SIMULATION OF THE EFFECT OF DIE RADIUS ON DEEP DRAWING PROCESS

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Abstract – This paper "SIMULATION OF THE EFFECT OF DIE RADIUS ON DRAWING PROCESS" is one of the most used Metal Forming Process within the industrial field. Different analytical, numerical, empirical and experimental methods have been developed in order to analyze it. This work reports on the initial stages of finite element analysis (FEA) of a Deep drawing process. The objective of this study is to determine the factors influencing a drawing process and analyzing the process by varying the Die radius and keeping the Friction, Punch radius and Blank Thickness as constant.

In this paper Punches, blank thickness of same geometry and dies of various geometries were drawn by using CATIA software. And an effort is made to study the simulation effect of main process variant namely die radius using finite element analysis. As the FEM code, the commercially available software DEFORM-3D is used here. Aluminium alloy 6061 is used for deep drawing with initial diameter as 56mm.

Keywords *– Die radius; FEA; CATIA V5; Deep drawing process; DEFORM 3D.*

I. INTRODUCTION

Mathematical description of the processes of Deep-drawing is very complicated because of varying loading history and complex stress state in each point of material. The parameters introduced in the mathematical models of deep drawing are normally taken from a simplest mechanical test such as uni-axial traction test. Lately some new tests were developed which are closed to forming processes. Deep-drawing of a cylindrical cup occupies a particular place between these tests since it allows to study material hardening, conditions of friction, wrinkling, plastic flow instability, fracture, some others effects.

Drawing is a manufacturing process very used in the industry due to its versatility and good mechanical properties (as good surface finish and dimensional accuracy) of the parts. Successful drawing operations require careful selection of process parameters and consideration of many factors.

The main variables involved in this type of process are :

1. Die radius
2. Friction
3. Punch Radius
4. Blank Thickness.

Deep Drawing

"Deep drawing is a compression metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch".

A cup-like cylindrical part, having the depth greater than its diameter, is formed as a result of deep drawing.

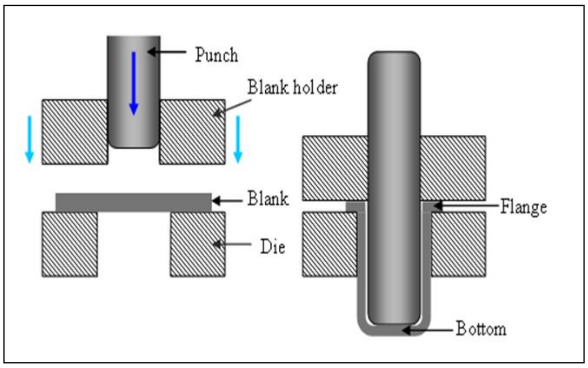


Fig. 1.1 : Deep Drawing

Method Of Analysis

In general, the complexity of these processes and the great number of factors involved in them making very difficult to select the parameter values properly. Then, different analytical, numerical and experimental methods are being developed in order to analyze the best combination of them.

Now-a-days analytical methods still continue being studied and developed in spite of numerical methods allow obtaining solutions with high precision and detail levels in the analysis of this type of process.

Finite element method has been used as well in several studies about metal forming processes recently.

The main objective of this paper presented in it is the multi stage deep drawing analysis. According to John Monaghon [1] et al, as the die radius is reduced, this increases the amount of force required to draw the material. The increased force on the punch and the greater difficulty in getting the material around the die radius causes stretching marks on the cup wall and an uneven thickness distribution. To verify the above experimental results and to validate the simulation done, several simulations were performed by varying the die radius. Furthermore, the effect of the above process parameters on the formability and quality issues are studied.

Outline of this Paper

The outline of this paper is to present the CATIA V5 and DEFORM-3D software, also gives the methodology of various process variables used and how deep drawing has been simulated for those combinations with more emphasis on finite element tool used. The results of Deep Drawing process are in the form of graphs and also figures with short discussions. And lastly of this paper, the main conclusions are recapitulated.

