Design and Development of a Stamping Die for a Sheet Metal Part at 100-ton Press Machine

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A thesis submitted in partial fulfillment of the requirements for the degree
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Abstract

Bending is one of the most frequently used process in manufacturing industry. The bending operation involves springback, which is elastic recovery of the part during unloading. It is still a practical problem to predict the final geometry of the part after springback. To resolve that, this experimental study investigates the effect of punch displacement, sheet thickness, friction coefficient and material type during the sheet metal bending process under room temperature condition. Furthermore, the effect of R/t ratio and clearance is also studied. The amount of springback, total deformation, the total equivalent plastic strains, and the equivalent von Mises stresses are also observed. Moreover, the finite element method results are compared with experimental results.

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CHAPTER 1: INTRODUCTION

1.1 Introduction:

Sheet Metal forming though conventional is the process of forming technologies that have been extensively used in nearly all manufacturing field. Primary Shapes of products are made through plastically deformations, which can be done through forging, rolling, extrusion, hydroforming and sheet metal forming. In the deformation process, sheet metal forming is a significant procedure in which raw material is shaped into the desired form with relatively simple tools by applying force beyond the yield strength (Grover & Groover, 1996). By doing so, a variety of complex shapes can bend or stretch. Many metallic components of aircraft, automobiles, household apparatus and building products are made by deformation methods.

Parts that are made through sheet metal forming have great strength and good surface. In recent times, the demand for reducing fuel consumption with increasing safety factor and increasing the efficiency of an engine is one of the most important challenges for automotive manufacturers. Reduction in weight is one of the feasible solutions for it. Lightweight materials with high strength can help regarding this matter and can be made into the desired form by sheet metal forming technique.

Sheet metal forming processes comprise the following as shown in figure 1.1.

- Bending
- Stamping
- Deep drawing
- hydroforming
- Hemming
- Seaming
- incremental sheet forming
- ironing
- rolling
- spinning
- stretch forming
- DE cambering

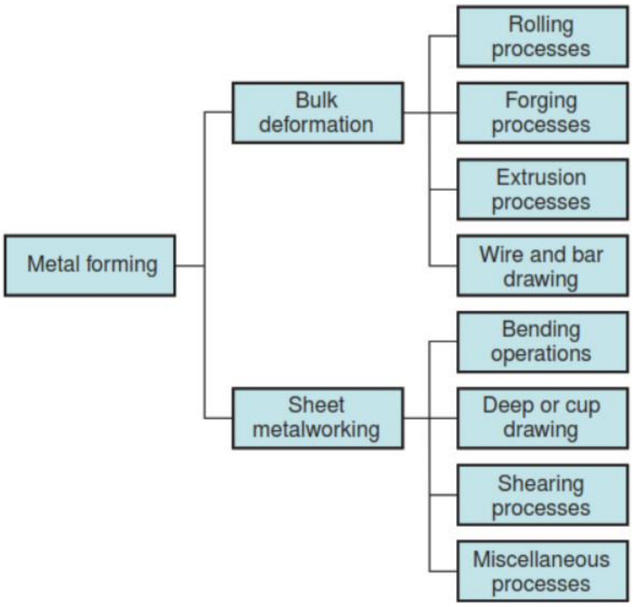

Figure 1.1: sheet metal forming types (Grover & Groover, 1996)

Sheet metal forming is commonly done on a press machine with the help of tool die set. The top part is called a punch and the lower part is called die. Parts that are made through sheet metal forming are sometimes referenced as stampings. Depending on the complexity of the formed part, sheet metal forming can be done in a single stage or multiple stages to convert the workpiece to the desired final outcome. Multiple stages bending is done in progressive or transfer die. Sheet metal is usually formed cold. However, parts can be made through warm or hot forming (Grover & Groover, 1996).

Parts are usually inexpensive and easy to bulk manufacturing. However, unacceptable products may produce through sheet metal forming with cracks, poor dimensions and precision. Except tools and parameters are properly selected. All forming process takes place in the plastic region. Therefore, to investigate springback, nonlinear material properties, which include stress-strain connections in the nonlinear areas, are needed. The strength of the work part shifts through plastic deformation as a function of different material and process parameters as shown in the following equation.

$$\sigma = (C, K, \varepsilon, \varepsilon', n, m, r_n, T)$$

In the preceding equation, are strength coefficients C and K are used to calculate plastic stress through strain (ε) and strain rate (έ), sequentially. Stress calculation in terms of strain depends on strain hardening exponent (n). n indicates the increase in material strength during plastic deformation. r_n indicates the normal anisotropy which is a plastic strain of material and significantly influences the behavior throughout plastic deformation. Normal anisotropy is the measure of the deviation of material properties with direction (Erdin & Atmaca, 2016).

1.1.1 Sheet Metal Bending:

Bending process results in both tension and compression in the sheet metal forming. By the outside surface, undergo tension and expands while the inside surface experiences compression and contracts, the phenomena may be linked to bending allowance and bend deduction as shown in figure 1.2 (Akinlabi & Akinlabi, 2017).

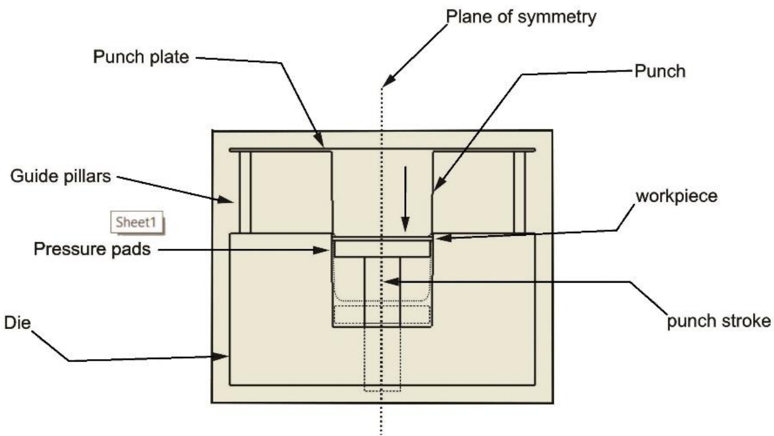

Figure 1.2: Sheet Metal Bending Process

According to T and Dametew (2017) bending processes is one of the important and widely used processes in sheet metal forming. There are different types of bending some of the bending process types are as follows.

- U bending
- V bending
- W bending
- Edge bending
- Air bending
- Rotary bending

In the sheet metal product industry, bending tools and dies have significant importance which is generally used to manufacture sheet parts of different dimensions used in nearly all industrial processes. However, product quality and success depend upon the designer experience as well as operating parameters like material properties, working condition, clearance, punch/die geometry, friction condition, etc. During all mechanical process, some defects are due to material resistance characteristics for making it to the required form.

Springback/spring go is one of these defects and occurs in the sheet metal bending process. After releasing the forming tools from the formed component, the component tries to return to its original shape which is called springback. During certain conditions, when the initial bend angle can possibly be greater than the final bend angle, it is called spring-go. So, in the bending process spring go back/spring should be in the notice and in acceptable tolerance while the design of bending dies.

1.1.2 Cold Stamping:

Metal forming conducted at room temperature or slightly above is known cold working. The advantage of cold working is to get Great strength and good surface finish without wasting furnace and fuel cost. On the other hand Higher forces and power are required for cold stamping (Grover & Groover, 1996). Mostly non-heat treatable alloy components are formed through cold stamping process using rigid die (Zheng, Politis, Wang, & Lin, 2018).

1.1.3 Finite Element Method in Sheet Metal Forming:

In the past, Trail and error experiments were used for metal forming tool designs. furthermore, it depended on the experience of engineers (T & Dametew, 2017). These methods are quite expensive and time-consuming. So, it is necessary to develop and use well organized and scientific methods for the two main causes as follows: First, the prediction precision by the analytical method is limited because of the lack of mathematical modeling of a method and solving technique. The Second nonlinearity and other method complexities produce some limitations to calculate springback of the material. Also, the elastic recovery phenomenon is determined by a combination of different factors (Cho, Moon, Moon, & Kang, 2003).

So, in order to overcome these problems, Finite element analysis is one of the latest techniques, which can be applied in sheet metal forming to predict the springback in the material without any cost. This can be implemented to the sheet forming process to estimate the response and the mechanical properties of the material under loading. Finite element analysis software provides efficient and strong tools and settings to model and simulate different processes.

Finite element Analysis in stamping design has the following stage. The die designers develop the tools and die for the required part shape in any cad software based on the experience of the designers. Repeated FE simulation is done to check the feasibility of the tool, die designs and workpiece final shape and the best one is chosen.

FE simulations are used to predict the springback in the formed part after forming and compensate for springback in die design such that the formed part is within the tolerance limits. Thus, Finite element analysis can be acted as a virtual press in the stamping industry to check the feasibility of forming. After design and simulations, physically dies and tools can be made as per a feasible design. Thus, Finite element analysis is an integral part of the simultaneous engineering approach to product development and stamping process development in different industries. In recent times numerical simulation based on finite element methods in coinciding with different optimization methods has become of great importance in multiple engineering fields due to the need for mass production of quality products having dimensional precision especially in aerospace and automotive and so far, excelled the conventional design methods.

1.1.4 Problems in Sheet Metal Bending:

In sheet metal bending, dimension accuracy is a primary interest due to elastic recovery during unloading of the die, called springback effect. Based on different material properties and process parameters, springback may be less or more. Sometimes the resulting bend angle is higher than the actual bend angle which is called spring go as shown in figure 1.3. According to Erdin and Atmaca (2016) Springback is the most discussed issue in bending.

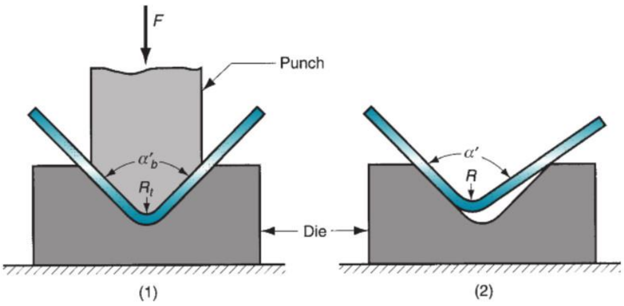

Figure 1.3: Springback in sheet metal bending (Grover & Groover, 1996)

Different process parameters i.e. sheet thickness, anisotropy, tool/die shape and dimensions, frictional conditions and material properties determines Spring-back/ spring-go. (Shah, Sharma, & Patel, 2011).

Formula to detect springback in material is as follow

$$SB = \frac{\alpha - \beta}{\beta}$$

Where SB is the springback. α is the desired angle β is the final angle. Springback is essential to control for accurate precision of part in sheet metal bending. Compensation for springback can be achieved by many methods. Two most common method is bottoming and over bending (Grover & Groover, 1996).

1.1.5 Applications:

In all industrial fields, U bend shaped parts have increased. Products that are made through bending are automotive (doors, hoods, fenders), air craft industry (wings, fuselage), trains, aerospace vehicles, Home appliance industry, Food industry, house panels, machine housings, pressure vessels, medical equipment, farm equipment, furniture, computer equipment, machine equipment, beverages cans etc. Historically, an essential application of sheet metal was in plate armor used by cavalry.

Handling, comfort, better performance, and fuel average can be achieved by reduction automobile weight by forming of lightweight high strength material i.e. aluminum as shown in figure 1.4. Medium or high strength aluminum alloys can be used for outer panel structures. (Zheng et al., 2018).

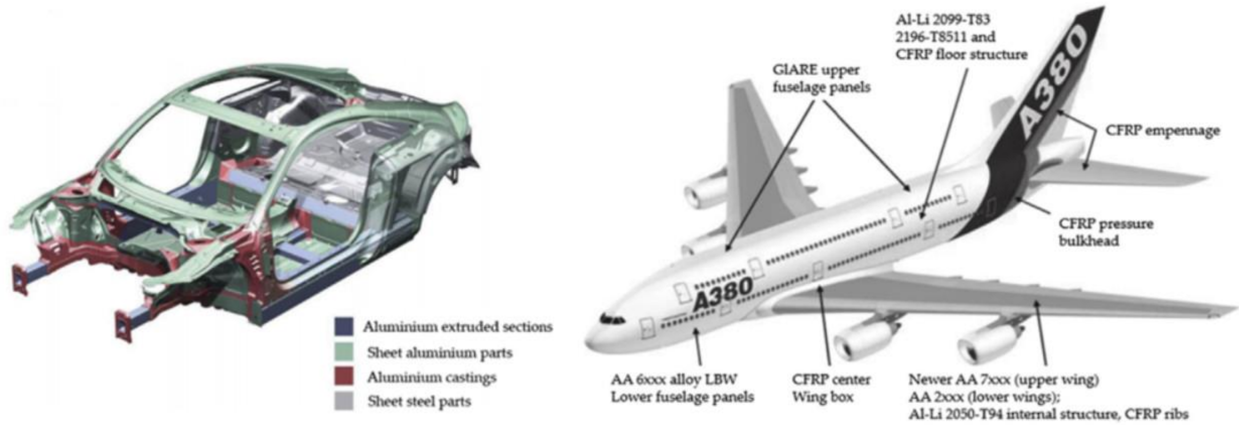

Figure 1.4: Applications of Aluminum Alloy panel structures in a automobile and aircraft (Zheng, Politis, Wang, & Lin, 2018)

Copper alloys are generally employed in electrical and electronics industries for its excellent properties and formability.

