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PARAMETERS STUDY OF THE DEEP DRAWING CYLINDRICAL PARTS USING FINITE ELEMENT ANALYSIS AND EXPERIMENTAL VALIDATION

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Abstract: *The complexity of the deep drawing process is given by many parameters that must be established in order to run the process in the best conditions. In this paper, several numerical simulations of the thickness of a deep drawing cylindrical part were made by modifying the parameters that define this process. Finite element analysis is the method used for modeling and simulating the process of plastic deformation. The analyzed parameters are the punch radius, die radius, the blank holding force. The model was verified by performing several experimental tests under the same conditions. Several deep drawing parts were obtained. The thickness of these parts was measured with the coordinate measuring machine. The material used in the numerical model and in the experimental tests is DC04 steel.*

Key words: *deep drawing, finite element analysis, punch radius, die radius, blank holder force.*

1. INTRODUCTION

Improving sheet metal deformation behavior is one of the priority areas in the automotive industry. The deep drawing process is one of the most complex operations due to many parameters that influence the deformation: material properties, geometric shape of the punch and die, the blank holder force, the contact between the surfaces of the punch and die with the blank, and the type of applied lubricant

Deformation prediction can be achieved by using dedicated finite element analysis software. Thus, process parameters like friction between die, punch and blank, the geometry of the punch and the die can be optimized.

Experimental verification of numerical simulation results is required. Dengiz, CG et al [1] propose different models that are compared and with the experimental data to determine the model closest to the real one. There are also studies related to the thickness of the deep drawing parts and different approaches regarding their measurement methods [2].

The problems raised by the optimization of the deep drawing process are multiple. Also by using the finite element method, the problem of spring back and the appearance of wrinkling on flanges can be studied [3]. In addition to the used modeling and simulation techniques, programs such as MATLAB can be used for multi-objective optimization based on genetic algorithm to determine the optimal design input parameters. [4] [5].

Amir Atrian et al [6] build a model using the ABAQUS program to study the of wrinkling deep drawing cup and the variation of the force required for the deep drawing process. [7].

Studies have been made on the parameters of the deep drawing process depending on their importance. Thus, Masoud Kardan et al [8] demonstrated that the punch force in correlation with the thickness of the sheet metal, punch and fie radius, as well as the blank holder force are the main essential parameters. All these studies have a common denominator, namely the attempt to validate numerical models through experimental tests.[9]

2. DEFINING THE NUMERICAL MODEL OF DEEP DRAWING PROCESS

The aim of this study is to design a valid numerical model of the deep drawing process of a part with a height of 50 mm and a thickness of 0.8 mm. The speed at which the punch operates is constant.

The blank that is in contact with the punch, the die and the blank holder will form the cylindrical part.

During the deep drawing process the blank is subjected to radial stresses. When the sheet metal is pulled into the cavity of the die, appear stretching and compression on the material.

The die has the dimensions of 101.8 mm and the radius value of 3 mm, 5 mm 8 mm 10 mm. The rigid punch is 100 mm in diameter and the radius of the punch is variable. The blank holder can be considered flat because the material does not come into contact with its edges. The geometry of the deep drawing model assembly is illustrated in figure 1.

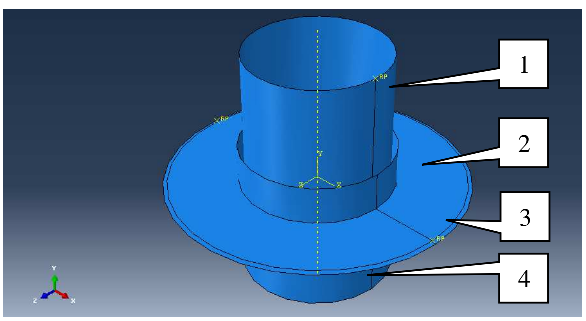

Fig 1 3D model of deep drawing geometry assembly 1-punch 2- blank holder 3-blank 4 -die

The model has 4 components that interact with each other: blank, die, punch, blank holder (Fig. 1). The blank is defined as a deformable component, and the other three components are defined as rigid.

