An Investigation Into the Effects of Friction and Anisotropy Coefficients and Work Hardening Exponent on Deep Drawing With FEM

R. Hosseini [*a], A. Ebrahimi mamaghani [b], A. Asa [c]

[a]*Department of Mechanical Engineering, University ofTehran*
b Department of Mechanical Engineering, Tarbiat Modares University
c Department of Mechanical Engineering, University of Tehran

,ARTICLE INFO

Article history:

Received 2 Sep 2012
Accepted 12 jan 2012
Available online 20 May 2013

Keywords:

Deep drawing
Simulation
Forming Limit Diagram
Friction coefficient
Work hardening coefficient
Anisotropy coefficient

ABSTRACT

Large strains, anisotropy of mechanical properties of materials and Coulomb friction in contact regions are some properties in the analysis of deep drawing process. In this research, the effects of different parameters such as anisotropy coefficient, work hardening exponent and friction coefficient on deep drawing process of drawing quality steel are studied. For this purpose, the finite element method (FEM) to simulate the process is used. A 2D finite element simulation (axis symmetric) in ABAQUS is done and the results are validated with valid appropriate reference. Then Forming Limit Diagrams (FLD) for different friction coefficients, different anisotropy coefficients and different work hardening exponents are obtained. Finally, changes in FLD are discussed and it is observed that the friction coefficient is the most effective parameter on FLD and anisotropy coefficient and work hardening exponent are the least effective parameters on FLD.

1. Introduction

Nowadays, forming of sheet metals has found a wide range of applications from kitchen utensils to aircraft manufacturing. Also, with the presence of competitions in all industries and the efforts of manufacturers to reduce costs, the old production processes are constantly being optimized. Deep drawing which is one of the most widespread methods of forming sheet metals has an elastic-plastic and nonlinear characteristic and has drawn much attention of the researchers for a long time. In deep drawing, the sheet boundaries are held by a blank holder and then drawn into the die by a rigid punch, thus taking the shape of the punch. In Fig. 1 deep drawing process and its different parts are shown. In this process the blank holder holds the sheet metal in such a way that it can slide into the die. The blank needed for production of the part should have enough material for making the desired part. In deep drawing the design and construction of the tools such as the die demand high costs. The most important variable in deep drawing process is the initial sheet metal, since the type and thickness and mechanical properties of the sheet metal specify the dimensions of the die such as corner radius and the clearance of the die components as well as depth of drawing and the blank holder force.

*Corresponding author. Tel.: +989127573175
*E-mail address:*rhosseinimech@gmail.com&r_hosseini@ut.ac.ir(R. Hosseini).

Therefore, precise analysis of the process and making sure about its success in producing a completely flawless product is necessary so that the procedure of construction of the die and other tools does not involve the costly "trial and error" method. In this manner, knowing the distribution of strain in the product is the best way for prediction of wrinkling or rupture during the process and therefore making sure about the flawlessness of the product. For this purpose, strain distribution for deep drawing process through finite element method (FEM) has been studied and the results have been validated with valid appropriate results from other references.

Woo [1] has employed numerical methods to analyze the deep drawing of a cylindrical cup with a semi-spherical-headed punch. Sowerby et al. [2] have presented another method to measure the strains of the surface of deformed flange during the process of deep drawing with cylindrical punch. Chung et al. [3] formulated a finite element modeling program for simulating a general three-dimensional sheet stretching operation. Chen and Sowerby [4] presented a method to calculate the dimensions of the initial blank for optimum deep drawing process and developing optimum (or near net) blank shapes. Sukhomlinov et al. [5] presented a computational method for the analysis of the axisymmetric sheet metal forming processes such as deep drawing. Anderson [6] has done a numerical analysis based on finite element method (FEM) to study the symmetric deep drawing process.

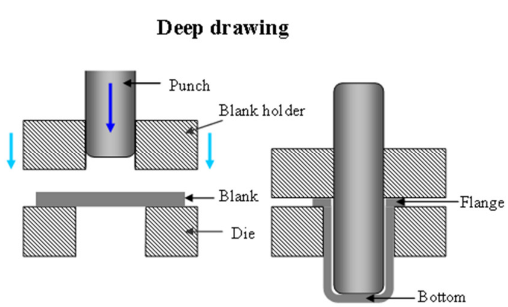

Fig.1. Deep drawing process and its parts.

