FINITE ELEMENT ANALYSIS OF COLD DEEP DRAWING PROCESS FOR CONICAL CUPS OF AA- 1100

A major project report
submitted in partial fulfilment of the
requirements for the award of degree of

BACHELOR OF TECHNOLOGY
IN
MECHANICAL ENGINEERING

Submitted by

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DEPARTMENT OF MECHANICAL ENGINEERING

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CERTIFICATE

This is to certify that the major project entitled

"Finite Element Analysis of Cold Deep Drawing process for Conical cups of AA -1100 "

submitted by

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In partial fulfilment for the award of degree of Bachelor of Technology in the Department of Mechanical Engineering, JNTUH College of Engineering Hyderabad.This is a record of bonafide work carried out under our guidance and supervision during the academic year 2020-2021. The results of investigations enclosed in this report have been verified and found to be satisfactory. The results embodied in this report have not been submitted to any other university for the award of any Degree or Diploma.

PROJECT GUIDE

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DECLARATION

We, hereby declare that the major project entitled **" FINITE ELEMENT ANALYSIS OF COLD DEEP DRAWING PROCESS FOR CONICAL CUPS OF AA - 1100 "** submitted for the degree of **Bachelor of Technology in Mechanical Engineering** is our original work and the project has not formed the basis for the award of any degree, diploma, fellowship or any other similar titles.

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ABSTRACT

Deep drawing is one of the most widely used processes in sheet metal forming. Apart from its use in many other sectors, it is applied in the automotive industry for the manufacturing of car body parts, packaging industry, aviation and model construction .The most common examples of deep drawing are probably the soft drinks cans we buy. So, understanding the mechanics of the cup drawing process helps in determining the general parameters that affect the deep drawing process. It is thus a shape transformation process with material retention.

In this present work, Taguchi techniques and finite element analysis were implemented to assess the formability of cylindrical cups using a cold deep drawing process. The process parameters are punch velocity, coefficient of friction, strain rate and displacement per step. The study was conducted by using DEFORM-3D . DEFORM-3D supports user routines and user defined variables. Complex multiple deforming body capability with arbitrary contact allows users to simulate mechanical joining and coupled die stress analysis. The purpose of presented work is to analyze the deep drawing process of thin walled, AA 1100 , conical cup shape by means of a finite element simulation. In the presented study, simulation of the deep drawing process for determining distribution patterns of state variables in the drawn component for a particular displacement is carried out .

The process parameters were punch velocity, Thickness, Coefficient of friction, Displacement per step.The thickness of the blank, punch velocity, and coefficient of friction have been found influencing the quality of the cup.It is evident from the results that considered parameters can alter the physical characteristics of the cup obtained at the end of the drawing operation.

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1.INTRODUCTION

1.1 DEEP DRAWING:

Deep drawing process is an essential process used for producing cups from sheet metal in large quantities. It is a tensile compression forming process in which usually an open-top metallic hollow body is created.This process is widely used in automobile, aerospace, electronics and allied industries to produce hollow parts. This 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.The process is considered "deep" drawing when the depth of the drawn part exceeds its diameter. This is achieved by redrawing the part through a series of dies.

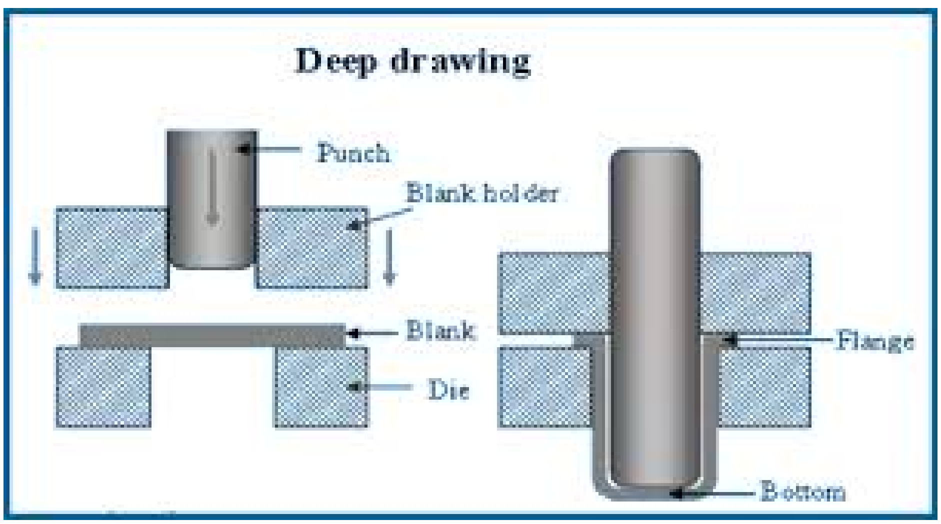


Fig 1 : Process of deep drawing

1.2 BENEFITS:

There are usually many different ways of making any particular metal fabrication. You can do a lot with stamping or shearing, bending on a press brake and welding, but deep drawing has at least six advantages. These are

1. Speed.

No other process can match the speed of a punch press moving up and down. It’s usually the most efficient method if you need a large quantity of parts making.

2. Eliminates assembly steps

Deep drawing produces shapes with closed ends. That avoids the need to cut and weld multiple pieces.

3. Seamless.

A deep drawn can or tube shape has no joins. That makes deep drawing an ideal process for anything that needs to be water or gas-tight.

4. High accuracy.

Parts coming off a forming press are extremely repeatable. Assuming the tooling was made correctly, they’ll also conform very closely to the drawing.

5. Produces complex geometries.

We’ve talked here about simple shapes like cans and sinks, but deep drawing can create more complex forms. Like the oil pan for an engine or complex filter housings

6. Produces very strong parts

Many metals work-harden as they deform. Essentially, their crystal structure allows a certain amount of movement but beyond that it becomes locked. Deep drawing subjects metal to a lot of deformation, so can result in very hard finished parts.The finished components are measurably stronger than machined or cast metal components.

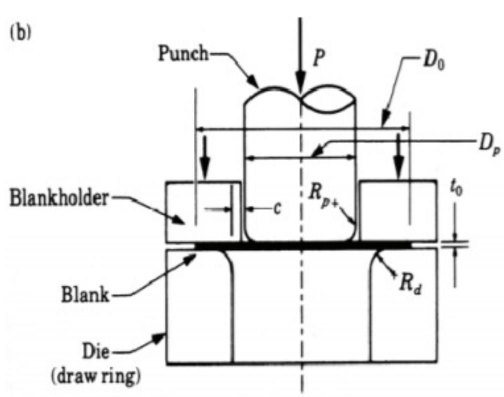
7. Cost:

Although initial setup costs are often high, the overall process can be automated, making it very easy to produce quantities in the thousands and even millions as well as minimum labor for production.

1.3 PROCESS:

Starting with a metal blank, the disc of metal cut from a larger sheet is pushed into a cavity around a die, which begins the deep drawn process of drawing the blank into the desired shape. This is completed in gradual steps to ensure an even distribution of the metal across the final shape, which is important for preserving the integrity and strength of the finalised deep-drawn component.

The rigid tools consist of a punch, die and binder.The sheet is clamped between the die and the binder. This process slows down the flow of the sheet while it is being drawn and thereby prevents wrinkles from forming under the binder. The punch stretches the sheet over the die radius and forms it in the die. The amount of punch force necessary for forming is thereby continually increased up to the lower dead center of the punch.



D_o	**:** Diameter of a circular sheet blank.
to	: Thickness of the circular sheet blank.
Rd	: Corner radius of the die opening.
Dp	: Punch diameter.
Rp	: Corner Radius of the punch.
Wp	: Plastic Work required for deep drawing
Vo	: Initial volume of blank to be drawn
Vc	: Volume of drawn cup.
R	: Drawing Ratio Do/Dp.
ē	: The effective strain.
ó	: Effective stress.

Fig 2 : Variables of deep draw in cylindrical cup

Fig 3 : Deep Drawing Machine

ti

1.4 COMMON DEFECTS IN DEEP DRAWING

The three major common defects which occur during Deep Drawing are fracture, wrinkling and earing.

1.Fracture:

Fracture occurs when the sheet metal is subjected to strains exceeding the safe strain limits of the material. For ductile sheets this fracture usually occurs near the punch corner. It is because maximum forming load appears in the material in this region and also stress concentration lines are converging in this section. Once this necking exceeds beyond a certain value, fracture appears in the drawn cup.

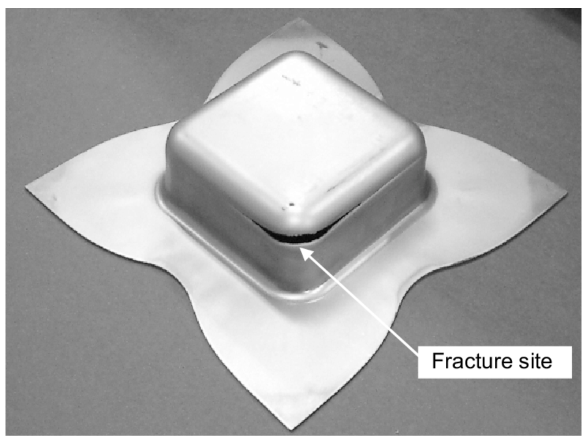


Fig 4 : Fracture in deep drawn cup

2.Wrinkling:

Wrinkling occurs in the flange when compressive stresses in the circumferential direction reach a critical point of instability. It can occur in regions where the workpiece is unsupported or when the blank holding force is insufficient. The wrinkling can be prevented by increasing blank holder force and by using a draw bead . The draw bead bends and unbends the workpiece material as it passes through the blank holder. This bending over the bead increases the radial tensile stresses and thus reduces the possibility of wrinkling.