II. LITERATURE REVIEW

The stamping of thin metallic sheets is a widely used industrial material forming process. It allows production of thin walled parts with complicated shapes such as automotive panels or structural parts. The process consists of the plastic deformation of an initial at blank subjected to the action of a rigid punch and die while constrained on the periphery by a blank holder.

The main variables involved in this type of process are :

- Die Radius
- Friction
- Punch Radius
- Blank Thickness.

These factors determine the maximum punch load in drawing, the sheet-thickness variation after drawing, and the maximum limit drawing ratio. If the height of the work piece in industrial production is too high, multi-redrawing is necessary in order to obtain a successful product.

The finite element method has recently been sufficiently developed for the analysis of metal forming processes. Hence, much research has been performed using the finite element method. The purpose of this study is to clarify the mechanics of ductile fracture in bulk metal forming processes.

The following four kinds of ductile fracture criteria, that is to say, freudenthal's fracture criterion, Cockcroft and latham's fracture criterion, Brozzo et al.'s fracture criterion and oyane's fracture criterion are used. These four kinds of ductile fracture criteria are used in the analysis of deep drawing. The analytical results of the work using Cockcroft and latham's fracture criterion and using Brozzo et al.'s fracture criterion agree satisfactorily with the experimental result.

Damage Mechanics

Damage specifies the damage factor at each element. Fracture occurs when the damage factor has reached its critical value. Critical value of Damage Factor must be found through physical experimentation. The basic idea of damage mechanics is to translate the underlying microscopical failure phenomena to a macroscopical description that can be used in a phenomelogical model. In all cases, the models are considering one or more parameters and when these parameters reach a critical value failure is expected.

In this case more properties are needed, for instance the strain rate, stress tri-axiality and temperature. Most crash simulations of today do not use damage models due to a lack of information on which damage models that under given conditions give reliable predictions, and how the damage parameters should be determined.

Phenomelogic Failure Models :

The Phenomelogical models describe the failure in the material in terms of mechanical variables such as stress, strain, temperature, strain rate etc. In all models presented in this paper the failure model is a function which depends of these variables and if the functions reach a critical value, failure is expected in the material.

Stress Dependent Failure Criteria

One of the simplest models to predict failure is to consider that failure occurs when the stress reaches a critical value. Below follows a short review of some of the basic stress dependent failure criteria. All the models presented are isotropic, i.e. they have the same property in all directions of the material.

Maximum Principle Stress Criterion

The maximum principle stress criterion is also known as the Coulomb or Rankine failure criterion. It only depends on the principle stress to predict failure. To predict failure one considers two material parameters describing the maximum allowed stress in compression σ_c and tension σ_t, respectively, and state that failure is not to be expected as long as the principle stresses is in between these values, i.e

$$\sigma_c \leq \{\sigma_1, \sigma_2, \sigma_3\} \leq \sigma_t .$$

III OVERVIEW

Deep Drawing

"Drawing is a operation in which the cross-sectional area of a bar is reduced by pulling it through a converging die'' i.e. the process consists of reducing or changing the cross-section of work piece such as wires, rods, plates, making pass them through a die by means of a pulling force (a tensile force), applied on the exit side of the die.

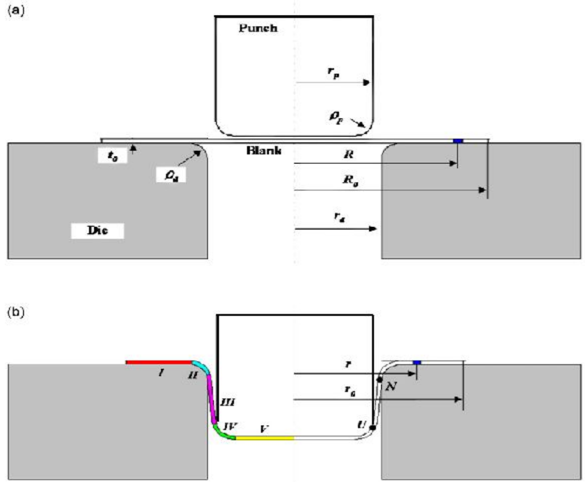


Fig. 3.1: Deep drawing for a circular cup (a) initial stage and (b) intermediate stage.

