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DEVELOPMENT OF A METHODOLOGY TO OBTAIN THE IDEAL BLANK SHAPE IN DEEP DRAWING PROCESSES USING FINITE ELEMENT ANALYSIS

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Abstract. *Although metal forming processes have extensive industrial application their uses are based mainly in experimental techniques. With the development and easy access to more powerful computers, numerical simulations become reliable tools for product, process and cost optimization. In this paper a geometric methodology for blank shape optimization is developed, integrated to a commercial finite element analysis software - the ANSYS/LS-Dyna3D. In order to validate the proposed methodology, it is applied to two different blanks used to obtain the same part, analyzing the convergence and number of iterations to reach the desired part shape within a prescribed error.*

Keywords: *Sheet metal forming; finite element method; ideal blank shape; deep drawing.*

1. INTRODUCTION

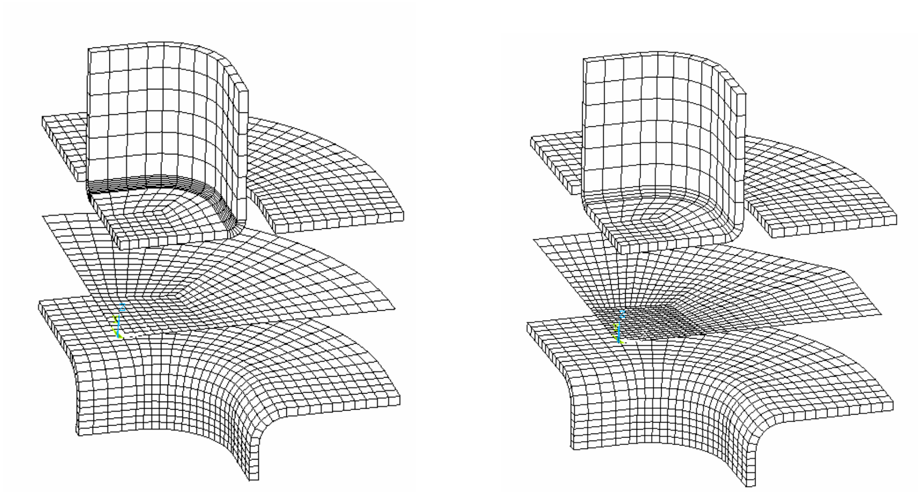
The metal forming technology permits the production of parts with higher mechanical properties and minimal material waste. This process, although, has an expensive tooling and become attractive only in mass production or for parts which need the mechanical properties obtained only in forming processes. A numerical method with large use in forming processes simulation is the finite element method. It permits a prediction of the metal flow behavior during the sheet forming operation, permitting the implementation of an ideal blank shape methodology. An ideal profile for the blank is that one which the part has a constant flange after the operation, minimizing or eliminating the trimming operation and material waste. Many researchers have studied several methods in order to obtain the ideal blank profile, as presented by Moreno et al (1999, 2000). In the proposed implementation, the forming process is simulated in a finite element code and the information is exported to an optimization program, which applies the methodology and produces a new initial blank profile. The information about the new profile is exported back to the finite element software, and a new simulation is made. If the final part is within a specified range the optimization process is finished. Else, the process starts again. Results applied to a square cup part forming are presented and analyzed.

2. PROBLEM MODELLING

Details about the finite element formulation and the solution algorithm using an explicit integration scheme can be found in classical literature as Bathe (1996) and Hallquist (1993). The element used to mesh the geometric blank model was the SHELL163 from LS-Dyna element library, with the standard Hughes-Liu formulation. This is efficient when large strains are expected. For the die, punch and blank-holder the element SOLID164 3D structural explicit was used. These three bodies were considered as rigid in all simulations.

2.1. Geometry Building

The dimensions used to the proposed problem was the same proposed by Mamalis et al (1996), since the referred article present results comparing the simulations with experimental data for different drawing highs. Only a quarter of the part was modeled in order to save computational effort. In the blank modeling two shapes were used, circular and octagonal (Toh & Kobayashi, 1985) presented in Fig. (1). In the first case, the radius of the blank was 60.5 mm and in the octagonal case the imposed condition was that both cases have the same surface area. The sheet thickness in both cases was adopted as 0.84 mm.