Fig 5 :Wrinkling in deep drawing

3.Earing:

Earing is because of planar anisotropy of the blank material. Deep drawing of anisotropic sheets results in a drawn cup with an uneven top edge .

Fig 6 :Earing in deep drawing

2.OBJECTIVE AND GOAL

2.1 OBJECTIVE :

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 when the depth of the drawn part exceeds its diameter. As the blank is drawn radially inwards the flange undergoes radial tension, circumferential compression. Wrinkling in the flange occurs due to compressive buckling in the circumferential direction. Tearing occurs because of high tensile stresses that cause thinning and failure of the metal in the cup wall. Our objective is to find the optimal procedure for deep drawing cups with least effects and high limiting drawing ratio.

2.2 GOAL :

The variables that affect the metal during deep drawing are radius on punch ,draw radius on the die ,speed, load ,die clearance, friction. The important factor for a deep drawing process is the ductility of material. Another factor that increases load on forming equipment is the rate at which the forming process is carried out. At higher rates of strain the flow stress of material increases leading to higher loads on the equipment. When a forming process is carried out the recrystallization is also present along with strain hardening and strain rate effect. Friction is an important parameter that influences the deep drawing process. In metal forming processes, friction influences the strain distribution at tool blank interface and drawability of metal. A finite element method is developed to study the elastic-plastic deformation of sheet materials in the presence of large strains and large displacements. It is based on updated Lagrangian type formulation and membrane shell theory. The sheet is assumed to be isotropic ,The method is used for modelling deep-drawing with the appropriate boundary conditions, numerical solutions are compared with the experimental results.In the present work, the formability of cold deep drawing process was assessed during the fabrication of AA1100 conical cups. The optimal cup we focussed on the parameters such as punch velocity, coefficient of friction ,strain rate and displacement per step. The cold deep drawing process was executed using the finite element analysis software DEFORM - 3D.

3.MATERIAL AND METHODS

3.1 ALUMINIUM ALLOY 1100:

Aluminum 1100 is among the softest aluminum alloys and therefore is not used for high-strength or high-pressure applications. Cold-working is the most common way to form **Aluminum alloy 1100.** It is just one of several common aluminum alloys and is soft, low strength and, at 99% min aluminum, is the commercially pure aluminum. Copper, iron, magnesium, manganese, silicon, titanium, vanadium and zinc comprise the remaining elements. It cannot be hardened by heat treatment and is very formable.

Table 1 : Alloy composition of ALUMINIUM ALLOY 1100

Aluminium	99.0–99.95%
Copper	0.05–0.20%
Iron	0.95% max
Manganese	0.05% max
Silicon	0.95% max
Zinc	0.1% max
Residuals	0.15% max

It has precisely been used in various industries requiring a high level of ductility, flexibility, and corrosion resistance and has good machinability. It possesses greater and stronger corrosion resistance toward acid and other acidic solutions. The alloy is said to be highly sensitive at an elevated temperature ranging somewhat between 200°-250° C or 392-482° Fahrenheit. It may lose its strength due to a harsh and tough environment. However, it is said that the strength can be increased accordingly at subzero temperatures thus making it an ideal alloy for low-temperatures.

Features

- Corrosion resistant
- Durable functioning
- Malleable
- Heat resistance
- High strength
- Excellent conductivity
- Impeccable finish
- Enhanced service life
- Precisely designed

3.2 APPLICATIONS:

Aluminum 1100 can be shaped into many different products, including chemical equipment, railroad tank cars, fin stock, dials, name plates, cooking utensils, rivets, reflectors and sheet metal. The plumbing and lighting industries also use aluminum 1100, as do a wide variety of other industries.

Table 2 : Mechanical properties of ALUMINIUM 1100

Properties	**Values**	**Conditions (T (°C))**
Density (x1000 kg/m2)	2.71	25
Poisson's Ratio	0.33	25
Elastic Modulus (GPa)	70-80	25
Tensile Strength (Mpa)	110	25
Yield Strength (Mpa)	105	25

3.3 TAGUCHI METHODS:

Genichi Taguchi, a Japanese engineer, proposed several approaches to experimental designs that are sometimes called "Taguchi Methods." These methods utilize two-, three-, and mixed-level fractional factorial designs.Initially it was developed for improving the quality of goods manufactured, later it was expanded to many other fields . Fields such as Engineering, Biotechnology ,Marketing and Advertising. Sometimes called robust design methods.

Taguchi refers to experimental design as "off-line quality control" because it is a method of ensuring good performance in the design stage of products or processes. Some experimental designs, however, such as when used in evolutionary operation, can be used on-line while the process is running.The most common goals are minimizing cost and maximizing efficiency. This is one of the major quantitative tools in industrial decision- making.

Taguchi method contains system design, parameter design, and tolerance design procedures to achieve a robust process and result for the best product quality. Taguchi designs provide a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. Experimental design methods were developed in the early years of the 20th century but they were not easy to use.

4.DESIGN PARAMETERS

4.1 PARAMETER DESIGN:

The aim here is to make a product or process less variable in the face of variation over which we have little or no control. Taguchi's radical insight was that the exact choice of values required is under-specified by the performance requirements of the system. In many circumstances, this allows the parameters to be chosen so as to minimize the effects on performance arising from variation in manufacture, environment and cumulative damage. This is sometimes called robustification.

4.2 LISTING OF CONTROL PARAMETERS :

ALUMINIUM ALLOY 1100 was used to fabricate conical cups. For the finite element analysis, the chosen control parameters are summarized below**.** In the present work, the formability of the cold deep drawing process was evaluated during the fabrication of Aluminium alloy 1100 conical cups. The investigation was focused on the process parameters such as punch velocity, coefficient of friction, displacement per step and strain rate.

Table 3: Control parameters

Factor	**symbol**	**Level 1**	**Level 2**	**Level 3**
Punch velocity, mm/s	**A**	2	3.5	5
Coefficient of friction	**B**	0.1	0.15	0.2
Strain rate, 1/s	**C**	1	10	100
Displacement per step mm	**D**	0.50	0.75	1.00

Table 4: Orthogonal array (L9) and control parameters**.**

Trial No	**A**	**B**	**C**	**D**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

4.3 DESIGN OF DEEP DRAWN CONICAL CUPS:

The blank size was calculated by equating the surface area of the finished drawn cup with the area of the blank. The diameter of the blank is given by:

$$d_b = \sqrt{d12 + (d1 + d2)\sqrt{(d1 - d2)2 + 4h2}}$$

Where d1and d2are the top and bottom diameters of the cup and h is the height of the cup.

The top and bottom diameters of the punch are those of the cup. The height of the punch is that of the cup. The drawing punch must have a corner radius exceeding three times the blank thickness (t).

However, the punch radius should not exceed one fourth the cup diameter (d). The punch radius is expressed as:

$$r_p = \frac{12t + d}{8}$$

For smooth material flow the die edge should have generous radius preferably four to six times the blank thickness but never less than three times the sheet thickness because lesser radius would hinder material flow while excess radius would reduce the pressure area between the blank and the blank holder. The corner radius of the die can be calculated from the following equation:

$$r_d = 0.8\sqrt{(D - d)t}$$

The material flow in drawing may render some flange thickening and thinning of walls of the cup inevitable. The space for drawing is kept bigger than the sheet thickness. This space is called die clearance.

$$\text{Clearance}, c_d = t + \mu\sqrt{10t}$$

Where μ is coefficient of friction

The top diameter of the die is obtained from the following equation:

$$d_{d1} = d_1 + 2c_d$$

The bottom diameter of the die is obtained from the following equation:

$$d_{d2} = d_2 + 2c_d$$

5. FINITE ELEMENT ANALYSIS SOFTWARE

5.1 DEFORM -3D:

DEFORM is tailored for deformation modelling . A user-friendly graphical user interface provides easy data preparation and analysis so engineers can focus on forming. **DEFORM-3D** is a powerful process simulation system designed to analyze the three-dimensional (3D) flow of complex metal forming processes. **DEFORM-3D** is a practical and efficient tool to predict the material flow in industrial forming operations without the cost and delay of shop trials.The simulation engine is capable of predicting large deformation material flow and thermal behavior with astonishing precision. **DEFORM** is the most widely used simulation program in the world by leading research institutes and manufacturers. As the key component of this is a fully automatic,optimized remeshing system tailored for large deformation problems. An advanced mesh generator automatically applies an adaptive, optimized mesh to parts and tooling. This captures important model detail while minimizing the simulation time. User-defined meshing tools allow advanced users to customize the mesh to their requirements.

Typical applications include:

- Closed die forging
- Open die forging
- Machining
- Rolling
- Extrusion
- Heading
- Drawing
- Cogging

- Compaction
- Upsetting

Major components of DEFORM

1.Pre Processor

A pre-processor for creating, assembling, or modifying the data required to analyze the simulation, and for generating the required database file. The DEFORM pre processor uses a graphical user interface to assemble the data required to run the simulation

2. Simulation

A simulation engine for performing the numerical calculations required to analyze the process, and writing the results to the database file. The simulation engine reads the database file, performs the actual solution calculation, and appends the appropriate solution data to the database file. The simulation engine also works seamlessly with the Automatic Mesh Generation (AMG) system to generate a new FEM mesh on the workpiece whenever

3.Post Processor

A post-processor for reading the database file from the simulation engine and displaying the results graphically and for extracting numerical data. The post processor features a graphical user interface to view geometry, field data such as strain, temperature, and stress, and other simulation data such as die loads. The post processor can also be used to extract graphic or numerical data for use in other

6.EXPERIMENTATION & PROCEDURE

6.1 FINITE ELEMENT MODELING ANALYSIS:

Using D-FORM 3D software finite element modeling and analysis is done. First cylindrical blank sheet is created with desired diameter and thickness with calculated parameters using cad tools.The Conical punch and Hollow die are designed by using UNIGRAPHICS software. The inner and outer radius, corner radius and clearance between punch and die is calculated by using the above equations.

