NUMERICAL AND EXPERIMENTAL STUDY OF SHEET THICKNESS VARIATION IN DEEP DRAWING PROCESSES

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Abstract: In the present work, an attempt is made to obtain FEM solution of sheet thickness variation and its experimental verification in deep drawing processes. A commercial steel sheet was chosen as a test material which in widespread used in automotive and kitchenware industry. Firstly, the forming limit tests were performed to construct the FLD. Then, different blank holder forces applied with gas springs and double-acting press was created by using them. FEM simulations were carried out a commercial software programme called AUTOFORM. A good agreement was found between the measured and the predicted values of the thickness variations.
Key words: Deep Drawing, FLD, FEM, AUTOFORM.

1. INTRODUCTION

Sheet metal forming is a technique by which most body parts are produced in automobile industries. In sheet metal forming, a thin blank sheet is subjected to plastic deformation using forming tools to confirm to a designed shape. During the process, the blank sheet is likely to develop defects if the process parameters are not selected properly. Therefore, it is important to optimize the process parameters to avoid defects in the parts and to minimize production cost. Optimization of the process parameters for instance die radius, blank holder force, coefficient of friction, etc. can concluded according to their degree of importance on the sheet metal forming characteristic. Deep drawing is one of the major industrial sheet metal forming processes. It is used to manufacture a variety of products such as pans food containers, kitchen sinks and automotive fuel tanks are manufactured by means of the deep drawing process. In this process, a round sheet-metal blank is firstly positioned over a circular die and is held in place through the instrumentality of a blankholder during forming to prevent wrinkling of the blank during the process. After that a circular punch moves downward and forces the sheet-metal blank into the die cavity so as to a cup is latest formed. The resulting hollow component has a wall thickness nominally the same as the blank. The design and control of a deep drawing process depends not only on the workpiece material, but also on the condition of the tool-workpiece interface, the mechanics of plastic deformation, the equipment used and the control of metal flow (Moshksar, 1997). When the drawing process continuous, sheet-metal components are essential to control the flow of metal between the die and the blank holder in order to prevent the occurrence of failures such as tears and wrinkles in the drawn part. While insufcient metal flow makes tears or splits. Excessive metal flow is going to cause wrinkles in the part either. Prediction of the forming results, for example determination of the punching force, blank holder forces and the thickness distribution of the sheet metal will decrease the cost of production and time be formed. The blank holder is an important factor for controling the metal flow with predefined blank holder force (BHF). When the BHF is too low or too high, there are some situations likely to occur. Such as when the BHF is too low wrinkle can be seen or when the BHF is too high fracture can be seen. It seems that wrinkle is the main factor pf restrictive for forming when the BHF is too low. Furthermore when the BHF is too high it seems that fracture is the main factor of restrictive for forming, either.

There have been many attempts (Zeng and Mahdavian, 1998; Wang and Cao, 2000) to obtain the minimum blank holding pressure that prevents wrinkling. Yu and Johnson (1982) studied the effect of blank holder pressure on the buckling behavior of the flange. Agrawal (2007) studied to predict the minimum blank holding pressure required to avoid wrinkling in the flange region during deep drawing process. The influence of drawing temperature and blank holder force (BHF) on sheet formability was investigated by Chang et al (2007). Padmanabhan et al (2007) aimed to determination of the effect of these three important process parameters, namely blank holder force, die radius and friction coefficient, on the thickness variation of the part. Last three decades, the numerical simulation techniques have found so important solutions in studying for many of scientific problems and engineering processes including metal forming operations as well with extensive progreses in hardware and software. Many researchers studied the deep drawing process by means of the finite-element (FE) method. Triantafyllidis and Needleman (1980) investigated the effect of blank holder stiffness on wrinkling behavior using elasto-plastic FEA. Shulkin et al (2000) designed and built an eight-point BHF control system with a flexible blank holder as a part of an experimental viscous pressure forming (VPF) machine. FEM simulations of hydroforming with a multi-point BHF control and an elastic blank holder were conducted to fine-tune the control system as well as to predict the forming loads. Sheng et al(2004) aimed to determine a feasible BHF profile in a single FEM simulation. He selected two conical cup geometries to verify the proposed adaptive simulation method. Qun et al (2007) proposed a new strategy to optimize the variable blank holder force (BHF) and determine the drawing limit under the constant and variable BHF by using FEM. The effect of controlling blank holder motion by a newly proposed algorithm on deep-drawability was investigated by Yagami et al (2007) for a circular cup deep- drawing process of a thin sheet metal. Finite element (FE) simulations of the deep drawing process were also conducted to investigate the effect of the method on fracture damage reduction. Savas and Secgin (2007) aimed to increase deep drawing ratio and to decrease blank holder forces. For this purpose they prepared five kinds of blank holder and die shapes by giving an angle to die and blank holder. ABAQUS software has been used by Kumar (2007) to simulate the deep drawing of circular blanks into axisymmetric cylindrical cups. An acceptable range of blank holding force and the tearing zone were identified with the help of the numerical simulation for high strength stainless steel SS304. He also suggested a range of safe blank holding force as 20-80kN for drawing defect free cylindrical cups.

