B.TECH. PROJECT REPORT

On

Simulation and Analysis of Incremental Sheet Forming Process

BY

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DISCIPLINE OF MECHANICAL ENGINEERING

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Simulation and Analysis of Incremental Sheet Forming Process

A PROJECT REPORT

Submitted in partial fulfillment of the
requirements for the award of the degrees
of
BACHELOR OF TECHNOLOGY
in
MECHANICAL ENGINEERING

Submitted by:
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INDIAN INSTITUTE OF TECHNOLOGY INDORE
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CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Simulation and Analysis of Incremental Sheet Forming Process"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Mechanical Engineering' completed under the supervision of **Dr. Pavan Kumar Kankar, Associate Professor, Mechanical Engineering,** IIT Indore is an authentic work.

Further, I/we declare that I/we have not submitted this work for the award of any other degree elsewhere.

(ASHISH MEENA)

CERTIFICATE by BTP GUIDE

It is certified that the above statement made by the students is correct to the best of my/our knowledge.

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Preface

This report on "**Simulation and analysis of Incremental sheet forming process**" is prepared under the guidance of Dr. Pavan Kumar Kankar.

Through this report we have tried to give a detailed design on incremental sheet forming as to how it is more convenient than other process and try to cover every aspect of the new design, the design is technically and economically beneficial and feasible.

We have tried to the best of our abilities and knowledge to explain the content in a lucid manner. We have also added 3-D models and figures to make it more illustrative.

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Acknowledgements

We wish to thank Dr. Pavan Kumar Kankar for his kind support and valuable guidance. It is his help and support, due to which we became able to complete the design and technical report.

Without his support, this report would not have been possible.

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Abstract

Incremental sheet forming is a technique where a sheet is formed into the final a workpiece by a series of small and small and regular incremental deformations. It’s is a very advanced flexible mechanism which is helpful in making complex 3D products. Incremental sheet forming is a non-traditional method of sheet forming from ductile material. Incremental sheet forming is very different from conventional sheet forming in that die or punch are required to make a product but in incremental sheet forming those are not required. And the forming forces required too much less comparing to conventional deep drawing. Incremental sheet forming can deform a metal sheet to a greater degree compared to conventional forming processes. In the last decade, Incremental Sheet Forming process is quickly developed to a fact that it is capable of delivering custom made parts or batch products economically as per the market needs. In Incremental Sheet Forming the tool imparts local plastic deformation on sheet and tool movement along the sheet forms it into the required shape. Simple simulation has also been carried out.

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Chapter 1 Introduction

1.1 Introduction of Incremental sheet forming process

Modern forming is the backbone of the modern manufacturing industries besides being a major industry in itself. Every year millions of tons of metal go through metal forming process throughout the world. As much as 15 – 20 % GDP of the industrialized nations comes from metal forming industries. The incremental sheet forming process originated from stretch forming and metal spinning process. Thus incremental sheet forming process has combined the advantage of the stretch forming process and metal spinning process. Incremental sheet forming process has been developed in the context of sheet metal forming to increase the flexibility of that important industrial process. Incremental sheet forming is mainly used to produce small batch size or as a rapid prototyping process. Incremental sheet forming is a technique where a sheet is formed into the final a workpiece by a series of small and small and regular incremental deformations. During the last few years, incremental sheet forming process is quickly developed to a fact that this process is capable of custom made products economically.

This process is carried out at room temp on a CNC machine and requires a spherical headed tool with a simple arrangement to clamp the sheet that is being formed. The tool imparts plastic deformation on the sheet and the tool movements along with the sheet form it into the required shape. Geometry accuracy is considered to be the weak aspect of incremental sheet forming in a single point, incremental forming can achieve Higher depth as compared to two-point incremental forming but there will be some consequences in geometry accuracy. Incremental sheet forming is formally compatible with today’s technology and easy to use so it most likely used very wide areas like medical field, industrial field, automobile sectors and much other different variety of fields and as well as industrial based robots are most likely compatible with the today’s technology so it is used in various fields to generate parts related to process or if the whole body if possible. In this type of incremental sheet process of industrialized robots no die is required and the process can be done without dies and complex parts can be made with it with easier ease compared to other processes and it’s maintaining cost and processing cost is much lower compared to other and it’s processing time is much lower.