The material properties are assigned using predefined materials in the material library. For this experiment ,Aluminum alloy 1100 is selected.

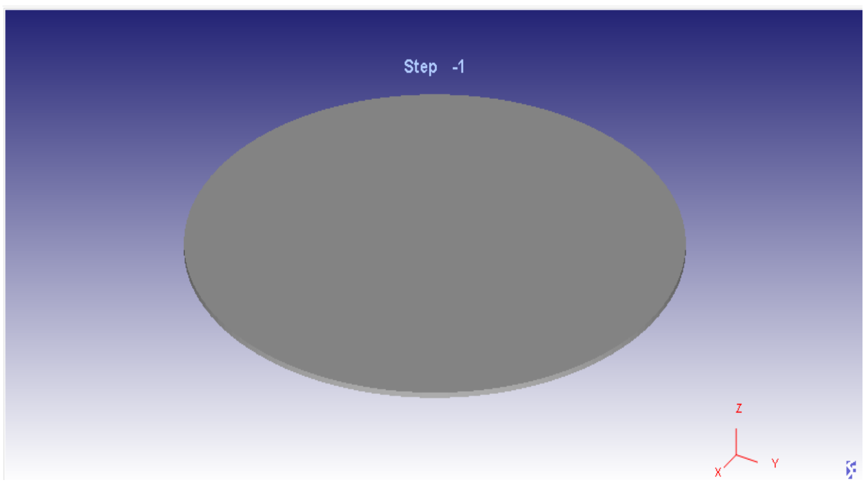


Fig 7 : Cylindrical blank sheet

After adding material ,meshing is done. Discretisation is done with tetrahedron elements with minimum size of 1 mm and size ratio of 2.5. The number of elements and nodes observed to be 20,000 , 2480 respectively.

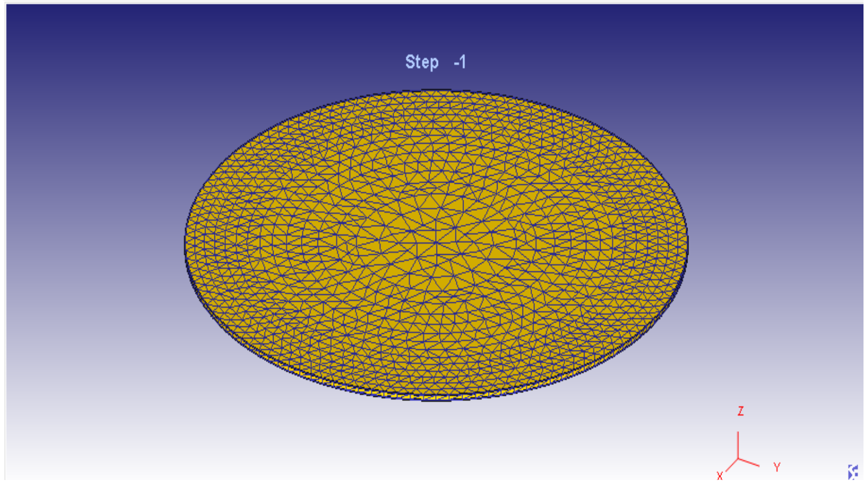


Fig 8 : Mesh generation of cylindrical blank sheet

Material properties are assigned to the blank from the material library.

In the next operation top die modeling is done. The top die is designed using the CAD tools as per dimensions obtained from the design equations.

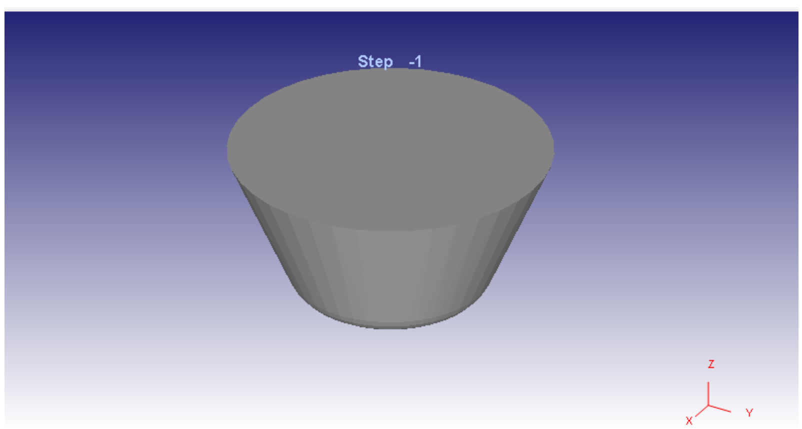


Fig 9 : Top Die

The bottom die is designed as per the dimensions and is shown in the image below.

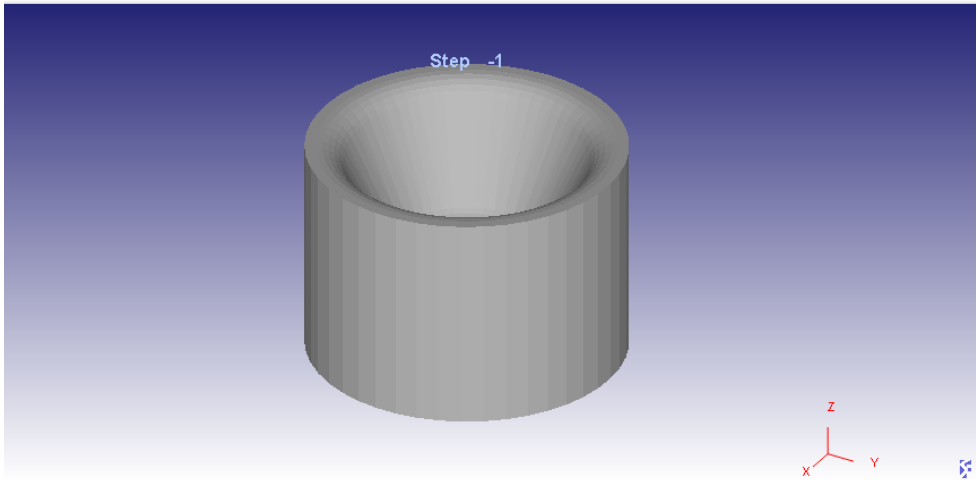


Fig 10: Bottom Die

The blank and the two dies are assembled as shown below.

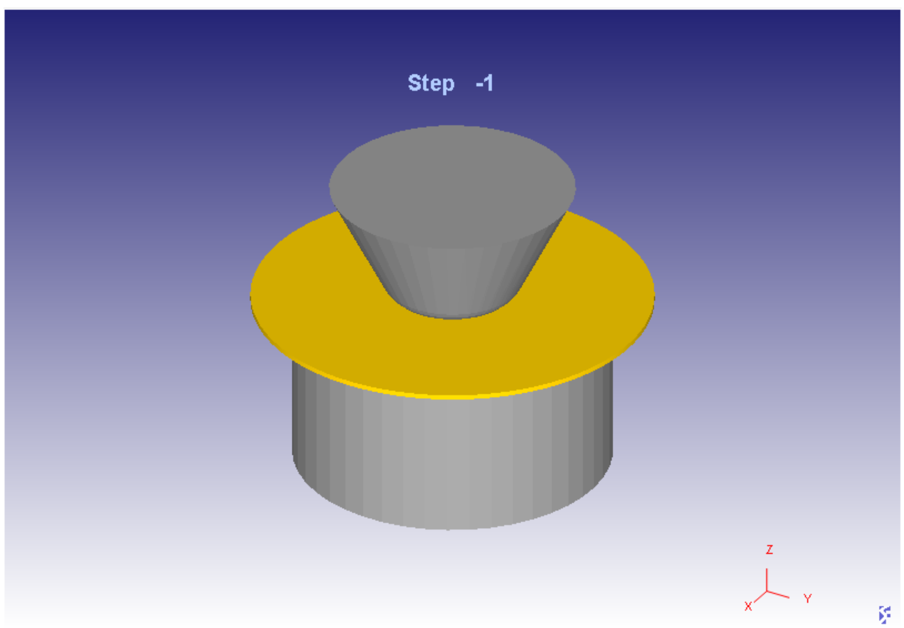


Fig 11: Assembly of blank and dies

The control parameters are assigned according to the trials given in the orthogonal array (L9) and simulations are done in the "Simulation operation" of the software.

7.RESULTS

ANOVA technique was adopted to determine the influence of each process parameter on the formability of deep drawn conical cups and executed by using the finite element analysis software namely DEFORM-3D.For the ANOVA (analysis of variance) the Fisher's test was carried out on all the parameters (A, B, C and D) at 90 % confidence level.

