Modeling and Experimental Investigation of Springback in Brass Alloy Sheet Metal V-Bending

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ABSTRACT

One of the most important criteria in a good bending is springback. Springback can be defined as the amount of shape recovered after bending load. Springback value is somehow influenced by some factors like bending force, die opening, bend radius, bend angle, sheet metal thickness and punch holding time, and heat treatment.

In this study, springback is investigated in v-bending for yellow brass material (UNS C27000 brass). The investigation of the springback will consider three parameters. The selected parameters to be varying will be the thickness of sheet metal (1.5mm 3mm and 5mm), the die opening (22 and 35mm), and the punch holding time (0 5 and 10 seconds) and all the other parameters will remain constant like the die angle and punch angle (85°). A full factorial multilevel design of experiment (DOE) method is used to conduct the experimental test. Finite element simulation (FEA) using ANSYS IMPLICIT, and experimental investigation results are compared. In addition, machine learning with ANN and SVM methods are used to predict the springback. The analysis of the result done with ANOVA showed interesting facts. The Pareto chart reveals that in comparison with the two other parameters, the sheet thickness has the highest significant effect on the springback and the die opening has the lowest significant effect. In overall the metal behaved approximately like the other metals because the springback decreased when the die opening increased and also when the holding time increased, and also when the sheet thickness increased. However, the brass material went in contradiction with the previous researches on the 3mm sheet thickness.

Keywords: springback, finite element analysis (FEA), SVM, ANN, ANOVA.

ÖZ

İyi bir bükülmedeki en önemli kriterlerden biri geri esnektir. Geri yaylanma, yükün bükülmesinden sonra geri kazanılan şekil miktarı olarak tanımlanabilir. Geri yaylanma değeri bir şekilde bükme kuvveti, Kalıp açma, Bükülme yarıçapı, Bükme açısı, sac kalınlığı ve zımba tutma süresi ve Isıl işlem gibi bazı faktörlerden etkilenir.

Bu çalışmada sarı pirinç malzeme (UNS C27000 pirinç) için v-bükülmede geri yaylanma araştırılmıştır. Geri esnemenin araştırılması üç parametreyi dikkate alacaktır. Değişecek olan seçilen parametreler sac levha kalınlığı (1.5 3mm ve 5mm), kalıp açıklığı (35 ve 22mm) ve zımba tutma süresi (0 5 ve 10 saniye) ve diğer tüm parametreler sabit kalacaktır. kalıp açısı ve delme açısı (85 °). Deneysel testi yapmak için tam faktöryel çok düzeyli DOE yöntemi kullanılmıştır. ANSYS IMPLICIT kullanılarak sonlu elemanlar simülasyonu (FEA) ve deneysel araştırma sonuçları karşılaştırılmıştır. Ayrıca geri yaylanmayı tahmin etmek için YSA ve SVM yöntemleri ile makine öğrenimi kullanılır. ANOVA ile yapılan sonucun analizi ilginç gerçekler göstermiştir. Pareto şeması, diğer iki parametreye kıyasla, levha kalınlığının geri yaylanma üzerinde en yüksek anlamlı etkiye ve kalıp açıklığının en düşük önemli etkiye sahip olduğunu ortaya koymaktadır. Genel olarak metal yaklaşık olarak diğer metaller gibi davrandı çünkü kalıp açıklığı arttığında ve tutma süresi arttığında ve ayrıca sac kalınlığı arttığında geri esneme azaldı. kalınlık.

Anahtar Kelimeler: geri yaylanma, sonlu elemanlar analizi (FEA), SVM, YSA, ANOVA.

TO MY PARENTS CONSTANCE AND DONMEGUILE MEDA AND MY FAMILY.

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
ANOVA	Analysis of Variance
CAE	Computer Aided Engineering
DOE	Design of Experiment
FEA	Finite Element Analysis
GA	Genetic Algorithms
ML	Machine Learning
MLR	Multiple Linear Regression
PSO	Particle Swarm Algorithm
RSM	Response Surface metamodeling
SB	Springback
SMB	Sheet Metal Bending
SMF	Sheet Metal Forming
SVM	Support Vector Machine

Chapter1

INTRODUCTION

1.1 Background: brass alloy applications and advantages

Brass is a non-ferrous metal in which copper and zinc are the main constituent elements of overall composition. Brass is a unique material that is a copper alloy with an increasing demand (Figure 1.1). This material has a lot of advantages due to its properties [2]:

- Ease of fabrication by drawing
- Very high cold workability
- Good corrosion resistance
- Excellent anti-bacterial property

Figure 1.1: Different price rates in dollars per ton of metals such as copper [1].

Due to these properties brass find plenty applications in many domains (Figure 1.2).

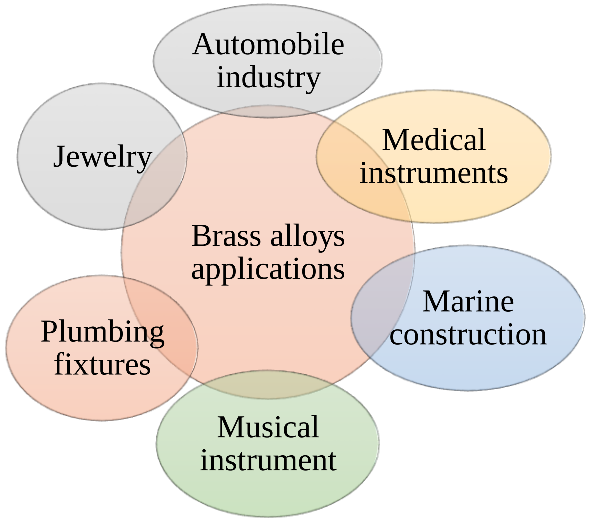


Figure 1.2: Applications of brass in different field [2].

1.2 Importance and advantages of sheet metal v-bending

Sheet metal v-bending is a very wide used process for forming sheet plates and tubes. V-bending process is very important because it is one of the process that is the most applied industry and it has three main advantages:

- A simple tool design
- An economical setup time
- A wide range of sizes and complex shape can be formed with the process.

1.3 Springback phenomenon

1.3.1 Definition

A very short moment after releasing the pressure on the material, a certain quantity of elastic energy remain on the loading area [3]. This energy causes the metal to back up a little bit to its original shape or position (Figure 1.3). This phenomenon is known as Springback. Briefly Springback is elastic recovery of the metal right after unloading [4]. In the V-bending process that we are studying springback causes the increase in included angle of the bend relative to the included angle of the forming tool after the tool is released (Figure 1.4).

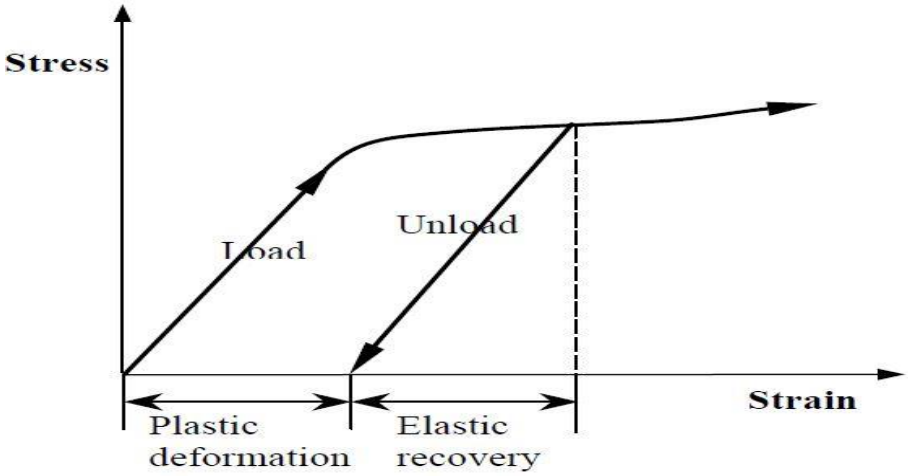


Figure 1.3: Schematic of the springback elastic recovery region[5].

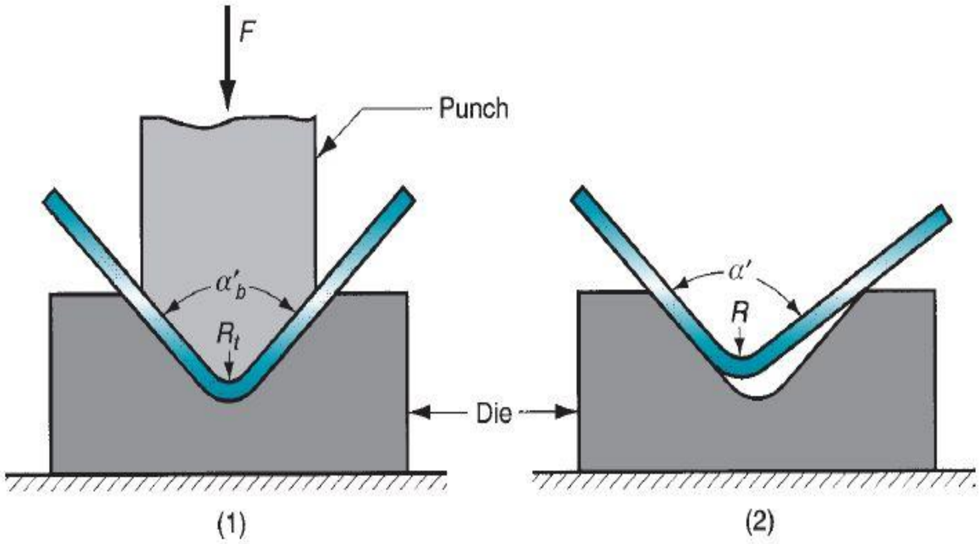


Figure 1.4: Springback phenomenon [6].

In Figure 1.4 at (1) during the process the plate is forced to take the shape of the die with the radius R_t and included angleα'_b. (2) After removal of the punch the plate springs back to R and included α’. F represents the applied load necessary to bend the metal work.

Briefly following figure1.6 springback can be expressed as follow:

$$SB = \frac{\alpha' - \alpha'_t}{\alpha'_t} \quad (1.1)$$

1.3.2 Factors affecting springback

Factors that affect springback angle are quite much (Figure 1.5). These factors are responsible of reducing or increasing the springback [7]. Springback can be negative as well as positive.

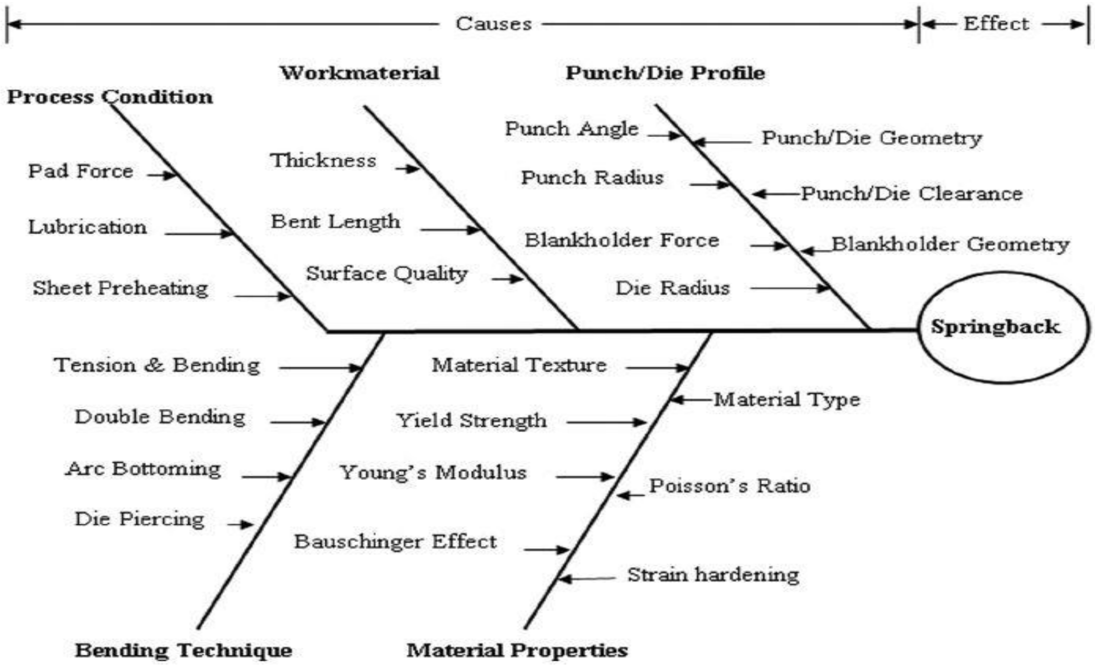


Figure 1.5: Cause-effect Ishikawa diagram showing the effect of various process parameter on springback [8].