Success in sheet metal forming depends on a variety of elements such as the degree of formability, the forming tools, the surface conditions of the sheet metal, lubrication, speed of forming and so on. This results in complicating the analysis of the forming process. Specification of regions of plastic non-stability and ultimate safe mode application of the sheet are possible through calculation of stress-strain distribution on the sheet metal surface by using analytic or computational methods and then comparing the results of stress-strain limits of the sheet metal. On the other hand, due to their high stiffness, proper weldability and formability, steel sheets have found many applications for deep drawing purposes in different industries especially automobile manufacturing. In order to use steel sheets for deep drawing purposes and forming processes it is necessary to affirm their formability and their appropriateness for forming by using formability tests. Specifying the value of maximum principal strains in different forming methods is one of the most effective ways in determining formability of sheet metals. Sheet metal formability depends on the type of steel, the design of the product, working tools, surface conditions of sheet metal, type of lubricant and the texture developed in the sheet metal. Formability limits in forming processes of plane sheet metals are determined in terms of principal strains by forming limit diagrams (FLD) [7, 8]. In fact in these diagrams it is shown how far the material can be strained. In other words, FLD determines limit strain values in sheet metals up to which the material can sustain necking or fracture. This limit is expressed in terms of combinations of major and minor principal strains formed on the sheet by using FLD's. Based on the values of these major and minor strains the forming limit of sheet metal under different conditions is specified [9,10]. The parts lying below the curve show the suitable areas for forming. Therefore, to improve the formability, the range of safety zone should be widened; in other words, the forming limit curves should move toward the upper part of diagram. Since FLD curves show the beginning of plastic non-stability, to determine the highest deformation the material can undergo during the forming process these curves have attracted much attention. Besides, these curves depend not only on the parameters of the material but also on geometry, friction and thickness of the sheet metal. Any point on this diagram is acceptable if it is located below the curve and if it lies above the curve, the dual strain of that point causes fracture in sheet metal. At this stage fracture implies the beginning of necking and not necessarily rupture [11]. Keeler and Goodwin have previously studied the use of this curve [12, 13]. These two researchers constructed forming limit diagrams for low-carbon steels, known as Keeler-Goodwin curves.

Along with the advances in designing technologies and manufacturing complex and critical parts, the use of appropriate scientific methods to enable savings in terms of time and costs as well as removing the problems and meeting the demands of industries is an important and vital issue, because ideal designing and manufacturing of complex products cannot be accomplished merely by relying on experience. Nowadays, a flexible software in solving problems through finite element method (FEM) in engineering research centers all over the world is ABAQUS which is employed as an influential, prominent engineering software in research centers of many industries. Most of the presented models of deep drawing process of sheet metals overlook the change in thickness of the sheet metal and the effects of friction during drawing process, thus providing a deficient analysis of this process. In the present project ABAQUS 6.10 software was employed for careful analysis of a deep drawn axisymmetric model. ABAQUS/Explicit is a product for special purposes suitable for simulation of transient dynamic problems such as collision, explosion, hitting test or semi-static or nonlinear problems (such as forming) in which the contact conditions are liable to change.

2. Effective parameters in deep drawing process

Studies reveal that many parameters can be influential in the degree of deformation of the parts produced by deep drawing method. Therefore, in order to optimize deep drawing process and to increase the precision of parts dimensions, it is necessary to know the effective process parameters, hence completely controlling the process. In deep drawing process, parameters such as the type of the used material, friction coefficient, anisotropy coefficient and work hardening exponent are effective.