1.2 Problem Statement and Description:

The final geometry of part is still a problem in manufacturing because of springback (Esat, Darendeliler, Gokler, & design, 2002). Due to which unacceptable parts with poor dimension precision usually produces (Fouda, El-Bana, & Samuel, 2015). Although the outcomes of some factors on spring- back/spring-go in U-bending process were studied, the bending mechanism explanation on these outcomes has not been described (Phanitwong, Sontamino, & Thipprakmas, 2013). The non-linear behavior of plastic deformation makes it hard to calculate springback value analytically in the bending process (Erdin & Atmaca, 2016). So, in order to check the springback of different material through Finite element method and experimental work, a tool and die is designed for a sheet metal part of the 100-ton press machine. The amount of total deformation, stresses and strains occur in sheet metal part, overcoming of springback through different techniques and selection of optimized parameters are developed in this research.

1.3 Overall Aim:

The overall aim of this project is to design tool and die for a 100-ton press machine and to analyze the effect of various parameters on springback in sheet metal bending part. It also includes investigating the extent to which advance software methods can be used to estimate springback in sheet metal bending process and to improve optimization procedure in order to control the springback to an acceptable level.

1.4 Objectives:

Following are the objectives of this research

1. To conduct a literature review of the analysis of the sheet metal bending, springback prediction and related optimization techniques
2. To design a tool die set on parameters extracted by literature in any cad software i.e. SOLIDWORKS 2018
3. To evaluate to feasibility of tool die set design by software simulations and check the springback of materials by applying different factors and conditions

4. To conduct the experiments for u bending process in actual environment and check the springback in sheet metal part and compare it with simulation result
5. To conduct the parametric studies using another software MINITAB 18 and study the impact of the main factors on springback through ANOVA technique
6. To develop appropriate optimization techniques to minimize the springback in sheet metal bending operation

1.5 Literature Review:

In most sheet metal forming processes, the shape of the rigid components tool and die is kept according to the final shape of the workpiece. In some sheet metal forming process, a holder is needed. However, there is no holder in the air bending process. Manufacturing industries manufacture more than 55% of sheet metal components by press-brake bending. In order to understand the bending mechanism, understanding of springback, bend force evaluation, press capacity selection, strength examination and design of dies should be in consideration. Many scholars studied the springback effect of U-bending because the deformation of U-shaped is complicated more than other shapes and this process is usually used to produce sheet parts like channels, beams, and frames (Sae-Eaw et al., 2013). A lot of researchers investigated and attempted to understand the basics of springback/spring go behavior of different materials (Shah et al., 2011). Esat et al. (2002) studied about the springback in L bending of aluminum alloys in finite element analysis and concluded that springback generally depends on the angle ratio and metal mechanical properties. It increases by increasing the strength and decreasing the yield modulus of the material. Ling, Lee, and Cheok (2005) investigated about finite element method work on the L bending of aluminum alloy. Die clearance, die radius, step height and step distance effects were studied on the springback of material and concluded some equations to calculate spring ack and design of die but there are limitations of the reliability of the analytical equations for the calculation of springback of other materials. Shah et al. (2011) studied the effect of bending orientation, thickness, material strength and tip radius on the springback of aluminum alloy, DD1079 and EDD513 in the finite element. Springback decreases when the tip radius decreases and sheet thickness and material strength increase. When material strength decreases the springback effect changes into spring go effect and anisotropy of orientation is nothing but the ability of the material to resist against thinning. Results of material strength are in conflict with previous literature (Esat et al., 2002). So there is some more investigation needed for the effect of material strength on springback. Akinlabi and Akinlabi (2017) studied the effect of punch stroke upon U bending by finite element analysis on MARC MSC software 2015. According to researchers, punch stroke is directly proportional to the resulting bend angle and plastic. Stresses and strains can have an adverse effect if not controlled and monitored properly. There is a limitation of using any particular material type in this research. Tekıner (2004) studied springback analysis of sheet metals in hydraulics v bending with several thicknesses and materials. The researcher developed a methodology in which punch is kept on the workpiece with different force and time span. The longer the load is kept the lesser the springback in the material. Springback increases as the R/T ratio and yield stress of the material increases and the elastic modulus decreases which confirm the results of Esat et al. (2002) modulus on springback of material. Sae-Eaw et al. (2013) studied the effect of punch radius and blank holder force effect on springback of UHSS material experimentally. The standard and comparison of results are NUMISHEET 2011. So, when the punch radius decreases, and the blank-holding force increase the plastic strain in the material increase in bending material and springback decreases. The researcher also studied the bending force effect by varying the punch radius and blank holding force. Increasing the punch radius and decreasing the blank-holding force, the bending force also decreases. Yield strength also affects the springback of the material, the higher yield strength of materials higher is springback. The results of this paper confirm the punch radius effect on springback of previous simulation work of Shah et al. (2011) and material strength of Esat et al. (2002). Choi and Huh (2014) studied the Impact of punch speed on springback in the U-bending process experimentally and concluded that the impact of punch speed has very less effect on the springback for both steel sheets. In steel sheet springback increases by high punch speed. Hence punch speed should be in consideration to increase the dimensional precision. Ramulu, Rao, and Yimer (2016) studied the effect of load, displacement and die angle on springback of aluminum alloy in v-bending experimentally. The effective range of springback for current material is observed between 75º and 98º die angles and the effects of roll direction on springback are very sharp and prominent. Some deviation and cracks occurred due to impurities present in sheets and die should be designed to accommodate various angles of bending. Phanitwong et al. (2013) studied the outcomes of different parameters on the spring-back/spring-go feature of aluminum 1100-O on finite element analysis as well as experimentally. According to the researcher springback of workpiece increases as the punch/die radius and workpiece length increases and workpiece thickness and u channel width decreases. U channel width to length ratio is surely counted in order to achieve the required angle. Punch radius effect on springback is good agreement with (Sae-Eaw et al., 2013); Shah et al. (2011). Fouda et al. (2015) studied the die profile radius effect, punch profile radius and coefficient of friction on U-bending of aluminum alloys and steel alloys. Researchers studied these parameters in the finite element method as well as experimentally. Springback value increases as the punch profile radius and strain hardening exponent increases. Punch profile radius effect on springback is good agreement with Phanitwong et al. (2013); (Sae-Eaw et al., 2013; Shah et al., 2011). While increasing the die profile radius and anisotropic value of the material, springback decreases. According to researchers, the value of springback of Aluminum is highest than stainless steel and mild steel. It is because the value of yield stress to the modulus of elasticity ratios for mild steel is greater than stainless steel and aluminum. A higher value of this ratio, anisotropic value and lower value of strain hardening exponent, lower is the springback in material. Hattalli and Srivatsa (2018) studied about the frictional effects, punch/die radius, yield stress and Young's modulus on springback in metal forming and sheet metal bending. The reduction of tool/sheet radius causes the reduction of strain rates. However, friction has a very low effect on springback. Increasing the punch/die radius, yield stress and hardening exponent also increases the springback in the sheet. Springback angles increased with an increasing yield stress and increasing hardening exponent. However, springback has a counter relation with the values of Young's modulus. Punch/die radius and strain hardening exponent is good agreement with previous literature. Sharad, Nandedkar, and Engineering (2012) studied the effect of sheet thickness and bending angle to rolling direction on springback of CK67 in the bending process with the finite element method and experimental approach. According to researcher increasing the sheet thickness decreases the springback with more accurate sheet angle with respect to die. In addition, the second factor also affects the springback and has a positive correlation with it. In CK67 bending there is not any spring forward and all the faults are springback. S Jafar and Gatea (2013) studied heat treatment effects on the springback in the U bending process of carbon steel material AISI 1023. Heat treatment process annealing, normalizing and quenching has an evident effect on springback of the U bent part. According to researchers due to heat treatment, the value of springback increases while the yield stress decreases. In quenching; failure was noted in the bent part and the value of springback is the highest due to the Excessive distortion generated in the sheet after the quenching method because of its low thickness. Sharad and Nandedkar (2014) studied the effect of die radius, thickness, strength coefficient and R/t ratio on springback with the help of the finite element method for two various material. Researchers developed the methodology of the neural network approach to calculating the springback gained from finite element analysis and the result has good agreement with simulations for various factors. According to the researchers springback increases by increasing the R/t ratio and strength coefficient. While springback decreases by increasing the thickness and strain-hardening exponent. Strain hardening exponent on springback is different as explained in Fouda et al. (2015); (Hattalli & Srivatsa, 2018) probably because of different material models. While the other factors results are good agreement to previous literature. Erdin and Atmaca (2016) studied the effect of holding force on annealed aluminum 1050-h14 plates springback behavior in v bending experimentally. Annealed material on 120 degrees with 20 minutes and anisotropy of 0, 45 and 90 has been used. According to researchers, annealing and holding force together reduce the springback because of bending area strain hardening and removal of residual stresses. The greater the rolling direction the greater is the springback which is a good agreement in previous research (Sharad et al., 2012). According to researchers, the outcome of heat treatment must be investigated further to describe different annealing temperatures and cooling requirements by examining the variation in microstructure and mechanical properties. SALVI, MESTRY, and KAVATKAR (2016) Investigated the effect of thickness and rate of feeding of springback of aluminum alloy in L bending using the Taguchi Design of Experiment. Researchers used reverse bending technique and time settling method for the minimization of springback in which the punch is kept for different time span on the sheets. The effect of sheet thickness is most significant on springback of material. Phanitwong and Thipprakmas (2017) studied the channel width effect on springback of aluminum 1100 through experiments and finite element method. Small channel width increases the springback as compared to when the large channel width is used. But somehow channel width variation has a very low effect on springback. For improving the quality of the parts, researchers studied u bending with pressure pads and without pressure pads. The stress formation is prevented in the lower surface and the legs of the workpiece with the pressure pads application in case of U-Bending. All these effects are reversed when no pressure pads are used. T and Dametew (2017) studied the effect of sheet thickness, material type, tool radius and friction coefficient on springback in sheet metal by using a mathematical model. Aluminum, copper, mild steel and high strength steel sheet metal parts are used for research. Springback decreases when sheet thickness increases and tool radius, die radius and friction coefficient decreases. In addition, springback for the differential die is lower than edge bending die. As for as material type which showed low to high springback is aluminum, copper, mild steel and high strength steel respectively. Researchers developed mathematical modeling and investigate the effect of each parameter.

Moreover, these predictions are associated with earlier studies and optimization is achieved. Some of the suggestions are given in this literature is using finite element simulations to compensate springback in die design, to investigate the tool material effect in springback and development of springback prediction is carried in warm and cold sheet metal condition. Alhammadi, Rafique, Alkaabi, and Abu Qudeiri (2018) studied Experimental examination of springback in aluminum, stainless steel and brass. Despite the numerous current studies associated to springback, there is a need to explains the bending load effect at the end of the loading stage for multiple time spans. Artificial neural network (ANN) is employed for the prediction of springback on experimental data. Results show that lower elastic modulus gives higher springback as they generate higher strain. It is determined that the springback increases as the die opening increases but sheet thickness and springback have a negative correlation. The effect of elastic modulus on springback is good agreement with the results of (Tekıner, 2004) and the effect of punch time on material is good agreement with (Erdin & Atmaca, 2016; SALVI et al., 2016). Well most of the research papers are about to high strength steel and aluminum sheets but very few researchers studied about the copper alloy which is frequently used for connectors formed by press forming, and in a recent automotive, thousands of terminals are utilized (Hamasaki, Hattori, Furukawa, & Yoshida, 2014). Hamasaki et al. (2014) studied about Bauschinger effect through cold-rolled copper alloy sheet unloading and its effects on springback. Wang, Fu, and Ran (2014) Analyzed the Size Effect on springback Behavior in Micro-Scaled U-Bending Process of copper alloy 2689 R-H with different heat treatment process through the finite element method and experiments. In the micro-bending method, sheet thickness, the grain size, and their ratio are the main parameters affecting. For the low thickness, springback angle normally increases and it does not matter how high the grain size is for the same forming angle. The reason behind it is a large plastic deformation area. For the scenario with various punch radii, the springback angle has a diverse variation trend with grain size. Through the same punch radius, it increases with the average grain size. Due to the punch radius influence, the springback angle does not change with grain size. At higher punch radius, the metal sheet with the lowest and largest grain size gives a higher springback angle, while medium grain size sheet has the least springback.

Having seen almost all the relevant literature we can assume that a lot of research is being done on springback by examining a few variables i.e. punch radius, die radius and sheet thickness. Not much is done on other variables i.e. R/T ratio, friction coefficient and material strength. Also, very few literature are available in which a comparison of different materials is done. Even though the effects of springback can calculate through analytical models and numerical methods but all these numerical models have their own limitations. Thus, there is a need to develop a methodology for the prediction and controlling of springback by considering some more variables for different materials.

CHAPTER 2: METHODOLGY

2.1 Research Outline:

To achieve the research objectives, the research approach is divided into three major phases as shown in figure 2.1.

Phase 1: Problem identification, Detailed literature review and formulation of objectives.

Phase 2: Design and Development of a methodology to predict the optimal Tool and die shape that will result in a desired final formed part using software i.e. SOLIDWORS and Ansys.

Phase 3: Manufacturing of tool and die, experimentation, evaluation of finite element simulation and experimental results and optimization.

