DEFORMATION AND STRESS ANALYSIS OF A GALVANIZED-ANNEALED STEEL JAC390W USING AUTOFORM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF REQUIREMENTS FOR THE DEGREE OF

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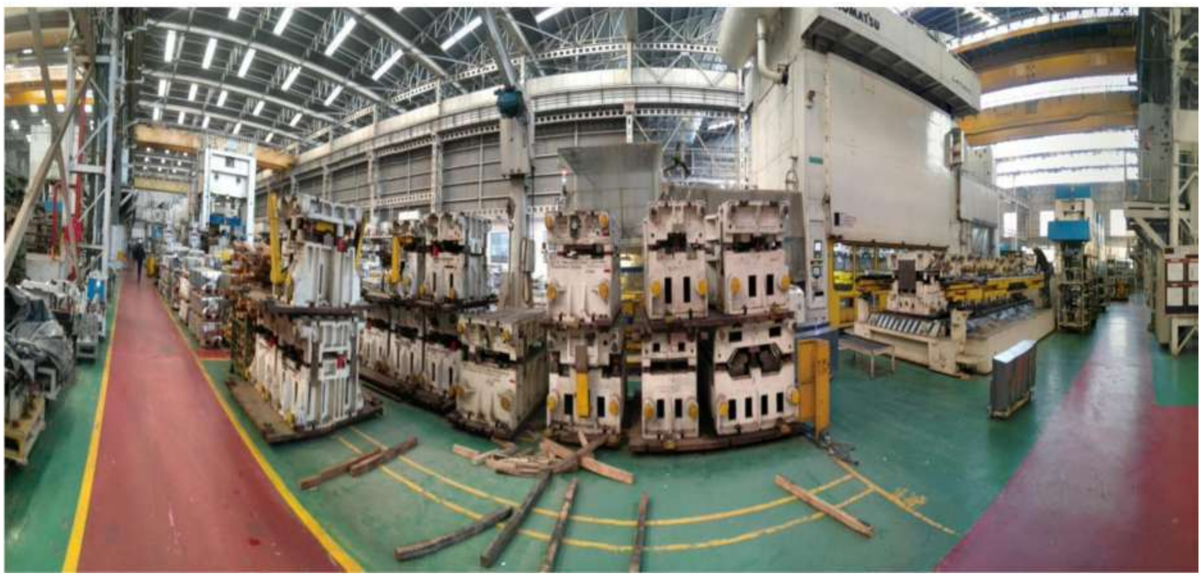

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CERTIFICATE

I hereby declare that the dissertation entitled "**Deformation and stress analysis of galvanized-annealed steel JAC390W using AUTOFORM**" was an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering** in **CAD/CAM Engineering** at **Thapar Institute of Engineering and Technology**, **Patiala** under the supervision of **Mr. Hardeep Singh Rawat (Manager, Design Department, JBM, Gurugram) Dr. Bikramjit Sharma (Assistant Professor, Mechanical Engineering Department)**. No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

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Abstract

In the automotive industry, parts are produced mostly by stamping the part with the help of die and punch. During the mass production of the part where heavy punch machines are involved, various defects like spring-back, wrinkle, thinning, etc can occur FEM simulation can be performed to identify and reduce the defects at the early stage. In the present work, surface analysis of a front seat panel is carried out on AUTOFORM R7. The purpose of this research is to study the effect of change in sheet thickness and blank holder force on wrinkle and spring-back during forming. Forming Limit Diagram is studied for limits to forming. The methodology can be implemented to design automobile components in the future.

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Chapter 1

INTRODUCTION

1.1 General

In the automotive industry, parts were produced mostly by cold forming by stamping the part with the help of die and punch. Different parts were produced in this manner like rear lamp panel, front seat bracket, etc. Different types of material were used like steel, aluminum, and iron. During the mass production of the part where heavy punch machines were involved the blank being deformed shows a series of defects like spring-back, wrinkle, thinning, etc. This led to reduced strength and accuracy of the part which ultimately led to rejection. To avoid such failure one of the most prominent methods used these days was analysis through FEM simulation that predicts the defects at the early stage where it could be minimized. This saves a lot of time and money from an industrial point of view.

The part was front seat panel made up of JAC390W galvanized-annealed steel whose yield and tensile strength of 242 MPa and 416 MPa respectively as given in fig 1.1.

Galvanized-annealing

Firstly, steel undergoes galvanization in which metal was immersed in the bath of molten zinc at 449ºC. At the completion of this process layer of zinc-carbonate was formed that provides corrosion resistance. After this when the steel was still in soft state annealing was initiated. Annealing involves heating the material to a certain temperature (500-565ºC) and then allowing it to cool at a controlled rate. Zinc and iron layer gives it a matte grey appearance. This led to recrystallization, recovery and grain growth which further enhances the cold forming characteristics of the material. It led to increased ductility, electrical conductivity corrosion resistance and eliminates internal stresses. Spot weldability was increased and material was rendered paintable with zinc phosphate coating treatment

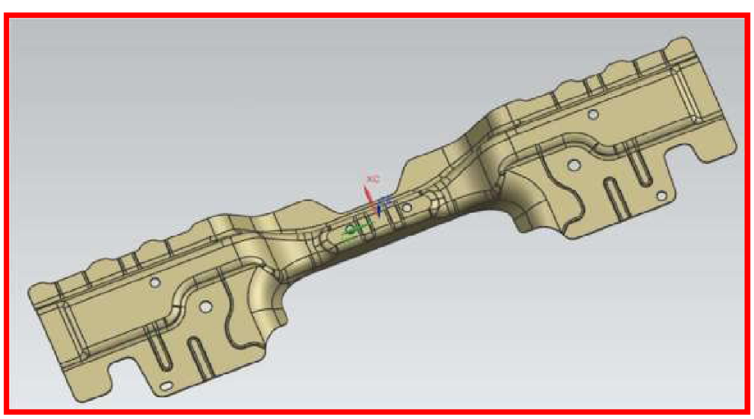

Fig 1.1 Front seat panel

1.2 History of FEM Simulation

A finite element analyswas was a simulation concept taken from the Finite element method. FEM was a numerical approach to solve boundary value problems of partial differential equations. This approach was applied to smaller subdivisions called elements and integrated into the whole structure using calculus.

In 1942, Hrennikoff and Courant developed mesh discretization method to solve elasticity and structural problems. In 1959, IBM collaborated with GENERAL MOTORS to Design Augmented Computer (DAC-1) to design vehicles. By 1965, NASA developed structural analyswas solver NASTRAN. In 1977, ISME initiated the first FEM code FIESTA. In 1987, MECHANICA was developed by RASNA corp. In 1991, the first-ever implementation of model hierarchies in FEA was accomplwashed. In 1993, Stress-Check was first released which set new standards for hierarchy modeling and error control in simulation. In 2001, P-version of FEM was found better than H-version for plastic deformation. In 2006, ASME guidelines were released for validation and verification in computational solid mechanics. In 2012, simulation governance was introduced that contained procedures for ensuring and enhancing the reliability of predictions in simulation.

1.3 Need for Surface analyswas using FEA

Part considered for analysis in thwas present work was a front seat panel of a car. Its complex shape and bigger size lead to a vast number of concerns like:

i. Discretization.
ii. Boundary conditions.
iii. Unique material composition.
iv. Higher order elements.

To meet the above challenges, the use of FEA becomes important as it was simple, compact and result oriented. Also, the series of iterations convergence and manipulations get automated and run on the backend of the software. Evaluated results were easy to view and compare.

1.4 Application of FEA

Nowadays, Finite Element Analysis was extensively used in industries for structure analysis. It has a wide werea of application in fields like aeronautical, biomechanical and automotive. This was due to the fact that the FEM package offers a working environment in thermal, electromechanical, fluid and structures. This permits the designer to develop parts ranging from heavy industrial machinery to light and sensitive parts. Structure in FEM package was one of the most used features whether designing a truss structure in bridges or a mechanical tool. Stiffness and strength can be easily controlled which ultimately led to minimization in weight, material, and cost.

1.5 Company Profile

JBM has acquired global presence being able to provide manufacturing techniques of global standards. This has been made possible because of dedicated design and engineering divwasion consistently working on to provide the latest manufacturing technology.

1.5.1 Products and Services

To modernize its facilities so as to improve its expertwase JBM embarks upon three motives:

Higher performance reduced wastage and reduced wastage and quality products. This was achieved by the best technology and manufacturing capability to meet customer need as in fig 1.2.

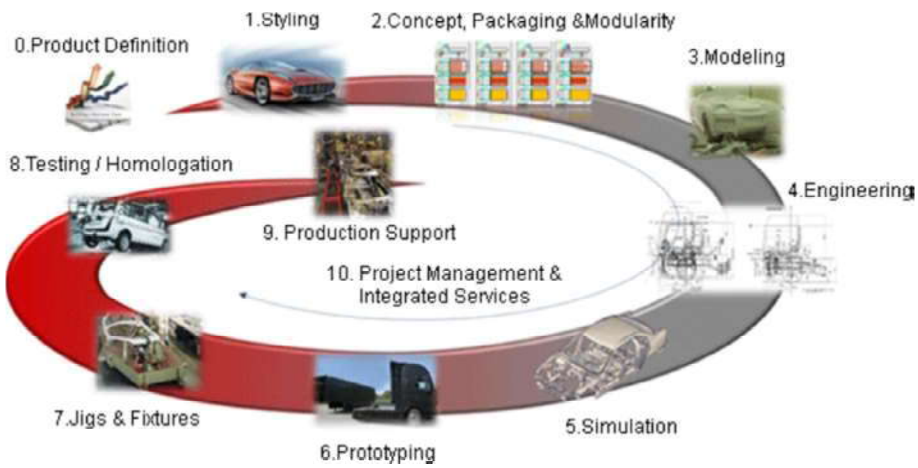

Fig 1.2 Product management cycle [23]

The Group's leading-edge products include:

i. **Skin panels:**

Fig 1.3 Skin panels

ii. **Shaped blank:**

Fig 1.4 Blank

iii. **Chassis:**

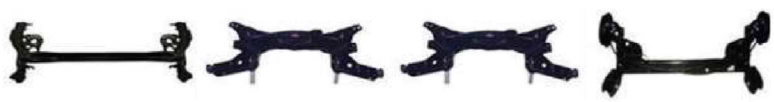

Fig 1.5 Chassis

iv. **Cross Member:**

Fig 1.6 Cross member [24]

1.5.2 Fundamental of Stamping

Stamping involves both forming and cutting operations. The sheet gets deformed between die and punch and a specific shape was obtained. Sheets of different materials were used like steel, zinc, copper, nickel, aluminum, and titanium. Material selection depends upon factors like hardness, toughness, ductility, electrical conductivity, etc.
Depending upon product type different force, speed and precision were defined. Presses were available in two types i.e. Mechanical and Hydraulic. A hydraulic press was preferred for heavy loading but oil leakage was one big drawback. The press comes in a different capacity, size, stroke length and speed.
Metal stamping was preferred over casting, forging, fabricating and machining due to the following reasons:

i. Die costs cheaper than the one used in forging and casting.
ii. Being mostly a cold forming process material used can be harder. This greatly enhances the product strength.

1.5.2.1 Forming operations:

i. Draw

In draw operation, severe deformation occurs over the punch shoulder and curvature. A cup was a perfect example of both forming and drawing where the was formed and sides were drawn. Stock used for making tunes, bars and wire were drawn first to reduce the diameter and increase length as in fig 1.7.

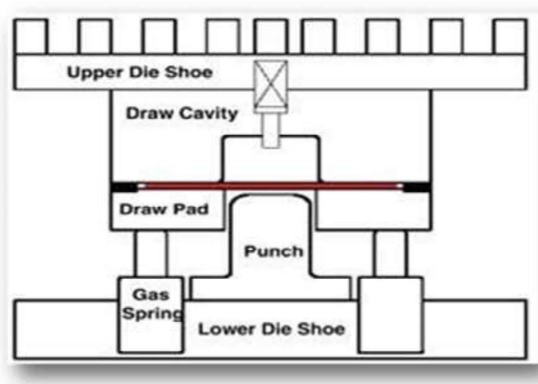

Fig 1.7 Draw [25]

ii. Restrike

Restrike operation was usually used at the end of operations to compensate for the following:

i. Spring-back in draw operation used previously.

ii. Sharp radii and small embosses.

This was considered as final finishing operations and uses tensile forces. But, compressive forces could also be used.

iii. Bending

Bending was used to produce V-shape, U-shape, and Chanel-shape in ductile materials. Equipment used for bending includes pan-brakes and brake-presses. Boxes produced using bending were electrical enclosures and rectangular ductwork. Using press-brake, three types of bending were achieved namely, Air-bending, bottoming and coining as in fig 1.8.

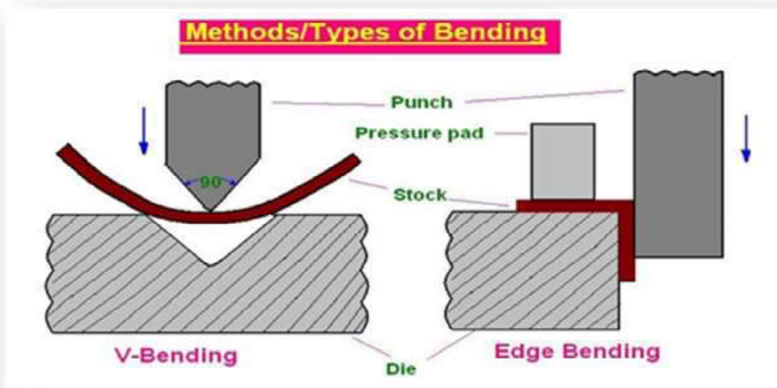

Fig 1.8 Types of Bending [26]

In bending using press-brake punch was attached to the ram using clamps. Die was stationary and attached to the bed of the press. The sheet was over-bent to compensate for spring-back which was caused due to residual stresses. Bend radius refers to the inside radius of the bend and was dependent upon the material product and sheet thickness as in fig 1.9.

Fig 1.9 Brake Forming [31]

1.5.2.2 Cutting operations:

In this operation, metal was cut by placing it between the bypassing tool section with a certain gap. Thwas gap was called cutting clearance. Thwas clearance was mostly taken as 10 % of sheet thickness. The shiny cutting edge after cutting was usually obtained due to intensive stretching of metal up to point of failure.

There were many different cutting operations, each with a special purpose. Some common operations were:

i. Trimming

Trim operation was usually followed by draw or another operation where the outer periphery of the formed part was cut and discarded as scrap as in fig 1.10.

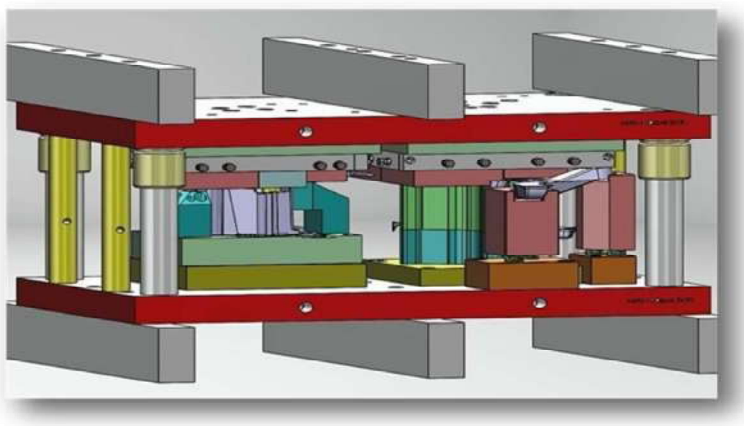

Fig 1.10 Trimming

ii. Notching

Notching operation was usually performed in a progressive die where multiple cutting operations were performed to obtain a particular strip of sheet. This was usually followed by bending and other forming operations as in fig 1.11.

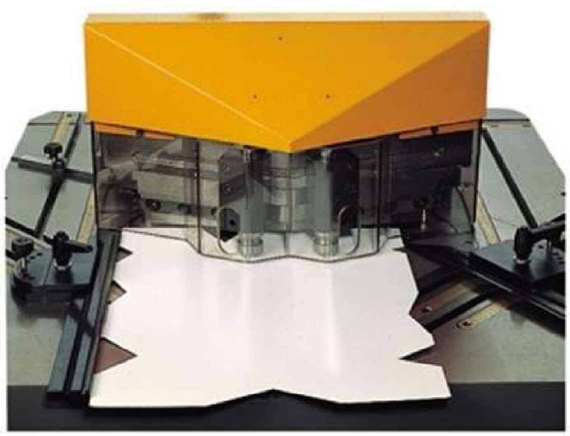

Fig 1.11 Notching [22]

iii. Blanking

Blanking was mostly preferred for cutting sheet where a major portion was removed and the remaining portion was called blank. This can be formed in any shape as per the die and punch as in fig 1.12.

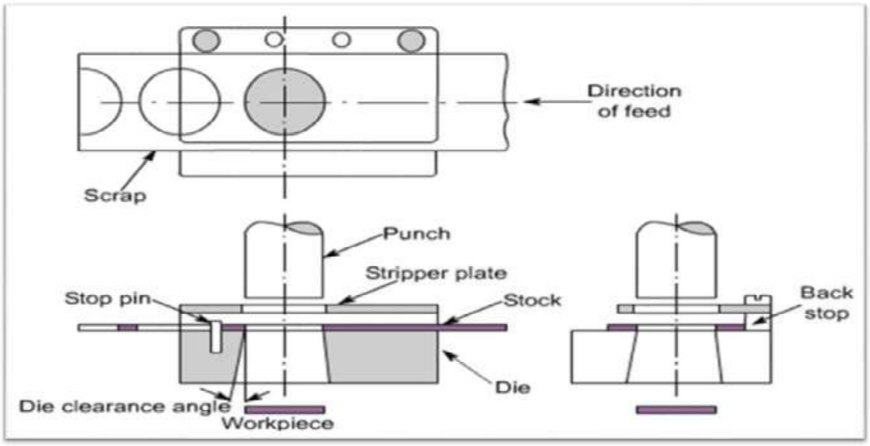

Fig 1.12 Blanking

iv. Piercing

In piercing, metal was perforated through to form holes of different shapes and sizes. It defers from blanking since scrap part was used further while removed metal in pierce was a scrap as in fig 1.13.

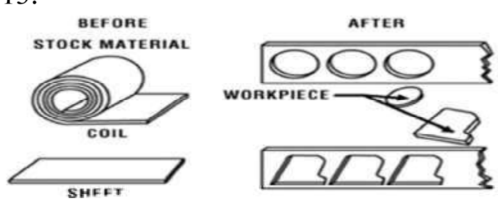

Fig 1.13 Piercing

v. Lancing

In Lancing, metal was sliced in order to form a slit or vent without separating the piece from the part. Lancing was usually preferred with progressive die to form a part carrier as in fig 1.14.

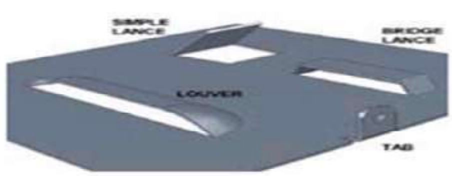

Fig 1.14 Lancing

1.5.3 Types of Defects

i. Wrinkle

The wrinkle was one of the most prominent defects found in sheet metal forming. Metal flow was linear along the straight edges of the blank at the punch shoulder and curved edged metal flow was restricted. This led to non-uniform stress distribution and so wrinkle occurs.

Several factors can cause wrinkles in deep drawn parts, including:

- Blank holder pressure
- Die cavity depth and radius
- Friction between the blank, blank holder, punch and die cavity as in fig 1.15.

Fig 1.15 Wrinkle

ii. Burr

A Burr was a rough edge ridge left on an object. Thwas occurs mostly due to machining operations like drilling, grinding, milling, etc. They were removed by a specifically designed operation called Deburring as given fig 1.16.

Fig 1.16 Types of Burr

Burr was of two types:

- **Hole burr:** This was caused due to the rough cutting edge of the punch.
- **Trim burr:** This was formed due to improper die clamping and blunt edge of the trim tool.

iii. Surface Scratches

Surface scratch was an uneven surface formed over part. They can be caused due to any of the reasons as follows:

- Improper clearance between die and punch.
- Insufficient lubrication between the surfaces making contact as given in fig 1.17.

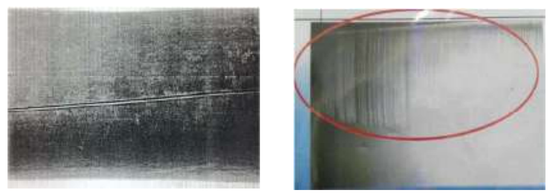

Fig 1.17 Surface Scratch

iv. Thinning

Thinning was defined as the reduction in the given specified thickness of the sheet metal due to stretching. In deep drawing process material of the flange undergoes compressive hoop strain and radial tensile strain. Due to this material tends to flow towards the center and tends to thicken. But, due to the curved profile of the punch and die metal undergoes thinning as given in fig 1.18.

