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DESIGN OF A CAR BODY PART USING REVERSE ENGINEERING AND FEM

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Abstract: *Deep drawing, as the main technology for obtaining car body parts, is one of the fields where the virtual design of parts and process is used for product development. The use of FEM in sheet metal forming processes is an efficient tool of virtual design that has replaced the physical try-out method in terms of costs and time consuming. In the paper steps necessary in virtual design and verification of a car body part are presented. The design process starts with the design analysis and the creation of the part model using reverse engineering. Then the model is analyzed using FEM. By numerical simulation is obtained the form and the dimensions of the blank. After defining the deep drawing tool the process of deformation is modeled. An analysis of part, in terms of geometry, thickness and stresses variation is made. It is presented the module of forming limit diagram of the program and the results of the analysis of the part using this module. Finally, the results of this study could be used and improved by the car manufacturers.*

Key words: *deep drawing, numerical simulation, car body design, reverse engineering, Dynaform.*

1. INTRODUCTION

At car body deep drawing, the active elements, the die and the punch, have the conjugate surfaces, Fig. 1. An initially sheet metal blank, is fixed between the die ring and the blank-holder (binder). The blank-holder (binder) applied a restrained force, which will control the material flow into the die cavity and prevent wrinkling [1, 2, 7].

The punch moved into the die cavity, transferring the profile of the punch and the die to the blank. During the deformation the material flows between the binder and the die ring in the die cavity, the material being subjected to compressive and tensile stresses. When a very high restrained force is applied, the deep drawing process becomes a stretching process [1].

The use of FEM in sheet metal forming processes is an efficient tool of virtual design that has replaced the physical try-out method in terms of costs and time consuming [4, 5, 10]. FEM assures a deeper understanding of the mechanics of deformation, and enables the designer to make changes in the forming model and to run again the simulation to study the new results. Therefore, effects of the different parameters affecting the deformed sheet metal part could be observed, and intelligent decisions based on these effects can be made to obtain better forming conditions.

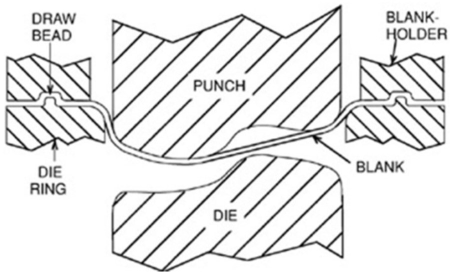

Fig. 1. Automotive deep drawing scheme.

The paper presents steps, based on reverse engineering and FEM, necessary in virtual design and verification of a car body part.

2. DESIGN ANALYSIS

As it is shown in Fig. 2 the part geometry is complex, and it is formed from two channels that intersect perpendicularly. The longest channel has a variable depth.

As a result the stamping process involves geometric nonlinear, material nonlinear and complex contact friction problem, forming the characteristics of a good surface quality with higher coordination.

From technological point of view, the part presented in Fig. 2, could be obtained by deep drawing, followed by cutting and holes punching. Because of the different depth of the longest channel the process of deformation is more pronounced in the region with the deeper depth. As a result the geometry of blank is non-symmetric.

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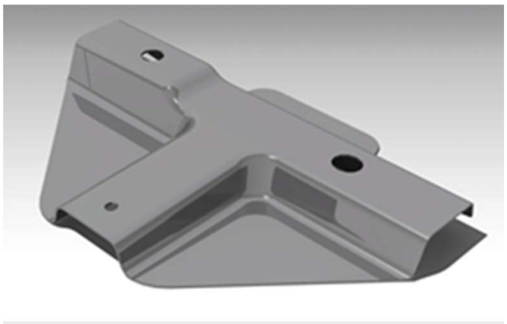

Fig. 2. Automotive part.

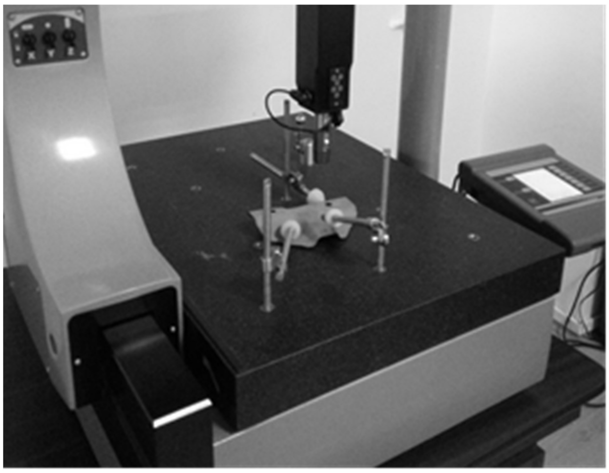

Fig. 3. Part measurement.