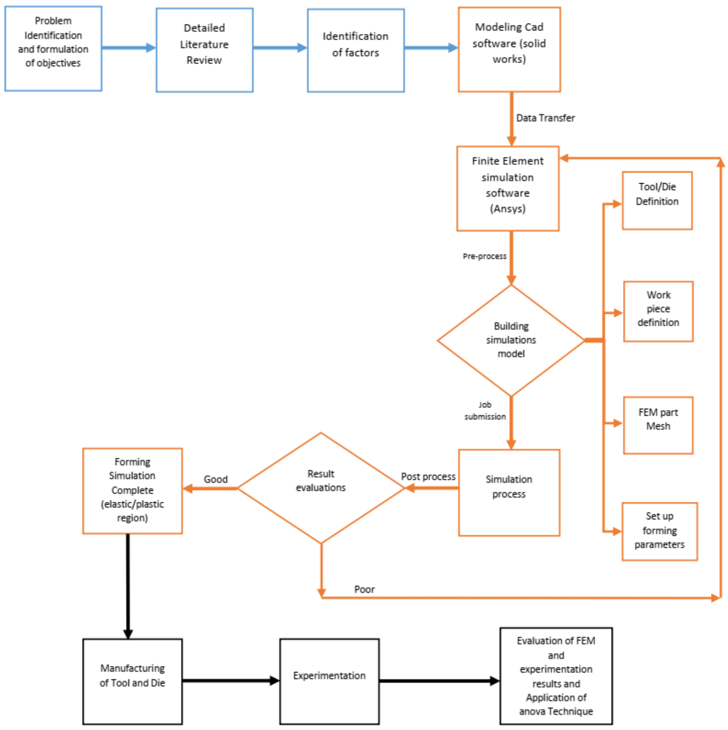

Figure 2.1: Research Outline

2.1.1 Material Selection:

Research has been conducted with Aluminum 2024-T3-T3, Aluminum 6061-T6-T6 and Cartridge Brass, UNS C26000 (260 Brass). The alloy 2024-T3 contains Al, Mg, and copper. The alloy 6061-T6 comprises Al, Mg, and Si while Cartridge Brass, UNS C26000 (260 Brass) comprises Cu, Zn, and Pb. The material selected for tool/die is AISI 1045 Medium Carbon Steel which contains Fe, C and Mn. The sheet metal part has 200 mm length and 48mm width. Sheet metal strip thickness is 2mm and 3mm. The reason behind such a small dimension is to save material cost. Material properties are shown in table 2.1.

Table 2.1: Material Properties

Sr#	Material	Density (kg/m^3)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Poison Ratio
1.	Aluminum 2024-T3	2780	290	440	73.1	0.33
2.	Aluminum 6061-T6	2700	276	310	68.9	0.33
3.	Cartridge Brass	8530	275	370	110	0.375
4.	AISI 1045	7870	310	565	200	0.29

2.1.2 Selection of Lubricant and Factors:

After the selection of sheet metal dimensions, the parameters of punch and die are selected which are kept at 4.5 mm. The reason behind the selection of punch and die parameters is to study the R/t ratio effect on the bending of the sheet metal part. R/t ratio is selected between 1.5 to 2.0 and 2.0 to 2.5. According to Sharad and Nandedkar

(2014) springback decreases when R/t=2 and after that, it can increase or decrease depending on the material type. So, there is a need for further investigation of R/t for different material models. In order to change the friction coefficient value and to avoid any cracking of material, a lubricant of ZIC 10 W-40 is selected. ZIC 10W-40 has a longer draining interval with a thick layer of protection. It has viscosity index 157, flash point 257 degrees and pour point is -35 degrees.

2.1.3 Design of Experiments:

The software MINITAB 18 is used as the statistical tool to examine the data and orderly outcome variables that affect product quality. The experiments are planned to examine the springback taken for various bending factors. The varied parameters are material type, material thickness, punch displacement, and friction coefficient. Each parameter has different levels. The total number of experiments are 24 as shown in table 2.2.

Table 2.2: Design of Experiments

Sr#	Materials	Displacement (mm)		Thickness (mm)	Friction Condition	
1	Al 2024-T3	D1	0	2	Lubricated	0.33
2	Al 2024-T3	D1	0	2	Non-Lubricated	0.5
3	Al 2024-T3	D1	0	3	Lubricated	0.33
4	Al 2024-T3	D1	0	3	Non-Lubricated	0.5
5	Al 2024-T3	D2	15	2	Lubricated	0.33
6	Al 2024-T3	D2	15	2	Non-Lubricated	0.5
7	Al 2024-T3	D2	15	3	Lubricated	0.33
8	Al 2024-T3	D2	15	3	Non-Lubricated	0.5
9	Al 6061-T6	D1	0	2	Lubricated	0.27
10	Al 6061-T6	D1	0	2	Non-Lubricated	0.5
11	Al 6061-T6	D1	0	3	Lubricated	0.27
12	Al 6061-T6	D1	0	3	Non-Lubricated	0.5
13	Al 6061-T6	D2	15	2	Lubricated	0.27
14	Al 6061-T6	D2	15	2	Non-Lubricated	0.5
15	Al 6061-T6	D2	15	3	Lubricated	0.27
16	Al 6061-T6	D2	15	3	Non-Lubricated	0.5
17	Cartridge Brass	D1	0	2	Lubricated	0.3
18	Cartridge Brass	D1	0	2	Non-Lubricated	0.45
19	Cartridge Brass	D1	0	3	Lubricated	0.3
20	Cartridge Brass	D1	0	3	Non-Lubricated	0.45
21	Cartridge Brass	D2	15	2	Lubricated	0.3
22	Cartridge Brass	D2	15	2	Non-Lubricated	0.45
23	Cartridge Brass	D2	15	3	Lubricated	0.3
24	Cartridge Brass	D2	15	3	Non-Lubricated	0.45

2.2 Design of Punch/Die Set:

The software SOLIDWORKS 2018 is a Mechanical 3D design modeler. This software makes it feasible for designers to instantly sketch designs and create models and detail drawings with various dimensions and features. Starting from the paper drawing then working on the SOLIDWORKS interface to make the components from the first sketch after that mating the parts mutually in one assembly to make the ultimate design. The final step is to create a 2D drawing before assigning the design to the workshop to produce the actual model. Figure 2.2 shows the four vital levels of SolidWorks

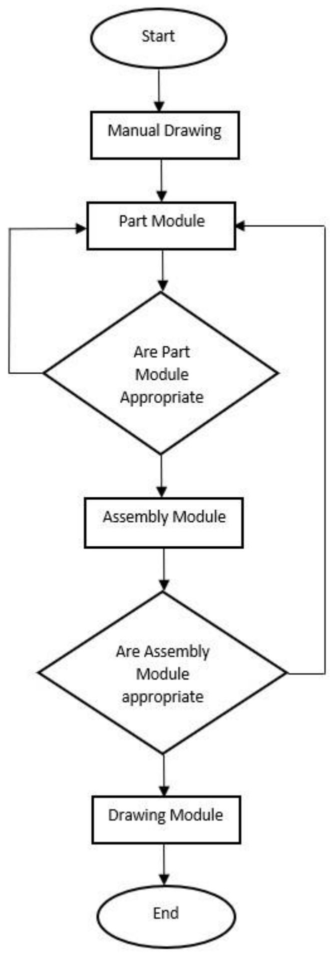

Figure 2.2: Systematic steps in designing using CAD software

2.2.1 Punch Design:

Designing steps are following the flow chart in figure 2.2. Initially, the dimensions decision of the punch part to make an appropriate design. The next step is 3D modeling of punch on the basis of selected parameters. Sketching of the part has done on a front plane with a punch radius of 4.5 mm by fillet command. A backup punch plate with guide pillars and shank has designed to hold the punch as shown in figure 2.3. The dimensions of the punch plate have kept by considering the necessary requirements of the press machine force and other safety factors.

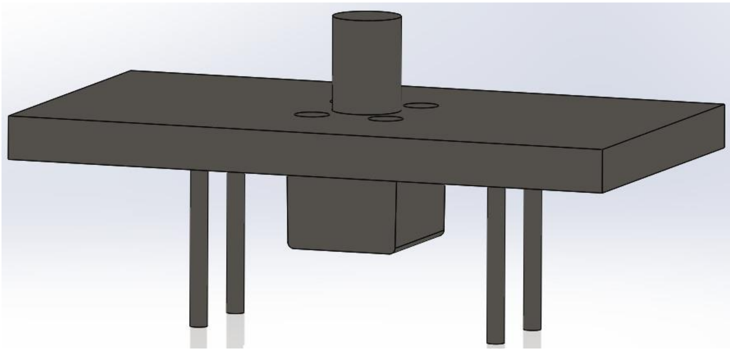

Figure 2.3: Punch Design with punch holding plate and guide pillars

2.2.2 Die Design:

Designing steps are following the flow chart in figure 2.3. Initially, the dimensions decision of the punch part to make an appropriate design. The next step is 3D modeling of die on the basis of selected parameters. Sketching of the part has done on a front plane with a punch radius of 4.5 mm by fillet command. A back up die plate is designed to hold the die and pad for the safety of workpiece as shown in figure 2.4

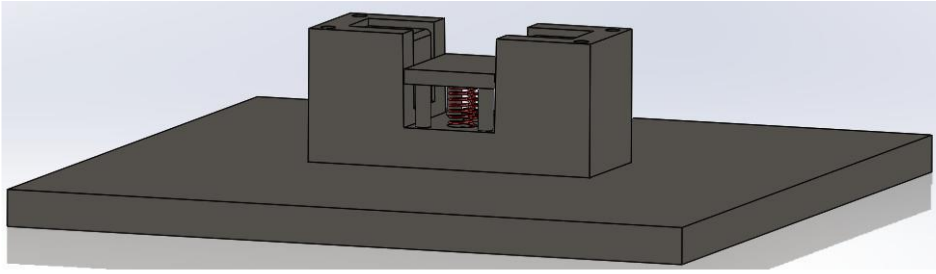

Figure 2.4: Die Design with die plate and pad

2.2.3 Final Assembly:

The final step is to connect every component and subassembly with each other to create the final design. The bottom-up method is applied in this step, which begins by creating the components then combine these components together using mates. These mates aid in limiting the movement of the components by creating geometric relations. Through these commands, the Punch plate is assembled with punch and guide pillars on one side and shank on the other side. While die is assembled with die plate. The whole assembly is shown in figure 2.5. Mass of material to manufacture the whole punch/die set is 143 kilograms.

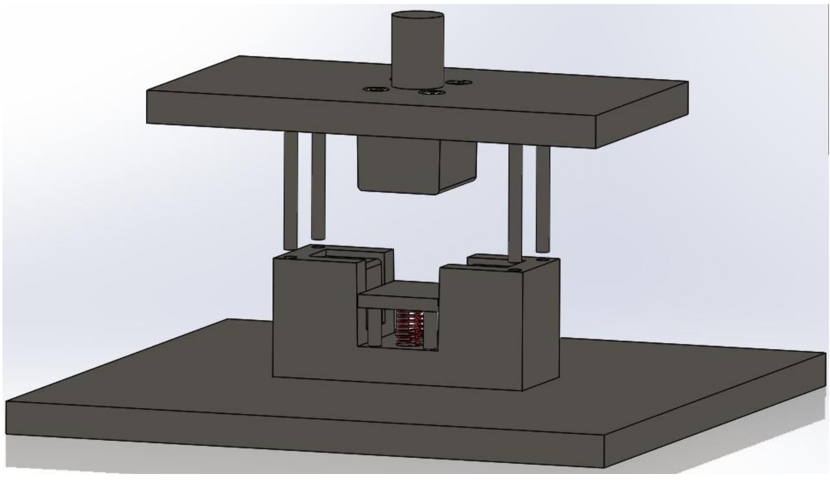

Figure 2.5: Final assembly

2.3 Finite element analysis with Ansys static structural:

Finite element analysis is used to predict the behavior of parts with respect to applied loads. Here in this work, ANSYS 19.0 software is used for analysis. Out of various modules, we have selected statics structural for our analysis as shown in figure 2.6. Stresses, strains, displacement, and forces in structures or components caused by loads are determined through static structural analysis. The forming process takes place in the plastic region that's why material elastic plastic characteristics are necessary for this analysis. Following types of loading in a static analysis

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain)

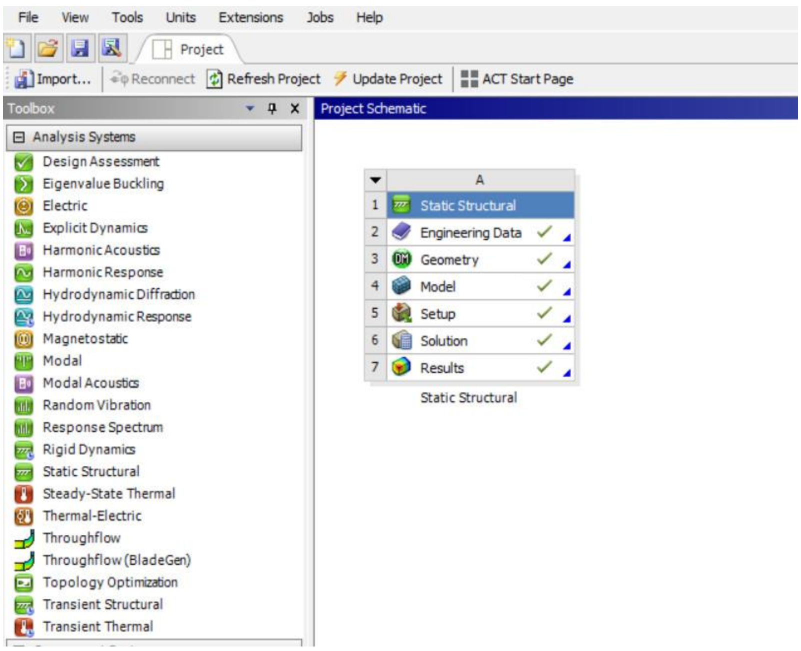

Figure 2.6: Ansys static structural

Here we have used for sheet metal pressing/forming

The following phases are followed in doing the static structural for the setup.