Fig 1.18 Thinning

v. Waviness

Waviness was a non-uniform surface formed which makes assembling of different parts together difficult. This was due to less cushion pin pressure and the matching area between die and punch.

vi. Crack

A crack was a non-uniform line formed that renders a material useless although not separated into two pieces. This was caused due to high blank holder force and inferior material as given in fig 1.19.

Fig 1.19 Crack

vii. Overlap

The overlap was a type of defect in which sheet get one over the other which may be due to misfeed of the sheet into the press machine as given in fig 1.20.

Fig 1.20 Overlap

viii. Flange Fold

A flange was a defect which occurs because the sheet which was feed was shorter in size as compared to the required size as given in fig 1.21.

Fig 1.21 Flange

Cause -

- Improper placement of the blank on the die

ix. Misfeed

Mwasfeed was a type of defect in which the sheet was misplaced between the dies and this defect occurs due to operator carelessness as given in fig 1.22.

Fig 1.22 Mwasfeed

Cause -

- Wrong raw material size
- **The gap between blank and location**

x. Dent, Scrap Dent, Hole Dent

These types of defects arwase due to a problem in a die which may lead to oversize of the holes or scratch etc as given in fig 1.23.

Fig 1.23 Types of Dent

- **Die dent-**
  - Presence of dust in draw die
  - Long or loose plunger pin

- **Scrap dent-**
  - Presence of scrap on the die
  - Scrap was not removed timely

- **Hole dent-**
  - Defect in the cutting edge of the punch

xi. Damage

- Improper placement of part in the bin
- Overstocking of parts in the bin

Fig 1.24 Damage

xii. Rust

- FIFO (first in first out) should be maintained

- Preventive oil must be applied on the part in the rainy season

Fig 1.25 Rust

1.5.4 Checking Fixture

After the sample parts were formed then these parts were placed on the checking fixture. There were critical holes in the part which have to be used for mounting other parts. The position of these holes must be within tolerance. The sample part was checked on checking fixture for critical dimensions and if there was any variation in the sample part then the change was done in the die so that the parts produced from now on were having critical dimensions within tolerance. The checking fixture was designed keeping in mind the 3-2-1 rule. The rule that defines the minimum number of contact points necessary to locate a part within the datum reference. The primary datum requires three points, the secondary datum two points, and the tertiary datum one point as given in fig 1.26 and fig 1.27.

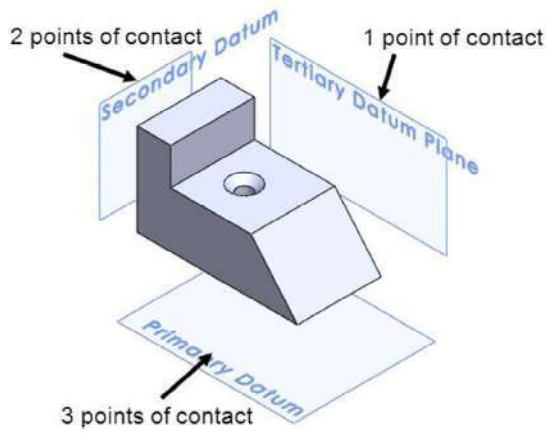

Fig 1.26 (3-2-1) Rule of GD&T [35]

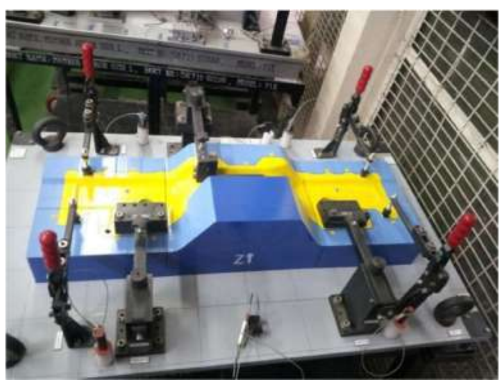

Fig 1.27 Checking Fixture

Chapter 2

LITERATURE REVIEW

In 1987, Manabe [1] proposed a new variable blank-holding force for plastic sheet laminates with poor deep draw-ability. In thwas method also called the fracture limit BHF, the load was taken slightly less than the fracture load limit of the blank. Successful implementation of thwas method led to an increase in limiting draw ratio and drawn cup height. The wrinkleless cup was drawn for blank with smaller limiting draw ratio than constant BHF as given in fig 2.1.

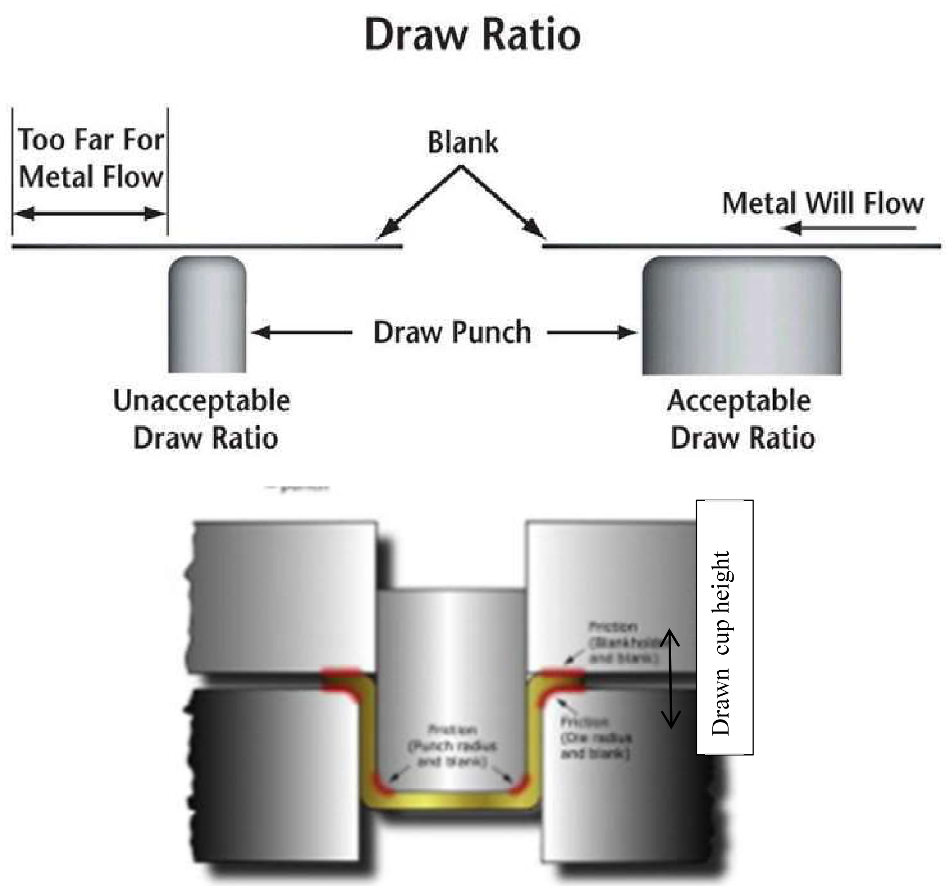

Fig 2.1 Draw ratio and Drawn cup height [28]

In 1997, Leu [2].studied the effect of changing parameters like normal anisotropic value R, strain hardening exponent n or thickness ratio $t/2\rho$ on factors like spring-back, bendability, maximum bending moment. Obtained results were compwered to experimental data to ensure validity. It was found that (i) spring-back increases with normal anisotropic value R, (ii) varies proportionally with decreasing strain hardening exponent n or thickness ratio $t/2\rho$ but, (iii) concentrates to a small range when former was increased. Minimum bending radius varies proportional to thickness and strain hardening exponent but inversely with normal anisotropic value R. Maximum bending moment stays proportional to normal anisotropic value R and thickness but inversely with strain hardening exponent n

In 2001, Livatyali [3] studied spring-back on a flange using two different FEM codes i.e. DEFORM and ABAQUS. Variables included were die-corner radius, punch die clearance, punch-nose radius, pad force, and material type. Both the results were simultaneously compared to the experimental data and sources of error were identified.

In 2002, Guo *et al.* [4] investigated the behavior of high toughness pipeline steels X-70 (Grade 500). The thickness and material delamination were varied to study the behavior of fracture toughness and crack growth. Thickness was found to vary proportionally with delamination which further initiates crack formation. Increase in delamination reduced the effect of thickness upon fracture as given in fig 2.2.

Fig 2.2 Delamination [27]

Delamination was a type of failure where material distorts into layers. Even steels can show delamination since sheets formed through cold rolling causes grain structure to arrange into layers.

In 2004, Tekiner [5] performed sheet metal bending of six different materials with four bending methods over 18 modular V-bending die. Spring-back data were obtained and converted into curves. Now curves along with the effect of bending methods on spring-back were studied so that a part can be produced within specified tolerance limits. An experimental bending test was performed over six different materials. Springback in minutes was obtained for different material at different bending angles. Thickness was kept constant at 1 mm as given in fig 2.3.

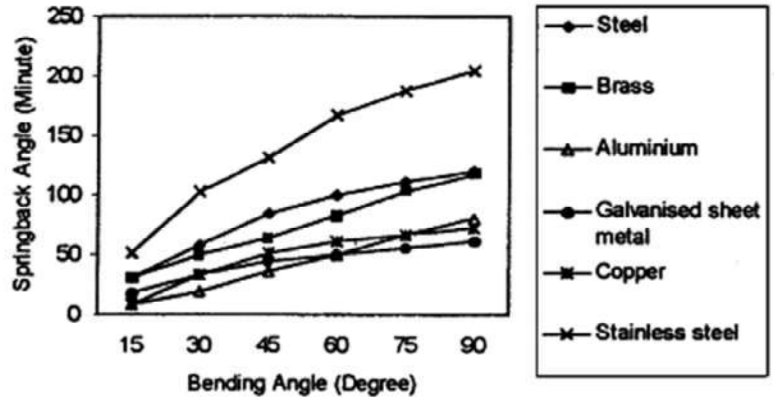

Fig 2.3 Spring-back v/s Bending angle for different materials [5]

From the graph, it was clear that on increasing bending angle spring-back rise quickly for stainless steel followed by steel and brass. In Aluminum, spring-back rise slowly in the start and then keeps on rising. In copper and galvanized sheet steel at higher values of bending angles spring-back gets constant.

In 2004, Ho *et al.* [6] investigated spring-back of two aluminum shapes i.e. Single curvature cylindrical component and doubly curved spherical component. Forming conditions and sheet thickness were varied to study stress relaxation and creep formation for both the components. Effect of varying sheet thickness and forming condition on spring-back was studied. Creep formation and stress relaxation for both components were compared.

In 2005, Herold *et al.* [7] investigated residual stresses in deep drawn AISI-1010 cups using neutron diffraction by keeping the wall thickness below 3 mm. Axial stress was obtained due to stretc.hing and circumferential stress were obtained due to sheet anisotropy. It was also concluded that thermal relief has an insignificant effect on sheet thickness and residual stresses.

Neutron diffraction was a method of obtaining information about the structure of a material. In thwas method, a sample was kept under the beam of neutrons. Although it was similar to X-ray its application was mostly focused for a bulk specimen.

In 2007, Gau *et al.* [8] performed the three-point bending test of brass to obtain spring-back. Sheet thickness and average grain diameter were varied to control spring-back. Consequently, T/D ratios were obtained and it was concluded that spring-back could be expressed in terms T/D if the thickness was below 350 μm.

Here, T was sheet thickness and D was average grain diameter.

When sheet thickness falls below 350 μm, the variation in spring-back in different sample comes excessively close and the rate of increase in spring-back also falls. That was why the conventional method of keeping the bending angle constant to study the effect of thickness on spring-back cannot be applied as given in fig 2.4 and 2.5.

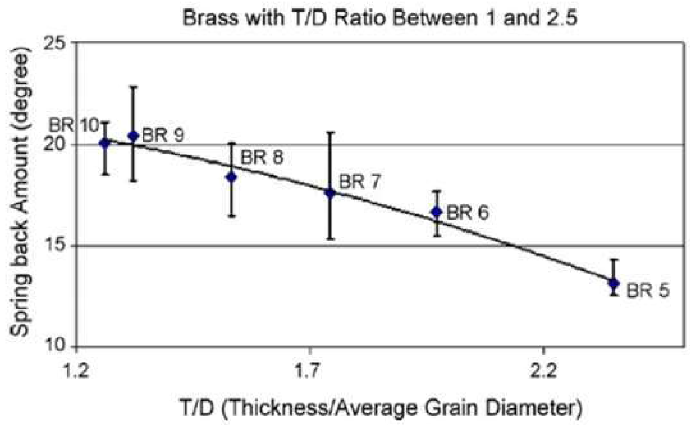

Fig 2.4 Springback v/s T/D ratio [8]

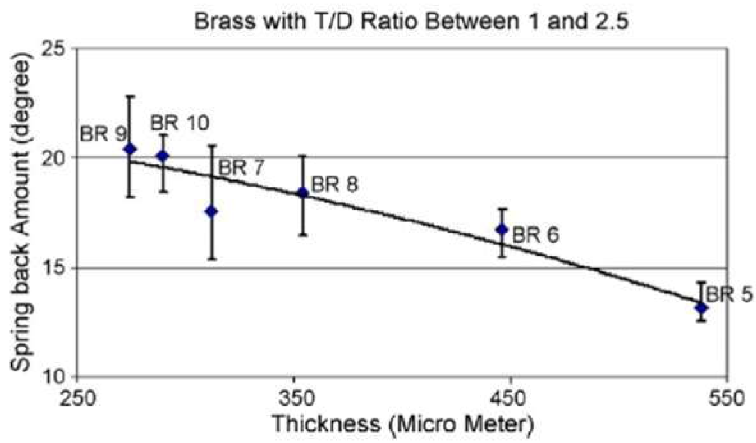

Fig 2.5 Spring-back v/s Thickness [8]

In 2007, Romeu *et al.* [9] applied air V-bending test to aluminum and stainless steel sheets for different thickness. Bending angles were varied (22º and 90º) and spring-back values were obtained. These were converted into graphs such that they could be further used to design airbending part or die as given in fig 2.6.

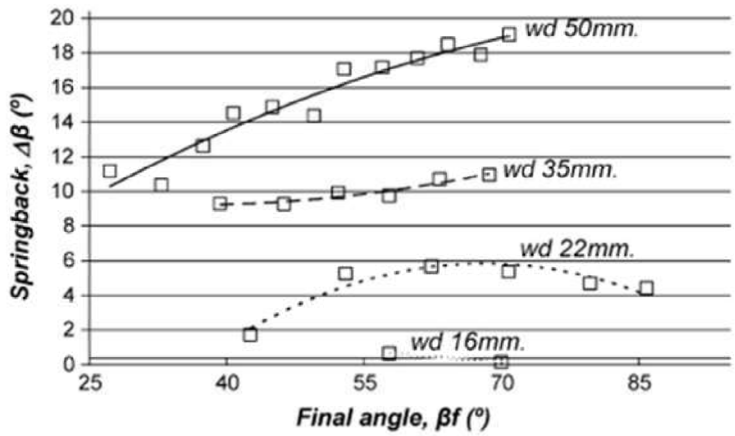

Fig 2.6 Spring-back v/s Bending angle [9]

The following curve shows the variation of spring-back with increasing bending angle for an aluminum sheet of thickness = 1.35 mm. Different curves were obtained for different die-width represented by w_d.

In 2007, Gajjar *et al.* [10] applied air bending problem to a part with planar symmetry plain strain condition. The part was modeled in 2D with symmetric boundary conditions in width. FEA results for stress and strain were compwered to 3D FEA results and experiments. Minimal variations in results were found and it extensively reduced solving time.

In 2007, Panthi *et al.* [11] performed bending analysis of sheet metal bend to predict spring-back using FEM code (RRL-FEM). Thwas code was based on Total Elastic Incremental Plastic (TEIP) algorithm which was capable of handling large elastic deformation. Effect of spring-back was analyzed over variable sheet thickness and radius of a die. The ratio of spring-back radius to initial radius (r_f/r_i) was found to be proportional to the ratio of spring-back radius to radius curvature(r_f/r_t). Effect of the load on spring-back:

i. Increases with the radius of curvature of the part. It means that for a part with a large radius of curvature more force has to be applied to decrease spring-back as given in fig 2.7.

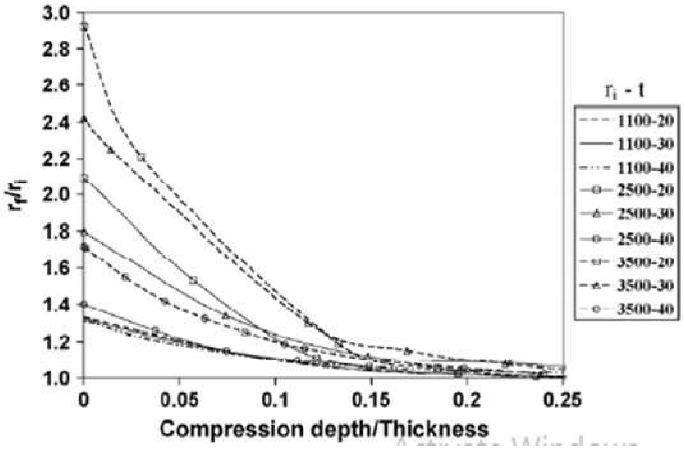

Fig 2.7 r_f/r_i v/s depth/thickness [11]

ii. Decreased with sheet thickness. It means that for thicker sheet, spring-back would increase even after increasing punch load.

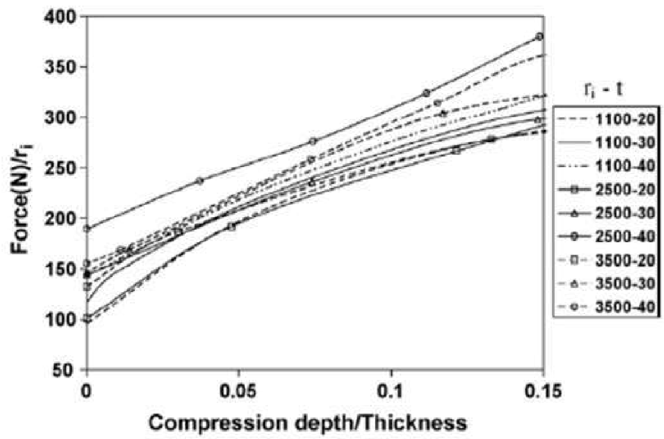

Fig 2.8 Force/r_i v/s depth/thickness [11]

In 2007, Dongjuan *et al.* [12] studied sheet spring-back in U-bending using NUMISHEET 93 2D. In U-bending metal was deformed over a U-shaped die. Plain strain condition hill48 yield criteria were followed along with three rules of material hardening i.e. Kinematic, Isotropic and Combined hardening. Various parameters were studied and the following results were obtained (i) When neutral surface shifts more than one-fourth of sheet thickness then spring-back remains proportional to blank holder force and friction between sheet and die. (ii) Spring-back was proportional to anisotropy and inversely proportional to sheet thickness. Anisotropic properties were material properties and were directional dependent.

In 2009, Lee *et al.* [13] considered three models of magnesium alloy sheet (i.e. Constitutive model for asymmetric hardening behavior, Isotropic constitutive equation and CHABOCHE Kinematic Hardening Model) and apply each model in ABAQUS via user material subroutine. For experimental validation, the spring-back of magnesium alloy sheet AZ31B was measured using cylindrical bending test of NUMISHEET 2002 and 2D draw bend test. Consequently, direct restraint force and long drawn dwastance were obtained.

In 2009, Jooybari *et al.* [14] investigated spring-back on CK67 anisotropic steel by varying parameters in V-bending and U-bending simultaneously. The purpose of this research was to study the variation and to design the part in the future with the necessary allowance. Effect of spring-back on bending angle and bending curvature was also studied.

i. **V-bending**: Spring-back was found to vary inversely with sheet thickness and proportional to the punch tip radius. Spring-forward varied inversely with sheet thickness and punch tip radius.
ii. **U-bending**: Spring-back varied inversely with sheet thickness and proportional to the punch tip radius. In U-bending, no spring-forward appeared.

In 2010, Hama *et al.* [15] studied spring-back on AZ31B magnesium alloy sheet by performing 2D draw bend test by varying temperature and blank holder force. Spring-back varied inversely with the change in blank holder force but the effect of temperature was much dominant. Following results were obtained (i) flow stress varied inversely with temperature. (ii) reverse bending of sidewall occurred at 150ºC and above. (iii) dynamic recrystallization occurred at 200ºC and above.

