Single Stage Steel Cup Deep Drawing Analysis using Finite Element Simulation

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Abstract **- The Design And Control Of A Deep Drawing Process Depends Not Only On The Work Piece Material, But Also On The Geometry And Material Of The Tools Like Blank Holder, Punch, Die Etc. And Also The Interaction Between Them. This Paper Aims At Simulating Single Stage Deep Drawing Process Of A Steel Cup Using Specifications Close To Industrial Specifications; And To Study The Effect Of Variation In These Parameters. 'Blank Holder Force', 'Die Fillet-Radius' And 'Friction Coefficient' Are The Key Parameters For Deep Drawing. The Effect Of These Parameters On 'Deformed Cup Thickness', 'Punch Reaction Force', And 'Equivalent Plastic Strain' Of The Final Product Is Analyzed. Fillet Radius Of Die Has Been Observed To Be The Most Sensitive Variable And Blank Holder Force Is The Least Sensitive Among Them.**

Keywords- Blank Holder Force, fillet radius, friction coefficient, equivalent plastic strain.

1. Introduction

Single stage deep drawing is a process of deep drawing involving one cycle of punch movement through the die and back to the original position resulting in deformation of the blank to a desired shape. In general it is a process of shaping flat sheets into hollow articles mostly cylindrical in shape without fracture or localized thinning [1].

There have been a lot of research on deep drawing process and as a result it has been continually improving. With the advent of new materials and advancement in computer technology there is a lot of scope for studying and further improving this process through computer simulation especially using the finite element method (FEM). A recent study employing FEM shows that limiting drawing ratio (LDR) of tailor welded blanks (TWB) could be improved by modifying the weld line [2]. Warm deep drawing was also simulated using FEM and a key finding was that formability improves when the die and blank holders were heated above 150° C [3]. FEM study on thermal deep drawing of carbon fiber woven composite shows that compression and shear between the fiber bundles is a key parameter for this material [4]. A variable blank holder force (BHF) scheme using numerical simulation was found out to be more effective for deep drawing of LPG bottles in a study done in Portugal [5]. One study proposes a novel procedure which eliminates the use of draw beads and blank holder by using conical dies [6]. This paper aims at successful numerical simulation of the deep drawing process of a steel cup, using the geometry and parameters close to the industrial specifications. Analyses of different test geometry and parameters of deep drawing components are carried out. This will help to identify which parameter has the most effect on the deep drawing process.

2. Model Definition

The geometry of the cup is first decided and the whole setup of the deep drawing components is designed around it. The dimensions are presented in table 1.Two dimension axisymmetric geometry is presented in fig 1. These specifications will remain the same and one parameter at a time will be modified for parametric study in the following sections.

Table1. Dimension specifications of the deep drawing setup

Component	Dimension(mm)
Punch diameter	38
Blank diameter	80
Blank thickness	1
Punch fillet radius	3
Die fillet radius	3
Friction coefficient	0.1
Clearance between die and punch	1
Drawing stroke	20

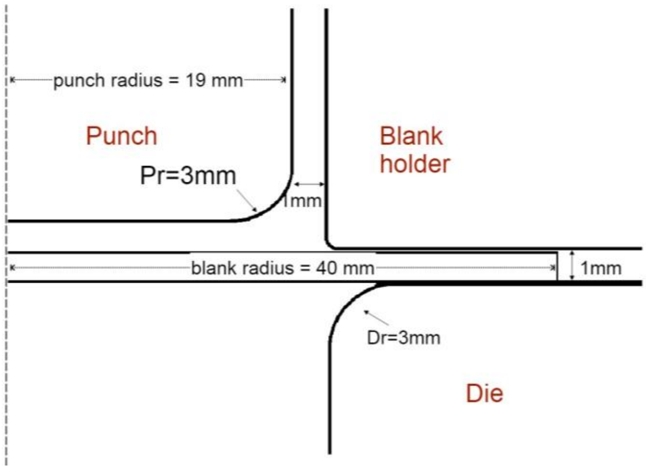

Fig. 1. Dimensions of the deep drawing components

3. Material definition

The blank used is of Austenitic (Cr-Ni) stainless steel, AISI 304 [7]. It is highly ductile, and has excellent drawing and forming properties [8]. Physical properties are shown below in table 2 and Chemical composition is shown in table 3.

