Simulation studies on Deep Drawing Process for the Evaluation of Stresses and Strains

A.Purushotham

Department of Mechanical Engineering, SreeNidhi Institute of Science & Technology, Ghatkesar, Hyderabad
A.P. India -501 301

ABSTRACT:

Deep drawing is a sheet metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch. It is thus a shape transformation process with material retention. The process is considered "deep" drawing as the depth of the drawn part exceeds its diameter. The flange region (sheet metal in the die shoulder area) experiences a radial drawing stress and a tangential compressive stress due to the material retention property. These compressive stresses (hoop stresses) result in flange wrinkles. Wrinkles can be prevented by using a blank holder, the function of which is to facilitate controlled material flow into the die radius. The present study therefore aims at estimating the pattern of radial and hoop stress and strain distributions and their variation under different blank holding forces (BHF) and friction forces. In the paper , comparison between the stress and strain distribution with steel and copper materials also made by changing the blank holding force (BHF) and the friction force (FF) between the punch and the blank during the deep drawing process. The investigation of effect of friction and blank holding force is performed using the numerical software tool ABAQUS. ABAQUS software is used to model the deep drawing process to evaluate stresses under BHF and FF.

Key Words: *Deep drawing, BHF, FF, Hoop stress, Radial stress, wrinkle, Necking.*

I. INTRODUCTION

Drawing [1] is a sheet metal forming operation used to make cup-shaped, box-shaped, or other complex-curved, hollow-shaped parts. It is performed by placing a piece of sheet metal over a die cavity and then pushing the sheet into the opening with a punch. The blank is held down flat against the die by a blank holder. The component developed in this process is subjected to the following state of stress☹i) Compression in the circumferential direction (the outer perimeter becomes smaller) (ii) Tension in the radial direction (iii)A relatively small compression in the thickness direction (iv)Since the volume of metal remains constant, and because the circumferential stress is relatively large, the sheet will thicken as it moves in the flange area. (This is why the clearance between the punch and die is higher than the sheet thickness by about 10%).The success of a drawing operation depends upon the several factors including:

The formability of the material being drawn, Limiting the drawing punch force to a lower value than that which will fracture the shell wall, Adjustment of the blank holder force to prevent wrinkles without excessively retarding metal flow, and Selecting materials for both die and blank to have sufficient coefficient of friction. Many literatures tried to model the process in order to study the influence the above mentioned parameters. In this paper, the process is modeled with ABAQUS software and studied the influence of BHF(Blank Holding Force) and coefficient of friction(FF) on the stresses and strains developed in the deep drawed components. The induced strains and stresses are the main responsible to reduce the defects such as wrinkling, tearing and necking. The paper is organized in the following manner:

Literature on modeling of deep drawing process is given in section two. The simulation modeling and the results obtained through the developed models are described in section three and four respectively. Section five drws the conclusions.

II. LITERATURE REVIEW

In 2005, Dr. Waleed Khalid Jawad [4] solved finite element program code (ANSYS 5.4), is used to perform the numerical simulation of the deep drawing operation. A simplified axisymmetric model of cylindrical cup has been developed, and the numerical results are compared with the experimental work.In 2007, A. Wifi* A. Mosallam [5] presented a finite element-based assessment of the performance of some non-conventional blank-holding techniques. This includes friction actuted, pulsating, and pliable blank-holding techniques. Ben Ayed, A. Delamézière, J.L. Batoz, C. Knopf-Lenoir] [6] optimized both a constant and a time dependent blank holder force. In this paper ,the numerical simulations are performed using ABAQUS Explicit. The optimization is based on a response surface method.

III. FINITE ELEMENT MODELING

Abaqus/Standard used for the analysis of friction conditions at the deep drawing of a cylindrical cup. Deep drawing of sheet metal is an important manufacturing technique. In the deep drawing process a "blank" of sheet metal is clamped by a blank holder against a die. A punch is then moved against the blank, which is drawn into the die. Unlike the operation described in the hemispherical punch stretching example, the blank is not assumed to be fixed between the die and the blank holder; rather, the blank is drawn from between these two tools. The ratio of drawing versus stretching is controlled by the force on the blank holder and the friction conditions at the interface between the blank and the blank holder and the die. Higher force or friction at the blank/die/blank holder interface limits the slip at the interface and increases the radial stretching of the blank. In certain cases draw beads, shown in, are used to restrain the slip at this interface even further. During the drawing process the response is determined primarily by the membrane behavior of the sheet. For axisymmetric problems in particular, the bending stiffness of the metal yields only a small correction to the pure membrane solution. In contrast, the interaction between the die, the blank, and the blank holder is critical. Thus, thickness changes in the sheet material must be modeled accurately in a finite element simulation, since they will have a significant influence on the contact and friction stresses at the interface. In these circumstances the most suitable elements in Abaqus are the 4-node reduced-integration axisymmetric quadrilateral, CAX4R; the first-order axisymmetric shell element, SAX1; the first-order axisymmetric membrane element, MAX1; the first-order finite-strain quadrilateral shell element, S4R; the fully integrated general-purpose finite-membrane-strain shell element, S4; and the 8-node continuum shell element, SC8R. Membrane effects and thickness changes are modeled properly with CAX4R. However, the bending stiffness of the element is low. The element does not exhibit "locking" due to incompressibility or parasitic shear. It is also very cost-effective. For shells and membranes the thickness change is calculated from the assumption of incompressible deformation of the material.

