American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-10, pp-198-205
www.ajer.org
Research Paper Open Access

Mathematical Modeling of the Effect of Different Parameters on Spring Back in Sheet Metal Formability Process

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ABSTRACT: *In the study, bending process was performed on the AISI304 sheet metals at different thicknesses (2 mm, 3 mm, 4 mm, and 5 mm) and different punch type radii (R2 mm, R4 mm, R6 mm, and R8 mm) by using air V bending technique. After the bending, the amount of spring backs in the sheet metals was examined. As thickness of the sheet metal increased, the value of spring back decreased; whereas, the values of spring back increased in the increasing punch tip radii. A mathematical model was obtained by analyzing the relationship between bending parameters and test results.*

Keywords –*Bending die, form ability, Sheet metal, Spring back, V air bending*

Date of Submission: 09-10-2017 Date of acceptance: 23-10-2017

I. INTRODUCTION

One of the main problems encountered in formability processes of sheet metal is spring back. After completing the bending process of the punch, the material attempts to return to its original state due to the elastic stresses occurring in the deformation zone of sheet metal but it cannot return due to the permanent plastic deformation. Therefore, the sheet metal opens backwards slightly and reveals the spring back. In the formability processes of sheet metal, knowing the spring back value in advance will save the time spent by trial and error method and material consumption by obtaining the products with proper angles.

When studies conducted on sheet metal technology in recent years are examined, it is found that there are studies generally on spring back and spring go occurring after the bending process. The common aim of the studies is to find out the parameters that affect spring back and spring go values in the bending. After the obtained values, appropriate mathematical models and equations were obtained and introduced to the literature. When studies conducted on spring back in the bending are examined;

Özdemir et al., investigated the spring back and spring go behaviors of sheet metals with different thickness and properties under different heat treatment conditions (unheat treatment, normalized and tempered), holding time, and different punch tip radii in order to examine the spring back and spring go values in formability processes of sheet metal. The sheet thickness, punch radius, holding time and heat treatment parameters were found to be effective in spring back and spring go values [1-4]. Thipprakmas et al., investigated the effect of parameters such as sheet thickness, bending angle and punch radius, and punch bending depth in the V bending processes on spring back and spring go values by using the finite element method (FEM) and ANOVA. After the study; it was determined that thickness of the sheet metal was effective on spring back value, bending angle was effective on spring go value [5-8]. Liu et al., examined the effect of sheet thickness, grain size, rolling direction, and punch frequency parameters on the spring back value by using the micro W bending method. It was determined as a result of the tests that while thickness of sheet metal was effective on spring back values, grain size was effective on spring go values. They analyzed the obtained results by using taguchi method [9]. Tekaslan et al., examined the effect of punch holding time, sheet thickness, and bending angle parameters on spring back by designing modular V bending die [10,11]. Bakhshi-Jooybari et al., numerically and experimentally examined the effect of important parameters including punch radius, rolling direction and sheet thicknesses. According to the results obtained, it was found that as the thickness of sheet metal increased, values of the spring go and spring back decreased. It was determined in the bending processes that spring back did not occur in the most suitable punch tip radius. It was determined that as the punch tip radius increased, spring go decreased and the spring back increased. Rolling direction was determined to be effective in spring back and spring go values [12]. Shukla and Gautam used low carbon steel sheet metal in different rolling directions in order to investigate the effect of sheet anisotropy. Tests were carried out by using a 7.5 mm punch tip radius in the V dip bending die. As a result of the tests, FEM results and experimental data were found to be close to each other. The rolling directions were found to be effective on the bending angle. In the bending process, the spring go value was determined to be formed instead of spring back [13]. Fei and Hodgson experimentally and numerically examined spring back behavior through the free V bending process. In addition, they investigated the effects of variable and constant elasticity modulus and friction on spring back analysis. While the effect of punch radius and punch stroke velocity on the spring back was found to be insignificant, die cavity and sheet thickness were determined to be effective [14]. Reche et al., analyzed air bending tests by using SEY. They examined the effect of sheet thickness, bending angle and loading conditions on spring back [15]. Inamdar et al., examined the effect on spring back by using different material properties, sheet thickness and bending parameters in air bending process by developing experimental and mathematical model [16, 17]. A similar study was also conducted by Garcia-Romeu et al,. They have contributed to the literature by obtaining spring back graphics by using different materials and bending angles [18]. Vasudevan et al., investigated the effect of processing parameters on spring back behavior occurring during the air bending process of electrogalvanized sheet metal. They examined the effect of parameters such as coating thickness, sheet rolling direction, punch radius, die radius, die clearance, punch velocity and punch movement on spring back [19]. Leu and Zhuang investigated the effect of punch radius, sheet thickness and material strength on spring back in air V bending process. They also developed a mathematical model. Moreover, effects of the thickness ratio, normal anisotropy, and the strain-hardening exponent on the spring back angle in the V bending process for high-strength steel sheets are theoretically examined [20]. Fu studied on the numerical simulation of spring back in the formation of the sheet metal by air V bending. Using ABAQUS FEA software, he analyzed the parameters, which were effective on spring back, in air V bending process [21]. Yilamu et al., conducted a study on investigation of the sheet metal thickness and spring back angle after air V bending process. They analyzed the experimental results by SEY [22]. Vin studied on the prediction of the curve formed by the spring back as a result of the bending of the metal sheet in the air [23]. Wang et al., studied spring back control of sheet metal in air bending process [24]. Yuinvestigated the variation of elastic modulus during plastic deformation and its effect on spring-back [25]. Narayanasamy and Padmanabhan compared artificial neural networks (ANNs) with regression analysis to predict the spring back behavior of sheet metal during air bending processes. ANN model was determined to obtain higher prediction compared to regression model [26]. Li et al., studied the effect of sheet metal width on spring back in air bending process [27]. Han et al., examined the effect of different materials and different methods on spring back angle [28]. Slota et al., conducted a numerical and experimental study on determination of spring back value by using parameters of material properties, bending depth, and die width in air bending process [29].

