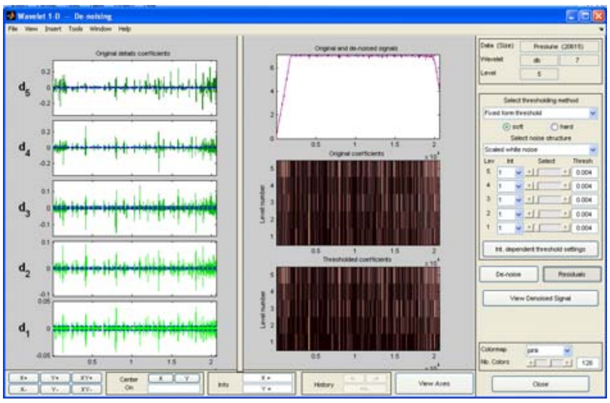

Fig. 10- Decomposition and denoising of the "sygnal"

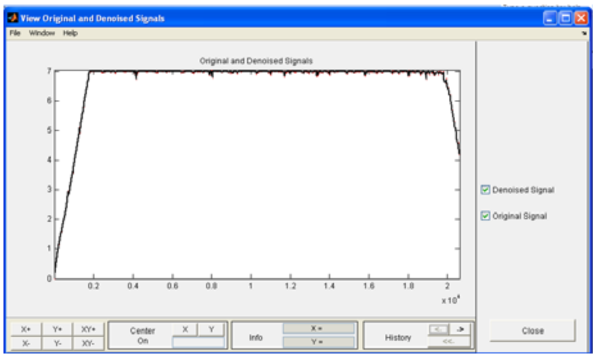

Fig. 11 – Original (red color) and Denoised Sygnals

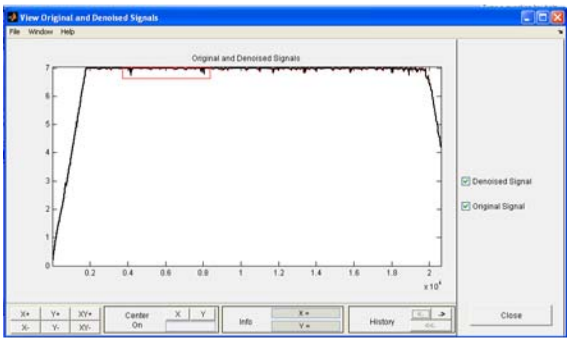

Fig. 12 – Delimitation of the zone of interest

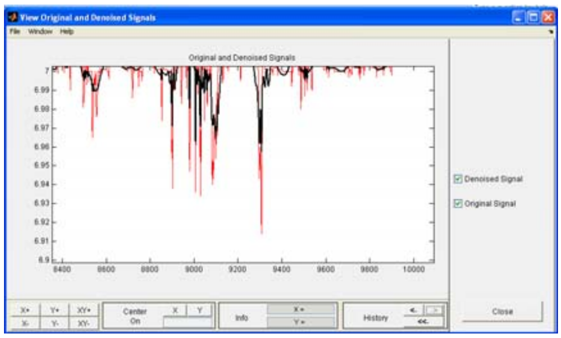

Fig. 13 – Zooming of the zone of interest

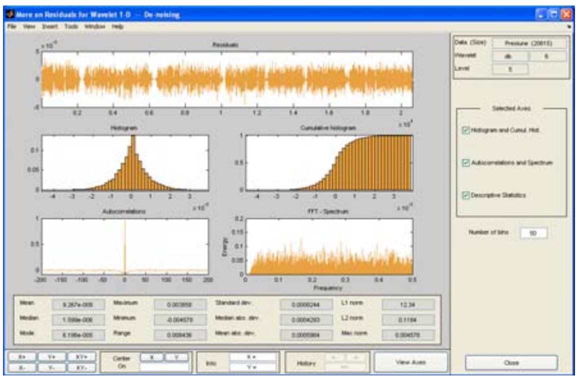

Fig. 14 – Statistics of the sygnal processing (residuals, hystograms, fft-spectrum)