1.2 History

One of most and very important factor in the incremental sheet forming is metal sheet. Noone knows where this sheet come from where were its origination when were it’s first formed or we can say invented who did it and when he/she did it. But one thing is sure after the invention of metal sheet it changed the whole world formed it into a new world which is easier than he last one and most likely smooth. Before the invention of sheets most favorable are like hammering the metals like iron, copper, aluminum, silver, gold to form a desired shape which is desired. And which is further used for like making shields, sword, household materials and daily to daily use materials.

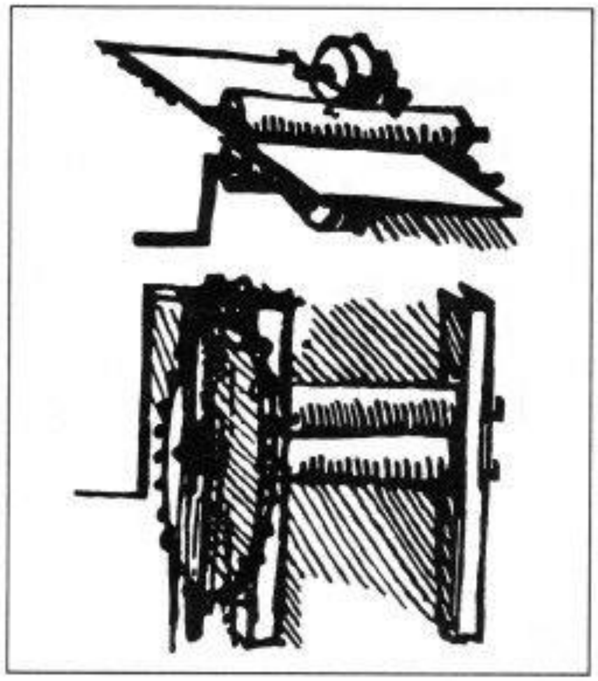


Figure 1   Design of rolling mill by Leonardo da Vinci [6]

This revolution occurred in metal sheet forming when first success happened by Leonardo da vinci in 1400s. The very first rolling machine is slitting mill and in the year 1590 and it became the important turning point in sheet metal forming process and after the first later many were introduced with slight modifications in the first one's and some in the one's which were later introduced. Initial one are not worth much firstly but as the time passes by more machines were introduced and later one's played a significant role in influencing the sheet metal forming. In initially thickness is a major problem which can be solved by first one's but it has it's own limits but in case of later one's it became more convenient as much of problem regarding the metal sheet is solved upto major extent.

Chapter 2 Material and Properties

2.1 Material

The material used in this project is Al1100. Aluminium is a chemical substance with the symbol Al and its atomic number is 13. Its appearance is silvery white and it's soft and ductile material. Aluminium is the third most abundant element after oxygen and silicon and the most abundant metal in the crust. The chief ore of aluminium is bauxite. Aluminium metal is highly reactive. Aluminium is known for its low density and its ability to resist corrosion. In Aluminum alloys in which aluminium is the predominant metal and, the other alloying elements are copper, magnesium, silicon, tin and zinc. Al1100 is the most heavily alloyed of the 1000 series. It is also the mechanically strongest alloy in the series. It is most commonly used aluminium alloy grade and it contains 99% aluminium. Aluminum 1100 alloy is widely used in fin stock, heat exchanger fins, spun hollowware, nameplates, decorative parts, gift types, cooking utensils, rivets and reflectors, and in sheet metal work. The material properties of the aluminium alloy are mentioned below.