Table.2 Physical properties of AISI 304 [9]

Physical property	Value
Modulus of elasticity	200 GPa
Poisson's ratio	0.29
Modulus of shear	86 GPa
Density	8000 kg/m^3
Ultimate tensile strength	550 MPa
Yield tensile strength	250 MPa

Table.3 Chemical Composition of AISI 304 [10]

Component	Composition by weight percentage (%)
C	0.08
Cr	18-20
Fe	66.345-74
Mn	2
Ni	8-10.5
P	0.045
S	0.03
Si	1

4. SIMULATION USING FINITE ELEMENT ANALYSIS

It is a computerized numerical analysis for solving complex mathematical models mostly in mechanical engineering for stress analysis [11]. It involves calculation of nodal forces and displacement throughout the model which is discretized in the form of mesh [12]. A 2-d axisymmetric model is chosen for the sketch creation in Abaqus. Two different material definitions are used namely 'deformable' and 'rigid'. Deformable is the blank and rigid are the rest of the model which are tools. Under tools come blank holder, punch and die. Material property is assigned in the property module (table 4).

Table.4 Elastic and Plastic properties of the assigned material

Isotropic Elastic	
Young's Modulus	200000 MPa
Poisson's Ratio	0.3
Isotropic Plastic	
Yield Stress (MPa)	*Plastic Strain*
400	0
420	0.02
500	0.2
600	0.5

5. FEA MODEL ASSEMBLY

The four components of deep drawing which are punch, die, blank-holder and blank are produced and assembled in Abaqus (fig 2). Now appropriate constraints and loads can be applied to the individual components.

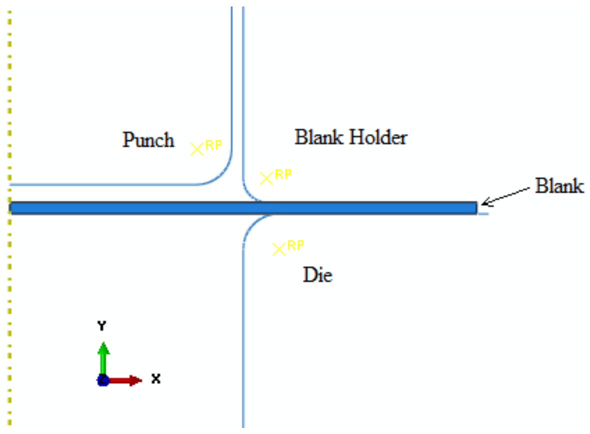

FIG. 2. FE MODEL ASSEMBLY

5.1 Loads

A load of 800 N is applied on the Blank Holder in the downward direction to simulate a contact between the Blank Holder and the Blank (fig 3).