Typical Stages of a Deep Drawing process are as follows:

1. **Shearing** a blank (round rectangular or other shape).
2. **Clamping** the blank on the die.
3. **Stretching** the blank by the punch forcing it into the die cavity.
4. **Returning** the punch and removal the part from the die.
5. **Trimming** the excess blank.

IV. METHODOLOGY

The Deep drawing processes have been analyzed for different combinations of process variables. The various assumptions and combinations are used in this study to investigate an effect of process variables on deep drawing process is presented in this chapter.

The material used in this analysis is Al 6061 an Aluminum alloy. The initial diameter is taken as 56 mm. The Deep drawing speed used here is 0.9 mm/sec. The friction between the blank and the punch, die interface has taken constant as 0.3.

Combinations Of Process Variables

The various combinations of the process variables are i.e. Die radius, friction, damage value, effective stresses and strains, Max. Principle stresses and strains.

1. Variation Of Die Radii With Constant Friction and Effective Stress
   1) 4------0.3-------148.
   2) 5------0.3-------155.
   3) 6------0.3-------163.
   4) 7------0.3-------188.
   5) 8------0.3-------172.
2. Variation Of Die Radius With Constant Friction and Damage Value
   1) 4------0.3-------6.51.
   2) 5------0.3-------5.35.
   3) 6------0.3-------8.30.
   4) 7------0.3-------3.99.
   5) 8------0.3-------5.50.
3. Variation Of Die Radius With Constant Friction and Effective Strain
   1) 4------0.3-------5.48.
   2) 5------0.3-------4.46.
   3) 6------0.3-------4.45.
   4) 7------0.3-------2.83.
   5) 8------0.3-------4.79.
4. Variation Of Die Radius With Constant Friction and Max. Principal Stress
   1) 4------0.3-------199.
   2) 5------0.3-------169.
   3) 6------0.3-------178.
   4) 7------0.3-------203.
   5) 8------0.3-------175.
5. Variation Of Die Radius With Constant Friction And Max. Principal Strain
   1) 4------0.3-------4.40.
   2) 5------0.3-------4.02.
   3) 6------0.3-------3.85.
   4) 7------0.3-------2.45.
   5) 8------0.3-------3.69.
6. Variation Of Die Radius With Constant Friction And Max. Load per Stroke.
   1) 4------0.3-------12749.17.
   2) 5------0.3-------13507.11.
   3) 6------0.3-------13913.89.
   4) 7------0.3-------13971.84.
   5) 8------0.3-------13952.45.

V. RESULTS AND DISCUSSION

Different simulations with different die radii were performed. According to John Monaghon [1] et al. , as the die radius is reduced, it increases the amount of force to draw the material, the increased force on the punch & greater difficulty getting the material around the die radius causes stretching marks on the cup wall and an uneven thickness distribution.

To verify the above experimental results and to validate the simulation done, several simulations were performed by varying the die radius.

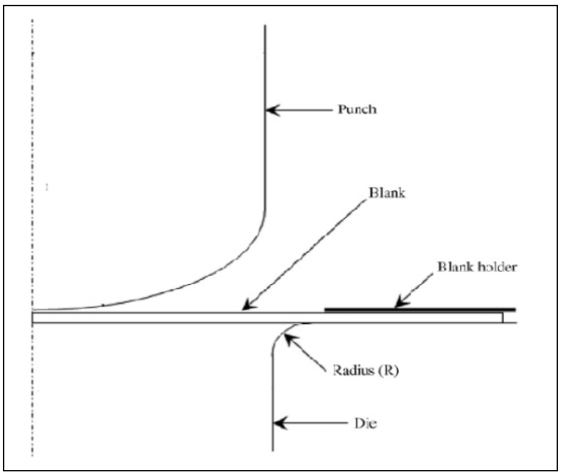


Fig. 6.1 : Geometry of The Die Profile

The following figures from 6.1 to 6.5 are the drawn cups showing effective stress values for different die radii ranging from 4mm to 8mm respectively.

