

A
DISSERTATION REPORT
on
**FEA Simulator Development for Sheet Metal
Deep Draw**

Submitted in partial fulfilment of the requirements for award of degree of

**MASTER OF ENGINEERING
IN
CAD/CAM**

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July 2014**

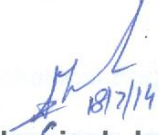
CERTIFICATE

I hereby certify that the thesis entitled "FEA Simulator Development For Sheet Metal Deep Draw" is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering in CAD/CAM** at **Thapar University, Patiala** under the supervision of **Mr. A. S. JAWANDA**, Associate professor, Mechanical Engineering Department, Thapar University, Patiala. The matter embodied in this report has not been submitted in partial or full to any other university or institute for the award of any degree.


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This is certified that the above statement made by the student is correct to the best of my/our knowledge and belief.


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ACKNOWLEDGEMENT

I express my sincere gratitude to my guide **Mr. AJAYINDER SINGH JAWANDA**, Associate Professor Mechanical Engineering Department, Thapar University, Patiala, for their invaluable guidance, proper advice and constant encouragement during the course of my work in this Seminar report.

I am also grateful to Mr Simardeep Singh Randhawa, Mr Harvinder Singh, Mr kailash Dahiya and Mr Ganesh R for technical support and valuable time given by him towards my work and giving me enhance knowledge in the field of sheet metal and FEA.

I would also like to thank my friends who helped me a lot. Special thanks to Mr Gurmeet Singh, Mr Satnam, Mr Satinder Singh Rana and Mr Sandeep Singh Mangat.

I am indebted to the technical staff of college workshop always being helpful to me.

I would also express my gratitude to **Dr. Ajay Batish**, Head, Mechanical Engineering Department for his inspirational guidance and wholehearted corporation which was helped me to present this Seminar.

I thank the entire faculty and staff of Mechanical Engineering Department, Thapar University, for their help and moral support.

The author acknowledges the use of facilities of State Initiated Design Centre (SIDC) for wood working of Mechanical Engineering Department, Thapar University, Patiala, set up under financial support from Handicrafts Division of Ministry of Textile, Government of India.

At last but most important I am highly thankful to my family for their love, support and care.

(SATPAL SINGH)

ABSTRACT

Deep drawing is a process of sheet metal widely used in automotive industries. The formability of the sheet is under plastic deformation. During the plastic deformation of the sheet, some defects appear on the sheet. Wrinkling, rupture, earing and tearing are defects during the deep draw.

This thesis work studies physical example of exhaust valve manufacture in Cheema industries, focal point Ludhiana. In this example the wrinkling is a defect which occurs during the deep draw. The defect appears on pneumatic press and was eliminated by replacing the press with hydraulic press.

Based on which the simulator is developed for this process. So that virtual experimentation could be done for arriving the optimum process and die design.

The simulator needs four distinct inputs. These inputs are:-

- Geometry.
- Material property.
- Module.
- Loading conditions.

ANSYS is used as CAE software. The selection of which is done from competitive software. Material properties of the plastic deformation were experimentally determined using stop motion video of standard tensile test performed, test samples of the sheet under test.

The development of simulator and its various inputs is presented. The simulation results of processes, producing wrinkling and one in which they are eliminated are validated against the physical processes in industry.

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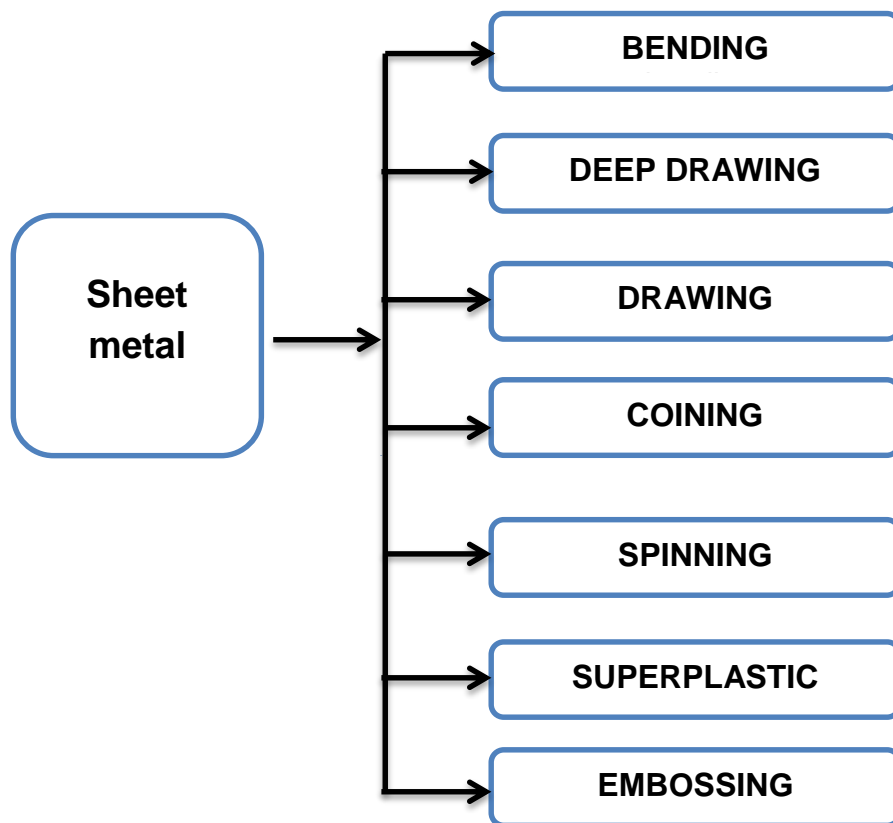
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1 INTRODUCTION

In steel industry, sheet metal is one of the important semi-finished products manufactured. Sheet metal forming knowledge is therefore an important engineering to be learned. It is characterized by a high ratio of surface area to thickness. It is mainly conversion of a flat sheet of confined dimension into a preferred shape of the product without defects like fracture or thinning or wrinkles. It has been widely applied in many industrial fields, such as automobile industry and the steel industry etc. The process of sheet metal forming comprises of localized or general bending, drawing, stretching, ironing and various combinations of all these methods of deformation. Parts produced by sheet metal deformations have the advantage that they have high elastic modulus and high yield strength. Understanding of sheet deformation procedure and the mutual contact involves in the process are chief to be under consideration during a particular sheet metal forming process. Distinctive examples are metal counters, bus bodies, aircraft wings, cans, auto bodies and different types of kitchen utensils. There are various types of sheet metal forming processes.



Deep drawing process involves formation of ampules from flat circular blanks. Deep drawing refers to the process that when the complexity of the drawn part outstrips its diameter.

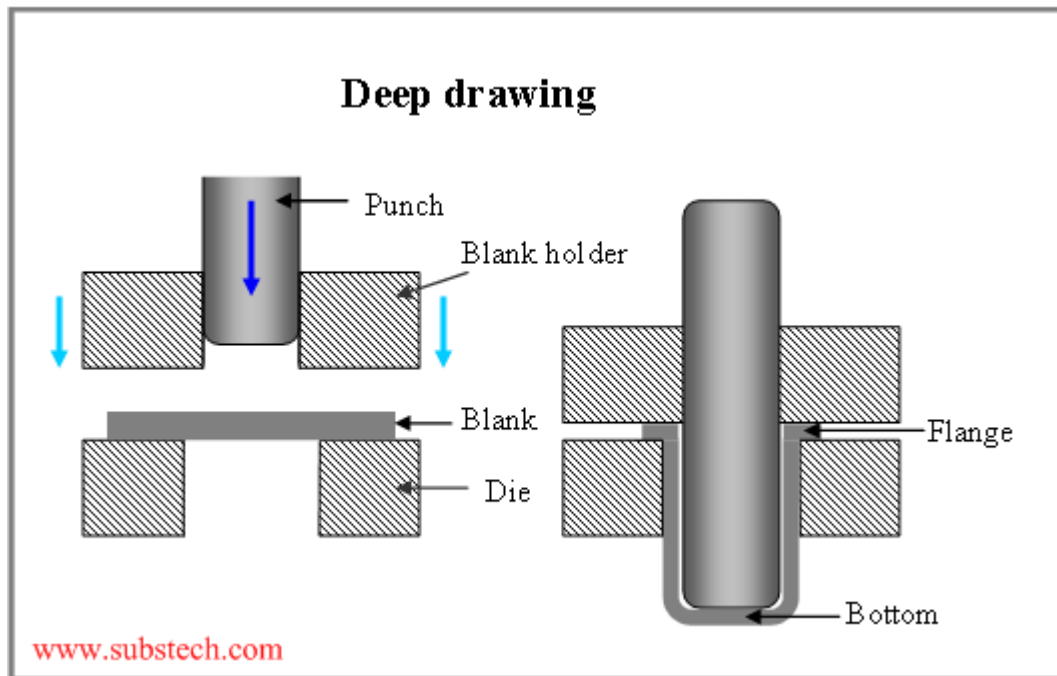


Figure 1.1 Deep Draw Process [32]

In order to get sheet blank of requisite shape without folding the corners, the principal helping hand of sheet forming, is blank when subjected to compression applied by punch onto a die. Double action blank holding force and punch force presses are generally used for forming.

Deep drawing and cold pressing are closely related to each other in such a way that it is very difficult to define each of them separately. The operations involve pressing in one stage to linking re drawing components that are produced from sheet. Deep drawing requires high ductility in sheet Complex shapes and cold draw products that are essential for today's automotive and other industries. These products are established with the help of data obtained from workshop experiments and thus enable the press and deep drawing development of sheet metals to be accurately forecasted. Thus proper knowledge regarding formation of sheet metals is necessary for the purpose of efficacious manufacture of deep drawn components and quality stamping.

1.1 DEFECTS DURING DEEP DRAW

Different defects during deep draw are:-

- Wrinkling: - wrinkling basic reason is the too much clearance between the punch and die or there is another possibility of improper pressure.

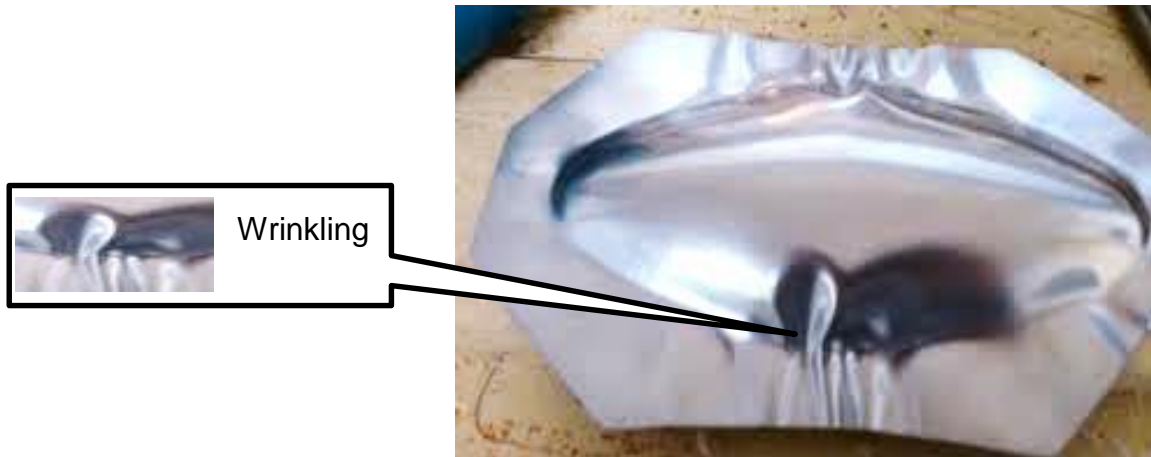


Figure 1.2 Wrinkling during Deep Draw [30]

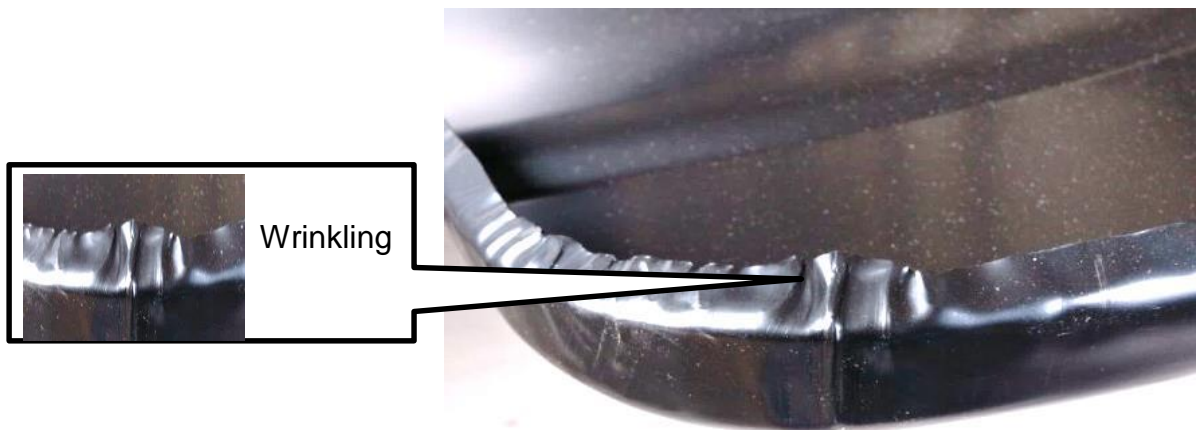


Figure 1.3 Wrinkling During Deep Draw [30]

- Rupture: - Rupture occurs due to improper draw ratio another reason can be improper die and punch radius.

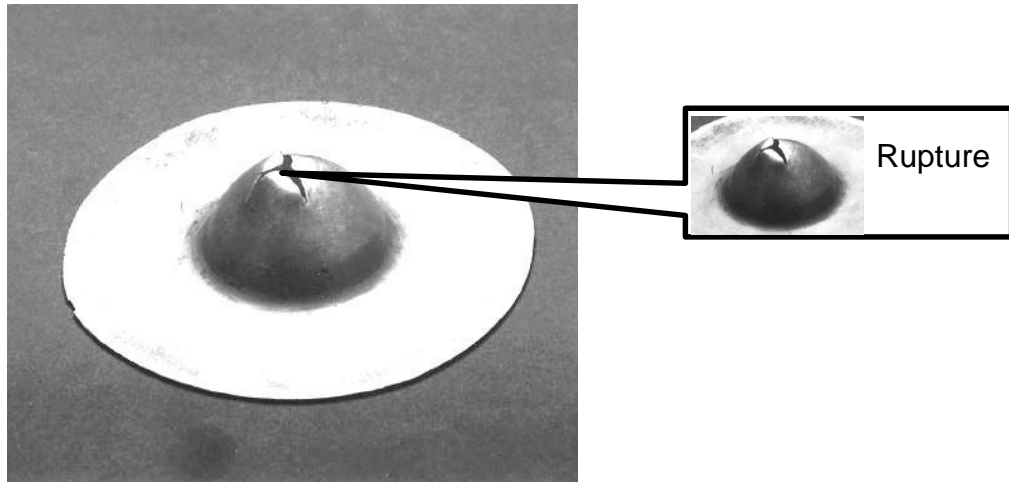


Figure 1.4 Rupture [13]

- Tearing: - reason behind tearing is sharp corner edges.