1.4 Significance of the study

This study done on v-bending is very important and quite interesting for two main reasons:

- The first reason is that, very few researchers have gone through springback investigation in brass material. Brass is more and more used in marine construction, music instruments manufacturing, and jewelry and so on [9]. The need of understanding springback behavior of brass especially yellow brass is high.

- The second reason is about the applications of machine learning in this field. Previous researchers have been more focused on experimental test. Then the experimental results are usually compared to simulation and no further machine learning technic of prediction is applied. Using ANN, MLR and RSM (response surface metamodeling), this research will also compare the true experimental value of springback with ANN then MLR simulation and RSM. Many researches on springback in v-bending are more focused on simulation too. Simulation is a long and a complex process to follow in order to reach good accuracy with experimental result. The risk of human error is high and the procedure requires skilled FEA user. However, using machine learning is easier and user-friendly. The process doesn't take a long time and achieves good accuracy.

1.5 Problem statement

Sheet metal bending is very important because this process is very simple and cheap to conduct. Due to the simplicity of the parts configuration and its economical setting time, sheet metal v-bending is widely used in the bending industry. However, Sheet metal bending have an unwanted post-bending effect called springback. Springback is a partial elastic recovery that cause the metal to back-up to its original shape after bending. Many factors affect the springback, however this study focus on three main factors that are:

- Punch holding time
- Die opening (or die width)
- And sheet thickness.

The springback is investigated with these parameters based on the literature review results which show that the three parameters have significant impact on springback.

1.6 Scope of the study

- UNS C27000 BRASS as the workpiece material
- V-bending die with 85° angle and with three different sheet thicknesses (1.5 3 and 5 mm) and two die openings (22 and 35mm), and three different punch holding times (0, 5 and 10 seconds).
- Machine learning (ANN and RSM) was conducted for modelling of the results.
- ANSYS WORKBENCH software with implicit static structural was used to simulate the bending behavior.

1.7 Aims and contribution of the study

The aim of this research is to evaluate the springback of yellow brass material with modelling and simulation and then compare it with the experimental results. The particular contribution of the work is:

- It is the first time that springback is investigated on yellow brass UNS C27000 (based on literature review).
- The use of simulation platform like ANSYS will enable future researchers directly use the FEA settings and investigate springback with different factors
- The use of machine learning (RSM and ANN) method will provide a faster way to predict springback and further lead to an optimization of the SB.

1.8 Objective of the research

This study conducted on UNS C27000 brass material has the following objectives:

- Evaluate the springback of yellow brass with different parameters such as holding time, die opening (or die width) and sheet sample thickness.

- Conduct a FEA modelling of v-bending on the yellow brass
- Modelling of obtained results (using machine learning), to predict the optimum parameter and springback value.

1.9 Thesis organization

To reach our goal the following process scheduling has to be accurately followed:

- Chapter2 is the literature review. It will consist of reviewing all the past studies and researches related to sheet metal bending in general and vee-bending in particular. This section is very important because it enables to record crucial data necessary to conduct a good and well-structured research. Also, from the literature review, we will choose the most important and interesting parameters to be highlight in this study. Another thing is that this section allows the researcher to know if the work he or she is currently doing is not already done somewhere else by someone else.
- In Chapter 3 the design of experiment is a very helpful and powerful tool we use to setup an experiment procedure. Also, this section guides the researcher and saves time by reducing the quantity of work to be done. In this DOE a L_{18} multilevel Full-factorial will be used to conduct the study.
- Chapter 4 and 5 represent the result and the discussion respectively. In these sections, the work essentially consists of display of the results and analyze and criticize carefully.
- Chapter6 is the last section is the conclusion and the future work or recommendation. Those two parts are the last of the study. There is the summary of the outcome from the study where important points will be noted and advances and recommendations will be given.

Chapter2

LITTERATURE REVIEW

2.1 Statistical representation of the past work

The literature review of springback in sheet metal v-bending requires some efforts in investigating the related papers. One good way is to first collect statistical data to understand interests and methods used by the researchers.

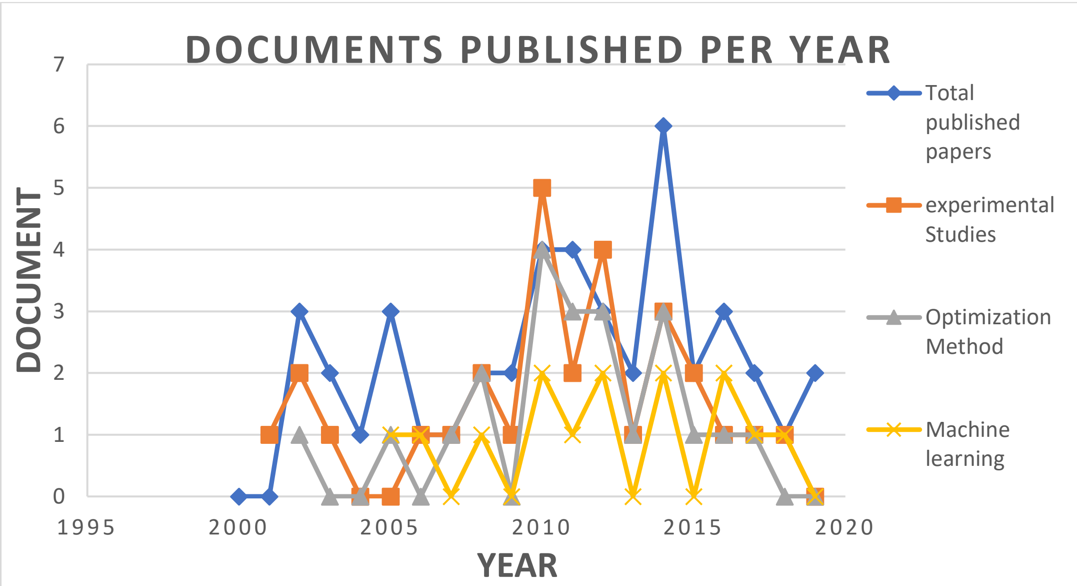


Figure 2.1: Published documents per year (adapted graph: data collected from Scopus).

The analysis of the Figure 2.1 can be resumed as follow:

- Researchers do more simulation methods than experimental, and the reason is that simulation is not expensive and time consuming.
- Simulation is usually conducted with optimization.
- Machine learning has been poorly applied in the beginning of the 21 century.

2.2 Parameters affecting springback

Sheet metal v-bending process is always affected by springback. However, springback too is affected by some parameters (Figure 2.2). Those parameters can be related to the geometry of the material or operational target. From figure1.7 the parameters are classified and group as material properties, work-material, and punch and die geometrical configuration, process condition and bending technique [8]. The researchers on springback v-bending have investigated almost all the known parameters of springback and given conclusions. Choudhury et al (2014) have investigated several parameters on aluminum alloy and applied ANOVA (analysis of variance) and discover that some parameters have more significant effect on the others (Figure 2.2).

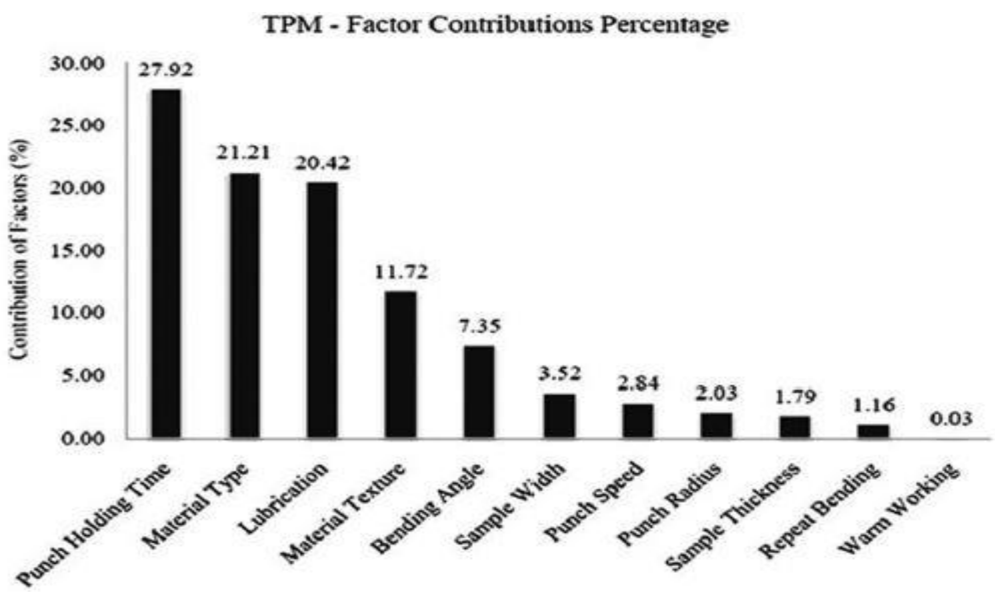


Figure 2.2: Pareto chart for TPM based on percentage contribution of factors. TPM: target performance measure [8].

Table 2.1 provides more details on the previous researches by type of factor/parameters studied.

2.2.1 Punch holding time

Punch holding time is the time the punch takes to stay stationary once it reaches the bottom of the die. Punch holding time is a very important factor for determining the springback. The influence on the springback is one of the highest among all the remaining factors [8]. Still according to Choudhury punch holding time increases bending duration and decreases significantly springback. They found that about 52% reduction of springback is possible within 1-minute holding time. They suggested to increase the bottoming as much as possible to minimize the springback. Using different material (high strength steel) another researcher reaches to the same conclusion that the time significantly reduce the springback [10]. This phenomenon can be explained by Karaagac et al (2017). The increase of holding time restrains the shape of the sheet metal allowing this sample to have a larger period of internal stress relaxation. This causes a decrease in internal stress of the bending side and the flattened arc leads to decreased elastic strain [11]. This behavior will cause the increase in permanent strain. Also, as the bottoming increases creep deformation increases and causes a reduction in elastic recovery. In summary the creep rate decreases following the holding time due to the decrease in internal stress [12].

2.2.2 Material type and texture

The material type is a very important parameter. The selection of the material requires particular attention because springback completely changes behavior from material to material. However, we can note in springback in v-bending the materials most used are steel alloys followed by aluminum alloyed [13-15]. Dongjun et al. shows the influence of the modulus of elasticity on the magnitude of the final springback strain on the sheet sample. Also, the texture dimensioning and the surface quality have significant effect on the springback [16-18].

2.2.3 Bending angle

Previous researches showed that bend angle change will affect the final sheet angle. However, bending angle is a delicate parameter because its behavior regarding to springback changes from a configuration to another one. Indeed, for Ahmed et al., (2014), Inamdar et al., (2002), and Jurcisin et al., (2012) the increase of bend angle increases the springback [16, 19, 20].

However, Panda et al., (2018) provides contradictory results in their study. They found that springback decreases with the increase of bend angle. Since they used different material (HSLA 420) [21], we can assume that springback behavior is not uniform for all the material some materials will therefore tend to increase their springback strain with the increases of bend angle while some will tend to decrease the strain.

2.2.4 Die width or die opening

In a previous study [22], the result shows that the function of die opening to springback is not linear and uniform direction like some parameters like holding time. For range of smaller die openings, the increase of the opening decreases the springback. However, once we pass this range the increase of the die opening will result in the increase of the springback. This range sensitively vary from material to material and also to thickness. That is why it is very important to make sure to use the appropriate die opening to thickness ratio (Table 2.2) for a proper experimental configuration.

2.2.5 Sheet or sample thickness

Sheet thickness is a very important parameter. The determination of sheet thickness is done according to the die opening size. In general, previous studies showed that springback tends to decrease with the increase of sheet thickness [23, 24]. The bigger the sheet thickness the smaller the springback and the final shape is getting closer to the ideal shape without post-processing for springback compensation. Also, Sharad et al., (2014) conducted a study to investigate the relation between springback and the ratio of bend radius to sheet thickness. They have found that springback is increase with the ratio R/t. That is why a proper selection of R/t ratio is always suitable before conducting any experiment (Table 2.2). Thipprakmas et al., (2017) showed that the effect can be very significant when the thickness is larger. And recommended to apply neural network technique to predict the springback and optimize the value [25].

Table 2.1: Classification of reviews by the type of parameters.