7.1 INFLUENCE OF PROCESS PARAMETERS ON EFFECTIVE STRESS

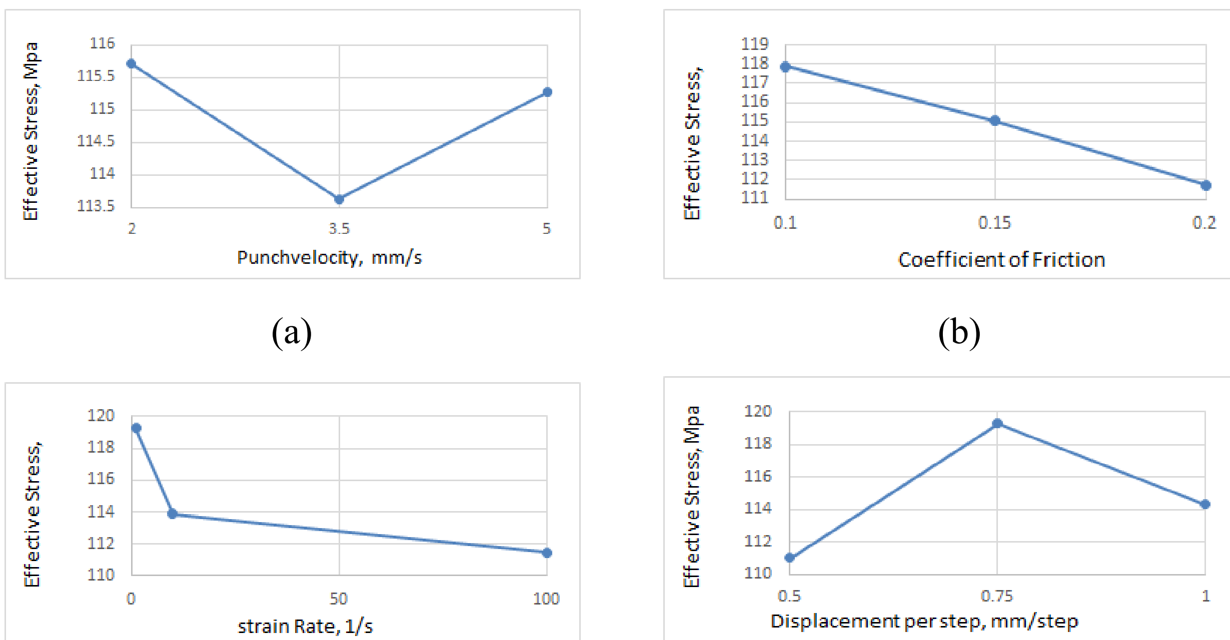
Table - 5 gives the ANOVA summary of the effective stress. The major contribution was of displacement per step(D) and strain rate(C) on the effective stress as they contribute more than half (75.52%) over the variation. The coefficient of friction(B) has a light contribution of 21.81% in the variation and punch velocity(A) had negligible contribution towards the effective stress

Table 5: ANOVA summary of effective stresses

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	347.06	340.911	345.831	7.05	1	7.05	1256.24	2.66
B	353.657	345.093	335.052	57.81	1	57.81	10301.14	21.81
C	357.838	341.651	334.313	96.59	1	96.59	17211.33	36.44
D	333.087	357.838	342.877	103.59	1	103.59	18468.66	39.08
e				0.01	4	0	0.00	0.01
T	1391.642	1385.493	1358.073	265.05	8			100

Note: SS is the sum of squares, v is the degrees of freedom, V is variance, F is Fisher's ratio, P is the percentage of contribution and T is the sum of squares due to total variation.

The effect of control parameters on the effective stress is given in figure 12. Effective stress is high when the punch velocity is 2m/s as shown in figure 12(a). Effective stress remains the same at initial state and shows no effect, but as coefficient of friction increases effective stress decreases as shown in figure 12(b). Effective stress decreases with increase in strain rate as shown in figure 12(c).As displacement per step increases effective stress is gradually increased and then decreases as displacement per step increases as shown in figure 12(d).



(a) (b) (c) (d)

Fig 12 : Effect of process parameters on effective stress of the cup

The final cup images showing effective stress values for each trial are presented below.

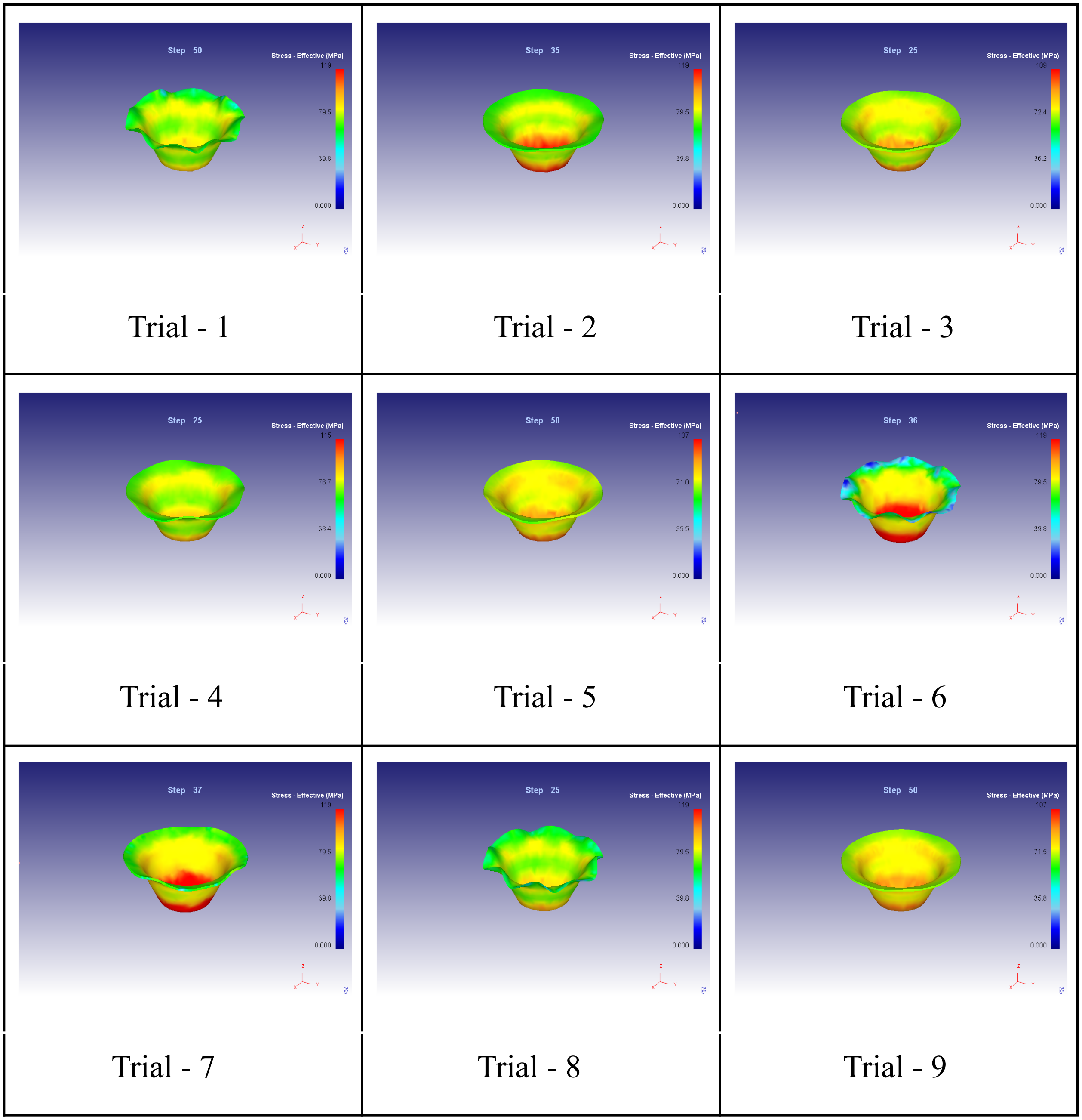


Fig 13: Cup images showing variation of effective stress

7.2 INFLUENCE OF PROCESS PARAMETERS ON SURFACE EXPANSION RATIO

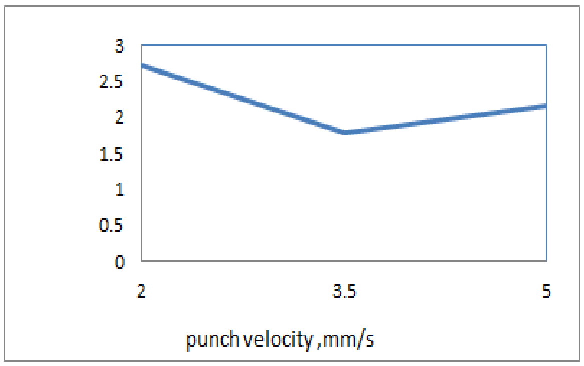
The ANOVA summary of surface expansion ratio is given in Table - 6. As per the Fisher's test, the punch velocity(A), coefficient of friction(B), strain rate(C) and displacement per step(D), respectively had contributed 13.59%,14.01%, 10.48% and 61.75% towards the total variation in the surface expansion ratio. Therefore displacement per step contributed the maximum in the variation of surface expansion ratio as it contributes more than half of the variation.

Table 6: ANOVA summary of surface expansion ratio

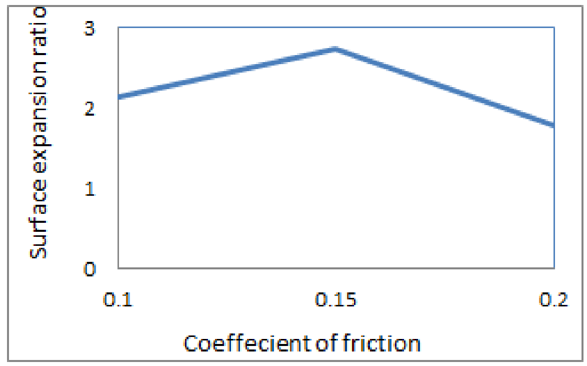
Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	8.15	5.36	6.47	1.31	1	1.31	80.86	13.59
B	6.42	8.19	5.37	1.35	1	1.35	83.33	14.01
C	5.5	7.96	6.52	1.01	1	1.01	62.35	10.48
D	4.89	10.11	4.98	5.95	1	5.95	367.28	61.75
e				0.0162	4	0	0.00	0.17
T	24.96	31.62	23.34	9.6362	8			100

The effect of control parameters on the surface expansion ratio is given in figure 14. Surface expansion ratio is high when the punch velocity is 2m/s and it decreases further as shown in figure 14(a). Surface expansion ratio remains the same at initial state and shows no effect, but as coefficient of friction increases surface expansion ratio also increases and then decreases as shown in figure 14(b).