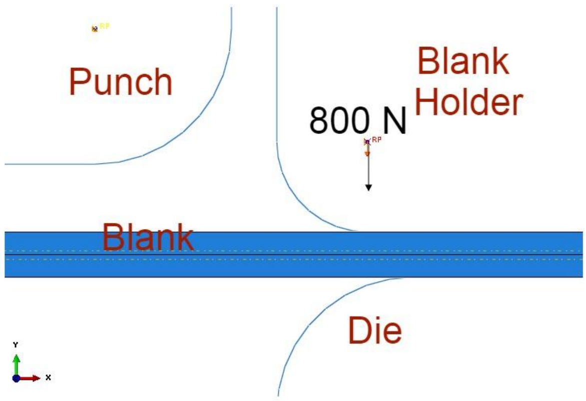

FIG. 3. 800 N BHF IN DOWNWARD DIRECTION

5.2 Boundary Conditions

Blank Holder has been left free for movement in the y direction. The die has been assigned 'encastre' property and cannot move in any direction (fig 4). Punch is displaced downwards along Y-axis first to establish contact with the blank, then a small displacement to commence drawing process, then full displacement to achieve full deep drawing of the blank and then it is released back to the original position to disengage from the deformed cup thus produced. Three surface to surface interactions have been created between punch-blank, blank holder-blank, and die-blank, each having coefficient of friction as 0.1 in the interaction module.

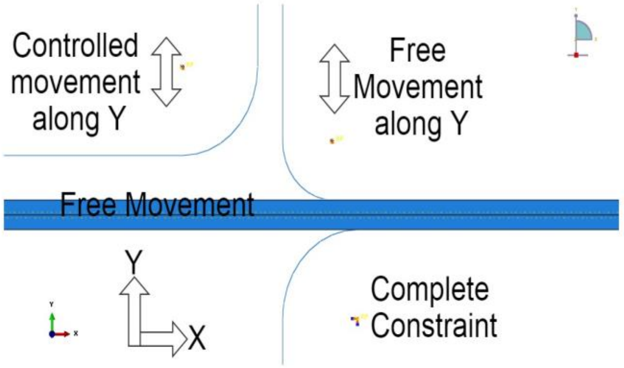

Fig. 4. Initial boundary conditions on each part

5.3 Mesh

The blank is meshed using global seed size of 0.5. The two dimensional blank face is partitioned into 2 units for easy meshing (fig 5). Quad-shape is used for meshing because of its simplicity and symmetric stress distribution.

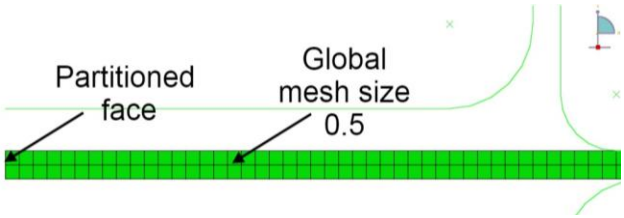

Fig. 5. Mesh generation

5.4 Simulation steps

NOW THE APPLIED CONSTRAINTS, DISPLACEMENT AND LOADS CAN ACT TOGETHER TO SIMULATE THE DEEP DRAWING PROCESS. THE DEEP DRAWING OF THE BLANK INVOLVES THE FOLLOWING STEPS:

1. INITIAL SETUP STEP.
2. CONTACT ESTABLISHMENT BETWEEN BLANK HOLDER AND BLANK.
3. APPLICATION OF BLANK HOLDER FORCE.
4. CONTACT ESTABLISHMENT BETWEEN PUNCH AND BLANK.
5. SMALL DISPLACEMENT OF PUNCH TO BEGIN THE MOVEMENT OF THE PUNCH FOR DEEP DRAWING.
6. FULL DISPLACEMENT OF PUNCH TO COMPLETELY DISPLACE THE PUNCH THROUGH THE DIE.
7. RELEASE OF PUNCH TO BRING BACK THE PUNCH TO ITS ORIGINAL POSITION.

THE UN-DEFORMED AND DEFORMED STATES OF THE BLANK ARE SHOWN IN FIGURE 6 AND FIGURE 7.

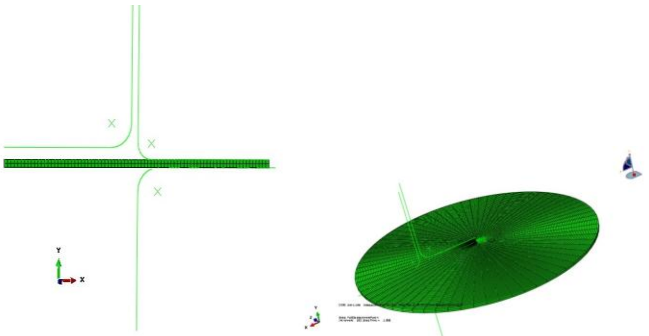

FIG. 6. UN-DEFORMED 2-D AND 3D VIEW.

