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SPRINGBACK EXPERIMENTAL EVALUATION AND VALIDATION OF AIRCRAFT INDUSTRY SHEET METAL

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ABSTRACT

The tendency of the metal to regain its original shape will result in the spring back when it is being formed to make aircraft components like outer body panels and brackets. When spring back occurs, the components will not meet the requirements of the design and there will be a need for shims to fit the component into place. This will lead to increase in weight, fabrication cost and also the assembly line time. So the Finite-Element Analysis (FEA) is used to accurately predict this deflection so that manufacturing processes can be optimized to produce a perfect output with least deviations from the design.

This thesis bridges a relation between the experimentally evaluated spring back and FEA calculated spring back. Also in order to validate the FEA Analysis regression analysis has been performed. Variations have been tabulated and graphed as it bridges the gap between experimentally evaluated spring back and analysis of the design.

INTRODUCTION

Aircraft construction involves a wide range of materials. Out of these sheet metal plays a major role. Sheet metal aircraft construction is the most prevalent aircraft construction material by all measures, used extensively from jetliners to light, single engine airplanes and kits over the past five decades. Furthermore, virtually all other aircraft types use sheet-metal construction to some degree - whether an instrument panel on a composite aircraft, or a firewall on a wood or steel tube and fabric design. New and modern metal alloys and materials have allowed aviation technology to advance, and is the reason it continues to dominate over other aircraft building methods. Steel's and Aluminum's unique combination of properties makes it one of the most versatile engineering and building materials in existence:

- Low weight / high strength relationship.
- Corrosion resistance, especially with newer alloys and modern primers.
- Low cost and widespread availability.

The Bending process is the forming of sheet metal where angled or other shaped parts are produced. The process involves the uniform straining flat metal sheets around a linear axis, but it also may be used to bend tubes, drawn profiles bars, and wire. In bending, the plastic state is brought by a bending load. In fact, one of the most common processes for sheet metal forming are bending, which is used not only to form pieces such as L, U or V-profiles. Bending has the greatest number of applications in the automotive, aircraft and defense industries and for production of other sheet metal products. Typical examples of sheet-metal bends are illustrated in Fig 1. The basic characteristic of bending is tensile elongation on the outer surface and compression on the inner surface as shown Fig 1.

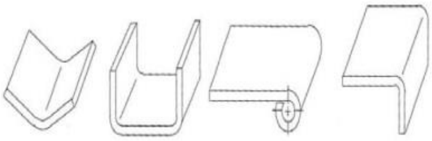


Fig 1: Typical examples of sheet metal bend parts.

The entire stress-strain curve is transverse, elastic stresses result in spring back and the residual stress pattern. Here, the bend radius Ri is measured on the inner surface of the bent piece. The bend angle φ is the angle of the bent piece and T is the material thickness. In bending process, since the outer fibers of the material are in tension and the inner fibers are in compression, theoretically the strain values on the outer and inner fibers are equal in magnitude and are given by the following equation:

$$e_0 = e_1 = \frac{1}{\left(\frac{2R}{T}\right)+1}$$

Experimental research indicate that this formula is more precise for calculating the deformation of the inner fibers of the material, e1, than for the deformation of the outer fibers, e0. The deformation in the outer fibers is notably greater, that is why neutral fibers move towards the inner side of the bent piece. As Ri/T ratio decreases, the bend radius becomes smaller; the tensile strain at the outer fibers increases and the Material eventually cracks.

LITERATURE SURVEY

Since sheet metal forming industry has become one of the major manufacturing centers for automobile and aerospace and defense industries, the popularity of sheet metal products is attributable to their light weight, great interchangeability, good surface finish, and low cost. There has been a growing interest during the past decade in using finite element method for Springback prediction following forming of arbitrary shapes. While it is apparently simple in concept, the prediction of Springback has proven challenging for a variety of reasons, including numerical sensitivity, physical sensitivity, and poorly characterized material behavior under reverse loading and unloading conditions. Springback of sheet metal parts after forming causes deviation from the designed target shape and produce downstream quality problems as well as assembly difficulties. Its economic impact in terms of delayed production, tooling revision costs, and rejection of unqualified parts is estimated to exceed $50million per year in the U.S. automotive industry alone. It is obvious that controlling Springback is a vital concern in manufacturing.Several studies has been done for past decades in order to develop Springback reduction and compensation methods. S. Nishino et al.[4] examined a new method of predicting a shape fixation property by combining free bending test data with the results of the computer simulations conducted using the finite element method (FEM). With the increased use Finite Element Simulation in tooling departments, the forming analyses of sheet metal components are used more frequently in the design feasibility studies of production tooling. These computer based tools allow the design engineer to investigate the process and material parameters controlling the material floe over the die surfaces. Several studies were done in past decade. M. Firat [17] studied U-Channel forming analysis to predict Springback. He established a kinematic hardening model based on additive back stress form in order to improve the predicted sheet metal deformation response .S.K.Panthi et al. [18] were also studied on a large deformation algorithm based on Total-Elastic-Incremental-Plastic Strain (TEIP) which was used for modeling atypical sheet metal bending process. The process involves large strain, rotation as well as Springback. N.Narasimham et al. [19] aimed to introduce a coupled explicit to-implicit finite element approach for predicting Springback deformations in sheet metal stamping that can be utilized for minimizing die prototype design time. In this study, they have utilized the explicit method initially to analyze the contact based forming operation of stamping process. Then an implicit solution has been performed to simulate the Springback developing in a blank after the forming pressure removed. They have coupled ANSYS/LS-DYNA explicit and ANSYS implicit codes to solve sheet metal forming processes that involves a high degree of Springback. One of the important studies of finite element analysis of Springback in bending was done by V. Esat [20]. In the mentioned work, V. Esat et al. developed a finite element simulation in order to simulate Springback by means of a Springback factor using commercially available finite element program. They reached a good agreement between the finite element simulation and empirical data. Their finite element model is based on 2-D shell elements and Chung-Hulbert dynamic implicit as time integration scheme. They used penalty method on analytically defined rigid bodies to handle contact algorithm. D.W.Park et al. [22] proposed a new shell element to improve accuracy and efficiency of Springback simulation by describing complicated bending deformation accurately. They applied the new element both implicit Finite Element Method and explicit Finite Element Method to conduct Springback simulation. Many studies had been carried out on different perspectives of Springback. Micari et al. [33] presented a Springback prediction technique in three dimensional stamping processes which is based on a combined approach in which an explicit finite element code has been employed to simulate the forming phase while a traditional implicit procedure has been used to analyze the Springback phase. Gauand Kinzel [34] performed an experimental study for determining the Bauschinger Effect on Springback predictions which seems very significant in wipe bending operations. Since Springback is a vital concern in manufacturing industry, beyond evaluating and simulating attempts of Springback, some researchers studied the parameters that effect Springback in sheet metal forming operations in order to control these disturbing parameters.