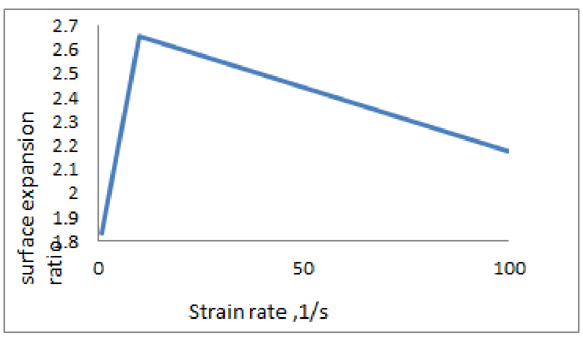
Surface expansion ratio increases as strain rate of cup increases as shown in figure 14(c).As displacement per step increases, the surface expansion ratio is gradually increased and then decreases as displacement per step increases as shown in figure 14(d).



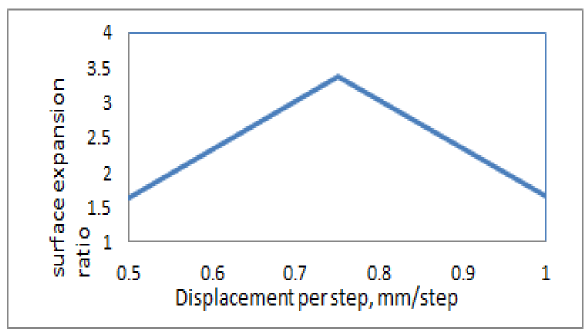
(a)



(b)



(c)



(d)

Fig 14 : Effect of process parameters on surface expansion ratio of the cup

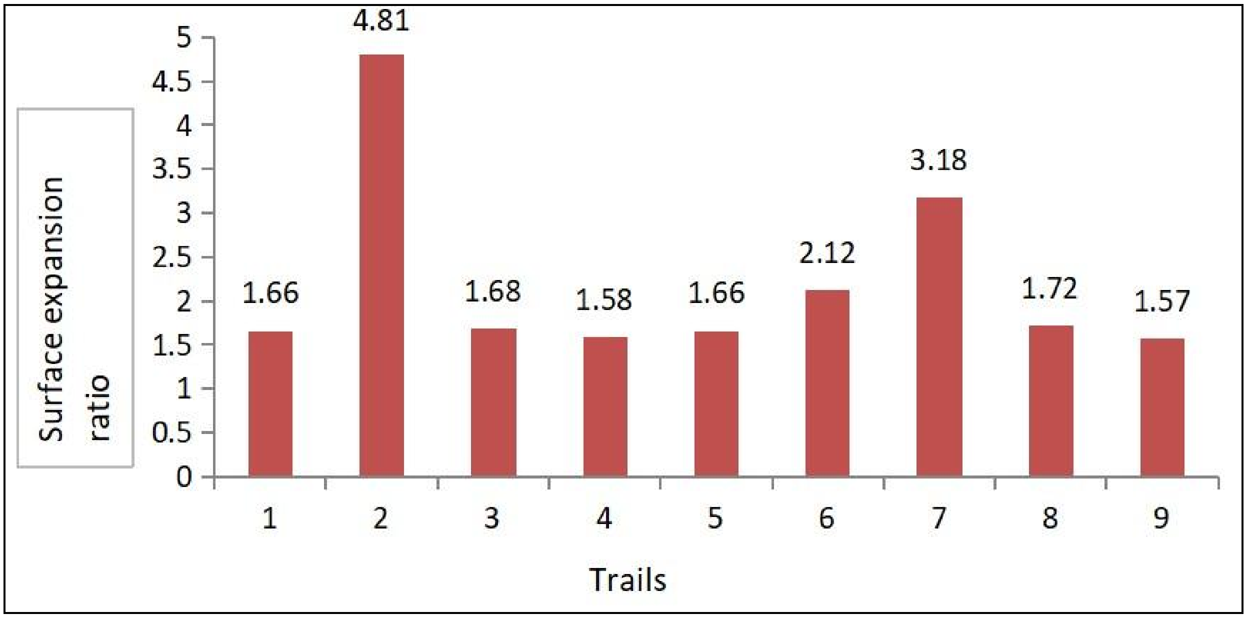


Fig 15 : Surface expansion ratios of cups with different tails of experimentation.

The FEA results of surface expansion ratio are revealed in fig 15 for various test conditions as per the design of experiments. The surface expansion ratio was 1.95 for the 9th trial under consideration.

The final cup images showing variation in surface expansion ratio for each trial are presented below.

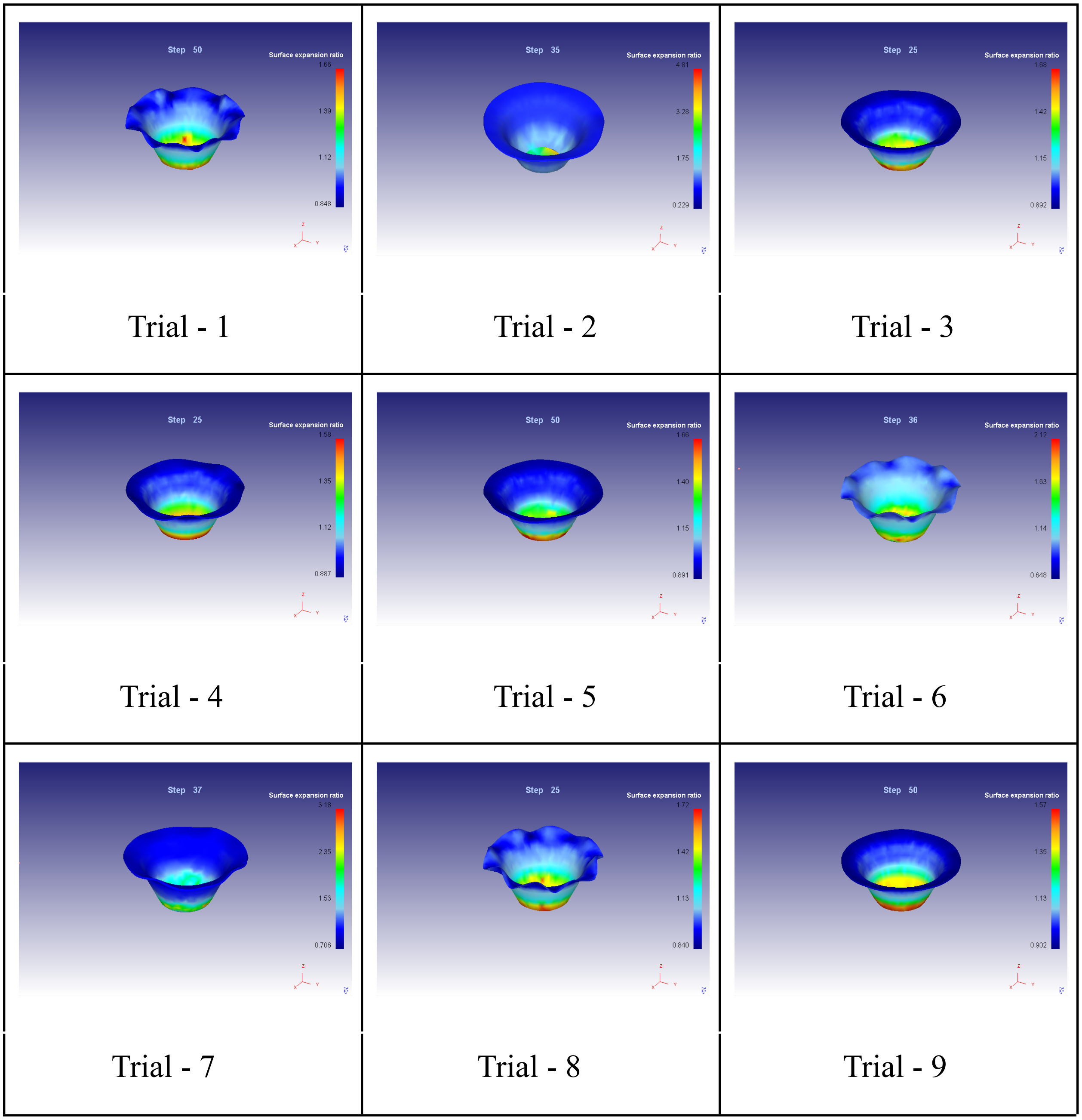


Fig 16 : Cup images showing variation of surface expansion ratio

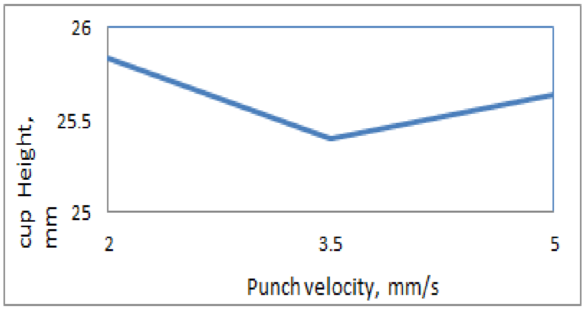
7.3 INFLUENCE OF PROCESS PARAMETERS ON CUP HEIGHT

As per the Fisher's test, the punch velocity (A) contributed 14.89 % variation observed in the cup heights (table 7). The coefficient of friction gave 7.98% and strain rate (C) gave 5.85% towards the total variation in the cup heights. The major contribution (70.74%) was from the displacement per step (D) on the cup height.