On the other hand, thickness distribution is one of the quality criteria in sheet metal formed parts. The thickness is unequal distributed in the part after deep drawing. Usually, the thickness is uniform at the bottom of the punch, minimum at the punch radius and vertical surface and more at the flange area. The occurrence of thickness variation may cause stress concentration to acceleration of damage mechanism in the leading part. So, failure in deep drawn parts usually occurs by thinning, therefore, it is important to determine the variation of thickness. Yossifon and Tirosh (1991) carried out a comprehensive experimental and analytical investigation on the behavior of the sheet blank materials, the properties investigated including strain hardening and anisotropy, the effect of friction and changes in metal sheet thickness. Hu et al (1998) predicted the thickness variations by the simulations along the circumferential and radial directions by using in an commercial elastoplastic finite element code named ABAQUS. Different methods of analysis such as analytical, numerical and experimental techniques were employed to estimate the required drawing force by Saniee and Monazeran (2003). In their study, the numerical simulations were conducted using the finite-element (FE) method. In these simulations, the effects of the element type on the forming load and the variation of thickness strain were studied. Padmanabhan (2007) aimed to determination of the effect of three important process parameters, namely blank holder force, die radius and friction coefficient, on the thickness variation of the part. The influences of the BHF on wall thickness during deep drawing of the aluminum alloy sheet material has been investigated through FEM simulation setup and the experiments by Demirci et al (2008). Based on the Demirci's study the distribution of wall thicknesses obtained by means of experiments and FEM showed a good agreement.

In this research, DIN EN 10130-99 (IF) steel sheet with low carbon and high quality formability and a thickness of 1 mm. has been used as a test material for axisymmetric deep drawing process. Previously determined three different blank holder forces applied to blank holder with gas springs and single-acting press was used instead of double-acting press. In this study, blank holder force how to effect the cup thinning was researched and it was simulated with a commercial software program called AUTOFORM. Thinning of the values obtained from experimental results were compared with the result of simulation.

2. EXPERIMENTAL STUDY

2.1. Material

As explained above, DIN EN 10130-99(IF) (Turkish grade ERDEMIR 7116) was chosen as test material for good deep drawing formability. This material can be used in automotive industry, white goods, kitchenware, radiator and air-condition equipments and durable consumer goods. Also it can be used when toughness, ductility and strength requested. Mechanical properties obtained from uniaxial tension test which performed on the INSTRON 8501 Universal Test Machine and chemical composition of material is shown in Table 1 and Table 2 respectively.