3.1 Deep Drawing Geometry Details:

From Fig.3.1, the following description can be made: The circular blank being drawn has an initial radius of 100 mm and an initial thickness of 0.82 mm. The punch has a radius of 50 mm and height from is 60mm. The die has an internal radius of 51.25 mm and is rounded off at the corner with a radius of 5 mm. The blank holder has an internal radius of 49 mm.

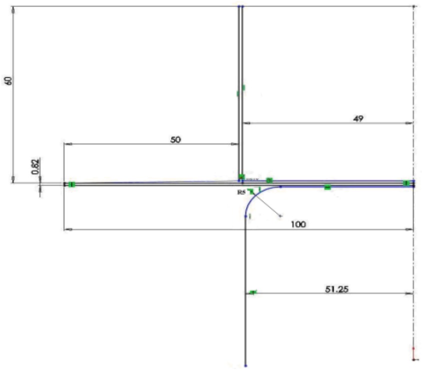


Fig. 3.1: Geometry deep drawing

3.2 Simulation Model:

The developed simulation model is shown in Figure 3.2.The blank is modeled using 40 elements of type CAX4R or 31 elements of type SAX1, MAX1, models. These meshes are rather coarse for this analysis. However, since the primary interest in this problem is to study the membrane effects, the analysis will still give a fair indication of the stresses and strains occurring in the process.The contact between the blank and the rigid punch, the rigid die, and the rigid blank holder is modeled with the contact pair option. The top and bottom surfaces of the blank are defined by means of the surface option. The rigid punch, the die, and the blank holder are modeled as analytical rigid surfaces with the Rigid body option in conjunction with the surface option. The mechanical interaction between the contact surfaces is assumed to be frictional contact. Therefore, the Friction option is used in conjunction with the various *surface interaction property options to specify coefficients of friction.

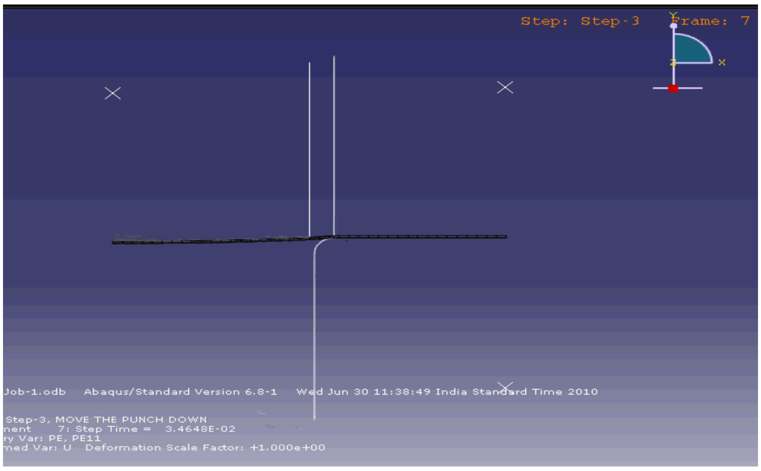


Fig 3.3 Simulation Model

IV. RESULTS AND DISCUSSIONS

Deforming shape in the drawing process for the CAX4R model is shown in fig 4.1. The profiles show that the metal initially bends and stretches and is then drawn in over the surface of the die. The distributions of radial strain, circumferential strain and thickness strain for the CAX4R model are shown. The thickness does not change very much, the change is very small. Relatively small thickness changes are usually desired in deep drawing processes and are achieved because the radial tensile strain and the circumferential compressive strain balance each other. The deformed shape after complete unloading is superimposed on the deformed shape under complete loading. The analysis shows the lip of the cup springing back strongly after the blank holder is removed for the CAX4R model. This springback in the CAX4R model is not physically realistic: in the first-order reduced-integration elements, an elastic "hourglass control" stiffness is associated with the "bending" mode, since this mode is identical to the "hourglass" mode exhibited by this element in continuum situations. In reality the bending of the element is an elastic-plastic process, so that the springback is likely to be much less.The deformed shape after complete unloading is superimposed on the deformed shape under complete loading. The analysis shows the lip of the cup springing back strongly after the blank holder is removed for the CAX4R model. No springback is evident in the shell models. As was noted before, this springback in the CAX4R model is not physically realistic: in the first-order reduced-integration elements an elastic "hourglass control" stiffness is associated with the "bending" mode, since this mode is identical to the "hourglass" mode exhibited by this element in continuum situations. In reality the bending of the element is an elastic-plastic process, so that the springback is likely to be much less. A better simulation of this aspect would be achieved by using several elements through the thickness of the blank, which would also increase the cost of the analysis. The springback results for the shell models do not exhibit this problem and are clearly more representative of the actual elastic-plastic process.