Friction is an important though not much known parameter which can affect the deep drawing process. Simulation of friction is somehow difficult since the amount of friction during deep drawing process tends to vary in different areas and its experimental measurement is also not that easily possible. Generally, in the analyses of deep drawing process by finite element method, friction coefficient is considered as constant [15,16]; but if friction leaves an important impact on the results of the experiment, an analysis based on various friction coefficients should be done. For instance in Zohoor et al. [17] the springback phenomenon and the parameters affecting it were investigated by using finite element method, the ways for reducing the amount of springback for different metals were presented and the effect of the type of primary material, blank holder force and the value of friction coefficient on this phenomenon was studied. On the other hand, directional mechanic properties of microstructure (R) or anisotropy coefficient is another effective parameter in deep drawing process. Increase of anisotropy coefficient (R) in deep drawing results in decrease of tensile strength in flange area and ultimately decrease of deep drawing force. Also, by increase of R coefficient, the change of thickness (thinning) of the wall areas will decrease, thus greater depth can be obtained. In some articles, anisotropy has been considered normal and in some other studies such as Ahangar et al. [15], mechanical properties of the material in nonlinear state have been explored and finally variations of different strains for different results have been studied. Moreover, work hardening exponent or n coefficient is another important factor in deep drawing process. For example, Wei et al. parametrically studied the influence of parameters such as friction coefficient, work hardening exponent and anisotropy coefficient on upper bound-lower bound pressure diagrams for hemispherical cups in hydroforming process. They obtained formulations for specifying working range by using energy method [18].

3. Presenting the problem and simulation of finite element

It has been proved that although the forming limit diagrams of strains are appropriate in the analysis of material formability, they can be used only when the strain path is proper. In other words, when the proportion between principal strains during forming process is constant, with the change of strain path the shape of forming limit curve and hence the decision of the designer is liable to change. Therefore, finite element method is considered as the principal way for precise calculation in forming limit diagrams. In this manner, geometric model of the workpiece is depicted on an x-y axis and y is chosen as axis of rotation. The process modeling has been accomplished in ABAQUS6.10 software; owing to its Dynamic Explicit methodology, this software is quite capable of modeling the problems related to metal forming processes. The model used in this study has been shown in Fig. 2. It can be seen that an axisymmetric model has been used for simulation of the process.

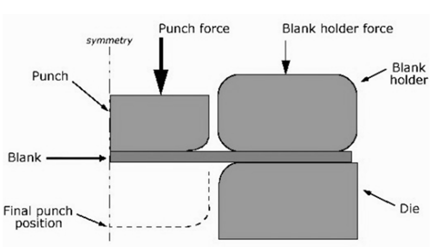

Fig.2. Model used in ABAQUS.

In this modeling independent samples have been used. Dimensional parameters of different modeled parts (mm) are presented in Table 1.
The distance between the punch and die is usually taken to be 1.3 times larger than the thickness of the sheet metal. Therefore by having the punch radius and the sheet thickness we can obtain the die radius. Dimensional geometry of different parts and the assemblies are shown in Fig. 3.

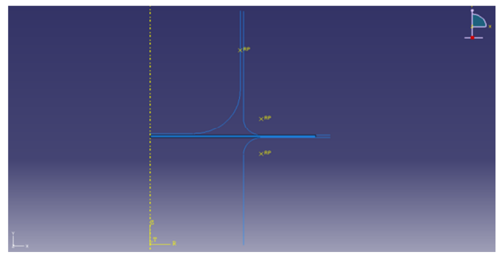

Fig.3. Parts model created in ABAQUS.

After modeling, a structured 1mm mesh was used for meshing the model. The blank shape after meshing is shown in Fig. 4. The blank holder force is considered 50000N.

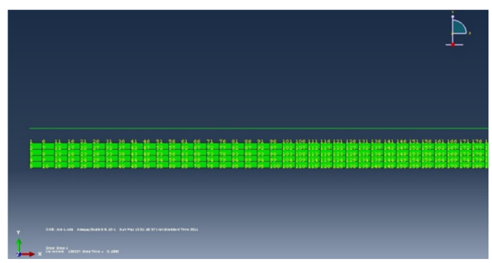

Fig.4. Meshed blank.

The studied material was Young module steel (E=200 GPa) and Poisson's ratio v=0.3 and follows the equation $\sigma=547\varepsilon^{0.18}$MPa. The model is then analyzed through Dynamic Explicit analysis in the present study. The accuracy of modeling should be inspected before the analysis. For this reason, the results for parameters presented in reference [19] have been obtained and compared with those found in our study, thus validating the latter results. In this manner, in this model and with the change of the values of parameters we are justified in generalizing the accuracy of results for other values, too.