In **dynamic recrystallization** grain growth and its nucleation occurs during the deformation process itself.

Properties of AZ31B Mg alloy:

- Light-weight
- High specific strength and stiffness
- Recyclable
- High electromagnetic shielding

Applications:

i. Automobiles
ii. Electrical devices
iii. The housing of the computer, cellphones.

In 2010, Chen *et al.* [16] studied the plastic deformation theory to calculate the sheet forming limit. The relation between plastic work criteria and strain path was established. Effect of strain hardening exponent, anwasotropy coefficient and initial thickness was studied on forming limit. Initially, only one strain path was taken i.e. uniaxial tension test. Different material properties, parameters, and necessary limit strain and expression of criteria were calculated. Later, limit strain calculation was done for other strain paths like equi-biaxial and bilinear.

In 2011, Liu et al. [17] proposed a constitutive model based on surface layer model to analyze spring-back after the micro-bending process. The sheet was divided into the surface layer and an inner portion. Flow stresses were calculated for both layers. For experimental validation three-point bending test of copper sheets were performed with thickness ranging from 0.1 to 0.6 mm. FE model was further developed to carry out analyswas in micro-bending. As per results (i) Spring-back varies directly with grain size but inversely with sheet foil thickness. (ii) Spring-back angle varied inversely with the number of grains in the thickness direction.

In 2011, Panich *et al.* [18] investigated the formability of an automotive part made of steel by comparing Forming Limit Diagram data with Forming Limit Stress Diagram data. Firstly, a Limiting Dome Height test was performed to FLD data. Then, FEM simulation of the LDH was done using FLD data. Major and minor strains obtained were used to obtain FLSC data. On comparing FLD and FLSC data the former was found more accurate for complex part shapes.

In 2012, Sulaiman *et al.* [19] carried out spring-back simulation using ABAQUS softwwere. Effect of different materials and sheet thickness on spring-back was studied. It was found that carbon fiber reinforced plastics showed lesser spring-back than the boron steel. Also, the spring-back was found to vary inversely with sheet thickness.

In 2015, Aurelian *et al.* [20] carried out simulations of two types of magnesium alloy strips of 1 mm thickness to study spring-back behavior in U bending with force varying from 15 to 35 KN. The analysis was performed over DYNAFORM 5.6 at constant room temperature. Spring-back was found to vary inversely with blank holder force.

2.1 Gaps In Literature

i. Influence of temperature and friction in cold forming Advanced High Strength Stee(AHSS) has not been studied.

ii. Stress and deformation analyswas of galvanized-annealed steel JAC390W using AUTOFORM were not reported.

2.2 Objective

In the present work, surface analysis of a front seat panel was carried out on AUTOFORM R7. Factors being analyzed include wrinkle, thinning, spring-back and strain. The purpose of this research was:

- To study the effect of change in sheet thickness and blank holder force on wrinkle and spring-back during forming.
- To study formability of the component using stress-strain plots and Forming Limit Diagram.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Surface analysis of an automobile part has been carried out. The part was a front seat panel of a car made up of JAC390W galvanized-annealed steel. Analysis has been carried out on AUTOFORM-R7. Separate studies have been done focused over forming defects and stress-strain distribution respectively.

3.2 Simulation of part:

3.2.1 Validation through meshing

The part in its final operation (i.e. flange) was being analyzed here for all three meshings available in AUTOFORM R7 (i.e. Ce, Ce+ and FV) after keeping inputs at nominal values i.e. sheet thickness = 1.6 mm and blank holder force = 83 ton. All the three required outputs obtained were analyzed for all the three random points taken as given in fig 3.1 and fig 3.2.

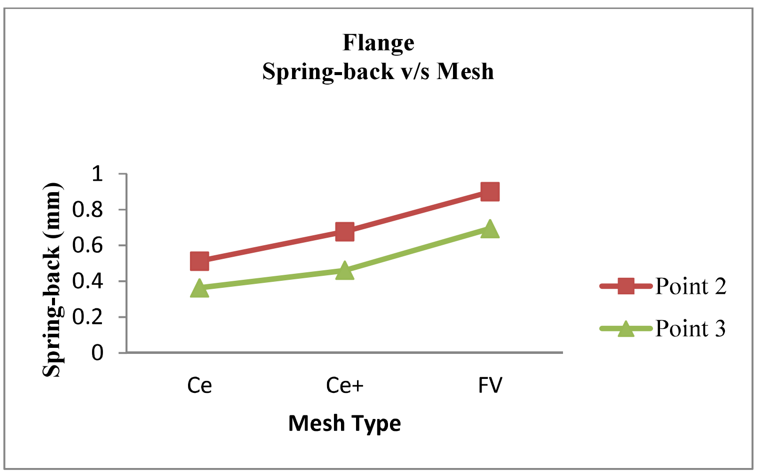

Fig 3.1 Spring-back v/s Mesh for flange

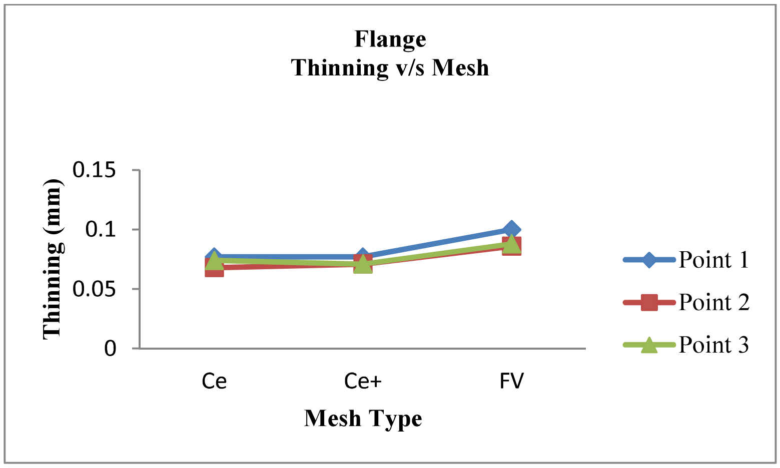

Fig 3.2 Thinning v/s Mesh for flange

Table 1 Comparison Of Mesh

S no.	Properties	Final Validation (FV)	Advanced Concept Evaluation (Ce+)	Concept Evaluation (Ce)
1.	Max Element Angle	22.5º	30º	30º
2.	Max Refinement Level	6	7	7
3.	Initial Subdivision Level	Half	Equal to Master	Equal to Master
4.	Initial Max Element Size	20 mm	40 mm	40 mm
5.	Number of Initial Elements	1548	387	387
6.	Element Type	EPS-11	EPS-5	BEM-5

- **Max Element Angle:** This was the maximum angle permissible between adjacent faces of two elements. It should be kept minimum to ensure good mesh quality.
- **Max Refinement level:** Thwas factor varies proportionally to mesh quality as the number of elements increases with the level.
- **Initial Subdivision Level:** This feature divides the mesh further so that a particular section could be worked and any changes were reflected in every section thereby minimizing work.
- **Initial Max Element Size:** Thwas should be kept minimum for better meshing thereby giving more precwase analysis.
- **The number of Initial Elements:** Number of initial elements would reduce the effort of the user thereby reducing mesh time.
- **Element Type:** All three elements used in this software were triangular in shape.
  - **EPS-11:** Elasto-Plastic shell element with 11 layers.
  - **EPS-5:** Elasto -Plastic shell element with 5 layers.

➢ **BEM-5:** Bending enhanced membrane with 5 layers.

Features of all the three meshing were compwered and meshing through Final Validation was found the best due to the following reasons:

i. **Maximum refinement level:** The smallest region can be filled with mesh.
ii. **Least element size:** Smallest region can be filled with mesh.
iii. **Max no. of initial elements:** Meshing time was reduced.

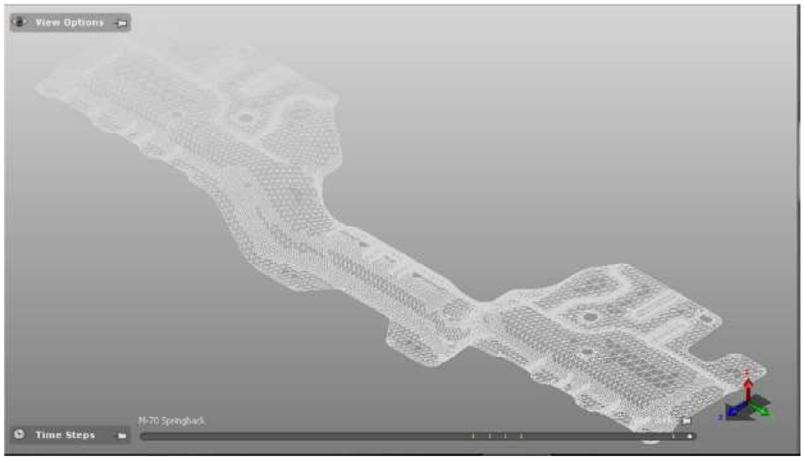

Fig 3.3 Mesh view of a part model

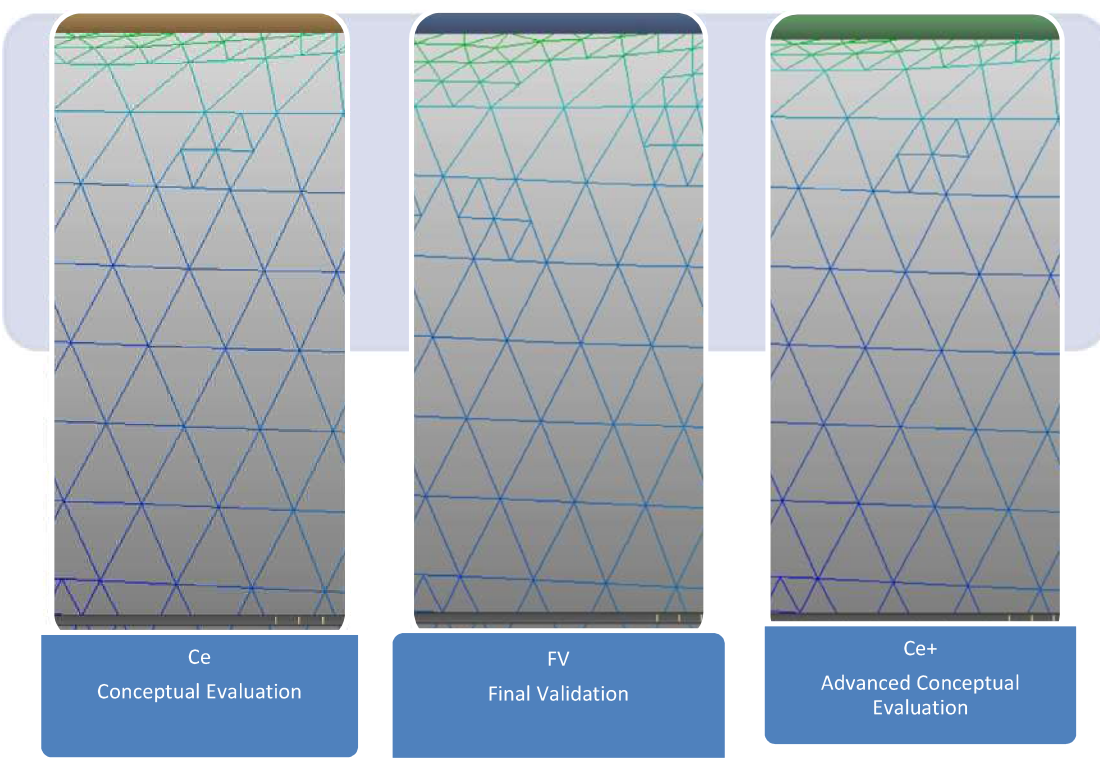

Fig 3.4 Comparison of three types of Mesh

3.2.2 Steps of Simulation

To produce a pair of die and punch die-face was required which was formed with the help of part given by the customer. The designer takes the part and accordingly designs the die-face. Then taking die-face as the surface and taking certain allowance die and punch were designed.

i. **Part**

- **Import:** In thwas step all the required part geometries, tool geometries and curves were imported
  - ➢ **Part Geometries:** The required part was imported on this page.
  - ➢ **Tool and additional Geometries:** Draw and flange die-face was imported.
  - ➢ **Curves and Points:** Trim-line and Blank outline was imported as given in fig 3.5.

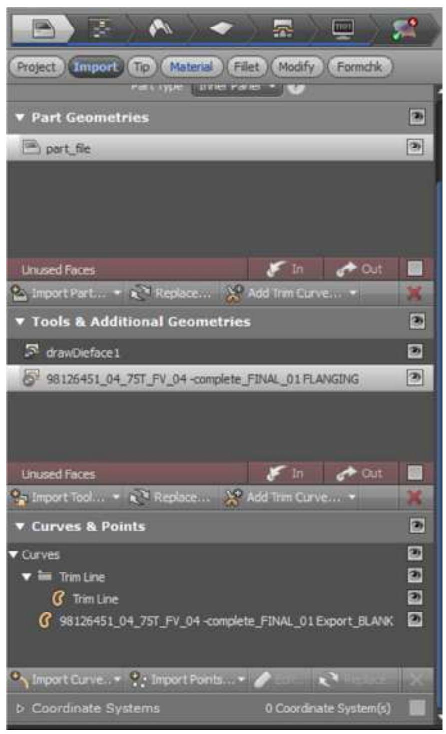

Fig 3.5 Import window

- **Material:** Most of the materials were available in the directory of AUTOFORM but few have to be formed manually depending on the use. The present material JAC-390W was annealed steel. This was formed using the softwwere feature where factors like yield strength $\boldsymbol{\sigma_0}$, tensile strength $\boldsymbol{R_m}$, work hardening coefficient *n*, Lankford coefficient *r*, strength coefficient *K* were required to form the material as given in fig 3.6.

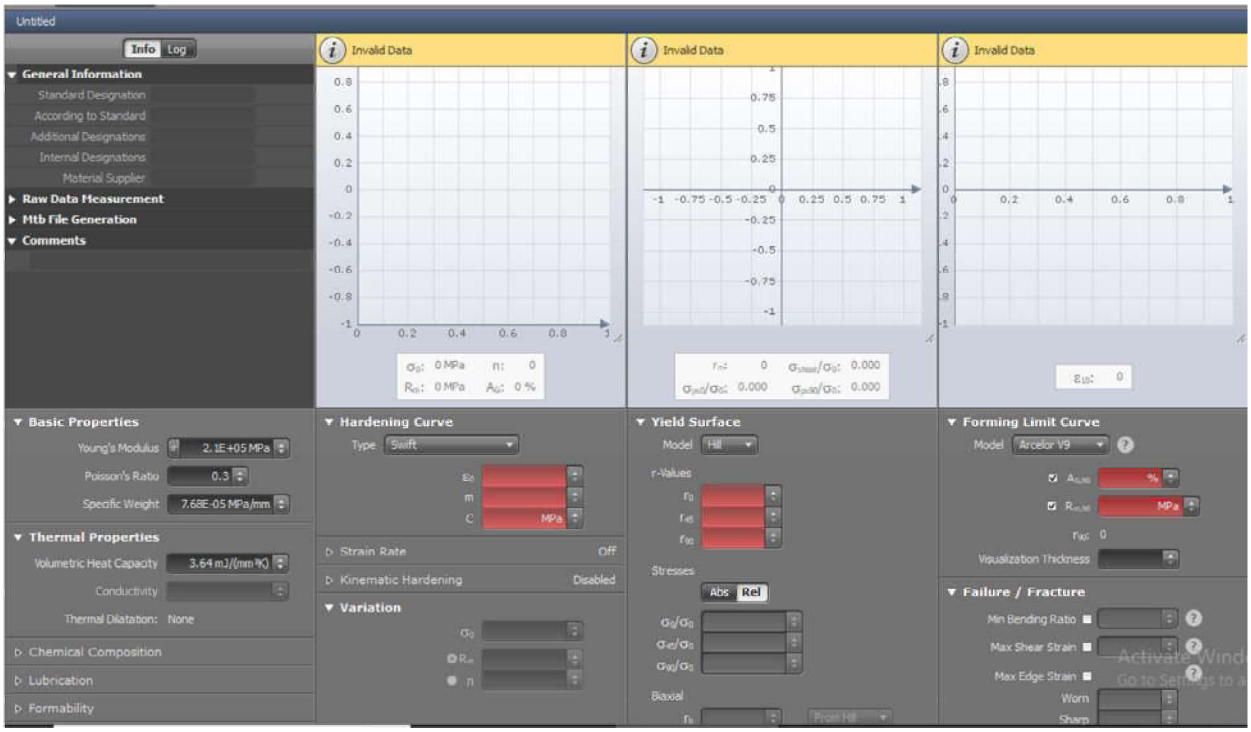

Fig 3.6 Window to create material

Now, this material can be added in this step and thickness can be defined as given in fig 3.7.

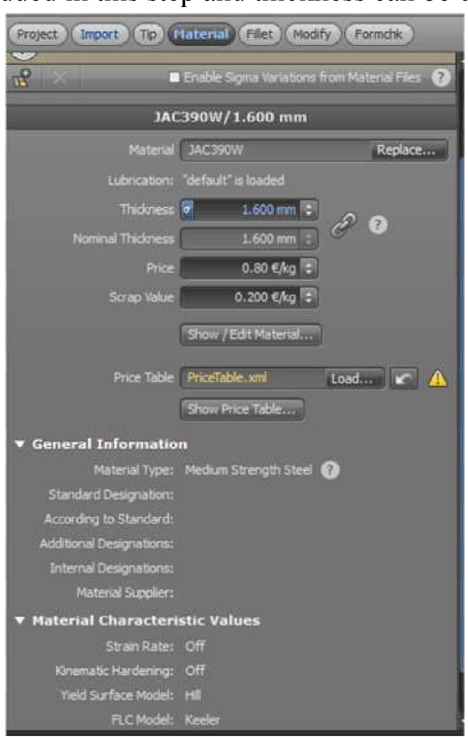

Fig 3.7 Sheet thickness was defined

ii. **Plan**

- **Production:** Each operation was allocated a press. Spring-back was also defined under measuring equipment after every operation as given in fig 3.8.

Abbreviations

D-20: Draw

M-30: Spring-back followed by Draw

T-40: Trim

M-50: Spring-back followed by Trim

F-60: Flange/Restrike

M-70: Spring-back followed by Flange

Fig 3.8 Operations assigned to Press line

- Plan:
  In this step features involved in each operation was defined.
  Abbreviations

 → **Draw**

 → **Trim**

 → **Pierce**

 → **Flange**

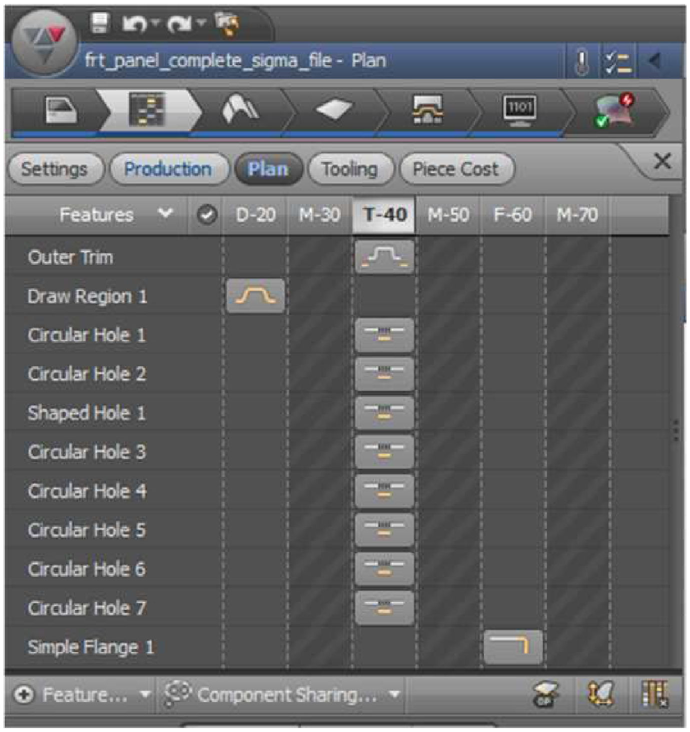

Fig 3.9 Assignment of a sequence of operations

iii. Die-face

An imported flange was used to define the region where flanging occurs after trimming as given in fig 3.10.