1. Design modeler, Importing the model into ANSYS structure
2. Material data base, Feeding material specification to ANSYS structure
3. Pre-processing, assigning material to each component, applying loads Supports and Meshing,
4. Solution, Problem Solving with desired settings in output control system
5. Post processing, viewing the results and discussions

2.3.1 Importing Geometry into ANSYS Model:

ANSYS design modeler accepts the SOLIDWORKS file which is made simple for importing the CAD model into the ANSYS. Figure 2.7 shows a very clearly sectional view of the imported model in ANSYS. The 3D model has made in simple form. Additional objects including punch/die plates have removed in order to reduce the time of analysis.

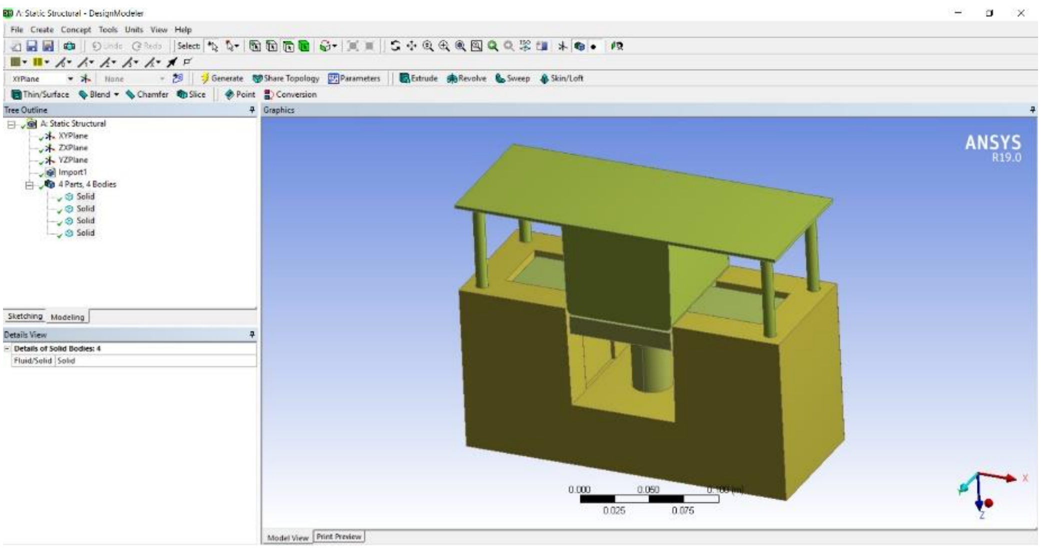

Figure 2.7: Model Imported into Design Modular

2.3.2 Feeding Material Data:

In ANSYS software, materials are chosen from the database provided by the software. Figure 2.8 shows a schematic material data base page in ANSYS 19.0 version.

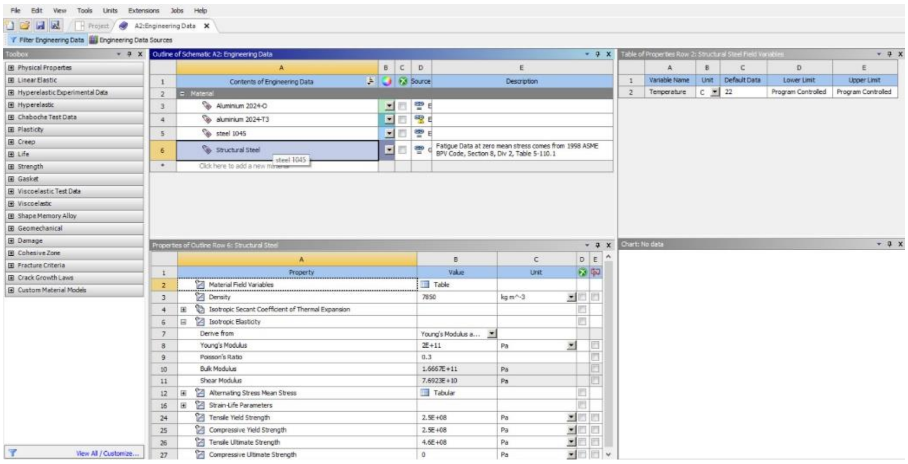

Figure 2.8: Selecting Material Database

2.3.3 Preprocessing:

Assigning materials to components in this phase, the above-selected materials are assigned to each component separately as shown in figure 2.9. The stiffness behavior of the tool and die is kept rigid while the stiffness behavior of the workpiece is kept flexible so that nonlinear behavior can be analyzed. Frictional contacts are made between tool/workpieces, workpiece/die and workpiece/pads. The values of friction coefficient change according to different conditions under the Design of experiments.

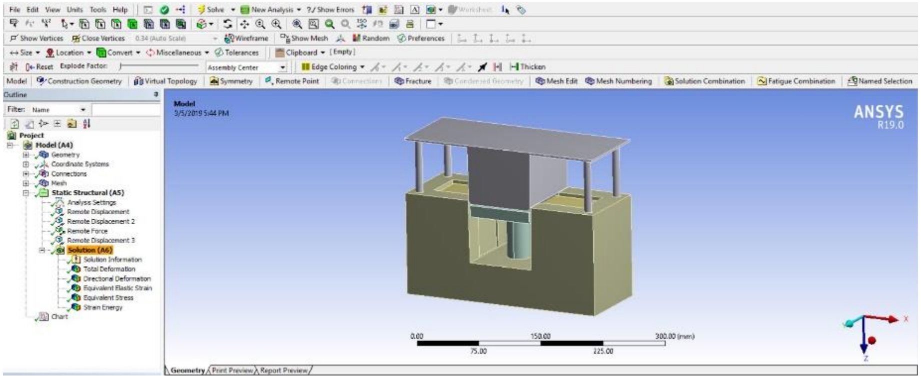

Figure 2.9: Ansys Preprocessing Space

2.3.4 Meshing:

Meshing is the process of dividing or splitting the model into the number of divisions to attain the result in a preferred location in the models. If the mesh size is fewer, more elements will be generated, which results in exact solutions. Firstly, patch conforming tetrahedron mesh is assigned to the workpiece with hard behavior and body size is kept 3.0 mm. the mesh size of the tool and die surface is kept 5.0mm. meshed model is shown in figure 2.9. In order to get accurate results of stresses of the corner, the mesh corner division is kept 8 mm. To make more accuracy and equality, a face meshing is done on the tool and die surface. The total number of nodes and elements are 29114 and 14240.

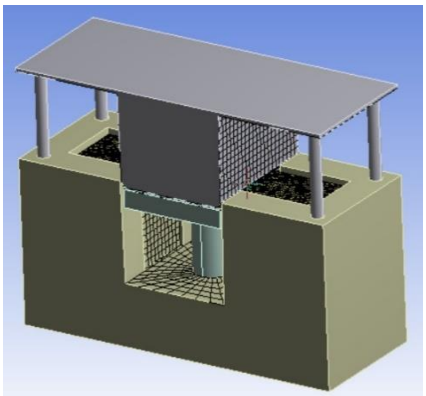

Figure 2.10: Meshing the Model

2.3.5 Applying Loads and Supports:

The whole forming process is divided into 10 steps. Boundary conditions for this setup constrain the following conditions.

Die – Fixed support

Tool– Remote Displacement of 130 mm and force-980665 N

Plate and Die – Frictional contact

The motion of tool is kept in Y direction while the motion is restricted in other directions as shown in figure 2.11

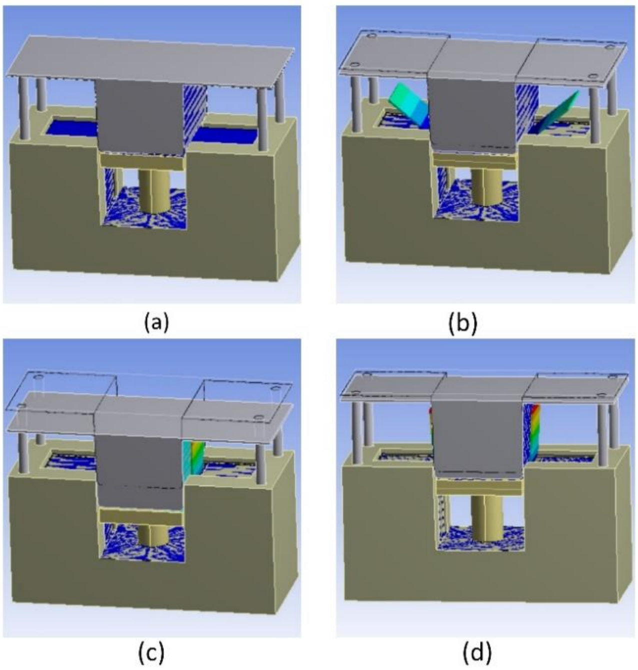

Figure 2.11: Sheet Metal Bending simulations step

2.4 Metal Bending Experimental set up:

Figure 2.12 shows an Experimental setup, which consists of a die, a punch, guide pillars, shank and back up holding plates. A pocket is made in die in order to avoid any slip of workpiece. The pad is fixed with the help of springs for easy insert the workpiece to the die. This technique can help to reduce springback with the implementation of Repeated bend technique. The punch insert is designed for changing the punch with different radius for future study. The die and the die plate are fixed to the press machine bed after alignment with the punch. Standard parts are used that could provide the perfect fit.

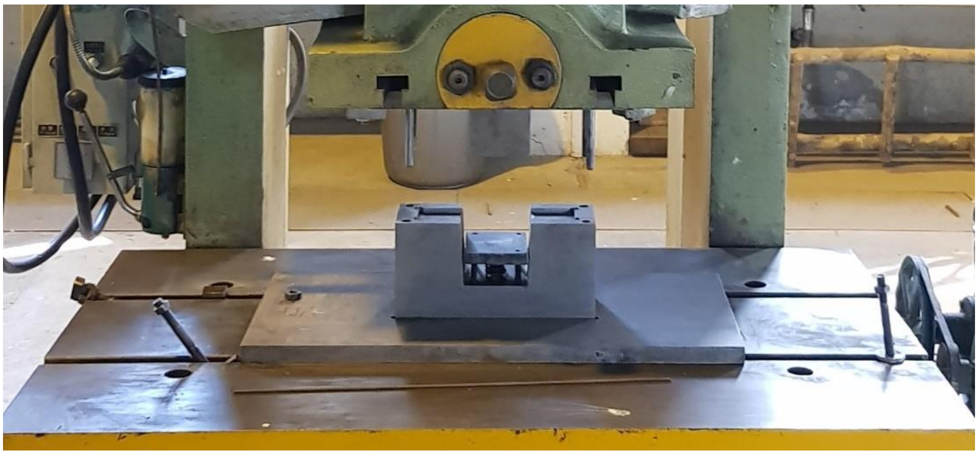

Figure 2.12: Experimental Set up

2.4.1 Hydraulic Press Machine specification:

All of the experimental studies are conducted on the J-23 series open power press machine with a fixed bed. The series of the press belongs to the universal press for sheet stamping. It can be used for punching, producing finished products, cutting, bending, shaping, shallow crawling and other stamping processes. Single or continuous strokes can be obtained with a capacity of 100 KN force. The press consists of frame, driving, clutch, slide block, brake, mechanism, and electric and centralized lubrication system. The technical specifications of machines are as follows in figure 2.13.

SPECIFICATIONS

Model		J23-10B
Capacity	kN	100
Nominal Force	mm	4
Slide Stroke	mm	60
SPM	min^{-1}	145
Max. Die Height	mm	130
Die Height Adjustment	mm	35
Between Slide Center & Frame	mm	130
Bolster (FB×LR)	mm	240×360
Bolster Opening (Up Hole Dia.×Dpth×Low Hole Dia.)	mm	Φ120×20×Φ100
Bolster Thickness	mm	50
Bolster Opening (Dia.×FB×LR)	mm	Φ130×90 ×180
Slide Area (FB×LR)	mm	150×170
Shank Hole (Dia.×Dpth)	mm	Φ30×55
Max. Inclined Angle	°	25°
Between Columns	mm	180
Motor Power	kW	1.1
Outline Size (FB×LR×H)	mm	915×700 ×1690
Net Weight	kg	600

Figure 2.13: Press Machine Specifications

2.4.2 Experimental procedure:

The workpiece set on the die pocket, the punch is driven down with a stroke length of 130mm and constant velocity, then moved up, punch speed was 1 mm/s, the radius of punches was 4.5 mm. The blank size was 200 x 48 mm. There are two stages of this process the first one when the tool moved down at the constant velocity with the punch travel of 130mm. The second stage is unloading in which the punch driven up. At different parameters and their levels total tests were performed are 24. The bend workpieces after springback are shown in figure 2.14.