Table1. Dimensional parameters of differentmodeled parts (mm)

depth	Die fillet radius	Die radius	Sheet thickness	Blank radius	Punch fillet radius	Punch radius
32	5	52	0.8	92	13	50

4. Analysis and comparison of results

The important point is that a path has been specified and a cross section of sheet metal (considering that it is axisymmetrical) has been chosen. The strains for that cross section along r and θ have been measured for each element, the maximum and minimum values have been specified and FLD curve has been constructed. Of course in drawing of experimental forming limit curves for comparison it should be noted that with the change of work hardening exponent and the value of anisotropy the curves are also liable to change.

As the first step in analyzing the results, a path in which the values of maximum and minimum strains along cross section of the blank should be specified for drawing FLD. The path was passed through mid plane of the blank. After choosing the path, the kind of output has been specified; in this work the maximum and minimum strains are needed. The initial values of anisotropy coefficient (*R* parameter) work hardening exponent (n) and friction coefficient (f) are 1.0, 0.18, and 0.05, respectively.

In the next step, by changing *R* parameter from 1 to 1.5 and keeping the other parameters constant, the sensitivity to anisotropy coefficient has been studied. In another step, by changing n parameter from 0.18 to 0.23 and 0.28 and keeping the other elements constant, the sensitivity to work hardening exponent has been investigated. Finally, by changing the value of coefficient of friction between blank holder, die, and the blank from 0.05 to 0.15 and 0.25 and keeping other coefficients constant, the sensitivity to friction coefficient has been analyzed. In the following figures, the diagrams of deep drawing for different frictions and various values of *R* and n have been shown. The specific points regarding each analysis are mentioned in the captions of each diagram.

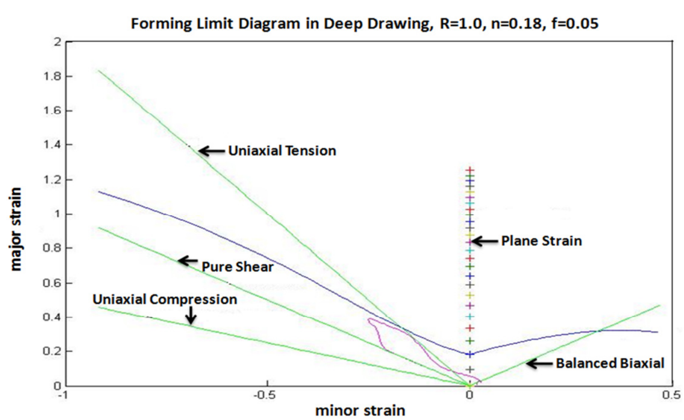

Fig.5. Forming Limit Diagram for R=1, n=0.18, f=0.05.

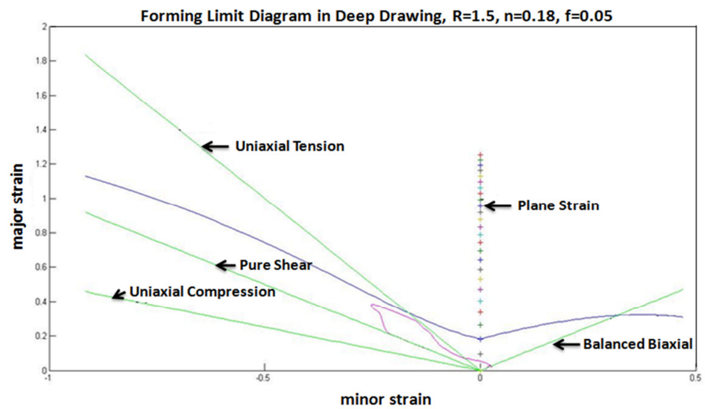

Fig.6. Forming Limit Diagram for R=1.5, n=0.18, f=0.05.