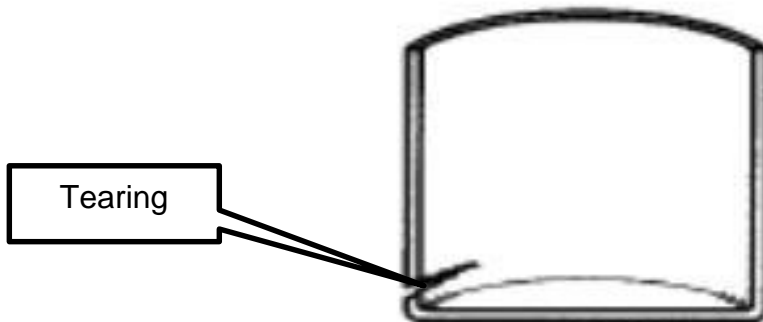


Figure 1.5 Tearing during Deep Draw [33]

- Earing: - occurs when the material is anisotropic.

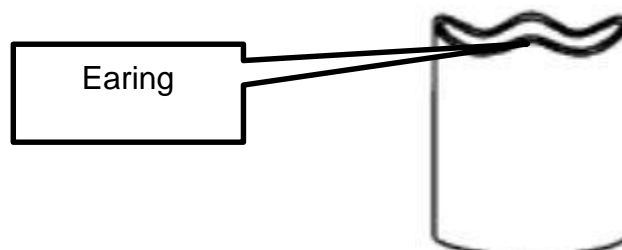


Figure 1.6 Earing during Deep Draw [33].

Wrinkles are the biggest problem during deep drawing. Wrinkles originate in the flange. Once wrinkling begins, it will continue to broadcast. It originate in the flange are pulled into the die and will stop in the part's walls. The flange of the blank undertakes radial stress and compressive tangential stress during the process, which often results in wrinkles. Wrinkling can avoided if the deep drawing system are designed properly.

1.1.1 VARIATIONS

Biggest problem while deep drawing is that of wrinkles. Wrinkles start in flange. It will continue to spread as soon as wrinkling starts. Wrinkles emerges in the flange are drawn into the die and will finish up in the part's wall. During stamping process flange of the blank experiences tangential compressive stress and radial drawing stress which at times result out in wrinkles. Wrinkling can be avoided if the stamped part and deep drawing system designed properly.

➤ CAUSES OF WRINKLING

1. Pressure on the blank holder.
2. Depth in the die cavity and radius.
3. Friction between the blank, blank holder, punch and die cavity.
4. Clearances between the blank, blank holder punch and die cavity.
5. Shape of the blank and thickness.
6. Part's final geometry.
7. Velocity with which punch moves.

There many other factors that can effect drawing process. Some of them include metal alloy of the blank and die temperature. Any variation in these factors can influence the potential for wrinkling or cracking in the deep-drawn part. The blank holder is used to hold the edges of the sheet against the pressure of the punch and deforms the sheet in the appropriate shape of the die.

However the blank holder is not used to hold the ends tightly in place. If this was the case, tearing can occur on wall of the cup. When frictional force between blank and the blank holder is provided that allows the blank to slide. When nitrogen cushion or

an air or a numerically controlled hydraulic cushion blank holder force is used sheet deforms very accurately. More the die cavity depth, the larger blank material has to be pulled down into the die and the larger wrinkling in the walls can come and flange of the part. Balance between the onset of wrinkling and the onset of fracture is the resultant of maximum die cavity depth neither of which is desirable. The radius clearance between the blank holder and the die is important otherwise, there are chances of wrinkling i.e. wrinkling can occur easily. Therefore clearance is always taken care off.

1.2 METHODS FOR PREVENTION OF WRINKLE DEFECT IN DEEP DRAW

➤ USING BLANK HOLDER

- Easiest approach of eliminating wrinkling in deep draw parts is by using a blank holder. Generally in deep drawing processes, a constant blank holder pressure is applied throughout the drawing action.
- Differential pressure is applied on blank holder with aim of wrinkles part. A pneumatic or hydraulic blank holder cushion helps in varying the pressure on the stroke of machine which helps in providing the allowable die cavity depth.
- Differential pressure is achievable with the help of numerically controlled (NC) die cushion. The NC die cushion helps in stopping the wrinkling and cracking.

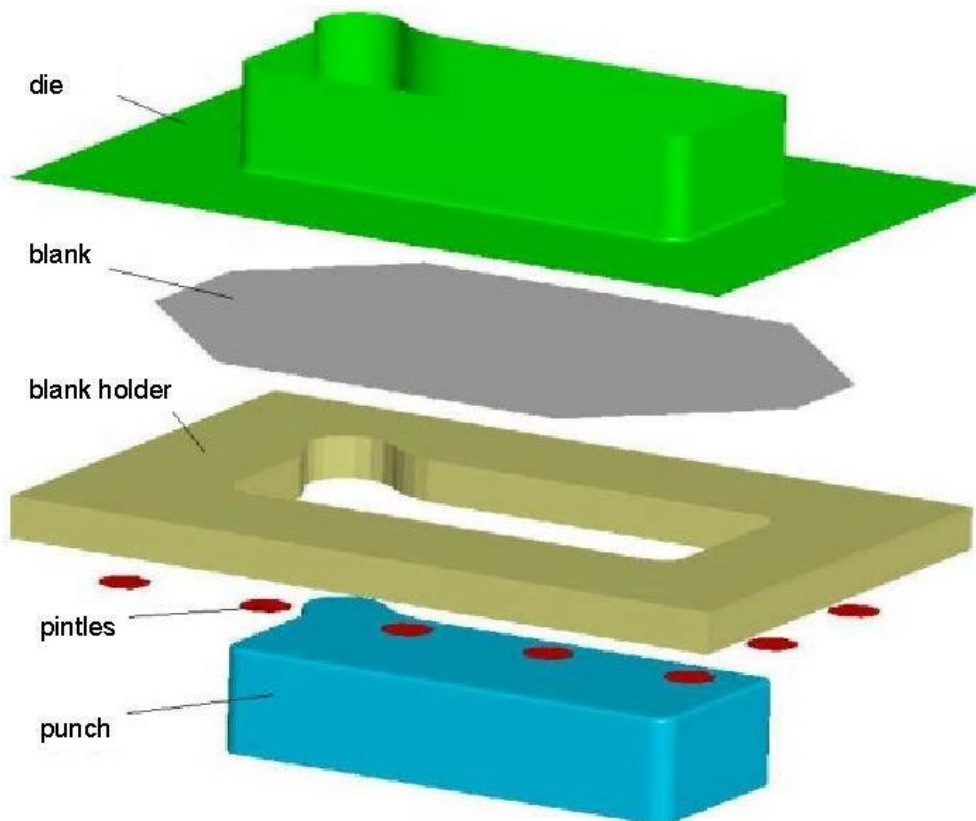


Figure 1.7 Represent the Usage of Blank Holder during Deep Draw [34]

➤ **DIE CAVITY DESIGN**

- When the wrinkling problem is reduced upto some extent, die cavity design can be easily optimized. In order to optimize the large wrinkles, it is the need to select an optimum flange radius which helps in preventing cracking. But the selection of the optimum values is considered on the basis of the experience. Wrinkling is avoidable in variable steps.
- It is important to design the blank geometry in order to minimize excess of wrinkling. The stresses can vary due to grain size of the sheet material. So the grain size should be symmetrical helps in minimizing the compound grain stress.

➤ **OTHER FACTORS TO BE CONSIDERED**

- For the purpose of improvement in overall performance, we can do surface conditioning of each component. Lubricants helps in reducing the friction between the blank and the punch and die cavity. In general, they are advisable to apply them on the blank before draw is to be done.
- Dry films are gaining importance because they help to reduce the washing after the fabrication. Whereas lubricants helps in material flow into the die cavity and helps in reducing the blank holding force in account helps in reduction of friction.

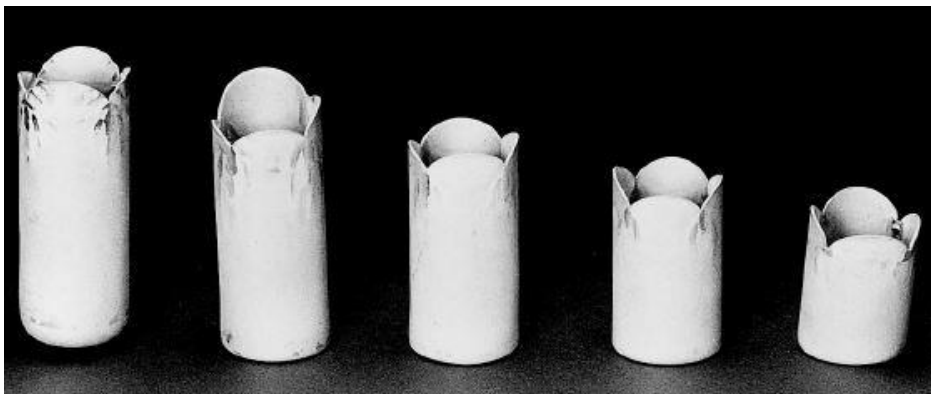


Figure 1.8 Draws having different defect [13]

- In the past, part and die design were optimized with the help of trial and error and operator experience. In order to generate part and die designs and to simulate deep drawing process, computer aided design and finite modelling are used. This helps in reducing cost of tooling and labour in design process.//
- Adequate forces should be considered for deep draw process for the proper deformation. Tearing of sheet metal may occur if the magnitude of force is too high or is applied incorrectly. Separate analysis should be done for the punch and for the blank holder force.
- For more knowledge of forces acting in the sheet, material flow is the base for the knowledge of forces in the sheet. Drawing ratio is also important part which needs to be calculated.

$$DR = \frac{D_b}{D_p}$$

D_b = Diameter of blank, D_p = Diameter of punch.

1.3 MECHANICAL PRESSES

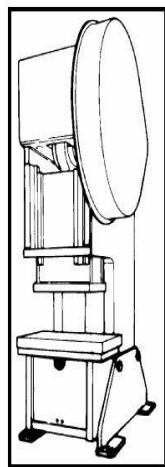
Mechanical presses belong to the class of machine tools that comprehend a wide range in types of machines. The mechanical presses works on the principal that rotational force of motor into translation forces that accomplish the pressing action. Mechanical presses are much faster than hydraulic presses. The constraint on which is to be taken care off while working on the mechanical press that correct range of the stroke is very essential. The mechanical power press machines are used to supply the forces to die that is used to blank, form, or shape metal or non-metallic material.

These presses are selected based on the characteristics of the manufacturing process. Basically used in the forging operations and sheet metal working. However for fast production mechanical presses are preferred due to fast, quick and repeatable operations. The most powerful presses have the capacity of 12,000 tons.

1.3.1 TYPES OF MECHANICAL PRESSES

Mechanical presses classified in two categories: - gap frame and straight side types. Gap frame types are used in mechanical presses are similar to hydraulic presses i.e. can be used as hydraulic presses.

Open Back Inclined (OBI) Gap Frame Press



Basic Straight Side Mechanical Press Nomenclature

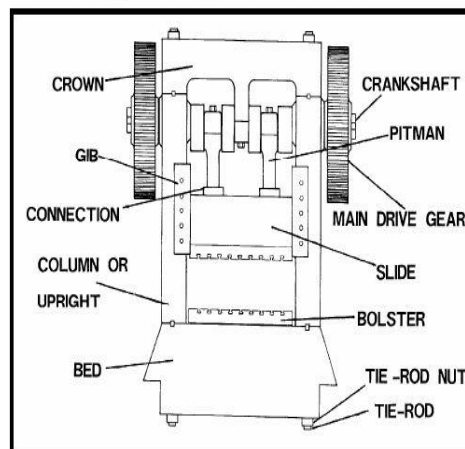


Figure 1.9 Different types of Mechanical Press [34]

1.3.2 HYDRAULIC PRESSES

Hydraulic presses are the most powerful in the class of machine tools, these presses derive the energy through hydraulic pressure. In these presses, a fluid chamber is installed in which fluid is stored that fluid is used for the pressure variations. This pressure variation is performed with the help of pressure pumps and valves. There are enormous benefits of hydraulic press but only one drawback i.e. slow operations as compared to mechanical press. These presses have the great potential in their segment. Largest force can be applied on the workpiece on hydraulic press is 75000 tons. Figure shows the hydraulic press working.

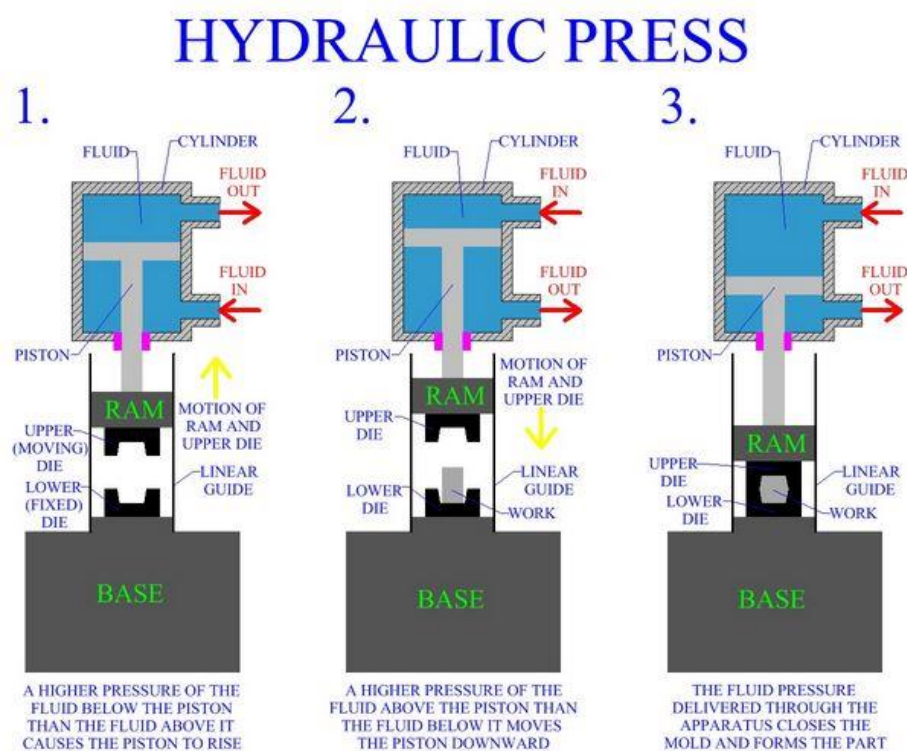


Figure 1.10 How Hydraulic Press Works [34].