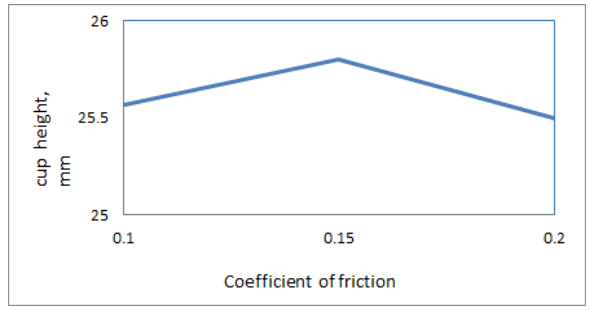
Table 7: ANOVA summary of cup height.

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	77.5	76.2	76.9	0.28	1	0.28	28.00	14.89
B	76.7	77.4	76.5	0.15	1	0.15	15.00	7.98
C	76.5	77.3	76.8	0.11	1	0.11	11.00	5.85
D	76.1	78.5	76	1.33	1	1.33	133.00	70.74
e				0.01	4	0	0.00	0.54
T	306.8	309.4	306.2	1.88	8			100

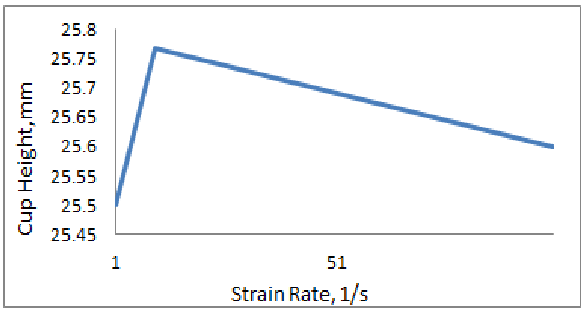
The effect of control parameters on the height of the cup is given in figure 17. The height of the cup is maximum when punch velocity is 2mm/s and minimum when punch velocity is 3.5 mm/s as shown in figure 17(a). Height of the cup increases when the coefficient of friction increases from 0.1 to 0.15. Further increase of coefficient of friction to 0.2, height of the cup decreases to 25.5mm as shown in figure 17(b). As strain rate increases, the cup height first increases and then gradually gets decreased as shown in figure 17(c). Cup height remains constant up to 75 steps and slightly decreases after 75 steps to 100 steps as shown in figure 17(d).



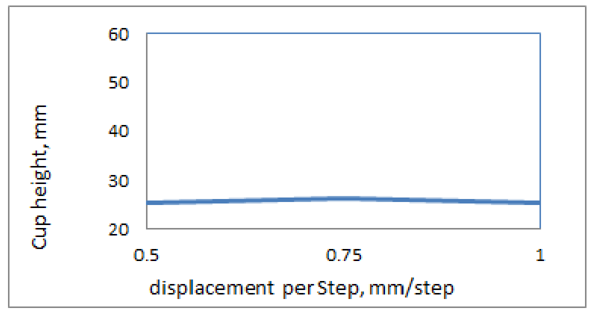
(a)



(b)



(c)



(d)

Fig 17 : Effect of process parameters on cup height.

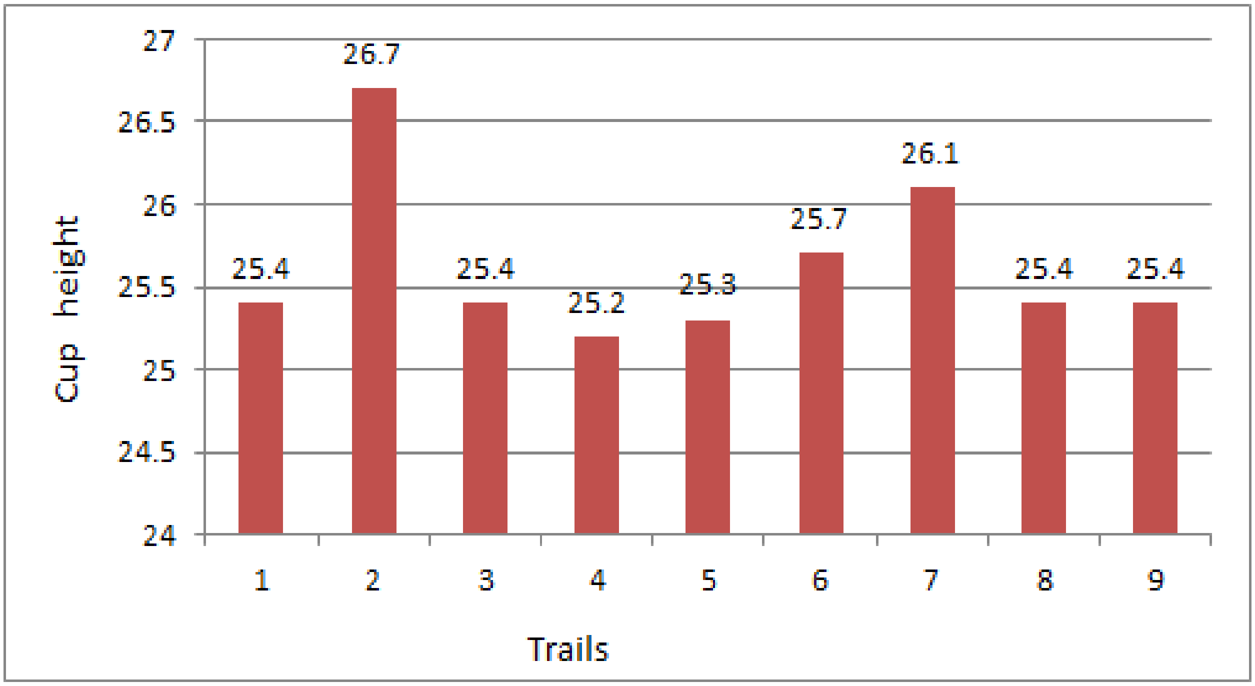


Fig 18 : Cup heights under different trials

The cup height is found to be maximum for 3rd trial with a value of 51.16 mm. The maximum values of cup heights were observed in the 3rd,4th and 8th trial for which the displacement per step values were 51.61,50.27 and 50.08 respectively.

The final cup images showing variation in total displacement for each trial are presented below.

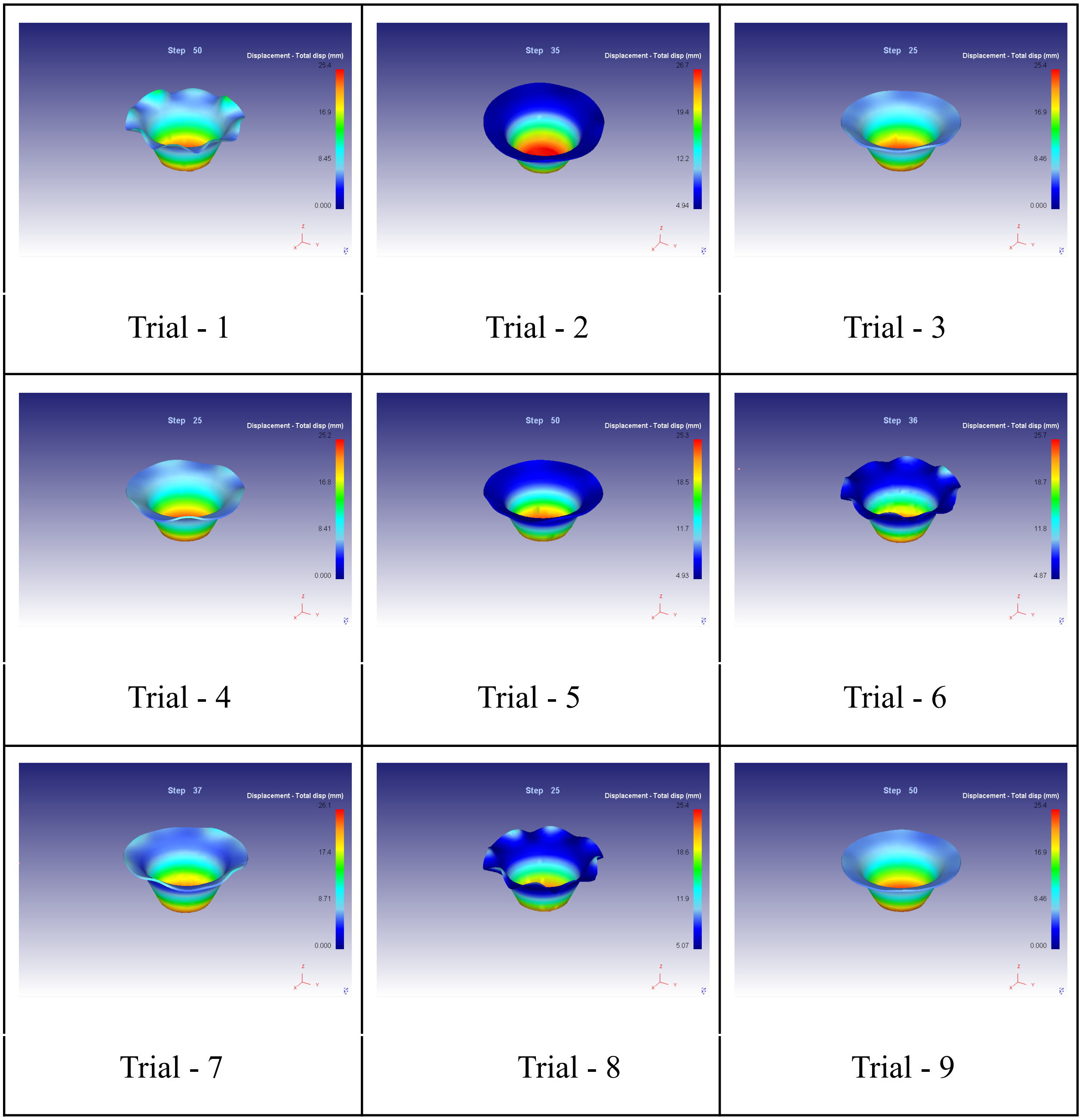


Fig 19 : Cup images showing variation of total displacement.