Geometric and Operational Target Parameters	Effect on SB	Research references
Die gap / width	• Increasing values of the die gap and die gap to sheet metal thickness ratio (w/t) leads to increase in SB in **air-vee bending** {Vasudevan, et al., (2011)– AKDQ; Inamdar, et al., (2002) - CPAl, Al-alloys, MS, HTS and DDS sheets; (Ján & Jurcisin, 2012) - mild steel, HSS and UHSS; Alhammadi et al., (2018) – Aluninium, brass and stainless steel} • Increase in die opening leads to SB reduction in **vee bending** (Panda & Pawar, 2018)- HSLA 420} but led to SB increase in (Garcia-romeu, Ciurana, & Ferrer, 2007) – Aluminum and Stainless steel	[19], [26], [21], [20, 27, 28]
Die and die corner radius	Decrease of die radius leads to a SB decreases	[29], [8], [26, 30]
Punch-die clearance	Decrease in tool clearance leads to a SB decreases.	[29],[31, 32]
Punch radius	Decreasing the punch radius decreases the SB. A high ratio of R/t (punch radius to thickness ratio) tends to reduce SB	[8, 31], [26], [33, 34], [12, 30, 35, 36]
Punch angle / Bend angle (vee bending)	• Increase in the punch / bend angle for a given sheet thickness, increases the SB {Ahmed et al., (2014) (Ahmed, Ahmed, Mohiuddin, & Sajid, 2014) – Material: mild steel}. • A higher punch / bend angle tends to reduce SB	[8, 16]

Geometric and Operational Target Parameters	Effect on SB	Research references
	{Choudhury & Ghomi, (2014) (Choudhury & Ghomi, 2014) – Material: Aluminum, Panda & Pawar (2018) (Panda & Pawar, 2018) – Material: HSLA 420}	
Bend angle- ϴ (air vee bending)	Increasing values of ϴ leads to increase in SB	[19, 20]
Step distance (SD)	Increasing SD (using the L-bending forming configuration) decreases the SB.	[31]
Step height (SH)	Increasing SH (using the L-bending forming configuration) decreases the SB	[31]
Blank holder force	Increase in blank holding force leads to a SB decreases.	[29]
Material type	• Material with low-yield stress results in lower SB compared to those with higher values of yield stress.	[8, 20, 27, 28]
Grain orientation	SB shows anisotropic characteristics varying with rolling direction of the sheet metal. However variation of SB with rolling direction is not linear. • Vasudevan et al. (2011): Steel sheets with 90° grain orientation showed a higher SB than sheets with 0° grain orientation (Vasudevan et al., 2011). • Soualem and S. Hakimi (2018): Steel sheets with 90° grain orientation showed a higher SB than sheets with 0° grain orientation while aluminium sheets showed higher SB with the 0° grain orientation than the 90° grain orientation (Soualem & Hakimi, 2018).	[21, 26, 37]
Material dimension (area)	Smaller material bending area aids SB minimization.	[8]
Material thickness	With increasing sheet metal thickness, the SB decreases.	[16, 27, 28, 34, 35]
Punch speed and stroke	Smaller punch speed was recommended from their study because they suspected that with slow deformation speed, the material has enough time to re-orient the grains during bending thus leads to SB reduction,	[26, 38]
Bottoming effect	A large punch holding time / bottoming minimizes SB.	[12, 39], [8]

Geometric and Operational Target Parameters	Effect on SB	Research references
Friction	For the range of conditions normally encountered in sheet metal forming operations friction has marginal influence on SB, but for the AA 6024-T4, SB increases with very low friction condition. • Jadhav et al. (2018): higher frictional coefficient results in lower SB • M. Sigvant et al (2016) & J. Hol, et al (2017): Realistic account of friction during forming simulations (rather than assuming constant friction co-efficient values) results in better forming and SB predictability	[32, 40]
Heat treatment	For the same material subject to different degrees of heat treatment e.g. AA 2014 (AA 2014-O, AA 2014-T4 and AA 2014-T6) Sarikaya (2008) (Sarikaya, 2008) and AA3003 (annealed – O temper, half-hard - H 22 temper and full hard – H 24 temper) Verma (2016) (Verma, 2016), due to the changes in mechanical properties after heat treatment, (i.e. increasing yield strength) the highest SB was observed in the T6 and 24 tempers while the least SB was observed in the O condition.	[5, 41]
Warm working	With increasing warm forming temperatures for the same combination of forming parameters, the SB decreases.	[8, 12, 31, 37, 39, 41],[12, 39, 42, 43]
Electric-pulse warm forming	SB and bending load decreases with increasing RMS current density, peak current density and frequency; attributed to the electro-plastic effect of the electro-pulsing during the electrical assisted forming process. Electric pulse assisted forming is less energy intensive compared to traditional warm forming process.	[42, 44-46]
Lubrication	The SB was observed to increase with lubrication	[8]
Material coating	SB tends to increase with increasing coating thickness	[26]

Table 2.2: Investigation of the relationship between die opening (w) and sheet thickness (t) ratio: w/t

INVESTIGATION OF THE RELATIONSHIP BETWEEN DIE OPENING (w) AND SHEET THICKNESS (t) RATIO: w/t				
Researcher	Material	Material dimension (mm)	Die opening (mm)	Die opening to sheet thickness (w/t) ratio
[21]	HSLA 420 steel and St12 steel;	90 x 30 x 2.4	25.2, 38.4 & 48mm	12, 16 & 20 (with respective punch and die angle of 86, 88 and 90 degs)
[27]	Aluminum and Stainless steel	130 × 50 x (1-3)	16, 22, 35 & 50	Al: 11.85 - 50 and Stainless steel: 5.33 - 50
[16]	Mild steel	100mm Length and (1.2/2/3) mm thickness	24, 30 and 55	6 to 50
[34]	AISI304 sheet metals	80 x 30 x (2, 3, 4, 5)	27, 29, 31 & 33	5,4 to 16.5
[30]	Stainless Steel SS 304	120 x 30 x 3	55 & 80	18 and 27
[26]	Aluminum killed draw quality (AKDQ) steel sheet	120 × 40 x 1	40, 60 & 80	40, 60 and 80
[19]	High tensile steel (HTS), Mild steel (MS), Aluminum alloy (NA), Deep drawing steel (DDS), Commercially pure aluminum (CA)	HTS-0.75mm, MS-0.8mm, Al alloy - 0.83mm, DDS-1.0mm, CA-1.35mm; Cross-section: 175 mm x 35 mm	20, 30 & 40	14 to 54
OUR THESIS WORK	BRASS and ALUMINIUM	1.5, 3 and 5	16, 22, 35 and 50	

Observation from the literature on factors affecting springback shows that researchers conducted investigation over a wide range of die width and sheet thickness (i.e. w/t) ratio Between 5.3 to 80, studying different sheet metals and sheet thicknesses (1-3mm).

From observation no researcher studied die width or sheet thickness effect on SB for a w/t ratio less than 5.33. Thus, sheet thickness of 5mm will not be used with the die opening of 16mm.

2.3 Application of machine learning in sheet bending.

Machine learning is a very useful tool in sheet metal bending. The previous researches have widely use machine learning techniques mostly to classify bending parameters or to predict the springback. A significant improvement in the techniques has been notice in this past 20 years. However, machine learning is a field that requires constant improvement. For example, neural network has been widely used in the recent years (till 2010) in sheet bending. Sachin Kashid et al (2012) noticed that all those previous researches focused exclusively on prediction techniques in sheet metal work using ANN (artificial neural network). The past researches could not use ANN technique to design the sheet metal dies (like compound, progressive, combination and blanking die) and prediction of die life to help designers in sheet metal industry[47].

Chapter3

METODOLOGY

This chapter will talk about the methodology of this paper with the following flowchart (Figure 3.1):

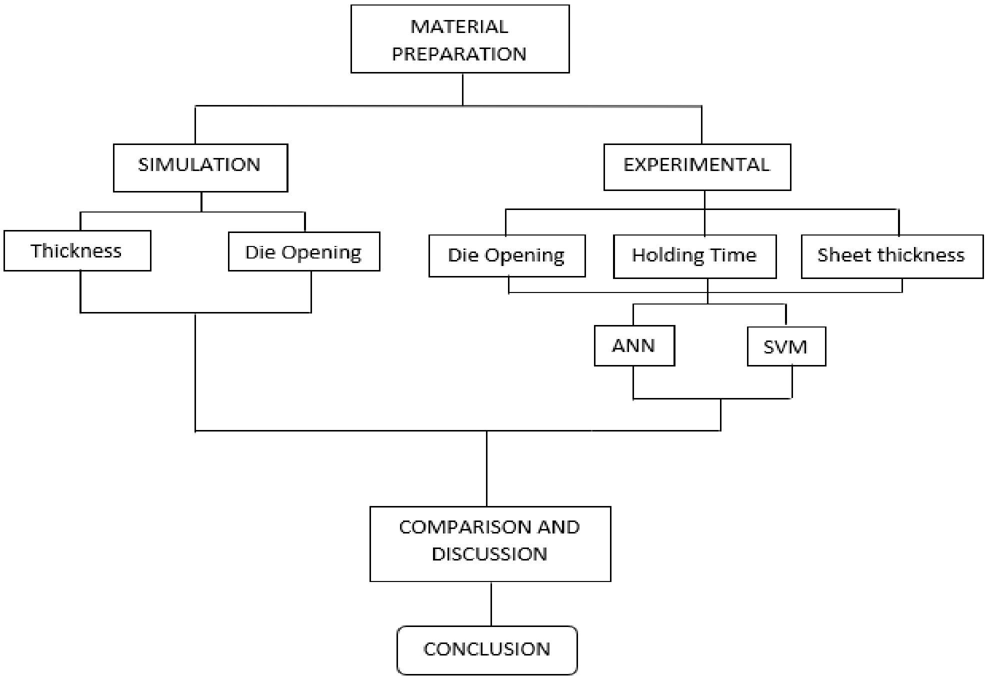


Figure 3.1: Methodology flowchart.

3.1 Experimental equipment

3.1.1 Bending machine and Die and punch fixation

This machine is composed of a hydraulic piston with a pressure of 500 bars which is sufficient to perform the folding (Figure 3.3). The bending machine is also composed of a control lever as well as a pressure indicator which makes it possible to note the pressure obtained during the contact phase of the punch and the sheet.

The punch and die used in this research are made by DENER company (Figure 3.3). In order to properly hold the punch and the die, a fixture has been manufactured. The fixture is composed of two main elements. The first one is the top holder. This part is responsible for properly hold the punch and fix is to the bending machine piston in order to apply the load on the sheet. The second main part is the bottom holder or bottom support. This is where the die sits and get fixed to receive the work sample. Both top and bottom holders are made from low carbon steel.

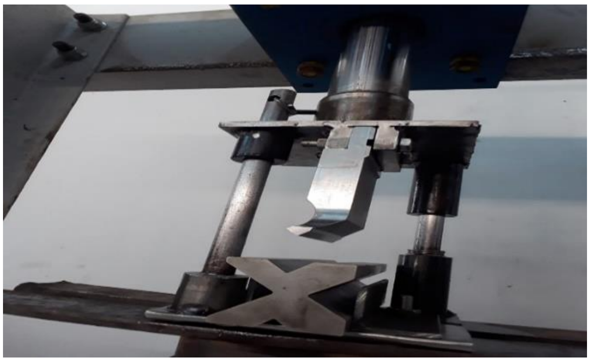


Figure 3.2: Fixture attached to the piston of the bending machine.

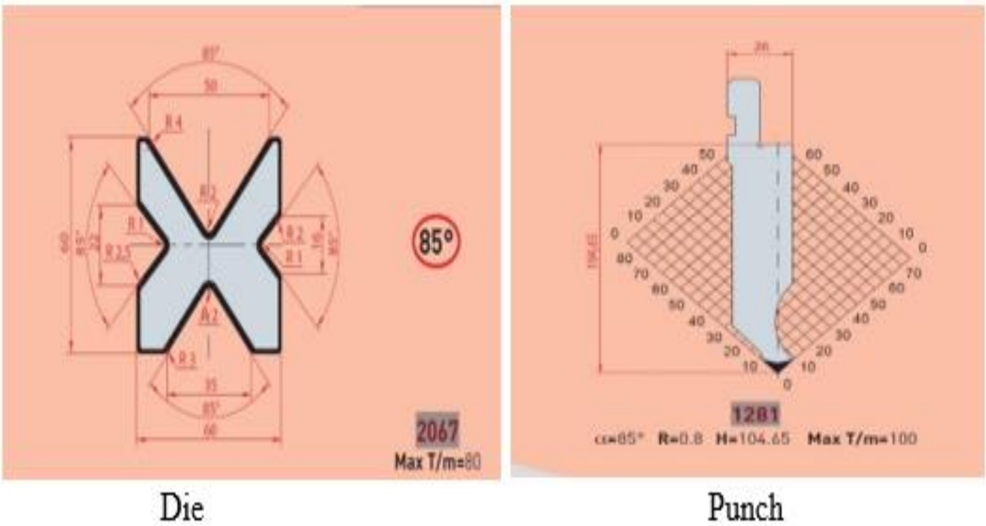
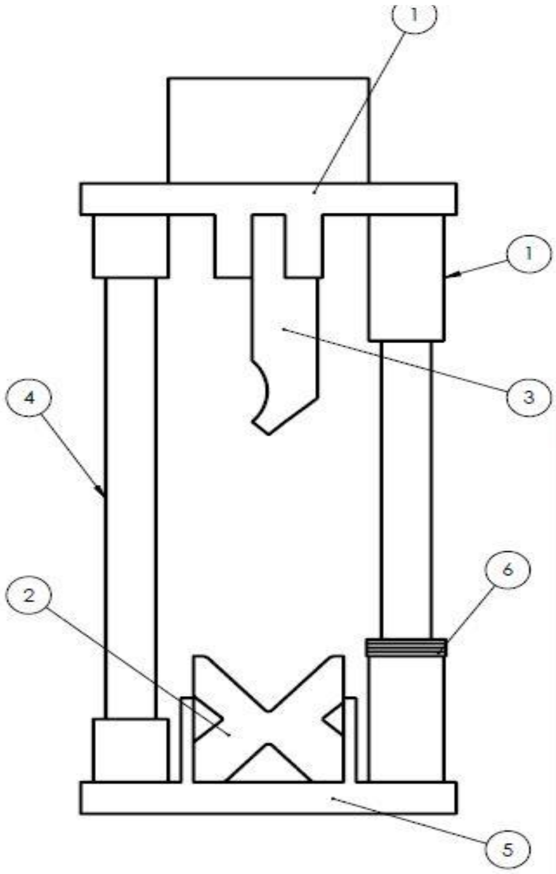


Figure 3.3: 2D drawing of die and punch.