From last 40 years hydraulic counter-pressure deep drawing is used and it has been last 30 years hydraulic counter pressure was actually applied to production. In the beginning, it was opted to overcome the drawbacks of deep

drawing. The hydraulic presses are also used to form the automobile body parts, because of merits in manufacturing cost-reduction of die. The figure 1.11 shows the hydraulic press.

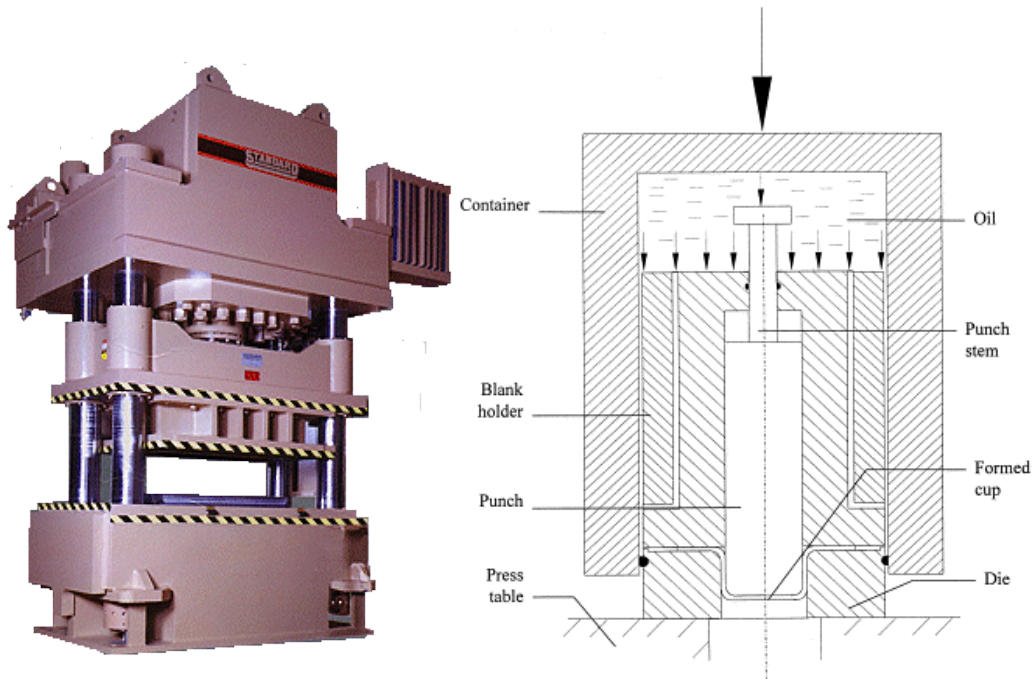


Figure 1.11 Hydraulic Press [13].

Generally it increases the diameter to depth ratio possible in deep draw. Maximum draw ratio up to 3.5 can be easily achieved. Phenomena for using these processes include a peripheral help to push the draw force to easily achieve the required force value.

2 PROBLEM STATEMENT

To find the solution of wrinkling during the deep draw and to get advanced knowledge of various processes of deep draw some automotive industries were visited. The problem of wrinkling was very common.

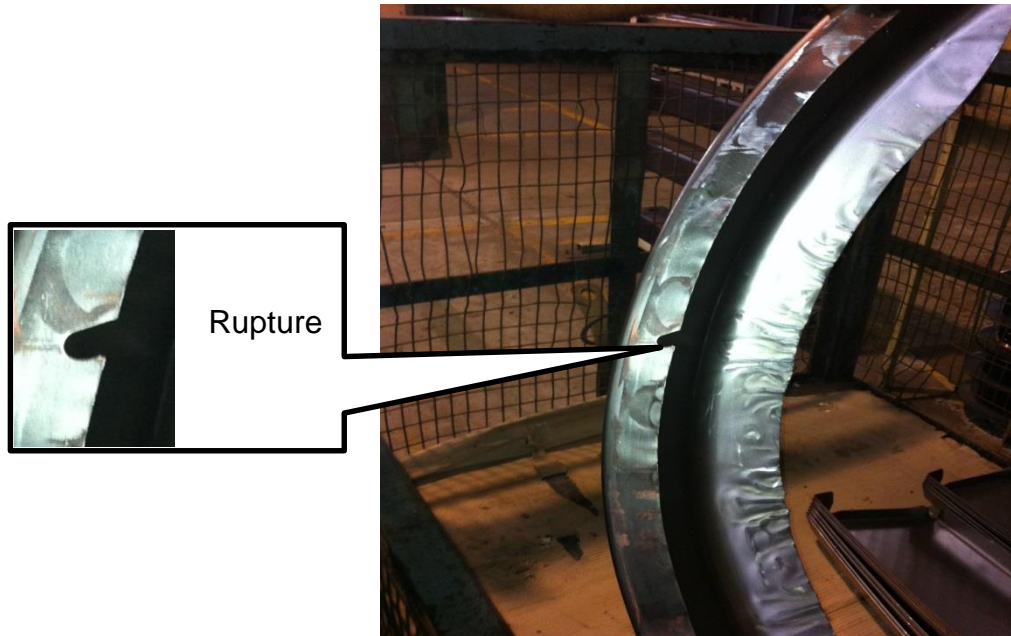


Figure 2.1 Rupture during Deep Draw

Figure shows 2.1 the wrinkling and rupture on the fender of J.C.B earth mover. Wrinkling occurred due to the radial stresses on the inner side of the fender. Machine used was a hydraulic press.



Figure 2.2 wrinkling on the part

Figure 2.2 shows the wrinkling on the GI sheet because for the draw, wood die was used and press used was mechanical press of capacity 20 KN reason behind the wrinkling was the blank holder was not used during the draw.



Figure 2.3 Wrinkles in Final Product.

In this part wrinkling occurred due to impact loading on the blank holder which results into that inappropriate load was distributed on the sheet due to which wrinkling appeared.

3 PROBLEM DEFINITION

During visits to different auto-motive industries, different problems related to deep draw were observed. Wrinkling was observed as a common problem faced by the automotive industry. There are different methods to resolve the wrinkling problem. Engineers in industry solve this problem on the basis of their experience. An optimum solution based on cost, process capabilities, available machine, material characteristics, expertise of operator etc. is sought. The experience of the engineer in dealing with such problems in metal forming is a major factor in the number of iterations, time and cost of experiments to solve the problem. An inexperienced engineer can use a simulator for finding alternate solutions to choose from virtual experimentation and arrive at an optimum workable solution. Development of such a simulator using FEA software which is costumed developed or adapted from a commercial package is a need which is addressed in this thesis.

As metal forming is for deformations in the plastic stage of the material, the simulator software needs to have the necessary coding of equations which represent plastic deformation. It needs to be explored which type of equations and commercial software in coding would be suitable for the simulator.

So simulator is best option to find the solutions of the problem. There many benefits of using the simulator. Benefits of the simulators are given below:-

- Predicts the product performance and reliability.
- Decreases physical prototyping and testing.
- Estimate different materials and designs.
- Enhance designs and reduce material usage.

The solution to wrinkling problem in component shown in figure 3.1 using material CR5 is taken as a representative example for development of a simulator.



Figure 3.1 Wrinkling in Component

4 LITERATURE SURVEY

Literature survey is divided in following two parts:-

1. **PROBLEM FACED DURING THE DEEP DRAW USING DIFFERENT PROCESS.**
2. **DIFFERENT SIMULATOR USED FOR THE SOLUTION OF THE PROBLEM.**

4.1 PROBLEM FACED DURING THE DEEP DRAW USING DIFFERENT PROCESS.

The large quantities of cups are produced from a sheet by using deep drawing process. In deep draw process of sheet metal blank is drawn over a die by a punch. The stresses produced in the radial direction due to flange moving in same direction. Hoop stresses are also produced due to circumferential punch force is acting.

Takeo et al. [2] have mentioned the principle of hydraulic pressure on sheet during the deep draw and investigated that as punch force becomes equal to hydraulic pressure deep draw can be attained. Hydraulic pressure was developed to reduce the frictional force during the deep draw. The various features that control the frictional forces are:

- Body wrinkling is controlled.
- Embellishment of dimensional accuracy.
- Proper thickness distribution.

The main requirements of hydraulic press machine are to control the hydraulic pressure, blank holding pressure, cushion and radial pressure. Taghipour and Assempour [5] had developed analytical models on hydro-mechanical deep drawing to calculate the effects of proportional load, plane stress and constant thickness. The material of the sheet was aluminium alloy (Al6016-T4) for the experiment and thickness was 1mm. Yossifon et al. [6-10] had conducted various experiments to analyse rapture and wrinkling in hydro-forming process. They had divided the formed part into three zones and had developed the antique theory of plasticity to obtain stress and strain in the flange and blank. Fazli and Dariani [11] had utilize the

analysis method of Yossifon et al [6-10]. HDD process of deformation zone in order to find the deformation zone in which the rupture is not likely to occur but these studies was just based on the assumption that strain and stress do not rotate during the forming process and loading conditions proportionally exist and had used the equation of quadratic yield function assuming the planar isotropy.

$$(d\varepsilon)_{ij} = \left\{ \left(\frac{1+R}{1+2R} \right) [2d\varepsilon_\theta^2 + 2d\varepsilon_\theta d\varepsilon_t + (1+R)d\varepsilon\varepsilon_t^2] \right\}^{1/2} \dots\dots\dots (1)$$

Shirizly et al. [12] had used the relationship between geometrical parameters and material of the limiting analysis of plasticity during deep draw. Thiruvarudchelvan S. and wang. H [13] had investigated, refined and developed an innovative process of hydraulic pressure augmented deep drawing process for the manufacturing of very deep cups from sheet. They successfully have drawn cylindrical cups from 1mm thick at draw ratio up to 3.5, the basic study of limiting draw ratio, strains and thickness variation on the drawn cup walls. For measuring thickness along the cut of the cup wall a pointed attachment along with a micrometre was used. For the series of the tests conducted many varieties of lubricants were used. One of the best lubricants was the lubricant made by spraying the dry graphite on both sides of the blank. Some other lubricants were made by adding Teflon in aerosol spray and thin layer of polyethylene spread on viscous oil. Emergence of cup at high speed was the problem that was faced initially. Due to this cup hit the floor and become complete damaged. The cause behind this was at the unstable situation, in the compressed liquid, energy emitted at a sudden that causes the damage. Eradication of this problem is placing an annular metal block over the blank holder, so that the volume of fluid is reduced. Moreover for longitudinal passage of the fluid four holes was made on the blank holder and there is a long bar attached to the punch, the surrounded space of the bar must be reduced. Urethane washer is used as a shock absorbent that is attached at the top of the rod. Shock is produced when metal block is hit by urethane washer. There is one more solution to the problem is to close the fluid flow at the cup periphery when the fluid flowing rate increases. For this ball valves can be used to shut the holes that made fluid to flow longitudinally. At unfavourable conditions different patterns are formed. Some patterns like fracture and bulging are formed due to fluid coming out at very high pressure from slots.

There are some conditions which makes the cup thin excessively. Aluminium blanks that are 1 mm are used to make cups. These cups are made by extending hydraulic-pressure deep drawing technique. Process simulation and analysis results are in accordance with the pressure-punch-stroke profile that is measured previously.

Distribution of strain and thickness of cups are also in accordance with the previously measured values. The problem of the fluid leaking is also diminished by reducing the volume of the fluid. Blocking the flow of the fluid from the top of the blank holder also helps in managing the speed at which cup comes out. By the means of investigation adverse conditions that are responsible for cup damage are identified and are eradicated. To achieve the draw ratio of cups up to 4, currently more investigations are being carried out. Investigation is also being carried out for drawing cups of square shaped. It is important to recognize variables in deep drawing operations. To increase the ratio of limiting draw some above discussed processes have various phenomena. The processes that are discussed above have various identical features with the hydraulic-pressure-augmented process of deep-drawing. One of the identical features is that the force that is requires holding the blank is created automatically. One more feature is the tooling and operation simplicity. The main idea behind the research is to develop and reform the processes that already exist. To have the far more good understanding theoretical and finite-element analysis are done. The load of deformation and the hydraulic pressure are directly proportional to each other. Also when the movement of blank is radially inwards then a pressure that is upward pressure acts on the blank holder's bottom over bigger annular area. So in order to balance the force a downward force acts upon the blank holder's top. The cups that have been drawn successfully by using the process of deep-drawing are drawn with great success. The cups are made up of blanks of aluminium of 1 mm thickness. Also the cups are drawn with single press action. During testing the highest hydraulic pressure was in accordance with the measured values.

FEM calculates the hydraulic pressure for various values of punch stroke for blank of measurement 50 mm was also approximate to the experiments of drawing. At the cup bottom FEA simulation depicts thinning up to some degree this thinning also appeared around the cup brim. The cause of this is large blank holding force. There are basically two classification of drawing, shallow drawing and deep drawing [14]. In deep drawing the drawn is deeper than one-its half diameter, however in shallow

drawing it is less than one half its diameter. Thinning of walls is more difficult in deep draw as compared to shallow draw [15]. To draw a blank the mechanisms that are used were very complex and there are various aspects to draw a blank and the blank drawing is affected by these aspects. In order to continue investigation on deep drawing process a tool that was instrumented and was created to work upon a hydraulic press, Norton, 20 t. The work that has been done on this tool previous showed positive results. Discussion of various things of blank holding pressure, punch and die geometry, lubrication, top-ram pressure and the speed at which steel cups with dimension of 0.9 mm. is drawn is done in this paper also the variation of these discuss above is investigated in this paper. To know more about these effects many cups were drawn using DOE, at this screening experiment was done. At various levels the aspects that were desired are varied upon. There are many factors that are punch and die profile, top-ram pressure, and the lubrication position. During measuring the punch load, these factors are very substantial. The punch and die can be lubricated on both sides and can be lubricated on one side only. The results are affected by the type of lubrication, if the die and the punch are lubricated both sides then the results that were produced are the best. When the die is lubricated on single side then also good results were produced and if punch side is lubricated the results produced were not as decent as compared to die. Full factorial experiment was performed to know the level of optimization for the minimum variation in material having thickness of 33 mm. Directing this experiments the results that were produced shows that the parameters that are optimum and they provide least variation are blank-holding pressure, top-ram pressure, 70 KN, 18 KN; and speed 100 mm/min. Johnson and Mellor [16] had discussed about the five processes which take place during the deep draw:

- I. The resultant hoop stress causes the blank thick as the pure radial drawing between the die and blank holder is acting downwards
- II. The thinning of the sheet is triggered due to the sliding and bending over the profile of the die.
- III. If a sheet fails to form the desired shape its due to tensile failure in the direction of the punch.
- IV. Bending and sliding over the punch profile helps in thinning up to some degree.