FACTORS AFFECTING BENDING

Bend radius Ri, is one of the most important parameter which affects bending operations of sheet metals. The bend radius in bending operations always pertains to the inside radius of bend. Minimum bend radius is dependent on the material thickness and the mechanical properties of the material. Minimum bend radii vary for various metals; generally, most annealed metals can be bent to a radius equal to the thickness, T and sometimes to T/2, for a given bend angle and bend length. Bend angle is another crucial factor in bending operations. As the bend angle becomes larger, especially with bend angles over 90°, many difficulties arise. In this case, the amount of bend radius become more critical and the material hardness becomes more detrimental to the success of the bending process. In bending process, some deformations occur in the bent-up region of the work piece depending on the dimensions of the work piece, bend angle, and bend radius. As the strength of the work piece is limited, the deformations should be restrained in some limits. In the other words, spring back describes the change in shape of formed sheet upon removal from tooling. Spring back is one of the key factors to influence quality of stamped sheet metal parts in sheet metal manufacturing areas. Spring back is influenced by several factors, such as; Sheet thickness, Elastic modulus, Yield stress, Work hardening exponent, Die and punch radii, Punch stroke etc.

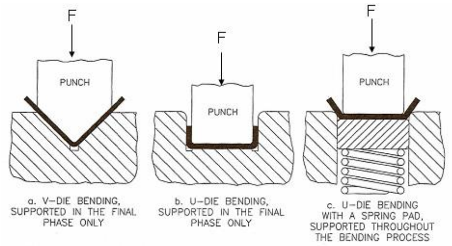


Fig 2: Supported bending.

SPRINGBACK TERMINOLOGY AND MECHANICS

Every plastic deformation is followed by elastic recovery. As a consequence of this phenomenon, changes occur in the dimensions of the plastic-deformed work piece upon removing the load. While a work piece is loaded, it will have the following characteristic dimensions as a consequence of plastic deformation as shown in Figure 3

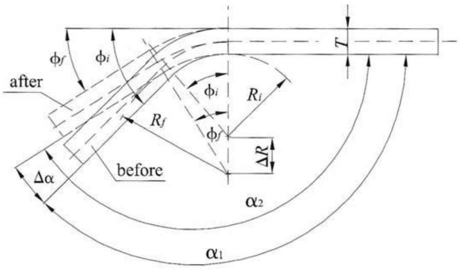


Fig 3: Schematic Springback Illustration.

- Bend radius (Ri)
- Bend angle ($\varphi i = 180° – \alpha 1$) and
- Profile angle ($\alpha 1$)

All work piece materials have a finite modulus of elasticity, so each will undergo a certain elastic recovery upon loading. In bending, this recovery is known as a Spring back. The final dimensions of the work piece after being unloaded are defined by Bend Radius (Rf),Bend Angle ($\alpha 2$), and Profile Angle ($\varphi f=180o - \alpha 2$), The final angle after springback is smaller ($\varphi f<\varphi i$) and the final bend radius is larger ($Rf > Ri$) than before. There are two ways to understand and compensate for spring back. One is to obtain or develop a predictive model of the amount of springback and the other way is to define a quantity to describe the amount of springback. A quantity characterizing springback is the Springback factor (*K*), which is determined as follows. The bend allowance of the neutral line (Ln) *is* the same before and after bending, so the following relationship is obtained by the formula:

$$Ln = (Ri+ \frac{T}{2})\Phi i= (Rf+ \frac{T}{2})\Phi f$$

From this relationship, the Springback factor is:

$$K = \frac{Ri + \frac{T}{2}}{Rf + \frac{T}{2}} = \frac{\frac{2Ri}{T} + 1}{\frac{2Rf}{T} + 1} = \frac{\Phi f}{\Phi i} = \frac{180 - \alpha 2}{180 - \alpha 1}$$

The spring back factor (K) depends on R/T. A Springback factor of K = 1indicates no Springback and K = 0 indicates the complete elastic recovery. To estimate Springback, an approximate formula has been developed in terms of the radii Ri and Rf as follows;

$$\frac{Ri}{Rf} = 4\left[\frac{Ri(YS)}{ET}\right]^3 - 3\left[\frac{Ri(YS)}{ET}\right] + 1$$

In case of plane strain bending, the following formula can be used [2]

$$\frac{Ri}{Rf} = 4\left[\frac{Ri(YS)}{ET}(1 - \vartheta^2)\right]^3 - 3\left[\frac{Ri(YS)}{ET}\right](1 - \vartheta^2) + 1$$

In V-die bending, the part radius at the unloaded state, R, may be estimated by:
$Rp = \frac{1}{\frac{1}{R} + 3\frac{YS}{TE}}$
Where,
Rp is punch radius.

BENDING EXPERIMENTATION AND SPRING BACK CALCULATION

It is observed that the metal outside the bend radius is stretched and the It is observed that the metal outside the bend radius is stretched and the metal on the inside of the bend radius is compressed. This means that the metal near the neutral axis may be stressed to values below the elastic limit and the metal far away from the neutral axis may be stresses beyond the yield stress.