The Reverse Engineering (RE) can be used in the product design and redesign process, from taking geometric shapes of solid objects with dedicated devices, which leads to the generation of digital models needed for analysis [6, 9, 11].

Because the part geometry is complex, the redesign of the part from the real one is difficult. So it was chosen to use RE and CMM for part reconstruction, Fig. 3.

Figure 3 presents the measurement system. The main dimensions of the part were measured point by point. A number of 300 points were measured. Due to the piece's deformations emerged at normal wear and car body's transport, it was necessary to redesign the part, using reverse engineering.

For this, the component surfaces and relative positions between these were identified and the functional dimensions of the part were measured. In following, the intersections edges between the piece's component surfaces were determined, as so as, the extremes points of these edges.

Next, using the CATIA software, Generative Shape Design module, a Geometric Set was creating. The Geometric Set is composed by intersection lines between the part's surfaces and the end points of these lines. The surfaces' numerical models were created using the Fill command, which allows to explicitly defining the boundaries of the generated surface.

Between the obtained surfaces, a limitation, of type Shape Fillet, is applied. Where was needed, the surfaces were separated using Split command.

In order to easy change the fillet radius, a length parameter was created. This parameter has the value of the

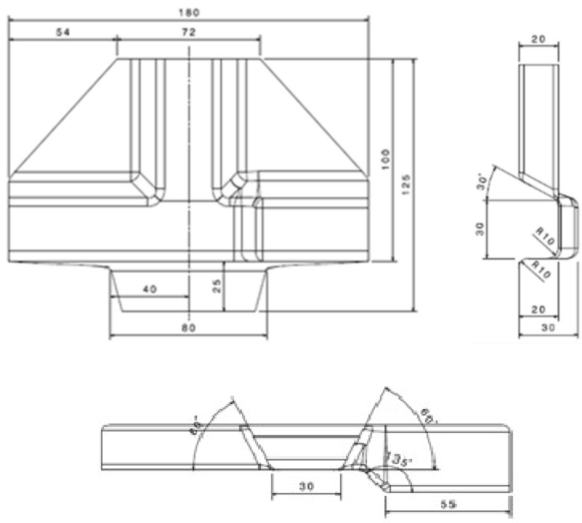

Fig. 4. Design parameters

initial fillet radius. The parameter was linked to the radii numerical value using a formula. In this way, changing the parameter's value, the values of the fillet radii are simultaneous changed.

The complex surface dimensions and form are presented in Fig. 4.

Next, the CatPART file was saved as .igs file in order to use it in Dynaform program.

3. NUMERICAL SIMULATIONS

The numerical tools helps developers to simulate and optimize their production before starting the manufacture with the objective to minimize as much as possible the rate of defective parts [3, 4].

ETA Dynaform is a numerical tool solution specially developed to simulate the sheet forming process and analysis the entire die system [12]. Dynaform allows "the reduction of overall tryout time, lowering costs, increasing productivity and providing complete confidence in die system design. It also allows evaluation of alternative and unconventional designs and materials for an optimal solution" [12].

3.1. Blank development

The drawing surface area and the blank area are approximately equal according to the principle of constant volume considering that material thickness basically remains unchanged after deep drawing. [6] Because the shape of the part is complex, it is difficult to accurately calculate the surface area of deep drawing part with conventional method of calculation. For calculating the blank outline of the complicated sheet metal part the finite element method could be applied.

Using Dynaform software engineering module (BSE) the blank's shape and area is obtained [12].

BSE assures accurate blank size estimation, gives nesting solution to maximize material utilization, provides piece price and scrap calculation [12]. BSE is based on a one-step algorithm. Potential forming failure due to excessive blank thinning is detected through an inverse method [12].