5. WAVELET TRANSFORMS COEFFICIENTS CHOOSING PROCEDURE

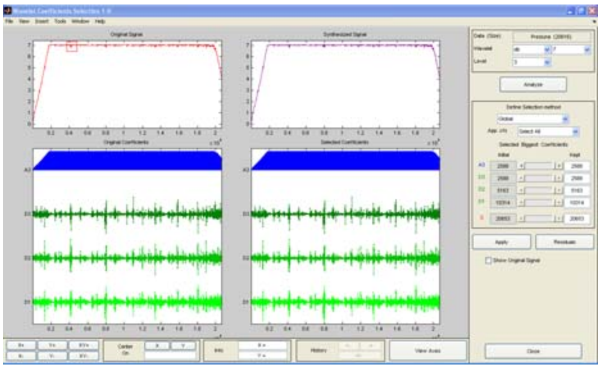

Fig. 15 – The original and synthezised sygnal with marks of interest zone

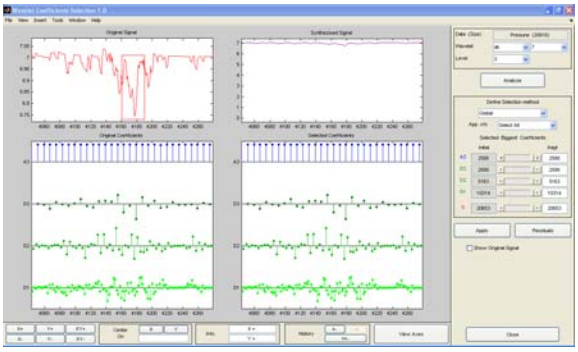

Fig. 16 – Zooming of the interest zone

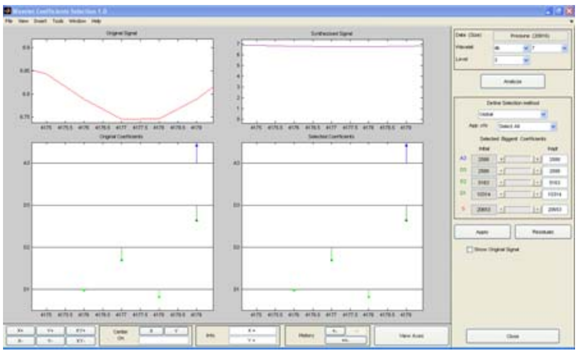

Fig. 17 – Repeated process of zooming of the interest zone

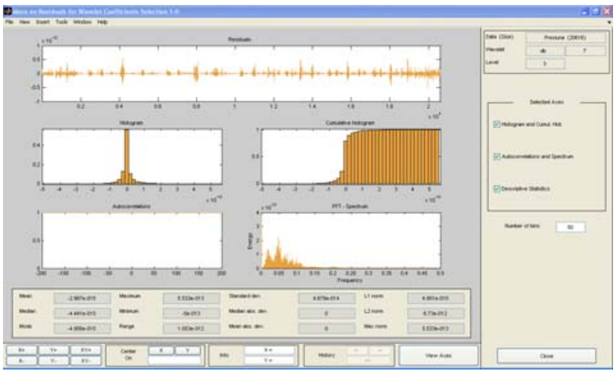

Fig. 18 – Statistics of the sygnal processing

6. DISCUSSION

The gasostatic superplastic deep forming process, such as a high complexity one, is governed by laws that are uncommon and no easy for modeling. Because the superplastic materials, commonly, at normal conditions, does not support plastic deformation (e.g. titanium alloys), any mathematical formulation have to constraint, to limits their viability.

7. CONCLUSION

Signal processing procedure it is obviously, applied on different technical process and data colected file, arranged such as matrix or array and structure data types, would be an advantage nevertheless versus any filter processing and other digital or analogues process. This procedure, wavelet families transforms, may be an valuable instrument for all those who use on their researches any proportional devices, feed-back system and regulators.

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