When the bending moment is removed, the elastic deformation tends to return to the original configuration but is restricted by the plastic deformation. The stress distribution changes until plastic and elastic zone inside the deformed sheet comes to equilibrium. This final configuration change is known as Spring back. In other words, Spring back is mainly due to elastic recovery of the bending process. Experiments have been carried out to measure springback angle of the work piece after V-bending operation with mild steel material under three different bend angles and three different thicknesses. The materials used in this thesis study are mild steel with a thickness of 1.2, 2 and 3 mm. This mild steel has a maximum limit of 0.3% carbon. The proportions of manganese (1.65%), copper (0.6%) and silicon (0.6%) are approximately fixed. The calculated average industry grade mild steel density is 7.85 gm/cm3. Its Young's modulus, which is a measure of its stiffness is 210,000 MPa. In this study, mild steel specimen of length100mm and different thicknesses such as 1.2mm, 2mm, 3mm, 4mm are considered. The experiment set-up is composed of a punch, a die and guide pins which are shown in Figure---, Figure3.3, and Figure3.4.Dimensions of the bending die are same as the ones used in Finite Element Analysis. A hydraulic press with capacity of 100 tons is employed and angles are measured for each case and results are tabulated

Fig 4: 60°, 90° and 120° V-Bending die

Fig 5: Hydraulic press machine and Optical angle measuring device

BENDING OPERATION VS FINITE ELEMENT ANALYSIS (FEA)

In this work, V-bending operation of mild steel material has been analyzed by FEM software, LS-DYNA. Several results such as spring back amounts, maximum von Mises stresses, stress distributions and plastic strains are presented. The input data are the material properties, boundary conditions, time vs. velocity tables to define motion of the punch, stress vs. strain tables to define the strain characteristics of the materials, and definition of the contact model and the load cases. The mild steel sheets used in this work are assumed to be free of residual stresses before the loading action. Finite element model used in spring back simulations is composed of a rigid punch and die and a deformable sheet metal. For all cases, rigid punch moves down to bend the work piece. The gap between die and punch, at the end of fully bending step, remains as the original thickness of the material. At beginning of the process, At maximum indentation of the punch tip necessary dimensions needed to model the processes are shown in Figure

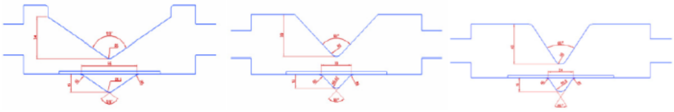


Fig 6: Schematic view of 60°, 90° and 120° V -bending with dimensions

COMPUTER AIDED DESIGN (CAD) MODELS

The Punch, Die and Blank are modeled using Autodesk Inventor software as below

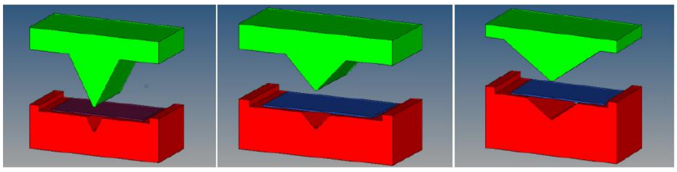


Fig 7: 3D CAD Models developed in Autodesk Inventor.

Once the CAD work is completed and they are saved into different format (.igs &.stp) all these assemblies are then imported into Hyper mesh for meshing. The mesh size considered is 2 mm. The blank is not meshed completely instead a mid-surface is generated and then given thickness in the LS-Dyna. The meshed models are given below:

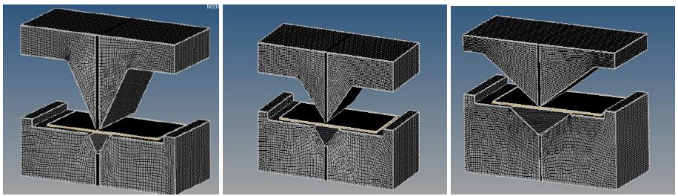


Fig 8: Meshed model of 60^0 Punch & 60^0, 90^0 & 120^0 die

ANALYSIS RESULTS

Results such as spring back, maximum Von Mises stresses, stress distributions and total plastic strain are obtained.

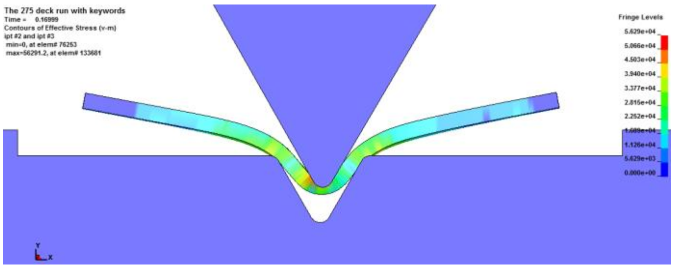


Fig 9(a)

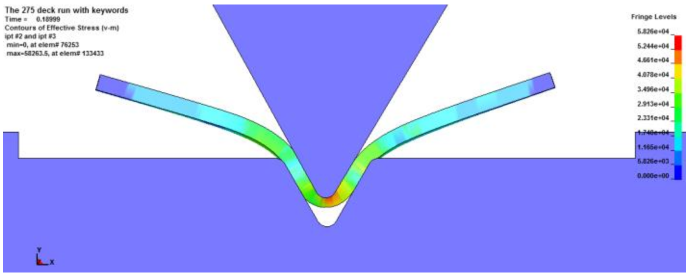


Fig 9(b)

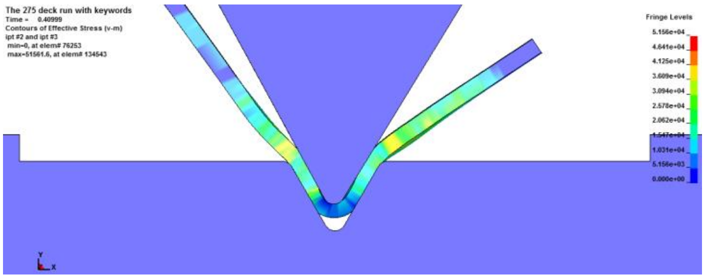


Fig 9(c)

Fig 9: Distribution of Von Mises stress for 3mm thick mild steel 60° V- bending at ; (a) The intermediate stage; (b) the fully loaded stage; (c) the unloaded stage.