***4.1 Simulated Diagrams with the variation BHF and friction*:** The simulated diagrams under two sets of BHF and friction given in the figures from 4.1 to 4.9.

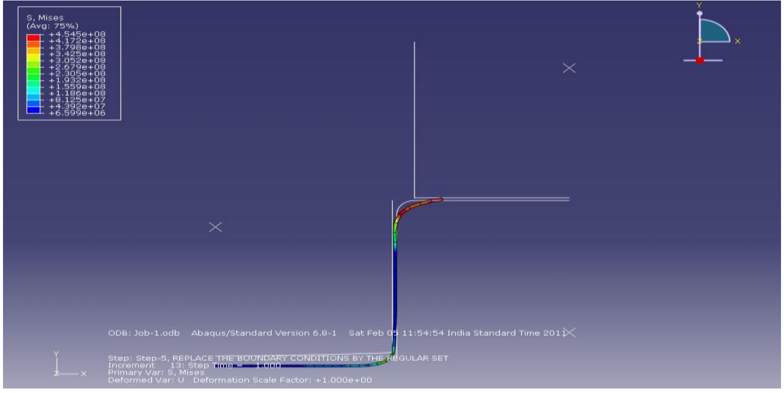
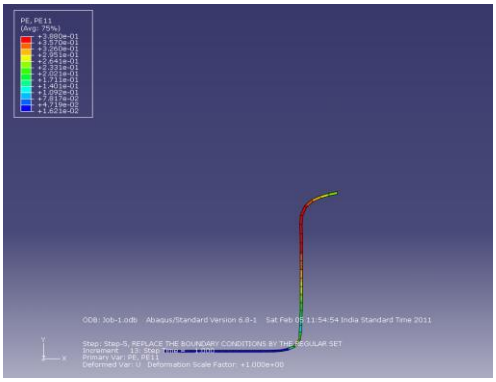


Fig 4.1 Von-Mises stress distribution when (B H F=10 kN, µ=0.1)



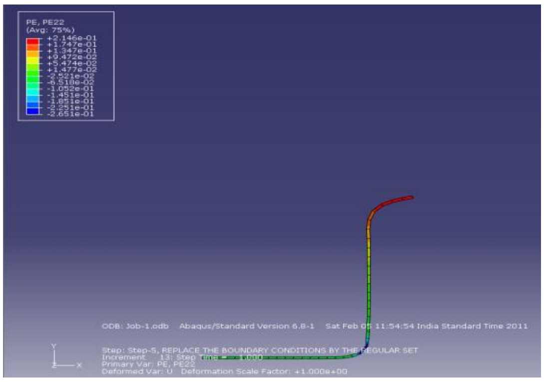
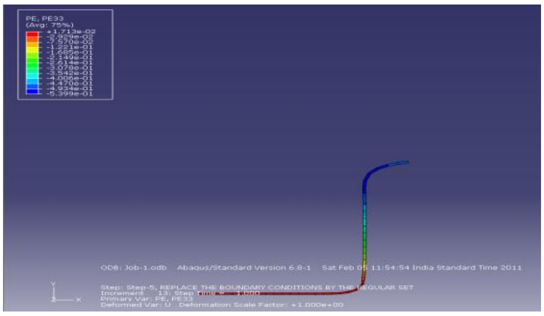


Fig 4.2 Radial Strain **Fig 4.3 Longitudinal strain**

4.2 The influence Blank Holding Force: From the Fig 4.10.it is observed that in case of steel Radial Strain increase from 0.3871to 0.489 as the Blank Holding Force is varying from 10 to 130kN. In case of copper the Radial Strain was Increasing from 0.404 to 0.454, when the Blank Holding Force is varying from 10 to 90kN.It is interesting to note that the rise in Radial Strain within the given range of Blank Holding Force is rapid when compare to steel. From the Fig 4.11. In case of steel Thickness Strain is observed to reduce from 0.2332 to 0.1932 and in case of copper it is reducing from 0.1972 to 0.1460 to the Blank Holding Force increasing from 10to 130kN in case of steel, and 10 to 90 in case of copper. It is



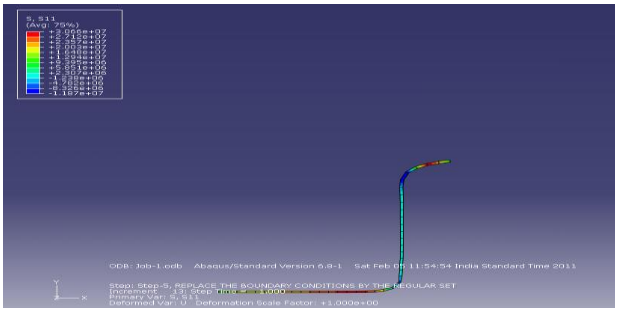
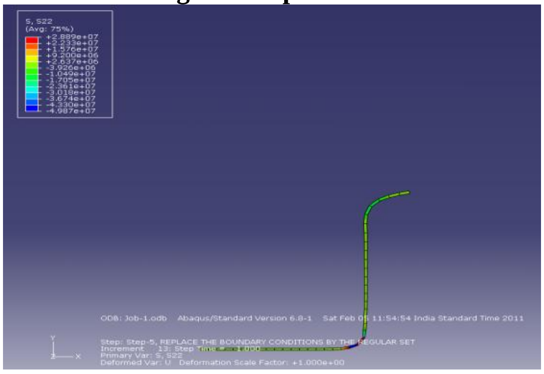