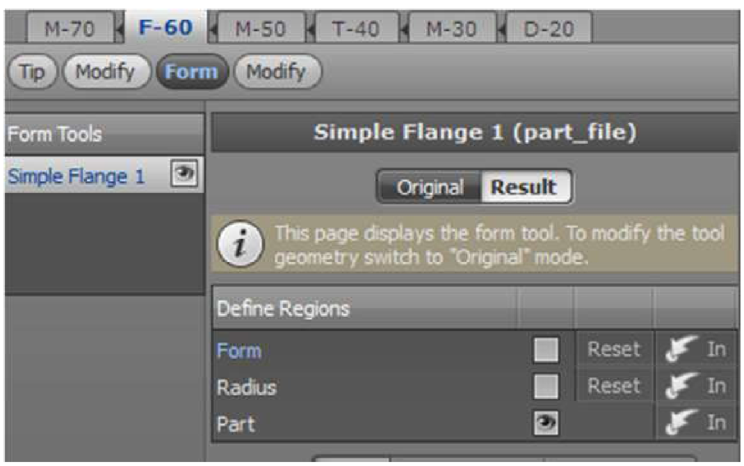

Fig 3.10 Die-face

iv. Blank

Outlining of the blank was done so as to cut it short enough for part manufacture. This was done click on the outline option and copying the blank outline from the imported directory. It also positions the blank with respect to the binder. Blank-size taken for front seat panel was 890×331×1.6 where the unit of length in mm as given in fig 3.11.

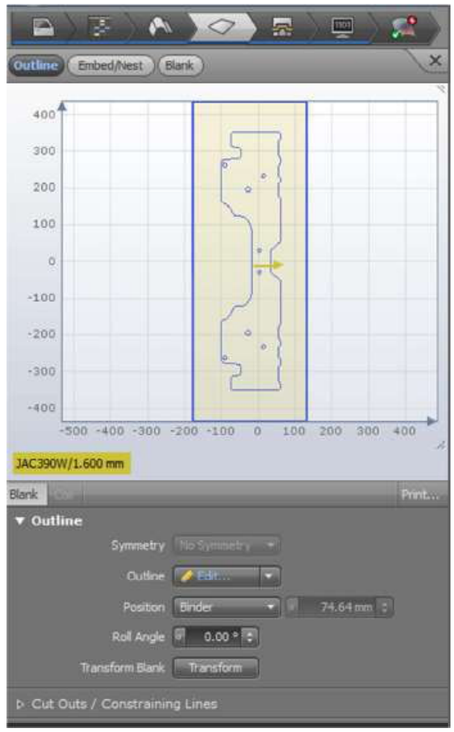

Fig 3.11 Assignment of blank

v. Process

- **PL (Production Line):** Here the coefficient of friction between the blank and the tool was defined viz. μ=0.15 as given in fig 3.12

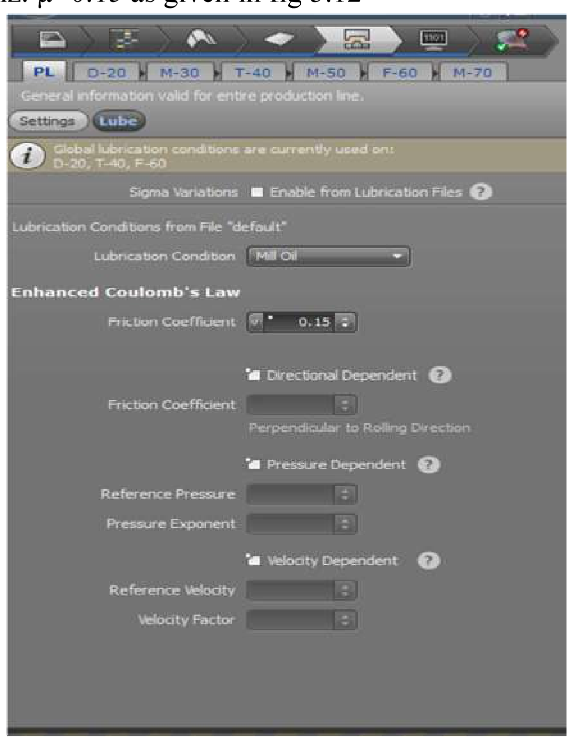

Fig 3.12 Define coefficient of friction.

- **Draw:**
  - **OP-Setup:** Go to scaling and check the box for all tools of this operation. Scaling value was automatically defined.
  - **Tools:** In this step die, punch and binder was defined by selecting a specific region from the imported draw die-face. Tool contact was on upper side of the blank for the die and lower for binder and punch. Binder support type was spring controlled and displacing tool was selected as a die.
    - ❖ In spring controlled type of support, force rises gradually with the displacement of the tool. Tool lifts up as soon as the sheet reaction force exceeds the preload force of the support.
    - ❖ Cushion stroke was the displacement of the cushion pin before coming in contact with the binder.
    - ❖ Tool Stiffness defines the distribution of forces. Lower the value even was the distribution as given in fig 3.13 and fig 3.14.

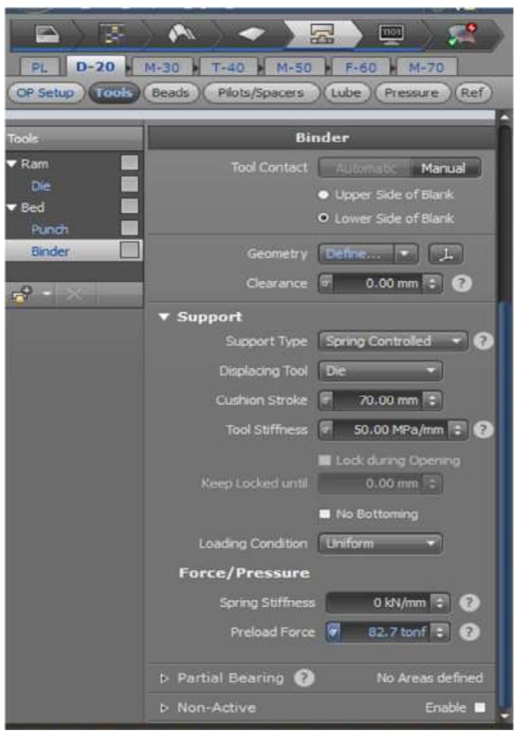

Figure 3.13 Assignment of Draw Tools

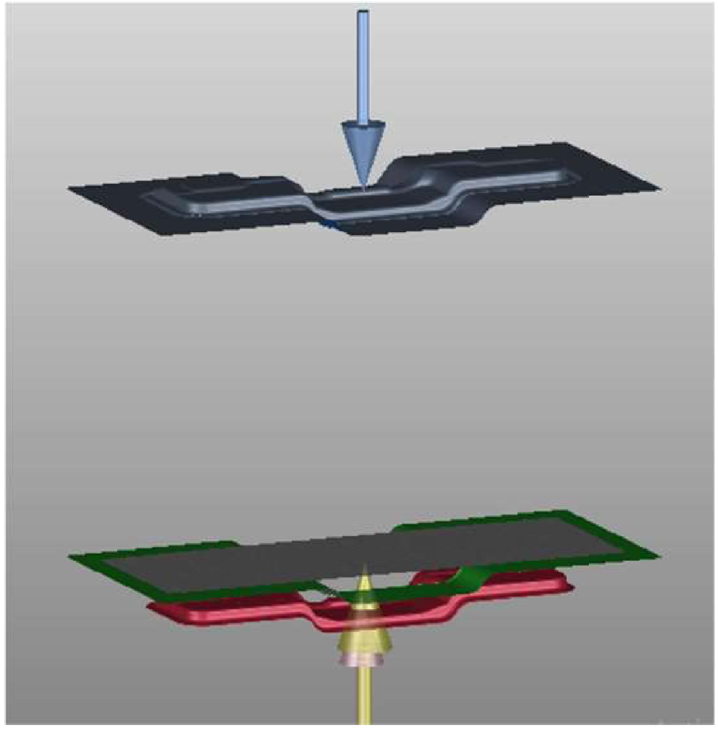

Figure 3.14 View of Die, Punch, and Binder

- **Trim**

Tools: Cutting tools were defined in ram. Box for projected cutting was checked since it projected the 3d cut before actual cutting.

- ➢ The first cutting tool runs in the outer direction because its cut curve was defined as trim-line copied from the imported directory.
- ➢ Rest of the cutting tools were circular holes so they run in the inner direction as given in fig 3.15.

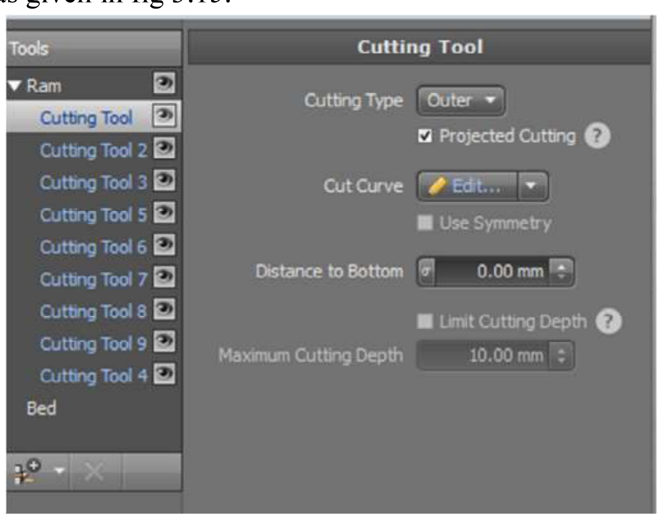

Figure 3.15 Assignment of Trim cutting tools

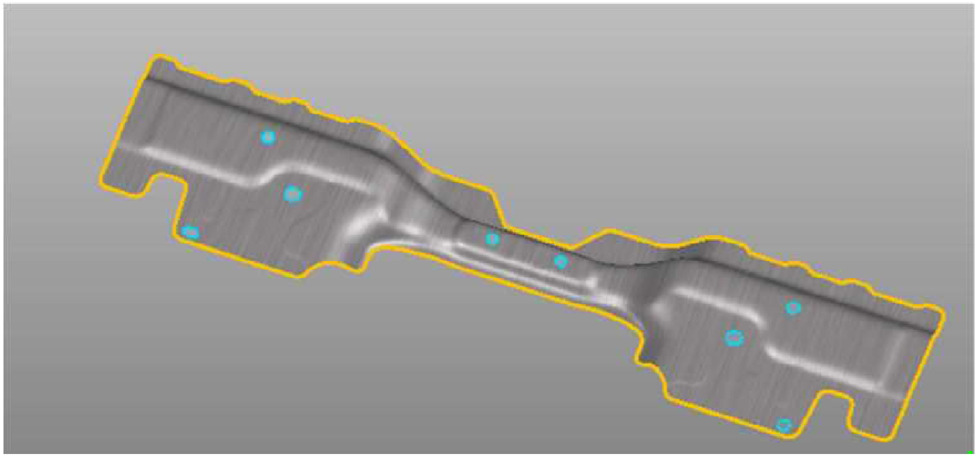

Figure 3.16 Assignment of Trimline

- **Flange/Restrike**

  Tools: Pad and steel tool contact on the upper side of the blank as they were attached to ram. The post was the displaced tool and pad was spring controlled. Each tool was defined in the same manner as in trim and draw.

  ➢ Cushion stroke here was the distance moved by the cushion pins to make contact with the pad as given in fig 3.17 and 3.18.

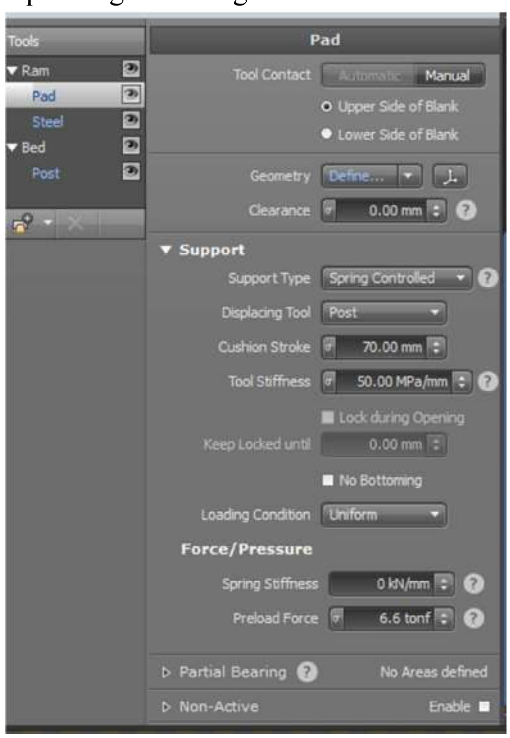

Figure 3.17 Assignment of Punch, Pad and Steel

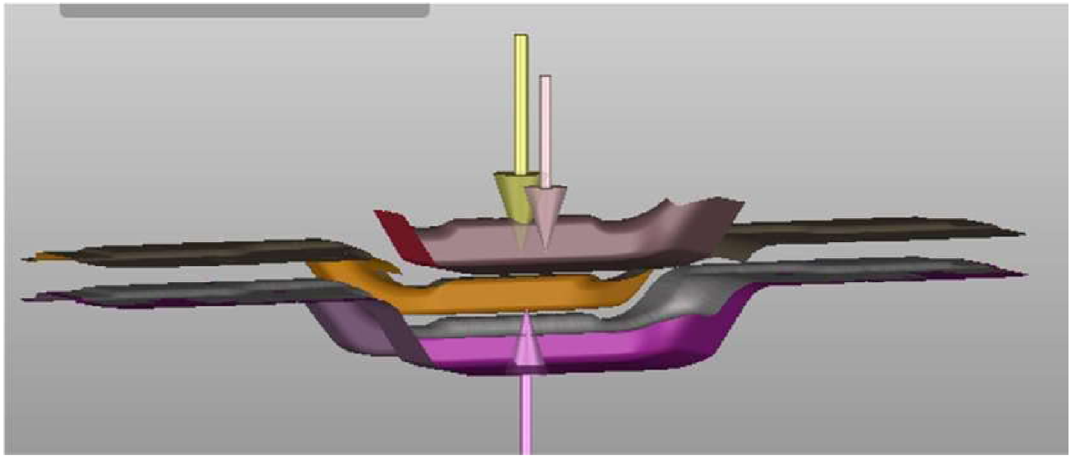

Figure 3.18 View of Post, Pad and Steel

vi. **Simulation**

- **Control**
  - ➢ **Mains:** Meshing type FV (Final Validation) was selected as given in fig 3.19.

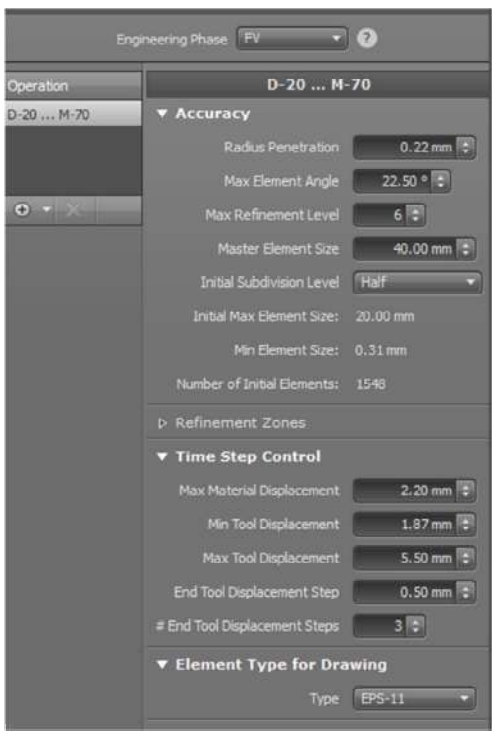

Fig 3.19 Assignment of Mesh

  - ➢ **Result:** All types of results were available in this section. Required results can be checked.
- **Start:** Simulation had been initiated here.

- **Log:** In this tab, the back end process of the software can be viewed.

vii. **Evaluation:** After the simulation had finished and the solution was obtained all the figures and FLD (Forming Limit Diagram) plots can be viewed here.

3.3 Analysis of forming defects

Three forming defects had been studied as follows:

- Spring-back.
- Wrinkle.
- Thinning.

These three parameters were analyzed over two input parameters i.e. Sheet thickness and Blank holder force. One of the input parameters was kept constant and the effect of another was studied over input parameters. Output parameters were varied in the following manner:

- **Sheet thickness (mm): 1.5, 1.6 and 1.7**
- **Blank holder force (ton): 75, 79, 83 and 87**

Three points were taken on the part and were kept constant throughout. For every point, resultant outputs were obtained and plotted against variable input.

Tabular form for variation of output against thickness at constant force has been given as an example:

Table 2 Sequence of experiments at a constant force

S no.	Sheet Thickness (mm)	Blank Holder Force (ton)
1	1.5	75
2	1.6	75
3	1.7	75
4	1.5	79
5	1.6	79
6	1.7	79
7	1.5	83
8	1.6	83
9	1.7	83
10	1.5	87
11	1.6	87
12	1.7	87

Table 3 Sequence of experiments at a constant thickness

S no.	Sheet Thickness (mm)	Blank Holder Force (ton)
1	1.5	75
2	1.5	79
3	1.5	83
4	1.5	87
5	1.6	75
6	1.6	79
7	1.6	83
8	1.6	87
9	1.7	75
10	1.7	79
11	1.7	83
12	1.7	87

After obtaining values they were plotted into graphs. This provides us with a series of outputs that could be used for making parts in future by taking necessary allowances that will lead to minimized defects.

Permissible Allowance Limit:

Table 4 Permissible Allowance

Input parameter	Min	Max
Blank Holder Force	-10 %	+30 %
Sheet Thickness	-10%	+10%

Output Parameter	Min	Max
Wrinkle	-	0%
Thinning	-	+20%
Spring-back	-0.5 mm	+0.5 mm

3.4 Analysis of stress and strains:

A section of a part was cut that showed significant stress (determined by color representation in contour plot) and several points were taken along the edge. Values of stress and strains (both major and minor) were taken over these points. Major stress v/s

Major strain and Minor stress v/s Minor strain were plotted to obtain a curve as given in fig 3.20.