In the study, AISI304 sheet metals with different thicknesses were shaped by using different punch tip radii and air V bending method. The mathematical model was obtained by comparing the spring back amounts with each other after the bending.

II. AİR V BENDİNG

In air bending; while sheet metal piece is supported by the sides of the below die, necessary bending angle forms by downward movement of the punch. As is seen in Figure 1, *w* is die clearance, R_p is punch radius, R_d is die radius, θ is the bending angle, and θ' is the punch angle before the bending. $\Delta\theta$ is the spring back angle. Although the sheet metal piece looks like a V dip bending in terms of the shape it took, edges of the sheet metal are free at the beginning and end of the bending process.

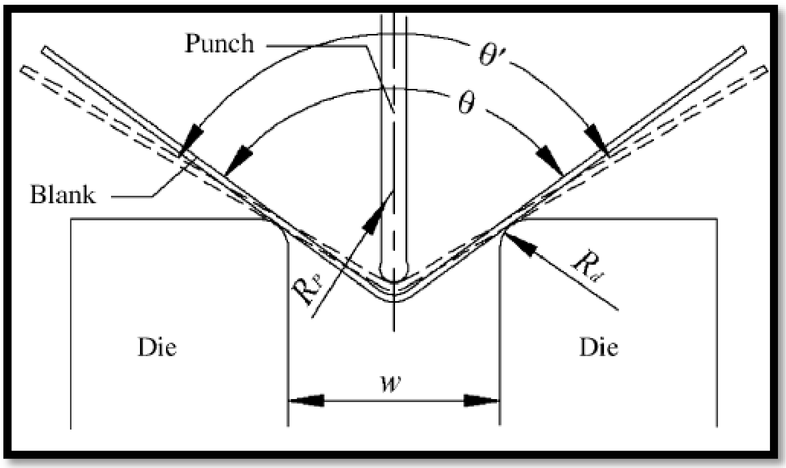

Figure 1. Free V bending process [14]

In formability processes of sheet metal; when the punch is lifted over sheet metal, compression stress occurs inside the sheet metal and tensile stress occurs outside of the sheet. The line separating the parts allocated for compression and tensile is called as the neutral axis [30, 31]. If it is accepted that the sheet thickness in the bending zone does not change, the neutral axis passes through the middle of the sheet metal. Due to stresses occurring on the material, shortening in the internal deformation zone and elongation in the external deformation zone occur (Figure 2). When the compression stresses are greater than the tensile stresses, spring back occur in the sheet metals [3, 5-8, 12].