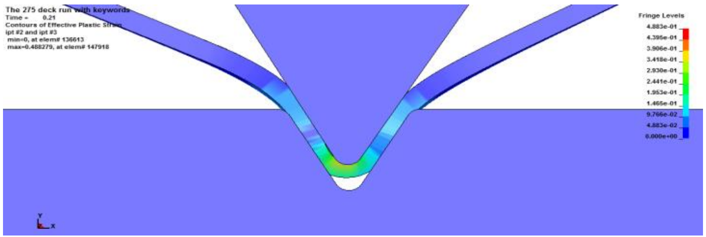


Fig 9(d): Plastic strain for 3 mm thick mild steel at 60^0 V- bending

As seen above the distribution of von Mises stresses are computed during intermediate stage, fully loaded stage and unloaded stage. As seen from the above figures maximum von Mises stress is evaluated as fully loaded stage where it is 58.263Mpa The spring back angle can be measured at the fully unloaded stage in LS- PrePost .It has been observed that the spring back angle is 2.94^0.The maximum plastic strain at 60^0 bending for 3 mm thickness sheet is recorded as 0.488.

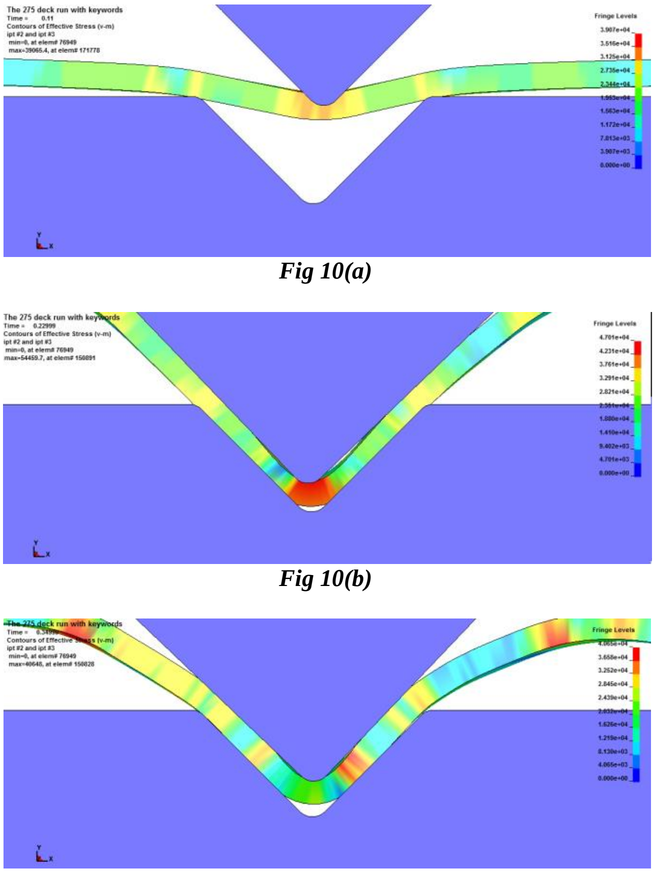


Fig 10(a)

Fig 10(b)

Fig 10(c)

Fig 10: Distribution of Von Mises stress for 3mm thick mild steel 90° V- bending at ; (a) The intermediate stage; (b) the fully loaded stage; (c) the unloaded stage..

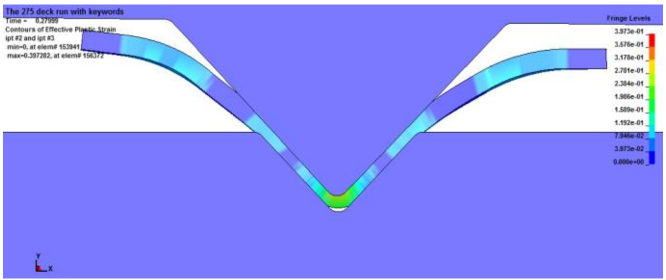


Fig 10(d): Plastic strain for 3 mm thick mild steel at 90^0 V- bending

As seen above the distribution of von Mises stresses are computed during intermediate stage, fully loaded stage and unloaded stage. As seen from the above figures maximum von Mises stress is evaluated as fully loaded stage where it is 54.5Mpa The spring back angle can be measured at the fully unloaded stage in LS- PrePost .It has been observed that the spring back angle is 1.92^0.The maximum plastic strain at 90^0 bending for 3 mm thickness sheet is recorded as 0.397.

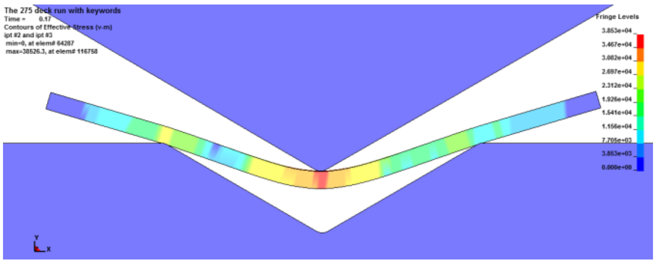


Fig 11(a)

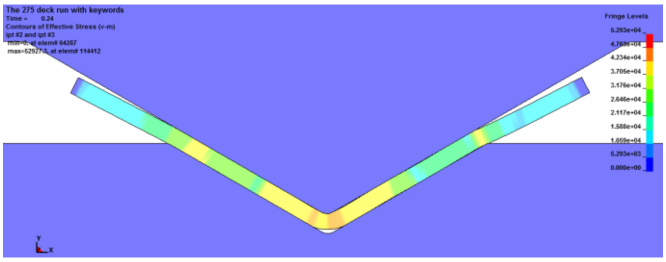


Fig 11(b)