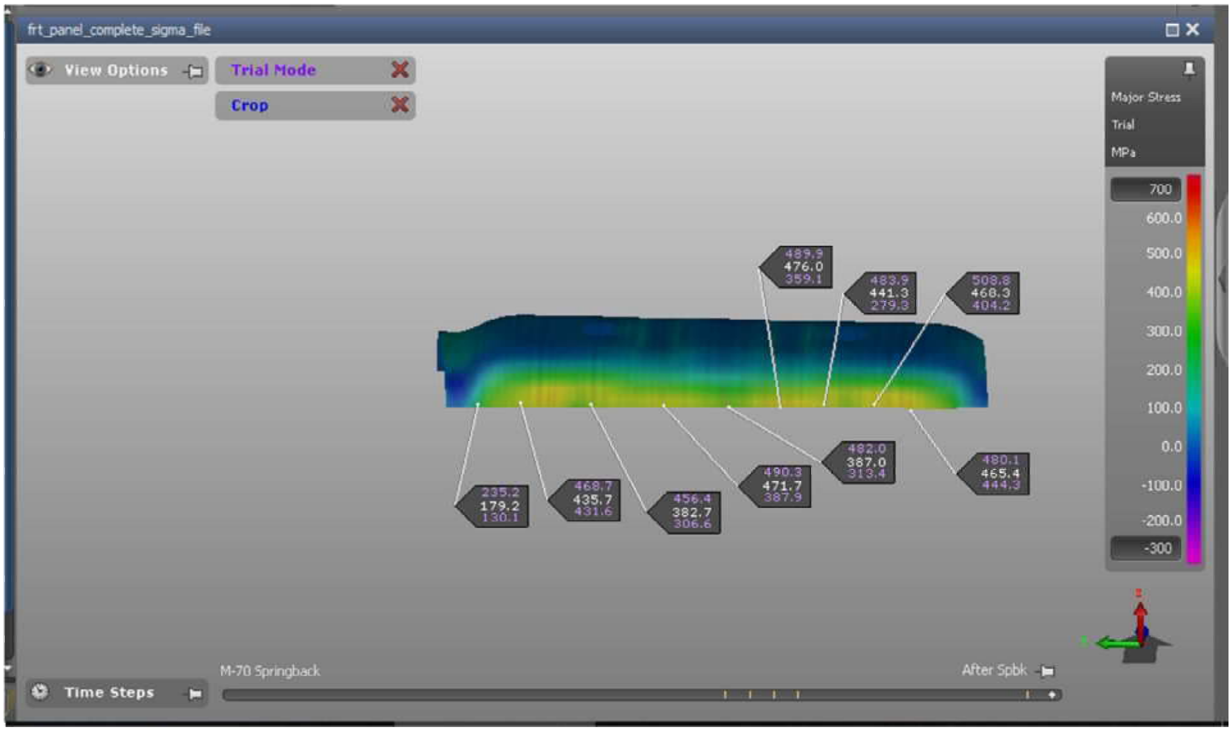

Fig 3.20 Stresses at different points of a section

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Effect of thickness and force on deformation causing factors:

4.1.1 Spring-back v/s Force at constant Thickness

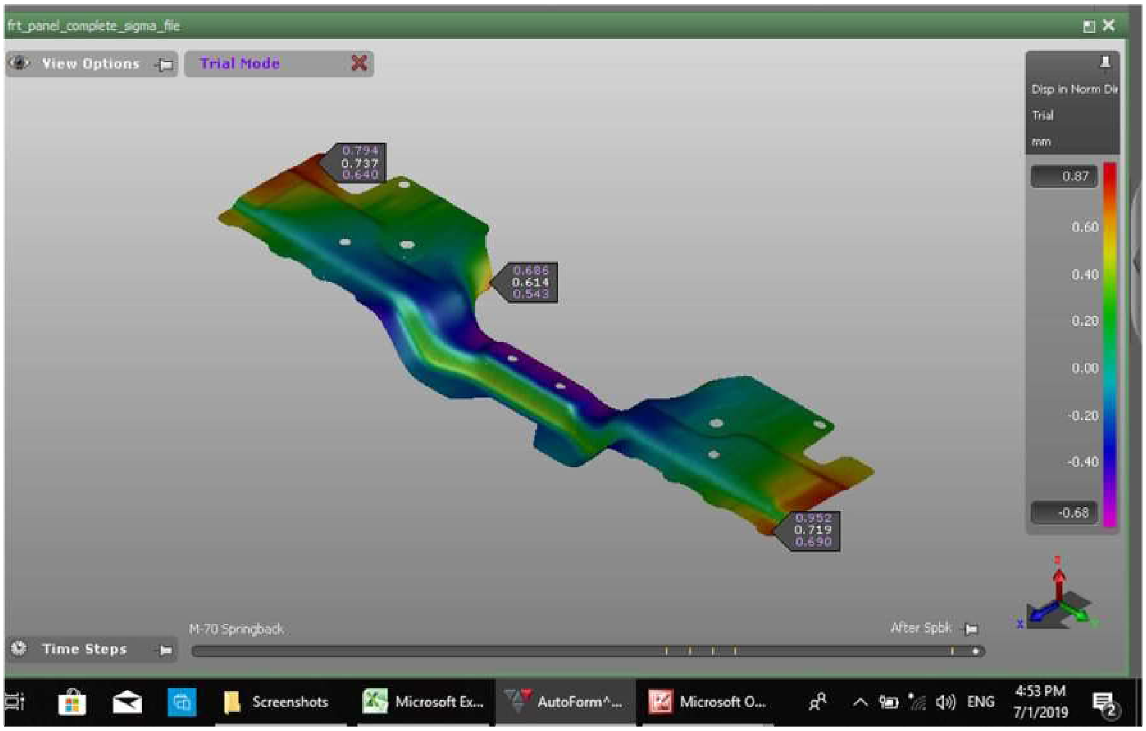

Fig 4.1 Spring-back at three points of a section

A decrease in spring-back was found in Draw region. This was due to the two factors:

i. In Draw, the material was deformed under force which led to elastic recovery of material on the release of that force. Graphical representation was almost flat for trim and flange operations.

ii. Higher force means more initial induced stress hence, more stress relaxation. Therefore, residual stress decreases and so the spring-back.
In trim operation can be justified from the fact that material was removed from the edges of the part which doesn't leave much tendency for spring-back.

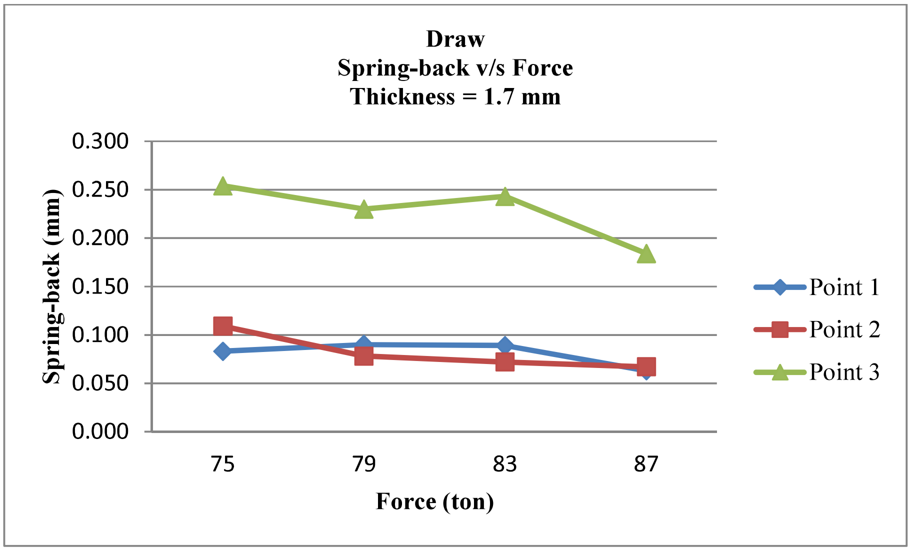

Fig 4.2 Spring-back in Draw at constant thickness=1.7mm

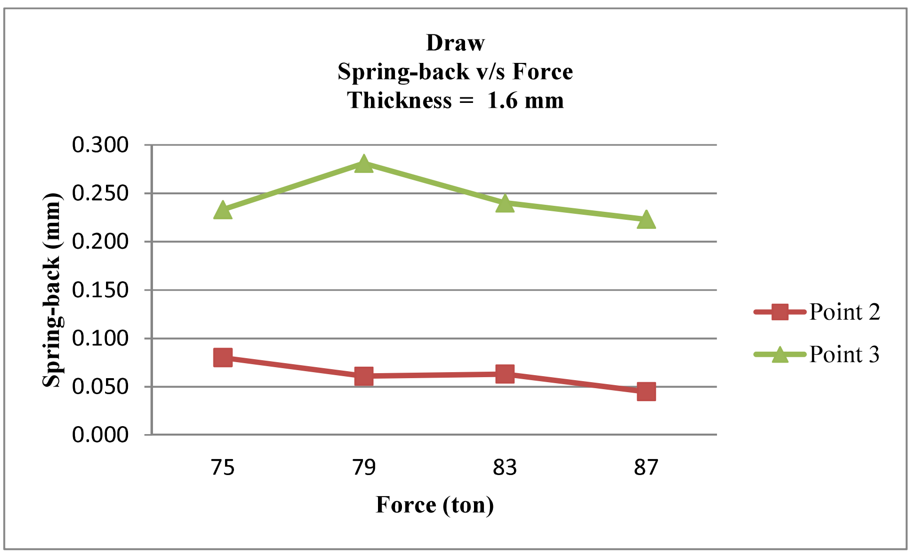

Fig 4.3 Spring-back in Draw at constant thickness=1.6 mm

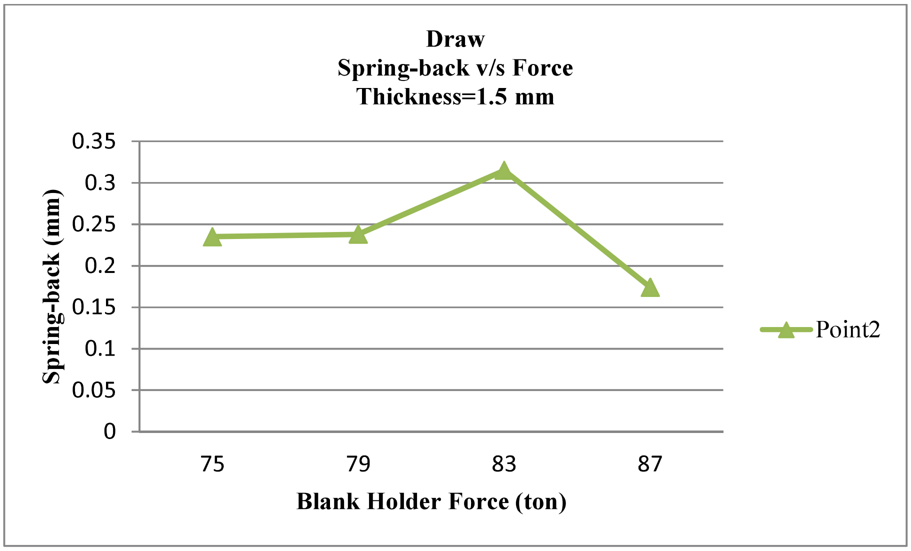

Fig 4.4 Spring-back in Draw at constant thickness=1.5 mm

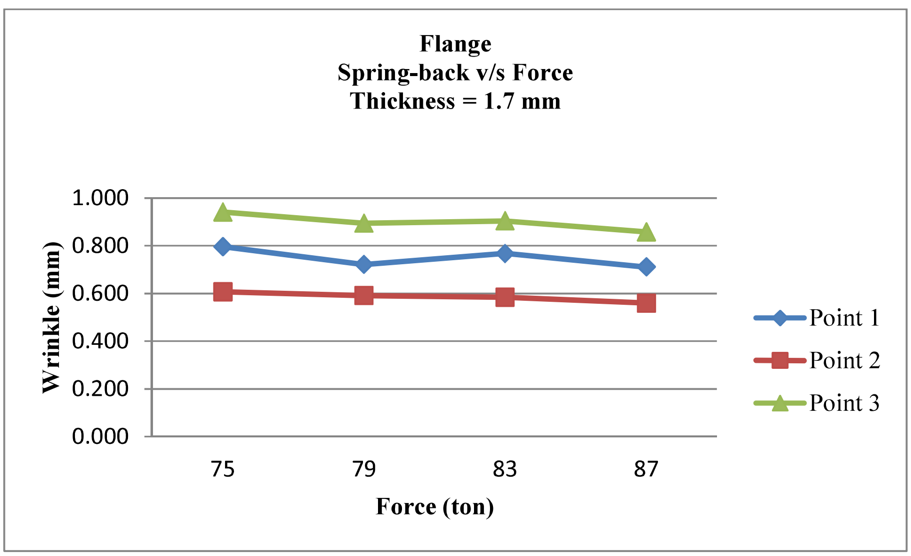

Fig 4.5 Spring-back in Flange at constant thickness=1.7 mm

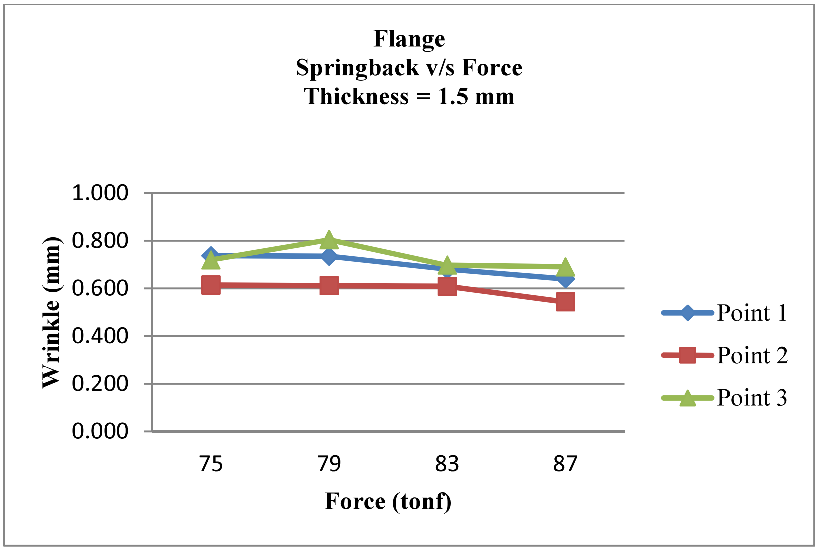

Fig 4.6 Spring-back in Flange at constant thickness=1.5 mm

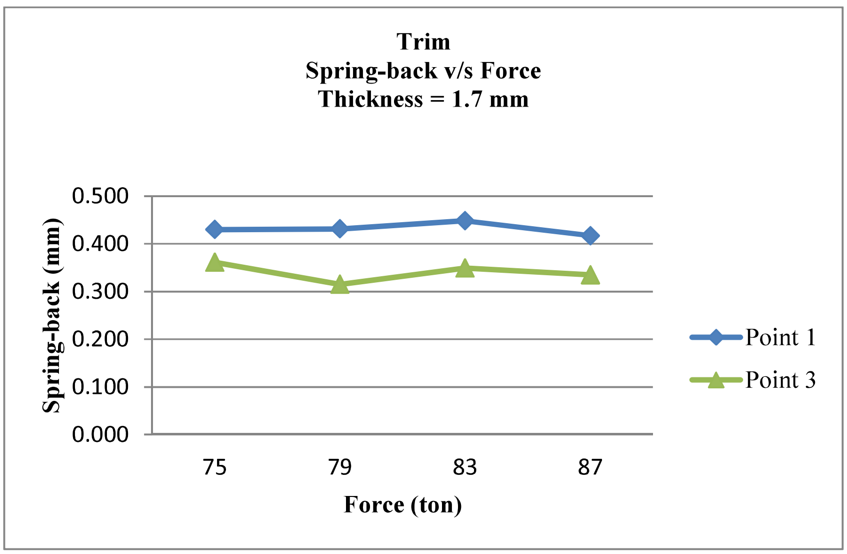

Fig 4.7 Spring-back in Trim at constant thickness=1.7 mm

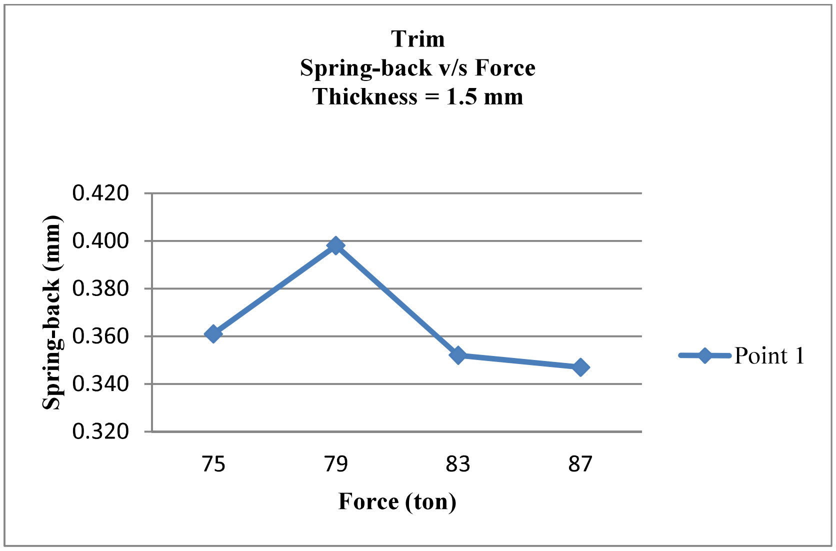

Fig 4.8 Spring-back in Trim at constant thickness=1.5 mm

4.1.2 Spring-back v/s Thickness at constant Force.

Significant decrease in spring-back was obtained in draw operation. Trim and Flange also followed the same variation but, with a certain variation. Spring-back varies inversely with sheet thickness due to two factors:

i. The thicker sheet has a higher rate of stresses and initial induced stress due to which stress relaxation was higher. This led to lesser residual stress and hence reduced spring-back.

ii. Spring-back also depends upon β where,

   $\beta = \boldsymbol{SCR/LCR}$

   $\boldsymbol{SCR}$= Significant Creep Region

   $\boldsymbol{LCR}$= Less Creep Region

   Thicker material has higher values of SCR while LCR does not change much since it represents the inner core region. As a result, β rises and plastic deformation starts. This led to reduced spring-back as given in fig 4.9.

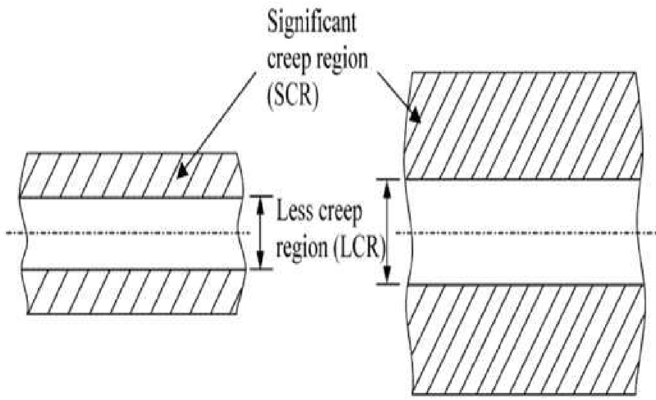

Fig 4.9 Creep region of material [37]