Fig 4.4 Hoop strain **Fig 4.5 Radial Stress**



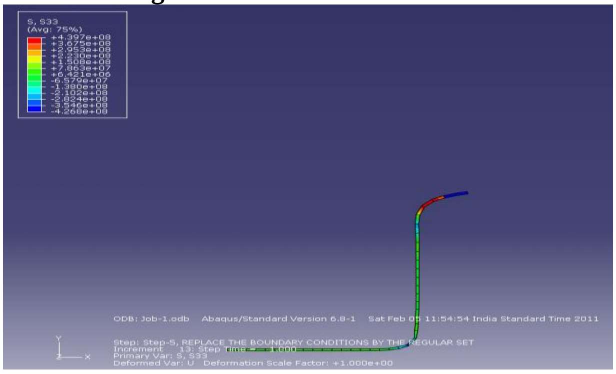
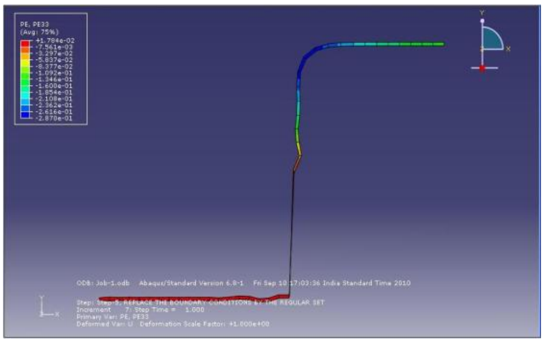


Fig 4.6 Longitudinal Stress **Fig 4.7 Hoop Stress**



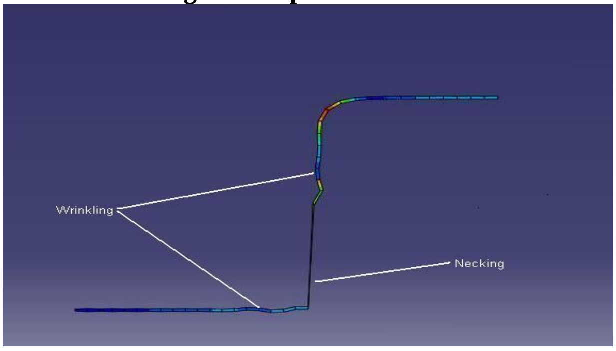


Fig 4.8 Failures in copper Radial Strain **Fig 4.9 Failure of a steel Cylindrical Cup (BHF=130 kN, μ=0.1)**

interesting to note that the fall in thickness strain in case of copper is more rapid when compare to steel. From the Fig 4.12.In case of steel Hoop strain is increasing from .0018 to .0036 as the blank holding force is increased from 10kn to 130 kN. From the Fig 4.13.In case of copper Hoop strain is decreasing from 0.0197 to 0.0191 as the blank holding force is increased from 10kn to 130 kN.