According to Mielnik [16] the actual maximum axial drawing force in a plastic region is

$$F_{max} = \frac{2\pi r_1 \sigma_f}{\eta} \ln \frac{D_0}{d_1} \dots\dots\dots (2)$$

Where F_{max} is the maximum axial drawing force, d_1 the punch diameter, σ_f the yield tensile strength, η the deformation efficiency factor and D_0 is the diameter of blank. With the experience, the material flow in the area has to be postponed by increasing the resistance force so that wrinkles can be prevented in the corner area. The pressure distribution on the flange should be accurate so that the defined shape can be attained. The shape of the blank has crucial influence on the formation of wrinkles at the corner region of the drawn cup; if this is not taken into consideration the wrinkles will be there at the corners of the drawn cup. For very deep tapered cup draw, low friction between the blank and blank holder is required. Dhaiban A et al. [17] introduced a new method for the deep draw process of the elliptical shaped cups without the use of draw beads and blank holder. In this method a circular blank is pushed using a flat headed elliptical punch through a conical shaped die and the shape produced is in a single stroke. They also investigated all the parameters which are required for the simulation by numerically for the optimal solution. They also performed the tensile test for the properties of the sheet and compared the experimental result with simulated results.

Shani and Salehinia [18] had performed deep drawing processes of a cylindrical cup experimentally and simulated the results using the finite element method to attain the knowledge on wear depth on the draw die arc segment. During the study they had assumed both the die and blank are deformable and also assumed the material of the blank as elasto-plastic and elasto-viscoplastic behaviours. With these assumptions the depth of the die shoulder was investigated. In the meantime effects of different process such as the blank holder force, die radius and also the clearance between the die and punch on the depth wear are also investigated. The material deformation and model used introduces the non-linearity behaviour. The aim of their

study was to know the effects of important parameters which are important in deep draw process and the important parameters are punch speed, the clearance between the die and the punch, blank-holder force and radius of the die shoulder. They also investigated that blank holding force up to certain value after that it start wearing the die. Christiansen and chiffre (1997) [19] had examined that progressive wear. This study process was simulated using the strip test for the equipment evaluation and concluded that at angle 20° and 70° maximum wear takes place. Padmanabhan .R et al. [20] had done the numerical study on the manufacturing of LPG bottles and the problem taken by them is based on the application in which both variable blank holder force and contact friction at some definite location during the deep draw. The blank holder force and friction condition plays an important role on flow of the material during the deep draw. Proper blank force is important consideration to restrict the wrinkling and tearing of the sheet during the deep draw. Similarly the coefficient of friction is also a constraint to be taken care off. The material used AISI (304) stainless steel. The material has one advantage that it is corrosion resistance because of the presence of chromium (18-20%) and also the brilliant heat resistance and also considered material behaviour as isotropic and was described using swift power law. For the simulation the blank holder force considered as 30 KN. After 220 mm the punch force drops due to existence of large plastic deformation. Necking failure between the punch and die radius is prevented due to low constant blank holder force. When the force remains constant the material flow is so smooth that the shaped is fully attained.

Kim seung et al. [21] the process parameters that are intermediate die geometry, sheet thickness, blank shape, lubrication, blank-holding force, etc. are required for the multi-stage deep-drawing designing process. Determination of these process parameters for optimum forming condition must be done prior to the designing process. Due to the lack of expertize the designing process with large aspect ratio of multi stage Elliptical or rectangular cup is difficult to achieve as at each stage it is required to know the number of punch shape and forming stages. The approach used by the experts that is trial-and-error is not time and cost efficient. To use an inverse finite element analysis could be the remedy for this problem. With the theory of deformation many attempts have been made in deformed part for distribution estimation of strain and blank shape designing. There are two problems that are

computing time inefficiency and the problem of convergence that are faced in finite element method of rigid-plastic or rigid-elastic. Thirumarudchelvan .S [22] had investigated deep drawing process with differential-pressure is the enhancement of the hydraulic process. The process was assisted by lower hydraulic pressure that was applied in the die cavity as it happen for increased draw ratios in other processes of drawing. Increase in radial push, increase in the pressure of blank holder and wall friction of punch cup these all are assisted by that pressure. Currently new designs have been proposed for tooling. New designs of tooling are proposed to use the advantages of differential-pressure augmenting principle and to have blanks with bigger diameter. There is some correlation among parameters of processes, to predict this correlation theoretical analysis is being attempted. Kumar .R [23] had studied which shows the distribution of strain under various condition in material. This study was made during punch stretching. Experimental results depict good outcomes for grain size and mechanical properties. By using specimens machined some tensile tests were carried according to ASTM standard E8M specification. Samples were tested along diagonal (45 degree), parallel (0 degree), perpendicular (90 degree) on 400 KN capacities. Schenck closed-loop servo-hydraulic testing machine. Jayahari L et al. [24] had investigated that mechanical properties, lubrication, metallography are the factors and Blank Holding Force, punch speed are the process parameters that are responsible for components success or failure. Currently many researches are made for the alloy material improvements. To understand the formability of improved material is also very crucial along with the development of alloy materials. Steel sheets of extra deep drawing and aluminium, magnesium alloys that are non-ferrous are also developed. For increased productivity and good product quality there are some factors that can be used in the drawn cup are lower residual stresses, reduced friction. The friction that is reduced is made possible by using lubricants of high temperature.

Moura G.C.R et al. [25] had manufactured the endcap using deep-drawing. That involves cylindrical die at which circular blank is situated over which the punch has been pressed. The constant load of 1.0 KN applied on blank holder. Blanks feeding were done manually. Blank was made up of AISI 1008 carbon steel material, with measurements 2.75 mm thickness and radius of 26.7 mm. D3 tool steel that is tempered and quenched is used to manufacture blank holder and die punch, after

this D3 tool steel is polished, polishing is done manually. The commercial software DEFORM 7.0 [5] was employed in forming process that was started using the method of finite element. For simulation in numeric way the punch, blank holder and the die are used as solid. The complexity of the problem of numerical analysis was reduced by using axisymmetric process. During the simulation the movement of die is restricted. Velocity = 10 mm/s that is the vertical punch speed, Force = 1.0 KN that is the load on blank holder. The rigid plastic is the material, used for drawing blank and the internal library of DEFORM has stress-strain curve that is for AISI steel. 0.10 s is the time that was required for the punch movement and 225 steps were required for the simulation.

4.2 SIMULATION SOFTWARE USED FOR PLASTIC FLOW ANALYSIS.

Shahani.A.R and Salehinia .I [18] had used the ANSYS 9.0, FE standard code for numerical simulation of the process with the aim of investigating the wear depth in the tool which was clearly seen to the most severe tribological condition. The blank and die were assumed as deformable. The material behaviour for blank was assumed to be elasto-plastic whereas the die was assumed to be elastic. Considering all the material conditions the effect of punch and depth of wear was analysed. Along with that the effect of different parameters such as clearance between the punch and die tool wear rate were also analysed. Mater.j et al. [13] had simulated the process using an elasto-plastic finite element analysis with FEM code MARC (v6.2), run on an Alpha Server 8400 5/440 computer system. For large displacement, isotropic hardening and elasto-plastic material langaransian method was selected. Simulation was performed to determine the forces which were necessary to deform the material. For the simulation the simulation software was used in which the total deformation and non-voices strain were determined. For all the above simulations, constant pressure and material behaviour were assumed. For the contact problem between the tool and blank as suggested MARC was used as the tool. Abdullah et al. [17] had also used ANSYS 14.0 FEA software for simulating the deep drawing process. ANSYS Parametric Design Language (APDL) is a scripting language which can be used to build the model. Building the model parametrically supports variable changes during the optimization process. The punch

and die was modelled as rigid bodies. The contact procedure was modelled by automatic contact option between the blank and tooling. For rigid-flexible (tool set-blank) contact, 3D 8-node quadrilateral target element (TARGET 170) was used to represent 3D target (tool set) surface which was associated with the deformable body (blank) represented by 3D 8-node contact element (CONTA174). Coefficient of friction in the blank–die inter-face was supposed to be 0.05. Jayaria et al. [24] had used LS-DYNA for the simulation of the deep draw during deep draw for the study of plasticity. Lang. h [30] had used LS-DYNA3D for the investigation of material flow in hydroforming. All the material consideration was also monitored for the simulator as applicable. Padmanabhana. R et al. [20] had done his numerical studies with the usage of the numerical software DD31MP which was specially developed for the simulation of sheet metal forming process. Sherbiny El. M et al. [28] had used ABAQUES/EXPLICIT for the validation and comparison of the experimental result. The aim of the finite element analysis simulation was to decrease the computation time and error in the hit trials method. Dyna-form is the only simulator developed for the sheet metal.

4.3 SUMMARY OF LITERATURE SURVEY

From the literature survey it has been concluded that a lot of work has been done on the sheet metal bending using different type of processes. Some of the researchers have used the mechanical, hydraulic and hydroforming presses respectively for the various types of forming operations to achieve the desired shape of the deep draw. Wrinkling was the major problem faced by them during the deep draw and some have faced the problem of distortion. To avoid wrinkling during the deep draw different types of methods were used. Different type of amendments were made to avoid the wrinkling and distortion such as draw bead, blank holder force and clearance between blank holder and the punch in the same process. Still some problems occurred during deep draw of the sheet i.e. the aspect ratio, draw ratio and thickness of the sheet. These problems occur due to the pressure variations on the sheet. For the validation of the experiments various simulators were used and some of them solved analytically also. Different simulator software's were used for the simulation of the problems. Following are the simulators:-

1. ANSYS
2. ABAQUES
3. DYNAFORM
4. QFORM
5. LS-DYNA
6. AUTODYN
7. Pre-LSDYNA

Different materials were used by each of them. All the materials have different material properties different chemical compositions. Based on this material properties and chemical properties different aspect ratio and draw ratio will be achieved.

Table 1 Summary of the Material used with Thickness, Draw Ratio and Method

SNo	Material	Thickness (mm)	Draw Ratio	Method
1	AISI 304	0.7	2.2	HYDRO FORMING
2	CRCA SHEET (CR1)	0.8	2.1 TO 2.3	HYDRAULIC PRESS
3	CRCA SHEET (CR2)	0.6	2.4 TO 2.6	HYDRAULIC PRESS
4	CRCA SHEET (CR3)	1	2.8 TO 3	HYDRAULIC PRESS
5	CRCA SHEET (CR5)	0.8	2.9 TO 3.2	HYDRAULIC PRESS
6	AISI 304	0.6	2.4	HYDRAULIC PRESS

Table 2 Summary of the Material Properties

S.No	Material	Young Modulus (GPa)	Tensile Strength (MPa)	Yield Strength (MPa)	Poisson Ration	Density x1000 (Kg-m ⁻³)
1	CRCA SHEET (CR1)	180	410	280	0.28	7.87
2	CRCA SHEET (CR2)	195	370	240	0.29	7.87
3	CRCA SHEET (CR3)	200	350	220	0.29	7.87
4	CRCA SHEET (CR5)	220	350	180	0.30	7.87
5	AISI 304	193	515	205	0.28	8
6	Al 08	210	380	230	0.30	7.80

Table 3 Summary of the Chemical Composition of Materials

Name	carbon	Manganese	Sulphur	Phosphorus	Titanium
CR1	0.15	0.60	0.035	0.05	-
CR2	0.12	0.50	0.035	0.04	-
CR3	0.10	0.45	0.03	0.25	-
CR5	0.06	0.25	0.02	0.02	0.2
AISI 304	0.08	2	0.03	0.045	-

4.3.1 SELECTION OF FEA PACKAGE

From the literature survey it has been investigated that a simulator is required for solving the problem of non-linear analysis. The development of software is a long research in itself and moreover if simulator is developed, the interface of the simulation software is compatible to use for that person who had developed the

simulation. So it would be beneficial to find such FEA software which is easily available for the use and the most important aspect to keep in mind that it can be used for nonlinear analysis. ANSYS 15.0 has the capability to solve the non-linear analysis in plastic region and also has the inbuilt capacity to solve the equations and code required for the non-linear analysis.

5 TEST PART SOLUTION METHODOLOGY

A exhaust valve component made from sheet CR5 material in CHEEMA SHEET PARTS 232 C focal point Ludhiana industry was studied as it exhibited the wrinkling problem see figure 5.1 below. The press machine used for the deep draw was double action pneumatic press with capacity of 150 KN. The punch moves with the speed of 75 mm/sec. Figure no 5.2 shows the tool used in the deep draw.

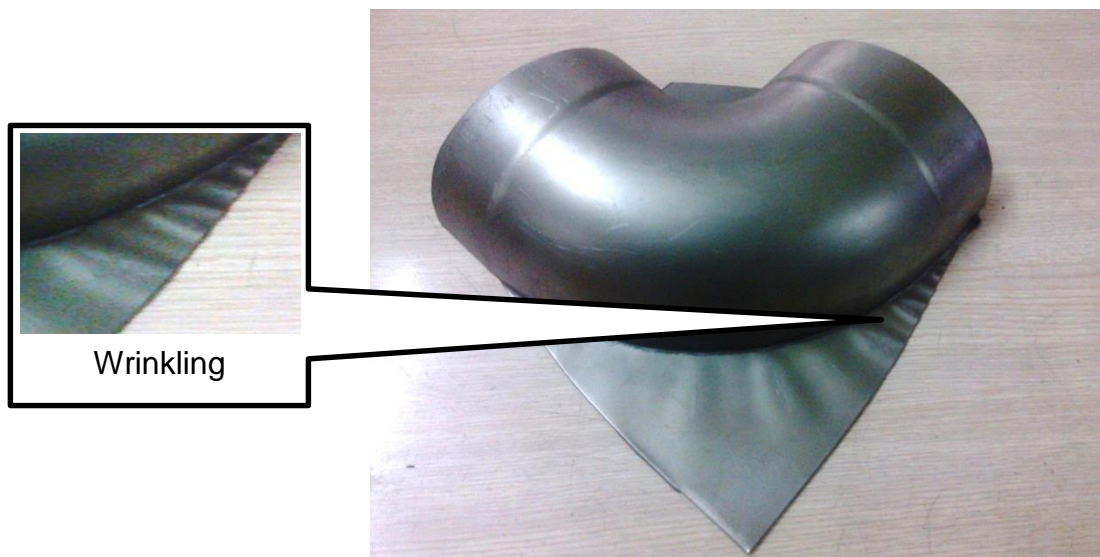


Figure 5.1 Wrinkle in Component

The tool consists of the punch, blank holder and die. The material of the tool is high chromium high carbon steel (D2 steel) which is very hard material specially used for the forming dies and moreover the other benefit of using D2 steel is the finishing of the product. The load produced by the mechanical press on the sheet is 120 MPa. During the deep draw on the mechanical press, wrinkling occurred. Figure 5.1 shows the wrinkles on the part. The material of the sheet was cold rolled closed annealed sheet (CR5) only used for the extra deep draw. Industrial engineer changed the process of the deep rather than making any changes in the tool.