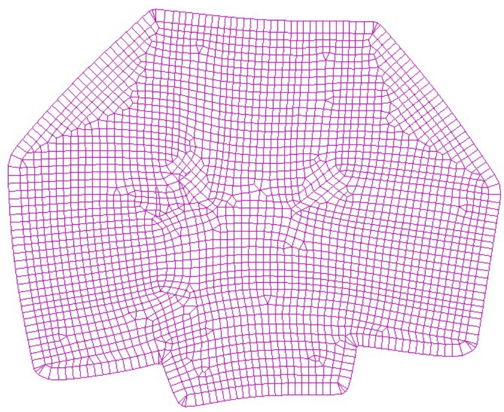

Fig. 5. Blank development.

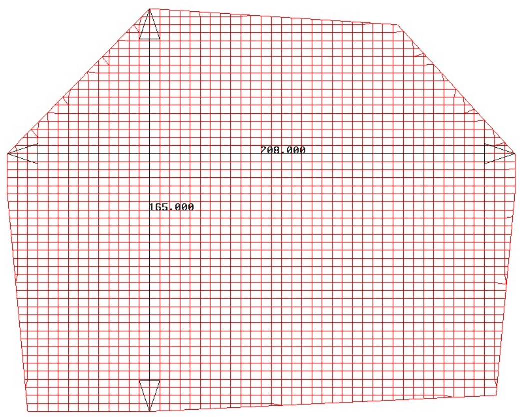

Fig. 6. Blank envelope.

In the first step the geometric model of the part obtained from the CAD system is imported.

In order to accurately reverse rough outline, we need to undergo a rigorous grid check, the unit overlapping check, normal direction check, unit size check and inner angle check, and make sure there is no holes inside.

Using the command Blank Size Estimation from the module BSE the form and the dimensions of the blank are obtained. The reverse irregular sheet shape is shown in Fig. 5. The contour is not favorable to the sheet metal cutting. So it was necessary to change this form.

Using rectangular envelope of the obtained blank, we get the shape shown in Fig. 6. For the blank dimensioning it was taken in consideration also a material addendum. The maximum dimensions are 208 × 165 mm.

3.2. Simulation model

Deep drawing simulation starts with the creation of FEM models: the punch, die face, and the blank, Fig. 7. Obviously, the most important model is that of the blank, which has been discretized using shells elements since their deformations are allowed during the forming process. 4-node Belytschko-Tsay shell elements were used, with five integration points through the thickness of the sheet metal.

Shell elements type Belytschko-Lin-Tsay are based on a combined co-rotational and velocity-strain formulation [5].

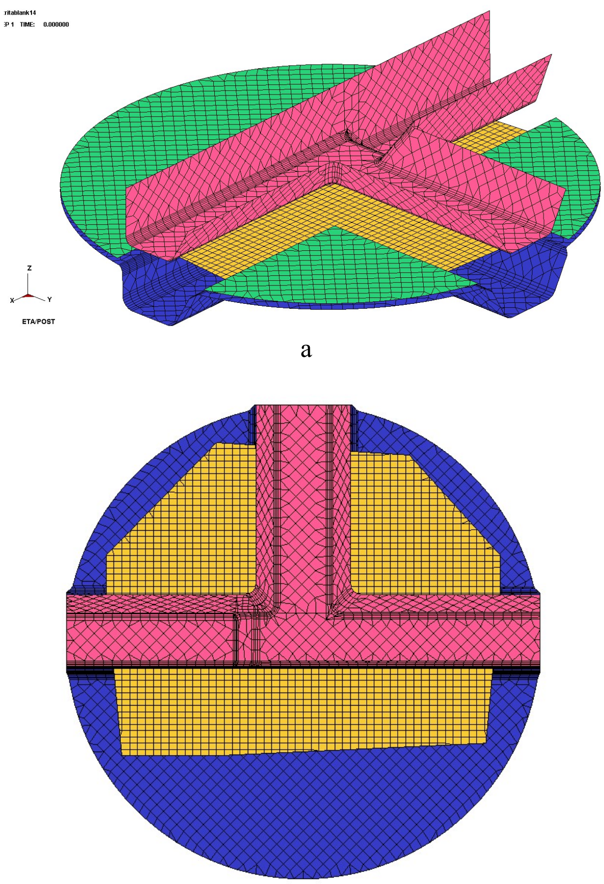

Fig. 7. Geometric models of punch, die face, blank-holder, and blank: *a* – isometric view; *b* – top view.

The die, punch and the binder are modelled using rigid shell, Fig. 7. The blank-holder applied a constant force of 25 KN

For building the die and the punch the command offset was used, having as reference surface, the part surface. The offset was established at 1.65 according to the material thickness.