Table 2.1 Material properties

Parameters	**Values**
Sheet Thickness	0.5 mm
Young Modulus	70 Gpa
Density	2710kg/mm^3
Poisson's ratio	0.33
Yield strength	105 Mpa

2.2 Geometry

The initial size of the metal sheet used in the project is 200mm x 200mm. The shape used for final workpiece is truncated cone and the base diameter of the cone is 130mm. In the process, the effect on the final product can be checked by changing the inclination angles. In the process, tool path is created on excel and for simulation, Abaqus is used. The feed rate is given 800mm/min which is kept constant for each and every case. The plan of the experiment table in which different wall angles related to different parameters is shown in table 2.2

Table 2.2 Available Data of experiment

Experiment No.	Wall inclination (degree)	Step Size (mm)	Tool Diameter (mm)
A	20^0	0.5	10
B	20^0	1	10
C	30^0	0.5	10
D	40^0	0.5	10
E	40^0	1	10

Chapter 3 Tool Path Generation

Incremental sheet forming is a technique where a sheet is formed into the final a workpiece by a series of small and small and regular incremental deformations. The tool path is created through excel. In incremental sheet forming, for making the complex products 3D CAD model is used to generate. The point defined on the tool is called a reference point (RP) shown in Figure 3.1

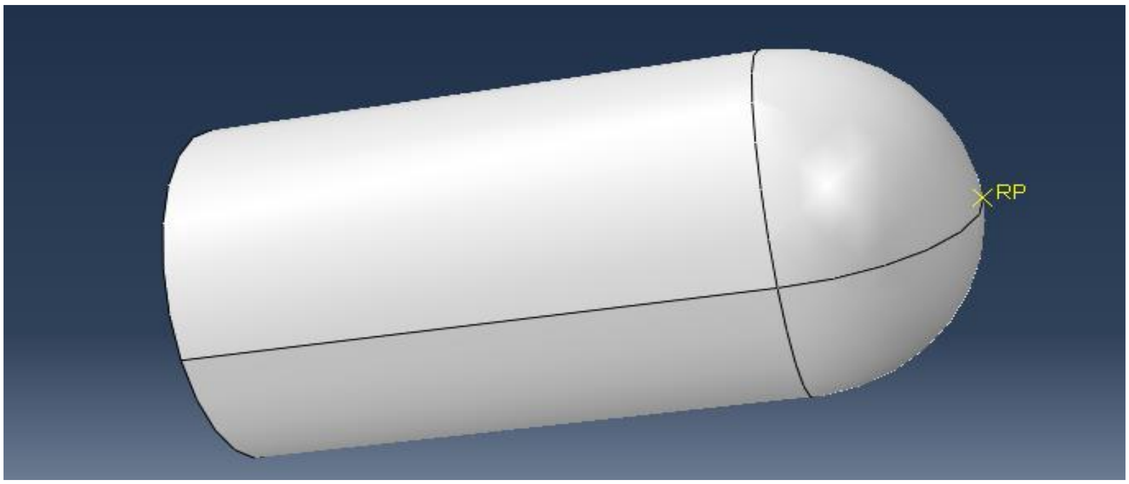


Figure 3.1 forming tool

The tool path in excel is formed by the formulas shown below

$$\theta = \frac{90*1.333*4}{2*\pi*R} \quad ; \qquad \varphi = \frac{\theta*\pi}{180} \tag{1}$$

$$X = R * \cos\varphi \quad ; \qquad Y = R * \sin\varphi \tag{2}$$

R = radius of the corresponding circle

θ= theta (angle) wall inclination angle wit vertical

φ = radian = θ * π/180

Here 1.3333 is the distance covered in one second. And X and Y are the coordinates.

In excel for making the amplitude data used in Abaqus first calculate radius on which want to calculate point. Then use that radius to get the angle covered in one second. Convert the angle to radians and by placing it in X and Y use it to get the coordinates. And by simply repeating the process for every circle final tool path can be obtained showing X, Y and Z coordinates concerning time.