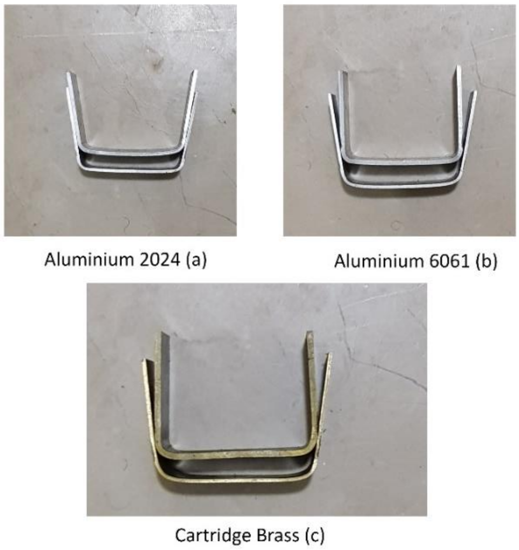

Figure 2.14: workpieces after U-Bend

2.5 Summary:

In forming process reduction of springback or spring-go depends on the selection of process parameters. Simulation and experimental work are done in order to get several parameters effect on the springback of three different Alloys. The simulations are conducted only for material type: AL2024-T3, Al 6061-T6, and Cartridge Brass, UNS C26000 (260 Brass). There is a need for simulation for different material types to confirm whether they will display behaviors similar to recognized for these materials in this paper. A total of 30 simulations run are performed to obtain a full set of data. every simulation run took many hours on the workstation. In other words, more than 320 hours of simulations are done to get the series of data given in this paper.

CHAPTER 3: RESULTS AND DISCUSSIONS

3.1 Analysis of Results:

In this study, the sheet metal bending process has been examined experimentally and in finite element method software Ansys static structural. Complex non-linear elastic-plastic bending process can easily be done in a comparatively short time. Time and effort can be saved with this feature by doing different configurations modeling and simulation. The FEA procedure delivers numerical technique to analyze and design bending dies and punches on selected parameters. The finite element method simulation and experiment results have good correlation in terms of various parameters.

Table 3.1: Design of Experiments with Results

Sr#	Materials		Displacement (mm)	Thickness (mm)		Friction Coefficient	Experimental		Simulations		Repeated Bend Technique				Total Deformation	Stress	Strain
1	Al 2024-T3	D1	0	2	Lubricated	0.33	73	17	72	18	-	-	-	-	69.114	283.57	0.004925
2	Al 2024-T3	D1	0	2	Non-Lubricated	0.5	73	17	72	18	-	-	-	-	70.163	282.76	0.0049241
3	Al 2024-T3	D1	0	3	Lubricated	0.33	77	13	76	14	-	-	-	-	72.619	318.73	0.0053756
4	Al 2024-T3	D1	0	3	Non-Lubricated	0.5	77	13	76	14	-	-	-	-	73.718	317.38	0.0051203
5	Al 2024-T3	D2	15	2	Lubricated	0.33	81	9	80	10	82	8	81	9	75.426	293.35	0.0049316
6	Al 2024-T3	D2	15	2	Non-Lubricated	0.5	81	9	80	10	82	8	81	9	75.5	292.99	0.0048845
7	Al 2024-T3	D2	15	3	Lubricated	0.33	87	3	86	4	88	2	87	3	78.945	324.29	0.0051979
8	Al 2024-T3	D2	15	3	Non-Lubricated	0.5	87	3	86	4	88	2	87	3	79.138	323.77	0.0051601
9	Al 6061-T6	D1	0	2	Lubricated	0.27	75	15	74	16	-	-	-	-	69.683	250.8	0.0042464
10	Al 6061-T6	D1	0	2	Non-Lubricated	0.5	75	15	74	16	-	-	-	-	70.712	246.1	0.0041918
11	Al 6061-T6	D1	0	3	Lubricated	0.27	80	10	79	11	-	-	-	-	73.636	289.2	0.0047126
12	Al 6061-T6	D1	0	3	Non-Lubricated	0.5	80	10	79	11	-	-	-	-	74.74	288.5	0.0046363
13	Al 6061-T6	D2	15	2	Lubricated	0.27	82	8	81	9	83	7	82	8	75.345	259	0.0043278
14	Al 6061-T6	D2	15	2	Non-Lubricated	0.5	82	8	81	9	83	7	82	8	75.421	257.08	0.0042966
15	Al 6061-T6	D2	15	3	Lubricated	0.27	87	3	86	4	88	2	87	3	79.066	296.13	0.0046478
16	Al 6061-T6	D2	15	3	Non-Lubricated	0.5	87	3	86	4	88	2	87	3	79.307	290.48	0.0045674
17	Cartridge Brass	D1	0	2	Lubricated	0.3	80	10	80	10	-	-	-	-	75.637	118.4	0.0012148
18	Cartridge Brass	D1	0	2	Non-Lubricated	0.45	80	10	80	10	-	-	-	-	76.748	117.36	0.0012094
19	Cartridge Brass	D1	0	3	Lubricated	0.3	82	8	82	8	-	-	-	-	76.915	152.04	0.0015893
20	Cartridge Brass	D1	0	3	Non-Lubricated	0.45	82	8	82	8	-	-	-	-	77.009	150.25	0.001522
21	Cartridge Brass	D2	15	2	Lubricated	0.3	87	3	87	3	88	2	88	2	80.474	125.59	0.0011954
22	Cartridge Brass	D2	15	2	Non-Lubricated	0.45	87	3	87	3	88	2	88	2	80.582	124.25	0.0011917
23	Cartridge Brass	D2	15	3	Lubricated	0.3	89	1	89	1	90	0	90	0	81.279	155.65	0.0015238
24	Cartridge Brass	D2	15	3	Non-Lubricated	0.45	89	1	89	1	90	0	90	0	81.401	151.61	0.0014817

3.2 Effect of Punch Displacement:

To obtain the influence of Punch displacement on springback and comparison of different materials and thickness, the experimental work and finite element simulations run for different conditions. Three different types of workpiece with a thickness of 2 mm and 3 mm is chosen for the study. The effect of punch displacement on springback is shown in figure 3.1(a) and 3.1 (b). The position difference between D1 and D2 displacement is 15mm. For different types of material and thickness, the deep is the punch stroke the less springback in the material. The results of the finite element method and experiments show good agreement with each other.

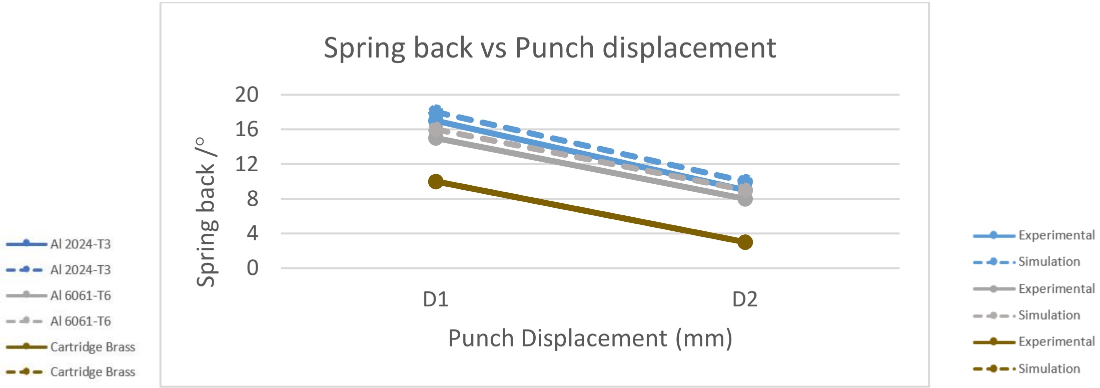

Figure 3.1 (a): Effect of Punch Displacement on 2mm Sheet Metal Part

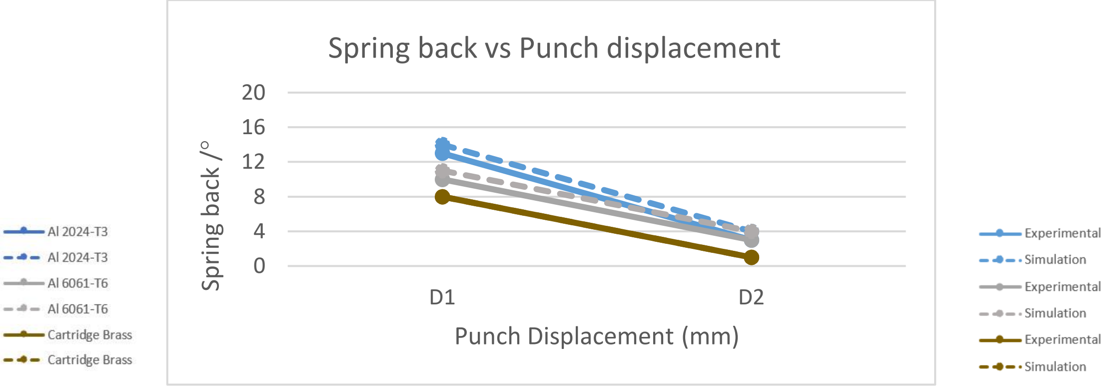

Figure 3.1 (b): Effect of Punch Displacement on 3mm Sheet Metal Part

3.3 Effect of sheet thickness:

To get the influence of sheet thickness on springback and comparison of different materials, the experimental work, and finite element simulations run for different conditions. The sheet thickness effect on springback is shown in figure 3.2 (a) and 3.2 (b) at different Punch displacements. At both conditions, it can be seen that higher the thickness lesser is the springback on all the material used in research. This result in accordance with previous work done on this parameter. As a result, the workpiece thickness was surely in consideration to get the required bending angle.

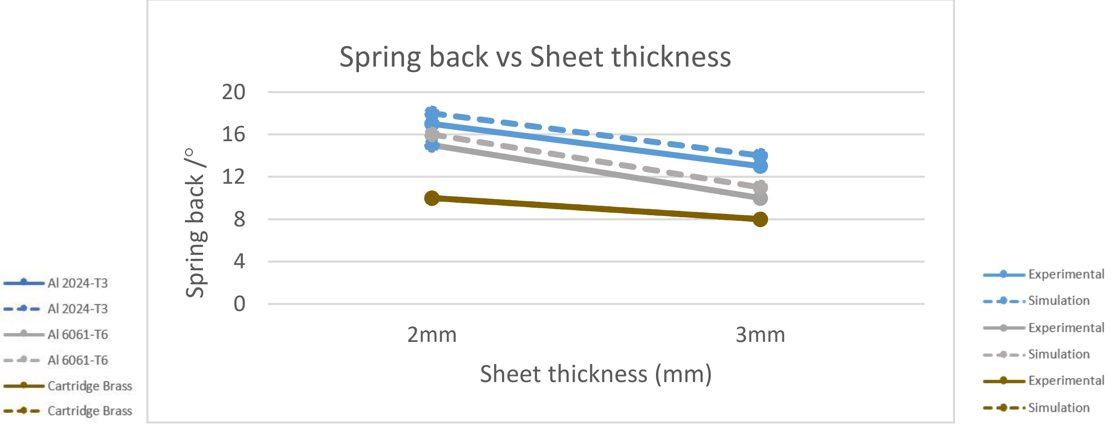

Figure 3.2 (a): Effect of sheet thickness on Sheet Metal Part at Displacement 1

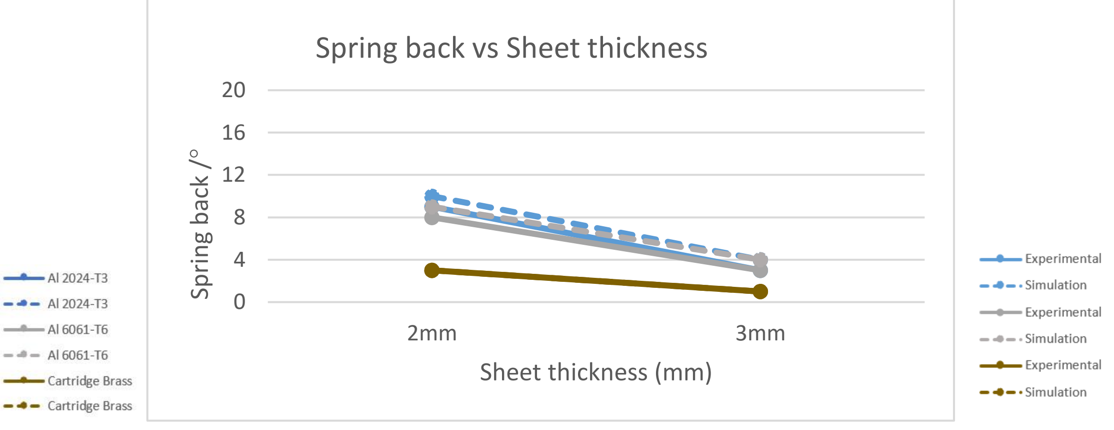

Figure 3.2 (b): Effect of sheet thickness on Sheet Metal Part at Displacement 2

3.4 Effect of Friction Coefficient:

Tangential forces generated between contacting surfaces are known as frictional forces which resist motion up to a point. It can be seen experimental and through finite element analysis that friction has no effect the forming angle. Friction only effect stress strain between tool and die and according to (T & Dametew, 2017) stress variation can be eradicated through high friction coefficient value among tool and workpiece. The results of friction coefficient are good agreement to previous literature.