Mild steel was used in the numerical experiments with a thickness of 1.5 mm. The input data for elastic material, density, Young's modulus and Poisson's ratio, according to implicit program values for steel.

The yielding of the material was modeled using a power law, as:

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

The material type was DQ. The properties of material were selected from the program library. According with the material characteristics, for simulation the n-value = 0.22 and K = 648 MPa. The R-values were set to: R_{00} – 1.87; R_{45} – 1.27; R_{90} – 2.17.

In the numerical simulation, defining contact is necessary between the sliding bodies of the metal forming process. In this paper for the contact between the punch, die, blank holder and blank, Contact_Forming_ One_Way_Surface_To_Surface algorithm was used

The punch speed was 1000 mm/second. The total distance of the motion path is 32.1 mm. For friction Coulomb law was used and 0.12 friction coefficient was considered.

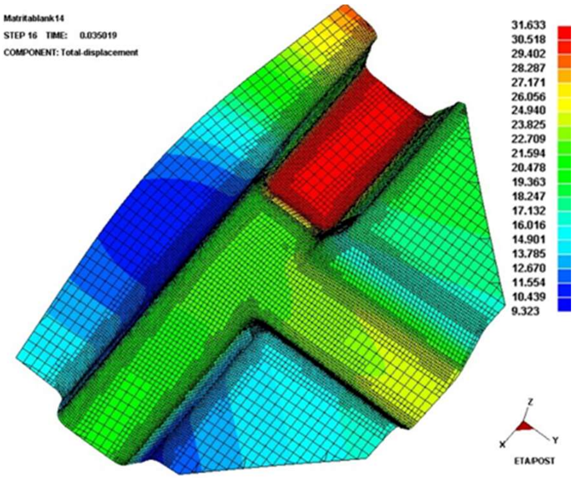

Fig. 8. Total displacement.

4. NUMERICAL RESULTS AND DISCUSSIONS

Because of the depth variation along the longest channel of the part the material flow is different in different zones of the sample. Figure 8 presents the total displacement of the material. These displacements vary from 9.32 mm to 31.63 mm. Differences both in *X* and *Y* direction will affect the stresses in material.

Figure 9 shows the edge movement at the end of the deformation process. As expected, the largest edge movement will occur in the part region with the greatest depth. It is observed that in other areas the edge movements are almost uniform, which will lead to a uniform stress and strain state.

The dimensioning and adjustment of the addendum represents a great problem for a complex part. From practical point of view several months are needed, until a tool works satisfactorily. The design of addendum takes place manually by using computer-aided design systems (CAD). The addendum in our case is the rectangular envelope which was defined in the chapter 3. Some solutions were tested till we chose the current envelope.

Figure 10 presents a comparative analysis of profiles between the designed part and the simulated part. The two profiles are similar. The simulated part has an addendum, as already discussed, that is necessary to be cut. In this way the simulated part will correspond with the designed part.

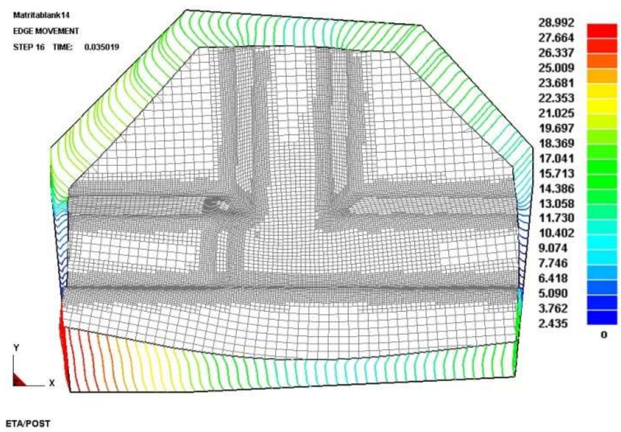

Fig. 9. Edge movement.