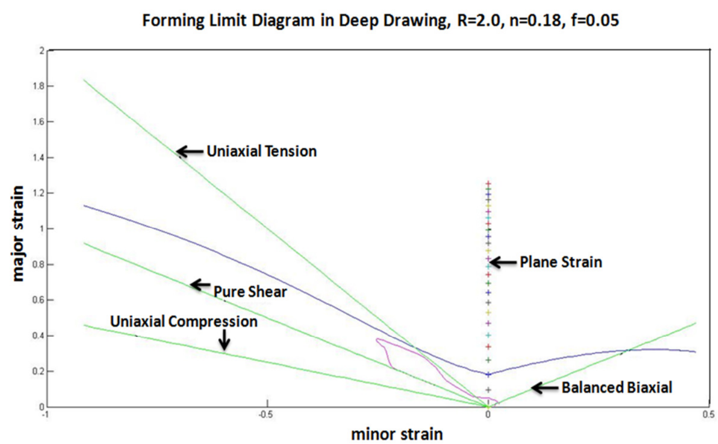

Fig.7. Forming Limit Diagram for R=2, n=0.18, f=0.05.

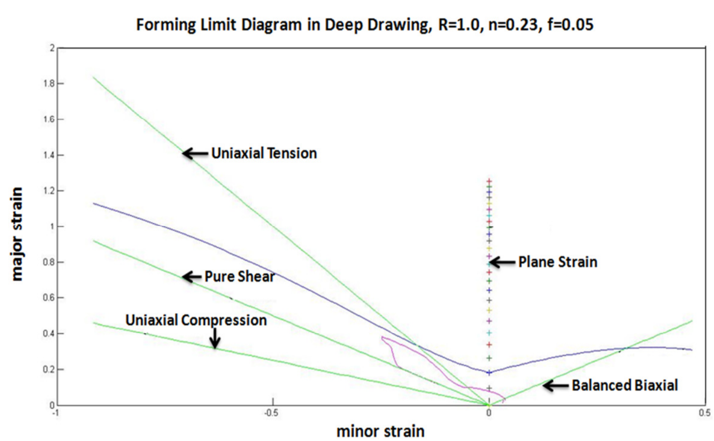

Fig.8. Forming Limit Diagram for R=1, n=0.23, f=0.05.

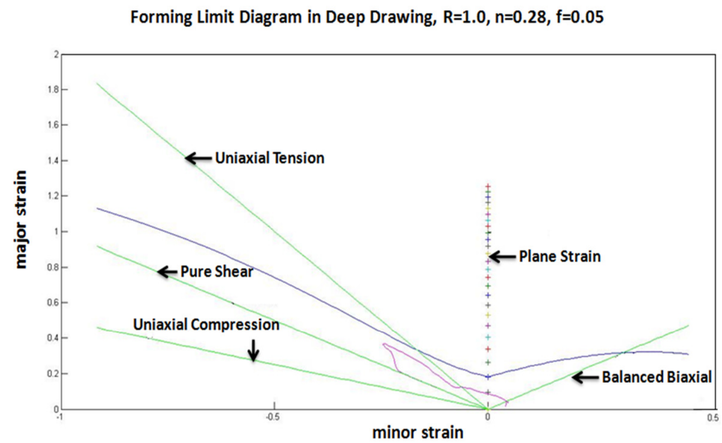

Fig.9. Forming Limit Diagram for R=1, n=0.28, f=0.05.

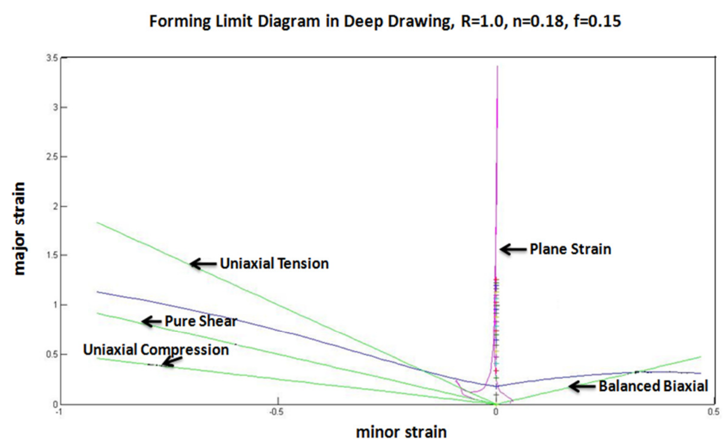

Fig.10. Forming Limit Diagram for R=1, n=0.18, f=0.15.