The material used in the numerical study is DC04 steel. Its mechanical properties are defined in table 1:

Table 1

Mechanical properties of steel DC04

Name	Values
Rm - Tensile strength (MPa)	270-350
E (GPa)	210
ReH - Minimum yield strength (MPa)	210-220
A - Min. elongation Lo = 80 mm (%)	37-38

In this study, several parameters were considered as variables. The simulation presented in this case is performed with the following considerations: DC04 material definition, the coefficient of friction is 0.18 for the blank holder, 0.18 for the die set and 0.20 for the punch, the punch speed is 1.12 m / s. In this study, a correlation is determined between the radius of the die, the radius of the punch and the thickness of the sheet metal. Variations of the die radius between 3 and 10 mm and punch radius between 3 and 5 mm were taken.

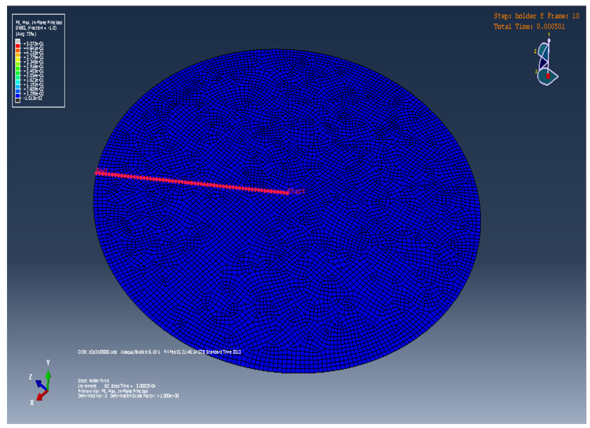

Fig 2 The points along the radius of the blank where the measurements are made

For each of these variants, the dimensional variation of the thickness along the radius of the blank was analyzed. The path for analyzing the thickness of the deep drawing part is illustrated in figure 2. The thickness distribution on the deep drawing part is shown in figure 3

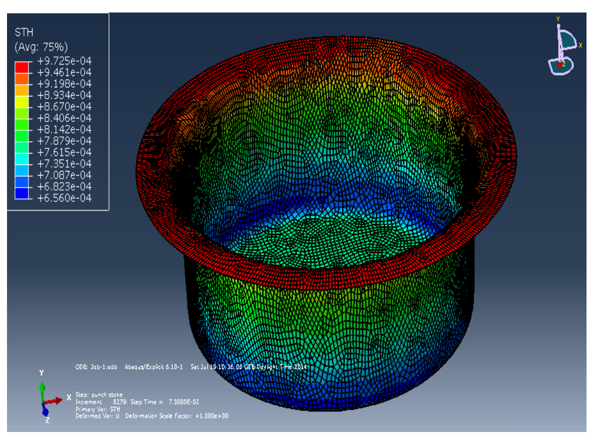

Fig 3 Distribution of thickness variation to a deep drawing cylindrical part

3. PARAMETRIC STUDY

Four distinct areas of analysis are highlighted in terms of thinning of the part. The first is the area of the bottom of the piece, the region where the lowest stresses appear. Most defects, such as cracks, occur in the area of the connecting radius of the bottom with the side wall, as shown in figure 5. With the transition to the side wall and flange the thickness of the part increases in size, above the initial value of the blank.

During the finite element analysis, several simulations were performed for different values of the die radius. The sheet thickness for each of these models is highlighted in figure 4:

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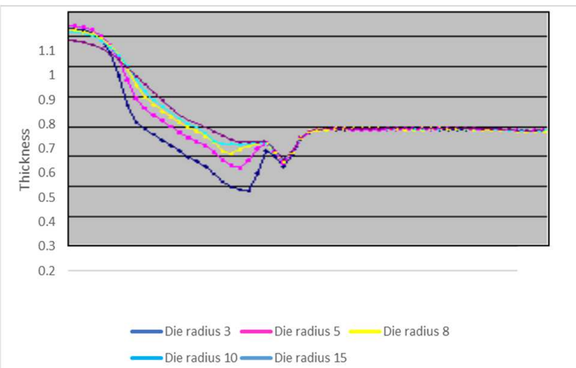