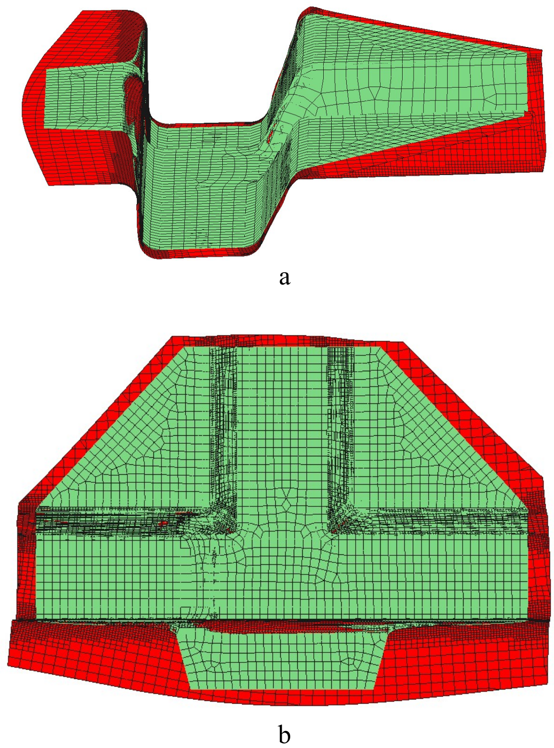

Fig. 10. Part: *a* –simulated; *b* – designed.

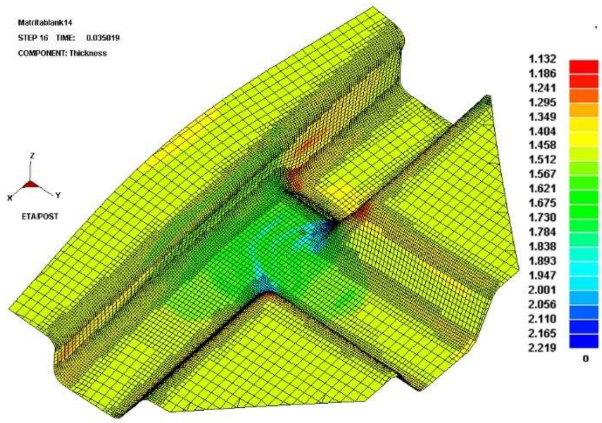

Fig. 11. Thickness variation.

Figure 11 presents the thickness variations in the part. In the edges zones the material is thinner than the initial thickness. A risk of cracks could appear in these zones. At the bottom the material in the interior edge of the short channel became thicker. A risk of material overlay exists in the middle of the part.

The Von-Mises is the equivalent uni-axial tensile/compression stress of a multi axial sate of stress. The variation of Von-Mises stress is presented in Fig. 12. Most of the material is in the plastic state. In the flange regions, the value of this stress is very low, which indicate that the material had flow without any deformation. Also some points have a great value of this stress, without any risk of cracks, as it will be shown in FLD analysis.

The forming limit curves, FLDs, is one of the method in examining the failure potential, which include a good representation of material's stretch ability and the easiness when used for fracture avoid [3, 4].

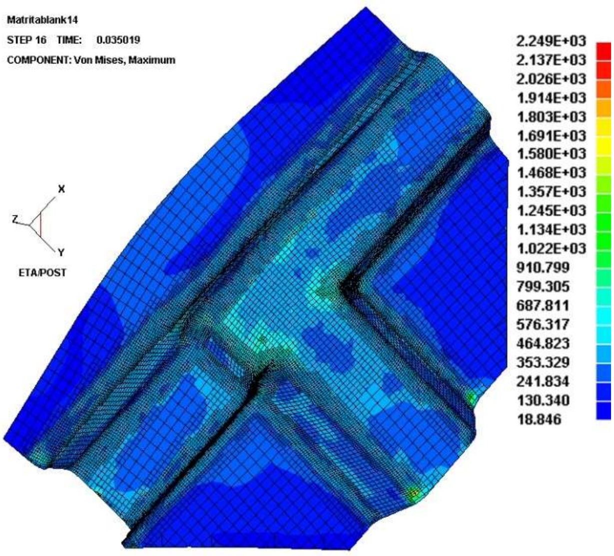

Fig. 12. Von Mises stress.

