MATHEMATICAL MODELING OF THE EXPERIMENTAL DATA FOR THE DEEP DRAWING FORCE

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Abstract: - The calculus of the deep drawing force is one important stage in the manufacturing design process. This paper aims to offer a new method for an accurate calculus of the force, based on the experimental data, collected during real experiments conducted by the authors. The values of the force were recorded with digital measurement equipment, together with the corresponding values of the punch stroke. After the experiments, a mathematical modeling in MathCAD was done, based on four types of regressions, most used in the field. There were considered three main parameters on which the force depends, namely the part's diameter and thickness and the deep drawing coefficient. The comparative analysis of the mathematical model with the experimental data has shown its accuracy.

1. INTRODUCTION

The manufacturing process by deep drawing is very useful in industrial fields such as automotive, home appliances, electrical equipment, due to its very high efficiency. On the other part, the optimization of the process is hard, because of the many parameters of influence, which often create instability.

In the case of deep drawing of cylindrical products have been carried out many studies regarding the variables of the deformation process. One of them is the forming force, usually called the punch load [1], [2], [8].

The correct estimation of the forming forces is one important issue which leads directly to the success of the manufacturing process. These values decide the type of press which will drive the forming die and are used for the strength calculus of the die components.

Most of the technical literature [1], [2], [4], [8], [10] present for the calculus of the deep-drawing forces both analytical and empirical equations, but still, their results are not as accurate as needed. Usually, the results of these equations give higher values than the real ones, conducting to an overload prediction of the forming device. The fact imposes researches in the field to try to establish some more accurate equations for the calculus of those forces.

This paper uses a new method for assessing the correct mathematical model for the calculus of the punch load by using experimental data which are modeled with suitable regressions. The accuracy of the method is high and the equations proposed are easy-to-use for manufacturing design and simulation purposes.

A modern equipment for experimental research was used, including a digital system for measuring and recording the process parameters, as well used in today modern experimental research, [3], [4], [6], [9]. Such a system was developed by the authors of this paper, under the frame of the national research platform *PlaDeTIno* [9], developed in the authors' department.

The experimental data was then modeled in MathCAD software, with the most appropriate regressions and a mathematical model is proposed, in the case of soft steel, named DC04 Am, SR EN 10130+ A1.

2. THE EXPERIMENTAL METHODOLOGY

The experiments were realized in the research lab of "Cold Forming Technologies", at Transilvania University of Brasov. The manufacturing equipment (fig.1) was driven by a hydraulic press (pos.1), with the nominal force F_n*=100 kN*. The deep-drawing die (pos.2) is provided with several sets of tools, having different values of the die hole diameter *d*. Each die has a set of punches, according to the sheet thickness, to assure the same punch-die clearance for all the tests.

The recording and measuring system is composed by a resistive transducer for tensile/compressive forces (pos.3) with the range 0…250 kN, an inductive transducer for movements (pos.4), with the range 0…200 mm and a digital measurement unit for data acquisition (DAQ), type HBM® Spider 8, with four channels. The unit was connected to a computer, which recorded the experimental data.

The measurement tasks with the Spider Pack system are relatively easy to carry out. The specialized software, catman® Easy, quickly recognizes the measuring devices connected to the computer and offers a wide range of visualization, recording and analysis of the data. The software can manage two major types of projects: data acquisition (DAQ) or data analysis. For each type, one can design its own configuration of the tasks and their visualization or can use previous designed ones.