Fig 4 Variation of the thickness of the blank for different die radius

On the edge of the piece there is a tendency of the deep drawing part to thicken and on the bottom of the piece the thickness of the piece tends to remain constant. The maximum thinning occurs on the side wall of the part and the second major thinning occurs at the area where the bottom of the part joins the side wall. If we superimpose the graphs for all the 5 punchs radii, we obtain a comparison of the influence of the die radius on the thinning of the sheet (fig. 4). Analyzing the variation of the thickness it can be seen that with the increase of the die radius, the minimum value of the thickness starts to increase.

Simulations were made using the finite element method for three values of the blank holder force 15KN, 30KN, 40KN. For each choice of the force, different punch radius, die radius were used successively and for each case the maximum level of thinning is highlighted in figure 5:

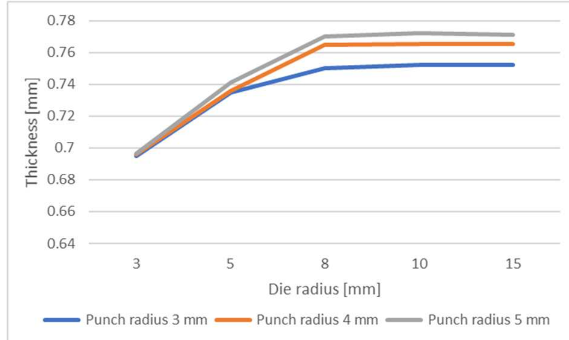

Fig 5 Minimum thickness of the part for a blank holder force of 15 KN

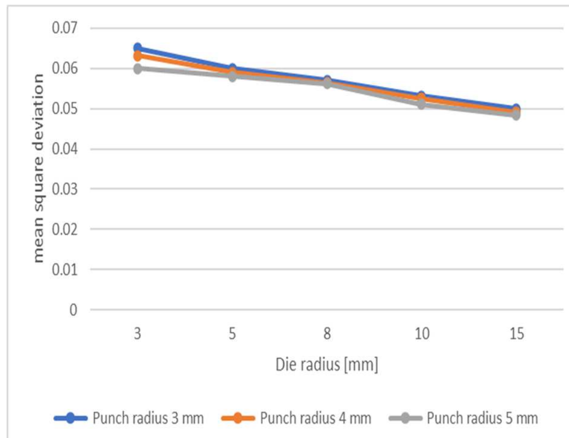

Fig 6 The mean square deviation of the thinning of the deep drawing part for the blank holder force of 15KN

For these data sets, the mean square deviation of the thickness variation was calculated, highlighting the way in which it tends to thin on the distance from the edge to the center of the piece (Fig. 6). It is observed that for larger punch radius the tendency of thinning is lower. At the radius of 5 mm, the slightest thinning of the sheet is obtained.

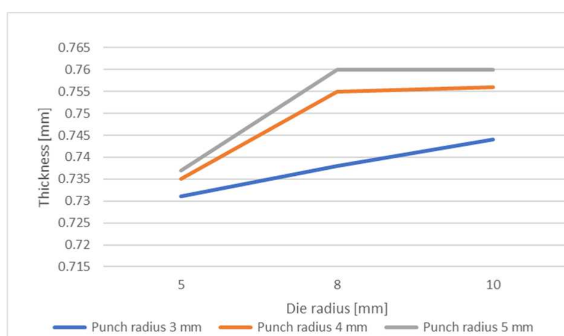

Fig 7 Variation of the thickness of deep drawing part for different punch and die radius, blank holder force 30kN

In the case of a blank holder force of 30 KN, the values of the thickness are illustrated in figures 7 and 8.