Table 1. Results obtained from the tensile test applied to samples

Material	Yield Strength (MPa)	Tensile Strength (MPa)	Fracture Elongation (%)
DIN EN 10130-99	164	290	44

Table 2. Chemical composition of IF in wt%

Material	C	P	S	Mn	Ti
DIN EN 10130-99	≤ 0.04	≤ 0.012	≤ 0.009	≤ 0.2	≤ 0.1

2.2. Determination the Formability of Sheet Metal

As it is known the formability of sheet metals is limited by localized necking or non-uniform strains that may occur within a small region in the plane of the sheet. The amount of strain that a sheet metal can tolerate just before localized necking is called limit strain. On this basis, forming limit diagrams (FLD) which has been a widely accepted criterion for fracture prediction in the sheet metal forming represent limiting major and minor available principal strains in the plane of the deformed sheet that can be achieved. According to literature (Moshksar and Mansorzadeh, 2003) FLD were introduced by Keeler and Goodwin in 1960. Different factors such as strain hardening exponent, anisotropy constant, tool geometry, friction effect, strain rate sensitivity, grain size influence the FLD’s (Stachowicz, 1989). A number of researhers investigated and detailed for the determination of the FLD’s by means of different parameters and some of them supported with FE analysis (Brunet, 1998; Zimniak, 2000; Butuc, 2003 and Kim, 2011).

In the presented study, in addition to basic mechanical properties, the forming limit tests were also performed to construct the forming limit diagram. To this end, the program, it’s called ARAMIS-v.6.2.0-3 was used. The sheet metal was cut as different width and specific sizes and it has created a scholastic distribution so that deformation could be measured optically. To determine the FLD, stretching test were carried out for sheet specimens with using a semi-sepherical punch. Forming limit diagrams were obtained with 10 different circle sample, which has different width, strain and stress, shown in Fig.1. The final report was taken any stage of the program and is seen on the Fig.2. As known, in the FLD, the higher the forming limit curve the beter is the formability. As seen in Fig.3. the specimens represent quite higher curve and this means that the material used the presented study is not easy to fracture and has good formability.

Fig.1. Deformed shapes of arc-shaped specimens obtained from the punch-stretch test.