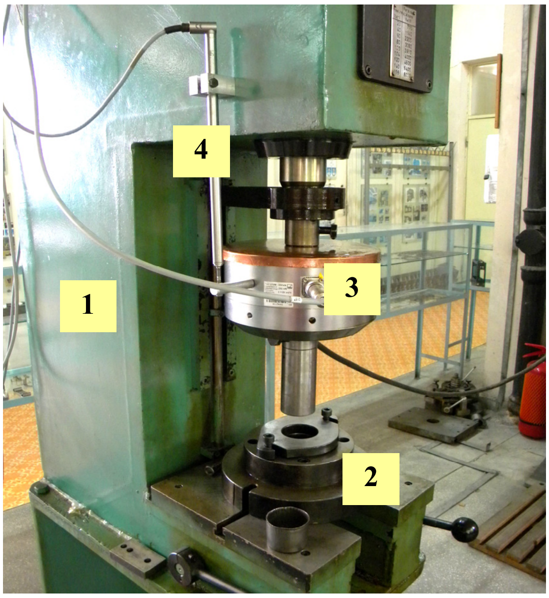

Fig.1 Experimental equipment

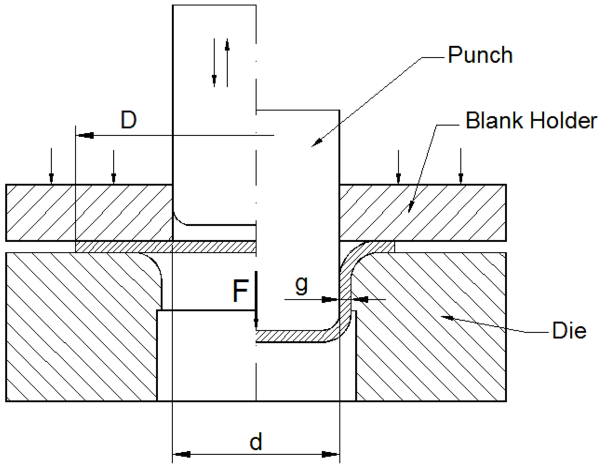

Fig.2 Principle of deep drawing of cylindrical parts, using planar blank holder

The experiments were realized when manufacturing cylindrical flangeless parts, made of soft steel sheet, type DC 04 Am, SR EN 10130+ A1. The range of the parameters used is the following:

- for the part's diameter *d*: 30, 40, 50 and 60 mm;
- for the sheet thickness *g*: 0.6, 0.8, 1.0 and 1.2 mm;
- for the drawing coefficient *m*: 0.5, 0.6, 0.7 and 0.8.

The notations are according to fig.2, where the deep-drawing principle is presented. The deep drawing coefficient was calculated with the well-known equation:

$$m = \frac{d}{D}. \qquad (1)$$

The working die had a planar holding ring and mineral oil was used as lubricant. The blank holder force was supposed invariant as it was realized by clamping with a screw-nut system.

The catman® Easy software can display the recorded data in several ways, such as table of all values or special ones like min, max or average or under the shape of graphs

F=f(time) or *F=F(h)*, where *h* is the punch travel. For example, for a certain test, the recorded data is presented such in fig.3.
In fig.4 there are presented some of the parts which were manufactured, having different values of the geometrical parameters.

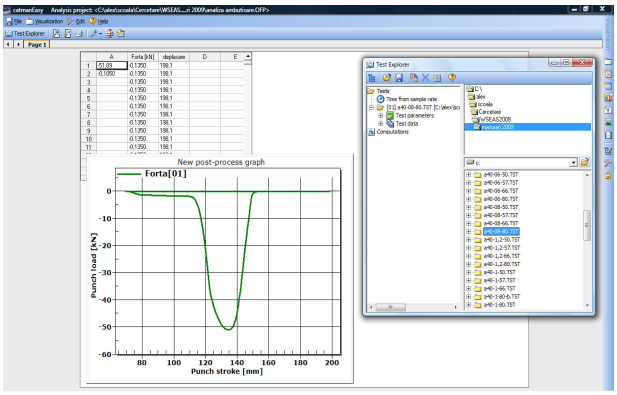

Fig.3 Dependence of punch load on the punch stroke, recorded with catman® Easy software

Fig.4 Parts manufactured during the experiments

The experimental data was analyzed by drawing some graphics, to present the laws of variation of the maximum values of the deep drawing force, depending on the main process parameters.
As shown in figs. 5 and 6, the values of the forces rise with the thickness *g* and with the diameter *d*, due to cross-sectional area increase of the part.
The influence of the deep drawing coefficient is as expected, meaning the force increases with the decrease of *m*, which intensifies the deformation process. The law of variation is presented in fig.7.

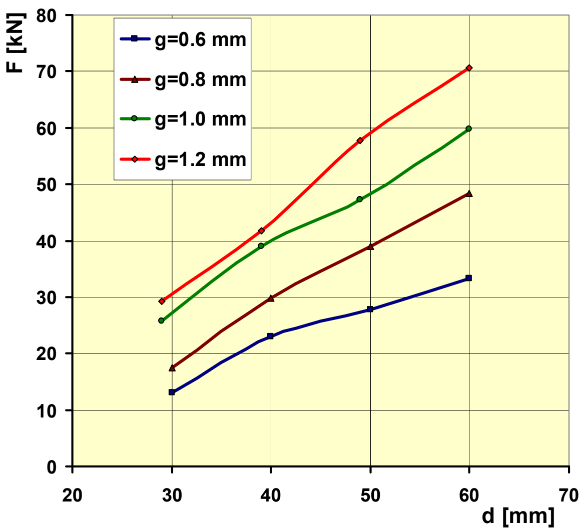

Fig.5 Deep drawing force depending on the diameter d, for several values of the thickness g, for m=0.6