(a) (b)

Figure 1. (a) Circular initial blank model. (b) Octagonal initial blank model

In order to describe the material behavior, a linear formulation was used in the elastic range and a power law in the plastic range. The material properties used in the numerical model are listed in Tab. (1).

$$\sigma = E\varepsilon_e \tag{1}$$

$$\sigma = k\left(\varepsilon_e + \varepsilon_p\right)^n \tag{2}$$

Where:

σ: True stress;
ε_e: Elastic strain;
ε_p: Plastic strain;
E: Young modulus;
k: Strength coefficient;
n: Hardening exponent.

Table 1. Steel properties of the blank

Property:	Unit:	Value:
Young Modulus	N/m^2	2.1×10^{11}
Hardening exponent	-	0.228
Strength coefficient	N/m^2	739×10^6
Density	kg/m^3	7850
Poisson coefficient	-	0.29

Figure (2) presents the Stress / Strain curve used in the simulations.

In the punch/blank, blank-holder/blank and blank/die interfaces a constant value Coulomb's friction coefficient of $\mu = 0.2$ was adopted as suggested by Mamalis et al. (1996).

The blank-holder force was adopted constant during the process with 26 kN. An initial constant velocity of 1.7 m/s was applied to the punch, 100 times greater than the real value to minimize computational effort (Mamalis et al, 1996).

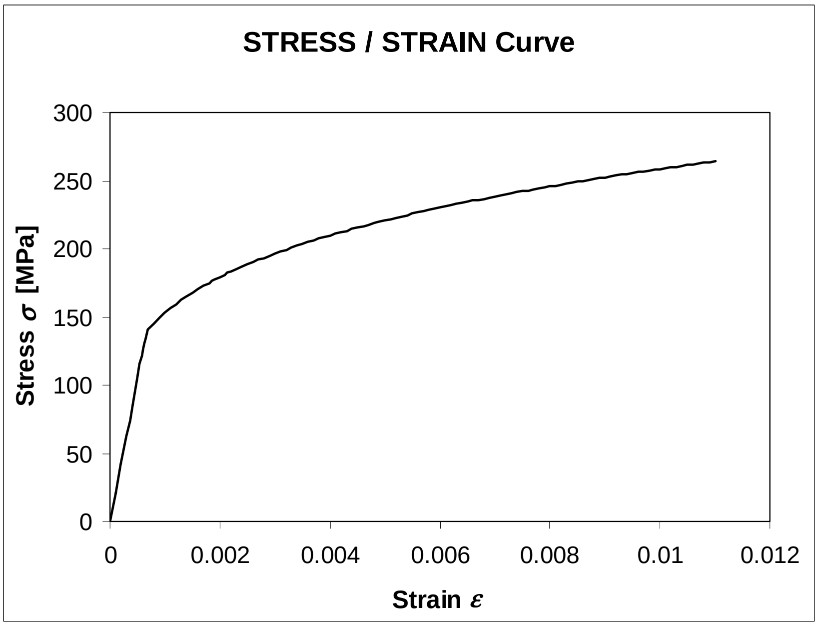


Figure 2. Stress / Strain curve used in the simulations

3. OPTIMIZATION METHODOLOGY

The blank shape optimization method follows the steps presented in Fig. (3). The proposed methodology is geometry based. The initial known values are the initial blank geometry, the desired final geometry and the conditions of the part forming process. The finite element method gives the blank profile after the process simulation. With this data the methodology gives a new initial blank profile, called optimized blank. This one is used to the process feedback to obtain by a iterative way the best blank initial profile.

3.1. Procedure to Obtain the Optimized Geometry Coordinates

For the methodology development, we will adopt that the area between the flange profile after simulation and the desired flange profile must be proportional to the area between the initial blank profile and the optimized profile. - $A1_n$ and $A2_n$, respectively, following the Fig. (4a).

$$A2_n = k\,A1_n \quad (3)$$

Where k is a proportionality constant which consider the non-linear effects and thickness changes.