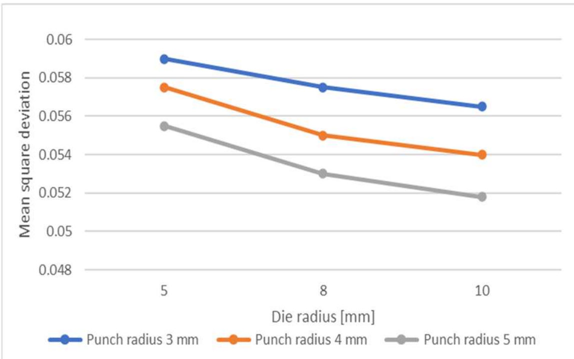

Fig 8 The mean square deviation of the thinning of the deep drawing part for a blank holder force of 30KN

For these simulation variants, where the holding force of 30KN was applied. the thinning of the material is higher than in the case of the force of 15KN.

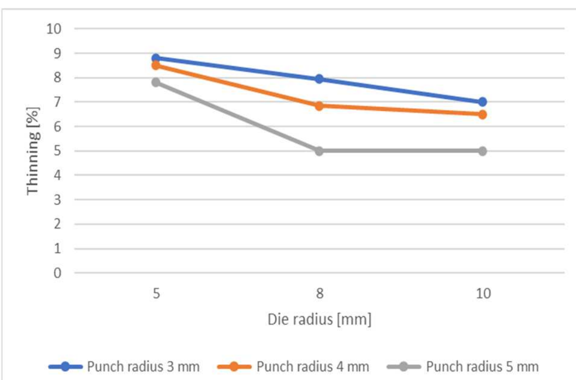

Fig. 9 Thinning of the deep drawing part in percent for a blank holder force of 30KN

For a radius of the punch and die radius of 8 mm and 10 mm, respectively, we obtain the minimum thinning (Fig. 9).

A third case studied is the deep drawing of cylindrical parts by applying a blank holder force of 40 KN. As expected, in this case, we are dealing with a more accentuated thinning of the material in the area of connection of the bottom of the piece with the side wall (fig 10,11). Figure 12 shows in percentage the maximum thinness of the sheet. For a punch radius of 3 mm and a die radius of 5 mm, a thinness of 9% of the initial value of the blank can be reached.

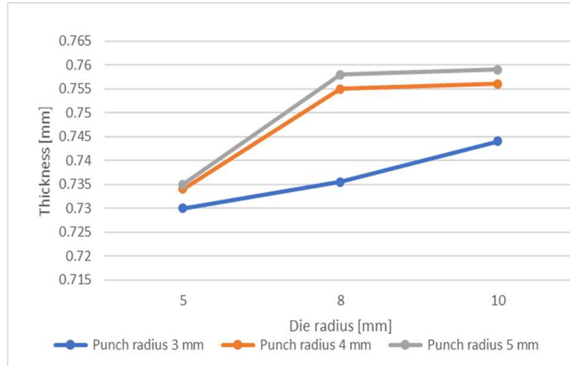

Fig 10 Variation of the thickness of deep drawing part for different punch and die radius, blank holder force 40kN

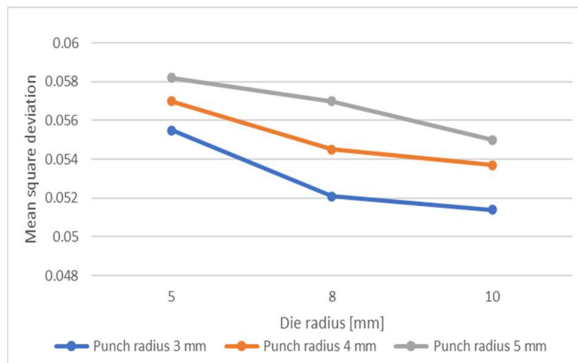

Fig 11 The mean square deviation of the thinning of the deep drawing part for a blank holder force of 40KN