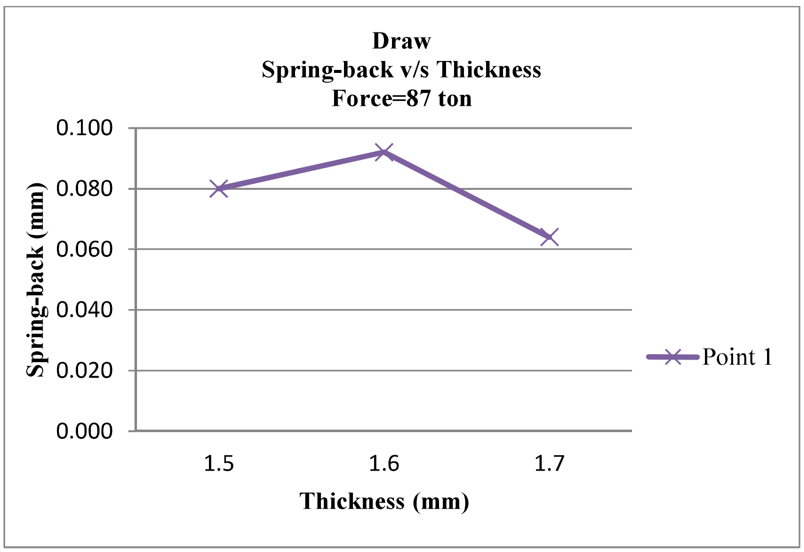

Fig 4.10 Spring-back in Draw at a constant force=87 ton

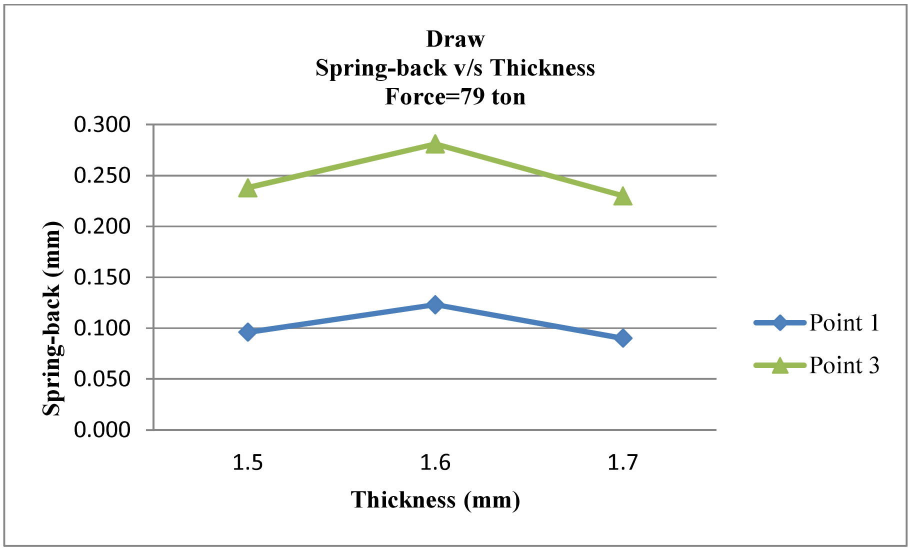

Fig 4.11 Spring-back in Draw at a constant force=79 ton

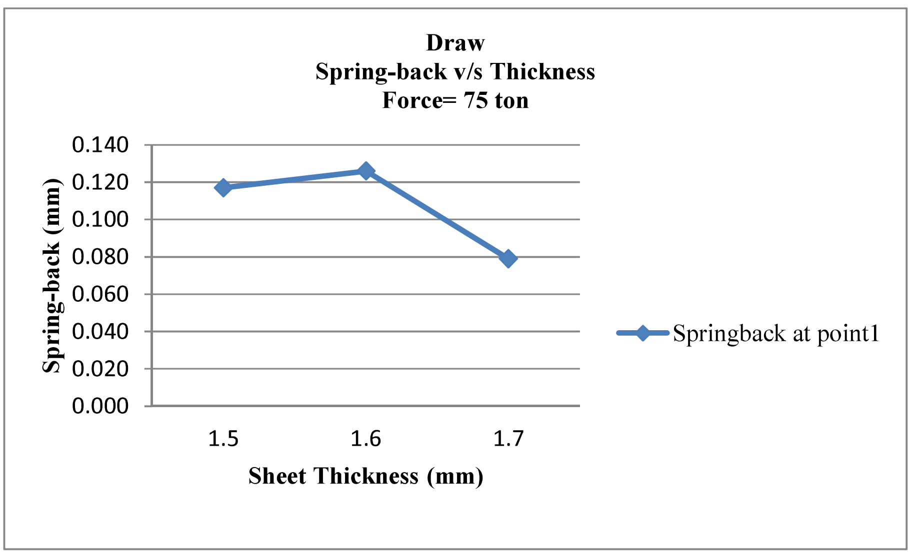

Fig 4.12 Spring-back in Draw at a constant force=75 ton

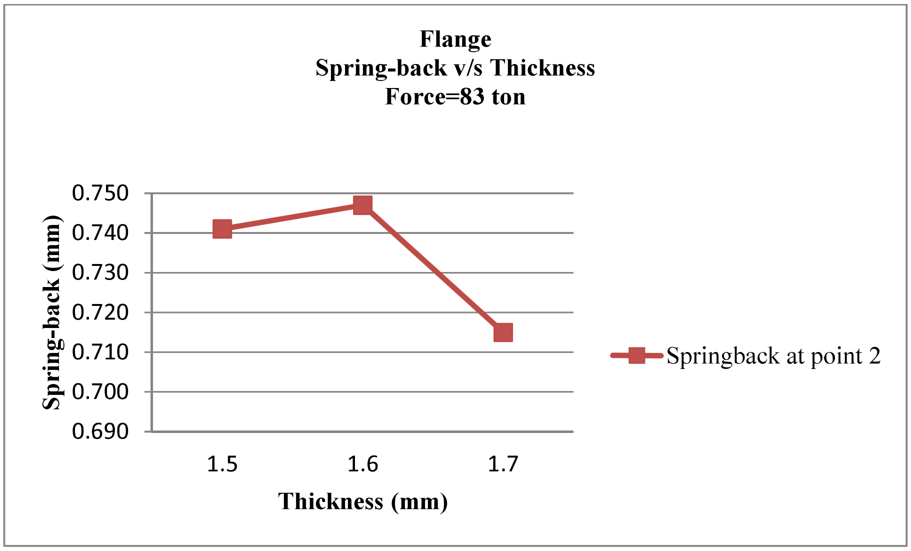

Fig 4.13 Spring-back in Flange at a constant force=83 ton

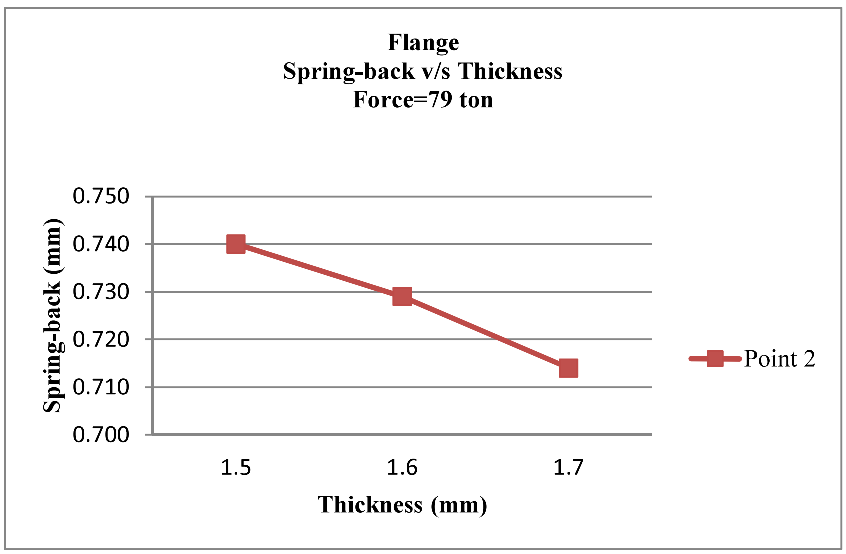

Fig 4.14 Spring-back in Flange at a constant force=79 ton

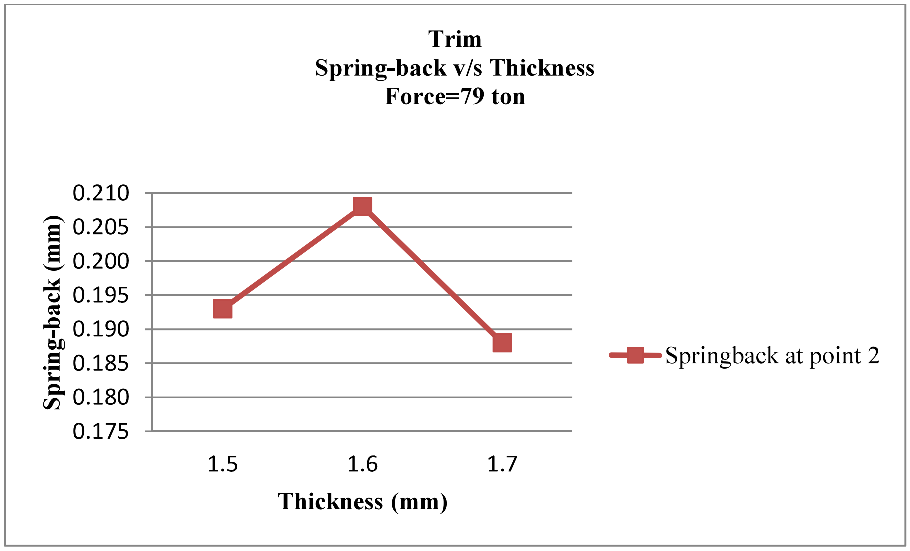

Fig 4.15 Spring-back in Trim at a constant force=79 ton

4.1.3 Thinning v/s Force at constant Thickness

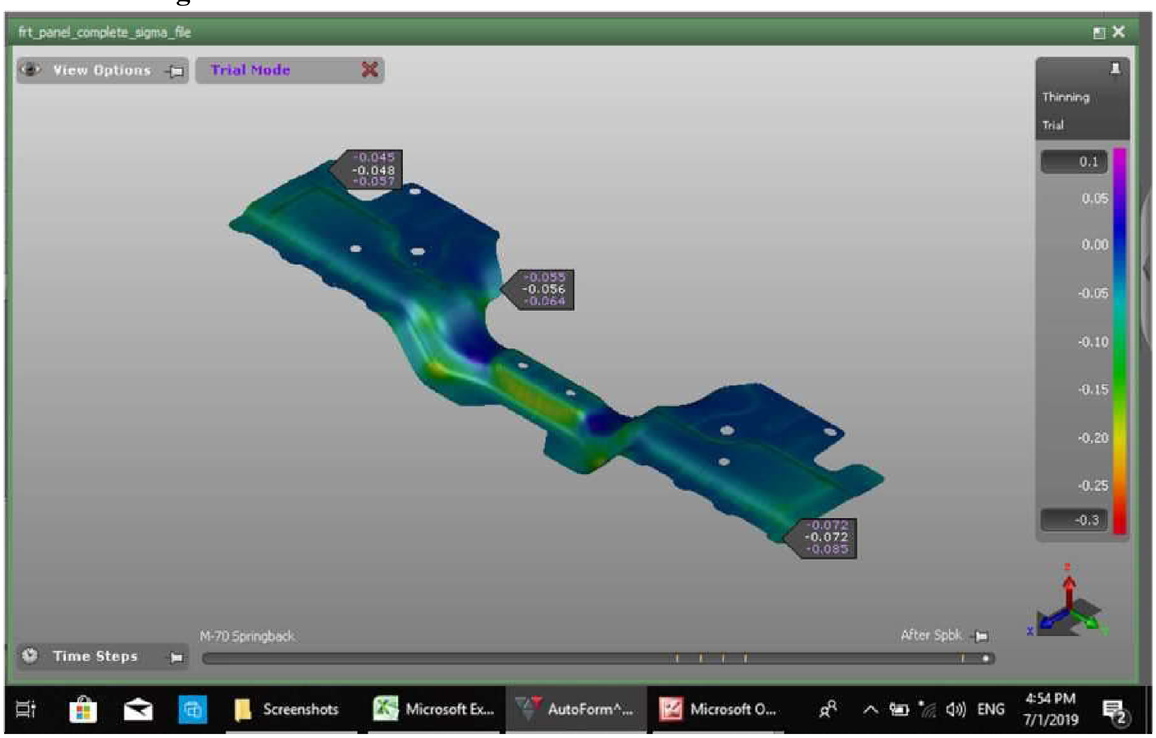

Fig 4.16 Contour plot of Thinning in Flange

In deep drawing process material of the flange undergoes compressive hoop strain and radial tensile strain. Due to this material tends to flow towards the center and tends to thicken. But, due to the curved profile of the punch and die, metal undergoes thinning. Moreover, metal at the bottom of the punch undergoes biaxial tensile stress. Hence the gap between the die and punch wall was subjected to longitudinal and hoop tensile stress. Metal was forced through the gap and due to restricted flow further thinning occurred. This type of thinning is called ironing.

In draw operation thinning varied inversely to force. There were no significant variations found in flange operation as given in fig 4.17.

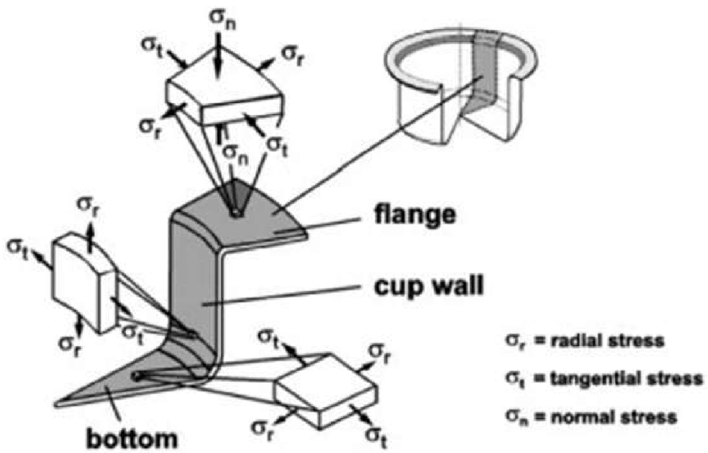

Fig 4.17 Distribution of stresses in Deep drawing [36]

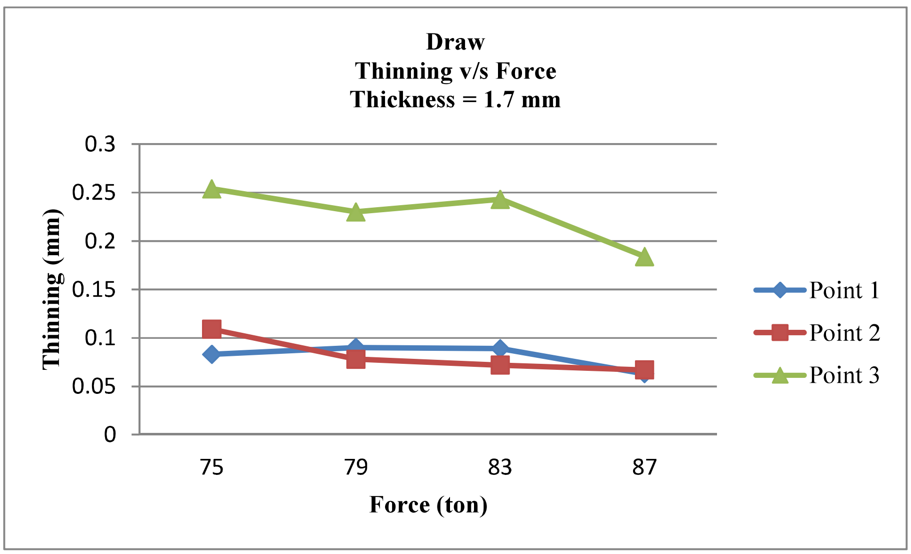

Fig 4.18 Thinning in Draw at constant thickness=1.7 mm

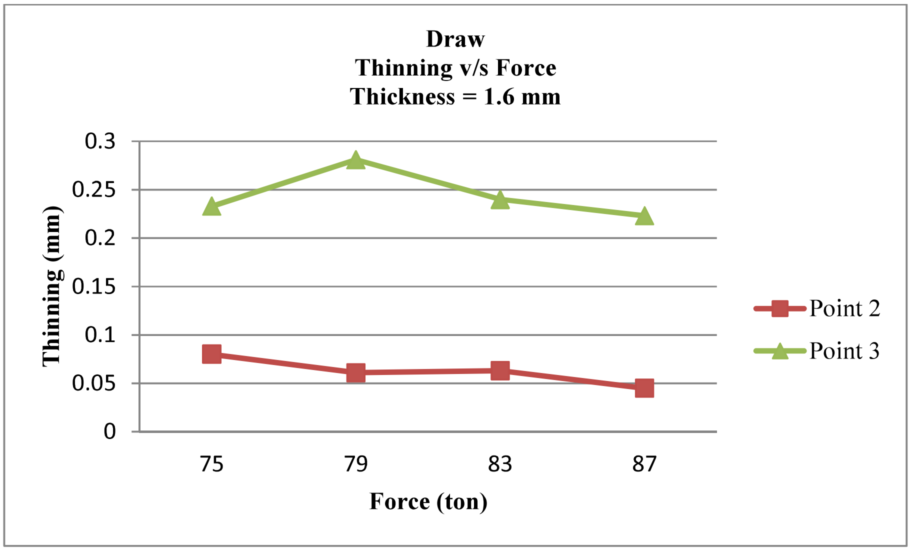

Fig 4.19 Thinning in Draw at constant thickness=1.6 mm

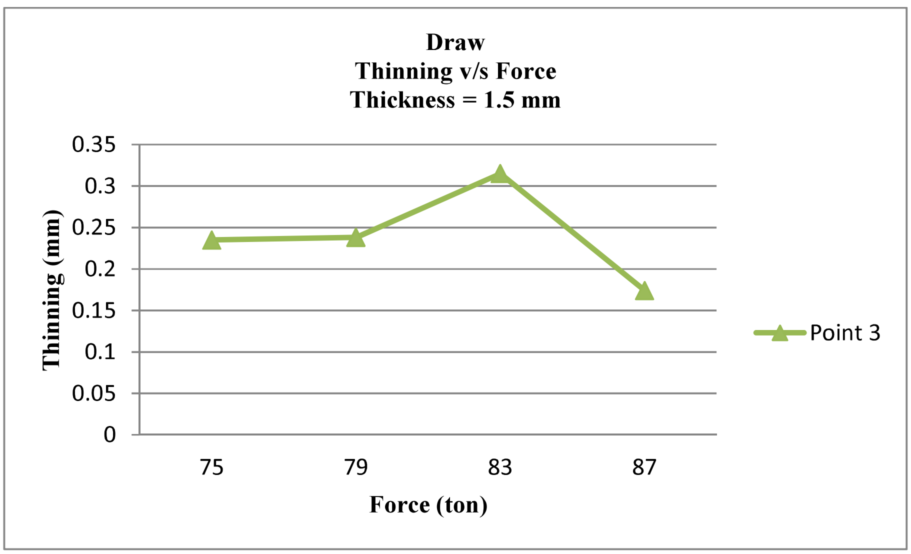

Fig 4.20 Thinning in Draw at constant thickness=1.5 mm

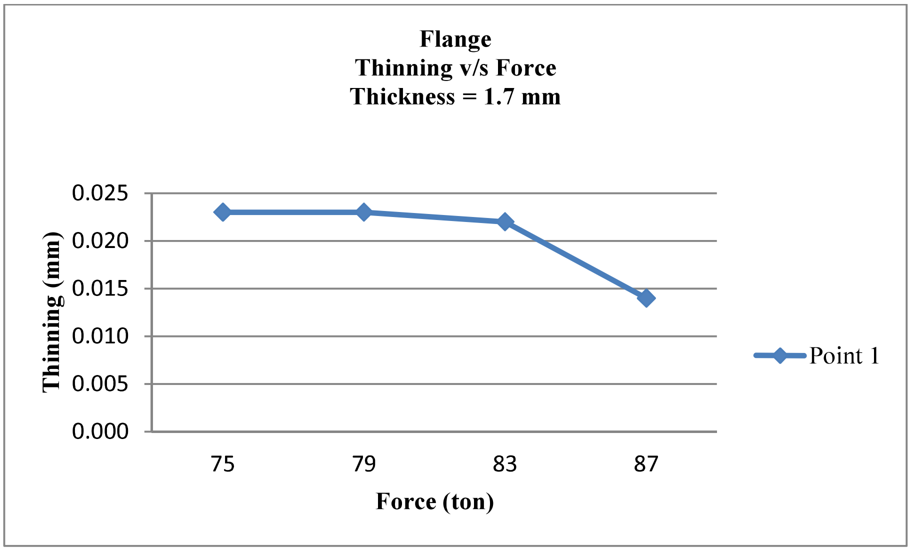

Fig 4.21 Thinning in Flange at constant Thickness=1.7 mm

4.1.4 Thinning v/s thickness at constant Force

In deep drawing process material of the flange undergoes compressive hoop strain and radial tensile strain. Due to this material tends to flow towards the center and tends to thicken. But, due to the curved profile of the punch and die metal undergoes thinning. Moreover, metal at the bottom of the punch undergoes biaxial tensile stress. Hence the gap between the die and punch wall was subjected to longitudinal and hoop tensile stress. Metal was forced through the gap and if it was insufficient for the metal thickening then further thinning occurs. This type of thinning was called ironing.

- Thinning varied proportionally to sheet thickness.