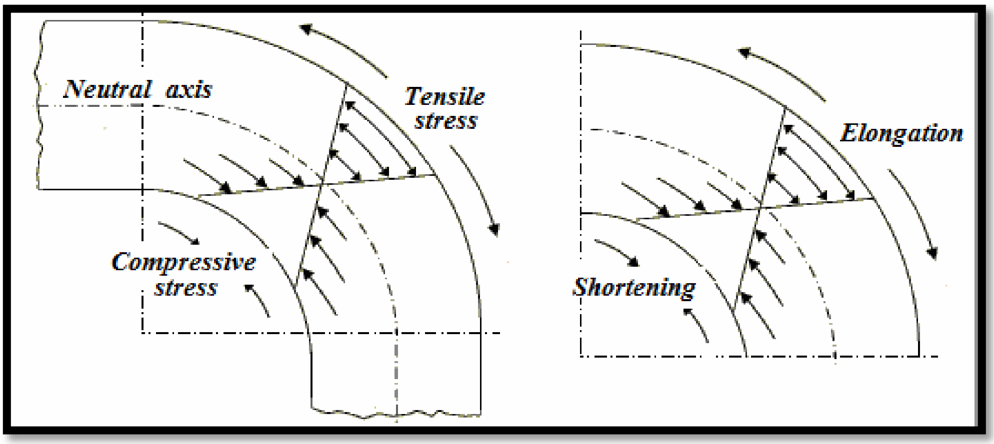

Figure 2. Compression and tensile stresses occurring as a result of the bending process

III. MATERİAL AND METOD

In the experimental study, 2 mm, 3 mm, 4 mm and 5 mm thick AISI304 sheet metals were used. The samples were prepared by being cut with hydraulic scissors in 30x80 mm dimensions in (0º) rolling direction. The burrs occurring on the side surfaces as a result of cutting were cleaned with grinding wheel. Table 1 shows the chemical composition of the sheet metals used in the experimental study.

Table 1. Chemical composition of materials used in the experimental study (wt.%)

Material	**C**	**Cr**	**Mn**	**Ni**	**P**	**S**	**Si**
AISI304	0.08	18.25	1.768	8.678	0.038	0.025	0.43

Air V bending die was designed and manufactured in order to perform the experimental study. Male punch and female die of the bending die used in the experimental study was precisely manufactured from C1390 shear steel in a wire erosion workbench. Wears occur on bending die material due to the friction. Therefore, stress relieving annealing was applied on the die material. Figure 3 shows the bending die.

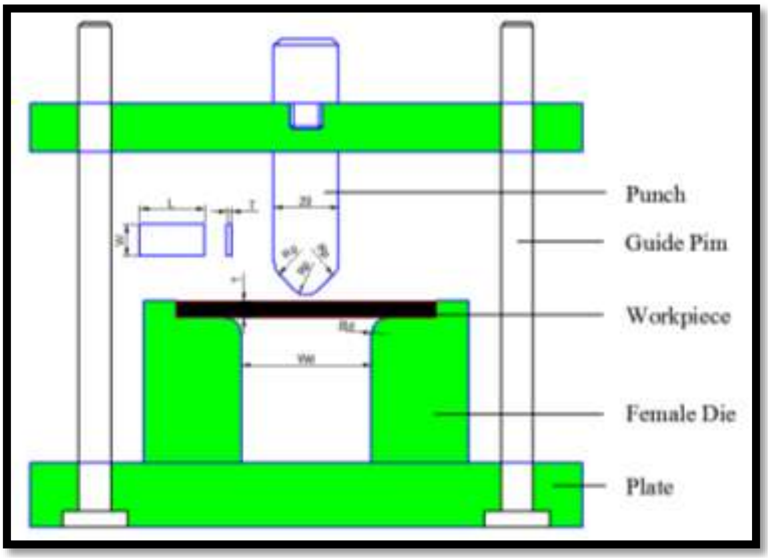

Figure 3. Air V bending die used in the experimental study

In air V bending process, formability processes of 2 mm, 3 mm, 4 mm, and 5 mm thick AISI sheet metals were performed with dies having R2 mm, R4 mm, R6 mm and R8 mm punch tip radii. Table 2 shows the process parameters used in the study.