To enable an accurate positioning of the punch in the die some washers have been added following the configuration of each die opening and sheet thickness. This allow the punch to stop at a determined location in the die (Figure 3.4). The punch speed is constant with value of 15mm/s.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	top support		1
2	die		1
3	punch		1
4	sleeve shaft		2
5	bottom support		1
6	DIN 988-S22x32		4

Figure 3.4: Schematic drawing of the whole fixture and die and punch assembly.

3.1.2 The angle measurement projector

Measurement of the springback angle is a very important step of the analysis part of the study. In order to measure the angle, an angle measurement projector was used. This device is simple in use and ease the entire work. The measurement precision is high and easy to perform. The device is a Leipzig angle projector (Figure 3.6). The procedure of taking the measurement is as follow:

- First before starting check if the machine illuminator delivers proper light and on-screen reading.

- Then place the sample on the operating table and position it well in front of the objective lens.
- Then calibrate the objective and magnify the picture on the screen to record the angle.


Figure 3.5: Angle measurement device.

3.1.3 Hardness test

The material used in this study is UNS C27000 brass. In order to confirm the physical properties of the material (bought in the market with properties sheet) a hardness test has been conducted. The machine applied a force of to allow the indenter to penetrate in the material. The performed test is a Vickers hardness test (Figure 3.7). The results are in (Table 3.1).

Figure 3.6: Hardness testing machine.

3.2 Material properties

UNS C27000 was used in this experiment. This type of brass is called yellow brass, because of its higher content of zinc material it turns to golden yellow material (Table 3.1). This is why this material is widely used in jewelry. It is also used in many different fields like marine construction field due to its high corrosion resistance properties. In medical industries is used for its anti-bacterial properties.

Table 3.1: Percentage weight of the UNS C27000 brass component composition.

Copper Cu	**Zinc Zn**	**Lead Pb**	**Iron Fe**
Balance	36%	0.1%	0.07%

This material is suitable for v-bending because of its good formability at room temperature. The material physical properties (Table 3.2) will play a very important role in the simulation setting.

Table 3.2: Physical properties of yellow brass.

Tensile yield strength	97 MPA
Ultimate tensile strength	315 MPA
Elongation at break	65%
Modulus of elasticity	105 GPA
Shear modulus	35 GPA
Density	8.47 g/cc
Hardness Rockwell	58
Hardness Vickers	139

The dimensions of the samples were the same except the thickness (25mmX60mm: Figure 3.8). Indeed, three different thickness are used which are 1.5mm, 3mm and

5mm. The choice of this size is justified by a literature parameter review in chapter2 (Table 2.2). It has been proved that springback is more accurately predict on small scale surfaces.

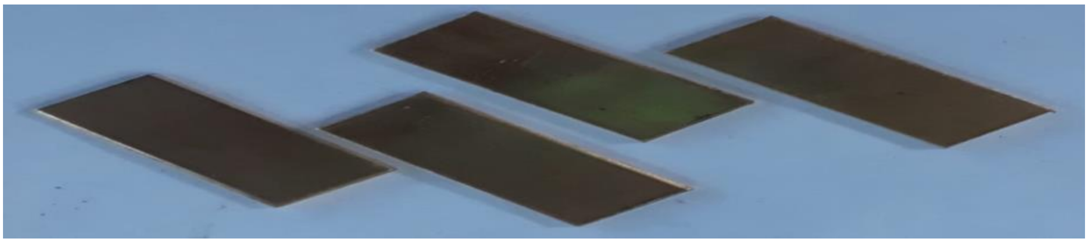


Figure 3.7: Sample material.

3.3 Design of experiment

In order to conduct the experiment with minimum number of test a proper design of experiment was done, all 3 parameters supposed to have any effect on the springback were considered in the DOE. In this DOE two process parameters with 3 level each and one process parameter with 2 levels are presented in (Table 3.3). The selection of the upper ranges and lower ranges of the level are done following previous experimental investigation and the literature review. So according to the literature review, sheet thickness, die opening and holding time have significant effects on springback.

Table 3.3: Selected parameters and their levels.

Factor	Description	Unit	Level 1	Level 2	Level 3
1	Holding time	Second (s)	0	5	10
2	Sheet thickness	mm	1.5	3	5
3	Die opening	mm	22	35	

The selected DOE method is a L18 multilevel dull factorial (Table 3.4). This method will be suitable for this particular experiment compare to the Taguchi method that is very suitable for the worse case analysis. Also, the method enables later the generation of a response of springback.

Table 3.4: DOE full factorial table arrangement.

Run Order	Sheet thickness	Holding time	Die opening	Designation
1	1.5mm	0 second	22mm	S1.5-H10-D22
2	1.5mm	5 seconds	22mm	S1.5-H5-D22
3	1.5mm	10 seconds	22mm	S1.5-H10-D22
4	1.5mm	0 second	35mm	S1.5-H0-D35
5	1.5mm	5 seconds	35mm	S1.5-H5-D35
6	1.5mm	10 seconds	35mm	S1.5-H10-D35
7	3mm	0 second	22mm	S3-H0-D22
8	3mm	5 seconds	22mm	S3-H5-D22
9	3mm	10 seconds	22mm	S3-H10-D22
10	3mm	0 second	35mm	S3-H0-D35
11	3mm	5 seconds	35mm	S3-H5-D35
12	3mm	10 seconds	35mm	S3-H10-D35
13	5mm	0 second	22mm	S5-H0-D22
14	5mm	5 seconds	22mm	S5-H5-D22
15	5mm	10 seconds	22mm	S5-H10-D22
16	5mm	0 second	35mm	S5-H0-D35
17	5mm	5 seconds	35mm	S5-H5-D35
18	5mm	10 seconds	35mm	S5-H10-D35

Based on this design bending experiment were conducted. And each experimental run was repeat 3 times (54 total runs for the experiment) and the average reading of the springback is considered for the analysis.

3.4 Finite element modelling

In this study ANSYS WORKBENCH software is used to perform the FEA process. Springback simulation in v-bending is a very long process that requires excellent pre-processing, loading and post-processing of the result. This kind of simulation process is considered as a non-linear plastic deformation situation subjected to large deflection effect [48]. The reason is that in a linear analysis the stress-strain curve is linear, and this is not our case where the curve is nonlinear. An FEA simulation can be nonlinear for three main reasons:

- The boundaries conditions linearity
- Geometrical non-linearity
- The material nonlinearity.

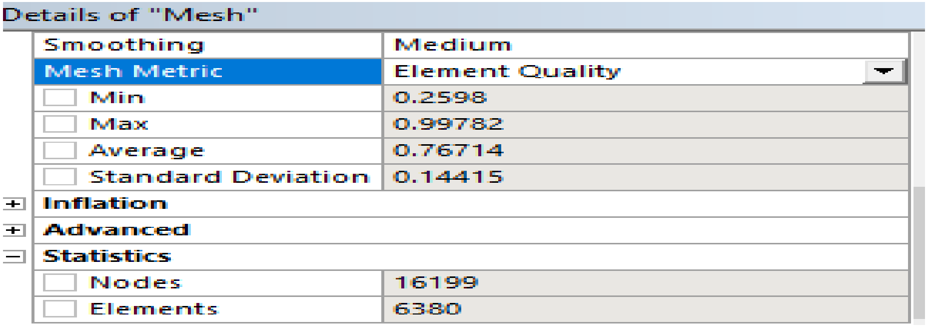
In order to properly conduct the simulation, a static structural implicit simulation procedure has been followed. Explicit function, also available in ANSYS could be used to conduct the experiment. However, the implicit codes is more suitable [49]. This is because the implicit code is more suitable for sheet metal forming and easier to use when we operate with ANSYS software [37]. Table 3.5 illustrate a comparison of implicit and explicit generic codes about their advantages and limitations using different commercial software.

Table 3.5: Commercially available FE codes for SMF simulation [37].

Software	**Implicit/Explicit**	**Specialty**	**Limitations**
ANSYS WORKBENCH	Implicit	Availability to user, user material model	There is convergence problems in nonlinear analysis and contact conditions
LS-DYNA	Explicit	Can handle complex problems with large deformation and has no convergence problems	Does not have pre-processor and complex post-processor
ABAQUS	Implicit or Explicit	large deformation, no convergence problems	No preprocessing tool

3.4.1 Mesh and element type

A good FEA simulation is done by setting properly the material properties and the mesh size and element type. Decreasing the size of the mesh will result in the increase of the accuracy of the prediction and the computing time. Also, high mesh resolution can cause convergence issues for large deformable elements [38]. The element type selected is a quadratic Solid187 tet10. This element type is suitable for the simulation of springback in 3D workspace for bending. This element is a new version of solid92 and is more modern. Its selection is justified because of its mixed formulation capability for simulating deformation of nearly incompressible elasto-plastic materials and full incompressible hyper-elastic materials. The performance of TET10 is high in Vee-bending and low in pure bending [50]. From Figure 3.8 we can see a maximum mesh quality of 0.99782 and an average mesh quality of 0.76714 with a standard deviation of 0.14415. According to the ANSYS APDL user guide, a good mesh quality has a value close to 1 and a poor mesh quality has a value close to 0. After meshing of the punch, the die and the sheet sample, the average mesh quality of 0.76714 (Figure 3.8) confirm that the meshing is properly done. Figure 3.9 shows the repartition of the elements like tet10, hex20 and wed15 in the total number of elements that forms the mesh. Here tet10 represent the biggest population of elements followed by hex20. Tet10 is present in the mesh of the die the punch and the sheet sample. Also, on the sheet sample only tet10 is used automatically by the software as recommended to take into consideration the plastic non-linear deformation.



Details of "Mesh"	
Smoothing	Medium
Mesh Metric	Element Quality
Min	0.2598
Max	0.99782
Average	0.76714
Standard Deviation	0.14415
Inflation	
Advanced	
Statistics	
Nodes	16199
Elements	6380

Figure 3.8: Mesh quality.

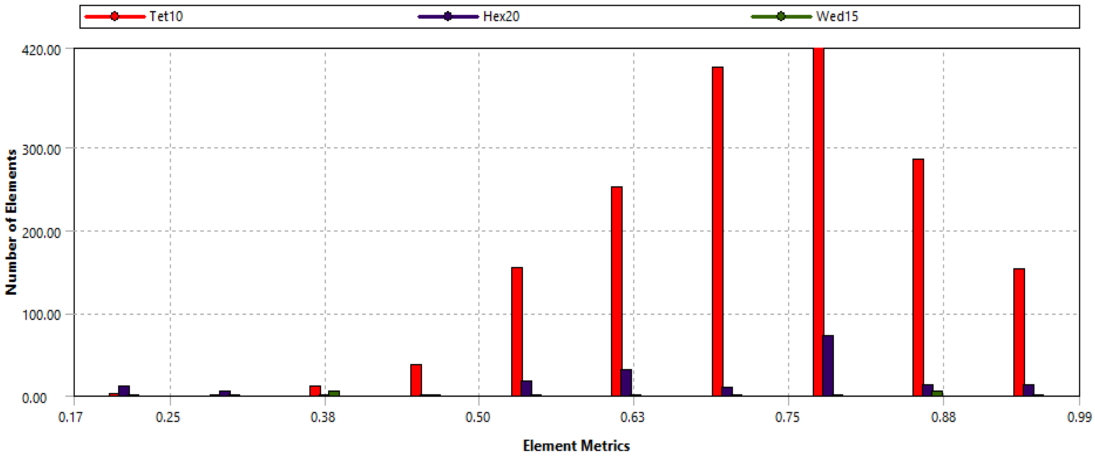


Figure 3.9: Mesh repartition.