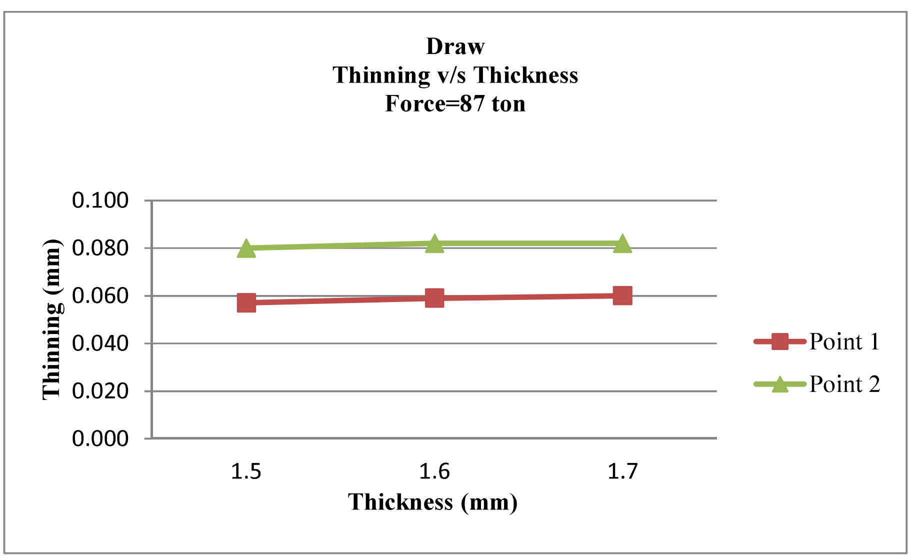

Fig 4.22 Thinning in Draw at a constant force=87 ton

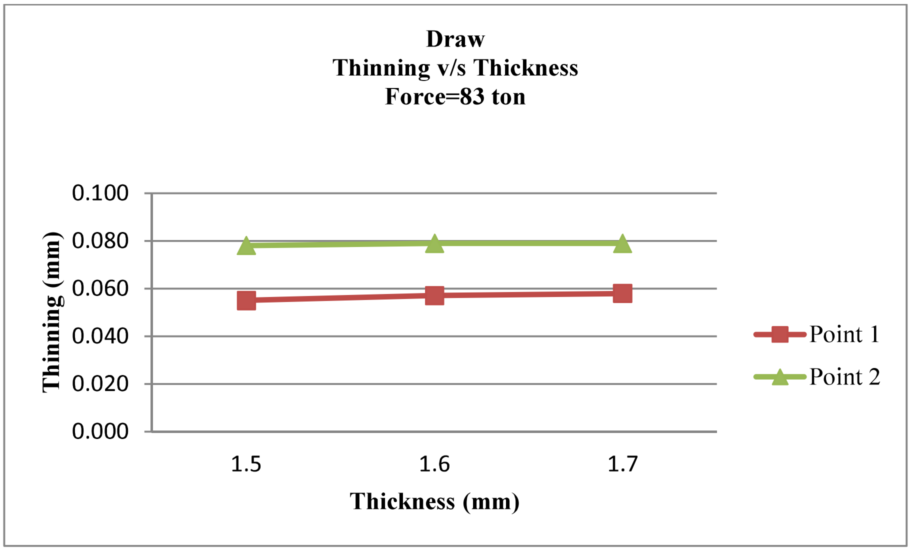

Fig 4.23 Thinning in Draw at constant force=83 ton

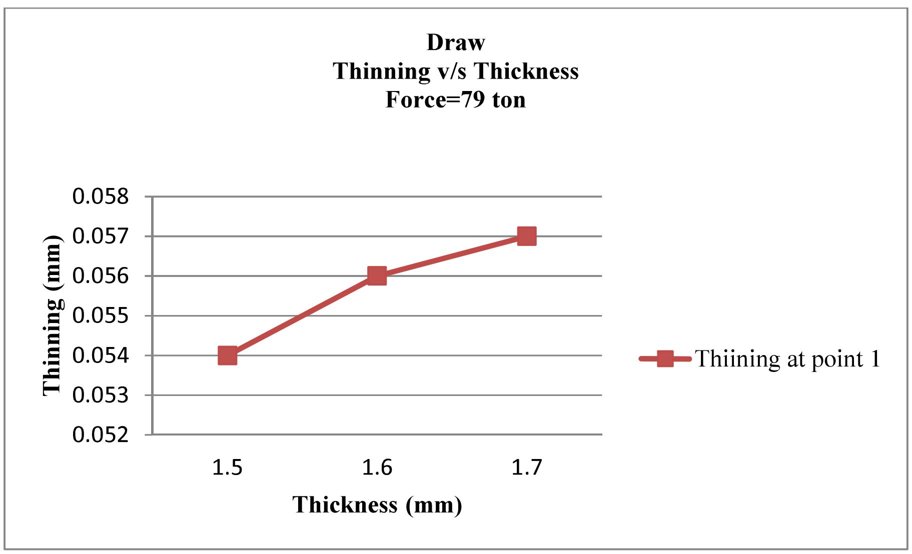

Fig 4.24 Thinning in Draw at a constant force=79 ton

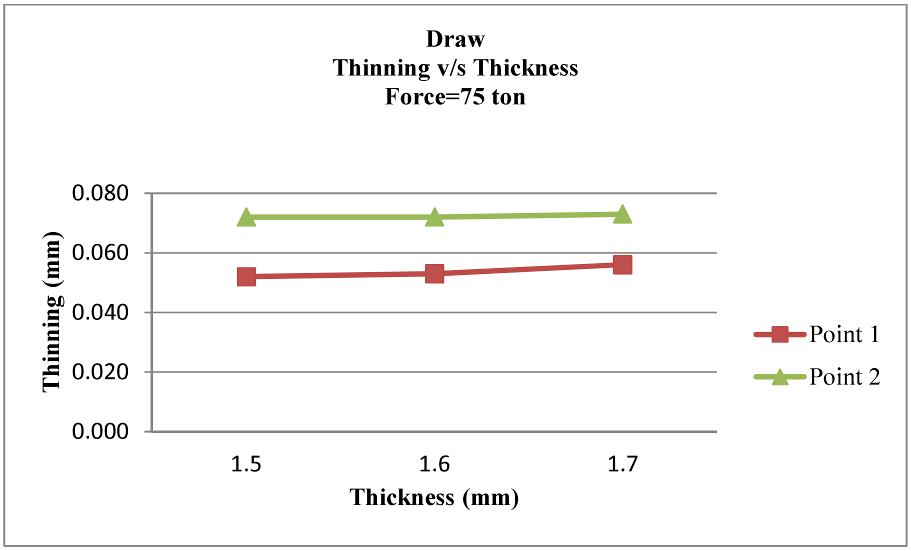

Fig 4.25 Thinning in Draw at a constant force=75 ton

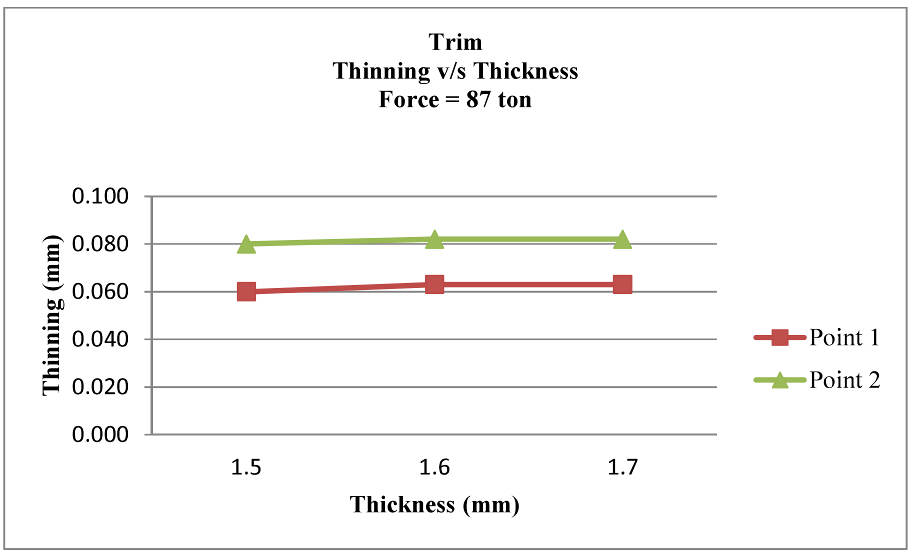

Fig 4.26 Thinning in Trim at a constant force=87 ton

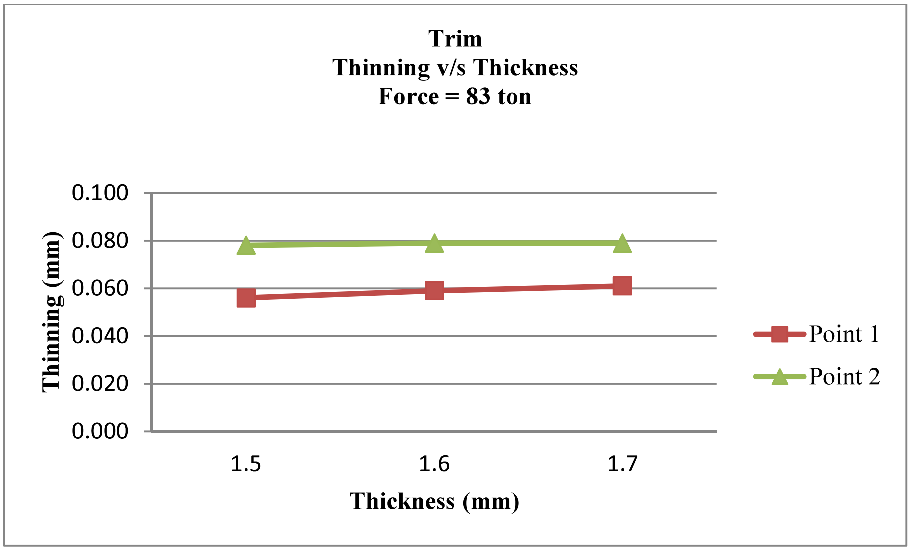

Fig 4.27 Thinning in Trim at a constant force=83 ton

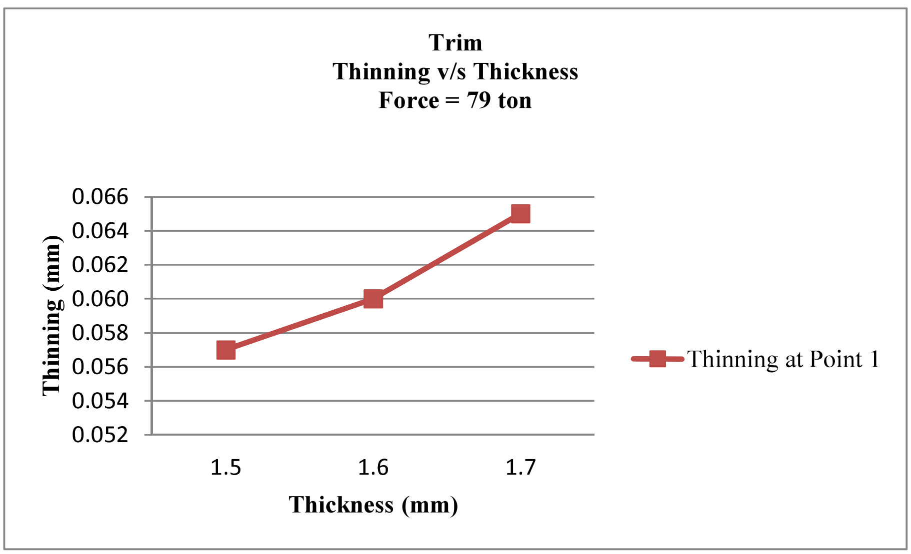

Fig 4.28 Thinning in Trim at a constant force=79 ton

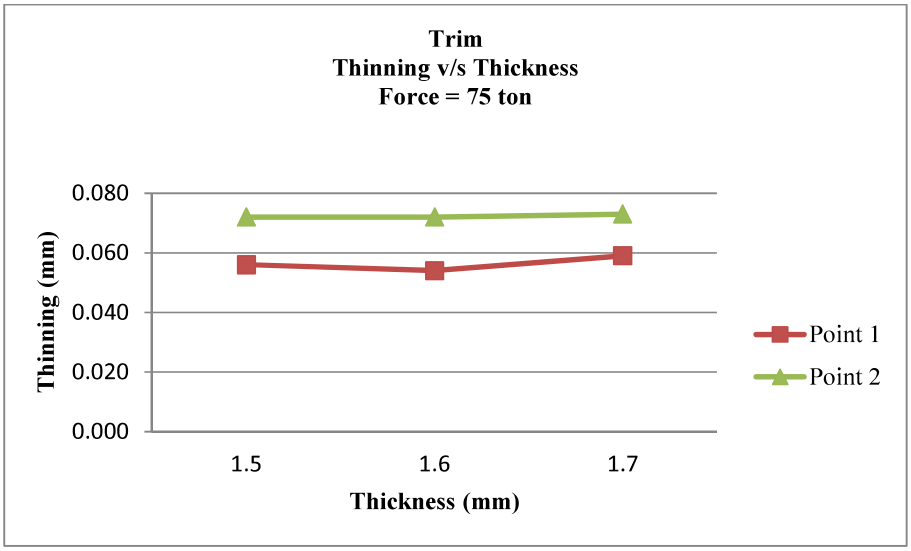

Fig 4.29 Thinning in Trim at a constant force=75 ton

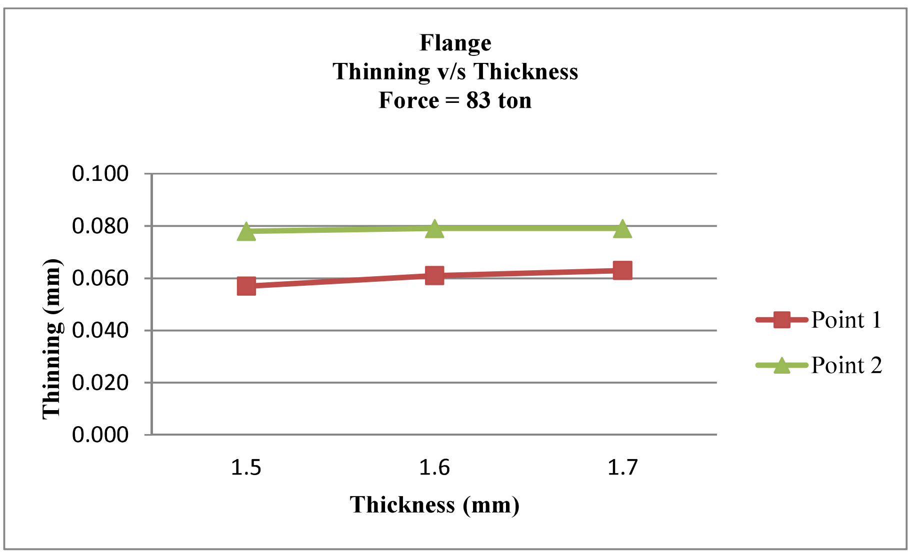

Fig 4.30 Thinning in Flange at constant force=83 ton

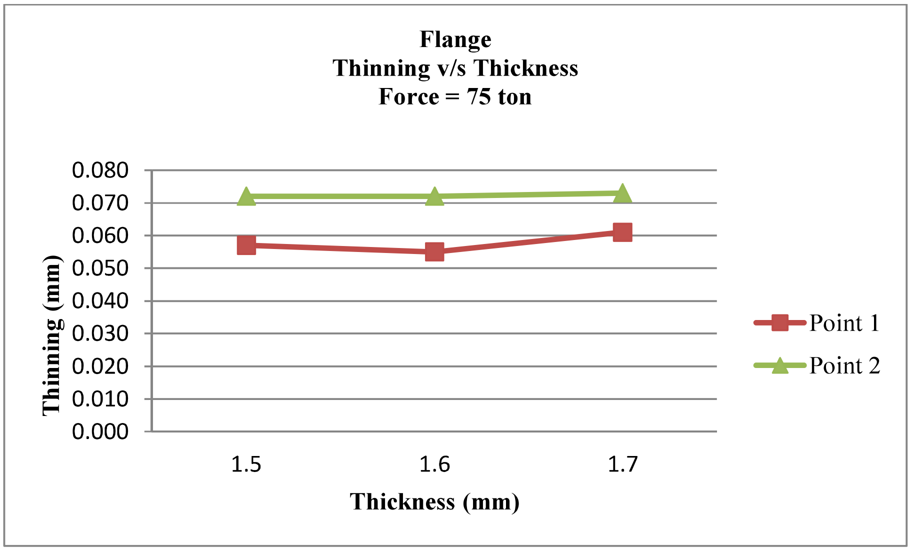

Fig 4.31 Thinning in Flange at a constant force=75 ton

4.1.5 Wrinkle v/s Force at constant Thickness

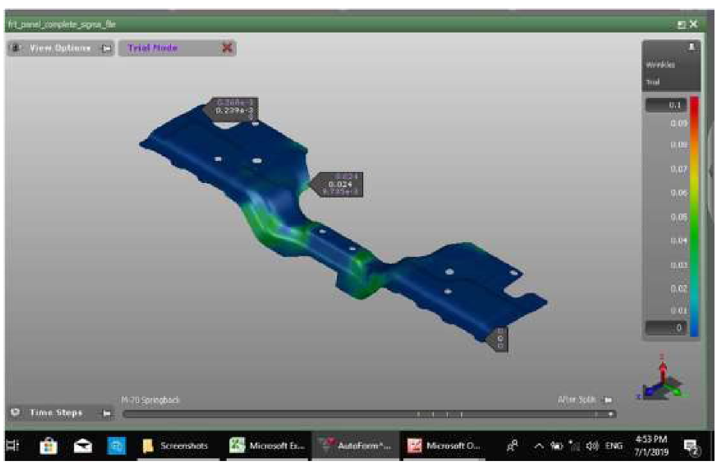

Fig 4.32 Contour plot for a wrinkle in a flange

In deep drawing process material of the flange undergoes compressive hoop strain and radial tensile strain. Moreover, metal at the bottom of the punch undergoes biaxial tensile stress. Hence the gap between the die and punch wall was subjected to longitudinal and hoop tensile stress. Metal was forced through the gap. Due to thwas material tends to flow towards the center but, due to the curved profile of the punch and die, metal flow was restricted and that was why wrinkling occurs. But on increasing blank holder force the stresses developed does not allow withholding of metal. Hence, wrinkling was decreased.

A significant decrease in wrinkle was observed in all the three consecutive operations while increasing the force and keeping thickness constant.