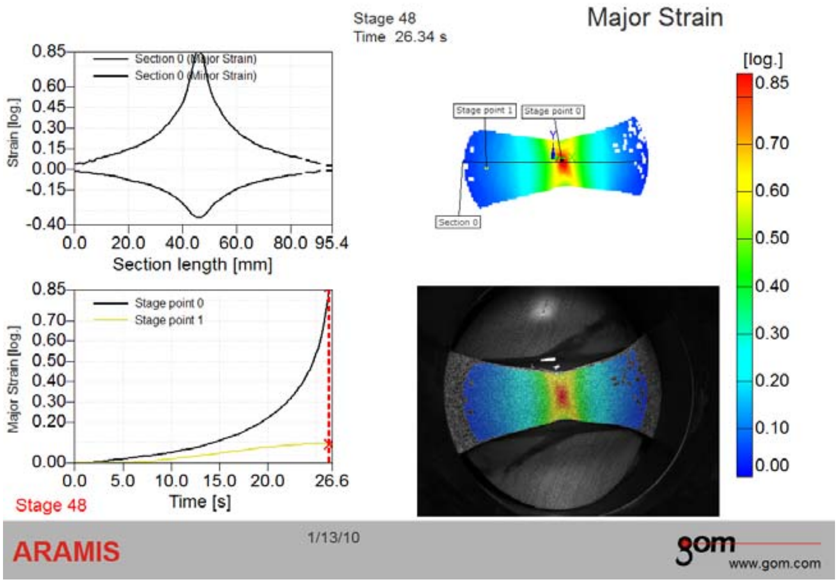


Fig.2. Final report of an any stage of the experiments

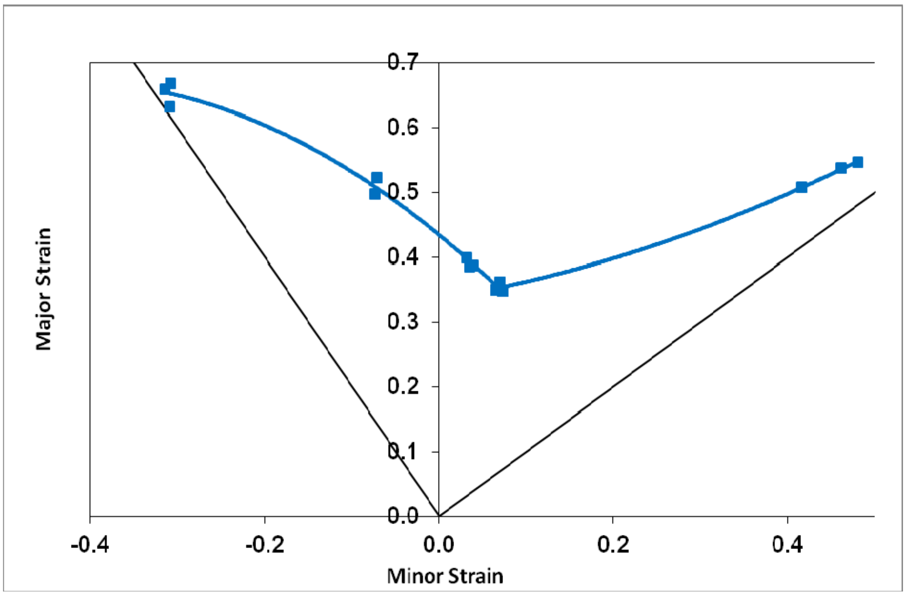


Fig.3. Static FLD's of steel sheets contructed on the basis of static punch-stretch test.

2.3. Equipment and Tool Set-up

Deep drawing experiments were carried out on a 125 metric ton capacity hydraulic press. Experimental set-up is shown in Figure 4a-4d. The punch has an outer diameter of 57.5 mm whilist the die ring has an outer diameter of 115 mm, an inner diameter of 59.7 mm and 40 mm in height. So upper limit of drawing ratio's was reached as 2.0. The die entrance radius was machined as 12 mm. Deep drawing force was calculated as 52 kN and blank holder force was calculated as 15.5 kN (Tonka, 2009). When the draw ratio is higher, punch force and stresses increases. That's why the max draw ratio is chosen in order to identify max thinning rates. Blanks were cut as diameter 115mm.