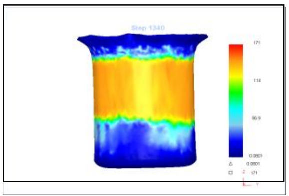


Fig. 6.2 Effective stress Values for 4mm Die radius.

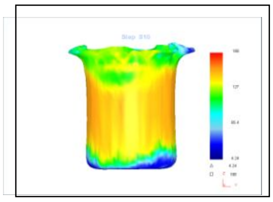


Fig. 6.3 Effective stress values for 5mm Die radius

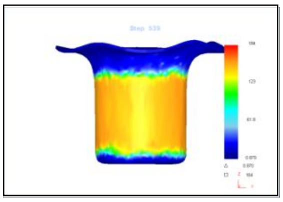


Fig. 6.4 Effective stress values for 6mm Die radius.

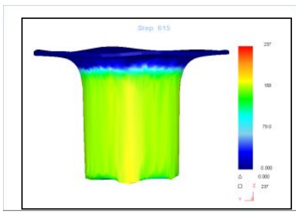


Fig. 6.5 Effective stress values for 7mm Die radius.

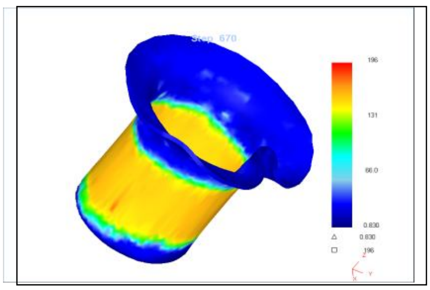


Fig. 6.6 Effective stress values for 8mm Die radius.

Comparing the effective stress values of the drawn cups, it was found that, effective stress value was increasing as the die radius is decreased as shown in Fig. 6.1-6.5. Comparing the Max. principal stress values of the drawn cups, it was found that, max. Principal stress values are increasing as the die radius is decreasing.

Comparing the effective strain values of the drawn cups, it was found that, effective strain value is decreasing as the die radius is decreasing.

Comparing the Max. Principal strain values of the drawn cups, it was found that, max. Principal strain values are decreasing as the die radius is decreasing.

Comparing the damage values of the drawn cups, it was found that, damage value is minimum for a die radius of 7mm and this die radii is recommended as an optimum die radii.

Comparing the load required of the drawn cups, it was found that, load is increasing as the die radius is decreasing.

Further, when the die radius was too small, the material, after considerable thinning process experienced Ear-ring type defect because, as the die radius was too small, the amount of force required to draw the material was large and the shear component of the load required in the deformation process is increased.

As for the above case, more force is needed to draw the material, it causes Stretching Marks and the end face of the cup twisted itself in its edge, forming earring type of error.

From the simulation performed, it is proved that, As the die radius is reduced,

- ❖ This increases the amount of force to draw the material
- ❖ The increased force on the punch & greater difficulty getting the material around the die radius causes stretching marks on the cup wall.
- ❖ Uneven thickness distribution.

With the above results, it can be seen that the simulation performed is validated.

Effect Of Process Variables On Damage Value

Fig. 6.7 shows the analysis result to investigate the effect of variation in die radii on damage value when the friction between the die and the blank are considered to be constant as 0.3 respectively and the die radii varies as 4, 5, 6, 7, 8mm.