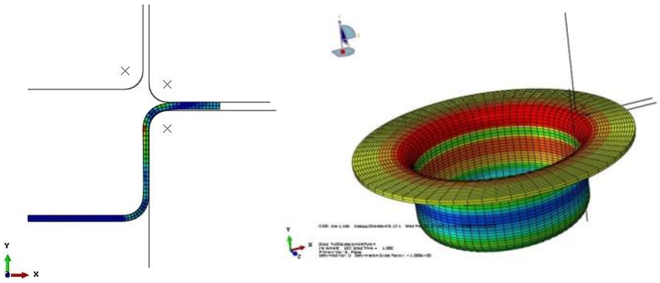

FIG. 7. DEFORMED 2-D AND 3-D VIEW.

6. SIMULATION RESULTS

Three parameters Blank Holder Force, Die Fillet Radius, And Friction Coefficient have been modified and their effect on punch reaction force, cup thickness and equivalent plastic strain has been analyzed.

6.1 BHF (Blank Holder Force)

Three values of BHF are studied- 640 N, 800 N, and 960 N, which are within 20% range of the mean 800 N force.

6.1.1 Punch Reaction Force

Punch reaction has been plotted along the displacement at different Fillet Radius of the Die as shown below (fig 8).

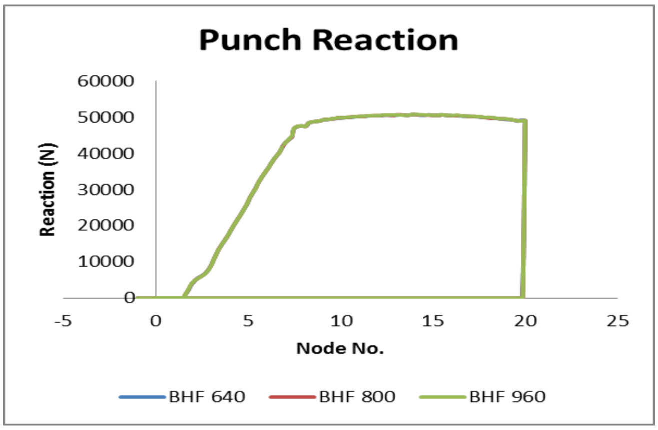

FIG. 8. PUNCH FORCE VARIATION AT DIFFERENT BHF

As seen from the graph there is not much difference in the punch reaction force along the displacement at different values of BHF. So BHF does not have a great impact on the punch reaction force.

6.1.2 Cup Thickness along the Element

The thickness is directly related to the stress the material has to undergo at the localized node [13]. The thickness of the deformed cup after deep drawing, starting from the center of the cup and moving towards the periphery are documented and depicted in the graph shown in fig 9, for various values of BHF.

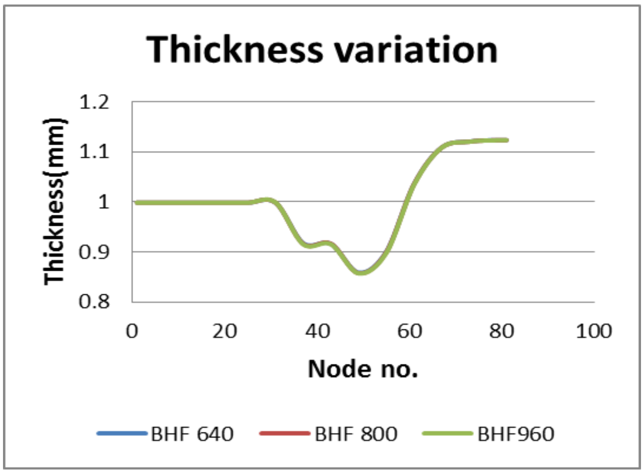

FIG. 9. THICKNESS VARIATION ALONG THE NODES

As seen from the graph there is very slight or virtually no difference in the thickness variation trend for different BHF values. So BHF does not have a great impact on the thickness variation.