To make it more understandable 24 different parameters are further categorize into following 4 conditions

1. Condition= (Displacement =D1, Thickness=2mm, Friction Coefficient = μ1, μ2)
2. Condition= (Displacement =D2, Thickness=2mm, Friction Coefficient = μ1, μ2)
3. Condition= (Displacement =D1, Thickness=3mm, Friction Coefficient = μ1, μ2)
4. Condition= (Displacement =D2, Thickness=3mm, Friction Coefficient = μ1, μ2)

Further graphs will be explained on the basis of these 4 conditions

3.5 Effect of Material:

To obtain the influence of material on springback and comparison of different materials, the experimental work, and finite element simulations run for different materials and conditions. Three different types workpiece material with a thickness of 2 mm and 3 mm is chosen for the study the results obtained are listed in the table and plotted on the graph in figure 3.3 (a), 3.3 (b), 3.3 (c) and 3.3 (d). It is noted that springback is highest for Aluminum 2024-T3 than those for Aluminum 6061-T6 and cartridge brass. The exception occurs at condition no. 4 where aluminum 2024-T3 and aluminum 6061-T6 shows same springback angle

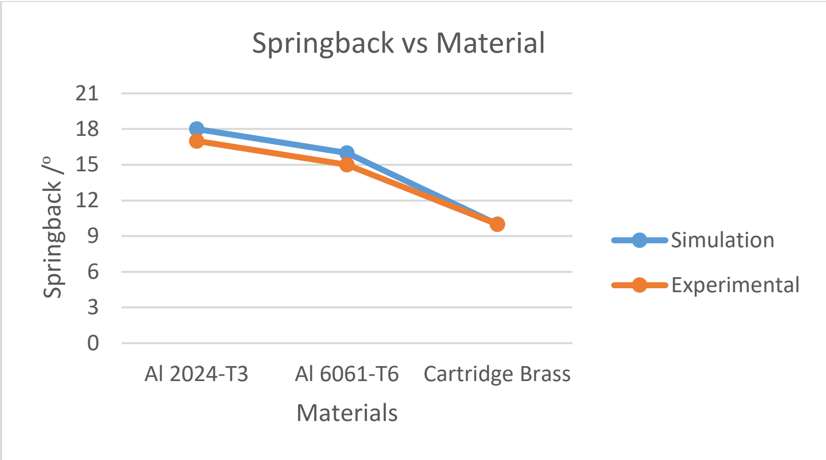

Figure 3.3 (a): Condition= (Displacement =D1, Thickness=2mm, Friction Coefficient = µ1, µ2)

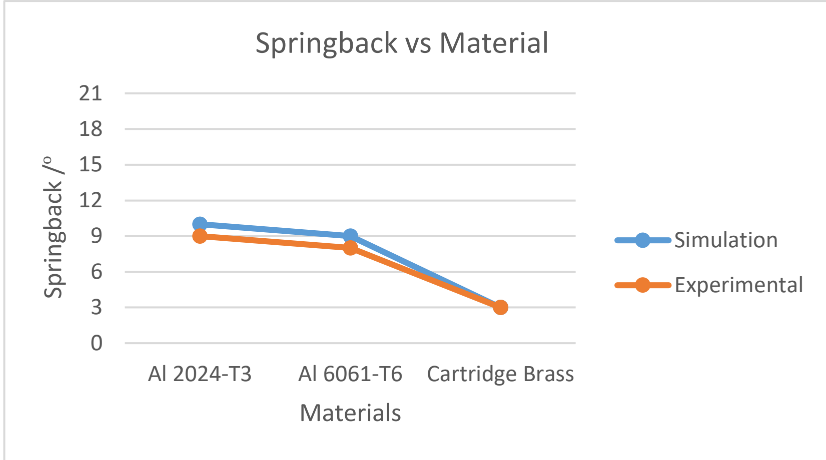

Figure 3.3 (b): Condition= (Displacement =D2, Thickness=2mm, Friction Coefficient = µ1, µ2)

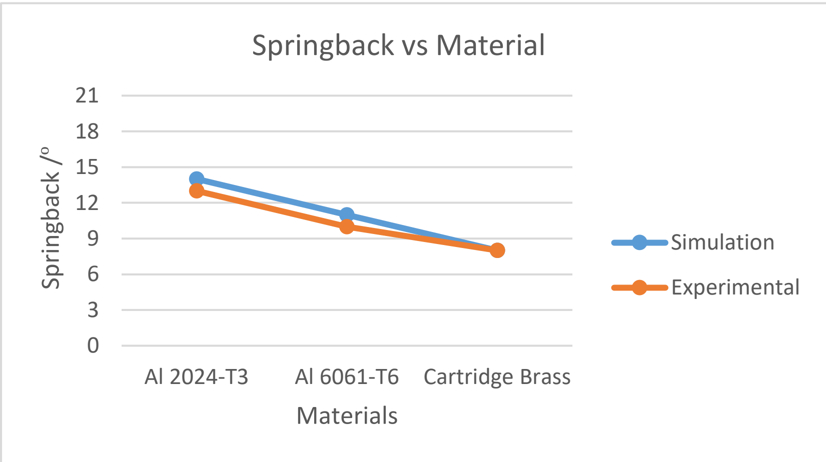

Figure 3.3 (c): Condition= (Displacement =D1, Thickness=3mm, Friction Coefficient = µ1, µ2)

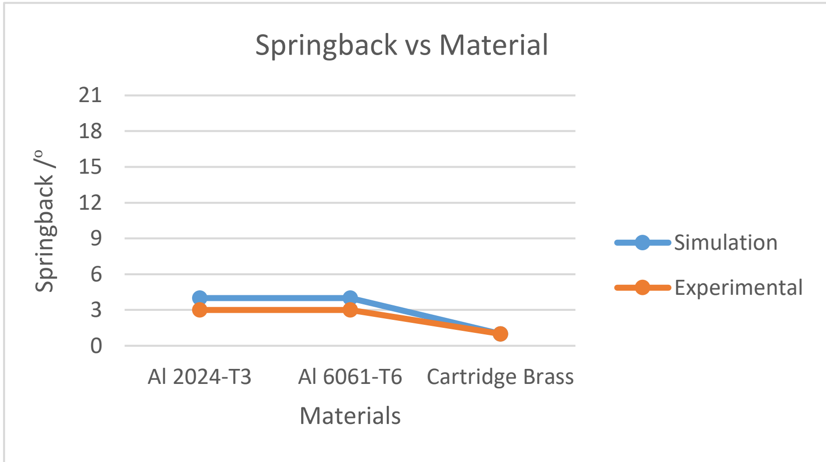

Figure 3.3 (d): Condition= (Displacement =D2, Thickness=3mm, Friction Coefficient = µ1, µ2)

3.6 Stresses on Sheet Metal Part:

Von Mises stress is a value used to determine if a given material will yield or fracture. To obtain the influence and comparison of von Mises stresses on different materials, finite element simulations run for different materials and conditions. Three different material types workpiece with a thickness of 2 mm and 3 mm is chosen for the study the results obtained are listed in the table and plotted on the graph in figure 3.4 (a), 3.4 (b), 3.4 (c) and 3.4 (d). At all conditions, it shows that stresses on Aluminum 2024-T3 are highest. The least stresses are found on cartridge brass. The average percentage difference of stresses at both frictional conditions for aluminum 2024-T3, aluminum 6061-T6 and cartridge brass are 0.25 percent, 1.25 percent and 1.4 percent respectively.

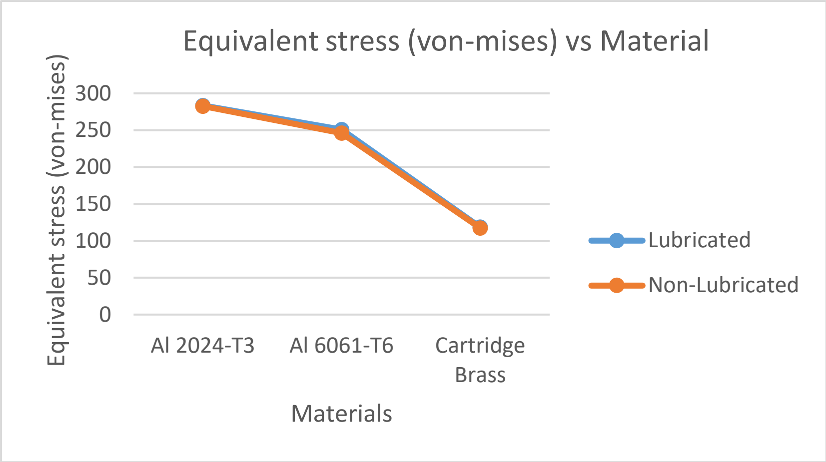

Figure 3.4 (a): Condition= (Displacement =D1, Thickness=2mm, Friction Coefficient = µ1, µ2)

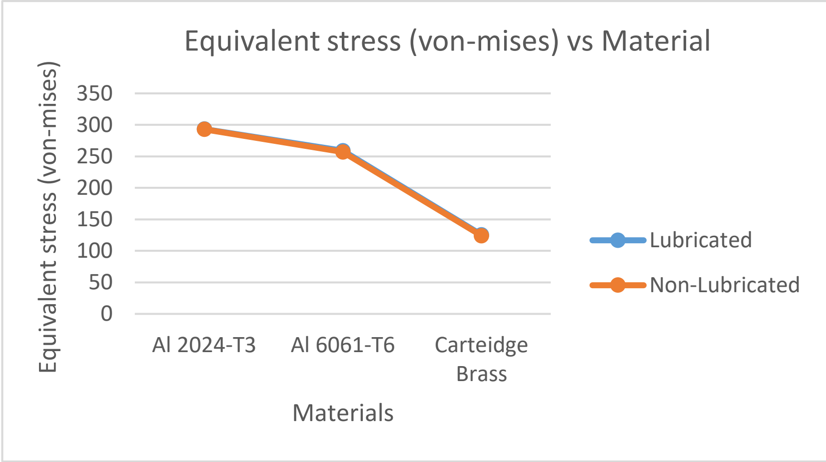

Figure 3.4 (b): Condition= (Displacement =D2, Thickness=2mm, Friction Coefficient = µ1, µ2)

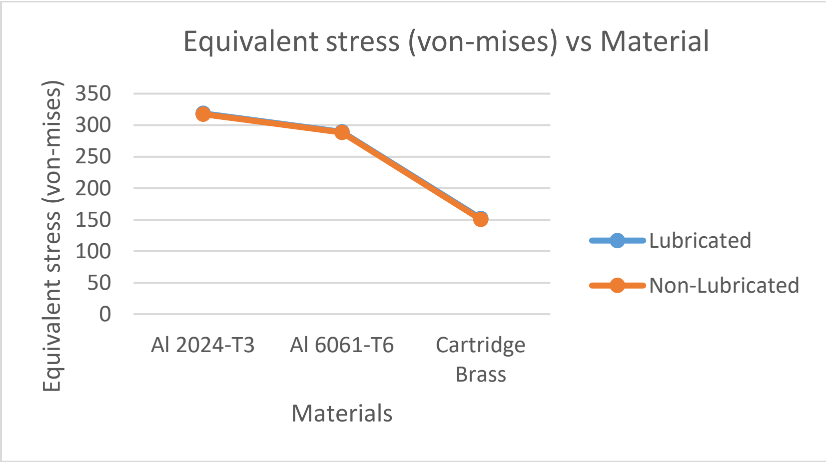

Figure 3.4 (c)= Condition= (Displacement =D1, Thickness=3mm, Friction Coefficient = µ1, µ2)

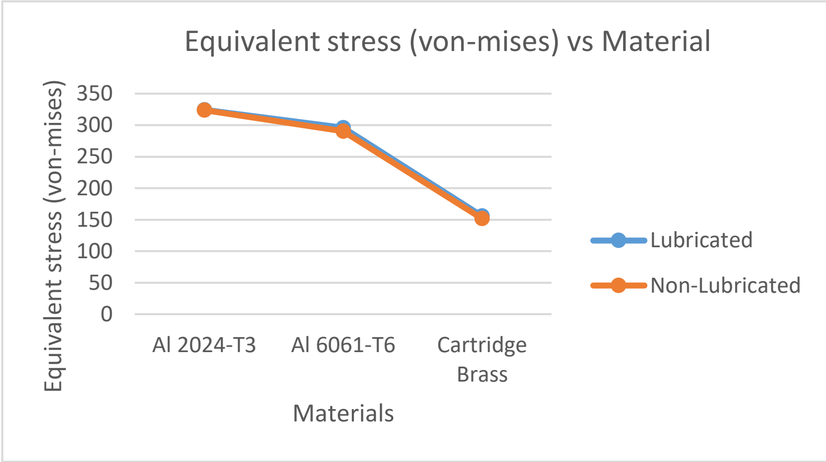

Figure 3.4 (d)= Condition= (Displacement =D2, Thickness=3mm, Friction Coefficient = µ1, µ2)

3.7 Strains on Material:

Permanent strain in material can be measured through equivalent plastic strain. In order to explain plastic strain, plastic material properties must be assigned. It can be a Bilinear Stress/Strain curve or multilinear Stress/Strain curve. To obtain the influence and comparison of von equivalent strains on different materials, finite element simulations run for different material. Three different material types workpiece with a thickness of 2 mm and 3 mm is chosen for the study and the results obtained are listed in the table and plotted on the graph in figure 3.5 (a), 3.5 (b), 3.5 (c) and 3.5 (d). At all conditions, it shows that strains on Aluminum 2024-T3 are highest. The least stresses are found on cartridge brass. The average percentage difference of strains at both frictional conditions for aluminum 2024-T3, aluminum 6061-T6 and cartridge brass are 1.63 percent, 1.32 percent and 1.9 percent respectively.