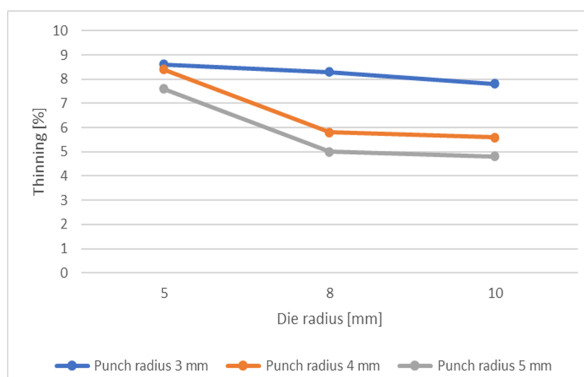

Fig 12 Thinning of the deep drawing part in percent for a blank holder force of 40KN

4. RESULT OF EXPERIMENTAL TESTS AND MEASUREMENT OF PARTS

In order to validate the results obtained in the modeling and simulation stage of the deep drawing process with the support of finite element method, a mold with interchangeable elements was designed and executed. The results obtained by the finite element method are not always very accurate due mainly to the different characteristics of the material in reality, as well as the rendering in the most accurate terms of the physical phenomena that occur during the deformation process such as the expression of the coefficient of friction.

Experimental tests were planned and performed using three dies with different radius 5 mm, 6.5 mm, 8 mm and blank holder forces of the 15KN, 30KN were alternated.

The validation of the numerical model obtained in the previous stage with the finite element method is done by comparing the experimental results with the numerical. A coordinate measuring machine was used to measure the thickness of the deep drawing cylindrical parts (fig. 13).

Fig 13 Measuring the deep drawing cylindrical part with the coordinate measuring machine

For each piece, 30 pairs of coordinates were generated, inside-outside, finally obtaining 30 values of the thickness of the parts

Table 2

Measured points

Name the part area	Number of points
The base of the piece	8
Radius connecting the base of the part with the side wall	7
Side wall	7
Radius connecting the side wall wuth the flange	6
Flange	2

It is important that the coordinates of these points where the measurement is made are the same, both in the experimental case and in the case of finite element simulation.

The accuracy of the measurements is very important in the study of the deep drawing process, because the minimum size of the thickness is located in the points in the connection area of the part bottom with the side wall, in an area very difficult to access with traditional tools.

5. EXPERIMENTAL VALIDATION OF THE NUMERICAL MODEL

The correctness of the simulation results of a finite element model can only be demonstrated by comparison with the experimental results. The ultimate goal is for the model to reproduce real physical phonemes as accurately as possible.

In order to validate the numerically obtained values we have data set measurements from the 6 pieces obtained experimentally.

In the case of the part obtained with 4 mm punch radius, 5 mm die radius and 15 KN blank holder force, the minimum value is 0.64 mm in the experimental case (EXP) and 0.75 mm determined by finite element analysis (FEA), the maximum value is 1.03 mm (EXP), 0.95 mm (FEA), and the average deviation of the thickness value between the measured points is 6.74% (fig 14)

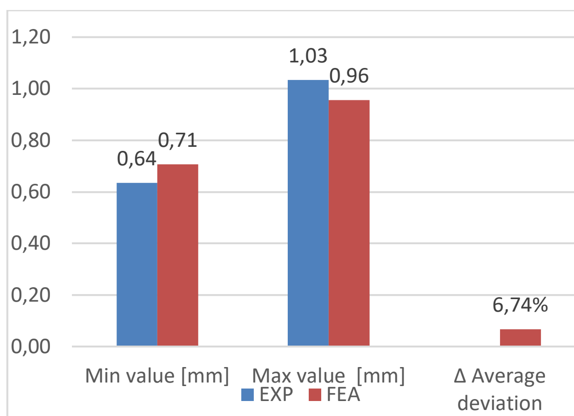

Fig 14 Part thickness - 5 mm die radius, 15KN blank folder force

For the part obtained with 4 mm punch radius, 5 mm die radius and 30 KN blank holder force, the minimum value of thickness is 0.63 mm (EXP) and 0.71 mm (FEA), the maximum value is 1.01 mm (EXP), 0.96 mm (FEA), and the average deviation of the thickness value between the measured points is 7.74% (fig 15)