Table 3.1 Tool Path coordinates with relation to the time at 20^0 at step size 0.5mm

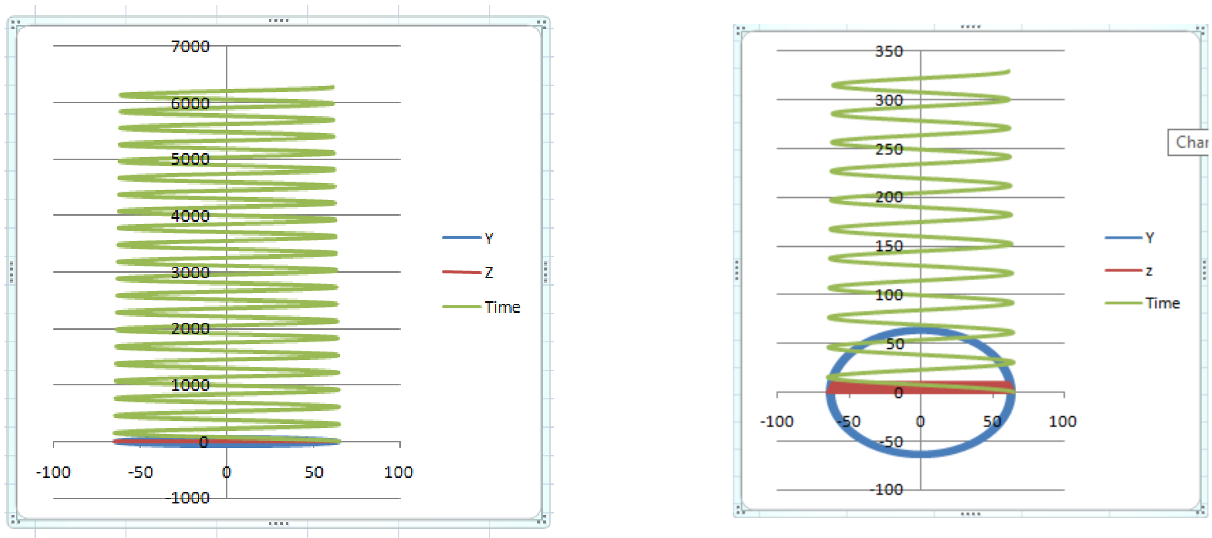
No	X	Y	Z	Time
1	65	0	0	0.1
2	64.98633	1.3329	0	0.2
3	64.94533	2.6653	0	0.3
4	64.87702	3.9965	0	0.4
5	64.78142	5.3261	0	0.5
6	64.6585	6.6532	0	0.6
7	64.5085	7.9780	0	0.7
-	-	-	-	-
-	-	-	-	-
10	59.5473	-14.804	-10	327.7
11	59.8549	-13.5069	-10	327.8
12	60.13422	-12.2035	-10	327.9
13	60.38513	-10.8943	-10	328.0
14	60.60754	-9.	-10	328.1
15	60.80134	-8.2611	-10	328.2
16	60.96645	-6.9383	-10	328.3
17	61.10279	-5.61236	-10	328.4
18	61.21029	-4.28369	-10	328.5
19	61.2889	-2.953	-10	328.6
20	61.33859	-1.62091	-10	328.7
21	61.36	0	-10	328.8

Table 3.1 shows the data of the tool path created in excel at 20^0. At a step size of 0.5 mm in this first circle point is calculated at radius 65 and later at corresponding step sizes up to 10 mm depth

Table 3.2 Tool Path coordinates with relation to time at 20^0 at step size 1mm

No	X	Y	Z	Time
1	65	0	0	0.1
2	64.98633	1.3329	0	0.2
3	64.94533	2.6653	0	0.3
4	64.87702	3.9965	0	0.4
5	64.78142	5.3261	0	0.5
6	64.6585	6.6532	0	0.6
7	64.5085	7.9780	0	0.7
8	64.33136	9.2992	0	0.8
9	64.12713	10.6153	0	0.9
10	-	-	-	-
11	-	-	-	-
12	60.80134	-8.2611	-10	627.0
13	60.96645	-6.9383	-10	627.1
14	61.10279	-5.61236	-10	627.2
15	61.21029	-4.28369	-10	627.3
16	61.2889	-2.953	-10	627.4
17	61.33859	-1.62091	-10	627.5
18	61.36	0	-10	627.6

Table 3.2 shows the data of the tool path created in excel at 20^0. First circle point is calculated at radius 65 and later at corresponding step sizes up to 10 mm depth at 1mm step size.