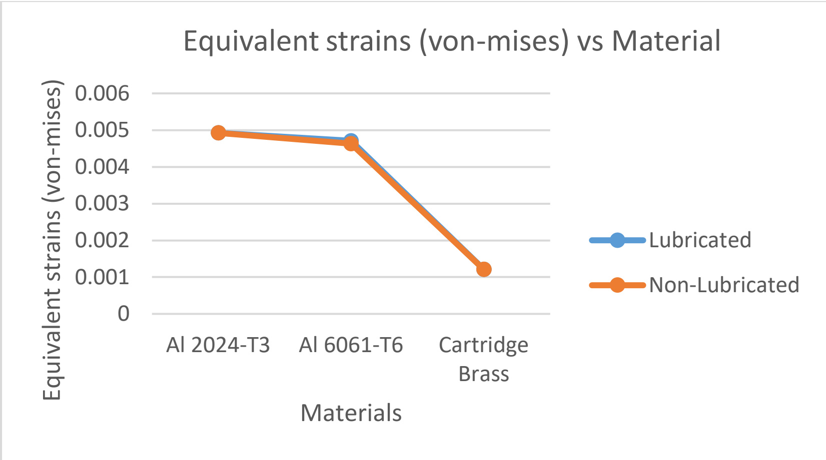

Figure 3.5 (a): Condition= (Displacement =D1, Thickness=2mm, Friction Coefficient = µ1, µ2)

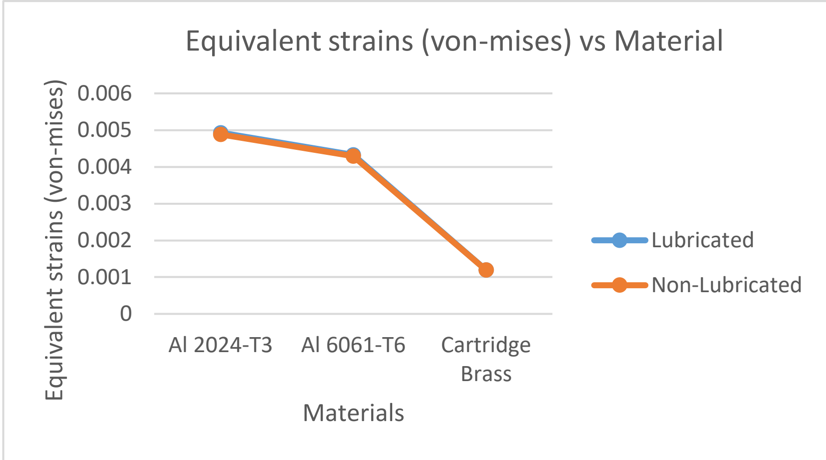

Figure 3.5 (b): Condition= (Displacement =D2, Thickness=2mm, Friction Coefficient = µ1, µ2)

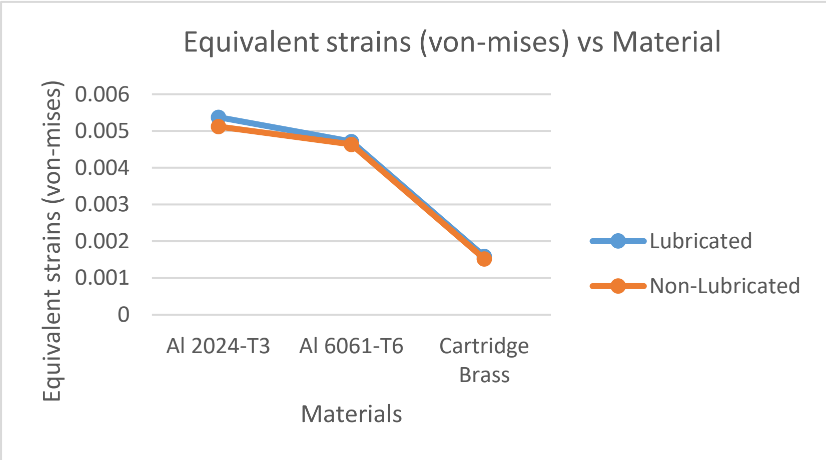

Figure 3.5 (c)= Condition= (Displacement =D1, Thickness=3mm, Friction Coefficient = µ1, µ2)

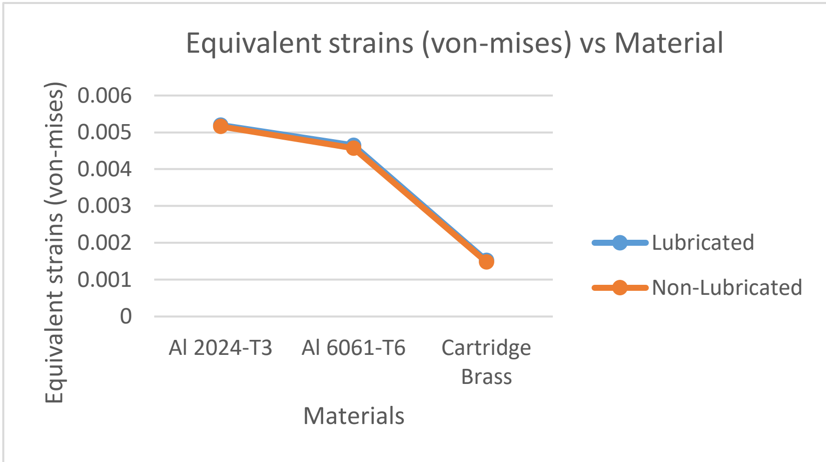

Figure 3.5 (d)= Condition= (Displacement =D1, Thickness=3mm, Friction Coefficient = µ1, µ2)

3.8 Total Deformation on Sheet Metal Part:

Total deformation is used to obtain displacements from stress. it gives a square root of the summation of the square of the x-direction, y-direction, and z-direction. Total deformation for cartridge brass is higher while for Aluminum 2024-T3 is least as shown in figure 3.6 (a), 3.6 (b), 3.6 (c) and 3.6 (d). The average percentage difference of total deformation at both frictional conditions for aluminum 2024-T3, aluminum 6061-T6 and cartridge brass are 0.83 percent, 0.83 percent and 0.46 percent respectively.

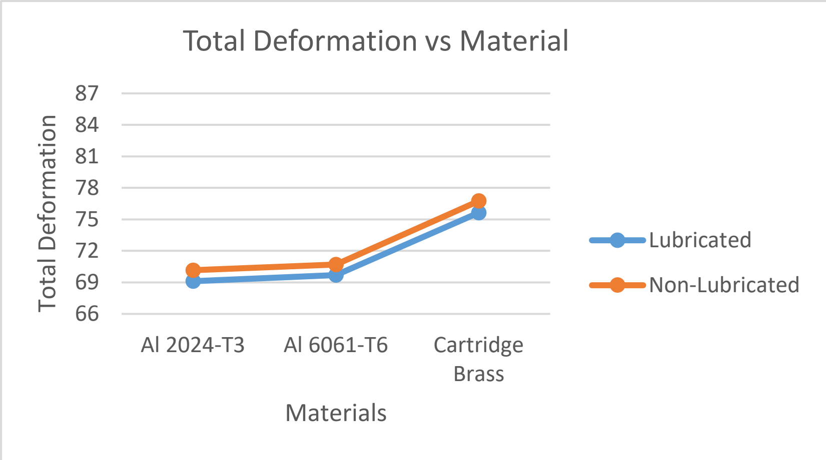

Figure 3.6 (a): Condition= (Displacement =D1, Thickness=2mm, Friction Coefficient = µ1, µ2)

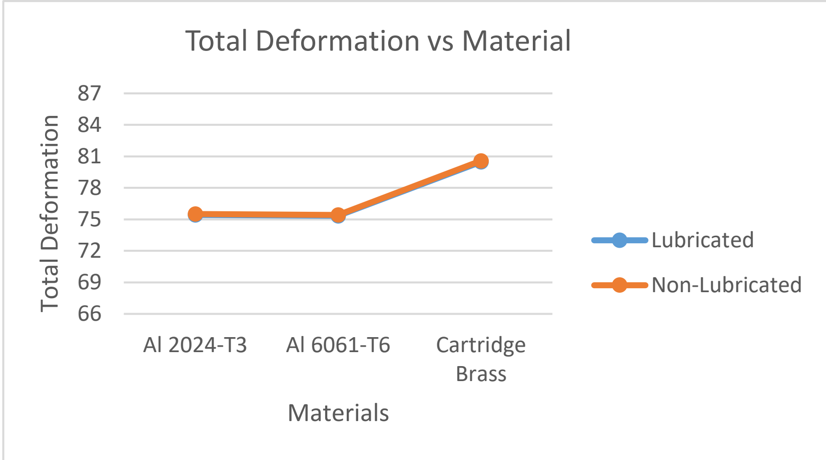

Figure 3.6 (b): Condition= (Displacement =D2, Thickness=2mm, Friction Coefficient = µ1, µ2)

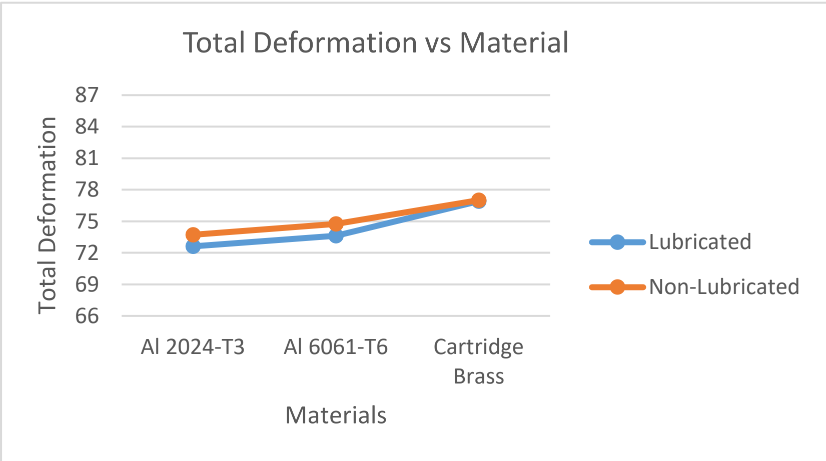

Figure 3.6 (c)= Condition= (Displacement =D1, Thickness=3mm, Friction Coefficient = µ1, µ2)

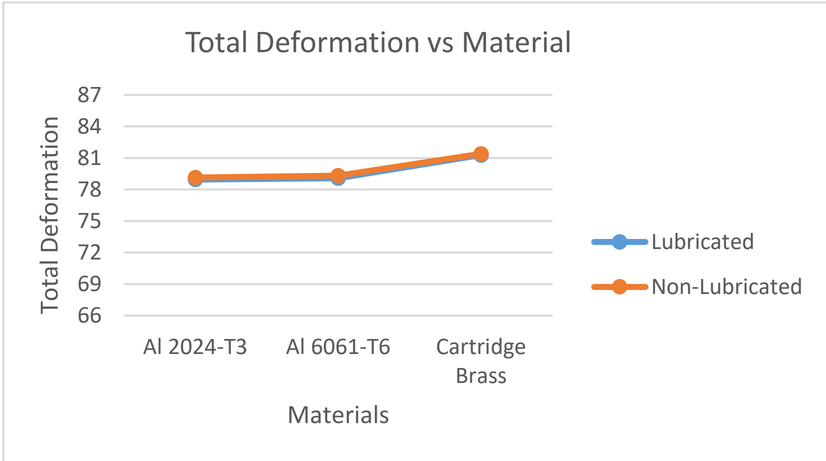

Figure 3.6 (d)= Condition= (Displacement =D2, Thickness=3mm, Friction Coefficient = µ1, µ2)

3.9 Effect of R/t ratio and Clearance:

The plasticized area is determined by forming punches and die radius. The proper die radius should be elected in proportion to material thickness. The lower the R/t ratio, the more stress it causes in the finished material. With more stress, the strain hardening becomes large and a demand for the forming force increases. Parts breakage happens whereby the bending force approaches the limits of the material (T & Dametew, 2017). The spring-back factor also depends on the bend angle, which is the novel springback factor (Phanitwong, Thipprakmas, & Design, 2016). R/t ratio and clearance have an evident effect on springback. The higher the R/t ratio and clearance, the higher is the springback in the material. Proper calculations of clearance and R/t ratio should be done for the accuracy and required shape of the part.

3.10 Repeated Bend Technique with Pads:

Springback is always present in sheet metal bending. The approach adopted here is to reduce the springback but not to eliminate it completely. In order to control the springback in sheet metal part a new technique has been introduced in this research which is called Repeated bend or multi bend technique with pads. The main purpose of the pad is to save material from cracking with repeated punch stroke. Furthermore, the formation of stress is countered in the lower surface of the workpiece with the application of the pad. This technique can help to reduce springback. Selected some parameters at which the springback is minimum and applied Repeated bend technique with pads. The results obtained are listed in the table and plotted on the graph in as shown in the figure 3.7.

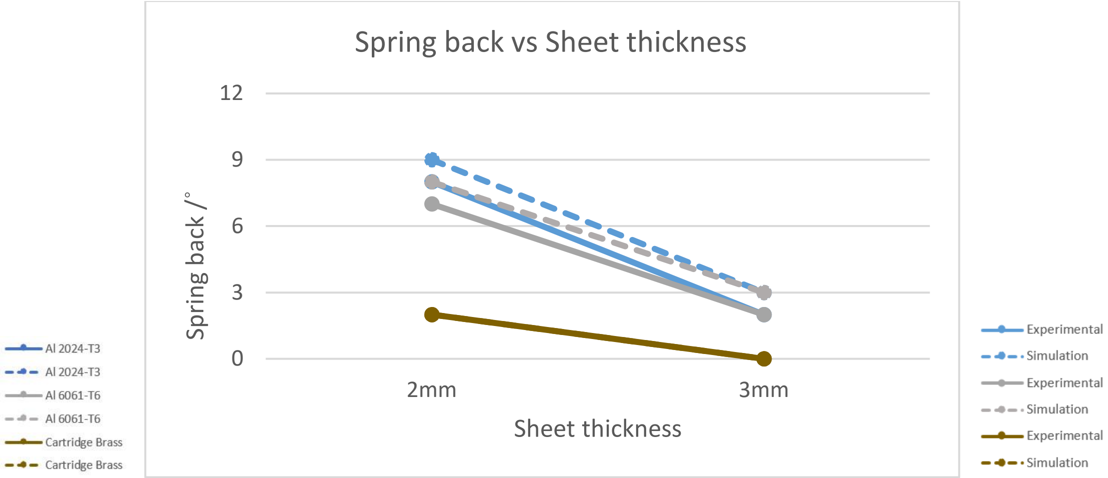

Figure 3.7: Double bend Technique with pads

3.11 ANOVA Analysis:

The ANOVA technique is also used to show the degree of significance of each process (A-Material Type, B-Sheet thickness and C-Punch Displacement and D-Friction Coefficient). parameter influencing springback in the air U-bending process. The significance level is determined by statistical p-value. If the p value is lower than 0.05 then it shows that the power level has a statistically substantial effect on the responses.