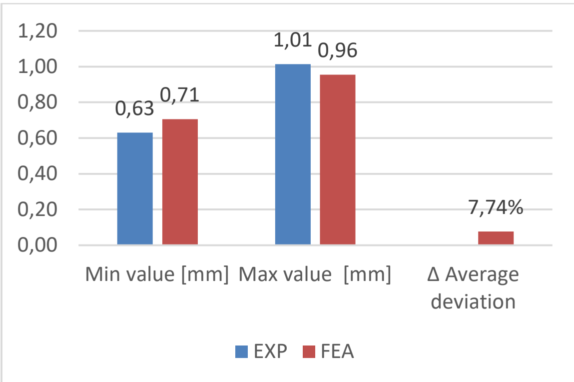

Fig 15 Part thickness - 5 mm die radius, 30KN blank folder force

For the part obtained with 4 mm punch radius, 6.5 mm die radius and 15 KN blank holder force, the minimum value of thickness is 0.66 mm (EXP) and 0.71 mm (FEA), the maximum value is 0.99 mm (EXP), 0.96 mm (FEA), and the average deviation of the thickness value between the measured points is 5.94% (fig 16)

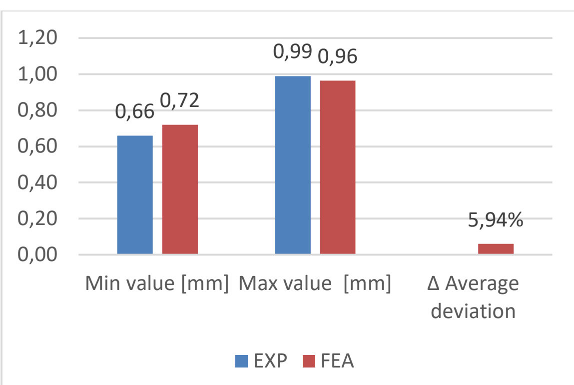

Fig 16 Part thickness – 6.5 mm die radius, 15KN blank folder force

For the part obtained with 4 mm punch radius, 6.5 mm die radius and 30 KN blank holder force, the minimum value of thickness is 0.63 mm (EXP) and 0.71 mm (FEA), the maximum value is 0.96 mm (EXP), 0.93 mm (FEA), and the average deviation of the thickness value between the measured points is 6.81% (fig 17)

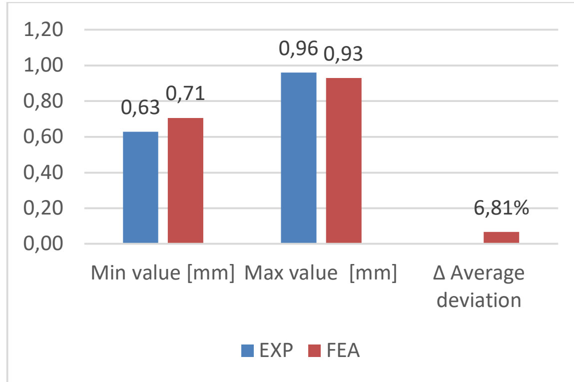

Fig 17 Part thickness – 6.5 mm die radius, 30KN blank folder force

For the part obtained with 4 mm punch radius, 8 mm die radius and 15 KN blank holder force, the minimum value of thickness is 0.69 mm (EXP) and 0.74 mm (FEA), the maximum value is 0.97 mm (EXP), 0.93 mm (FEA), and the average deviation of the thickness value between the measured points is 7.65% (fig 18)