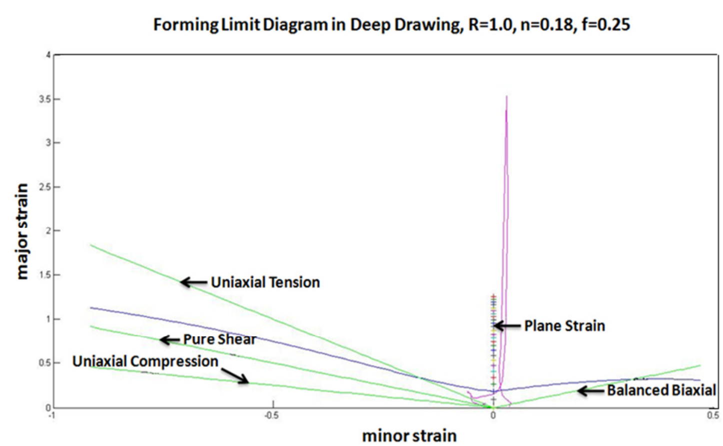

Fig.11. Forming Limit Diagram for R=1, n=0.18, f=0.25.

the deformed shape of the blank at the end of analysis (the last two diagrams), it can be seen that the blank has passed through the punch in the punch curvature because under the mentioned conditions and in the depth of 32 mm the blank is liable to rupture. This claim is justified by the relevant FLD in which the graph has cut the FLD. It can be observed that for high frictions between the blank and the blank holder (0.15 and 0.25) the process passes the forming limit and the workpiece is torn.
The main reason for occurrence of rupture is the large value of friction coefficient as well as the large value of blank holder force. If one of the parameters decreases to a specific extent, the rupture will occur and we obtain a hysteresis diagram. According to the solution of the problem for this friction coefficient, it can be seen that for $\mu = 0.05$ rupture does not happen.

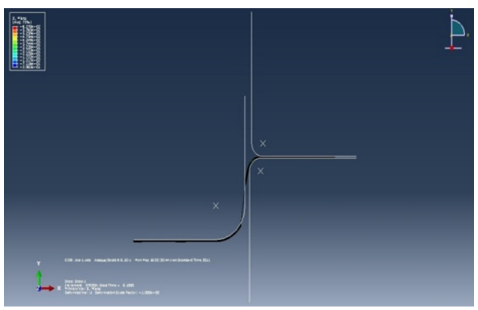

Fig.12. Final state of sheet for high friction.

4.1. Investigating the effect of work hardening exponent

For a better comparison of diagrams, forming limit curves (minimum and maximum strain curves for n = 0.18, 0.23 and 0.28, R = 1 and f =0.05 have been drawn simultaneously.
It is obvious that with increase of work hardening exponent the situation is improved and the intensity of rupture decreases. It can be seen that on the whole, the increase in work hardening exponent optimizes the forming process because with increase in n parameter the forming diagram moves toward the lower part of forming limit curve. It can be concluded that increase in the value of work hardening exponent can be effective to some extent, because in these two figures, despite the fact that the value of n has been doubled, the intensity of rupture has not considerably decreased (regarding the fact that some parts of the curves are located above the forming limit curve).

4.2 Investigating the effect of friction coefficient

Better comparison of diagrams, the forming limit curves (minimum and maximum strain curves) for friction coefficients f=0.05, 0.15 and 0.25, R=1 and n=0.18 have been constructed simultaneously.
It can be observed that increase and decrease in friction can be both beneficial (preventing rupture) and damaging (removal of the blank from under the blank holder). Here its damaging effect is witnessed since the blank has undergone rupture.

4.3. Studying the effect of anisotropy

The results of FLD's for three values of anisotropy coefficient r=1, 1.5 and 2, f=0.05 and n=0.18 have been simultaneously drawn in the following diagram.
As can be seen in the above diagram, with increase of anisotropy, the curve is widened and tends toward a hysteresis shape. This shows that the forming process is being optimized because the increase of anisotropy causes the decrease of tensile strength in the flange area as well as the decrease of deep drawing force; as a result, the thinning of wall thickness is lowered.
Of course this effect is not that much conspicuous; that is why we do not observe considerable changes in the diagram.