Table 2. Tool and process parameters

Parameter	Dimension
Work blank, L×W×T (mm)	80x30x(2, 3, 4, 5)
Punch radius, Rp (mm)	2, 4, 6, 8
Die radius, Rd (mm)	5
Die opening, Wd (mm)	27, 29, 31, 33
Punch velocity, V (m/dak)	50

Experiments were carried out by leaving a gap as many as the sheet thickness between the punch and die, in free bending force and a punch velocity (V) of 50 m/min. As shown in test parameters in Table 3, 16 different parameters were used in the experiments where 4 different thicknesses and 4 different punch tip radii were used. Each experiment was repeated 10 times and a total of 160 experiments were performed. While evaluating the experimental results, spring back graphs were prepared by taking the arithmetic means of the repeated values.

Table 3. Bending parameters used in the experimental study

Material	Sheet Thickness, (mm)	Punch Radius, (mm)	Yield strength (MPa)	Die opening, Wd (mm)	Number of tests
AISI304	2	2	215	27	40
	3	4		29	40
	4	6		31	40
	5	8		33	40
Number of total experiments					160

After the experiments were performed, the experimental samples were measured separately. Measurement processes were carried out firstly with a goniometer. After the premeasurement process, each sample was subjected precisely to a second measurement process by using the CMM device. In the measurement processes, 8 points were determined on the sample and the angle values between these points were precisely measured (Figure 4). Thus, the error to occur in this measurement was minimized and the reliability of the results was ensured.

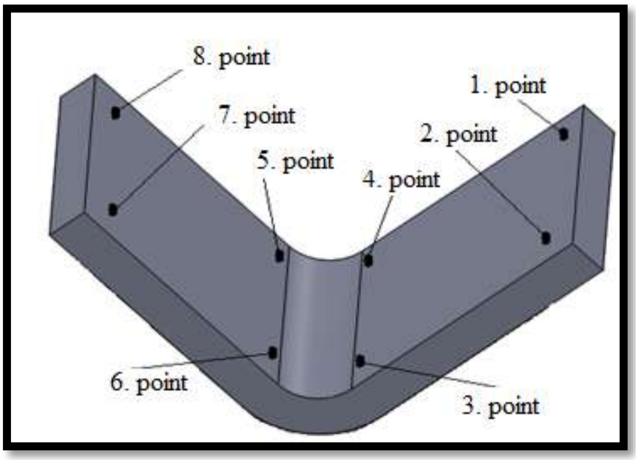

Figure 4. Points taken in CMM device

IV. STATISTICAL ANALYSIS OF DATA

The data obtained in the study were analyzed by using SPSS (Statistical Package for Social Sciences) for Windows 22.0 program. Mean and standard deviation were used as descriptive statistical methods to evaluate the data. Pearson correlation and regression analysis were applied between the continuous variables of the study. Correlation analysis was applied to determine the strength (degree) and direction of the linear relationship between continuous variables. Regression analysis was used to estimate the value of the dependent variable, which is difficult to obtain, by means of independent variables in order to determine the causality relationship between the continuous variables of the study. The obtained results were evaluated at the confidence interval of 95% and at the significance level of 5%.

V. EXPERIMENTAL RESULTS AND DISCUSSION

The bending process of 90° was performed in different punch tip radii (R2 mm, R4 mm, R6 mm, and R8 mm) for AISI 304 sheet metals in different thickness (2 mm, 3 mm, 4 mm, and 5 mm) used in air V bending process. Figure 5 shows spring back amounts and polynomial curve equations obtained as a result of bending the sheet metals having different thicknesses with punch tip radii.