For the die radii equal to 4mm, as the 56mm blank passes through the first die, damage value near the blank is found to be about 2.34 and damage value increases gradually and the region that damage increased its value is generated after it passes through 5th die. Similarly for other die radii equal to5, 6, 7, 8mm the damage value as the blank passes through the dies is tabulated and it is shown in table 6.1.

From fig. 6.7, By comparing the damage values of the drawn cups, it was found that, damage value is minimum for a die radius of 7mm and this die radii is recommended as an optimum die radii.

Table 6.1: Damage Values After Each Die Pass For Different Die Radius

No. of Drawing Die	**Max. Principal Stress**				
	Die radius of 4mm	Die radius of 5mm	Die radius of 6mm	Die radius of 7mm	Die radius of 8mm
1	199	169	178	203	175
2	161	122	155	172	146
3	122	94	96.74	111.2	87.4
4	65.5	50.7	31.1	67.4	28.1
5	11.79	14.5	4.85	4.28	8.21

Table 6.2: Effective strain after each die pass for different Die radius.

No. of Drawing Die	Damage Values				
	Die radius of 4mm	Die radius of 5mm	Die radius of 6mm	Die radius of 7mm	Die radius of 8mm
1	6.51	5.35	8.30	3.99	5.50
2	5.47	4.54	5.87	3.22	4.64
3	4.53	3.56	4.54	2.51	3.77
4	3.60	2.72	3.44	1.47	2.42
5	2.34	1.31	2.79	0.49	1.21

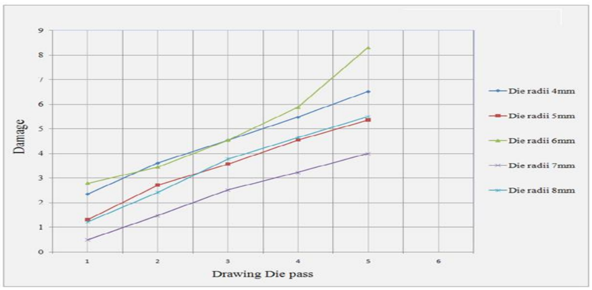


Fig. 6.7 : Damage Values After Each Die Pass For Different Die Radius.

Effect Of Process Variables On Effective Strain

Fig.6.8 shows the analysis result to investigate the effect of variation in die radii on effective strain when the friction between the die and the blank are considered to be constant as 0.3 respectively and the die radii varies as 4, 5, 6, 7, 8mm. Table 6.2 shows effective strain developed in drawing operation during each pass, for different die radii.

Comparing the effective strain values of the different die radii, it was found that, effective strain is decreasing gradually for a given die radii with lower strain after first pass. For a given constant friction, effective strain is decreasing with increase in die radii.

Table.6.8 shows the values of these effective strains. Effective strains is decreasing for larger die radii. For die radii of 4, 5, 6, 8mm the effective strain is almost constant with little variation and for 7mm die radii showing an decrease in effective strain.

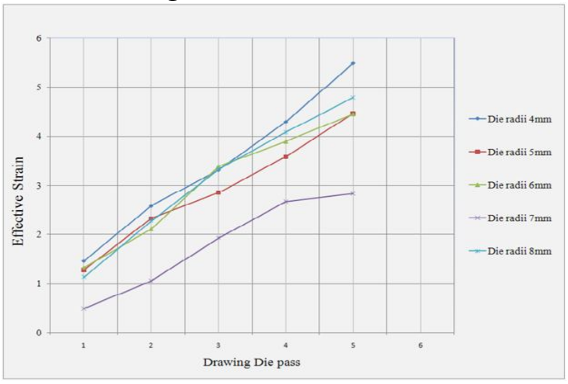
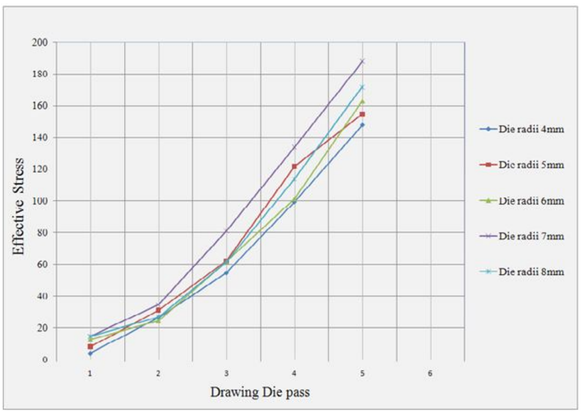