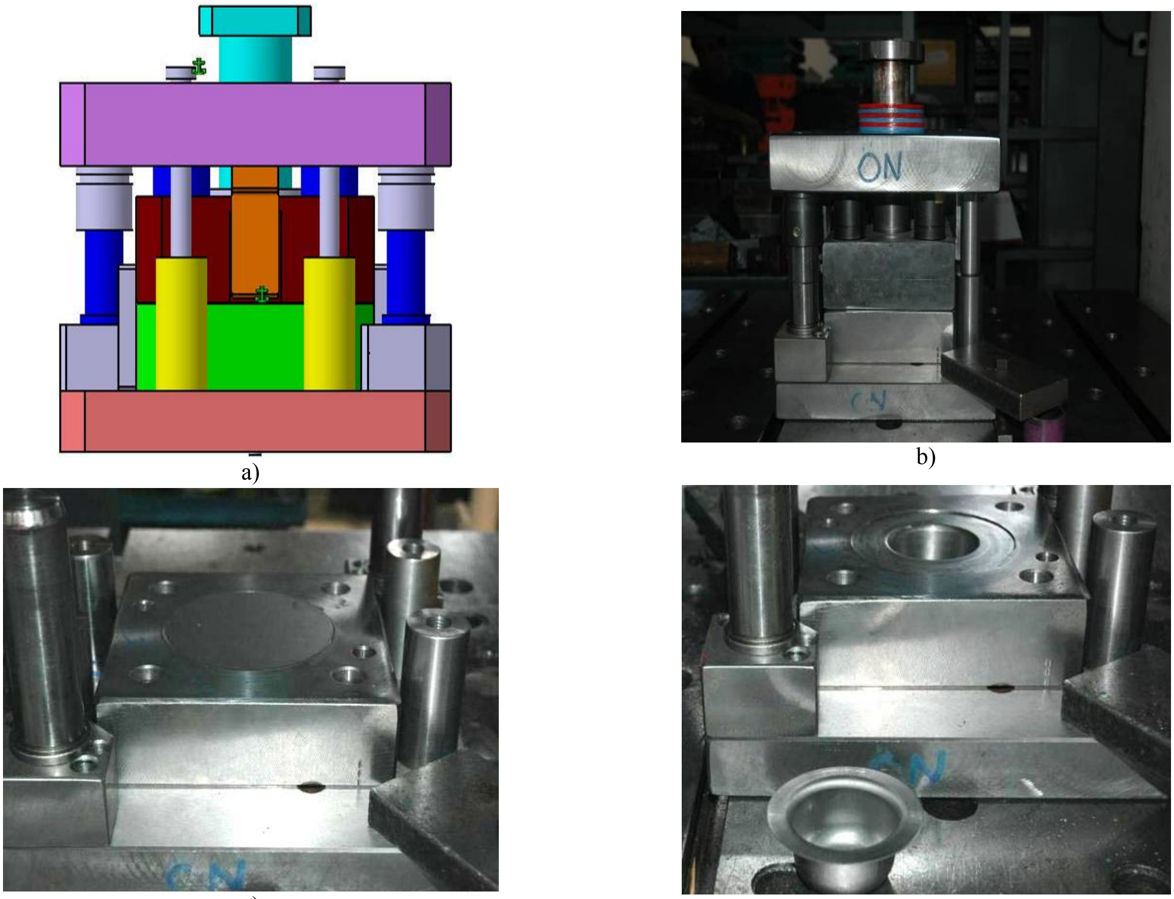
Thiruvarudchelvan et al (1999) explained in details that, in recent years three methods of applying the blankholding force in an inherently automatic manner in deep drawing have been introduced, developed and investigated experimentally and theoretically These are; 1) Friction-actuated blank holding, 2) The method using a short-stroke device, in which applicable to the common deep drawing of cylindrical cups at draw ratios of about 2.0 and, 3) The blank-holding force being generated as in 2 before, but differing in that the hydraulic pressure also augments the drawing process, thereby enabling larger drawing ratios of about 3.5. In this study a single-acting press was used but with gas springs, was created a double-acting press effect. When the gas springs were jammed in different stroke the force was increasing on the location, where the gas springs pressing. 4 gas springs were used in this deep-drawn, they were called HR700-63. In this die-set, blank holder force obtained blank pressing force from these gas springs and Boyle- Mariotte principle was used to find this blank pressing force (Tonka 2009). Firstly, gas springs were worked at 45 mm stroke. Total blank holder force was calculated 23 kN, when the relevant equations and graphs were used. Correspondingly, when 30 mm stroke was used 17 kN, 10 mm stroke was used 12,5 kN blank holder forces were obtained.

Three different blank holder forces were chosen in these tests. Total height was reached in 8 steps, when different blank holder forces used for every 5 mm stroke. There was no automatic stroke adjustment unit in that pres, which the tests were done. That's why 7 distance circular parts were used which having 5 mm thick. The circular part were used to obtain parts in the with different depth, between 5-40 mm. Three-dimensional measuring device used for measurement and thickness variation was measured from eight different points.

2.4. Autoform Solution

Numerical simulations and solid modeling programs are used commonly recently, to find optimum die surface before manufacturing to reduce of cost. One of those is Autoform which was used in this study. It reduces the number of training for die testing and surface. This program based on practical experience, industrial knowledge and expertise in sheet metal forming. It can find different solution for every step in the process to analyze and optimize. It is integrated and complete solution also has special functions for them. Thickness, % thinning, wrinkling can be showed, as well as, it can be used to take loads on the die elements, such as punch and forces.

In this study, when autoform simulation program is running, part and die elements position and stroke, the friction coefficient between sheet and die, finite elements with specific characteristics, material characteristics and unfold contour were entered as input values. Elasticity modules, poisson ratio, specific gravity, the values of anisotropy coefficients were entered as material data. In this way deep drawing force and values of wall thinning were obtained.



a) b) c) d)

Fig. 4. Deep drawing experimental rig a) Schematic representation of tools b)Tooling assembly c)Lower die with blank before the drawing d) After deep drawing.