(a) (b)

Figure 3.2 Tool paths at 20^0 (a) at step size 0.5mm (b) at step size 1mm

In figure 3.3 on Y axis, it indicated time, graph base is X-Y area but it's 2D figure so Only front axis shown which represent X-axis. It's the graph between X-Y and Time. Time is always positive so this graph is rising upward so if imagined you can see rising upward truncated cone.

Table 3.3 Tool Path coordinates with relation to time at 40^0 at step size 0.5mm

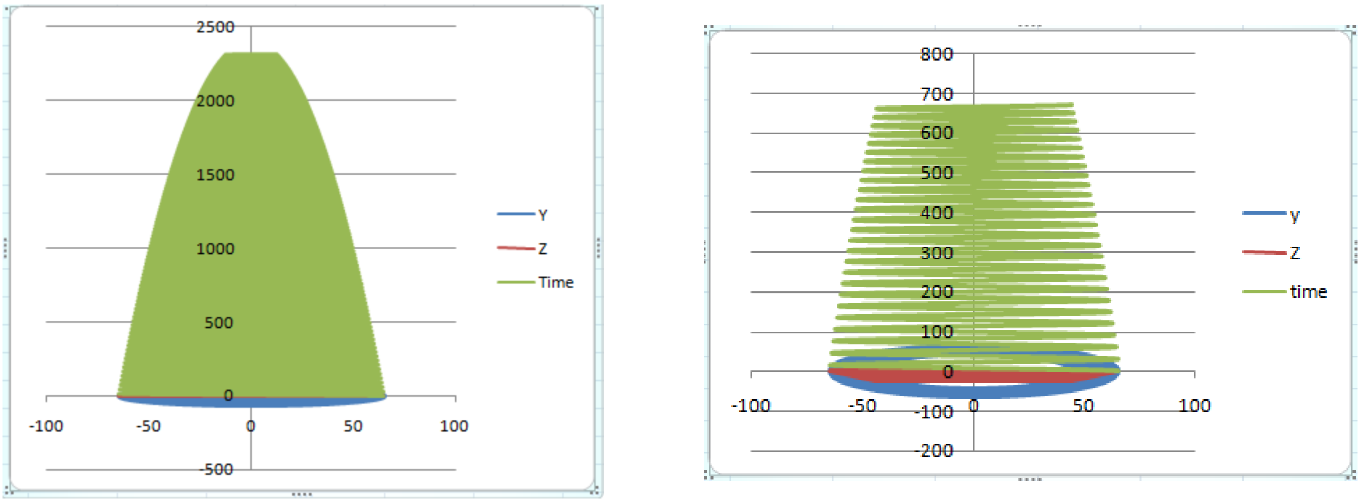
No	X	Y	Z	TIME
1	65	0	0	0.1
2	64.98633	1.3329	0	0.2
3	64.94533	2.6653	0	0.3
4	64.87702	3.9965	0	0.4
5	64.78142	5.3261	0	0.5
6	64.6585	6.6532	0	0.6
7	64.5085	7.9780	0	0.7
8	64.33136	9.2992	0	0.8
9	64.12713	10.6153	0	0.9
10	-	-	-	-
11	-	-	-	-
12	-	-	-	-
13	-	-	-	-
14	10.71615	-6.53198	-62.5	2317.1
15	11.04778	-5.95391	-62.5	2317.15
16	11.34826	-5.35906	-62.5	2317.2
17	11.61674	-4.74909	-62.5	2317.25
18	11.85246	-4.12573	-62.5	2317.3
19	12.05476	-3.49073	-62.5	2317.35
20	12.22307	-2.8459	-62.5	2317.4
21	12.35691	-2.1933	-62.5	2317.45
22	12.4559	-1.53399	-62.5	2317.5
23	12.51977	-0.87061	-62.5	2317.55
24	12.54833	-0.20479	-62.5	2317.6
25	12.55	0	-62.5	2317.65

Table 3.3 shows the data of the tool path created in excel at 40^0. At a step size of 0.5 mm in this first circle point is calculated at radius 65 and then at corresponding step sizes up to -62.5 mm.