Figure 5.2 Tool used for Deep Draw

The basic reason behind the wrinkling was uneven pressure in the sheet. This change in the process was just made on the grounds of experience only. The process opted was hydraulic deep drawing. The hydraulic press with double action has the capacity of 300 KN. The punch moved with velocity of 15 mm/sec. In hydraulic press proper pressure is transferred on the blank holder which leads to the proper deep draw of the sheet.

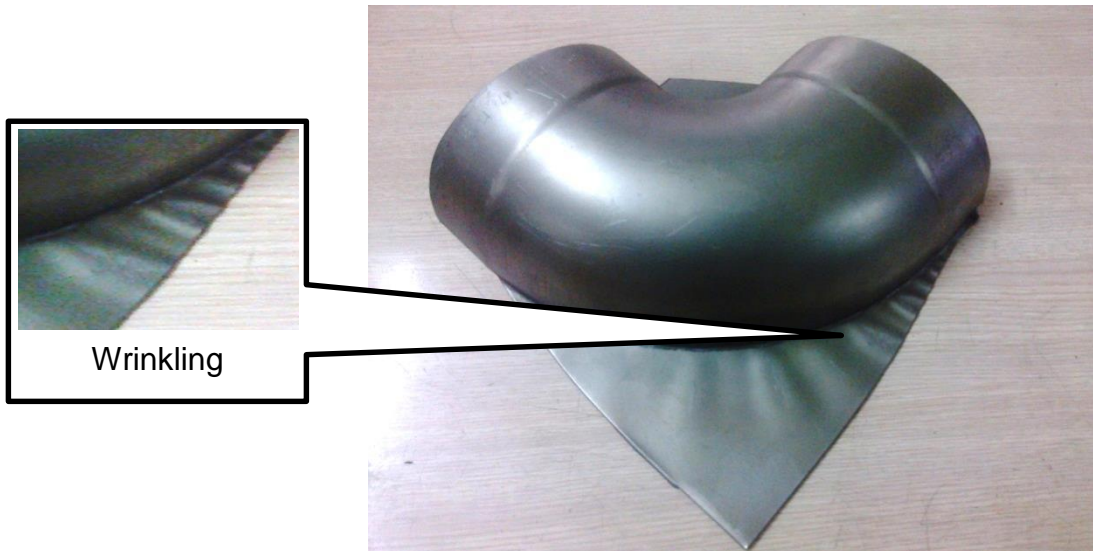


Figure 5.3 Wrinkling produced on Mechanical Press

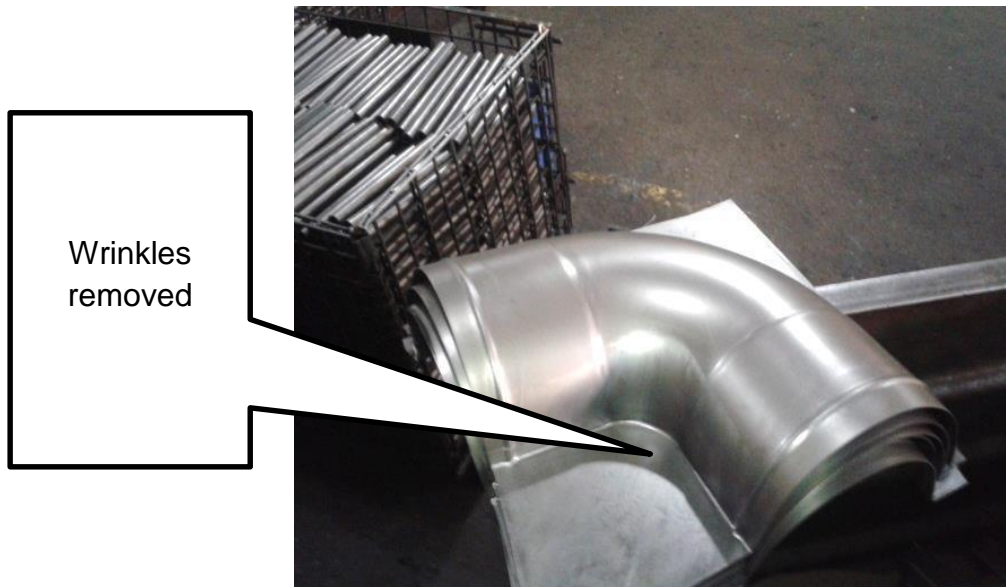


Figure 5.4 Wrinkles removed using Hydraulic Press.

All this process performed was on the basis of experience in the sheet metal field. For the unexperienced engineer it is very difficult to think that what should be the remedy for the problem occurring in the deep draw.

Table 4 Comparison of Processes using different presses.

S.No	pneumatic press	Hydraulic press
1	Capacity of the press 150 KN	Capacity of the press 350 KN
2	Double action	Double action
3	Blank holder used	Blank holder used
4	Load on the sheet 270 MPa	Load on the sheet 470 MPa
5	Impact loading rate 59 KN/ sec	Gradual loading rate 10KN/ sec
6	Wrinkles appeared	No wrinkles

6 DEVELOPMENT OF SIMULATOR FOR DEEP DRAW FORMING PROCESS

From the literature survey the simulator widely used by the researchers is ANSYS. ANSYS is the simulator which is good for non-linear analysis. For the simulator there are some inputs are required. For this kind of particular problem following steps are need to be fulfilled. Following are the steps:-

1. Geometry.
2. Module in which the simulation is to be done.
3. Material properties.
4. Loading conditions.

6.1 GEOMETRY

Geometry of the die was designed in the solids works 2013. Figure 6.1 shows the geometry designed of the die. The model of the tool was designed by keeping in mind the all design considerations. The geometry of the die is transferred in ANSYS for ANSYS the format of the geometry was changed to parasolid file.

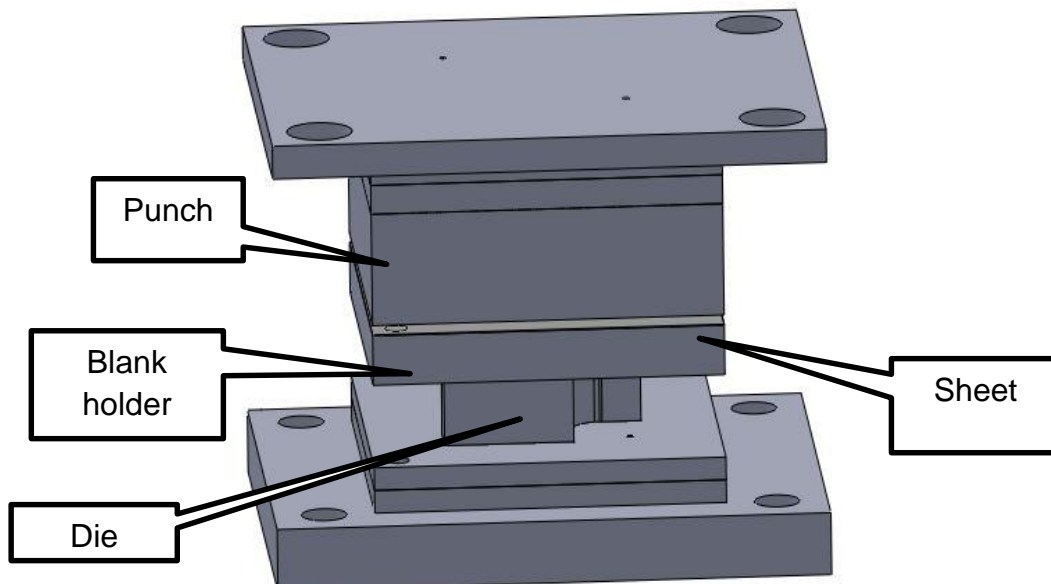


Figure 6.1 Geometry drawn in solid works 2013

6.2 MODULE

From the literature survey it has been investigated that in ANSYS explicit dynamics is the module which should be used for the simulation of the problem. Figure shows the explicit dynamics module. Explicit dynamics module is the module used for crash analysis also.

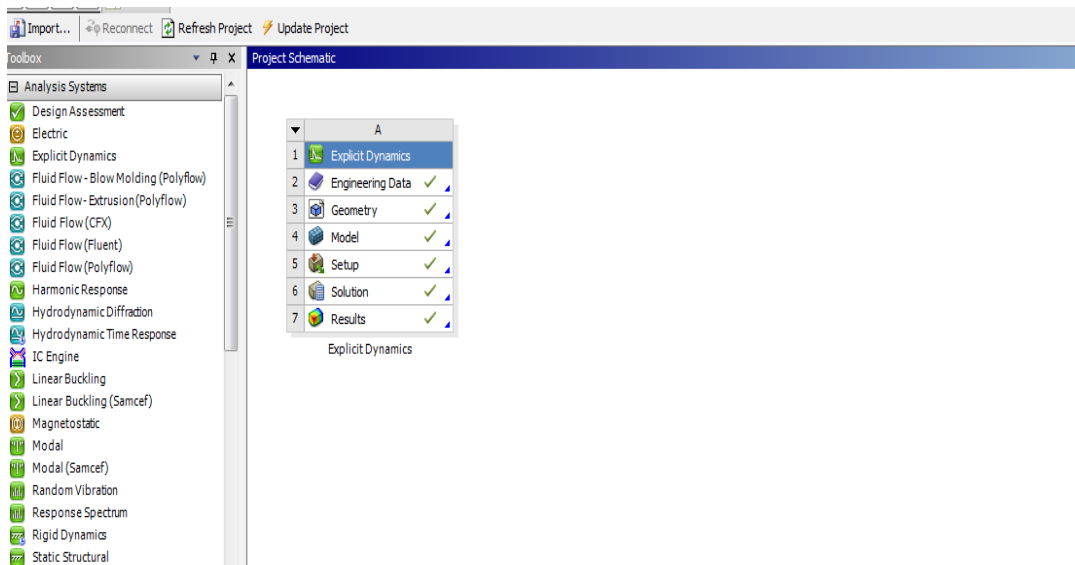


Figure 6.2 Explicit Dynamics Module

6.3 MATERIAL PROPERTIES

Material properties are the known as the back bone of the simulation. For simulation following are the material properties required.

1. Density
2. Yield strength
3. Young modulus
4. Poisson ratio
5. Tensile strength

Table 5 Different Material Properties used in Simulation

S.No	Material	Young Modulus (GPa)	Tensile Strength (MPa)	Yield Strength (MPa)	Poisson Ration	Density x1000 (Kg-m ⁻³)
1	CRCA SHEET (CR5)	220	350	180	0.30	7.87
2	D2 steel	210		220	0.30	7.7

All the above properties are available in the literature. The tool material is D2 steel. But for the non-linear analysis in plastic state elasto-plastic properties of the material is required. For the non-linear property true stress strain curve is needed because the material behaviour is elasto-plastic. Therefore the tensile test is required for plastic properties.

6.3.1 TENSILE TEST

Sahani. I and Salehinia. I. [18] had also used the same elasto-plastic properties of penazzi et al.[30] . Penazzi et al [30] in their work had performed the tensile test on the UTM with the sheet thickness of 0.66 mm and the dimension of their specimen was also according to ASTM. From the UTM the engineering stress strain graph was obtained but to obtain the true stress strain curve the perzyna rate dependent model was used:

$$\sigma = \left[1 + \left(\frac{\epsilon^{pl}}{\gamma} \right)^m \right] \sigma_{0(\epsilon^{pl})} \dots\dots\dots 4$$

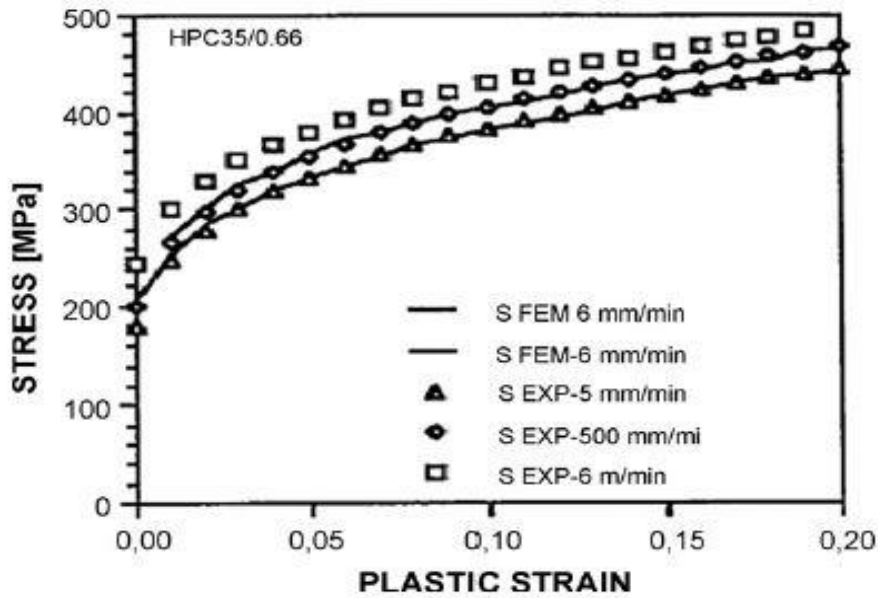


Figure 6.3 True Stress Strain Graph [30]

In equation no 4, σ is the yield strength with respect of plastic strain rate $\dot{\epsilon}^{pl}$, material viscosity parameter γ , strain hardening parameter m and the static yield stress $\sigma_{0(\dot{\epsilon}^{pl})}$.

6.3.2 EXPERIMENTAL SET UP

For the true stress strain curve the digital correlation approach was used [35]. The experimental set up was installed in the lab. The machine used for the tensile test has the capacity of 200 KN. It works hydraulically. Camera was installed on the front of the specimen and scale was engraved on the specimen. Front camera was used to see the elongation and other was used to record the reduction in the thickness of sheet. Figure 6.4 shows the experimental set up installed in lab for tensile testing.