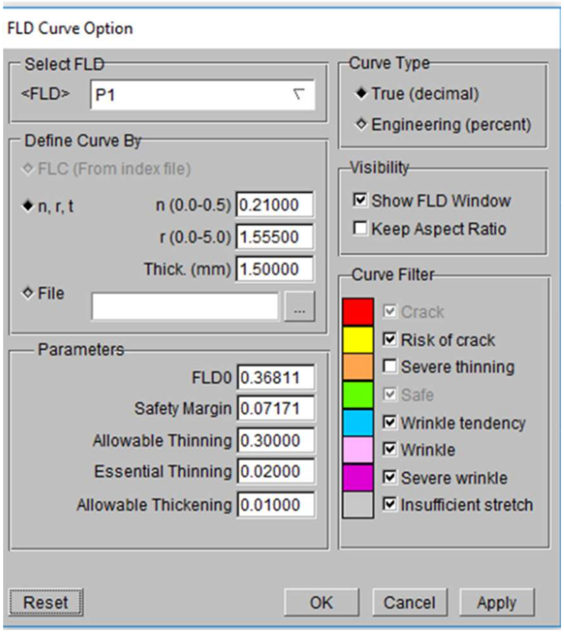

Fig. 13. FLD window in POSTPROCESSOR [10].

Figure 13 presents the window of FLD module in Dynaform and values which define the simulation parameters.

From the limit forming diagram, the overall deformation of the sheet is obtained, and it is easy to see what node is in safe or is in dangerous state.

Figure 14 presents the FLD curve for the deformed part. The deformation mode is different in different zones of the part. The main observation is that the part did not present risk of cracks because. All nodes are in the security zone and severe wrinkles appear in the middle of the part.

5. CONCLUSIONS

This paper uses CAE software to make numerical simulation analysis of an automobile part forming under constant blank-holder force.

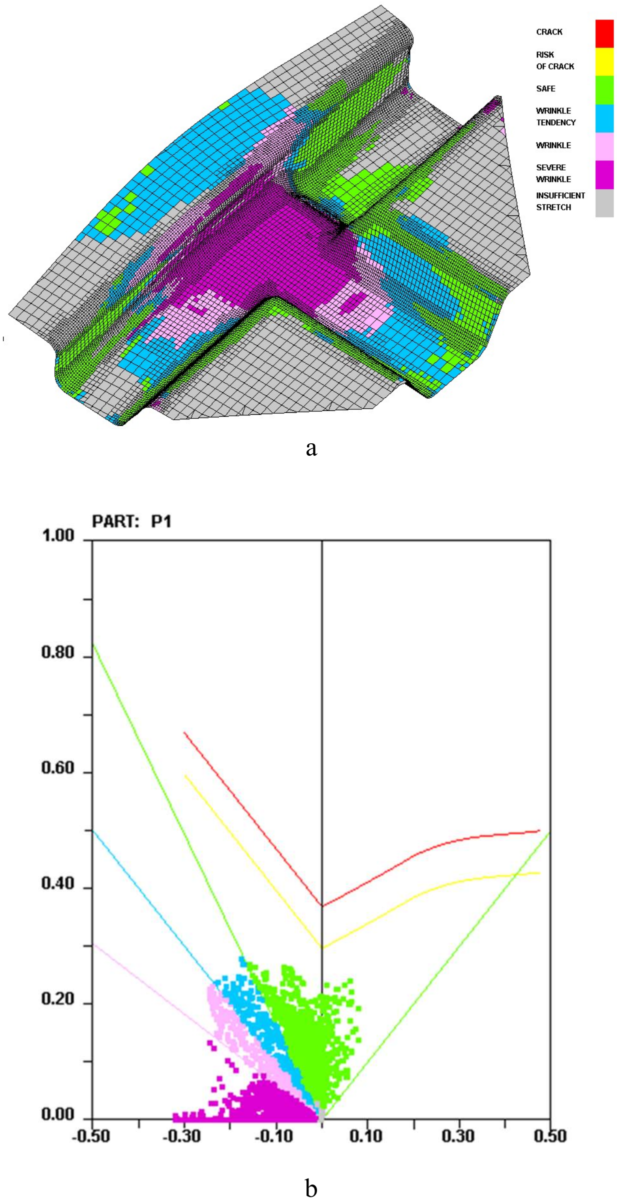

Fig. 14. Deformed part: *a* – deformed models *b* – FLD curve.

Starting from the real part, the Reverse Engineering (RE) and CATIA were used to create the part model.

Using the module BSE from Dynaform is was obtained the geometry of the blank from the part model.

For process simulation the blank geometry was modified to follow the cutting conditions.

The FEM analysis provides useful information for design of deep drawing process planning, as to shorten the production cycle, reduce cost and improve car body quality.

Future researches must take in account the springback phenomenon even the part is thicker. The blank geometry must be confronted with the real one.

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