Fig. 6.8 : Effective strain after each die pass for different Die radius

Table 6.3: Effective stress after each die pass for different Die radius.

No. of Drawing Die	**Effective Strain**				
	Die radius of 4mm	Die radius of 5mm	Die radius of 6mm	Die radius of 7mm	Die radius of 8mm
1	5.48	4.46	4.45	2.83	4.79
2	4.29	3.58	3.89	2.67	4.08
3	3.31	2.85	3.38	1.93	3.33
4	2.58	2.32	2.11	1.06	2.28
5	1.46	1.27	1.32	0.49	1.13



EFFECT OF PROCESS VARIABLE ON LOAD REQUIRED

Effect of die radii

Fig. 6.12 shows the analysis result to investigate the effect of variation in die radii on load required during drawing operation, when the friction between the die and the blank are considered to be constant as 0.3 respectively and the die radii varies as 4, 5, 6, 7, 8mm. Table 6.6 shows the load required in drawing operation during each pass, for different die radii.

The load required for a given die radii increases as the blank passes through the next die with highest load required for the third pass. For a given constant friction, the load required increases with increase in die radii. This is because for larger die radii the length of contact between the blank and die is high, thus it cause significantly high frictional losses, thus load required is high.

The load fluctuates periodically with increase in time. The load in actual drawing operation fluctuates gradually with time, while the load in the analysis fluctuates significantly for each die pass with increase in time. The reason for the fluctuation of the load in the analysis is, since the number of elements which come into contact with the drawing die is limited, the load fluctuates markedly when a node comes into contact with the drawing die or separates from the drawing die.

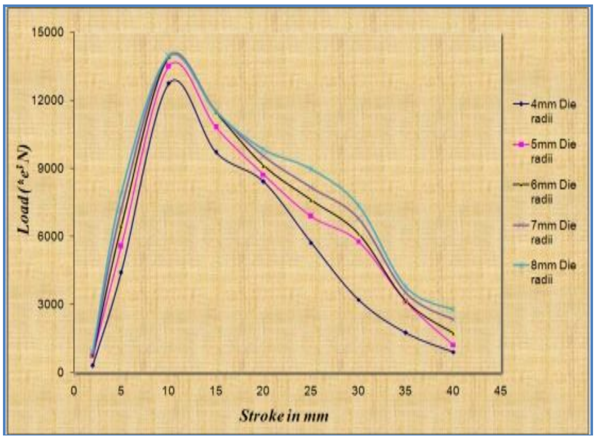


Fig. 6.12 Load per stroke for different Die radius.

VI. CONCLUSIONS

It is a finite element analysis based simulation has been done using Deform-3D for the deep drawing process.

1. The effect of die radius on the formability and quality characteristics of deep drawing process has been done.
2. It has been found that as the die radius is reduced, the amount of fore required to draw the material is increased.
3. A decreased die radius created stretching marks and earring type quality problems.
4. Because of the above issues, an optimum die radius was an important parameter to be obtained from the simulation studies.
5. It has been found that a die radius of 7mm gave an optimum deform levels with minimum damage.
6. It was found that the result of the simulation studies were in line with the experiments conducted by prof. john monaghon[1] et al., whose results have been published in journal of material processing technology.
7. The developed model, as it is validated can be used to simulate any problems in deep drawing process for any material.

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