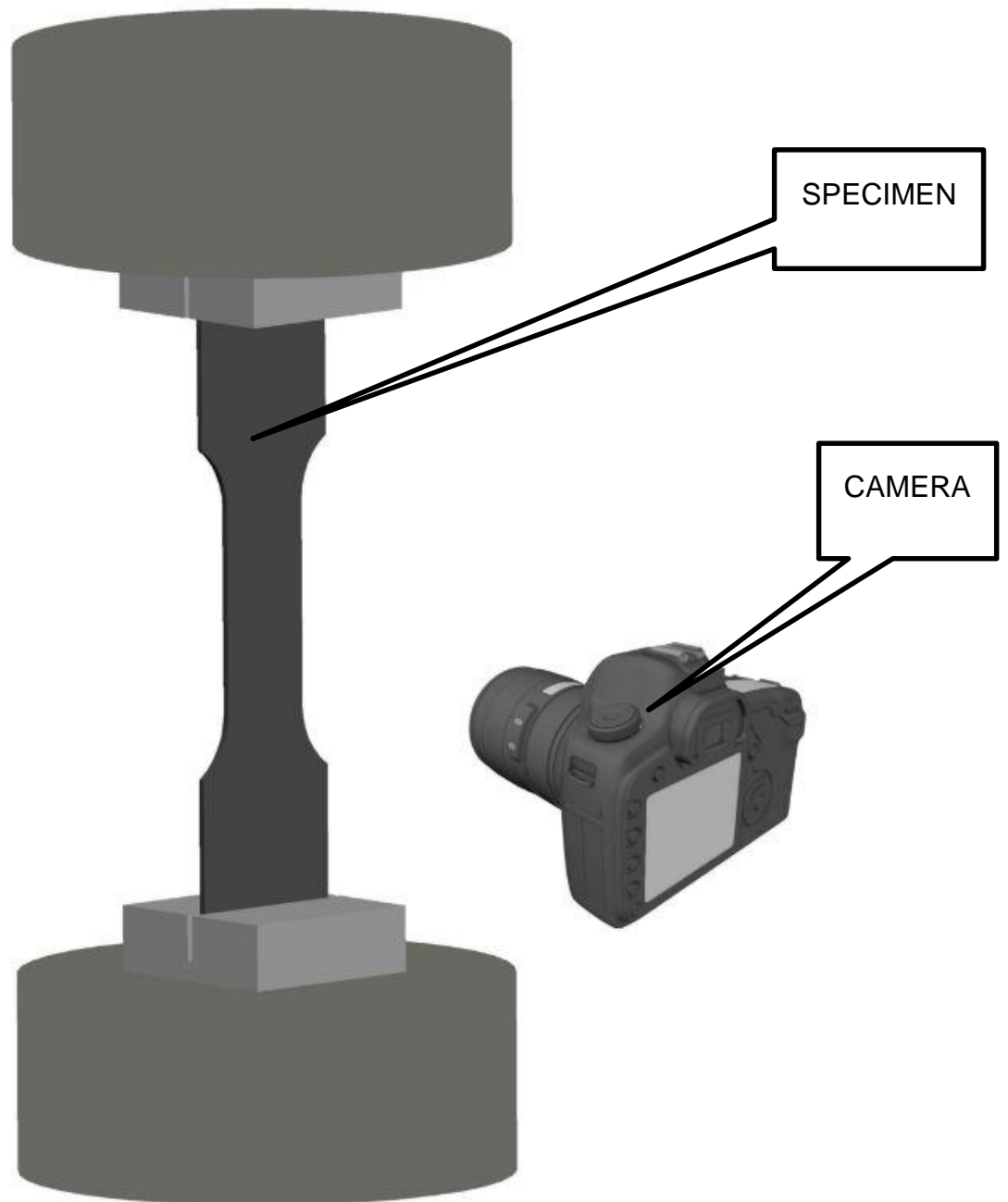


Figure 6.4 Experimental set up of Tensile Test

So the tensile needs to perform. Tensile test was performed on UTM with the capacity of 20 KN. The sheet thickness is 1mm and the specimen was made according to ASTM. The figure shows the specimen dimensions.

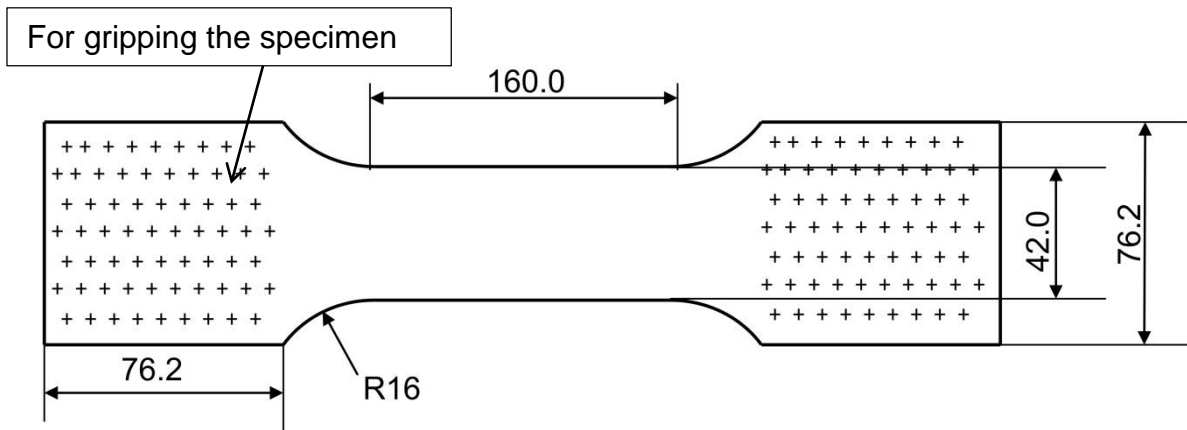


Figure 6.5 Specimen used for the Testing (all values in mm)

All the dimensions are in mm. A load of 2KN/mm was applied axially. Maximum load at which the sheet breaks was 11 KN. Total 4 specimens were made of CR5 sheet with same dimensions.



Figure 6.6. Specimen used for Experiment

Figure 6.5 shows the specimen made according to ASTM. Engineering stress strain curves were produced by UTM. Figure 6.7 Graph represents the engineering stress strain curve obtained from the UTM.

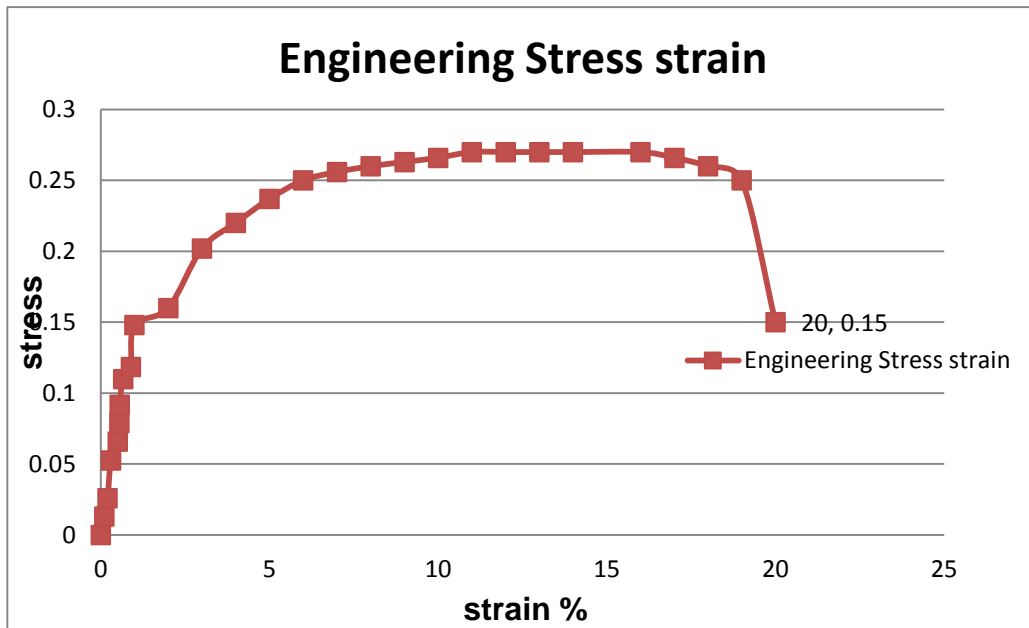


Figure 6.7 Engineering Stress Strain

For the digital correlation approach, the DSLR camera having the capacity 25 frame/sec was used. The camera was placed in the front of the specimen.

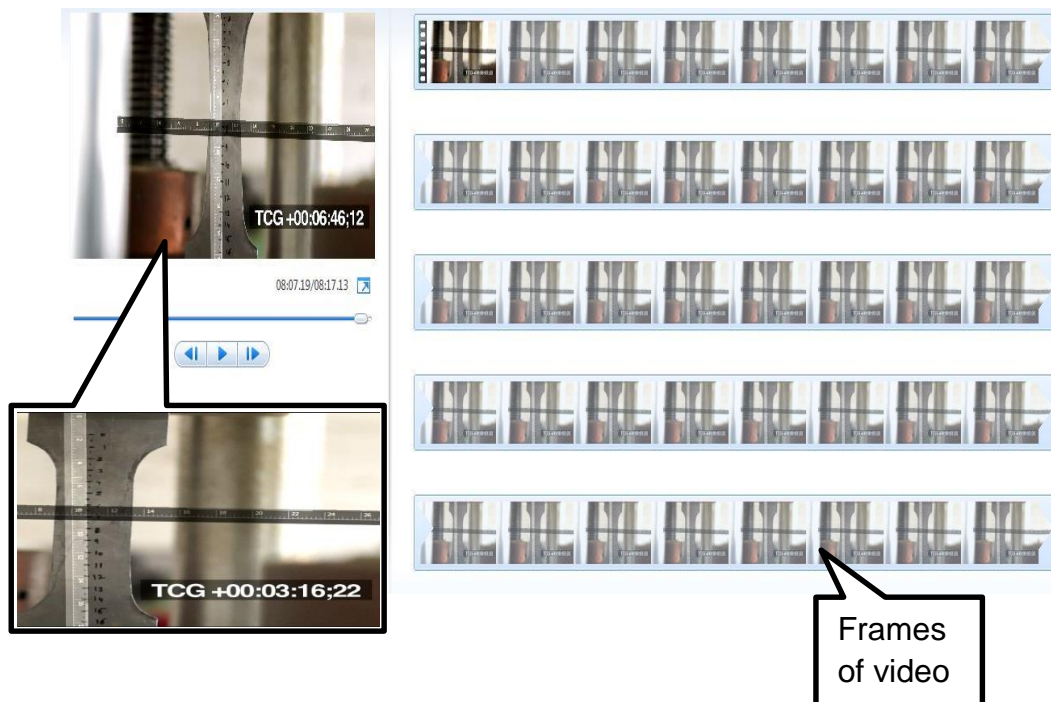


Figure 6.8 How the No of Frames were divided

Video of each specimen was recorded and then video was divided into frames using the windows live movie maker. Total 50 frames were made by the window live maker. In the frames the scale was inserted and the displacement per time in seconds was noted and then true stress strain graph was plotted. Figure shows how the frames were divided and also shows the scale which was inserted in the video.

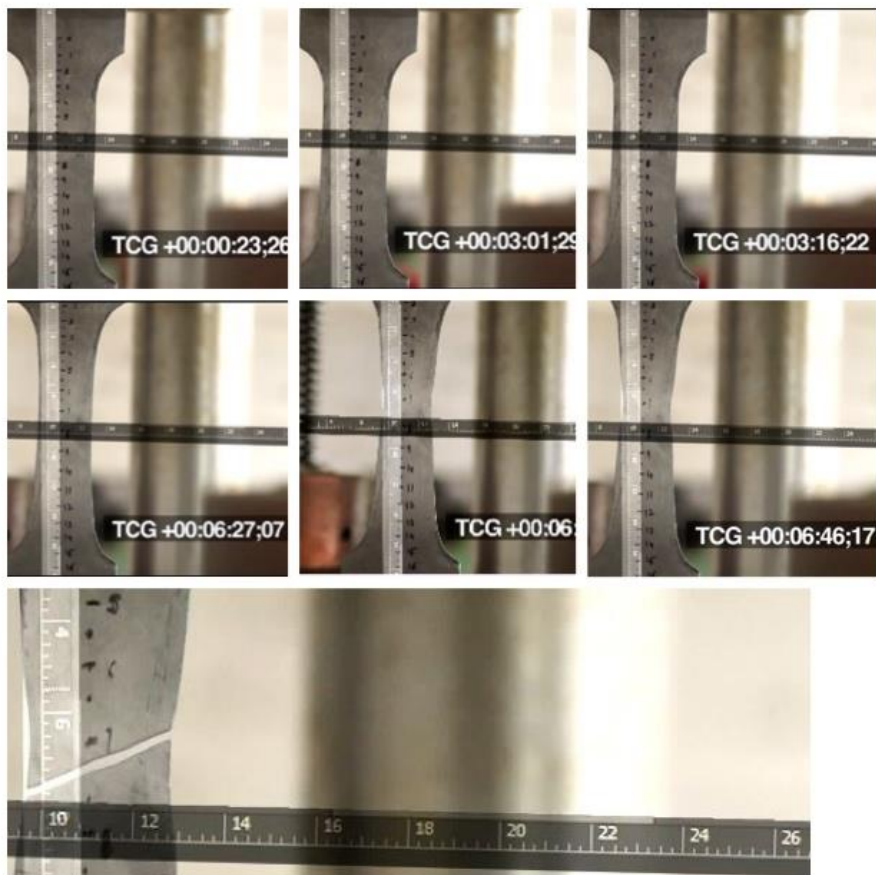


Figure 6.9 How the Frames were used

So the with respect to change in length w.r.t time was pen down and the load on the cross section was 2 KN/ mm so the stress stain graph was derived.

The values were also validated using the perzyna [17] model. The graph represents the true stress strain curve of the different 4 specimens.

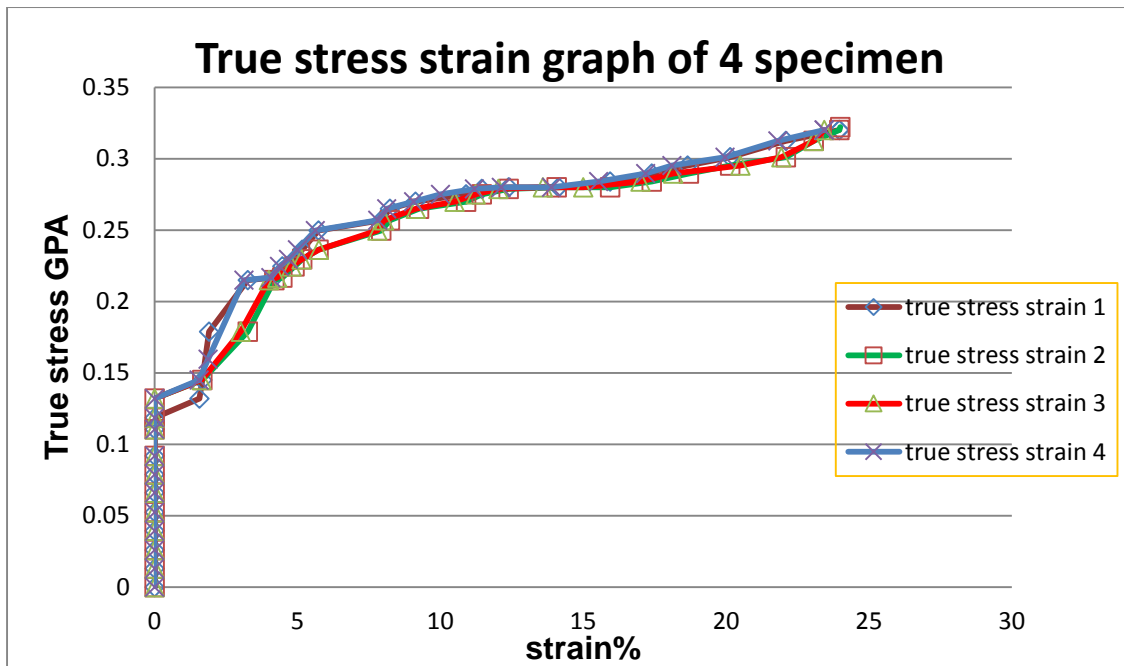


Figure 6.10 True Stress Strain Curves of the different Specimen.