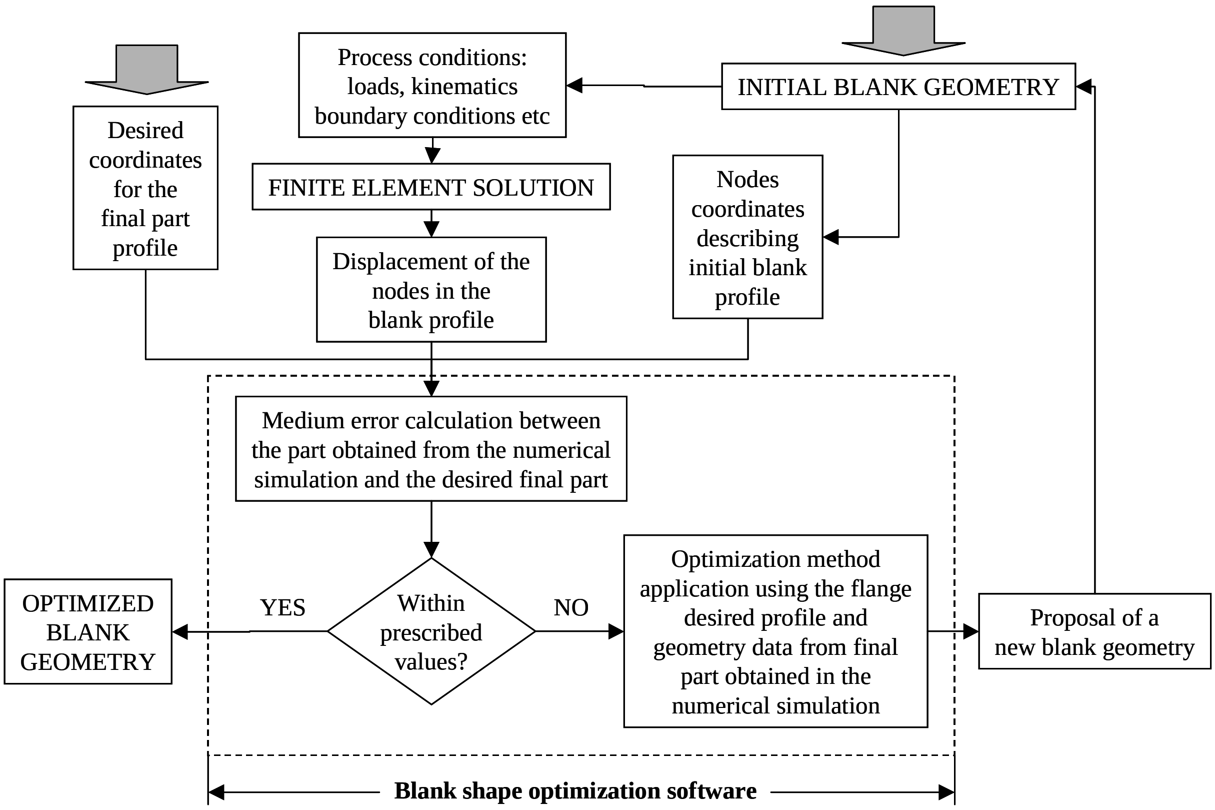


Figure 3. Flowchart of the proposed blank shape optimization methodology

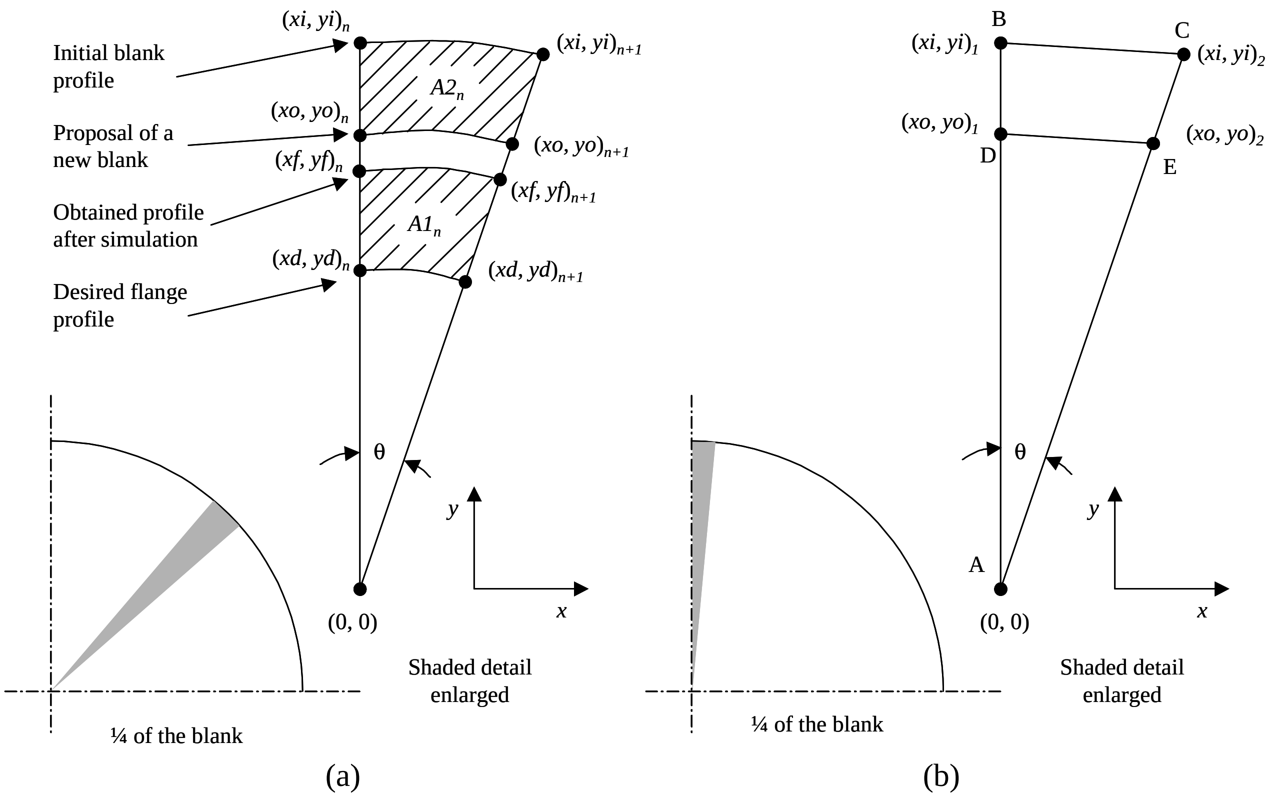


Figure 4. (a) Areas used in the expressions for new blank obtaining. (b) Similar triangles used in the initial values estimate

Figures (4a) and (4b) show the terminology followed in this development. By writing the areas as functions of the nodal coordinates, the follow equations can be obtained for the new blank profile:

$$xo_{n+1} = \frac{k\left(xf_{n+1}yf_n - xf_n yf_{n+1} + xd_n yd_{n+1} - xd_{n+1}yd_n\right) - xi_{n+1}yi_n + xi_n yi_{n+1}}{\left(tg(90 - n\theta)xo_n - yo_n\right)} \tag{4}$$

$$yo_{n+1} = tg(90 - n\theta)xo_{n+1} \tag{5}$$

Where, in agreement with Fig. (4):

xi_n, yi_n: coordinates of the initial blank profile;
xf_n, yf_n: coordinates of the flange profile after simulation with initial blank;
xd_n, yd_n: coordinates desired for the final part flange profile;
xo_n, yo_n: coordinates of the new proposed blank profile.

3.2. Initial Values Guess

We need an initial guess for the xo_n, yo_n values. A reasonable guess is the approach by similar triangles of the nodes 1 and 2 of the initial and optimized profiles, like showed in Fig. (4b).