3.4.2 Contact conditions

In this simulation the contacts were all frictional with a friction coefficient of 0.1. This friction coefficient is suitable for this situation and allows the parts to slide within a reasonable range. Also, the contact formulation used is the augmented Lagrange and the stabilization damping factor is 0.1.

3.4.3 Displacement configuration

The displacement in the simulation is set to follow the actual experimental value which is 15mm/s (Figure 3.10). Compared to the previous studies based on the literature review this speed is higher than the average displacement. However, this higher displacement is suitable to obtain smaller springback value and helps easily to narrow the accuracy of the prediction.

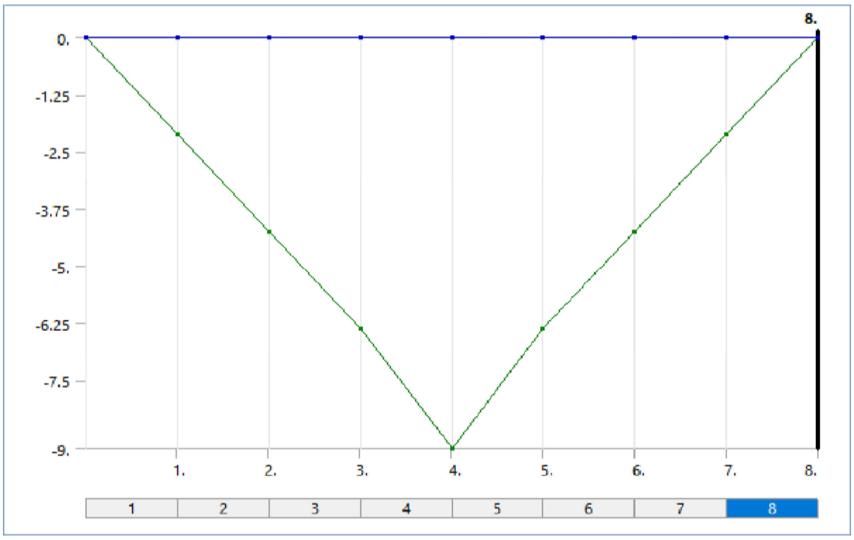


Figure 3.10: Graphical representation of the punch displacement.

3.4.4 Validation and testing of the setting from previous simulation paper results.

In order to ensure the quality of the setting and minimize the risk of error in the prediction of the springback values a test was performed on a previous simulation paper on springback [40]. Also, the dimensional configuration of the punch and die as well as the dimensions of the metal sample were taken from the paper and the result compared in Table 3.6.

Table 3.6: Comparison between previous paper springback and actual simulation springback.

	Springback Value		
Bending Angle	**Previous paper method**	**Actual research method**	**Prediction Error**
93.6	4.4°	4.75°	0.35°
101.4°	3.7°	4.15°	0.45°
112.3°	3°	3.2°	0.2°

The Table 3.11 shows a very high similarity with the method of (Esat & Darendeliler, 2014). This low level of error enables us to validate our simulation model and go on to the simulation of our samples.

Chapter4

RESULT OF EXPERIMENTAL AND SIMULATION

The experimental tests were successfully done as shown in Figure 4.1 and Figure 4.2. Final bending angle (inside angles) are represented in Table 3.1.

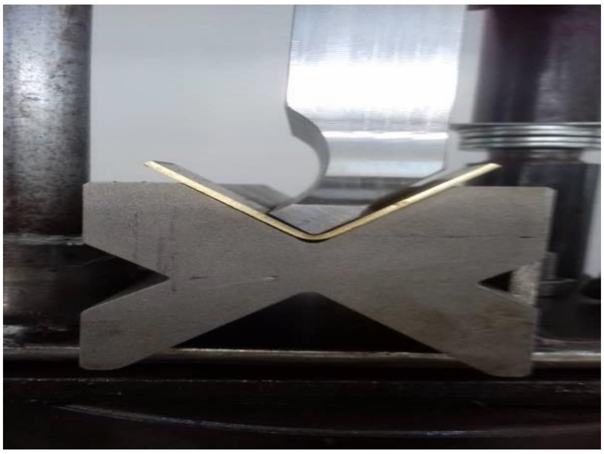


Figure 4.1: Loading process of 1.5mm sheet sample.

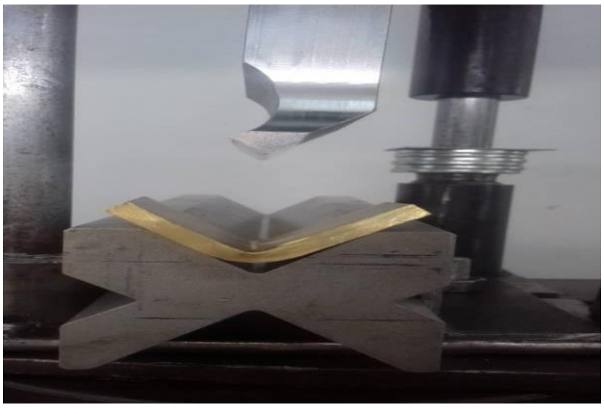


Figure 4.2: Unloading process of the 5mm sheet sample.

However, the springback have been calculated from the outside angles (Figure 4.4) to simplify the procedure.

4.1 DOE full factorial result

The DOE full factorial set represented in Table 4.1 shows the represents the results of the experimental tests. The results show a graphical representation of springback in

Table 4.1: DOE full factorial experimental results.

Designation	Outside angle 1	Outside angle 2	Outside angle 3	SB angle 1	SB angle 2	SB angle 3	Average SB angle
S1.5-H0-D22	42.5	42.5	41	5	5	6.5	5.5
S1.5-H5-D22	45	44.15	45.35	2.5	3.35	2.15	2.67
S1.5-H10-D22	45.2	45.15	45.3	2.3	2.35	2.2	2.28
S1.5-H0-D35	41	41.1	40.8	6.5	6.4	6.7	6.53
S1.5-H5-D35	42.9	43	43.95	4.6	4.5	3.55	4.22
S1.5-H10-D35	45	44.55	43.25	2.5	2.95	4.25	3.23
S3-H0-D22	43.8	44	43.35	3.7	3.5	4.15	3.78
S3-H5-D22	46.45	46.4	46.5	1.05	1.1	1	1.05
S3-H10-D22	47	47	46.55	0.5	0.5	0.95	0.65
S3-H0-D35	45.85	45.65	46	1.65	1.85	1.5	1.67
S3-H5-D35	45.95	46	46.5	1.55	1.5	1	1.35
S3-H10-D35	46.5	46.55	46.05	1	0.95	1.45	1.13
S5-H0-D22	45.8	46.85	44	1.7	0.65	3.5	1.95
S5-H5-D22	45.9	46.1	45.6	1.6	1.4	1.9	1.63
S5-H10-D22	46.6	46.65	46.5	0.9	0.85	1	0.92
S5-H0-D35	44.45	45.2	44.6	3.05	2.3	2.9	2.75
S5-H5-D35	45.65	45.25	44.8	1.85	2.25	2.7	2.27
S5-H10-D35	46.25	45.55	45.05	1.25	1.95	2.45	1.88

A graphical representation of the average angle represented in Figure 4.3 shows in a rough way the differences of effects from the factors on springback. A clear analysis of effect is provided in chapter 5, the discussion section with the ANOVA analysis.

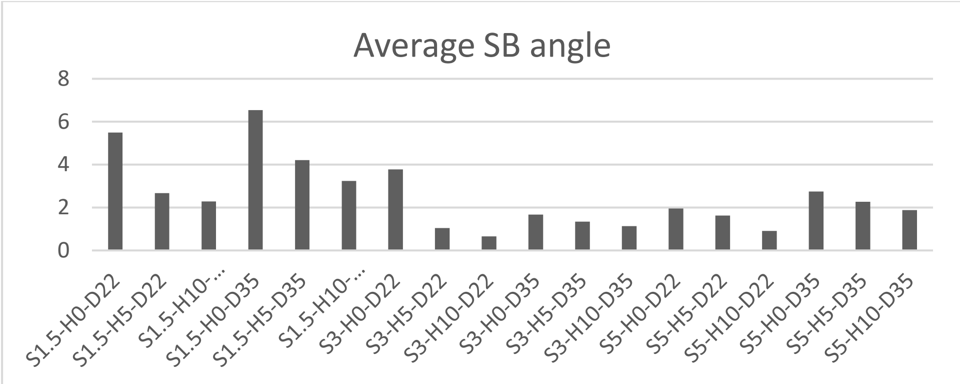


Figure 4.3: Graphical representation of the springback from DOE results table.

4.2 Response surface metamodeling

The response surface is 3-dimensional representation of the springback. The response surface is generated with MATLAB codes. Since response surface consider only three variables at a time the following three response surfaces will represents the full springback behavior according to the 3 factors.

Response surface 1: Sheet thickness vs holding time

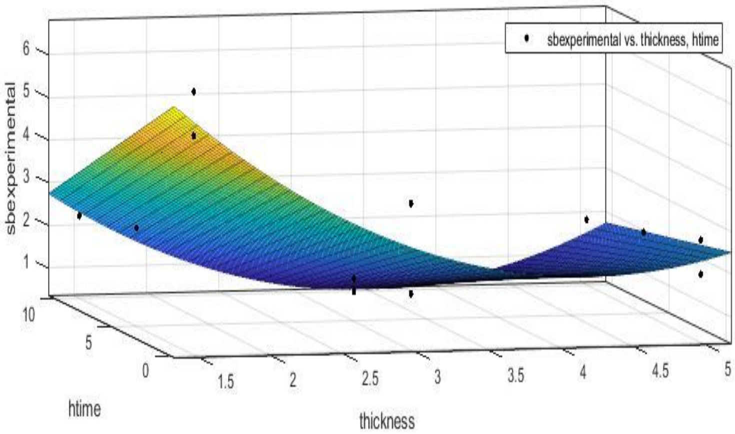


Figure 4.4: Response surface1 sheet thickness vs holding time.

Linear model Poly21 :

F (x, y) = 10.88 - 4.272*x – 0.4065*y + 0.5119*x^2 + 0.06477*x*y

Response surface 2: Sheet thickness vs die opening

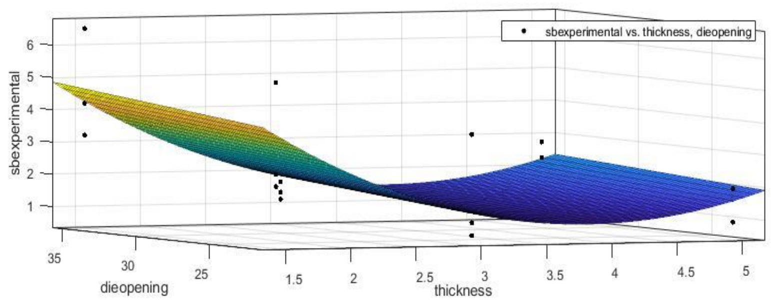


Figure 4.5: Response surface 2 Sheet thickness vs die opening.

Linear model Poly21 : f (x, y) = 1.474 - 1.041*x + 0.263*y + 1.114*x^2 – 0.05197*x*y

Response surface 3: Holding time vs die opening

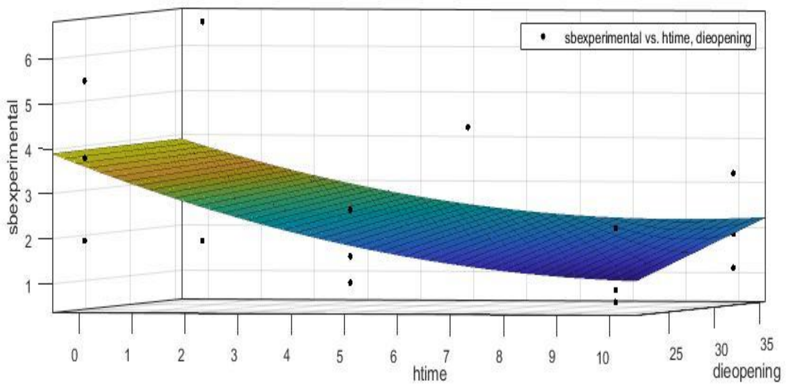


Figure 4.6: Response surface 3 holding time vs die opening.

Linear model Poly21 :

F (x, y) = 3.557 + 0.5947*x + 0.004915*y + 0.01972*x^2 + 0.00688*x*y

4.3 Simulation results

The simulation tests are performed using ANSYS implicit functions and the results are given for all the 0 holding time DOE sets. The results are shown from Figure 4.7 to Figure 4.15 and summarized in Table 4.2.