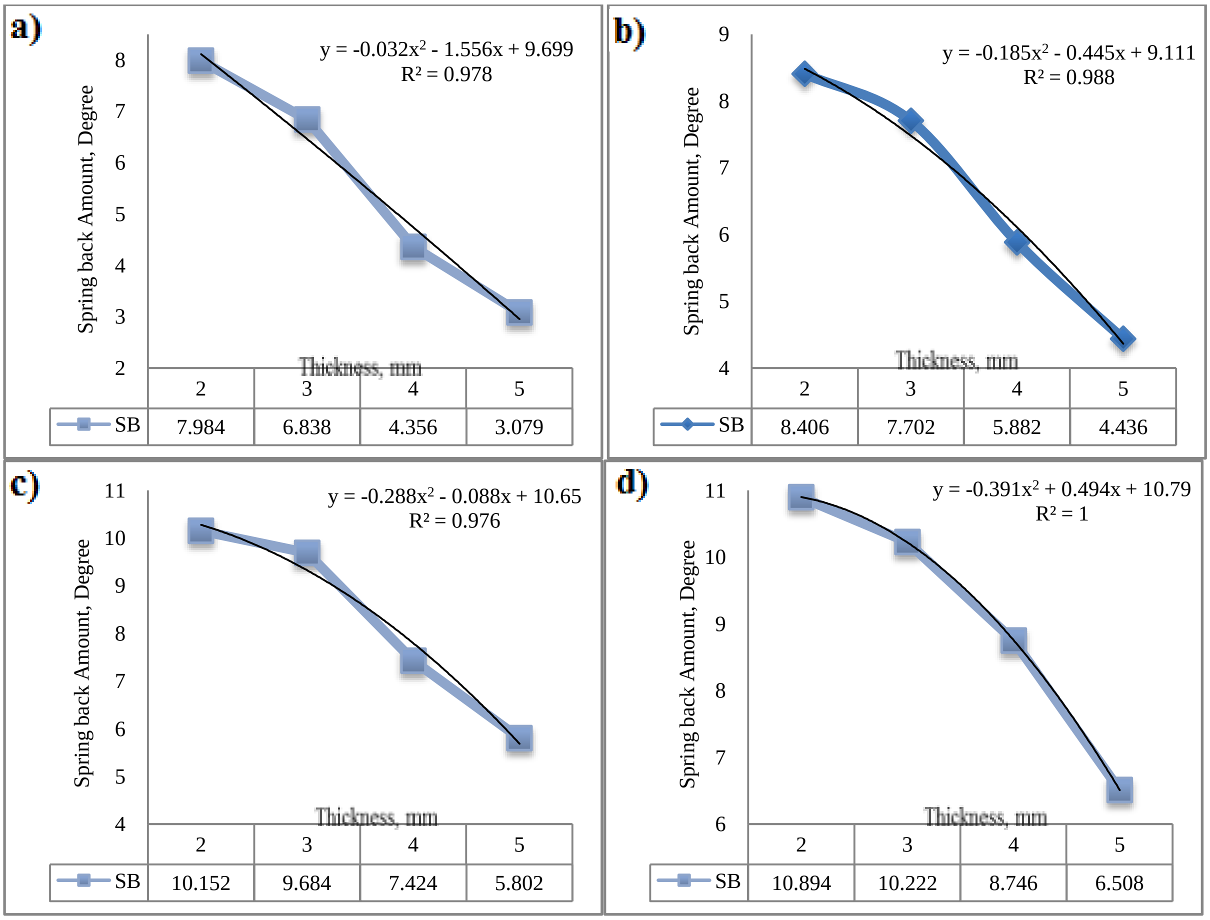

Figure 5. Spring back (SB) values obtained as a result of bending of the sheet metals having different thicknesses (t) with different punch radii (R); a=R2 mm, b=R4 mm, c=R6 mm, d= R8 mm

In the process of forming the material exhibiting elastic and plastic properties depending on the applied deformation, deviations occurred in the form of material as a result of the resilience energy accumulated in the internal structure of the material during the unloading process (lifting the punch) starting with the return of the punch giving the shape to the piece by applying forces in certain levels can be generally called as spring back [32]. Elastic redistribution of the stresses in meaning in the return characterizes the spring back. When the geometry of the parts in the die under the formability force was compared with the geometry occurring after the spring back, the degree of the observed deviations reveals level of the spring back.

Figure 5 shows the spring back amounts obtained as a result of forming the sheet metals having different thicknesses with different punch tip radii using the air V bending technique. When the figure was examined, it is seen that the spring back value decreased as thickness of the sheet metal increased. When Figure 5a was examined, spring back value of 5 mm thick sheet metal decreased at the rate of 61.43%; 54.97%; and 29.31% respectively according to2 mm, 3 mm, and 4 mm. In Figure 5b, bending processes were performed with a punch tip radius of R4 mm. When the figure was examined, it was determined that in the spring back values obtained as a result of the bending of the 5 mm thick sheet metal, there were a decrease of 47.42% compared to 2mm thickness; a decrease of 42.40% compared to 3 mm thickness, and a decrease of 24.58% compared to 4 mm thickness. When the spring back values of the 5mm thick sheet metal were compared with 2 mm, 3 mm, and 4 mm thicknesses in Figure 5c; it decreased at the rate of 42.84%; 40.08%; 21.84%, respectively. When Figure 5d was examined, the decreases in spring back amounts of the materials having 2 mm, 3 mm and 4 mm thicknesses were determined as 40.26%; 36.33%, and 25.58% compared to 5 mm thickness.