3. RESULTS AND DISCUSSION

In the presented study, the thickness variations of IF steel in deep drawing process was investigated as theoretically and experimentally in limit drawing ratio of 2.0 and with three different blank holder forces. To measure the thickness changes after the deep drawing experiments an optical micrometer was used and thicknesses were measured in 5 mm ranges. Fig. 5 shows the points along the cup wall at which measurements were taken for thickness.

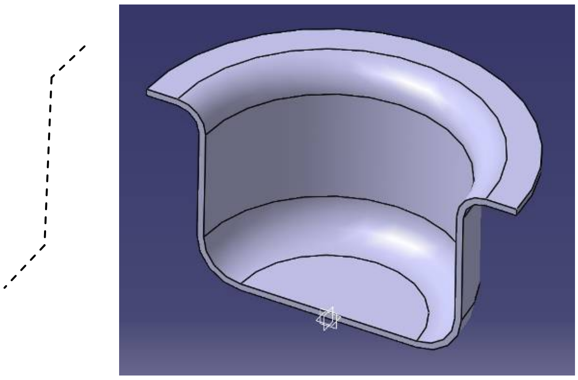
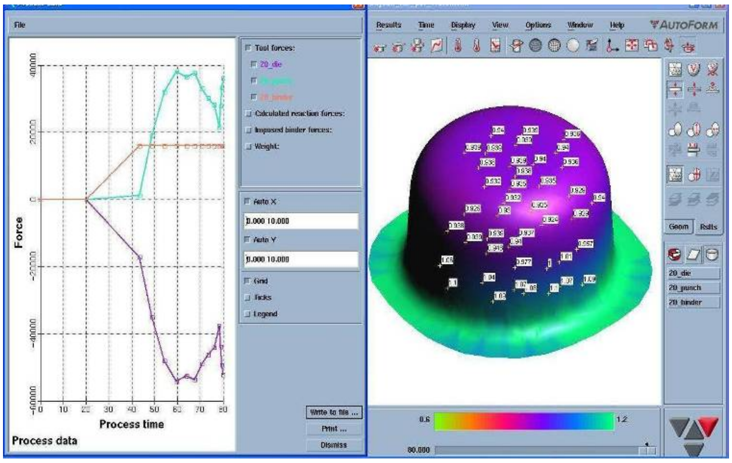
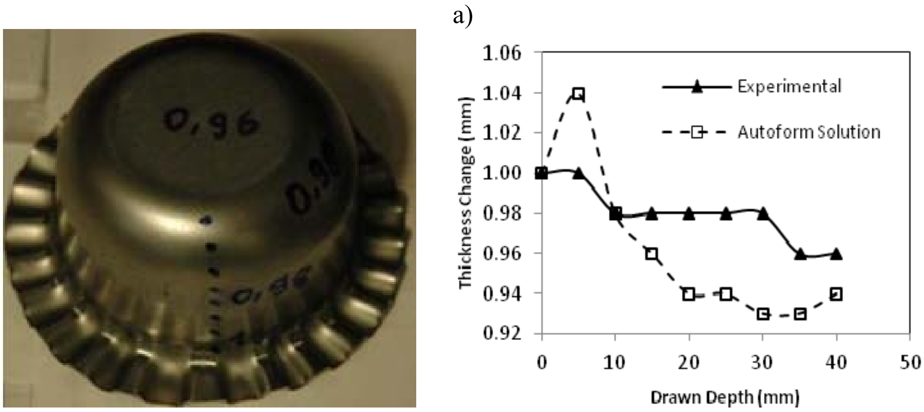


Fig.5. Schematic representation of thickness measurement line

The thickness variations predicted by the Autoform simulation and obtained from experiments for a cup drawn to a depth of 40 mm and a blankholder force of 12.5 kN are shown in Fig.6a and6b as comparable. As shown in the figures, there is a decrease in thickness from the top to bottom for 10 mm drawn depth and the thickness variation is only 2%. From this point on the thickness was fixed until 30 mm depth and the rate of thinning increased %4 on the deep part of cup. As known during deep drawing of cups wall thinning occurs at the bottom of the cup and thickening occurs near the top of the cup section and at the flange. However there was no thickness variation observed top of the cup section and at the flange against the other studies. Autoform program gaves thickness increase on the first 5 mm. The thickness decrease showed %6 on the mid of the part and %7 on the deep of the part. The average value for thickness is 5% greater for the predicted values for 12.5 kN blankholder force.