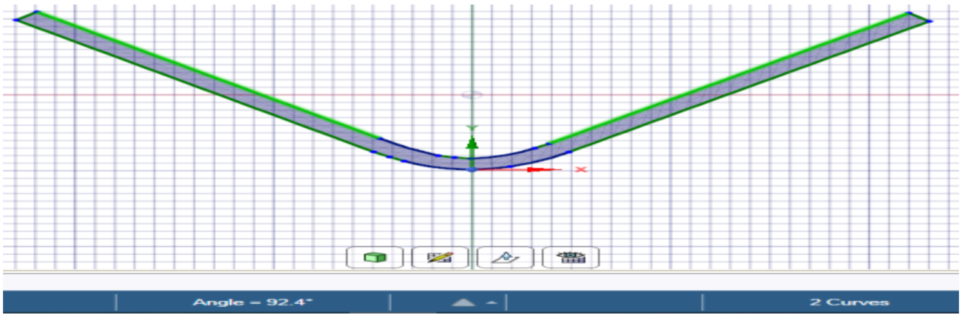


Figure 4.7: Measurement of springback angle after bending of 1.5mm sheet in 22milimeter die opening and 0 holding time.

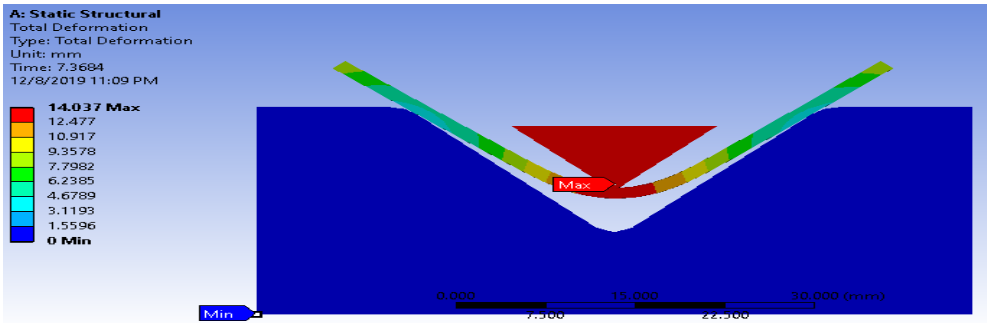


Figure 4.8: Simulation of 1.5mm sheet in 35 mm die opening (the unloading process).

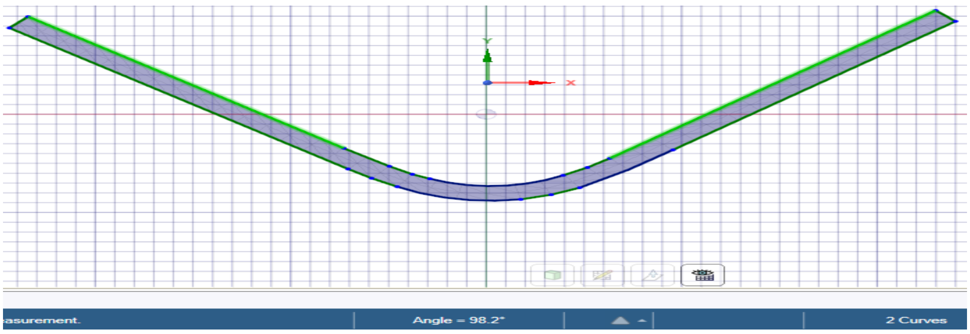


Figure 4.9: Measurement of springback angle after bending of 1.5mm sheet in 35milimeter die opening and 0 holding time.

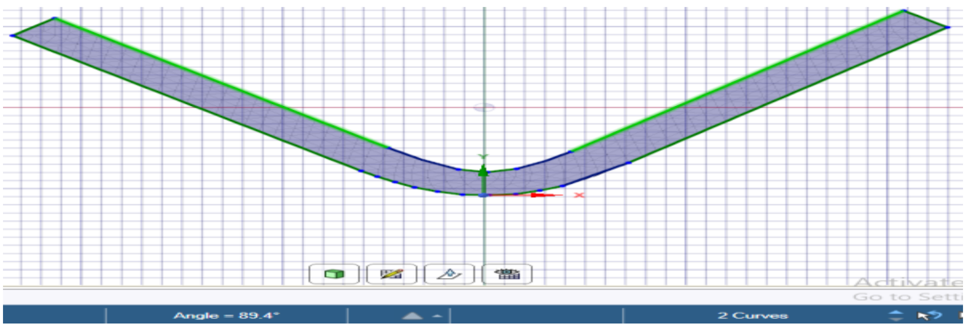


Figure 4.10: Measurement of springback angle after bending of 3mm sheet in 22milimeter die opening and 0 holding time.

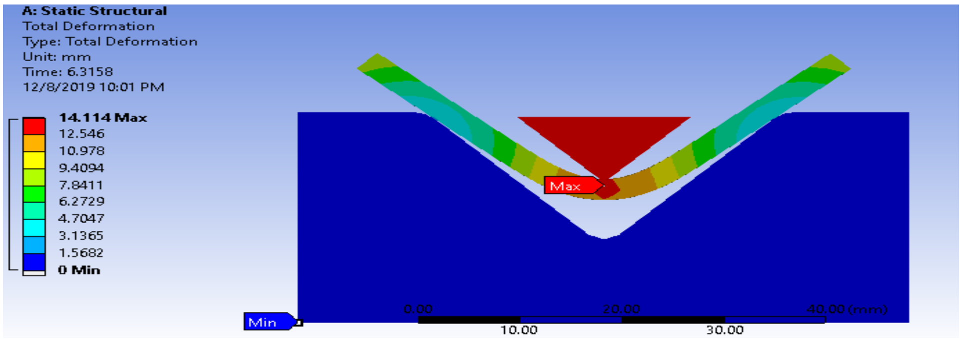


Figure 4.11: Simulation of 3mm sheet in 35 mm die opening (the unloading process).

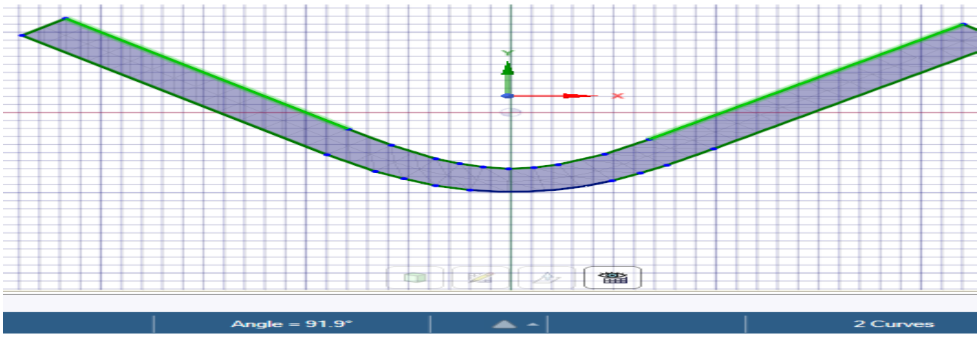


Figure 4.12: Measurement of springback angle after bending of 3mm sheet in 35mm die opening and 0 holding time.

Figure 4.13: Measurement of springback angle after bending of 5mm sheet in 22milimeter die opening and 0 holding time.

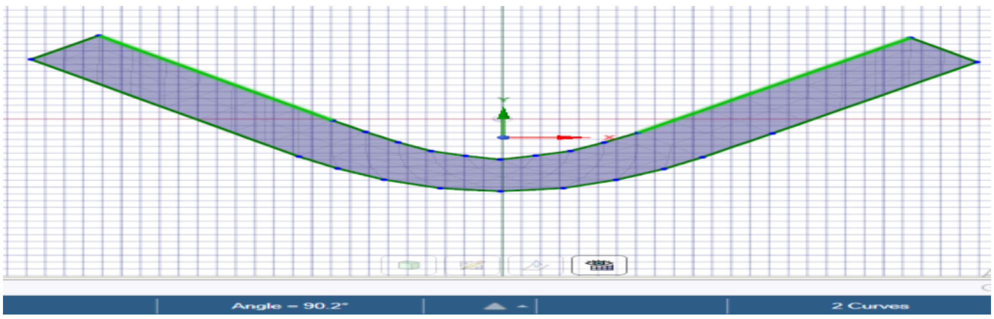


Figure 4.14: Measurement of springback angle after bending of 5mm sheet in 35milimeter die opening and 0 holding time.

Table 4.2: Summary of the simulation results.

Designation	final angle	SB simulation angle
S1.5-H0-D22	43.8	3.7
S3-H0-D22	45.3	2.2
S5-H0-D22	45.25	2.25
S1.5-H0-D35	40.9	6.6
S3-H0-D35	44.05	3.45
S5-H0-D35	44.9	2.6

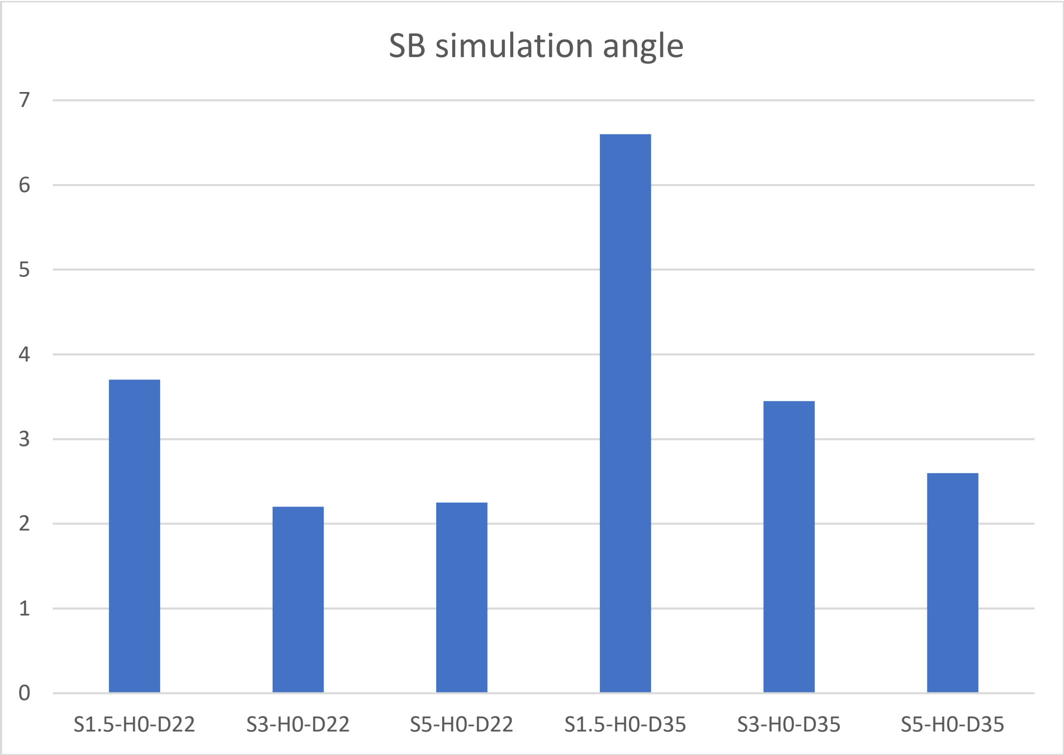


Figure 4.15: Graphical representation of springback from simulation.

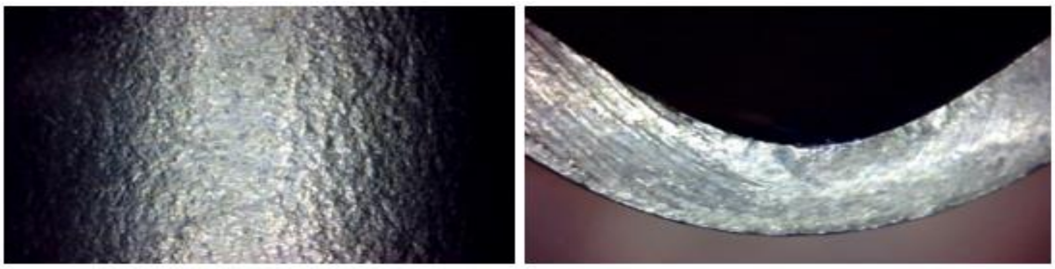
Chapter5

DISCUSSION

5.1 Crack and defects detection on the surface

This procedure is very important before analyzing any result. It confirms that the bending procedure has been well operated and conditions of a v-bending has been achieved. This surface analysis enables us to later relate some abnormal results and build a solid argumentation. In order to perform this operation, an usb microscope has been used. This microscope is an usb camera that can magnify the picture between 50 and 500times (Figure 5.1). We magnified the surface picture till 0 to 60 times (Figure 5.2 to Figure 5.4).

Figure 5.1: Usb microscope.



x60 of the bend region (1.5mm). Checking of thickness.