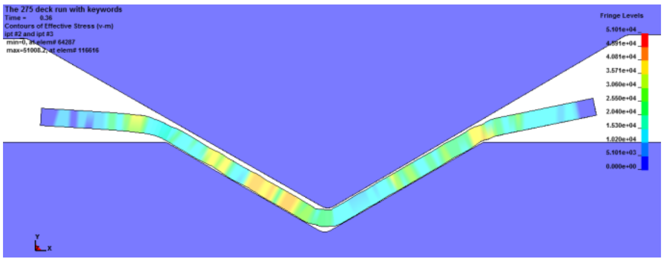


Fig 11(c)

Fig 11: Distribution of Von Mises stress for 3mm thick mild steel 120° V- bending at ; (a) The intermediate stage; (b) the fully loaded stage; (c) the unloaded stage.

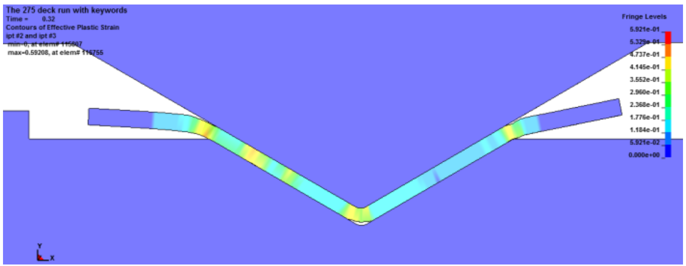


Fig 11(d): Plastic strain for 3 mm thick mild steel at 120^0 V- bending

As seen above the distribution of von Mises stress is computed during intermediate stage, fully loaded stage and unloaded stage. As seen from the above figures maximum von Mises stress is evaluated as fully loaded stage where it is 52.9Mpa The spring back angle can be measured at the fully unloaded stage in LS- Prepost .It has been observed that the spring back angle is 1.29^0.The maximum plastic strain at 120^0 bending for 3 mm thickness sheet is recorded as 0.592.

After all the experimental analysis, Springback angles are measured for each case and tabulated as below.

Table.1: Spring Back Angle Variation with different thickness at 60^0, 90^0 and 120^0 bending using FEA

Thickness (mm)	Angle = 60^o		Angle = 90^o		Angle = 120^o	
	Part angle (^{o})	Spring back (^{o})	Part angle (^{o})	Spring back (^{o})	Part angle (^{o})	Spring back (^{o})

1.2	59.26	.74	88.42	1.58	117.06	2.94
2	59.61	.39	88.81	1.19	117.93	1.92
3	59.71	.29	89.05	0.95	118.66	1.29

RESULTS AND DISCUSSIONS

The results from the FEA analysis using LS-DYNA and Experimental values of spring back are listed and compared below.

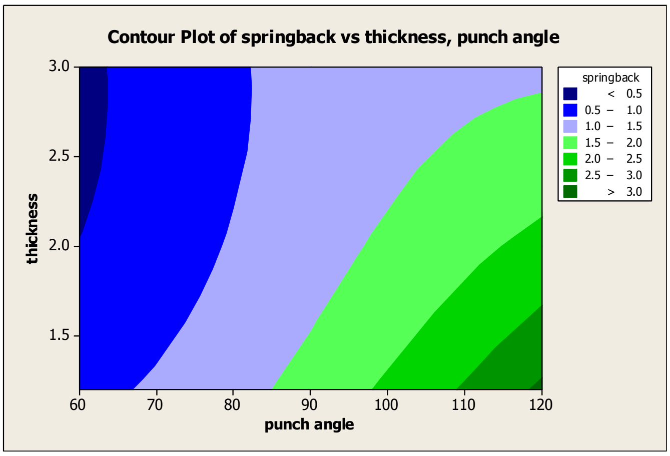


Fig 12: contour plot of Springback by varying the thickness and punch angle

Fig 12 shows the contour plot of Springback by varying the thickness and punch angle. In this analysis the Springback is calculated for various cases and the values of the Springback are 0.86°, 0.51°, and 0.38° for 1.2mm, 2mm and 3mm respectively for 60°V – bending. Also the Springback is 1.68°, 1.31°, 1.15° for 1.2mm, 2mm, and 3mm respectively for 90° V-bending.in the third case the Springback is 3.09 °, 2.15 °, 1.42° for 1.2mm, 2mm, and 3mm respectively for 120° V-bending. The above plot shows the Springback variation with color and also the regions are created with the respective punch angles and thickness.

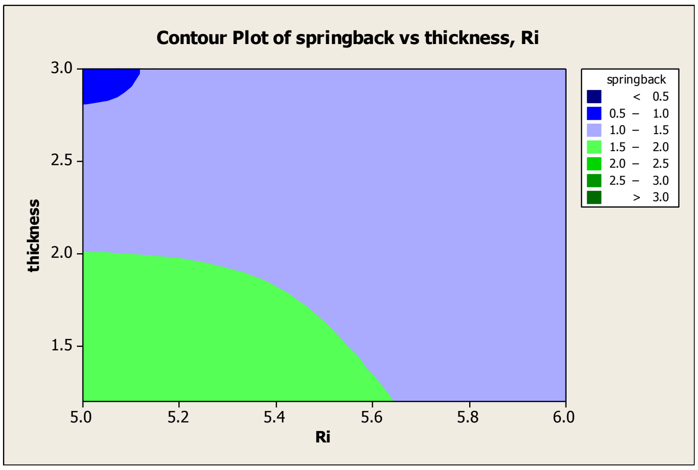


Fig 13: contour plot of Springback by varying the thickness and R_i

Fig 13 shows the contour plot of Springback by varying the thickness and initial radius (R_i). In this analysis the Springback is calculated for various cases and the values of the Springback are 0.86°, 0.51°, and 0.38° for 1.2mm, 2mm and 3mm respectively for 60°V – bending with initial radius as 5 mm. Also the Springback is 1.68°, 1.31°, 1.15° for 1.2mm, 2mm, and 3mm respectively for 90° V-bending with initial radius of 6 mm. In the third case the Springback is 3.09 °, 2.15 °, 1.42° for 1.2mm, 2mm, and 3mm respectively for 120° V-bending with initial bend radius of 5 mm. The above plot shows the Springback variation with color and also the regions are created with the respective thickness and initial radius (R_i). Validation of experimental and regression analysis values:

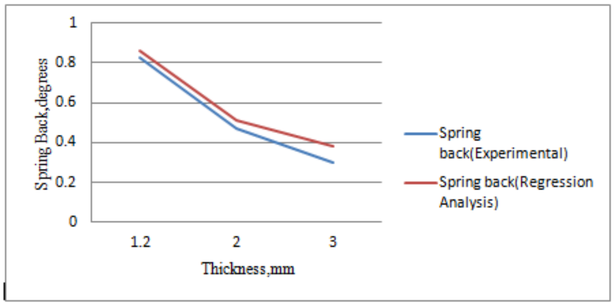


Fig 14: Variation of Springback with different Thickness at 60^0 V- bending

Fig 14 shown is a graph showing the variation of Springback with different thickness at 60º V-bending the difference between the experimental Springback and the regression analysis Springback is 0.03º, 0.04º, 0.08º for 1.2mm, 2mm, 3mm respectively.

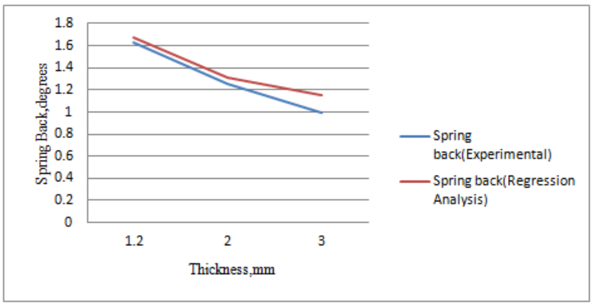


Fig 15: Variation of Springback with different Thickness at 90^0V - bending

Fig 15 shown is a graph showing the variation of Springback with different thickness at 90º V-bending the difference between the experimental Springback and the regression analysis Springback is 0.05º, 0.06º, 0.16º for 1.2mm, 2mm, 3mm respectively.

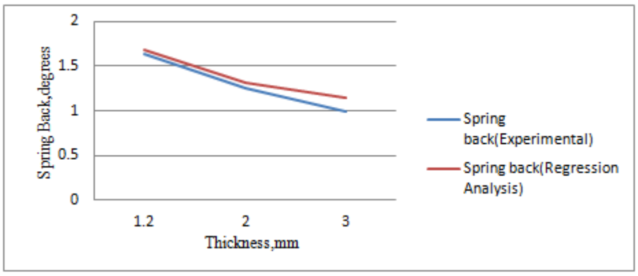


Fig 16: Variation of Springback with different Thickness at 120^0V - bending

Fig 16 shown is a graph showing the variation of Springback with different thickness at 120º V-bending the difference between the experimental Springback and the regression analysis Springback is 0.03º, 0.08º, 0.0º for 1.2mm, 2mm, 3mm respectively.

The results from the FEA analysis using LS- Dyna and Experimental values of spring back are listed and compared below. The spring back angle is calculated from the LS-PrePost.

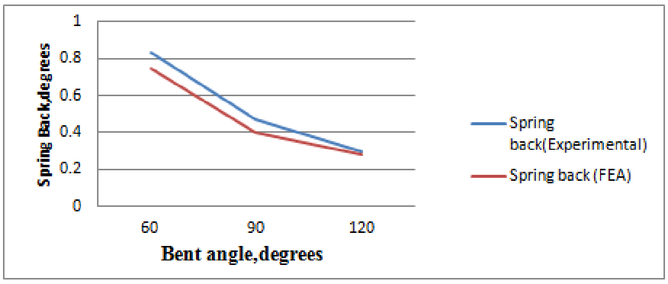


Fig 17: Variation of Springback with different Thickness at 60^0 bending

Fig 17 shows the variation in the Springback with the different thickness, as the thickness increases the Springback angle decreases. 0.83^0, 0.47^0, 0.3^0 are experimental Springback angles at 1.2mm, 2mm, 3mm respectively at 60^0 bending. Also the variation between the experimental Springback and the Springback obtained from FEA Analysis are plotted in the graph.

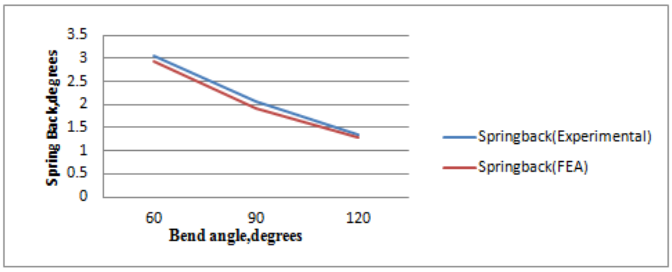


Fig 18: Variation of Springback with different Thickness at 90^0 bending

Fig 18 shows the variation in the Springback with the different thickness, as the thickness increases the Springback angle decreases. 1.63^0, 1.25^0, 0.99^0 are experimental Springback angles at 1.2mm, 2mm, 3mm respectively at 90^0 bending. Also the variation between the experimental Springback and the Springback obtained from FEA Analysis are plotted in the graph.