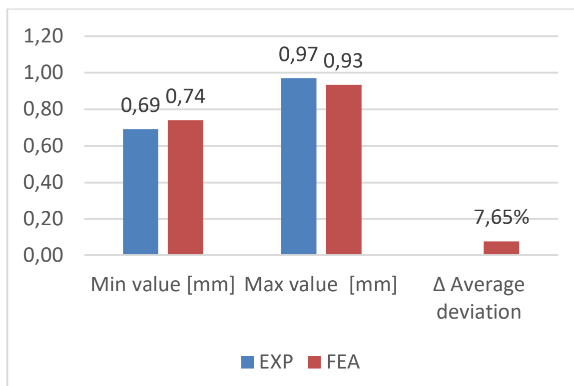

Fig 18 Part thickness - 8 mm die radius, 15KN blank folder force

For the part obtained with 4 mm punch radius, 8 mm die radius and 30 KN blank holder force, the minimum value of thickness is 0.68 mm (EXP) and 0.74 mm (FEA), the maximum value is 0.97 mm (EXP), 0.96 mm (FEA), and the average deviation of the thickness value between the measured points is 7.20% (fig 19)

Analyzing the results, we can see the differences between the thickness values of the part obtained by simulation and those obtained by experimental tests.

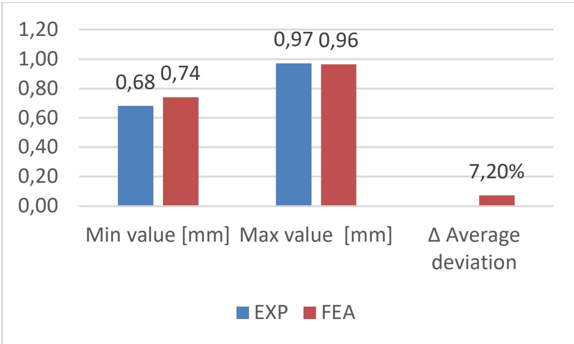

Fig 19 Part thickness - 8 mm die radius, 30KN blank folder force

The numerical simulation of the plastic forming process has a high sensitivity due to the difficulties of defining the exact boundary conditions, as well as the equations that describe the plastic deformation behavior of the defined material. It can be observed that in all the analyzed cases the average difference in thickness between the simulation and the experimental tests does not exceed 7.65%, and the maximum and minimum limits compared have close values.

6. CONCLUSION

Simulating the deep drawing process involves several steps: defining the geometric model, defining the characteristics of the material used, establishing contact areas and coefficients of friction, defining loads and boundary conditions, which act on the various components of the geometric model.

The main problems that appear in performing a correct simulation of the deep drawing process are:

- defining the material and establishing its mechanical characteristics;
- the use of friction coefficients corresponding to the experimental tests;
- speed of action of the punch.

The calculation time depends on the size of the discretization and the speed of movement of the punch. If the simulation speed increases too much, the solution obtained is not identical, as in the case of a lower speed due to the inertial forces that are dominant.

Based on the tests of the deep drawing process performed (both experimental and numerically simulated) we can conclude as follows:

- with the increase of the die radius of the and the tendency of the tendency of the part to thin is much smaller.
- the thickness of the deep drawing part also depends on the punch radius, obtaining small values of thickness at a small radius value.

Having a large number of simulations available due to the many parameters that influence the deep drawing process, the data obtained can be analyze in future works using machine learning algorithm.

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STUDIUL PARAMETRILOR PROCESULUI DE AMBUTISARE AL PIESELOR CILINDRICE AMBUTISATE PRIN UTILIZAREA ANALIZEI CU ELEMENT FINIT ȘI VALIDARE EXPERIMENTALĂ

Abstract: *Complexitatea procesului de ambutisare se datorează numeroșilor parametri care trebuie stabiliți pentru ca acesta să se desfășoare în cele mai bune condiții. In această lucrare a fost realizată o simulare numerică a variației grosimii unei piese cilindrice ambutisate prin modificarea parametrilor care definesc acest proces. Analiza cu element finit este metoda folosită pentru modelarea si simularea procesului de deformare plastică studiat. Parametrii analizați sunt raza poansonului, raza plăcii active, forța de reținere a semifabricatului. Modelul realizat a fost verificat prin mai multe încercări experimentale desfășurate în aceleași condiții ca simularea numerică. Un număr de 6 piese au fost obținute, a căror grosime a fost măsurată și comparată cu rezultatele simulării. Materialul folosit atât în modelul analitic cât și în testele experimentale este oțelul DC04.*

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