Figure 5.2: Surface checking for 1.5mm.

x60 of the bend region (3mm) Checking of thickness area

Figure 5.3: Surface checking for 3mm.

x60 of the bend region (5mm) Checking of thickness area

Figure 5.4: Surface checking for 3mm.

From the analysis of the microscope picture we notice two main things:

- From all bend regions no crack was observed.
- All the thicknesses have very non-significant reduction at the point of applied load.

These two observations enable us to validate the geometrical aspect of sample from v-bending. Thus, we can assert that our experiment respect and follow all the criteria of v-bending [41].

5.2 Analysis of results and ANOVA

The analysis is done with Minitab software. The main effects of plot for springback angle in Figure 5.5 shows that the 3mm sheet thickness has the lower springback at the same die opening and holding time. The Figure 5.6 showing the interactions of the different factors on springback revealed very interesting information. Indeed, the expected effect of holding time on springback goes right with decreasing of springback when holding time increase. However, on the 35-die opening graph we notice an abnormal level of springback between the 3mm sheet and the other 5 and 1.5mm.

The reason for using analysis of variance is to investigate and determine the parameters or combination of factors that influence the most the springback. All ANOVA result were compute using Minitab 19 software.

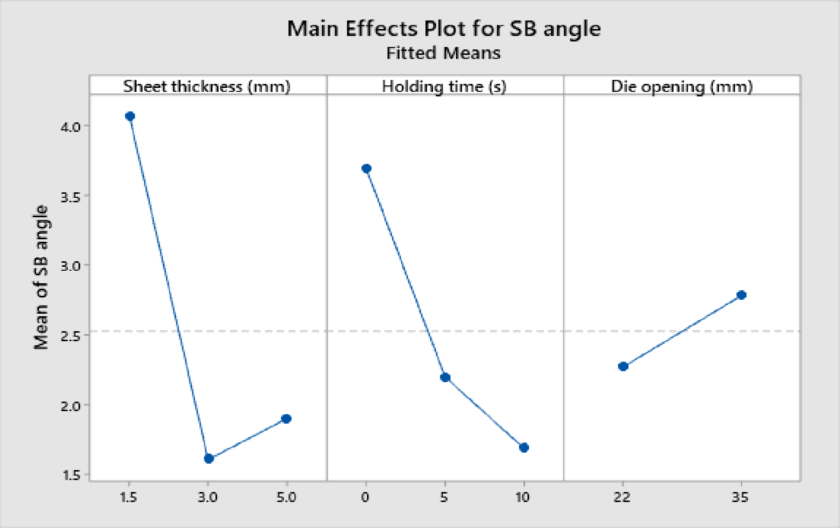


Figure 5.5: Main effects plot for springback angle.

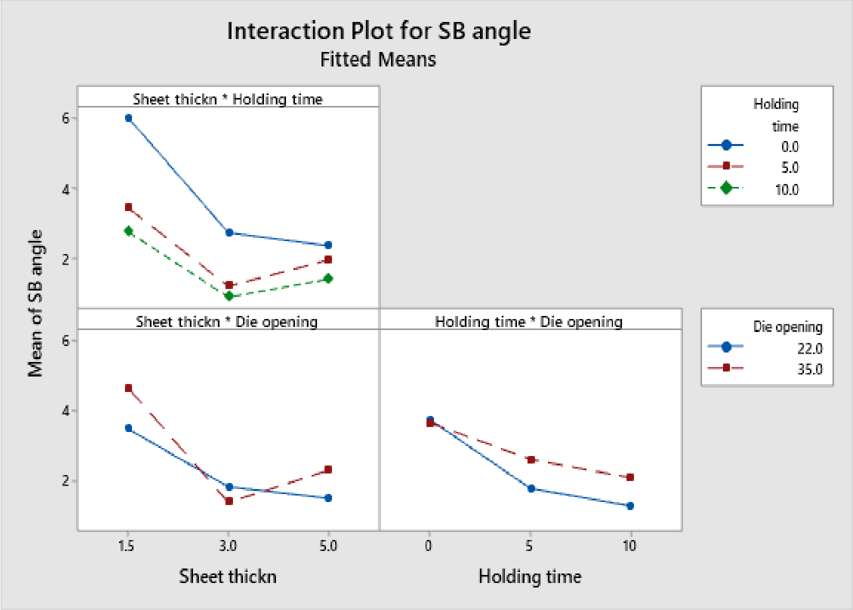


Figure 5.6: Interaction plot for springback angle.

The ANOVA results are as follow:

Table 5.1: Factor Information

Factor	Levels	Values
Sheet thickness (mm)	3	1.5, 3.0, 5.0
Holding time (s)	3	0, 5, 10
Die opening (mm)	2	22, 35

Table 5.2: Analysis of Variance

Source	P-Value
Model	0
Blocks	0.071
Linear	0
Sheet thickness (mm)	0
Holding time (s)	0
Die opening (mm)	0.001
2-Way Interactions	0
Sheet thickness (mm)*Holding time (s)	0
Sheet thickness (mm)*Die opening (mm)	0
Holding time (s)*Die opening (mm)	0.019

Figure 5.7 represent the Pareto chart of the standardized effects. This chart is very important for comparing factor between each of them and check the influence of each. From this Pareto chart of effect, we note that the holding time and the sheet thickness have the most significant effect compare to die opening. However, difference of the effects between sheet thickness and holding time is very small. But enough to confirm that the sheet thickness has more influence. Another remark from the chart is that the combination of holding time and sheet has the highest impact than any other combination of factors, which is logic. So, for future work it might not be necessary to investigate the die opening in the same doe configuration or it will be preferable to eliminate the die opening from the factors list when too many parameters are being operated at the same time.

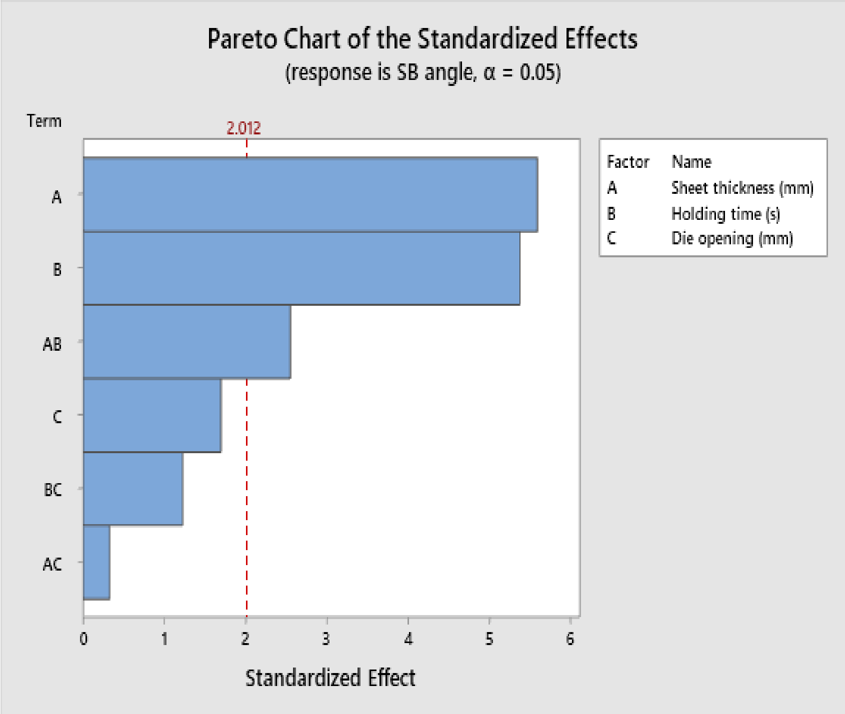


Figure 5.7: Pareto chart of the standardized effects.

5.3 Comparison of the simulation and the experimental results

After bending using experimental to compare with simulation helps to optimize the prediction accuracy of the simulation method. The Table 5.3 compares the springback from simulation and the springback from experimental. Figure 5.8 is a graphical comparison of the two springback.

Table 5.3: Tabular comparison of the experimental and simulation springback.

Designation	**final angle**	**SB simulation angle**	**SB experimental angle**	**% Error**
S1.5-H0-D22	43.8	3.7	5.5	32.72
S3-H0-D22	45.3	2.2	3.78	41.85
S5-H0-D22	45.25	2.25	1.95	15.38
S1.5-H0-D35	40.9	6.6	6.53	1.02
S3-H0-D35	44.05	3.45	1.67	107
S5-H0-D35	44.9	2.6	2.75	5.454

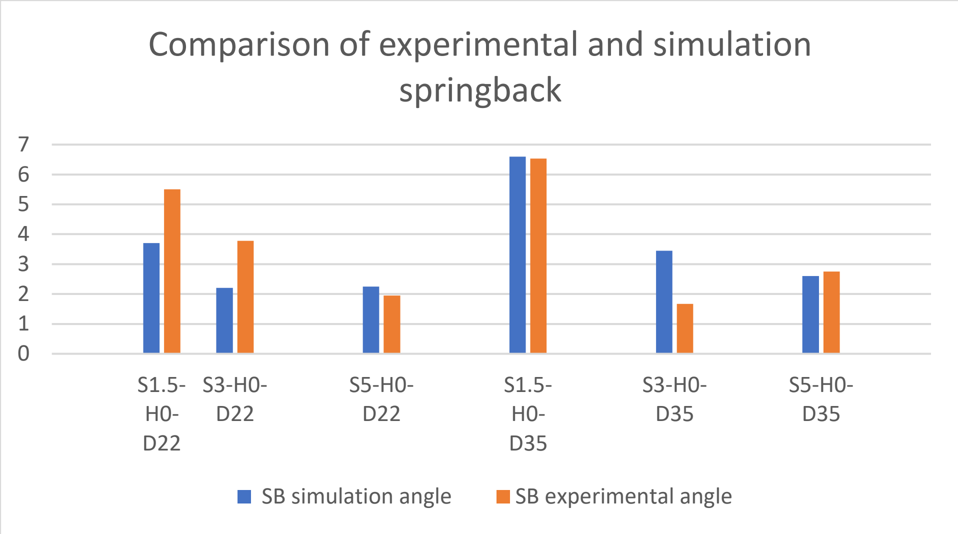


Figure 5.8: Graphical comparison of the experimental and simulation springback.

The simulation method has convergence problem at some combination of factors. The error in acceptable in general but at some points the error is high.

5.4 Application of machine learning

Machine learning is a tool used to predict and make classification in sheet metal bending process. We are using two methods here to predict the springback. The first method is ANN. This method is very popular in the domain of sheet metal work. It has been used many times to predict springback but very few researchers have applied it on brass material and especially on yellow brass. The second method is the multiple linear regression method. This prediction is not common in the field of springback prediction. This prediction way has never been applied on yellow brass. This is due to the simplicity of this method. Support vector machine regression is applied in this research because most of the time the springback response to certain factors usually follow a linear path. If this is the case, we are expecting to obtain a very accurate prediction and open a new discussion on the future use of SVM as a reference regression method to predict springback.

5.4.1 Application of artificial neural network

The application of neural network is done using MATLAB NNTOOL.

The ANNs become very prominent in many engineering fields because of their interesting features such as learning induction, speedy computation and less difficulty in implementation. ANNs are commonly consisting of number of simple and highly associated processing elements arrange in layers. (Ghetiya & Patel, 2014) has applied ANN in various fields like signal processing, manufacturing, bio-electric signal categorization pattern recognition and many more fields. (Muthu et al., 2018) acknowledge that ANN is a collection of biological networks of neurons utilized to resolve complex functions in different optimization techniques. ANN are stimulated from biological network order that consist of various simultaneous processing components called neurons.

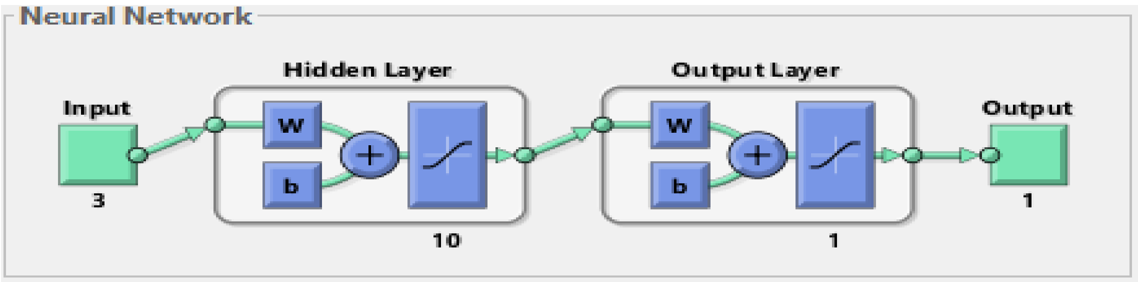


Figure 5.9: ANN network representation.