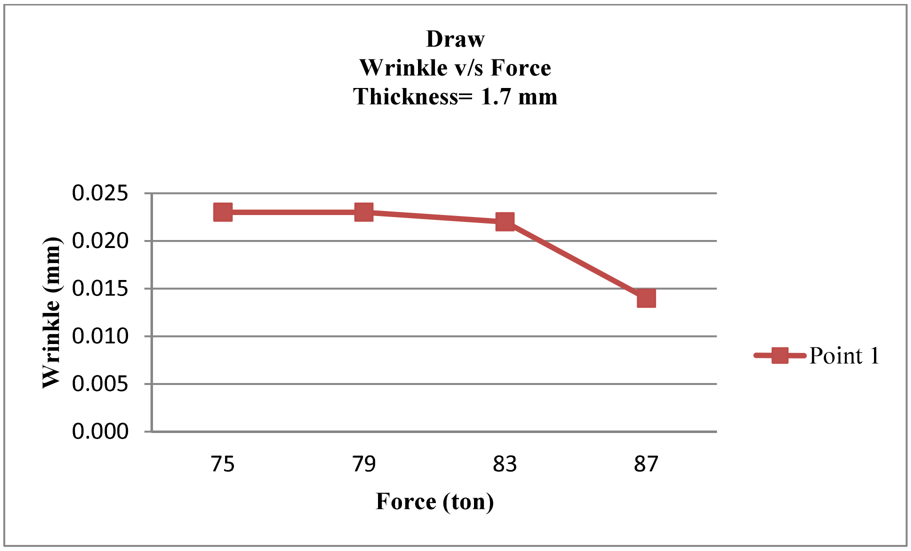

Fig 4.33 Wrinkle in Draw at constant thickness=1.7 mm

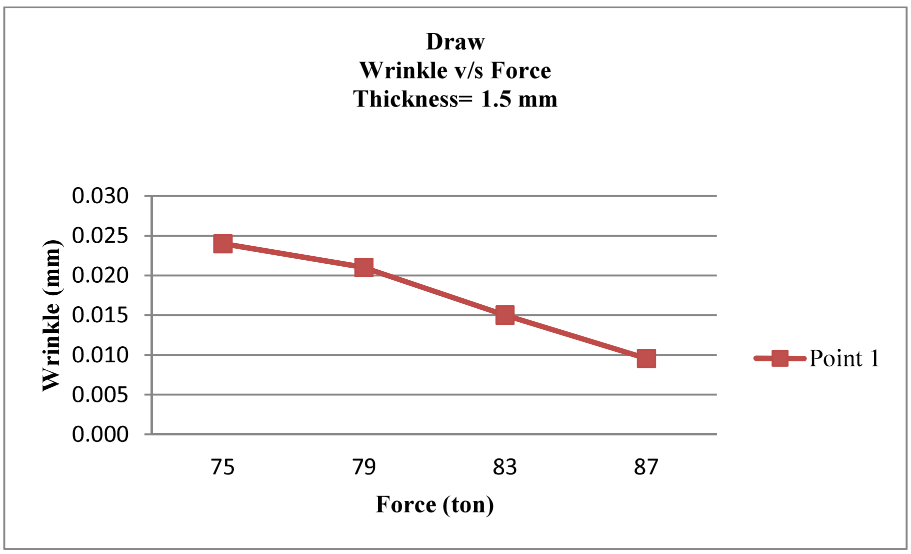

Fig 4.34 Wrinkle in Draw at constant thickness=1.5 mm

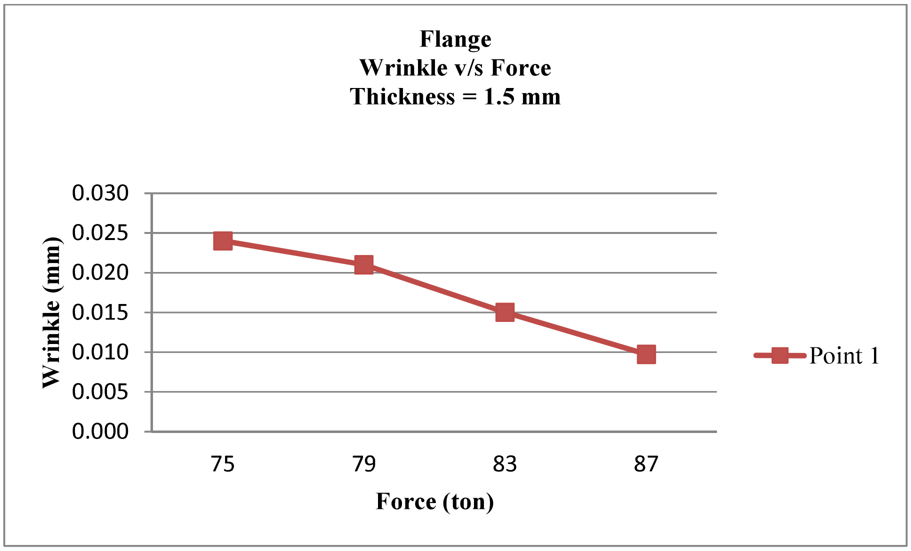

Fig 4.35 Wrinkle in Flange at constant thickness=1.5 mm

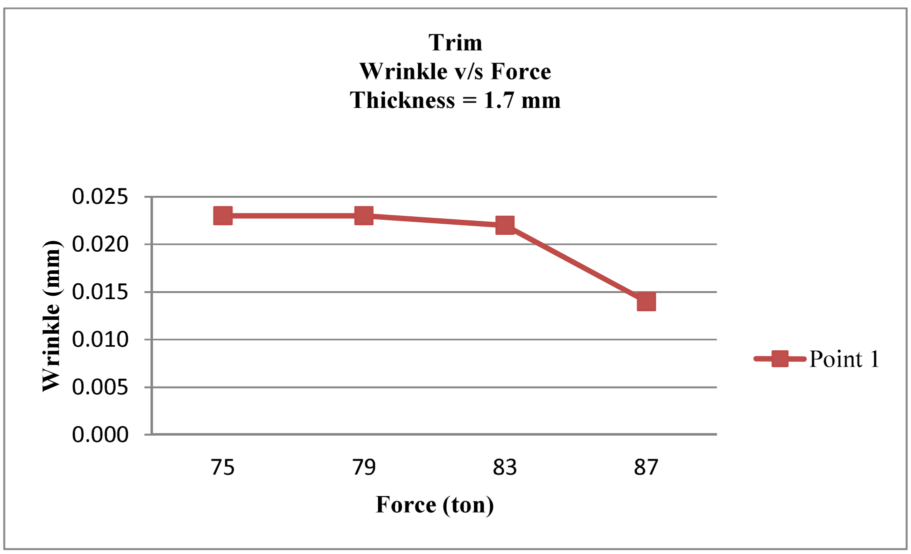

Fig 4.36 Wrinkle in Trim at constant thickness=1.7 mm

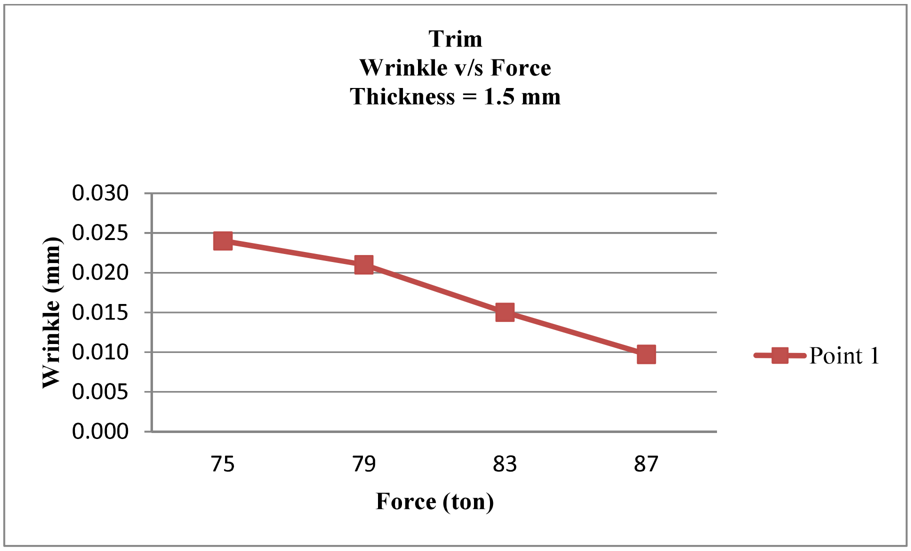

Fig 4.37 Wrinkle in Trim a constant thickness=1.5 mm

4.1.6 Wrinkle v/s. Thickness at a constant force

In deep drawing process material of the flange undergoes compressive hoop strain and radial tensile strain. Moreover, metal at the bottom of the punch undergoes biaxial tensile stress. Hence the gap between the die and punch wall was subjected to longitudinal and hoop tensile stress. Metal was forced through the gap. Due to this material tends to flow towards the center but, due to the curved profile of the punch and die, metal flow was restricted and that was why wrinkling occurs. On increasing sheet thickness and applying same force, material deformation was increased but the metal flow was restricted at punch shoulder and other curvatures. This led to an increase in wrinkling.

Wrinkle varied proportionally to sheet thickness for all three operations.

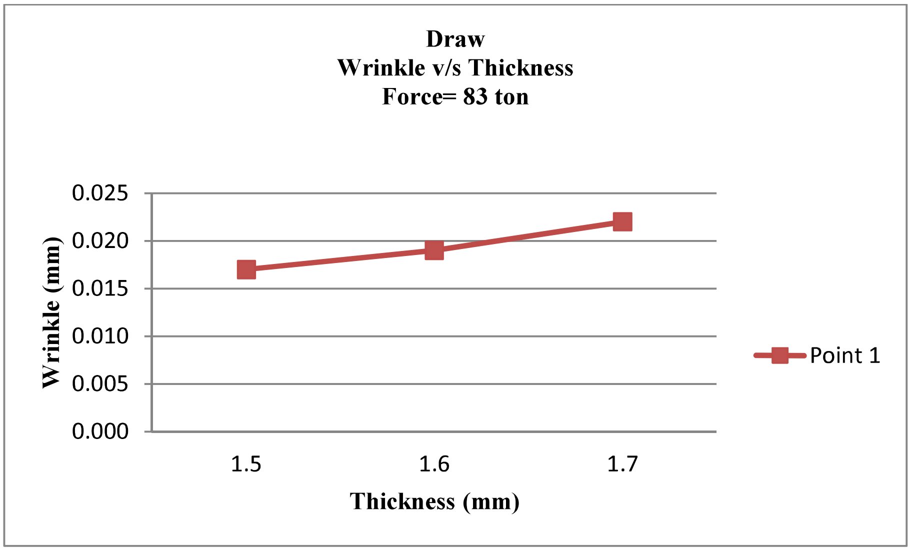

Fig 4.38 Wrinkle in Draw at a constant force=83 ton

Fig 4.39 Wrinkle in Trim at constant force =83 ton

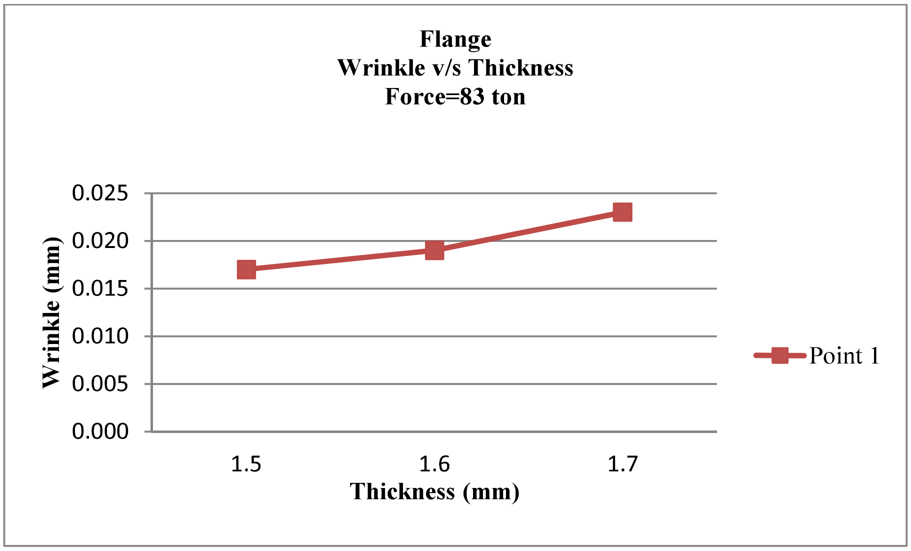

Fig 4.40 Wrinkle in Flange at a constant force=83 ton

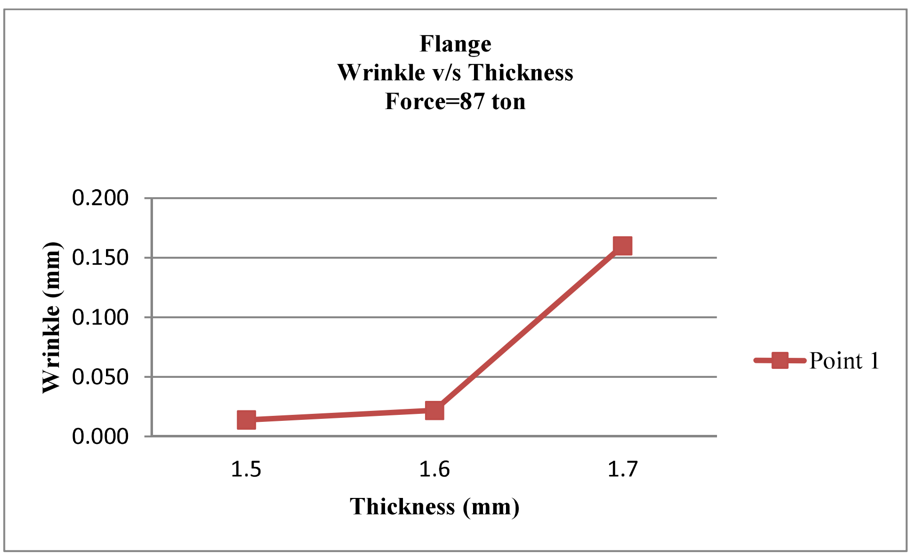

Fig 4.41 Wrinkle in Flange at constant Force=87 ton

4.2 Stress and Strain distribution

Stress was defined as a force acting per unit area. Strain in terms of metal forming was defined as deformation per unit length. The stress-strain curve was shown below.

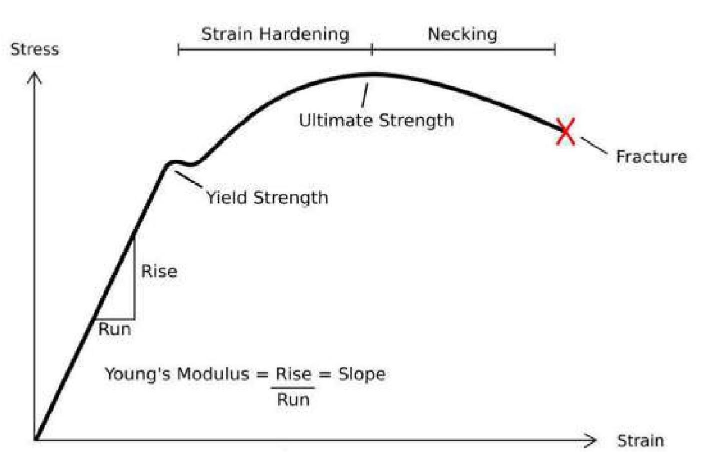

Fig 4.42 Theoretical Stress-Strain curve [34]

Similar, behavior was obtained between the plots of major stress v/s major strain and minor stress v/s minor strain.

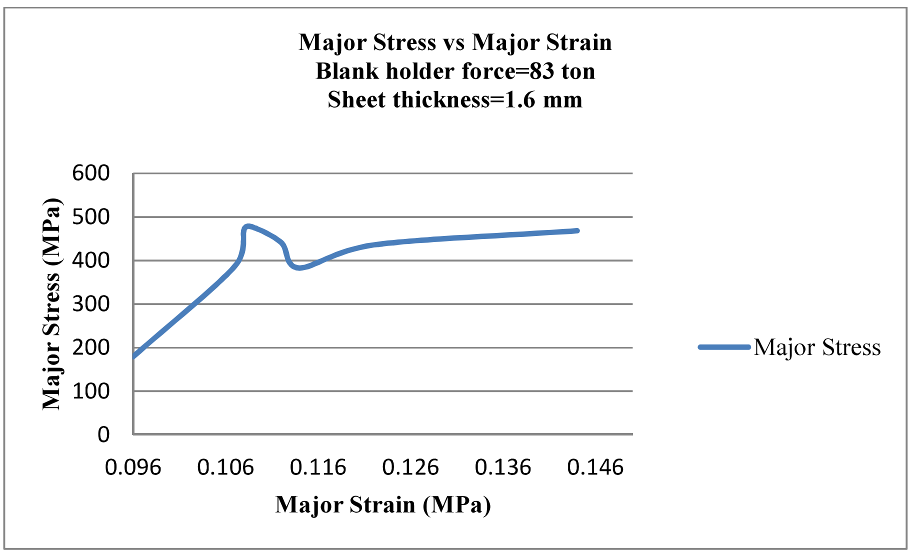

Fig 4.43 Major stress v/s Major Strain

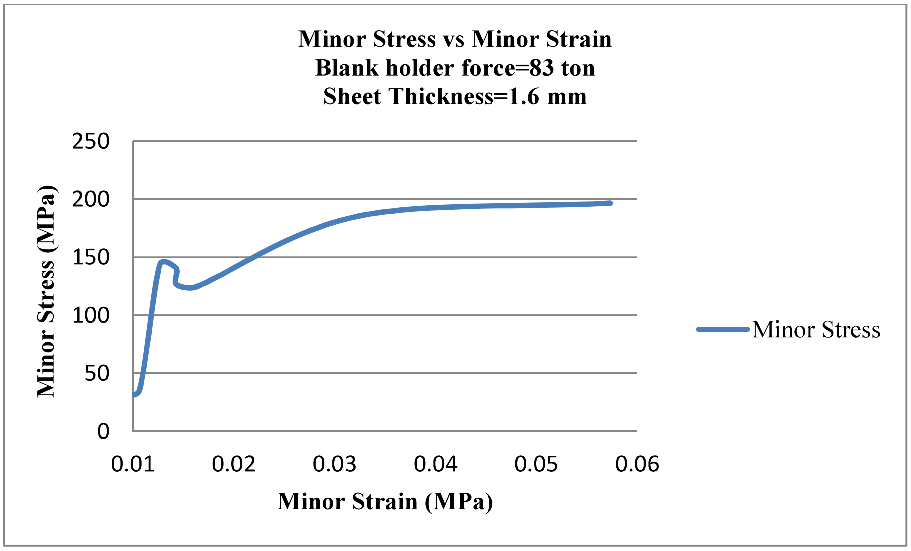

Fig 4.44 Minor Stress v/s Minor Strain

Major stress and Major strains were stress and strain respectively in the path of maximum deformation whereas, Minor stress and Minor strains were stress and strain respectively in the path of minimum deformation. In both, the plots, strain hardening was common after the yield limit was crossed. This was the beginning of plastic deformation. In this stage, more stress was required to bring little deformation.

Forming Limit Diagram

Forming limit diagram carries a lot of significance to study the deformation behavior of a part produced through metal forming. It designates different color schemes to a different region of the strain points obtained as given in fig 4.45.

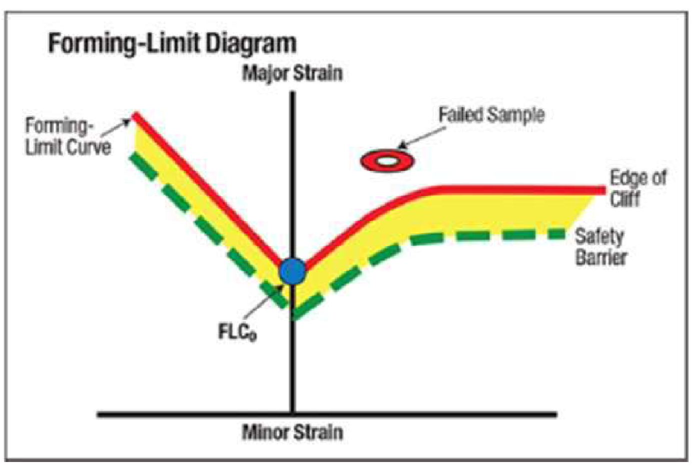

Fig 4.45 Theoretical Forming Limit Diagram [33]

Forming limit curve was plotted between Major true strain and Minor true strain. The region was obtained after analyswas over FLD. The region lying above the red curve shows necking or fracture while the region below the green curve was safe.

FLD plot for the current part i.e. front seat panel has been obtained and shown below.

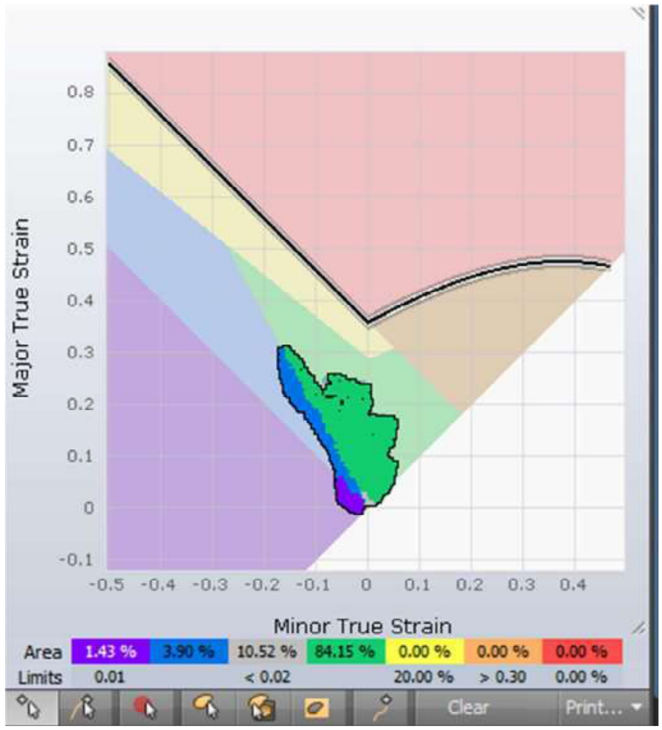

Fig 4.46 Forming Limit Diagram obtained from the analysis

Contour plot of formability has been shown along to give a representation of each colored region as shown in fig 4.47.

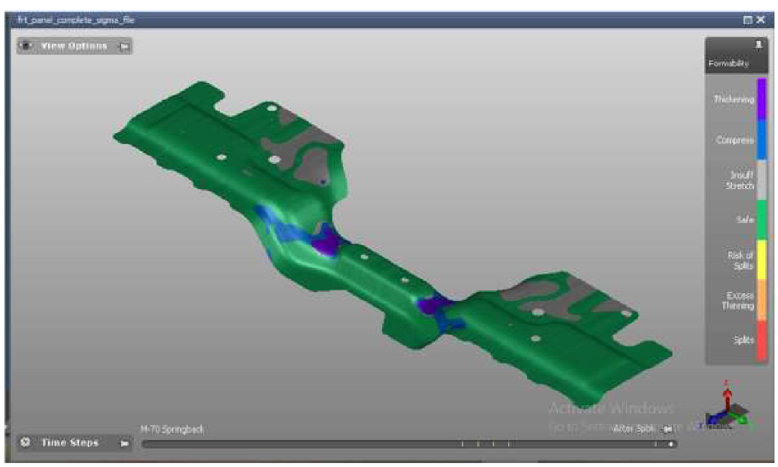

Fig 4.47 Contour plot of Formability

- From the contour plot, it can be stated that part was safe since none of the regions lies in the yellow, orange or red region.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

Surface deformation analysis of spring-back, thinning and wrinkle was done at the constant thickness and blank holder force using AUTOFORM R7. Following results were obtained:

i. At constant thickness, all the three output parameters were found to vary inversely with blank holder force.
ii. At constant force, wrinkle and thinning varied directly to sheet thickness. While spring-back showed an inverse trend.

Data obtained gives a clear trend of variation. These values can now be used to make the future part with considerable allowances as mentioned in methodology.

Two different curves were plotted i.e. Major stress v/s Major strain and Minor stress v/s Minor strain. These were found comparable to theoretical stress-strain plots.

Forming Limit Diagram obtained after analysis clearly indicates that all the points were far from Forming Limit Curve (FLC). So, the part was under safe forming region and no fracture have occurred.

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Chapter 1

INTRODUCTION

1.1 GENERAL

In the automotive industry, parts are produced mostly by cold forming by stamping the part with the help of die and punch. Different parts are produced in this manner like rear lamp panel, front seat bracket, etc. Different types of material are used like steel, aluminum, and iron. During the mass production of the part where heavy punch machines are involved the blank being deformed shows a series of defects like spring-back, wrinkle, thinning, etc. This leads to reduced strength and accuracy of the part which ultimately leads to rejection. To avoid such failure one of the most prominent methods used these days is analysis through FEM simulation that predicts the defects at the early stage where it could be minimized. This saves a lot of time and money from an industrial point of view.

The part is made up of JAC390-W galvanized-annealed steel whose yield and tensile strength of 242 MPa and 416 MPa respectively.

Galvanized-annealing

Firstly, steel undergoes galvanization in which metal is immersed in the bath of molten zinc at 449°C. At the completion of this process layer of zinc-carbonate is formed that provides corrosion resistance. After this when the steel is still in soft state annealing is initiated. Annealing involves heating the material to a certain temperature (500-565°C) and then allowing it to cool at a controlled rate. Zinc and iron layer is that gives it a matte grey appearance. This leads to recrystallization, recovery and grain growth which further enhances the cold forming characteristics of the material. It leads to increased ductility, electrical conductivity corrosion resistance and eliminates internal stresses. Spot weldability is increased and material is rendered paintable with zinc phosphate coating treatment as given in fig 1.1.

1