The initial guess is obtained by:

$$xo_1 = 0 \tag{6}$$

$$yo_1 = \sqrt{\frac{\left(k\left(xf_2 yf_1 - xd_2 yd_1\right) - xi_2 yi_1\right)yi_1}{xi_2}} \tag{7}$$

For all presented simulations, the used k value is 0.8. The medium error analysis between the flange profile of the part and the desired profile is suggested for Park et al (1999) like:

$$error = 1000\sqrt{\frac{1}{N}\sum_{i=1}^{N}[(xf_i - xd_i)^2 + (yf_i - yd_i)^2]} \tag{8}$$

Where N is the number of discrete nodes in the part flange profile.

4. RESULTS

4.1. Case 1: Circular Blank

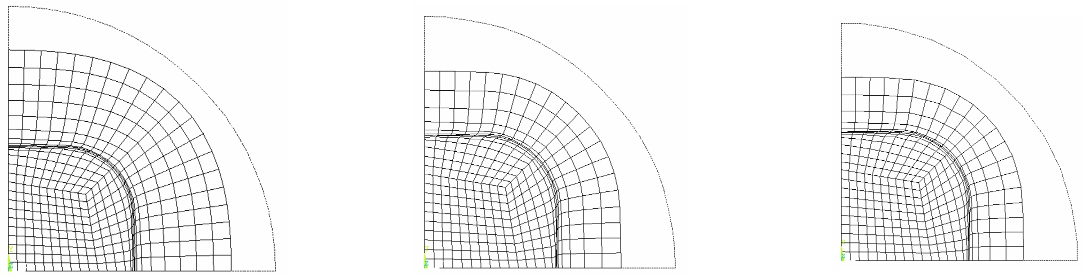
In this case the blank contour was divided in twenty-one nodes and the optimization loop was done until a medium error smaller than one millimeter was obtained.

1st Iteration: From an initial blank with circular shape and radius of 60.5 mm, the first numerical simulation is made. Figure (5) shows the obtained part where the flange profile can be observed at each step of the optimization procedure. At the first step, the medium error between the desired and obtained parts was 9.8 mm. The procedure is applied and a new blank profile is proposed as showed in Fig. (6a).

2nd Iteration: The new proposed blank is now the input for the second step. A new numerical simulation is done and the profiles involved are showed in Fig. (6b). The new medium error is 1.9 mm, so the stop criterion wasn’t reached and a new step is done.

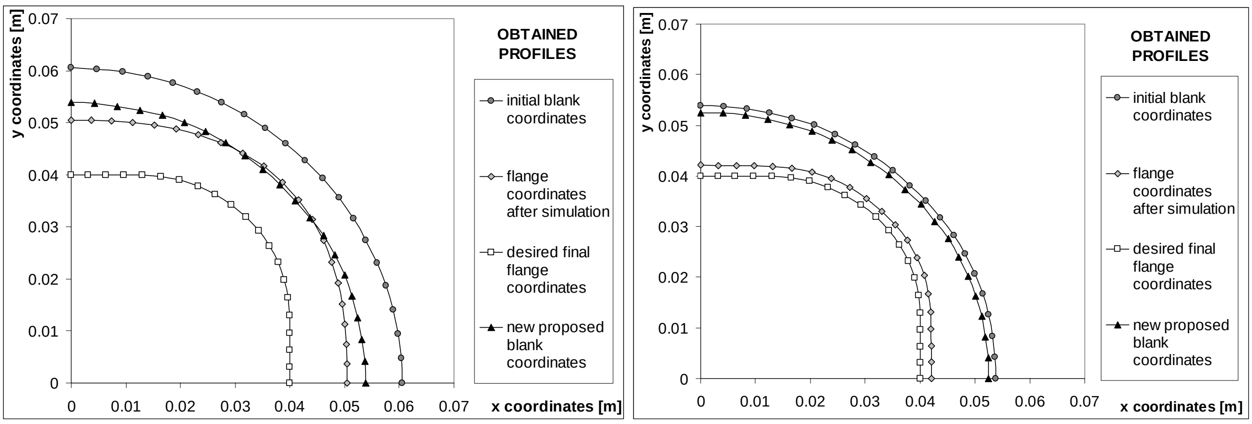
3rd Iteration: The same procedure is applied and in this step the obtained error was 0.41mm, smaller than the proposed admissible error. Figure (6c) shows the good precision obtained for the flange profile.