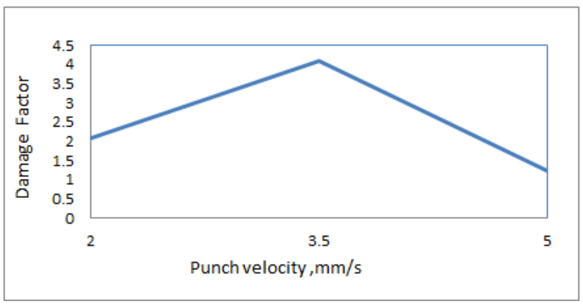
7.4 INFLUENCE OF PROCESS PARAMETERS ON DAMAGE OF CUP

The ANOVA summary of damage of cups is given in table -8. When the Fisher's test was applied to ascertain the influence of process parameters it was found that the punch velocity (A), coefficient of friction (B), strain rate (C) and displacement per step (D), respectively had contributed 13.80%, 13.88%, 12.47% and 59.83 of the total variation in the damages of the cups. As we can see from the values in the table - 8, displacement per step has the maximum contribution in the variation of cup damage (59.83%).

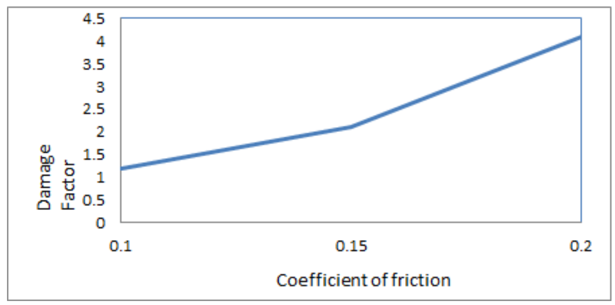
Table 8: ANOVA summary of cup damage.

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	6.22	12.28	3.67	13.03	1	13.03	1349.70	13.80
B	3.55	6.37	12.25	13.11	1	13.11	1357.99	13.88
C	12.03	6.32	3.83	11.78	1	11.78	1220.22	12.47
D	1.95	18.02	2.21	56.50	1	56.50	5852.50	59.83
e				0.01	4	0.00	0.00	0.02
T	23.75	42.99	21.95	94.43	8			100

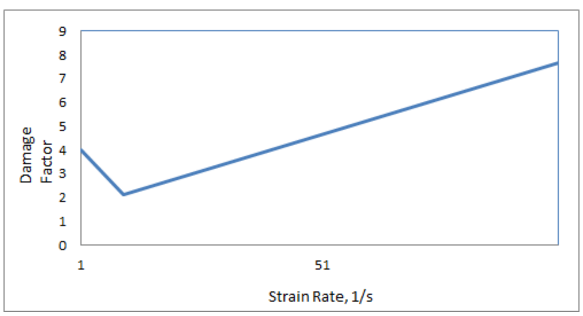
The effect of control parameters on the damage of cups is given in figure 20. Damage is highest when punch velocity is 3.5 m/s as shown in fig 20(a). The damage of cups is lowest when coefficient of friction is lowest as shown in fig 20(b). The damage of the cup slightly decreased first and then kept on increasing as the strain rate was increased as shown in figure 20(c). The damage of the cup is highest when displacement per step is 0.75 as shown in fig 20(d).



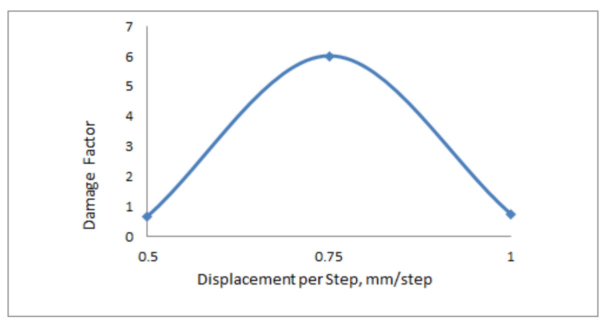
(a)



(b)



(c)



(d)

Fig 20 : Effect of process parameters on cup damage.

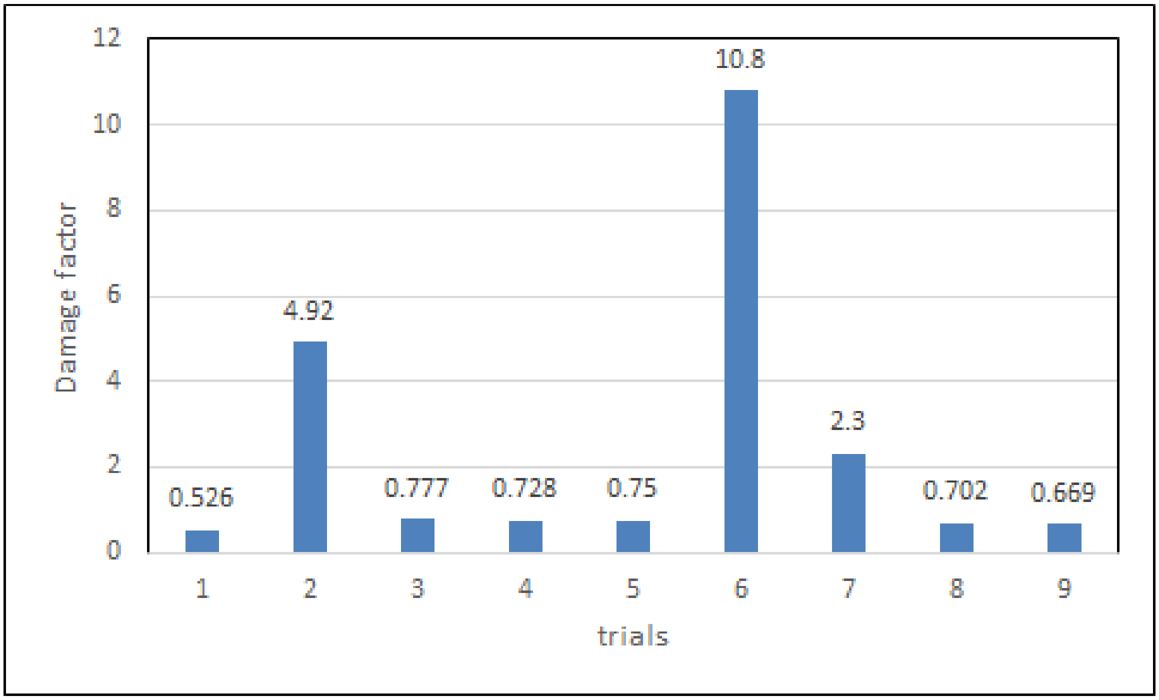


Fig 21 : Cup damage under different trials.

The cup damage is found to be maximum for the 6th trial with a value of 16.78 and the cup damage for the 7th trial is found to be 2.21 which has the minimum damage value. The maximum values of cup damage are observed in 6th for which the strain rate is minimum.

The final cup images showing variation in cup damage for each trial are shown below.