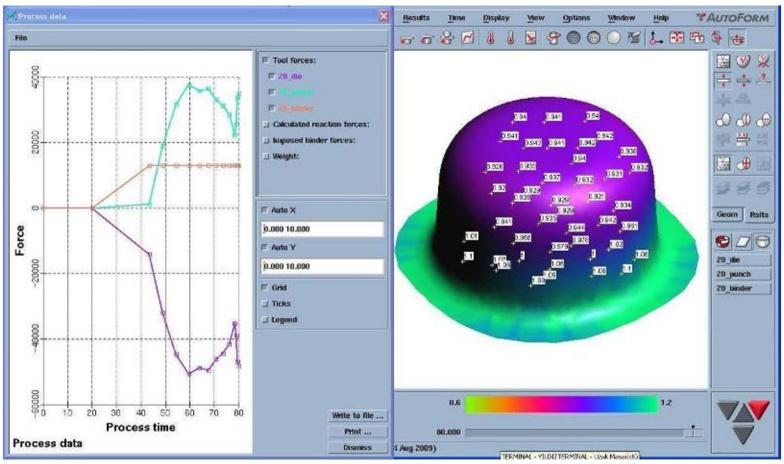
a)



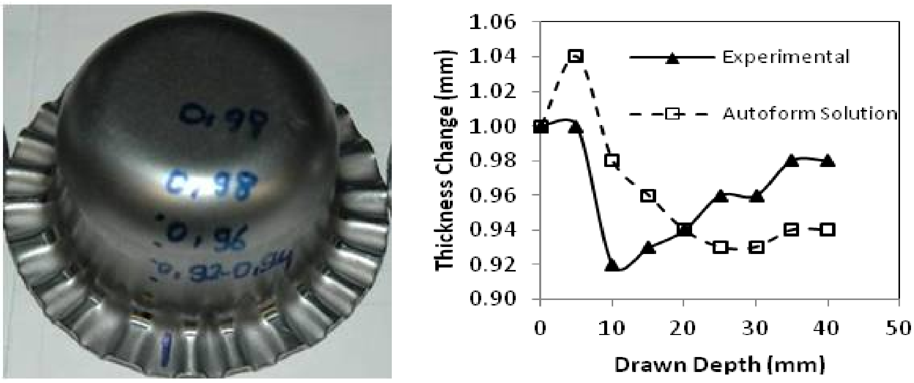
b)

Fig. 6. a) Autoform solution of wall thinning values for BHF=12.5 kN
b) Drawn cup and comparable thickness distribution of the cup wall for BHF=12.5 kN

The results of the experiment and Autoform solution are shown in Fig. 7a and 7b for 17 KN blank holder force. In the tests the thickness decrease reached until %8 for the first 10 mm but the value shown as %4 on the mid of part and as %2 on the deep of the part. On the other hand, according to Autoform result, the thickness increase was shown as %4 but after on the mid of part the thickness decrease was shown as %7 and on the deep of part was as %6. Values of wall thining in Autoform are more than measurements. The difference is max around %4.