1st Iteration: **2nd Iteration:** **3rd Iteration:**

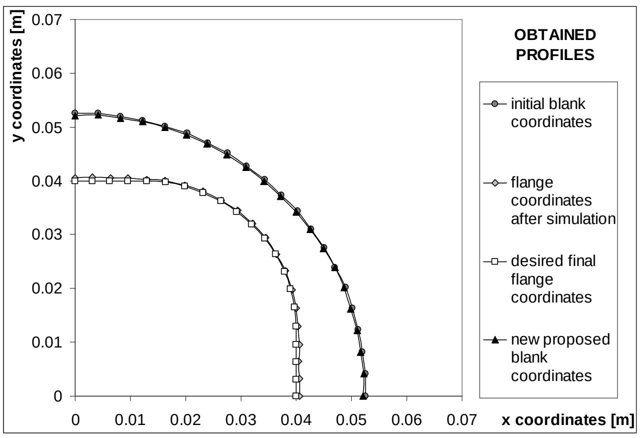


(a) (b) (c)

Figure 5. Unformed part profile and mesh in the final part for the three blank optimization steps.



(a) (b)



(c)

Figure 6. Initial and obtained profiles (a) first iteration - medium error: 9.80 mm, (b) second iteration - medium error: 1.90 mm, (c) third iteration - medium error: 0.41 mm. Dimensions given in meters

Once the initial objective was reached (success with initial round blank), a second case is proposed: the target part is the same of the case 1 but the blank has an octagonal shape with the same superficial area as compared to the circular blank case.

4.2. Case 2: Octagonal Blank

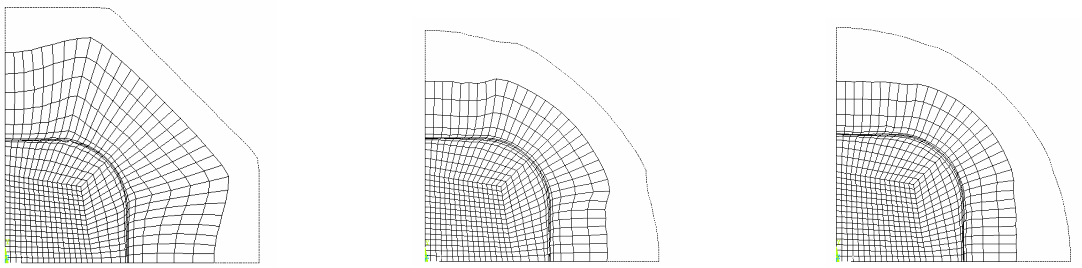
In this case the blank boundary was described with thirty-two nodes in order to get a good description of the more complex geometry, and, newly, the stop criteria for the optimization loop was to get a medium error smaller than 1 millimeter.

1st Iteration: The finite element simulation is done using the proposed octagonal blank shape – Fig. (7a). The initial error obtained is 9.98 mm. The application of the optimization procedure give a new blank profile, showed in Fig. (8a).

2nd Iteration: The simulation with the second blank is showed in Fig. (7b), in top view. The medium error in the second step was 1.85 mm. The target part shape was almost reached. The new proposed blank shape is similar to that one obtained in the second step of the case 1, Fig. (8b). So, we can anticipate the convergence of the applied method.