Table 3.4 Tool Path coordinates with relation to the time at 40^0 at step size 1mm

No	X	Y	Z	Time
1	65	0	0	0.1
2	64.98633	1.3329	0	0.2
3	64.94533	2.6653	0	0.3
4	64.87702	3.9965	0	0.4
5	64.78142	5.3261	0	0.5
6	64.6585	6.6532	0	0.6
7	-	-	-	-
8	-	-	-	-
9	40.37721	-17.4837	-25	670.2
10	40.88804	-16.2532	-25	670.3
11	41.36139	-15.0078	-25	670.4
12	41.79681	-13.7487	-25	670.5
13	42. 19392	-12. 4769	-25	670.6
14	42.55233	-11.1937	-25	670.7
15	42.87139	-9.90024	-25	670.8
16	43.15182	-8. 59769	-25	670.9
17	43.39259	-7.28726	-25	671
18	43.59309	-5.97015	-25	671.1
19	43.75386	-4.64757	-25	671.2
20	43.87451	-3.32072	-25	671.3
21	43.95494	-1.99083	-25	671.4
22	43.99506	-0.65911	-25	671.5
23	44	0	-25	671.6

Table 3.4 shows the data of the tool path created in excel at 40^0. First circle point is calculated at radius 65 and then at corresponding step sizes up to 25 mm depth at 1mm step size.



(a) (b)

Figure 3.3 Tool paths at 40^0 (a) at step size 0.5mm (b) at step size 1mm

In figure 3.3 on Y-axis, it indicated time, graph base is X-Y area but it's 2D figure so Only front axis shown which represent X-axis. It's the graph between X-Y and Time. Time is always positive so this graph is rising upward so if imagined you can see rising upward truncated cone.

Table 3.5 Tool Path coordinates with relation to time at 40^0 at step size 1mm

No	X	Y	Z	Time
1	65	0	0	0.1
2	64.98633	1.3329	0	0.2
3	64.94533	2.6653	0	0.3
4	64.87702	3.9965	0	0.4
5	64.78142	5.3261	0	0.5
6	64.6585	6.6532	0	0.6
7	64.5085	7.9780	0	0.7
8	64.33136	9.2992	0	0.8
9	64.12713	10.6153	0	0.9
10	-	-	-	-
11	-	-	-	-
12	-	-	-	-
13	-	-	-	-
14	8.118347	-3.01464	-97.5	3424.8
15	8.326168	-2.38136	-97.5	3424.85
16	8.48463	-1.173397	-97.5	3424.9
17	8.592854	-1.07632	-97.5	3424.95
18	8.65018	-0.41228	-97.5	3425
19	8.66	0	-97.5	3425.05

Table 3.5 shows the data of the toolpath created in excel at 30^0. First circle point is calculated at radius 65 and later at corresponding step sizes up to -97.5 mm depth at 0.5mm step.

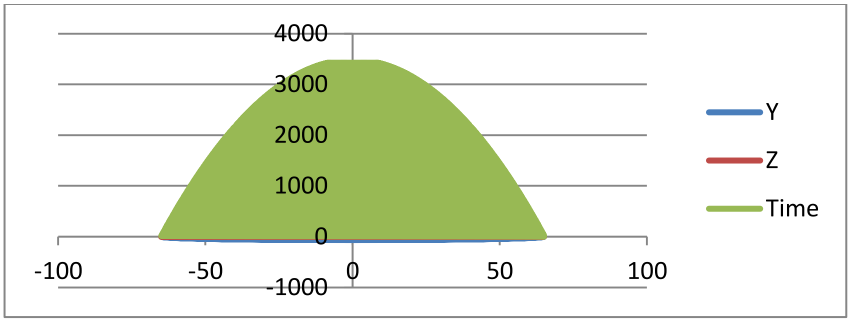


Figure 3.4 Tool Path at 30^0 at step size 0.5 mm

Figure 3.4 shows the graph of the toolpath created in excel at 30^0 on Y axis it indicated time, graph base is X-Y area but it's 2D figure so Only front axis shown which represent X-axis. It's the graph between X-Y and Time. Time is always positive so this graph is rising upward so if imagined you can see rising upward truncated cone with its base as XY plane.