5. Conclusion

In the present paper we discussed the effects of different parameters such as anisotropy coefficient, friction coefficient and work hardening exponent on forming limit diagrams along with the trend of the The important point is that if we pay attention to

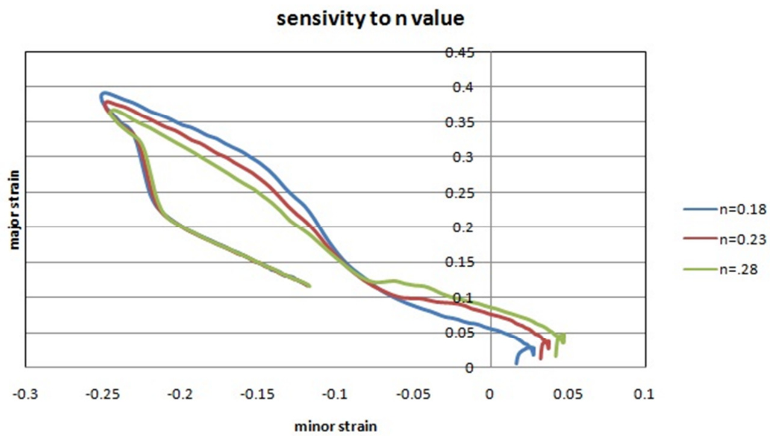

Fig.13. Forming Limit Diagram for variable values n (R=1, f=0.05).

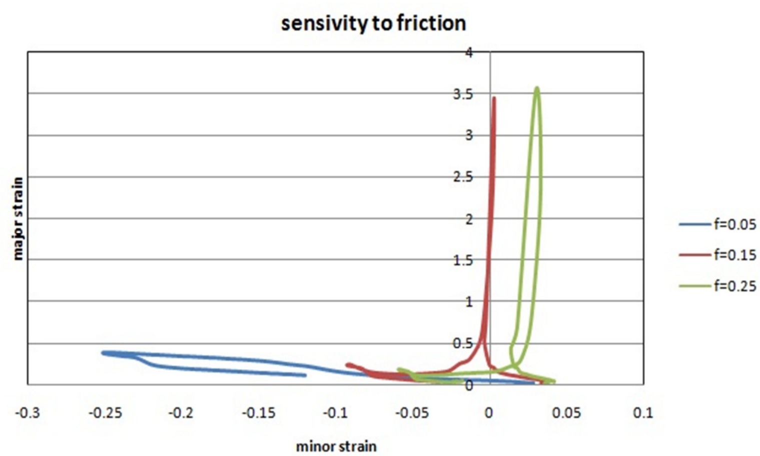

Fig.14. Forming Limit Diagram for variable values f (R=1, n=0.18).

.

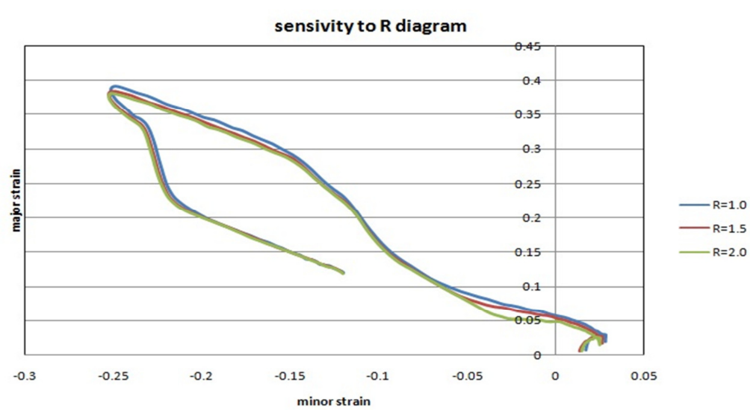

Fig.15. Forming Limit Diagram for variable values R (n=0.18, f=0.05).