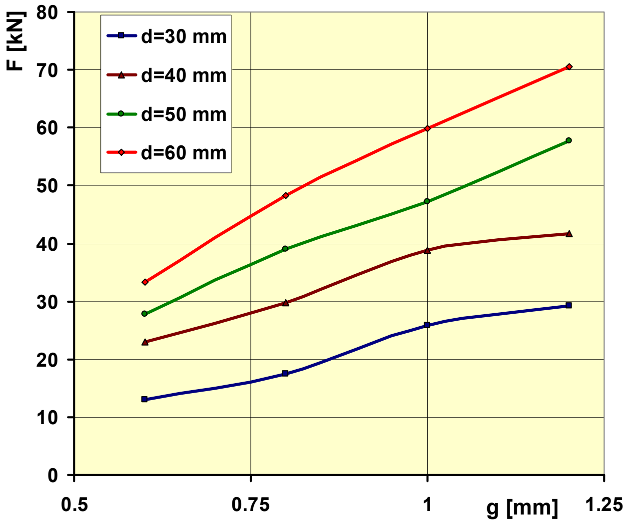

Fig.6 Deep drawing force depending on the thickness g, for several values of the diameter d, for m=0.6

As the digital equipment records also the punch stroke variation in time, the punch load depending on the punch stroke can be analyzed. A comparison between the different shapes of this diagram, for different values of the deep drawing coefficient, in a certain case of part's diameter and thickness, is presented in fig.8.

The use of diagrams presented in figs.5 to 7 for estimating the deep drawing force during the design stage of the manufacturing process is rather difficult. Technical literature, [1], [2], [7], [10] proposes empirical equations, using a correction coefficient to adjust the theoretical model of the maximum strain values which determines the values of the deep drawing forces.
This paper proposes a new approach, the mathematical modeling of the experimental data by regressions, aiming to obtain a simple, but more accurate equation for the calculus of the maximum value of deep drawing force.

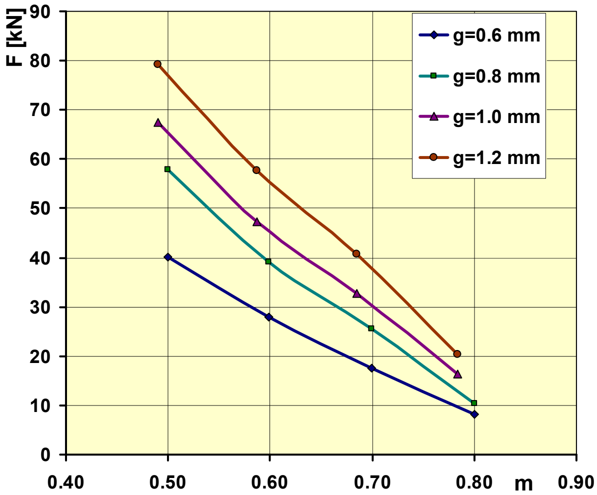

Fig.7 Deep drawing force depending on the deep drawing coefficient m, for a certain, d=50 mm

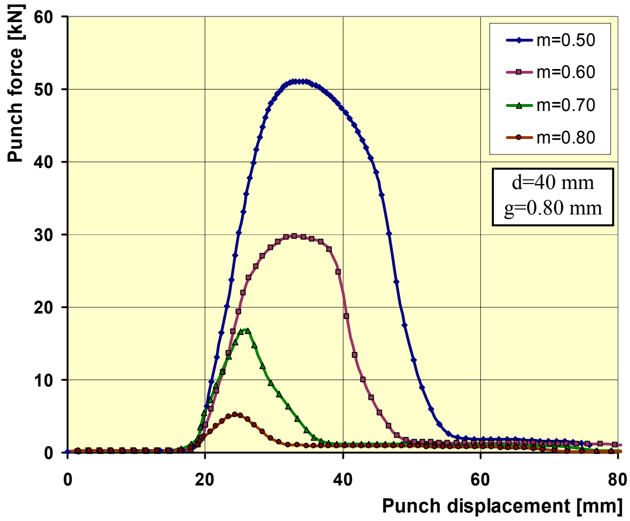

Fig.8 Punch load depending on the punch stroke, for d=40 mm and g=0.8 mm

3. MATHEMATICAL MODELING OF THE EXPERIMENTAL DATA

Usually, the dependence between the parameters of a manufacturing process can be represented [5] like a matrix:

$$T = \begin{pmatrix} x_1 & y_1 & \dots & t_1 \\ x_2 & y_2 & \dots & t_2 \\ x_3 & y_3 & \dots & t_3 \\ x_4 & y_4 & \dots & t_4 \end{pmatrix}, \quad (2)$$

meaning that parameter *T* is depending on the parameters *x, y,…and t*.
In the case of the present research, the values of the deep drawing force *F* is considered to depend on the part's diameter *d* and thickness *g* and the drawing coefficient *m*, calculated with the equation (1), meaning three parameters of influence.
To assess the mathematical equation which stays behind the matrix (2), a method of modelling with a suitable software can be used.
For the present research an application created under the MathCAD® environment [5], specially designed for the task, was created. The application can test four types of regressions, the power, the exponential and the 2nd and 3rd degree polynomial ones.
The application calculates the parameters of each type of regression and the correlation ratio,

$$R_c = \sqrt{1 - \frac{\sum_{i=0}^{n-1} (w_i - f(x_i, y_i, z_i))^2}{\sum_{i=0}^{n-1} (w_i - m(w))^2}}, \tag{3}$$

where w_i are the data values to be modelled and *m(w)* is the mean value of the data series.
As shown during the experiments, the deep forces depend on three parameters,

$$F = f(d, g, m). \tag{4}$$

After running the MathCAD application, the results were analyzed, considering a minimum acceptable value of the correlation ratio

$$R_{c\min} = 0.95, \tag{5}$$

which is usually recommended in such situations [4].
Among the four types of regressions analyzed, there was chosen the power type, as it passed the correlation ratio test and it is enough simple to be used by specialists during the design stage of the manufacturing process.
The general shape of the power regression is:

$$F(d, g, m) = c_1 \cdot d^{C2} \cdot g^{C3} \cdot m^{C4} + c_5, \tag{6}$$

and considering the values of the coefficients c_1, c_2, …, c_5, given by the MathCAD modeling, the equation is

$$F(d, g, m) = 0.083 \cdot d^{1.253} \cdot g^{0.903} \cdot m^{-2.521} + 0.2515. \tag{7}$$

To check the precision of the eqn.(7), a comparative graphical representation was done, between the experimental and the modelled data, for a certain set of parameter values. As shown in fig.9, the modelled values are quite near to the experimental ones.

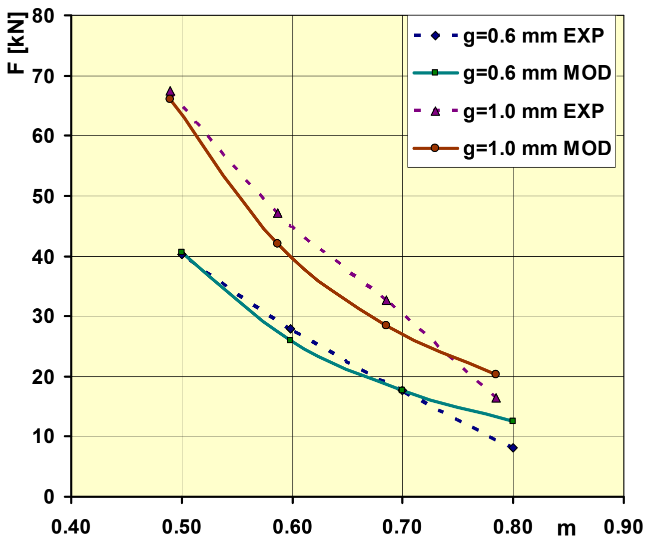

Fig.9 Comparative values of the experimental and the modelled data, for d=50 mm

The use of eqn.(7) is more convenient than using the diagrams presented in figs.5 to 7 and surely more accurate than the empirical equations given by the most technical literature.

4. CONCLUSIONS

The correct calculus of the deep drawing force is an important issue during the design stages of a manufacturing process by cold forming.

The method of determination of a suitable model for this calculus, proposed in this paper, gives more accurate results, also easy to apply in industrial environment.

The eqn.(6), assessed for DC 04 Am SR EN 10130+ A1 steel sheet, can be surely and successfully used by the design engineers to calculate the estimated value of the deep drawing force. The equation was determined by mathematical modeling with regressions of the experimental data, recorded during the tests conducted by the authors.

Further research can assess similar equations for different sheet materials, for different types of the blank holder system or for different values of the punch-die clearance.

5. BIBLIOGRAPHY

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