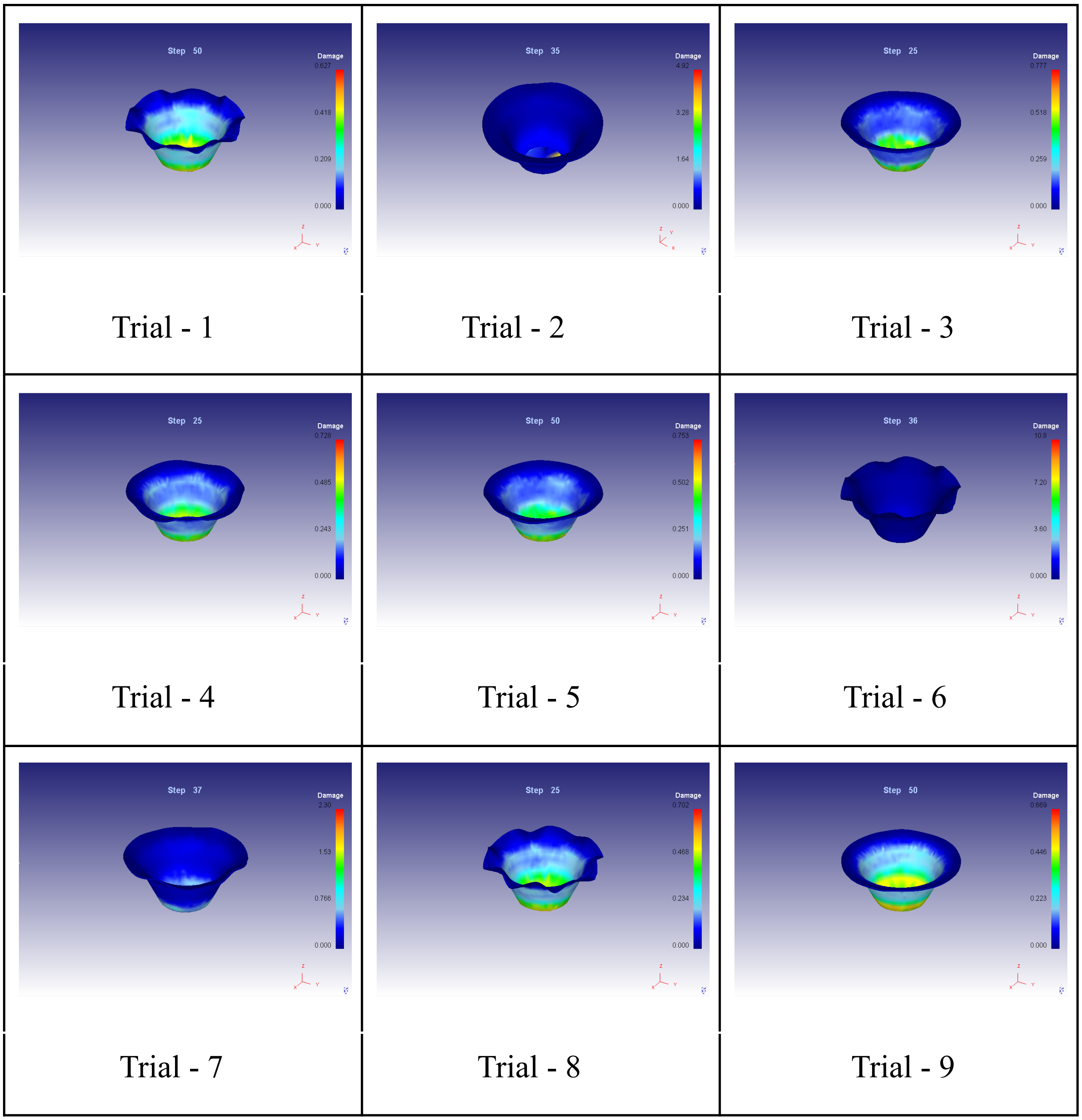


Fig 22 : Cup images showing variation of damage.

7.5 EFFECTIVE STRESS – EFFECTIVE STRAIN CURVES AFTER FINAL CUP FORMATION:

The data of effective stress values and effective strain values during the simulation of each trial are extracted and are plotted. During the cup formation the effective stresses are in proportion to effective strains up to a certain limit. When the material reaches the plastic region, as the material does not regain its shape the stresses are dropped as seen in the graph.

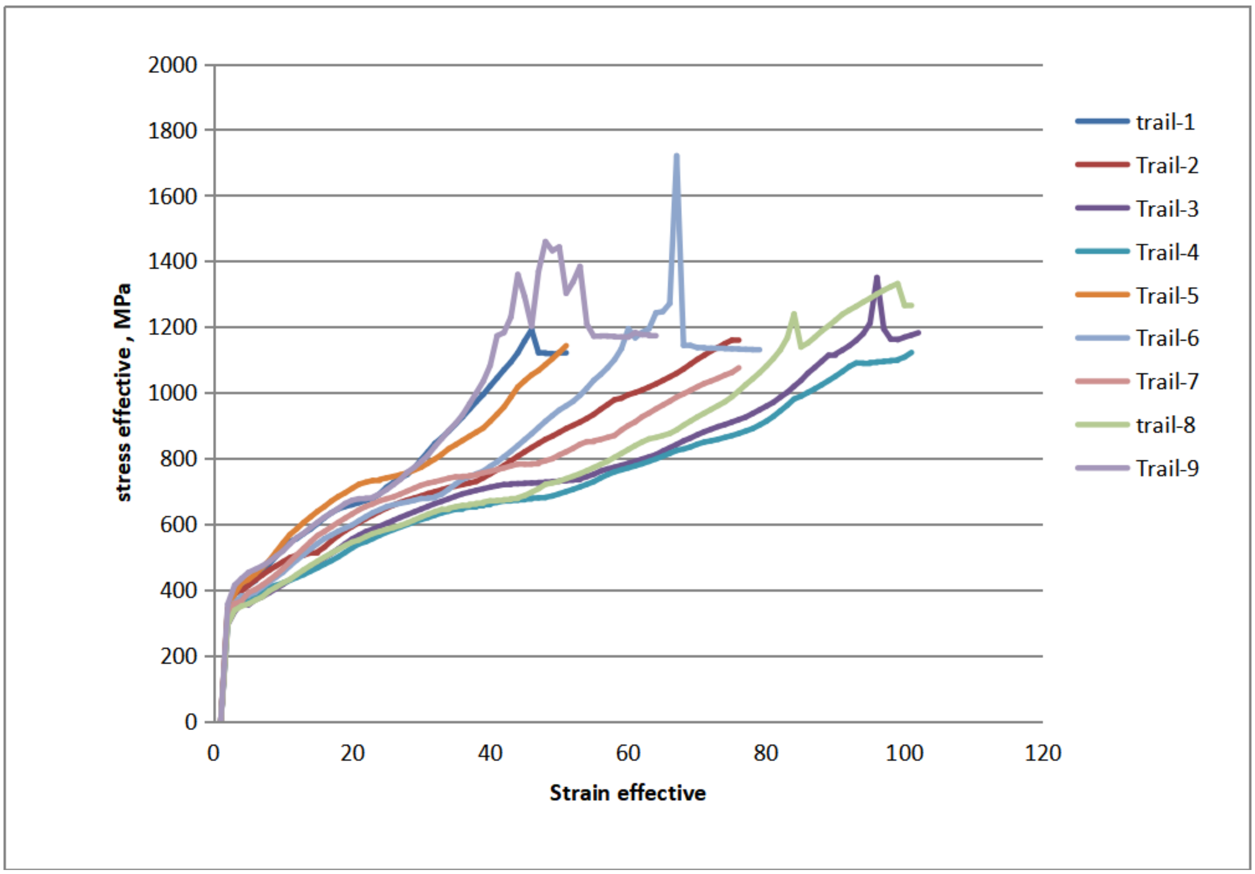


Fig 23 : Effective strain – effective stress curves during drawing operation.

7.6 LOAD - STROKE CURVES FOR ALL THE TRAILS

From the below graphs, it is observed that as the value of stroke increases, the load increases and reaches a maximum value at a certain point. However, when the final cup is formed, the load drops down from that maximum value.

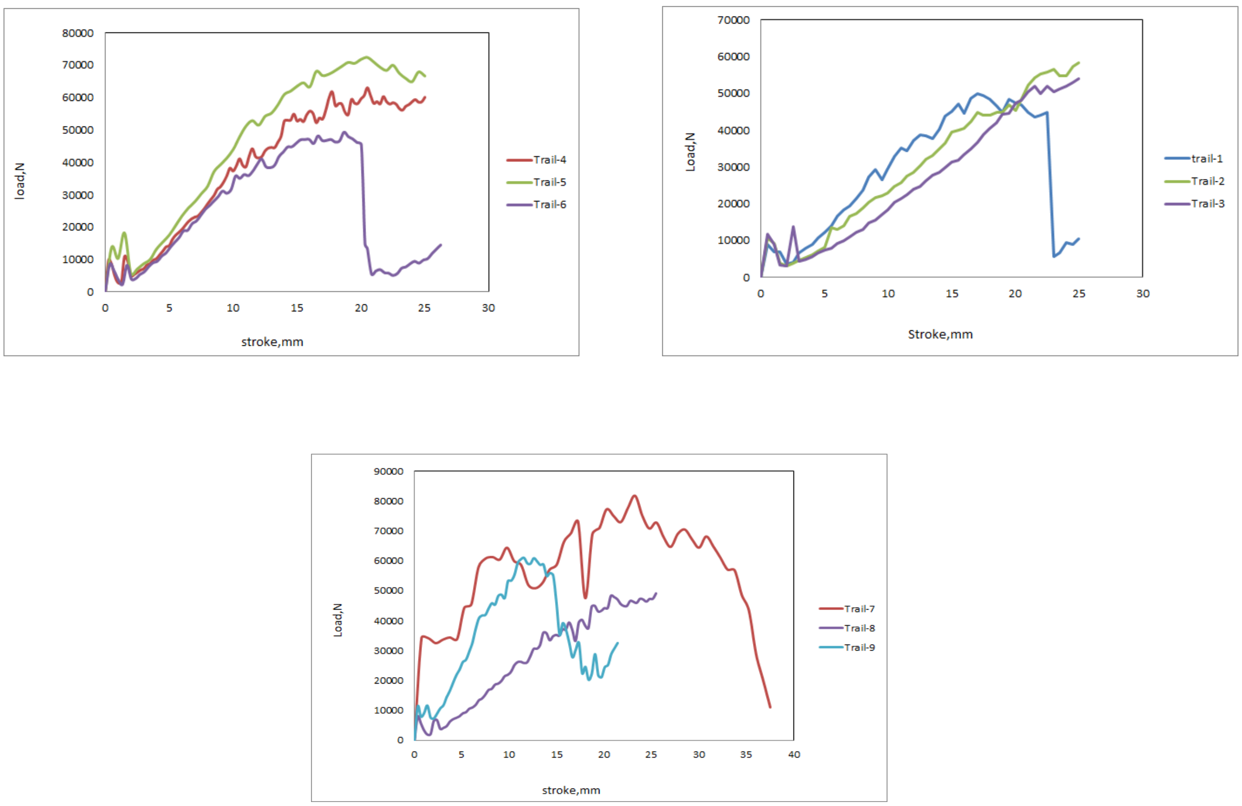


Fig 24 : Graph showing the variation of punch load with respect to stroke

8. CONCLUSION

The major process parameters which influenced the quality of the cup were coefficient of friction and displacement per step. The effective stress was mainly influenced by the coefficient of friction. The cup damage increased with an increase in coefficient of friction. The best value of coefficient of friction is 0.1 .As the displacement per step increased the height of the cup increasing.

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