The above Figure 5.9 is the ANN network model which was develop to generate the results. The Table 5.3 is the comparison between the experiment and ANN predicted results of the springback in sheet metal v-bending. As shown in Table5.3 the differences between the two value is not significant and this due to the accuracy of the prediction model. Indeed, the overall value of the model is found to be 0.98909 (Figure 5.10 and Figure 5.11) proves that the efficiency of the prediction from the model is good.

Table 5.4: Comparison between experimental springback and ANN springback.

Sheet thickness (mm)	Holding time (s)	Die opening (mm)	Experimental springback	ANN SB PREDICTED	ANN SB % ERROR
1.5	0	22	5.5	5.49	4.5E-05
1.5	0	35	6.53	6.533	0.0025
1.5	5	22	2.67	2.66	4.2E-05
1.5	5	35	4.22	5.16	22.5
1.5	10	22	2.28	2.283	0.00082
1.5	10	35	3.23	3.30	2.35
3	0	22	3.78	3.783	5.5E-06
3	0	35	1.67	1.66	0.00037
3	5	22	1.05	1.049	1.4E-06
3	5	35	1.35	1.05	21.94
3	10	22	0.65	0.65	0.025
3	10	35	1.13	1.42	25.84
5	0	22	1.95	1.949	1.63E-05
5	0	35	2.75	2.749	0.00068
5	5	22	1.3	1.63	0.0006
5	5	35	2.27	2.01	11.3
5	10	22	0.92	0.916	0.00034
5	10	35	1.88	1.883	3.03E-05

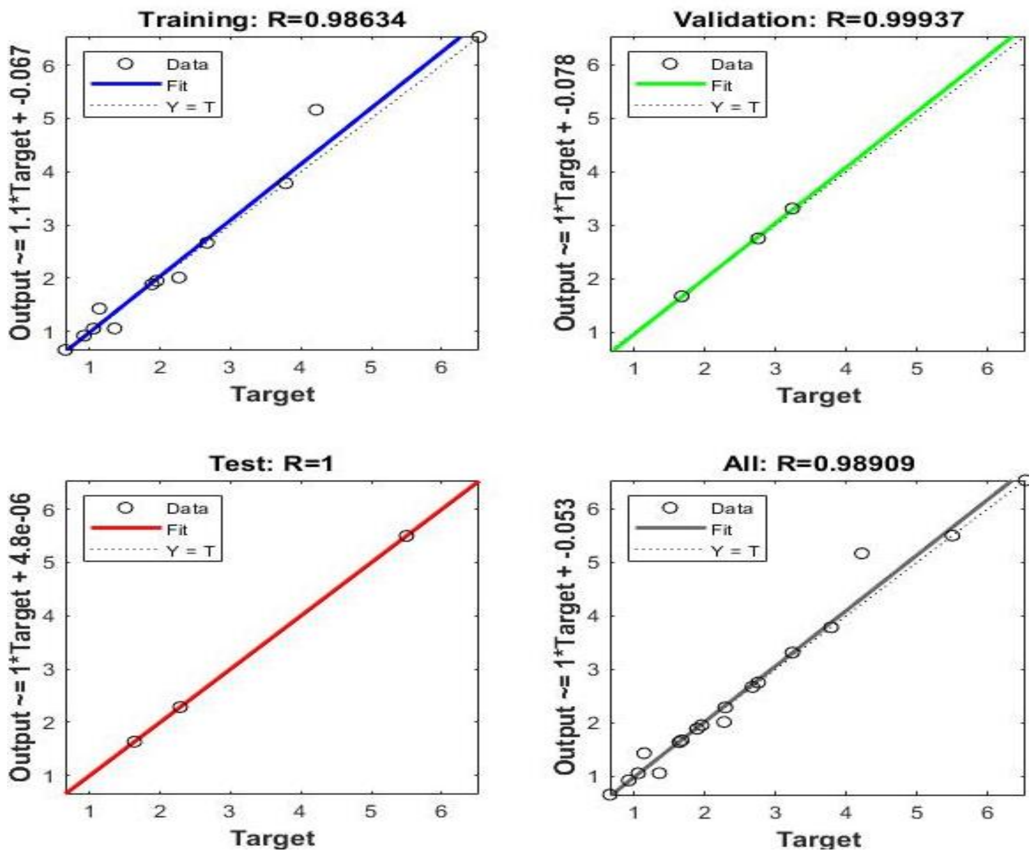


Figure 5.10: ANN regression graph.

5.4.2 Application of support vector machine regression

Support vector machine is a branch of supervised learning and a part of statistical learning which learn through series of examples. SVM becomes support vector regression (SVR) when it is applied to regression. [51] used SVR to predict springback in v-bending. In this paper the SVR uses a cubic kernel function and a cubic SVM preset as shown in Table 5.5. Figure 5.11 shows a graphical representation of the predicted data as well as the actual experimental data. The same picture shows the errors of the predicted springback. The overall accuracy obtained from this SVR method is 65%. This value compared to the ANN accuracy is small. We conclude that ANN predict springback with higher accuracy than SVR does.

Table 5.5: Setting of the SVM training.

Preset	Cubic SVM
Kernel function	Cubic
Kernel scale	Automatic
Box constraint	Automatic
Epsilon	Automatic
Standardized data	True
RMSE	0.98361
R-Squared	0.65
MSE	0.96748
MAE	0.79

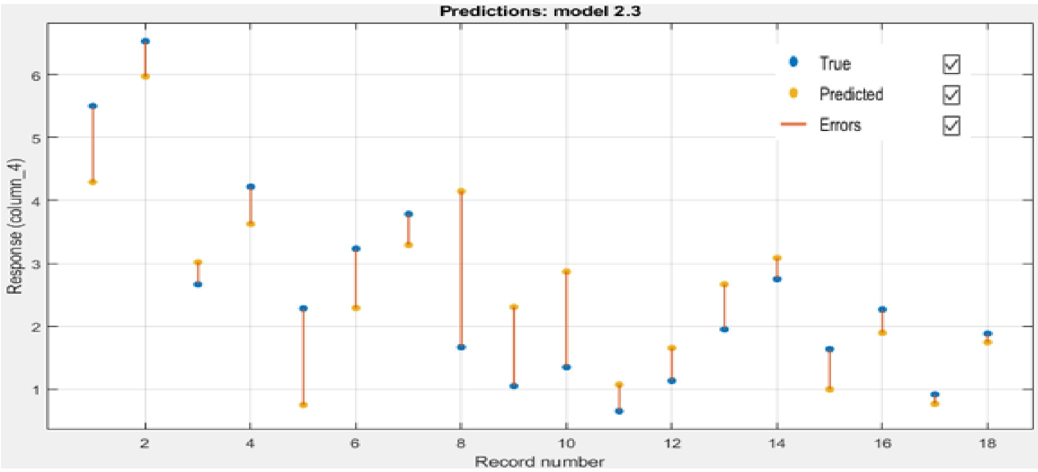


Figure 5.11: Graphical representation of the predicted value vs the actual value.

Table 5.6: Result and comparison of the SVR prediction with actual experimental value.

Sheet thickness	Holding time	Die opening	Experimental SB value	SVM predicted SB value	Error
1.5	0	22	5.5	5.3592	0.1408
1.5	0	35	2.67	5.6432	-2.9732
1.5	5	22	2.28	3.4391	-1.1591
1.5	5	35	6.53	4.0767	2.4533
1.5	10	22	4.22	2.1435	2.0765
1.5	10	35	3.23	3.0971	0.1329
3	0	22	3.78	3.423	0.357
3	0	35	1.05	3.6909	-2.6409
3	5	22	0.65	2.006	-1.356
3	5	35	1.67	2.5584	-0.8884
3	10	22	1.35	1.0075	0.3425
3	10	35	1.13	1.8066	-0.6766
5	0	22	1.95	2.1077	-0.1577
5	0	35	1.63	2.6079	-0.9779
5	5	22	0.92	1.4321	-0.5121
5	5	35	2.75	2.1246	0.6254
5	10	22	2.27	0.9001	1.3699
5	10	35	1.88	1.7471	0.1329

Figure 5.12 represent the graphical comparison of experimental, ANN and SVM results. The figure shows that ANN has the best predicted springback value followed by SVM. This proved once again that ANN is one of the best prediction algorithms suitable for springback prediction. The simplicity of the ANN makes him easier and faster to use compare to the other regression methods. Despite the prediction accuracy of 65% from the SVM, we don't recommend it for brass.

The result obtained from the simulation is justified with Govik et al. (2012) research. The simulation platform showed weaknesses when it comes to convergence of the solution. That is why it is suggested to combine different programs for preprocess and the postprocess to get a good accuracy and reduce convergence issue [49].

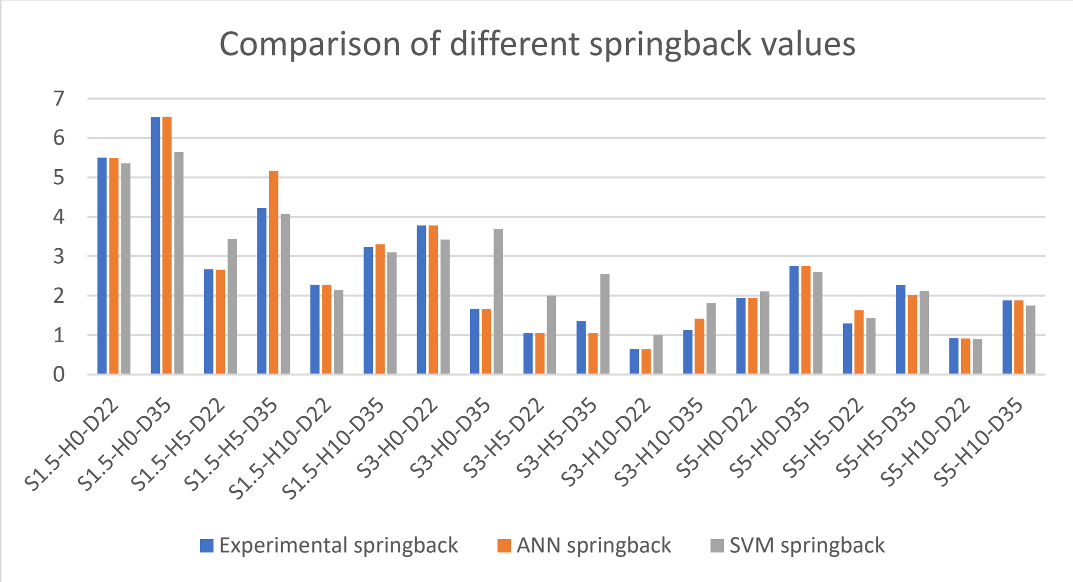


Figure 5.12: Comparison of the experimental, the ANN and SVM springback values.

The experimental results showed that the increase of the holding time decreases the springback. Using different material (high strength steel) another researcher reaches to the same conclusion that the time significantly reduce the springback [10]. This phenomenon can be explained by Karaagac et al (2017). The increase of holding time restrains the shape of the sheet metal allowing this sample to have a larger period of internal stress relaxation. This causes a decrease in internal stress of the bending side and the flattened arc leads to decreased elastic strain [11]. This behavior will cause the increase in permanent strain. Also, as the bottoming increases creep deformation increases and causes a reduction in elastic recovery. In summary the creep rate decreases following the holding time due to the decrease in internal stress [12].

Chapter6

CONCLUSION AND FUTURE RECOMMENDATIONS

6.1 Conclusion

The effect of die opening punch holding time and sheet thickness are investigated on springback of UNS C27000 yellow brass sheet metal on v-bending. From the design of experiment a total of 18 experiments times 3 have been conducted. The display of the result has been analyzed using the ANOVA method of 2ways. Some researchers have applied FEA simulation previously with different type of brass, but none of them applied the two different machine learning technics used in this research that are response surface method and artificial neural network. In this research ANN has been applied to develop the Meta model of springback especially for yellow brass material. The main results are compiled as follows:

- The increase in the die opening increases the springback
- The increase of the sheet thickness decreases the springback
- The increase of the holding time decreases the springback
- The machine learning prediction through ANN method showed high satisfactory results due to the very small value of the predicted springback compare to the actual value from the experimental.
- From the Pareto chart, the sheet thickness has the most significant effect on the springback compare to the holding time and die opening.
- The prediction through SVM method showed a lack of prediction with the 3 mm sheet thickness, but an overall acceptable accuracy of 65%.

6.2 Future recommendations

My future recommendations in this research are the following:

- The effect of the 3mm sheet thickness can be more explored because of the abnormal results we got.
- The effect of the punch loading and speed can be investigated.
- The use of optimization methods to suit the v-bending of brass will be a great achievement.
- A deep research on creep simulation in v-bending will help enlarge the capabilities of the FEA through ANSYS and helps control the effect of the time.
- Other DOE method can be applied like Taguchi for uncertainty and worst-case analysis.

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