Figure 6 shows spring back (SB) amounts of sheet metals bent with different punch tip radii. The fact that R^2 values of the experimental results obtained as a result of the bending processes in the polynomial curve equation are close to 1 indicates the sensitivity of the experimental results.

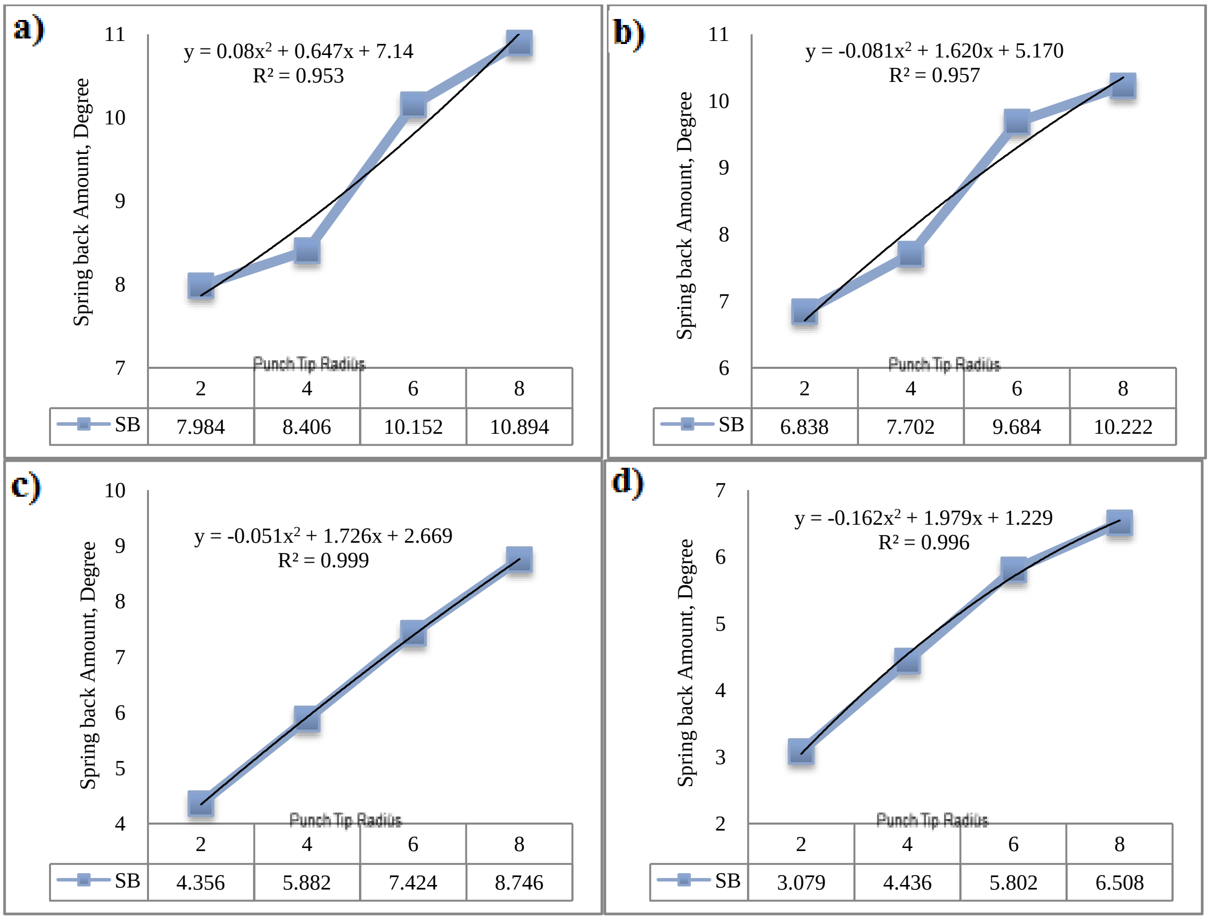

Figure 6. Spring back values obtained as a result of bending the sheet metals having different thicknesses with different punch radii (R); a=2 mm, b=3 mm, c=4 mm, d=5 mm

After spring back, radius value of bending zone increased. The effect of the bending radius (R) on the spring back is related to the R/T ratio. As the ratio of R/T increases, spring back on sheet metal also increased [7, 33, 34]. As the bending radius value increased, the forces coming to the die decreased. As the bending radius decreased, the forces coming to the sheet metal increased. For this reason, as the punch tip radius value increased, the values of spring back also decreased.