6.1.3 PEEQ (Equivalent Plastic Strain)

Equivalent plastic strain is an important indicator for failure of an isotropic material like steel [14]. Different values of Equivalent Plastic Strain have been obtained at different BHF values (fig 10). Maximum PEEQ value (0.5516) is found to be when BHF was 640 N.

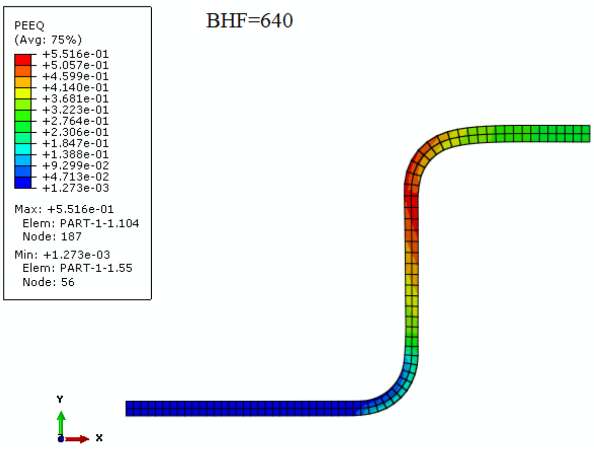

FIG. 10. EQUIVALENT PLASTIC STRAIN AT BHF = 640 N

There is no significant variation in Equivalent Plastic Strain values. But it is worth pointing out that the maximum PEEQ value (red) is near to the die curvature area where the material first begins to deform. Also the minimum value (blue) is near the head of the punch or the base of the deformed cup.

6.2 Fillet Radius of Die (Rd)

Different values of 'die fillet radius' are used and the simulation is run. The values chosen are 3mm, 4mm and 5mm.

6.2.1 Punch Reaction Force

Punch reaction has been plotted along the displacement at different Fillet Radius of the Die as shown below (fig 11).

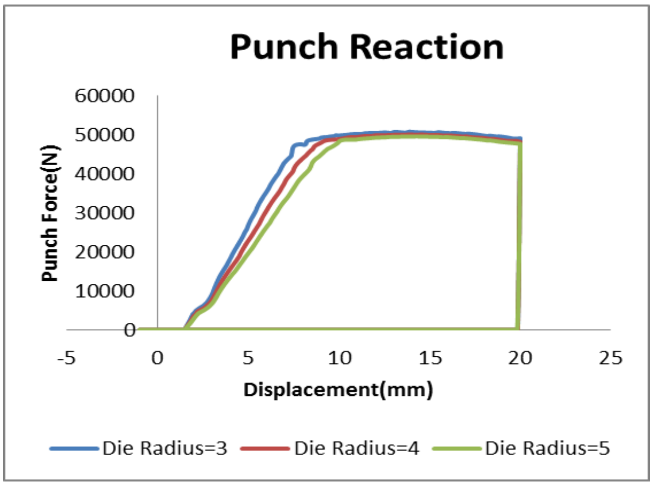

FIG. 11. PUNCH FORCE VARIATION AT DIFFERENT DIE RADIUS

Maximum Punch reaction has been observed with die radius 3 and minimum with 5. Therefore to reduce the punch reaction the die radius can be increased, but it cannot be said that the radius would be appropriate for obtaining the desired result.

6.2.2 Cup Thickness along the Element

The thicknesses of the deformed cup is noted for different values of Rd and plotted along the nodes (fig 12).