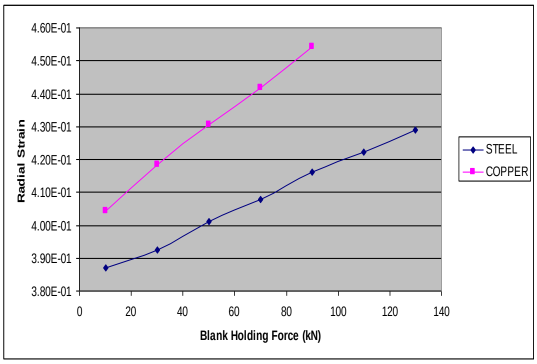


Fig 4.10 Radial strain Vs Blank Holding Force

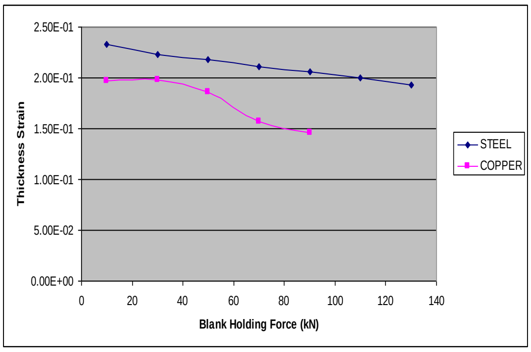


Fig 4.11 Longitudinal Strain Vs Blank Holding Force

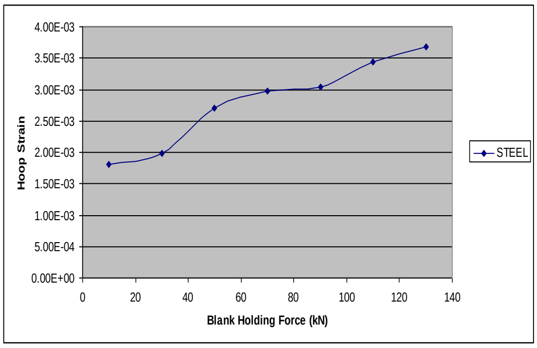


Fig 4.12 Hoop Strain Vs Blank Holding Force

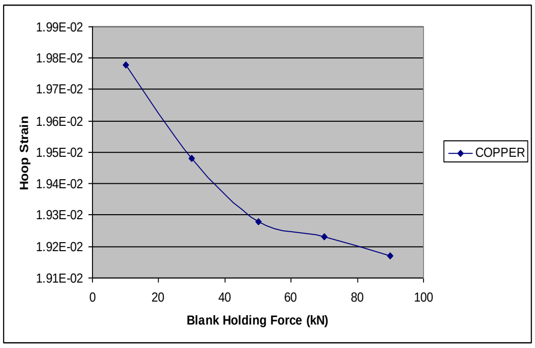


Fig 4.13 Hoop Strain Vs Blank Holding Force

From the Fig 4.14.In case of steel von mises stress is decreasing from 4.598E2 to 4.575E2 as the blank holding force is increased from 10kN to 130 kN. The decrease in von mises stress decreases the failure of cylindrical cup which is the major requirement in the cup forming process. From the Fig 4.15.In case of copper von mises stress is decreasing from 3.421E2 to 3.212E2 as the blank holding force is increased from 10kN to 130 kN.It can be seen that the fall in von mises stress is more in copper compared to steel.

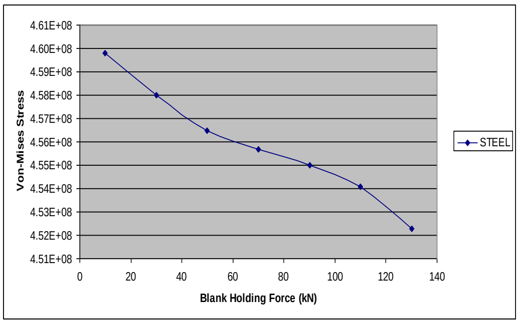


Fig 4.14 Von-Mises stress Vs Blank Holding Force

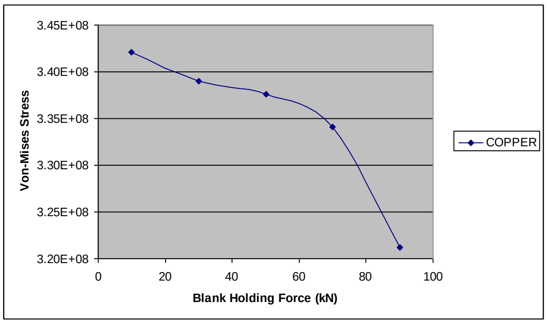


Fig 4.15 Von-Mises stress Vs Blank Holding Force

From the Fig 4.16.In case of steel Radial Stress is observed to increase from 28.38Mpa to 31.28Mpa as the Blank Holding Force is varying from 10 to 130kN.In case of copper the Radial Stress was Increasing from 18.26 to 25.08Mpa, when the Blank Holding Force is varying from 10 to 90kN.It is interesting to note that the rise in Radial Stress within the given range of Blank Holding Force is rapid when compare to steel.From the Fig 4.17.In case of steel Thickness Stress is observed to increase from 15.26 to 21.08Mpa and in case of copper it is increasing from 22.84 to 29.23Mpa as the Blank Holding Force increasing from 10 to 130kN in case of steel, and 10 to 90kN in case of copper. It is interesting to note that the rise in thickness stress in case of copper is more rapid when compare to steel. From the Fig 4.18. In case of steel hoop stress is observed to increase from 4.41E2 to 4.62E2 as the Blank Holding Force is varying from 10 to 130kN.From the Fig 4.19. In case of copper the hoop stress was increasing from 3.1E2 to 3.32E2, when the Blank Holding Force is varying from 10 to 90kN.