Figure 6a, 6b, 6c, and 6d show spring back graphs obtained as a result of bending the sheet metals having 2 mm, 3 mm, 4 mm and 5 mm thicknesses with different punch tip radii. When Figure 6a was examined, materials bent with die having R2 mm punch tip radius decreased the spring back value at the rate of 26.71% compared to R8 mm punch tip radius. It was determined that the punch having R2 mm radius decreased the spring back value at the rate of 33.10% compared to R8 mm in Figure 6b, 50.19% compared to R8 mm in Figure 6c, and 52.68% compared to R8 mm in Figure 6d.

VI. NUMERICAL ANALYSIS

In the formability process of sheet metal, the sheet metal thickness (T) and punch tip radius (R) were used as independent variables,and the obtained spring back (SB) value was used as the dependent variable. Table 4 shows the correlation of thickness and punch tip radius parameters with spring back values.

Table 4. Correlation of thickness (T) and punch tip radius (R) with spring back (SB)

		T	R
SB	r	-0,766	0,616
	p	0,001	0,011

There was a high, significant and negative correlation between SB and T (r=-0.766; p=0.001<0.05). There was a moderate, significant and positive correlation between SB and R (r=0.616; p=0.011<0.05).
A hierarchical regression analysis was applied to determine the cause and effect relationship between T, R, and SB. Table 5 shows the effect of T and R variables on SB is shown in.

Table 5. Effect of T and R values on SB

Dependent Variable	Independent Variable	ß	t	p	F	Model (p)	R^2
SB (Model 1)	Constant	12,708	10,138	0,000	19,897	0,001	0,557
	T	-1,522	-4,461	0,001			
SB (Model 2)	Constant	4,321	3,775	0,002	8,580	0,011	0,336
	R	0,612	2,929	0,011			
SB (Model 3)	Constant	9,647	21,678	0,000	190,215	0,000	0,962
	T	-1,522	-15,197	0,000			
	R	0,612	12,227	0,000			

Regression analysis performed to determine the cause and effect relationship between T and SB and between R and SB (Model 1, Model 2) was found to be statistically significant (Model 1: F=19.897; p=0.001<0.05; Model 2: F=8.580; p=0.011<0.05). As a determinant of the SB level, its relationship with T variables (explanatory power) was observed to be very strong compared to R variable (R^2=0.557).

The model was reobtained by adding R and T variables to the dependent variable (Model 3). The regression analysis performed to determine the cause and effect relationship (Model 3) between T, R, and SB was found to be statistically significant (F=190.215; p=0.000<0.05). As a determinant of the SB level, its correlation with variables T and R (explanatory power) was found to be very strong (R^2=0.962). T decreased the SB level (ß=-1.522). R level increased SB level (ß=0.612). The mathematical model related to the regression model is given below.

$$\mathbf{SB = 9{,}647 + (-1{,}522)T + (0{,}612)R + \ldots + \varepsilon}$$

VII. CONCLUSIONS

The spring back results obtained as a result of the formation of AISI sheet metals having different thicknesses by using air V bending technique with different punch tip radii are as follows:

- It was determined that as the sheet metal thickness increased, spring back amount decreased.
- As punch tip radius increased, the amount of spring back increased.
- The lowest spring back value in air V bending technique was 3,079° as a result of the bending of 5 mm thick sheet metal with R2 mm punch tip radius; the highest spring back value was 10.894° after the formability of 2 mm sheet metal with R8 mm punch tip.
- The material bent with R2 mm punch tip decreased the value of spring back at the rate of 71.34% compared to the material formed with R8 mm radius.
- The relationship between dependent and independent variables was significant because p = 0,000 <0.05.
- There were a negative correlation between SB and T and a positive correlation between SB and R.
- A variation of 40.5% was determined in the explanatory power by addition of R to the model in the effect of thickness (T) on SB. According to this result, T and R had a very strong effect together.

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