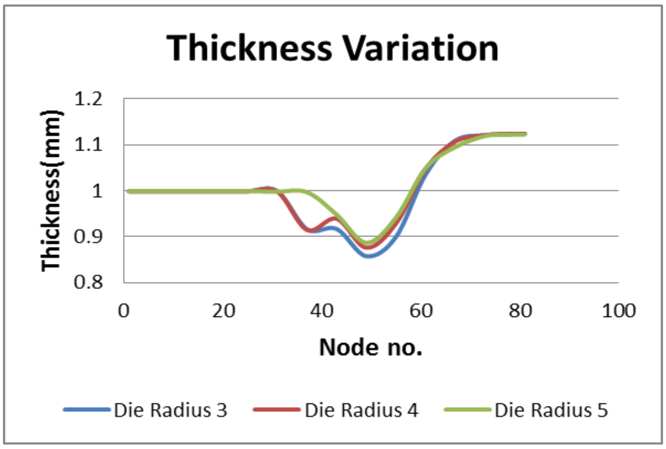

Fig. 12. Thickness variation along the nodes

The best result with minimum variation is obtained with Die Fillet radius 5 mm (green color), and maximum variation is obtained with excessive thinning at Rd = 3 mm (blue color).

6.2.3 PEEQ (Equivalent Plastic Strain)

Different PEEQ values are obtained at various fillet radius of 'die'. The maximum PEEQ value (0.5497) is obtained at Rd = 3 mm (fig 13).

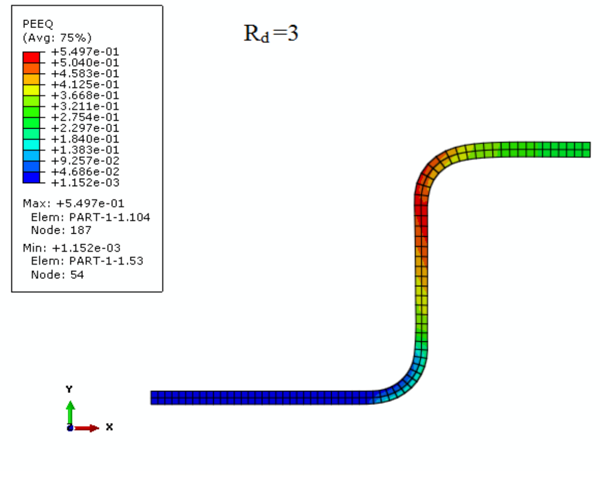

Fig. 13. PEEQ at die fillet radius, (Rd = 3 mm)

The minimum value is almost same in the three cases. The deformation as expected is near to the die fillet radius region.

6.3 Friction Coefficient

Friction Coefficient between the materials is modified to change the material interaction, and analysis is carried out as follows.

6.3.1 Punch Reaction Force

Punch Reaction has been plotted at different values of friction coefficient i.e. 0.01, 0.05, and 0.1 (fig 14).

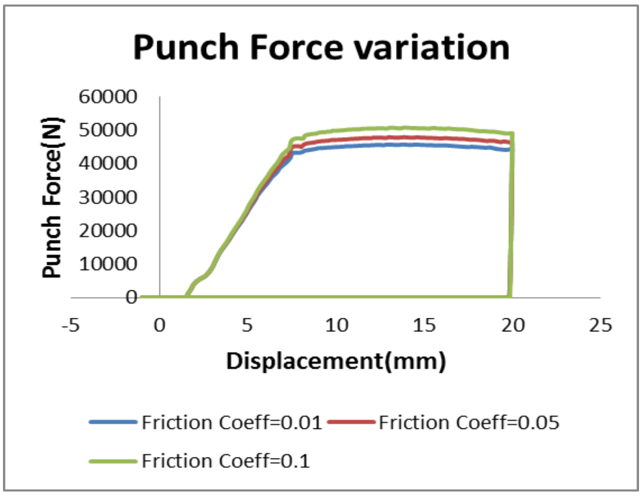

Fig. 14. Punch Force variation at different Friction Coefficient

Maximum Punch Reaction is measured with higher Friction Coefficient (0.1) and minimum punch reaction is measured with lesser Friction Coefficient (0.01).