Chapter 4 Simulation model

Finite Element Analysis

Finite element method is used to most likely problems related to engineering aspect and mathematical related also. It has a variety of problem-related areas temperature related, heat transfer, fluid flow, mass flow and other variables also. In this project, Abaqus is used and these are the following steps which are performed while simulation.

- Creating solid parts
  In this, we create solid parts which are required in the model. In this, we require 2 parts first one is sheet whose size is 200x200 mm and which is 0.5mm thick. The sheet is deformable and solid and same can be said for the tool which is 10 mm in diameter and has a hemispherical end and 10 cm long. Both the parts are deformable and solid these are the categories used.
  The tool deforms the sheet when it applies the force on it which forms the sheet into the desired final shape.

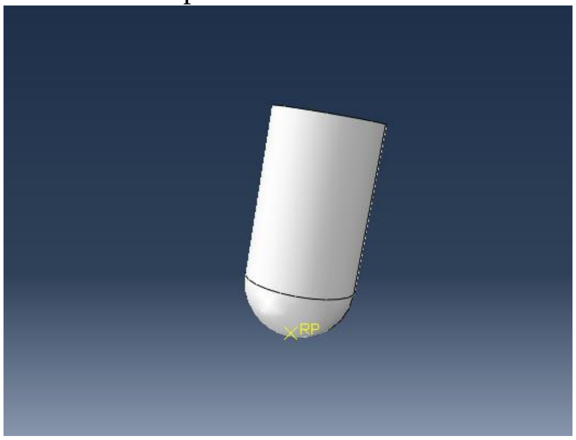


Figure 4.1 Forming tool

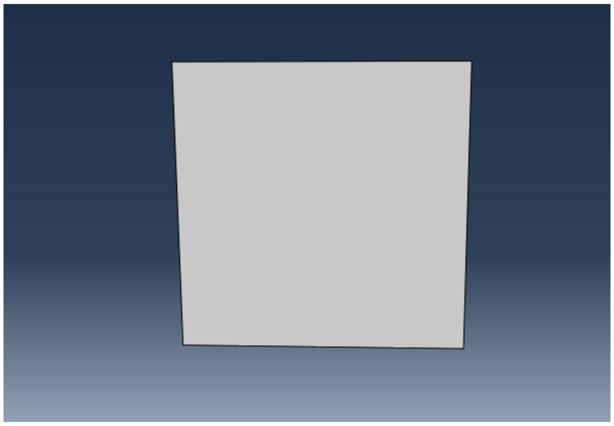


Figure 4.2 sheet

- Define the material model give the material values and assign the material to the section
  In material selection firstly create section select solid and homogeneous and then later step is to assign the section created select the part with the material properties.
- Create assembly and move the tool to its initial position of tool path

Select both the forming tool and the sheet. The tool is assigned at origin and the tool path starts from 65,0,0 so shift the tool to the tool path initial position.