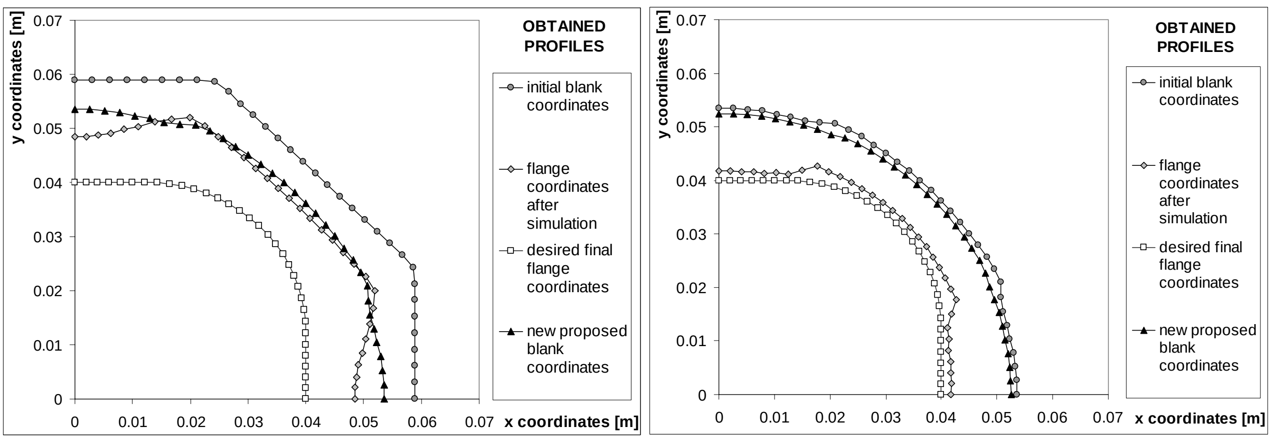
3rd Iteration: The simulation with the third blank is showed in Fig. (7c). In this step the medium error obtained was 0.35 mm. In Fig. (8c) the desired and obtained profiles are showed superposed.

1st Iteration: **2nd Iteration:** **3rd Iteration:**



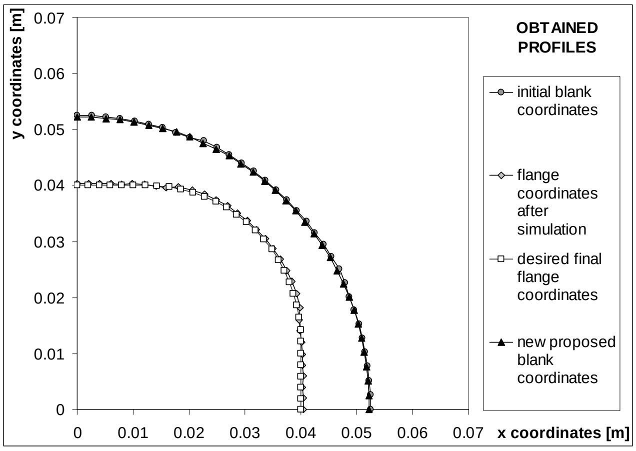
(a) (b) (c)

Figure 7. Unformed blank profile and deformed mesh (top view) for the three blank optimization steps



(a) (b)

Figure 8. Initial and obtained profiles (a) first iteration - medium error: 9.98 mm, (b) second iteration - medium error: 1.85 mm. Dimensions given in meters



(c)

Figure 8. (Continued) Initial and obtained profiles (c) third iteration - medium error: 0.35 mm. Dimensions given in meters

Table 2. Medium error estimated at each step in both cases

Step	CASE 1: Circular initial shape *error* [mm]	CASE 2: Octagonal initial shape *error* [mm]
1st.	9.80	9.98
2nd.	1.90	1.85
3rd.	0.41	0.35

Table (2) shows the values of function *error* - Eq. (8) - calculated at end of each simulation of the sheet forming process.

5. CONCLUSIONS

An optimization methodology was derived and implemented to work in association with a commercial finite element software. It can be considered effective since it gives good results in a small number of iterations. From two different blank shapes for the same part we get same optimized blank profile.

The simulation using a power law material behavior gives a better description of the results without a significant impact in the simulation processing time.

The second geometry employed (octagonal) calls for a bigger quantity of nodes in the boundary to get a better description of the blank shape. This fact leads to the use of smaller size elements and, consequently, to an amount in the finite element processing time.

The optimization algorithm can be applied to more generic models, although they still must have a high degree of symmetry.

6. ACKNOWLEDGEMENTS

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