6.3.2 Cup Thickness along the Element

The thicknesses of the deformed cup is noted for different values of friction coefficient and plotted along the nodes (fig 15).

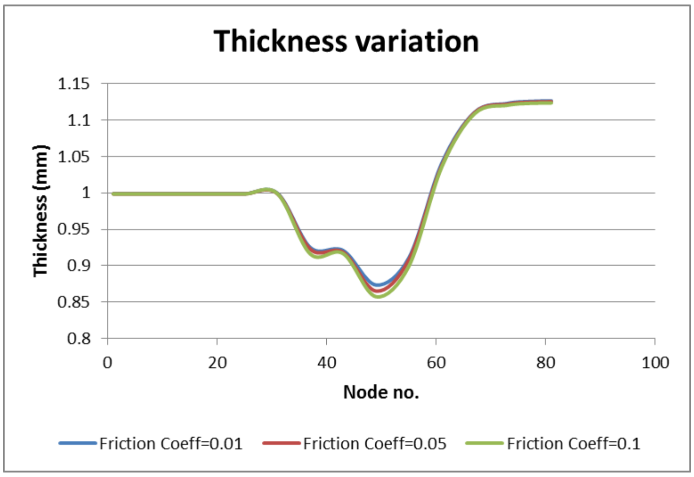

Fig. 15. Thickness variation along the element

There is very slight difference in the thickness variation, but still noticeable, greater amplitude of variation is observed with high friction coefficient (0.1), and less variation is observed with low friction coefficient (0.01).

6.3.3 PEEQ (Equivalent Plastic Strain)

Different PEEQ values were obtained at various values of friction coefficient and maximum (0.5497) was found to be corresponding to 0.1 friction coefficient (fig 16).

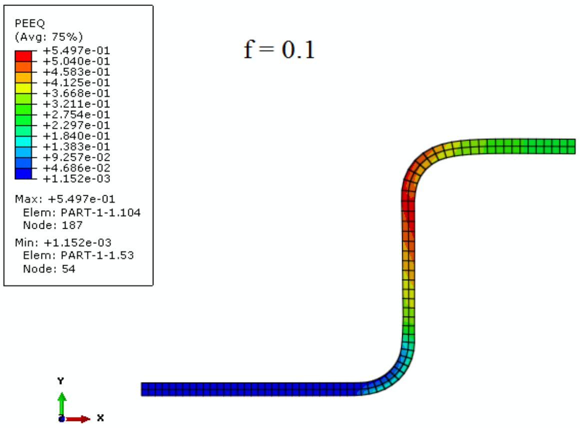

Fig. 16. PEEQ at friction coefficient 0.1

High values of 'equivalent plastic strain' are confined to the region near die-radius. Also Minimum PEEQ value is observed in the least Friction Coefficient, i.e. at f = 0.01. Maximum deformation is almost the same in all the three cases.

7. CONCLUSION

The technique of simulation in Abaqus clearly demonstrates that it is a successful and useful tool for simulation and analysis of the deep drawing process. *Blank holder force* does not have a great impact on the drawing process but since large forces were not tested, it cannot be said that it can be eliminated from the essential design variable for the forming process. *Die fillet radius* is responsible for great variation in the thickness of the finished product, also for the Punch Reaction Force and PEEQ values, therefore it is an important design variable. The *friction coefficient* is also responsible for great variations in the Punch Reaction and PEEQ values, and very slight variation in the finished product thickness. By using the simulation above it is possible to significantly improve the drawing process and find the optimum values for each design variable so that the quality and efficiency of the process can be enhanced.

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