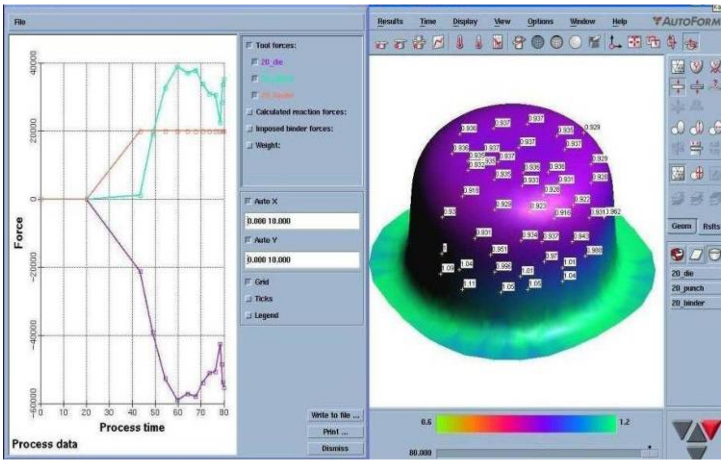
a)



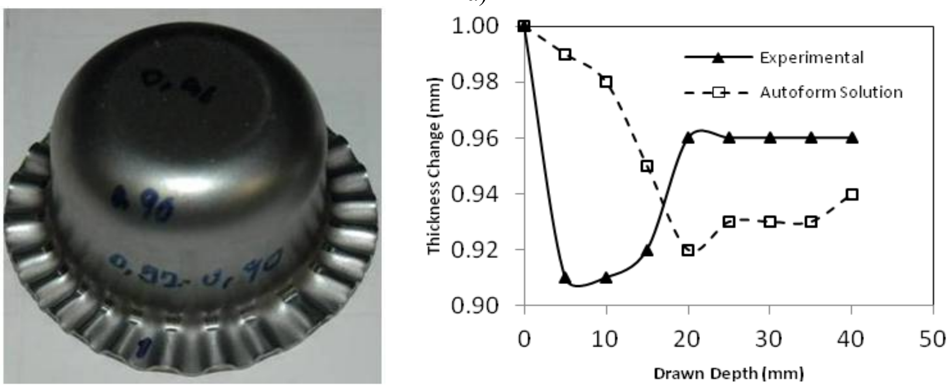
b)

Fig. 7. a) Autoform solution of wall thinning values for BHF=17 kN
b) Drawn cup and comparable thickness distribution of the cup wall for BHF=17 kN

Results obtained from Autoform and measured from experiments for 23kN blankholder force are shown in Fig.8a and 8b. In these tests, in the depth of first 10 mm, thickness dicrease is %9, then between mid and deep of the part is fixed, %4. Autoform gave more than these values and the difference is about %3. So, it can be said that Autoform can be used safely such operations.



a)



b)

Fig. 8. a) Autoform solution of wall thinning values for BHF=23 kN
b) Drawn cup and comparable thickness distribution of the cup wall for BHF=23 kN

That's why for the present die set Autoform was used to obtain the max. blank holder force which tearing occurred.200 kN was obtained and presented in Fig.9.

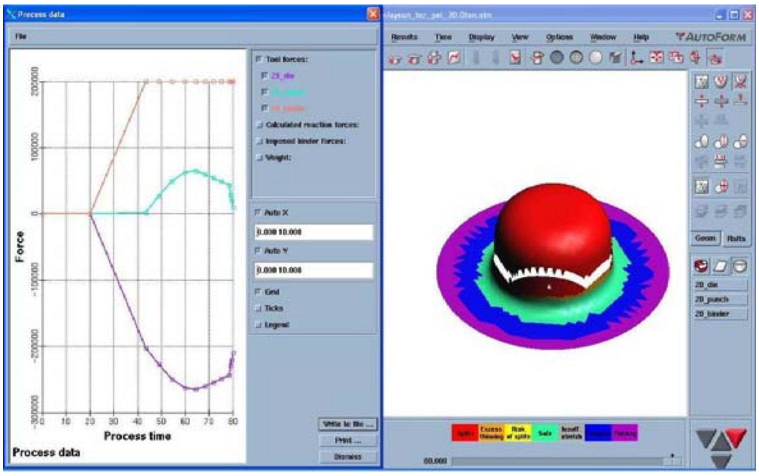


Fig. 9. Determination of max. BHF by using the AUTOFORM

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