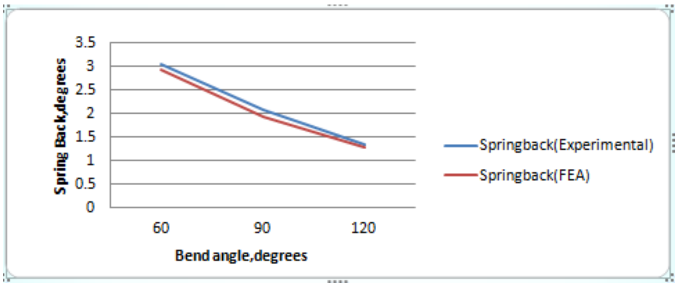


Fig 19: Variation of Springback with different Thickness at 120^0 bending

Fig 19 shows the variation in the Springback with the different thickness, as the thickness increases the Springback angle decreases. 3.04^0, 2.07^0, 1.34^0 are experimental Springback angles at 1.2mm, 2mm, 3mm respectively at 120^0 bending. Also the variation between the experimental Springback and the Springback obtained from FEA Analysis are plotted in the graph.

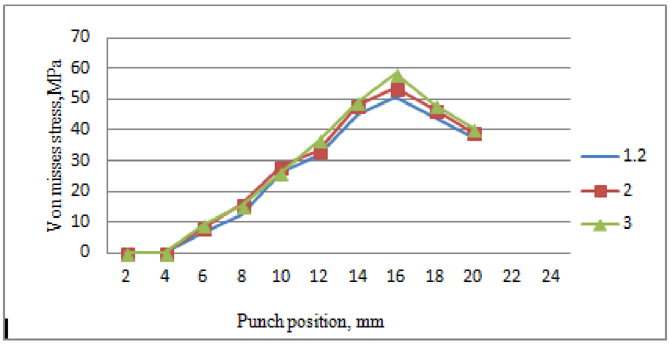


Fig 20: Variation of Von Mises stress with different Punch position at 60^0 bending

Fig 20 shows variations of Von Mises stress with the different punch position at 60^0 bending, the stress increases as the punch position increases till a maximum value and then decreases. Here the maximum Von Mises stress for 1.2 mm, 2mm, and 3mm thickness is 51.89 MPa, 49.71MPa and 40.01MPa respectively.

Fig 21: Variation of Von Mises stress with different Punch position at 90^0 bending

Fig 21 shows variations of Von Mises stress with the different punch position at 90^0 bending, the stress increases as the punch position increases till a maximum value and then decreases. Here the maximum Von Mises stress for 1.2 mm, 2mm, and 3mm thickness is 53.69MPa, 48.41MPa and 42.09MParespectively.

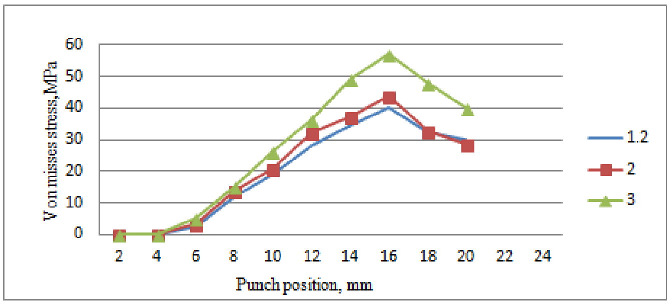


Fig 22: Variation of Von Mises stress with different Punch position at 120^0 bending

Fig 22 shows variations of Von Mises stress with the different punch position at 120^0 bending, the stress increases as the punch position increases till a maximum value and then decreases. Here the maximum Von Mises stress for 1.2 mm, 2mm, and 3mm thickness is 58.63MPa, 54.5MPa and 52.9MPa respectively.

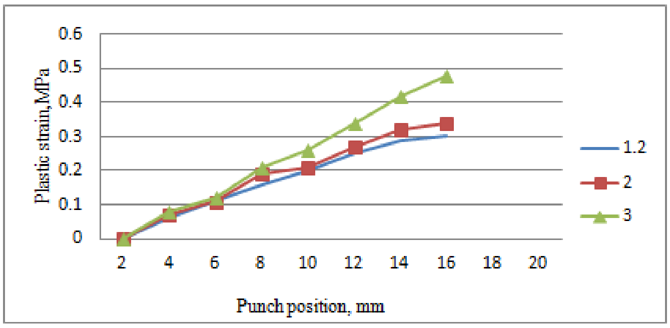


Fig 23: Variation of Plastic strain with different Punch position at 60^0 bending

Fig 23 shows variations of Plastic strain with the different punch position at 60^0 bending, the plastic strain increases as the punch position increases till a maximum value and then remains unchanged. Here the maximum Plastic strain for 1.2 mm, 2mm, and 3mm thickness is 0.303, 0.350 and 0.488 respectively.

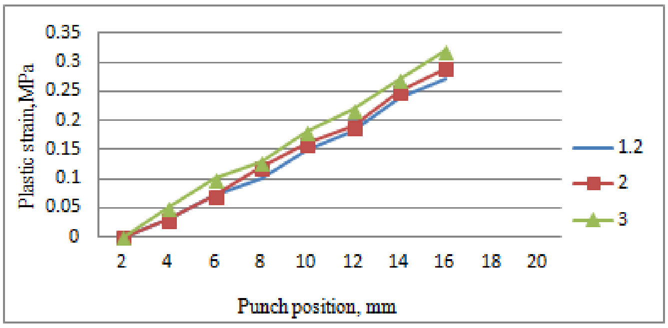


Fig 24: Variation of Plastic strain with different Punch position at 90^0 bending

Fig 24 shows variations of Plastic strain with the different punch position at 90^0 bending, the plastic strain increases as the punch position increases till a maximum value and then remains unchanged. Here the maximum Plastic strain for 1.2 mm, 2mm, and 3mm thickness is 0.271, 0.267, and 0.397 respectively.