Figure 6.10 represents the true stress strain curves of the different specimen. From this curves a mean values value was calculated. The figure 6.11 shows the mean values of the curves. In this curve lower yield point, upper yield point and plastic region is also shown.

- Lower yield point - plastic deformation continues at a more or less constant stress until work hardening begins.
- Upper yield point - maximum stress reached before the load drops.
- Plastic region – is the region where material starts deforming into permanent shape.

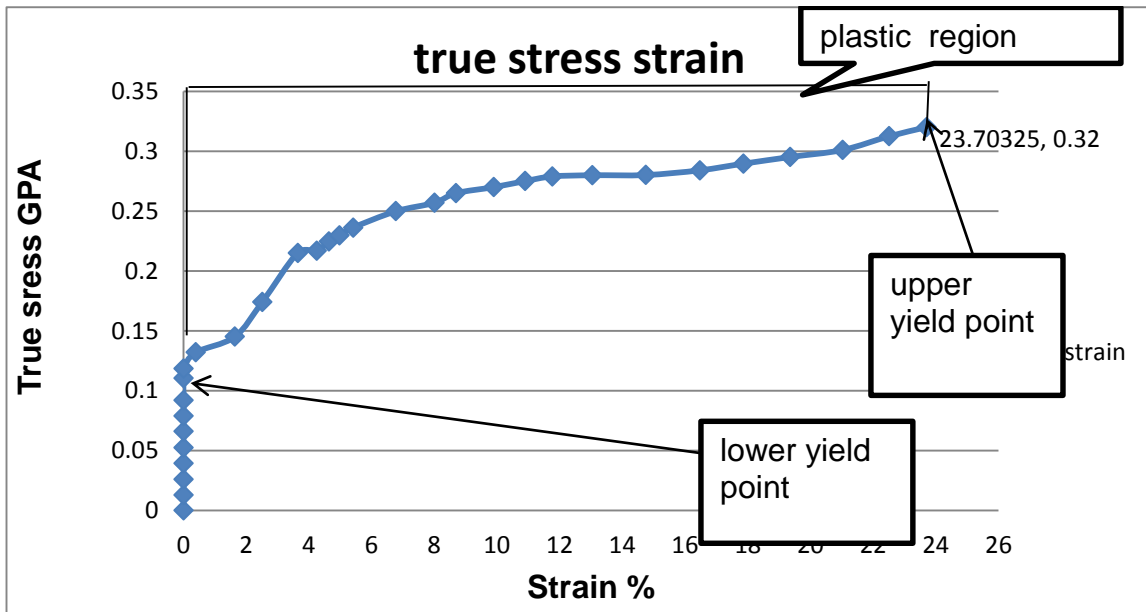


Figure 6.11 True Stress Strain graph

These properties were used in the simulator as the material of the sheet chosen was elastoplastic properties. Figure 6.12 shows where the material properties are used in ANSYS.

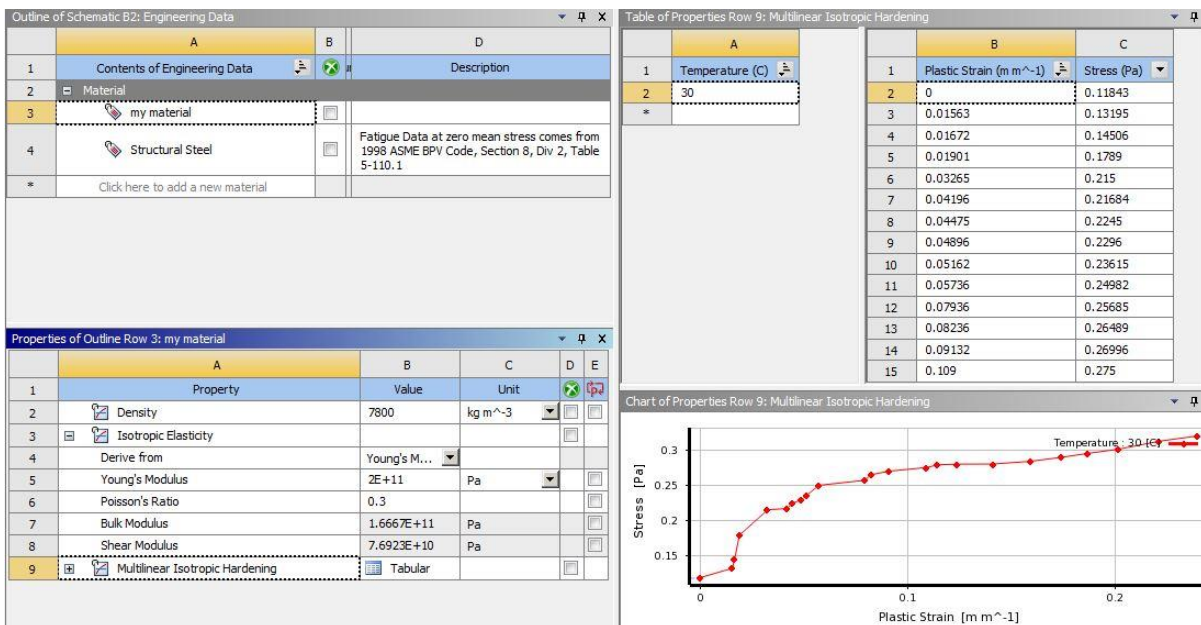


Figure 6.12 Where Material Properties are used in ANSYS

The material of the die, punch and blank holder was assumed to be rigid. The materials properties of the tool are defined in table no 5.

6.3.3 LOADING CONDITIONS

After defining the material properties, loading condition needs to be defined. In explicit dynamics the punch velocity is given same as the practical work that is 15 mm/sec. The analysis time is given as 600 sec and the die was constrained as the fixed. The langrangian method was used.

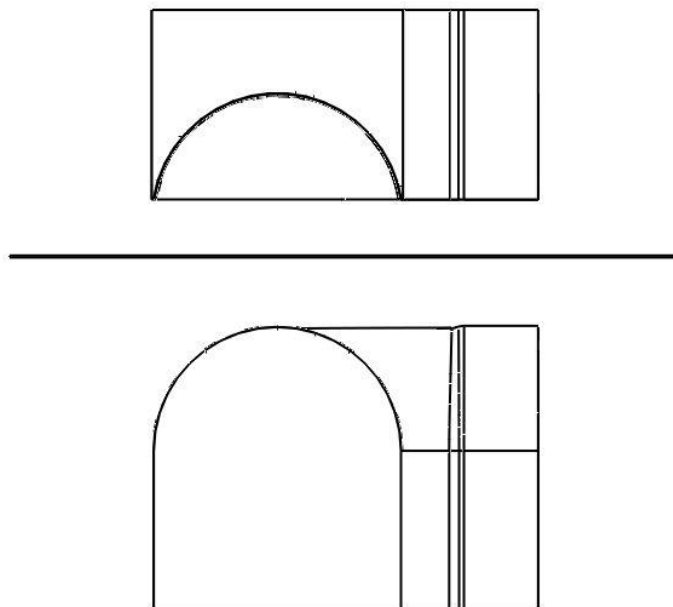


Figure 6.13 Wire Frame Model of the Tool

Automatic contact procedure in ANSYS 15.0 was assumed for the complex interaction between the punch, blank and die. For rigid-flexible (tool set-blank) contact, 3D 8-node quadrilateral target element (TARGET 17.0) was used to represent 3D target (tool set) surface which was associated with the deformable body (blank) represented by 3D 8-node contact element (CONTA174). Conventional shell elements have to be applied with the special care where in significant deviation from plane-stress behaviour is expected. Shell elements used as compared to solid elements as they take more computational time. Minimum configuration requires is 24 GB. Therefore whole model was shell modelled with the thickness of 1 mm.

Triangular mesh was taken for the punch and the die but for the sheet the quadrilateral meshing was taken. The total no nodes are 17123 and the elements were 46336. Figure 6.14 shows the meshed model of the geometry. All other conditions of the simulator remain the same. Now meshing the shell model and putting the same loading conditions. The shell element was taken as 281(SHELL 281) because shell element works for the planar shell and also linked with elastoplastic, linear elastic and creep properties.

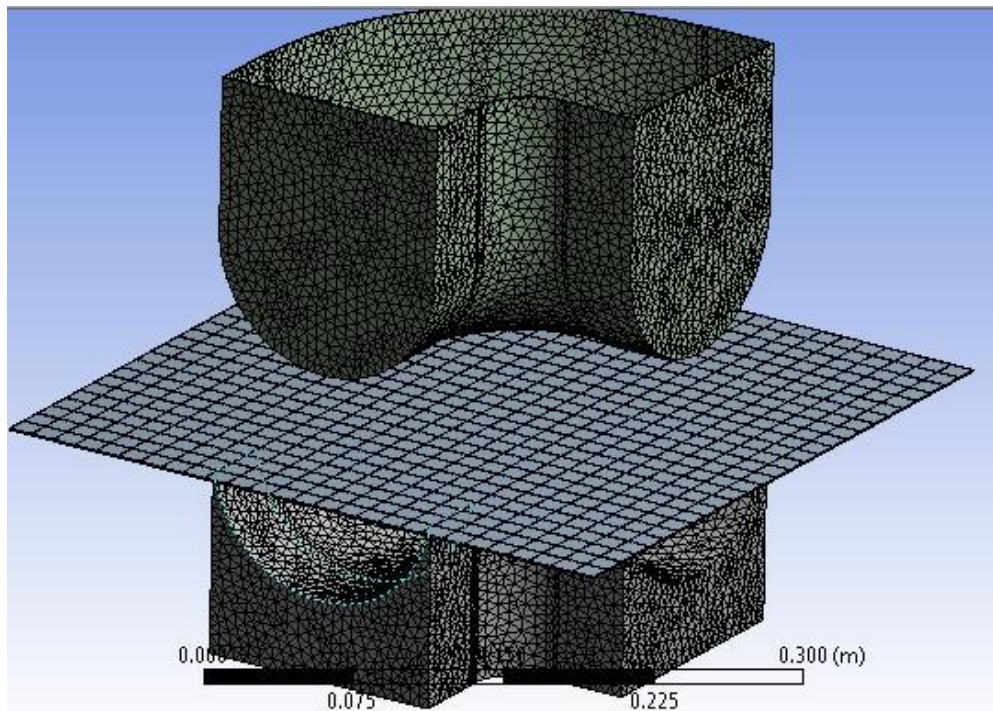


Figure 6.14 Meshing of Tool

The contact and target surfaces constituted a “contact pair”, which was used to represent contact and sliding between surfaces of tool set and blank. Constant friction coefficients are assumed during the drawing process. Coefficient of friction in the blank die interface was assumed to be 0.05. This selection was based on consistency between simulation and experimental results.

6.4 ANALYSIS

After the material properties, meshing and loading conditions, the analysis is to be done. In analysis the total deformation and total strain effects is to be analysed. Using the actual loading values in ANSYS was also assigned i.e. when the impact loading rate is applied on the punch the wrinkles generate. The velocity with which the punch moves down towards the blank holder and the pressure on the blank as measured was also assigned. Velocity 75 mm/sec and rate of loading 270 MPA was assigned. The analysis shows the wrinkles on the same area. Figure shows the analysis of the impact loading conditions.