changes of each parameter while keeping the other ones constant. Initially, an axisymmetric simulation of the deep drawing process was done in ABAQUS. For analysis of the results a path which passed through the mid plane of the blank, in which the values of minimum and maximum strains along the cross section of the blank are presented for construction of FLD, was specified. Finally, three values for friction coefficient, three values for anisotropy coefficient and three values for work hardening exponent were chosen and each time with keeping the other two parameters constant, the sensitivity of forming limit diagrams to the changes of variable parameter was investigated. It can be seen that increase of work hardening exponent optimizes the forming process, because with increase of the value of n the forming diagram passes below the forming limit curve. However, these changes are not very considerable, so this parameter can be ignored by a good estimation. It is also observed that increase and decrease of friction can be both beneficial (preventing rupture) and damaging (removal of the blank from under the blank holder). In this study its damaging effect was observed because the blank was torn. On the whole, a specific conclusion about the effect of friction coefficient cannot be arrived at as the results will vary for each case study. Regarding the effect of anisotropy it is revealed that increase in anisotropy causes the decrease of tensile strength in the flange area and decrease of deep drawing force. Thus the thinning of the wall is lowered. Of course this effect is not conspicuous and we do not observe considerable changes in diagrams.

References

[1] D.M.Woo, "On the complete solution of the deep drawing problem",*International Journal of Mechanical Sciences*, Vol. 10, 1968, pp. 10-26.

[2] R. Sowerby, J. Dunean, E. Chu, "The modeling of sheet metal stamping", *International Journal of Mechanical Sciences*, Vol. 28, 1986, pp. 415-430.

[3] L. Chung, R.H. Wanger, Y. Germain, "A rigid-viscoplastic finite element program for sheetmetal forming analysis",*International Journal of Mechanical Sciences*, Vol. 31, 1989, pp. 1-24.

[4] X. Chen, R. Sowerby, "The development of ideal blank shapes by the method of plane stresscharacteristics",*International Journal of Mechanical Sciences*, Vol. 34, 1992, pp. 159-166.

[5] L.G. Sukhomolinov, V.K. Englsberg, N.M. Dargdov, "A finite element membrane model forthe analysis of axisymmetric sheet metal forming processes",*International Journal of Mechanical Sciences*, Vol. 34, 1992, pp. 179-193.

[6] B.S.Andersin, A numerical study of the deep – drawing process, Number. Mech. Indust. Formingprocess, 12th- 16th July, Sunsea, U.K., 1982.

[7] S.P. Keeler, "Determination of forming limits in automotive starnpings",*Sheet Met Ind.*, Vol. 42, 1965, pp. 683-691.

[8] E.J.Obermeyer, S.A.Majlessi, "A review of recent advances in the application of blank-holder force towards improving the forming limits of sheet metal parts",*Journal Materials Processing and Technology*, Vol. 75, 1998, pp. 222-234.

[9] S.L. Semiatin, J.J. Jonas, "Formability and workability of metals: Plastic Instability and Flow Localization (Asm Series in Metal Processing, 2)", Asm Intl, 1984.

[10] W.F. Hasford,R.M. Caddel, "Metal forming mechanics and metallurgy", Prentice Hall PTR, 2 edition, 1993.

[11] E.D.George, "Workability testing techniques", American society for metal, 1987.

[12] S.P. Keeler, "Determination of forming limits in automotivestampings",*Sheet Metal Ind.*, Vol. 42, 1965, pp 683–691.

[13] A.K. Ghosh, J.V. Laukonis, "Mechanical Behavior of Materials", *Second Int.Conf.*, Boston, 1976, pp. 125-132.

[14] M. Grumbach, G.Sanz, Rev. de Metall, Vol. 1, 1972, pp. 145.

[15] R. Ghafooriahangar, F. Javanroudi, M. Pakbaz, "Effect of hydroforming deep drawing parameters and comparison of usual techniques by Finite Element method",Modares Technical and Engineeri ng, 1387. pp. 69-86.

[16] A. Razi, M. Moradi, B. Ghasemi,Aluminium deep drawing analysis with ABS system by Finite Element Method, M.S Thesis, Islamic Azad University Branch of Najaf Abad, 1388.

[17] M. Zohoor, A. Abbas beygi, "An investigation into springback in deep drawing by Finite Element Method",*Journal of faculty of Engineering, University of Tehran*, Vol. 40, 1385, pp. 65-71.

[18] S.-W. Lo, T.-C. Hsu, W.R.D. Wilson, "An analysis of the hemispherical-punch hydroforming processes",*Journal of Materials Processing Technology*, Vol. 37, 1993, pp. 225-239

[19] Abaqus documentation, v6.10, Dassault S.