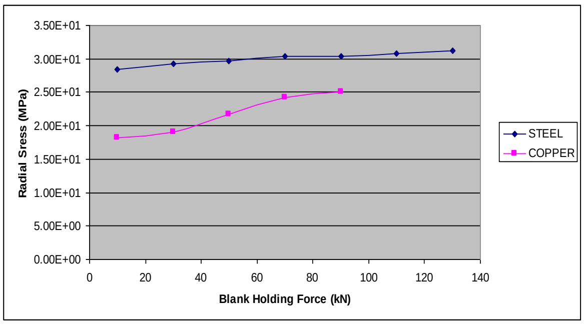


Fig 4.17 Thickness Stress Vs Blank Holding Force

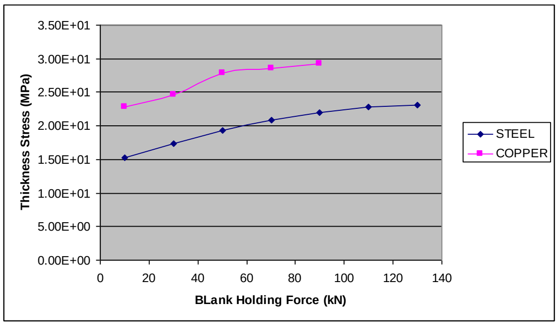


Fig 4.16 Radial Stress Vs Blank Holding Force

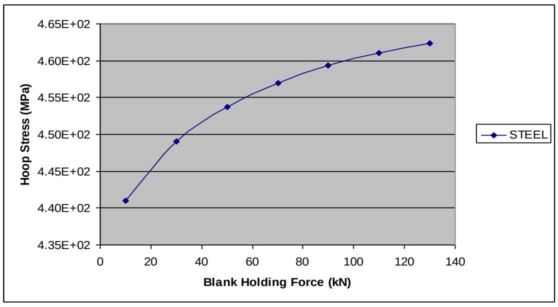


Fig 4.19 Hoop Stress Vs Blank Holding Force

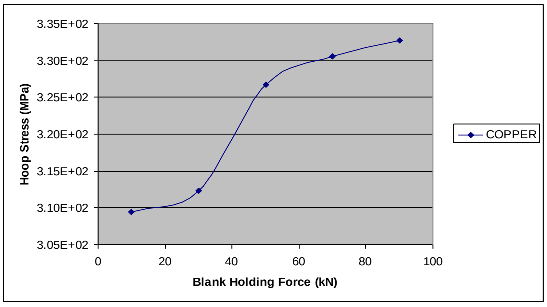


Fig 4.18 Hoop Stress Vs Blank Holding Force

4.3 The influence of Coefficient of friction:

From the Fig 4.20.In case of steel Radial Strain is observed to increase from 0.378 to 0.389 as the coefficient of friction is varying from 0.1 to 0.45.From the Fig 4.21.In case of copper as the coefficient of friction is varied from 0.1 to 0.45, the radial strain is decreasing gradually from 0.404 to 0.401.From the Fig 4.22.As the coefficient of friction is varied from 0.1 to 0.45 in case of steel the thickness strain is increasing from 0.2146 to 0.239. From the Fig 4.23.As the coefficient of friction is varied from 0.1 to 0.45 in case of copper the thickness strain is increasing from 0.1954 to 0.1993. From the Fig 4.24.In case of steel as the coefficient of friction is varied from 0.1 to 0.45 hoop strain is decreasing from 0.01713 to 0.1273 and where as in copper it is decreasing from 0.0233 to 0.0179.

From the Fig 4.25.As the coefficient of friction is varied from 0.1 to 0.45 von mises stress is increasing from 4.545E2 to 4.666E2 in case of steel.

From the Fig 4.26In case of copper also as the coefficient of friction is varied from 0.1 to 0.45 von-mises stress is increasing from 3.423E2 to 3.452E2.From the Fig 4.27.As the coefficient of friction is varied from 0.1 to 0.45 radial stress is increasing from 28.29 to 30.66 Mpa in case of steel.From the Fig 4.28.In case of copper as the coefficient of friction is varied from 0.1 to 0.45 radial stress is decreasing from 22.47 to 22.25 Mpa. It is interesting to note that radial stress is increasing in steel and in copper radial stress is decreasing as the coefficient of friction is varied from 0.1 to 0.45.From the Fig 4.29.The thickness stress is increasing from 15.26 to 34.99Mpa in case of steel as the friction is increased whereas in copper thickness stress remains constant from friction value of 0.1 to 0.2 and after 0.2 thickness stress is increasing.From the Fig 4.30.Hoop stress is increasing from 4.39E2 to 4.522E2 Mpa as the coefficient of friction is varied from 0.1 to 0.45 in case of steel.From the Fig 4.31.whereas in case of copper Hoop stress is increasing from 4.39E2 to 4.522E2 Mpa as the coefficient of friction is varied from 0.1 to 0.45.