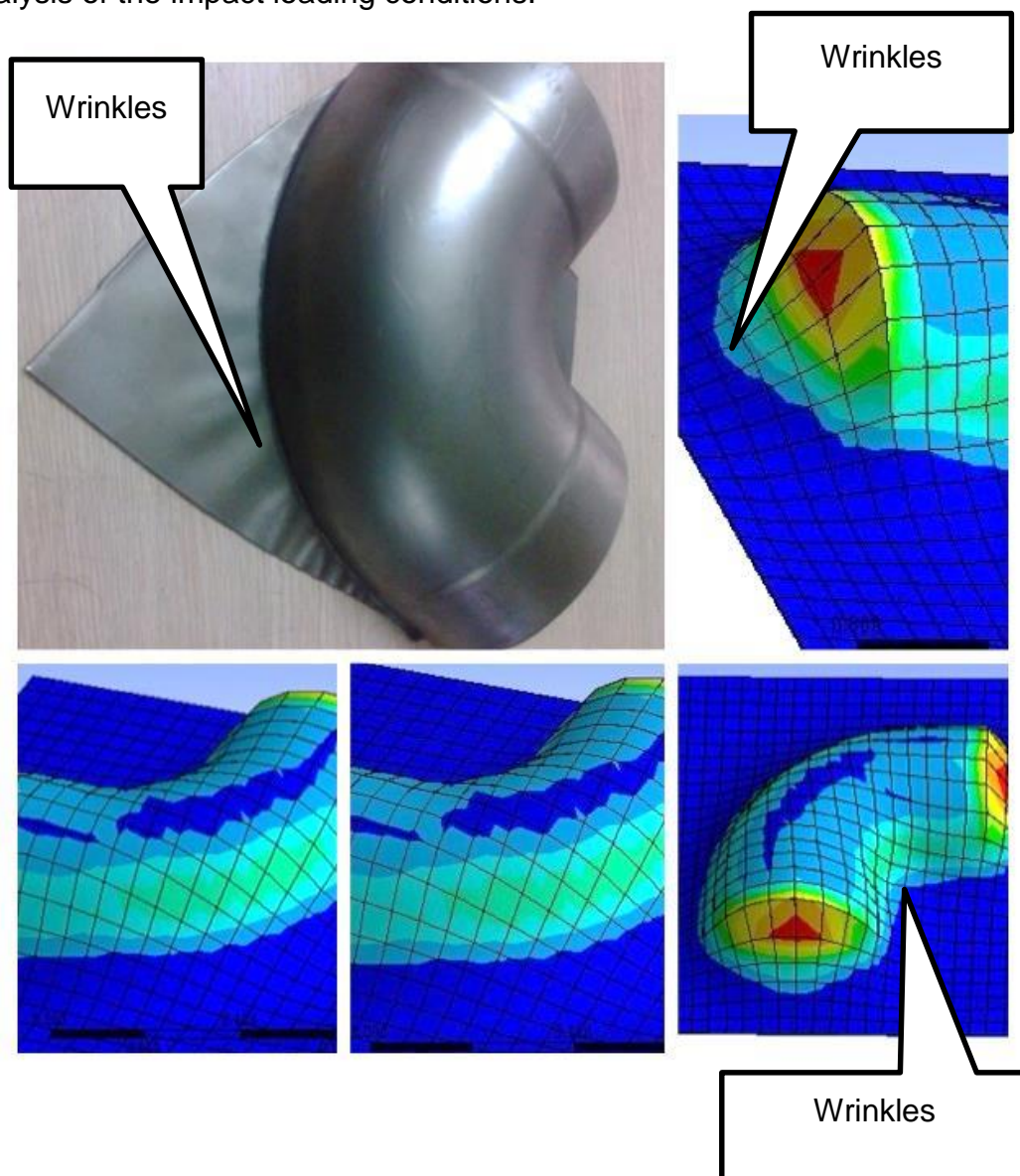


Figure 6.15 Result of Analysis from ANSYS

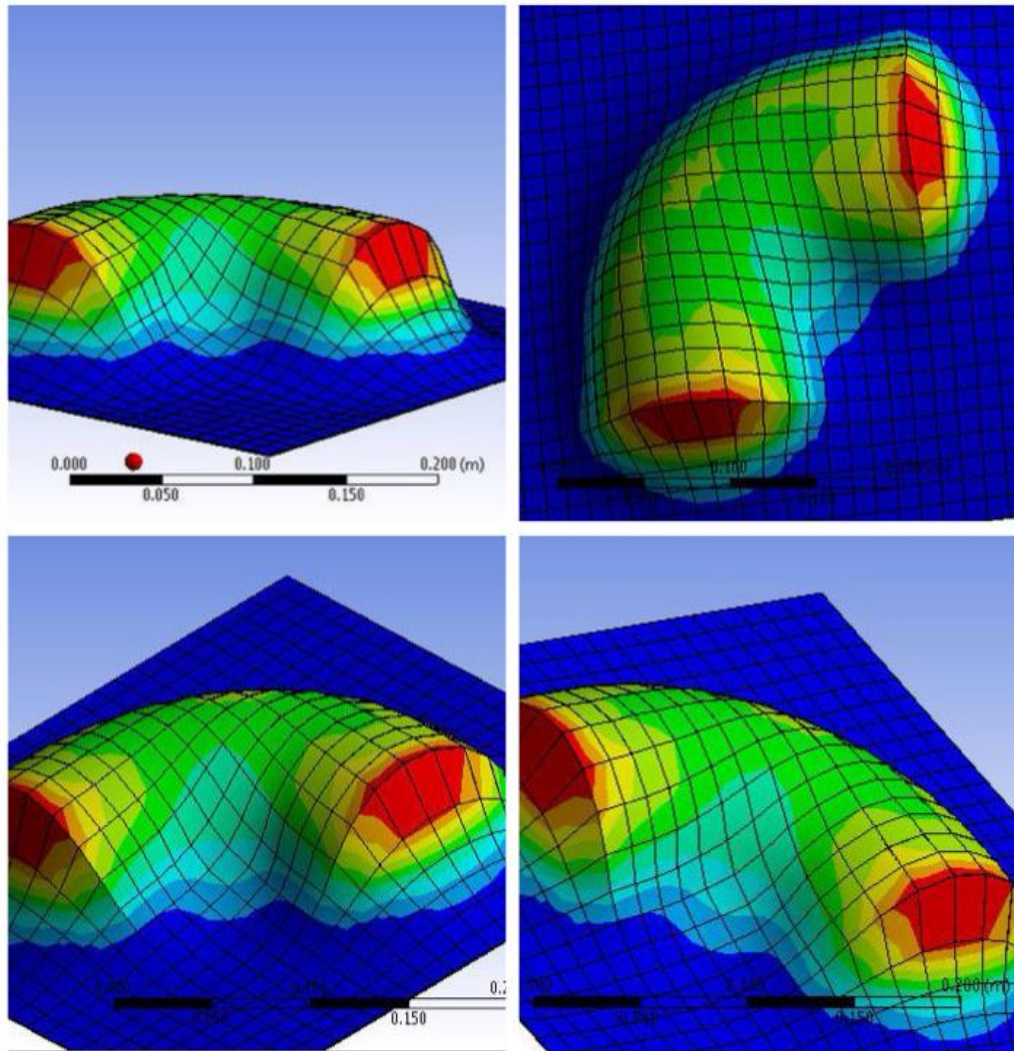


Figure 6.16 Wrinkles with Meshing

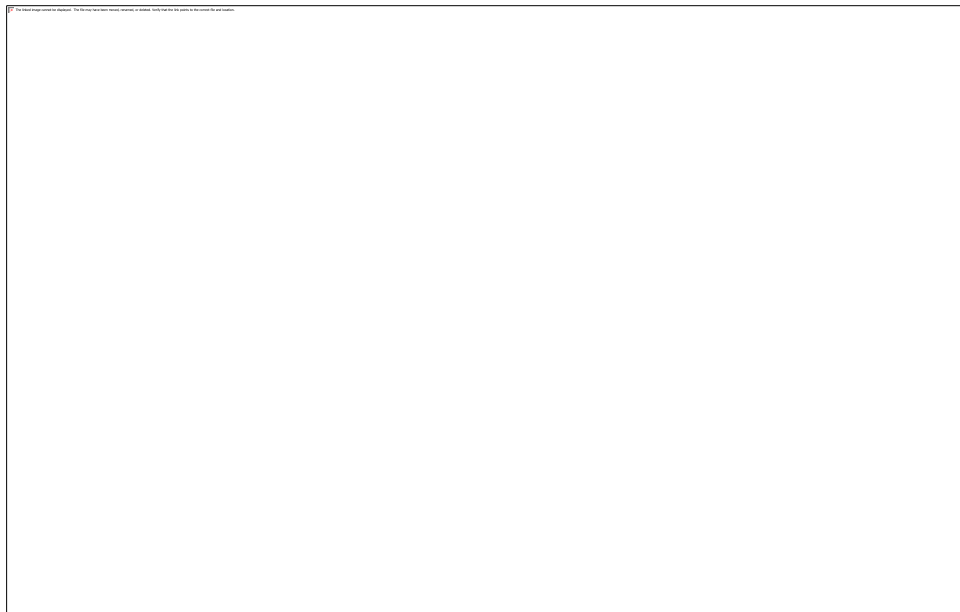


Figure 6.17 Displacement and Time Graph during Bending

In figure 6.17 displacements versus time graph during the analysis, when the deformations were taking place. It also represents the maximum depth which is to achieve that is 937.3 mm. By changing the loading conditions, punch velocity was assigned as 15 mm/sec and load on the blank holder was assigned as 470 MPa. So the analysis was performed and the wrinkles were eliminated and draw was properly seen.

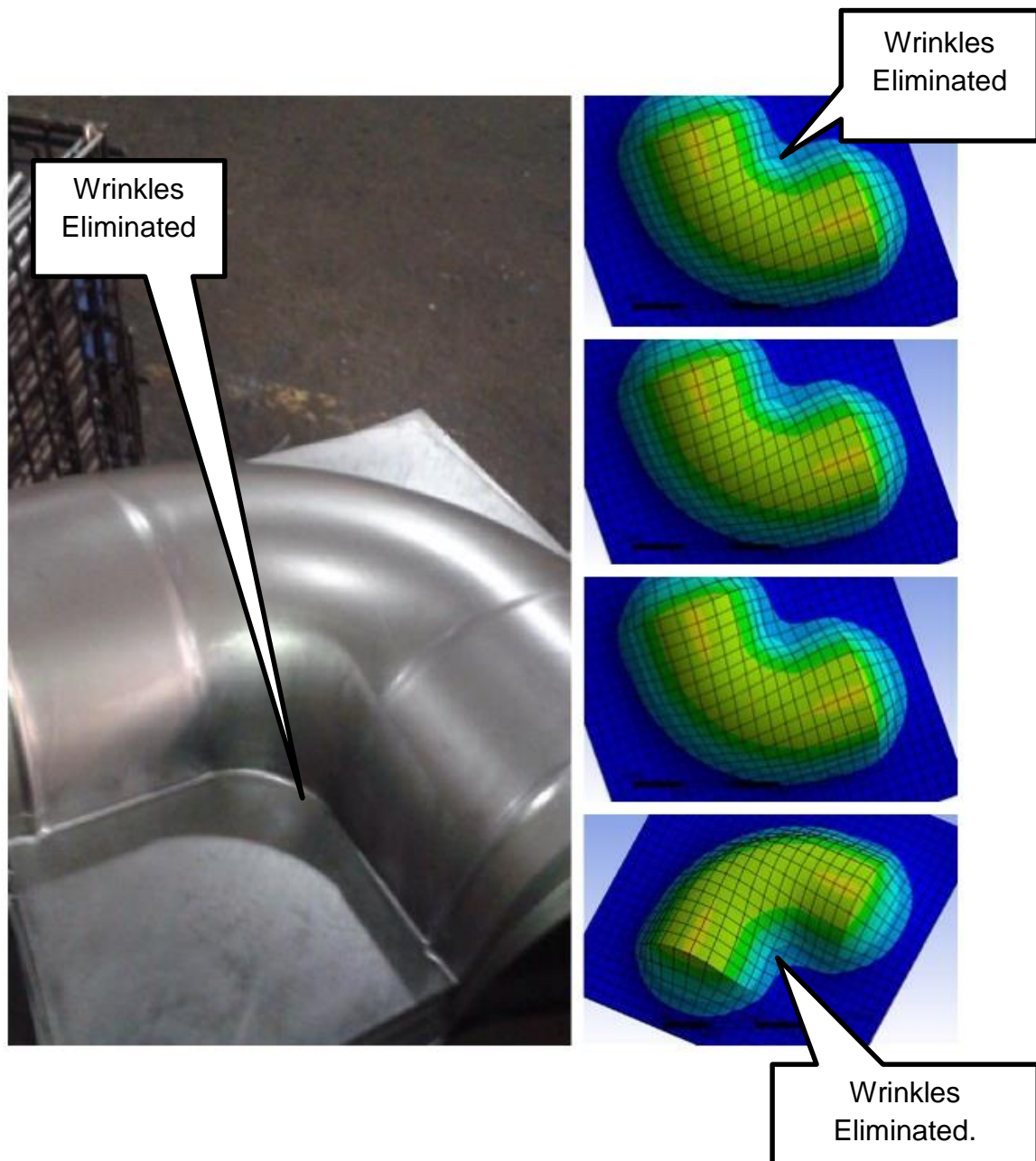


Figure 6.18 Results of Analysis from ANSYS

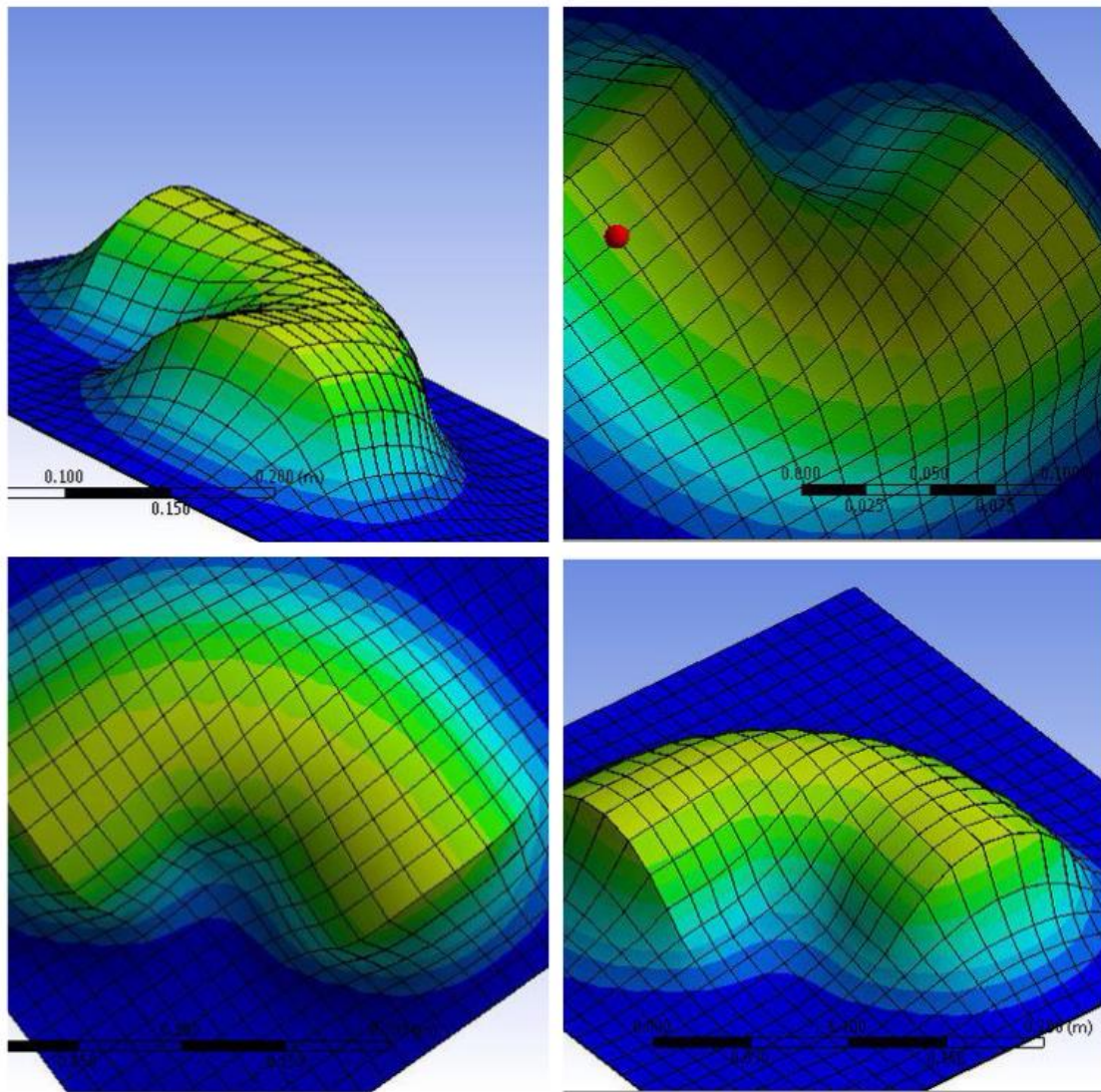


Figure 6.19 ANSYS Results with Meshing

The results achieved from the simulator developed using ANSYS. CAE software is validated by the results of physical process observed in industry. The developed simulator is capable of showing the results if materials of part and tool, geometry of part, geometry of tool dies, loading conditions and conditions of holding the work piece are changed.

For further work the simulator needs to be modified to show effect of heat generation due to plastic deformation, heat transfer across material, thermal deformation in the die and in the part, transient conditions of heat transfer and spring back action.

The use of a simulator for deep draw is only for reducing physical experimentation, reducing cost of experiments, reducing time in finding a solution to problem like wrinkles for an engineer with limited experience. A simulator does not show all aspects of the physical deep draw forming operation but is a close approximation and should be used considering this.

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