The significant effect of factors, evaluated by plotting the percent against the standardized effect of the spring back, is shown in Table 3.2 and figure 3.8. The most influential parameter, Punch Displacement signifies the highest contribution about 61.51 percent in the springback of U bending operation. After that Material type showed a contribution up to 18.37 percent. At last, the thickness of the plate showed a 16.74 percent contribution in the springback. The friction coefficient has no contribution on springback.

Table 3.2: Percentage Contribution of each parameter by ANOVA Analysis

Sr#	Factor	Sum of Squares (SS)	Degree of freedom (DF)	Mean Squares (Adj MS)	Contribution %
1	Punch Displacement	352.667	1	352.667	61.51
2	Materials	105.333	2	105.333	18.37
3	Friction Coefficient	0.000	1	0.000	0.00
4	Thickness	96.000	1	96.000	16.74
5	Error	19.333	18	1.074	3.37

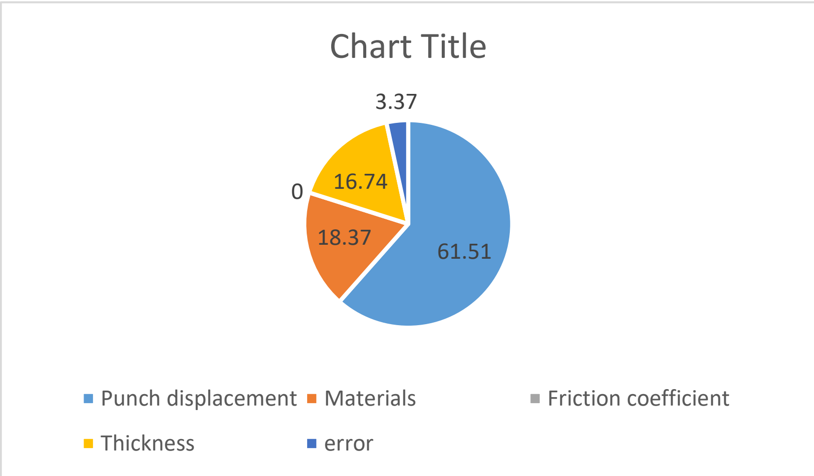

Figure 3.8: Pie chart of percent contribution

3.12 Correlation of Experimental and Finite Element Method:

Laboratory experiments are conducted to authenticate the accuracy of FEM simulation. In this study, three samples of bent parts are bent to each condition. The investigated bending angles are compared as shown in figure 3.9 (a) and 3.9 (b). The various material types, punch displacements, sheet thickness and coefficient of friction are examined and correlated with those obtained by experiments. Experimental and FEM simulation have good correlation, in which the error is about in the range of 0 to 3 %.

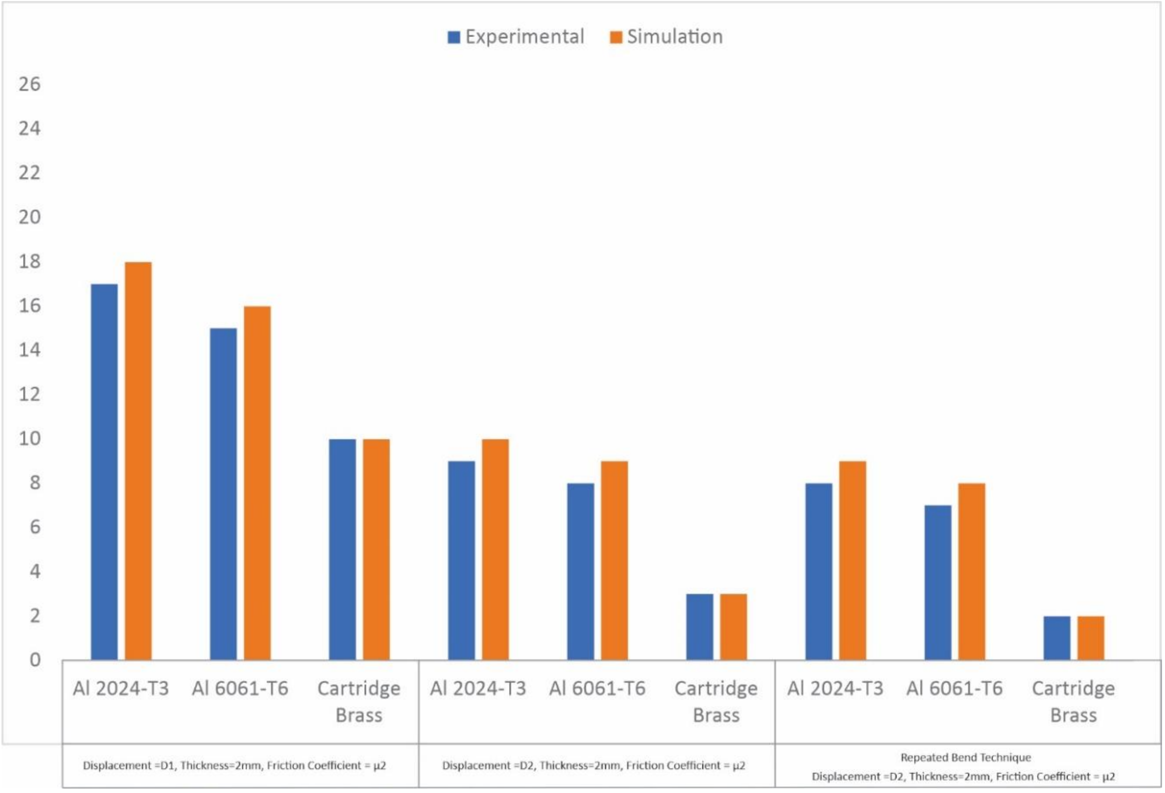

Figure 3.9 (a): Comparison of bending angle between experimental and FEM results of 2 mm sheet metal part

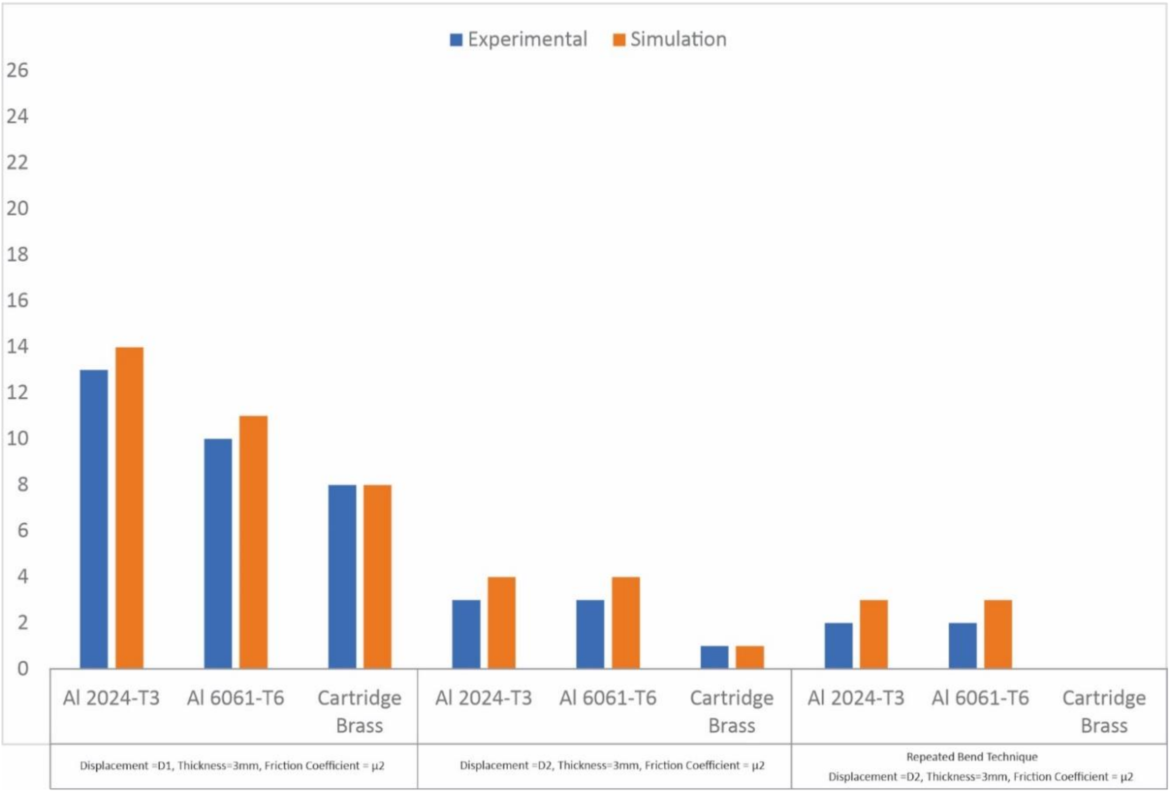

Figure 3.9 (b): Comparison of bending angle between Experimental and FEM results of 3mm sheet metal part

3.13 Results Summary:

This paper has provided the experimental and FEM simulations study of the springback of different materials. In this study, the Finite element simulation is done to investigate the different parameters effect on spring-back/spring-go feature in the U-bending process, including punch displacement, sheet thickness, material type, and friction coefficient. Punch stroke have significant role in sheet metal bending operation. The deep punch stroke produces less springback in the material. Determining the best value for sheet metal thickness is essential for the purpose of using proper values in the design step. The increase in the sheet thickness causes the increase of the bending attributes, as well as the decrease of the springback. In addition, in terms of workpiece material type, Aluminum 2024-T3 shows the highest springback while cartridge brass shows minimum springback. The association among the springback and material properties can influence the materials' applicability in manufacturing. Ductile materials have low spring back as compared to hard. This term can be defined in terms of strength and elastic modulus. High strength and lower elastic modulus create more springback because of more strains in the material. According to the results, strains produce in Aluminum 2024-T3 is higher than Aluminum 6061-T6 and Cartridge brass. Friction has no evident effect on springback. A suitable design for part geometry is necessary to gain the required bending angle. The error between simulations and laboratory experiments is in the range of 0 percent to 5 percent depending on the different conditions and material types. There are many advantages of using finite element simulation software in the sheet metal bending process. One of the benefits of this software is to implement required design variations very fast in order to optimize design. With the benefit of this feature, many configurations can be modeled and simulated successively, saving time, material, effort and cost. On the other hand, traditional trial-and-error methods take much time and result in wastage of materials, effort, and cost.

CHAPTER 4: CONCLUSIONS AND FUTURE RECOMMENDATIONS:

4.1 Conclusions:

This paper has used a combination of experimental and simulation methods to examine the effect of punch displacement, sheet thickness, friction coefficient, and material type. FEA Ansys software has been utilized to simulate complicated non-linear elastic plastic bending applications in a relatively short period. It is concluded that springback depends upon the material and process parameters. The results show that by combining CAD/CAE will be much helpful. By the implementation of the computer in design, the precision of design is increased and the design method time is decreased drastically than by conventional methods. Many design difficulties that are complex to eliminate by traditional methods are eliminated by applying the CAD system. To avoid time-consuming simulations, complete simulation operates for small dimensions of material types and parameters to notice if a model can be built. Once such a model is built, a method can be formed so that a complete data set can be created by conducting simulation runs for some decisive configurations for each new material type. Thus, problem size can be overcome. The effect of the following results was gained from the present research:

1. Springback angle Decreases in the range of 0˚- 8˚ by increasing 15 mm in Punch Displacement depth
2. Springback angle Decreases in the range of 0˚- 4˚ by increasing sheet thickness from 2mm to 3mm
3. Aluminum 2024-T3 have higher springback (0˚ - 6˚) than Aluminum 6061-T6 (0˚ - 4˚) and cartridge brass (0˚ - 2˚). The exception occurs at condition no. 4

where aluminum 2024-T3 and aluminum 6061-T6 shows same springback angle

4. The coefficient of friction has no effect on springback angle.
5. R/T ratio and clearance should be in consideration while designing the punch/die set. Increases R/T and clearance increases springback in the workpiece
6. Repeated bend technique with pads was used to reduce springback in the range (0˚ - 1˚) of without cracking the workpiece. Due to pads stresses was avoided at the bottom of the workpiece
7. According to the ANOVA Technique, punch displacement has a contribution of 61.51 percent, material type 18.37 percent and sheet thickness 16.74 percent.

4.2 Recommendations for future works:

Some future recommendations for further studies are:

1. Investigation of springback of material sheets attained by friction stir welding
2. Investigation of springback by using warm and hot tool/die set
3. Study the effect of different tools and workpiece material for springback effect

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