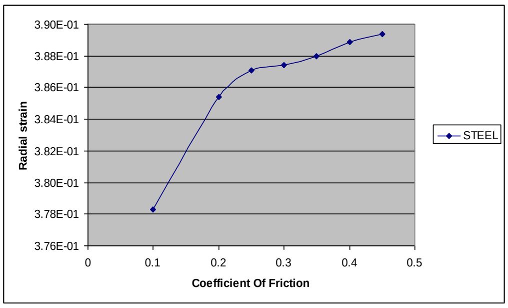


Fig 4.21 Radial Strain Vs Coefficient of Friction

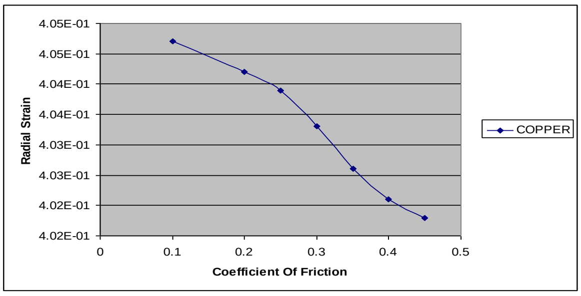


Fig 4.20 Radial Strain Vs Coefficient of Friction

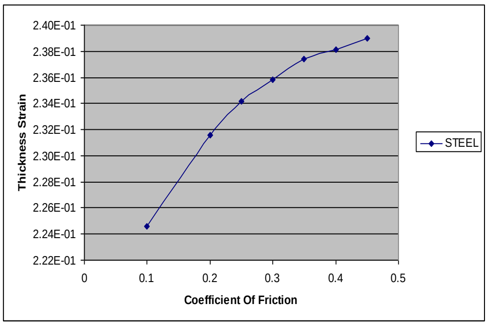


Fig 4.23 Thickness Strain Vs Coefficient of Friction

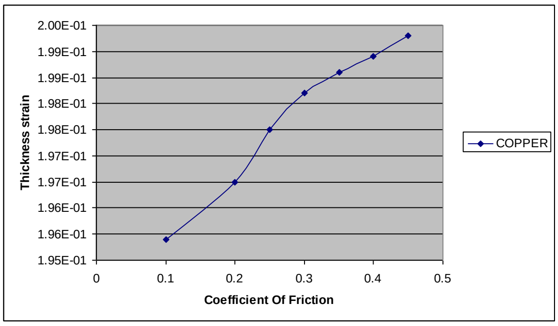


Fig 4.22 Thickness Strain Vs Coefficient of Friction

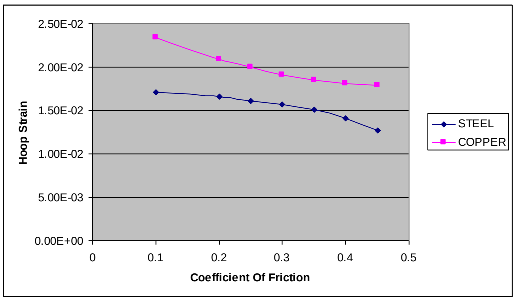


Fig 4.25 Von-Mises Stress Vs Coefficient of Friction

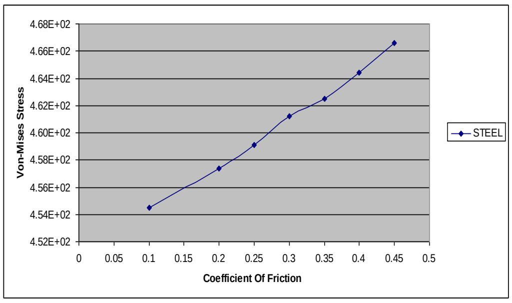


Fig 4.24 Hoop Strain Vs Coefficient of Friction

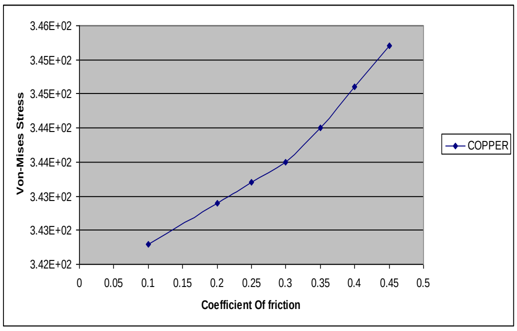


Fig 4.26 Von-Mises Stress Vs Coefficient of Friction

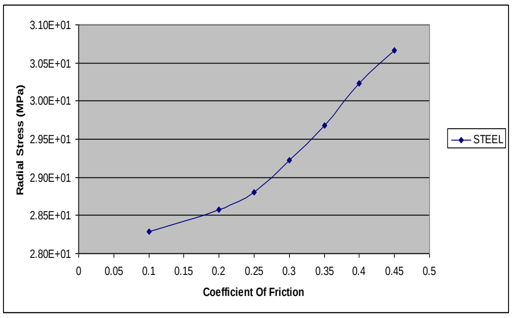


Fig 4.27 Radial Stress Vs Coefficient of Friction

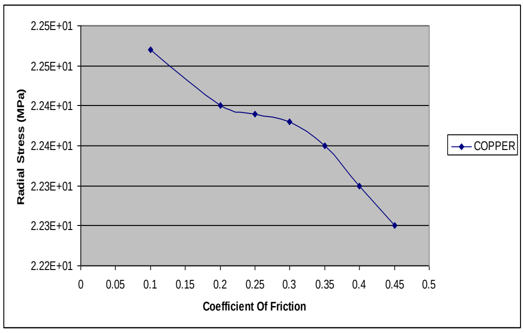


Fig 4.28 Radial Stress Vs Coefficient of Friction

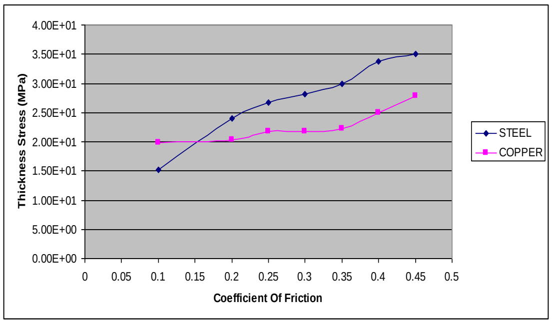


Fig 4.29 Thickness Stress Vs Coefficient of Friction

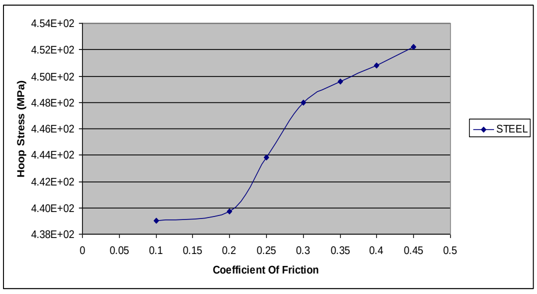


Fig 4.30 Hoop Stress Vs Coefficient of Friction

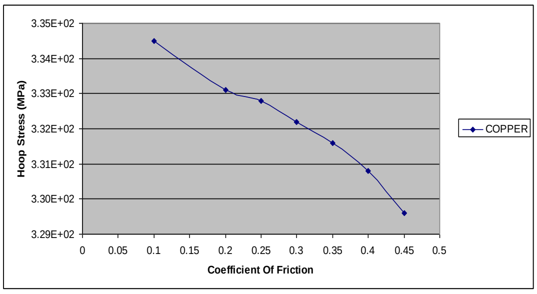


Fig 4.31 Hoop Stress Vs Coefficient of Friction

V. CONCLUSIONS

In this simulation , an attempt is made to understand the effect of BHF and the friction between punch and the blank on the formation of a deep drawing of cylindrical cup.The following conclusions are made from the simulation studies:

- A finite element procedure using ABAQUS is established to simulate the deep drawing process. This includes the selecting proper element type, the matrial model , the loading sequence and the process parametrs like friction and blank holding force for successful deep drawing pros\cess to estabish cylindrical cups.
- When increasing the BHF, the thickness stress increases and thickness strains decreases thereby the formation of wrinkles are restricted and prevents necking and rupture.
- The BHF of upto 130KN was safe for froming steel without introducing wrinkles and necking as compared to copper.
- The friction value of 0.05 between punch and blank and a BHF of 10KN is oberved to be wrinkles free forming for steel as compared to copper.
- The optimum BHF to eliminate wrinkles largely depends on its mechanical flow properties of the material considered.