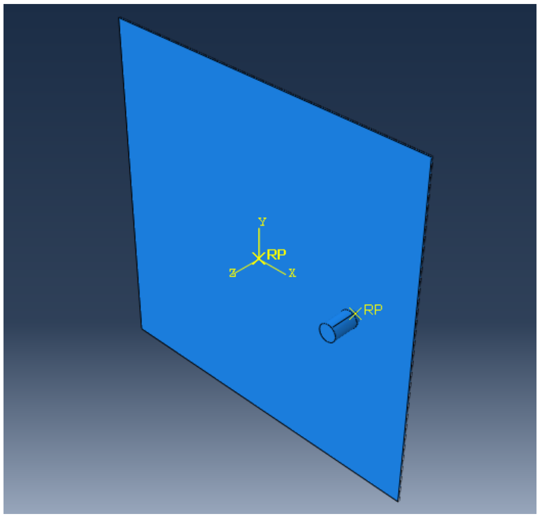


Figure 4.3 Assembly

- Step = dynamic explicit

  The analysis is divided into 3 steps first one is Initial step. The initial step is where the interaction between the tool and the sheet and the contact controls are defined these properties are propagated into the further steps in the simulation. They are the second and third step in which time of the process is defined.
- Define the Amplitude of the X, Y and Z directions as Amp1 X, Amp2 Y and Amp3 Z.
- Load

  In defining the Boundary conditions. The initial step in boundary condition is fixing the edges of the sheet using the encastre command which will make U1, U2, U3 which are the displacements in all the 3 directions and UR1, UR2 and UR3 which are the rotations about x, y and z axes of the cells along boundary of the sheet zero i.e. ENCATRE(U1=U2=U3=UR1=UR2=UR3=0). Later one for assign the displacement of the tool in x, y and z directions with the corresponding amplitude i.e U1 to Amp1 X, U2 to Amp2 Y and U3 to Amp3 Z.
- Mesh

  In a simulation using the finite element method meshing plays a key role in determining the accuracy of the simulation model. In this one is master surface and the other one is slave surface for a greater value of accuracy slave surface is fined meshed than the master surface. The only sheet has meshed as the tool is an analytical rigid part.

- Result

Chapter 5 Results and Discussion

The experiments were carried out according to the above mentioned plan of the experiment. Through simulation maximum depth reached is measured. The results are shown in Table 5.1

Table 5.1 Result

Experiment No	Wall inclination (degree)	Step Size (mm)	Maximum Depth Reached (mm)
1	20^0	0.5	9.3
2	20^0	1	9.1
3	30^0	0.5	97.3
4	40^0	0.5	69.2
5	40^0	1	23.1

Incremental sheet forming is the result of the plastic deformation and elastic deformation, where plastic deformation plays a significant role in incremental sheet forming as it is permanent compared to elastic deformation which is recoverable in nature as it has the ability to springback causing thee component to springback. Incremental sheet forming is a technique where a sheet is formed into the final a workpiece by a series of small and small and regular incremental deformations. The tool imparts the plastic deformation on the sheet repeatedly. Thus the springback effect is very less in incremental sheet forming. The stresses in the system intuitively increase as the depth or the tool motion in the z-direction increases.

It can be seen from the results that sheet with wall inclinations 20° were unable to reach the desired depth. It was shown in the two cases of 20° i.e. the two simulation models in Abaqus at 20° the simulation stops at a depth below 10mm which conclude that for the step size of 0.5 mm and 1mm sheets with a wall inclinations 20° cannot be formed with single point incremental forming as its depth is below 10mm. As seen from the result that sheet with wall inclination 40° at a step size of 0.5mm and 1mm the maximum depth reached is 69.2mm and 23.1mm. And in case of the sheet with wall inclinations, 30° at a step size of 0.5mm the maximum depth reached are 97.3mm.

Chapter 6 Conclusion

The research work done in this project was aimed to analyse the maximum depth reached in the incremental sheet forming process. This kind of experiments was performed simply for the purpose of evaluation of geometric accuracy of the part manufactured along with the determination of the maximum forming depth or maximum forming angles for the aluminium materials tested. These simulations were conducted keeping the forming angle and step size changing to analyse the changes in products obtained as the diameter for the forming tool is kept fixed. Depending upon the above results certain conclusion can be drawn.

- Sheet with wall inclination angle 20° cannot be formed in single point incremental sheet forming.
- The stresses in the system intuitively increase as the depth or the tool motion in the z-direction increases
- Sheet with wall inclination angle 30° provide more freedom compared to Sheet with wall inclination angle 40° and 20°

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