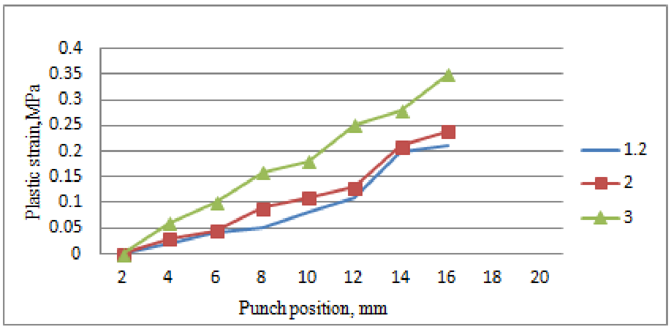


Fig 25: Variation of Plastic strain with different Punch position at 120^0 bending

Fig 25 shows variations of Plastic strain with the different punch position at 120^0 bending, the plastic strain increases as the punch position increases till a maximum value and then remains unchanged. Here the maximum Plastic strain for 1.2 mm, 2mm, and 3mm thickness is 0.129,0.154 and0.592 respectively.

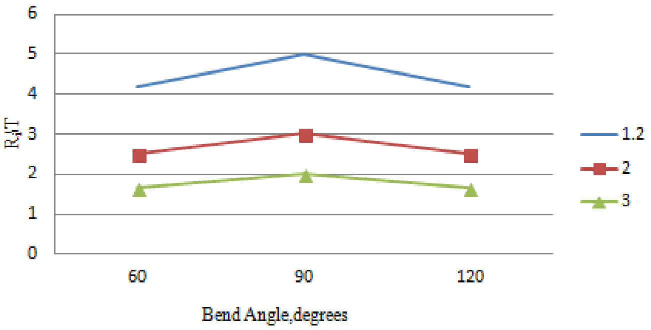


Fig 26: Variation of R_i/T with different values of Bend angle.

Above figure shows graph of Variation of R_i/T with different values of bend angle the R_i/T factor is maximum at 90° for 1.2mm V-bending.

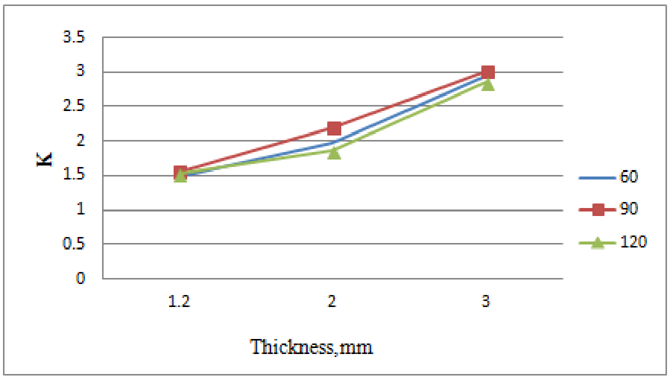


Fig 27: variation of stiffness (K) with different values of T

COMPARISON

The one to one comparison with Experimental and FEA results are tabulated as below

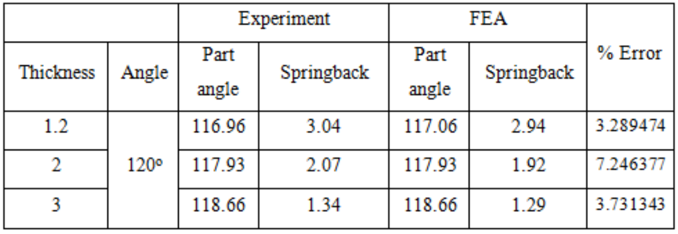
Table 2: Comparison of Experimental Springback and FEA Springback at 60^0 bending

		Experiment		FEA		% Error
Thickness	Angle	Part angle	Springback	Part angle	Springback	
1.2	60°	59.17	0.83	59.25	0.75	9.638554
2		59.53	0.47	59.6	0.4	14.89362
3		59.7	0.3	59.72	0.28	6.666667

Table 3: Comparison of Experimental Springback and FEA Springback at 90^0 bending

		Experiment		FEA		% Error
Thickness	Angle	Part angle	Springback	Part angle	Springback	
1.2	90°	88.37	1.63	88.42	1.58	3.067485
2		88.75	1.25	88.81	1.19	4.8
3		89.01	0.99	89.03	0.97	2.020202

Table 4: Comparison of Experimental Springback and FEA Springback at 120^0 bending



		Experiment		FEA		% Error
Thickness	Angle	Part angle	Springback	Part angle	Springback	
1.2	120°	116.96	3.04	117.06	2.94	3.289474
2		117.93	2.07	117.93	1.92	7.246377
3		118.66	1.34	118.66	1.29	3.731343

CONCLUSIONS

In this thesis, Springback effect is evaluated under various thicknesses and angles. Also FEA Study has also been done with the help of LS Dyna.

As the thickness increases for the same bend angle Springback is also increases. Also it has been observed that as the bend angle increases for the same thickness the Springback is increases.

The FEA study is done in LS-Dyna and the von Mises stresses and total plastic strain are considered and plotted. Von Mises stresses in each case reach a maximum limit and then reduces depending on the thickness and bend angle. Total plastic strain increases to a maximum value anf the remains stable.

The experimental Springback values are also compared with the regression analysis and their respective graphs are drawn. This will helps us to predict the angle required to achieve the exact bend angle so that deviation in assembly level can be reduced. This also helps in reducing the usage of Shims, which accounts a enormous decrease in the aircraft weight.
Future Scope:

- One of the future studies related to this study may be the simulation and analysis of different forming operations such as Stretch forming, U-die bending and bending with flexible tooling. In such a case, the tooling configurations may be varied and the changes in the processes may be investigated. As stretch forming is used for Producing aircraft skins, the springback analysis will help in avoiding the deformation after stretching.
- Further more iterations by summing up the springback value obtained to the required angle will predict the exact angle to be bent for obtaining the exact bend angle.
- Another further study may be to analyze more complex bending operations by utilizing hot forming processes. Effect of material model to the bending and Springback simulation may also be studied.
- Finally, FEM may be used in addition with optimization by which new algorithms may be created and tooling design of complicated bending processes may be accomplished

Vibrational study of the blank and punch by using sensors to study the vibrations involved in the whole punching action. The study involves in the use of sensors that are installed on to the blank and punch.

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