The outcome of the simulation studies reveled the fact that it is essential to control the slip between the blank and its holder and die and if the slip is restrained too much, the material will undergo severe stretching, thus potentially causing necking and rupture. If the blank can slide too easily, the material will be drawn in completely and high compressive circumferential stresses will be developed, causing wrinkling in the drawn product. Appropriate conditions are proposed and studied in this thesis to control blank holding forces and friction in order to limit the circumferential stresses there by wrinkles are minimized in the product.

ACKNOWLEDGEMENT

The author thanks the H.O.D. Mechanical Engineering and Executive Director , SreeNidhi Institute of Science and Technology: Hyderabad for financial and resources help in bringing out this paper.

REFERENCES

[1] **R.K.Jain**, “*Production Technology”*,Khanna Publishers,2006.

[2] **Amitabha Ghosh,Asok Kumar Malik, “***Manufacturing Science”*,Affiliated East- west Press Private Limited,2000.

[3] **P.N.Rao**,**“***ManufacturingTtechnology,”*TataMcGraw-Hill,1999.

[4] **Dr. Waleed Khalid Jawad “***Investigation of Contact Interface between the Punch and Blank in Deep DrawingProcess”*Eng.&Technology,Vol.25,No.3,2007.

[5] **A. Wifi** co-operating with **A. Mosallam “***Some aspects of blank-holder* force *schemes in deep drawing” process,*Department of Mechanical Design and Production, Faculty of Engineering, Cairo University,Giza12316,EgyptAMMEJ.,VOLUME,24,2007

[6] **L. Ben Ayed, A. Delamézière, J.L. Batoz, C. Knopf-Lenoir “***optimization and control of the blank holder force in sheet metal stamping with application to deep drawing of a cylindrical cup”* European Congress on Computational Methods in Applied Sciences and Engineering ECCOMAS 2004.

[7] **Jonathan Mckinley”** Warm Forming of Aluminum Brazing Sheet”.

[8] **Shang, H.M., Chau, F.S., Tay, C.J. and Toh, S.L.,** "Hydro forming Sheet Metal Into Axisymmetrical Shells With Draw-In of Flange Permitted” Transaction of the **ASME**, Vol. 107, 1985, pp 372-378.

[9] **Lee, P.K., Choi, C.Y. and Hsu, T.**C., "Effect of Draw-In on Formability in Axisymmetric Sheet Metal Forming,"J.ofEngineeringforIndustry,Nov.,1973,pp925-930.