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Pengaruh Variasi V-Dies *Bending Angle* pada Material *Electrolytic zinc-coated Steel Sheet* (SECC)

The Effect of V-Bending Parameters Utilizing Electrolytic Zinc-Coated Steel Sheet (SECC) Material

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Abstract

This study discusses the phenomenon of spring-back and spring-go in the bending kinematic forming using V-bending dies process and Electrolytic zinc-coated steel sheet (SECC/JIS G 3313) material. The zinc layer on the galvanized steel surface should not be damaged during the material forming process. The zinc layer on the galvanized steel sheet will affect the metal forming process. This study uses an experimental design with four input parameters, namely v-die opening L (mm), punch angle (degree), punch speed (mm/minutes), and bending force (kN). The smallest spring-back was obtained in the 4th test sample: the v-die opening of 35 mm, the punch angle of 40°, the punch speed of 30 mm/minute, and the bending force of 7.50 kN. The minor spring-back degree was 1.67°. Meanwhile, the smallest spring-go obtained in the second sample, namely the v-die opening of 30 mm, the punch angle of 50°, the punch speed of 40 mm/minute, and the bending force of 7.00 kN, the minor spring-go degree of 0.92° was obtained. These results show that the best spring-back degree for SECC/JIS G 3313 material is obtained when the bending process is performed with the v-die bending parameter of 30 mm, punch angle of 50°, punch speed of 40 mm/minute, and bending force of 7.00 kN.

Keywords: *bending force, electrolytic zinc-coated, spring-back, spring-go, v-dies bending.*

***SDGs*:**

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Abstrak

Penelitian ini membahas fenomena *spring-back* dan *spring-go* pada proses *bending kinematic forming* menggunakan proses *V-bending dies* dan material *Electrolytic zinc-coated steel sheet* (SECC/JIS G 3313). Lapisan seng pada permukaan baja galvanis tidak boleh rusak selama proses pembentukan material. Lapisan seng pada lembaran baja galvanis akan mempengaruhi proses pembentukan logam. Penelitian ini menggunakan desain eksperimen dengan empat parameter input yaitu *v-die opening* L (mm), *punch angle* (derajat), *punch speed* (mm/menit), dan *bending force* (kN). *Spring-back* terkecil diperoleh pada sampel uji ke-4: bukaan v-die 35 mm, sudut *punch* 40°, kecepatan *punch* 30 mm/menit, dan gaya bending 7,50 kN. Tingkat pegas minor adalah 1,67°. Sedangkan *spring-go* terkecil didapatkan pada sampel kedua, yaitu bukaan *v-die* 30 mm, sudut *punch* 50°, kecepatan *punch* 40 mm/menit, dan gaya bending 7,00 kN, minor spring- diperoleh derajat go sebesar 0,92°. Hasil ini menunjukkan bahwa *spring-back degree* terbaik untuk material SECC/JIS G 3313 diperoleh saat proses *bending* dilakukan dengan parameter v-*die bending* 30 mm, sudut *punch* 50°, kecepatan *punch* 40 mm/menit, dan gaya lentur 7,00 kN.

Kata Kunci: *bending force, electrolytic zinc-coated, spring-back, spring-go, v-dies bending.*

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1. INTRODUCTION

An electrolytic zinc-coated steel sheet (SECC/ JIS G 3313) is sheet steel coated with molten zinc (Zn) so that it has good corrosion resistance (BSN, 2004). Electro galvanized sheet steel is widely used in the automotive industry (Sukarman *et al.*, 2021). The zinc coating on SECC/JIS G 3313 steel makes the bending process parameter that must be considered so as not to damage it (Suchy, 2006). In the bending process, the applied stress exceeds the elastic limit of the sheet material but has not yet exceeded the yield stress (Altan, 1998). In the bending process, spring-back material is the most prominent issue (Khoirudin *et al.*, 2022). Spring-back prevents the product from obtaining precise measurements and increases the time spent by trial and error methods, thereby increasing material consumption (Rahardja *et al.*, 2020). Spring-back is defined as a change in bending angle due to elastic recovery after the loading on the forming process is removed (Özdemir, Dilipak and Bostan, 2020). The spring-back phenomenon in the bending process contributes to a relatively large setup time (Troive *et al.*, 2018). Spring-back is a complex physical problem, and its value is influenced by the natural deformation of a component/workpiece (Leu and Zhuang, 2016).

The spring-back phenomena was studied in order to examine the structural features of high-strength steel (HSS) automobiles. Application software evaluated with a prototype V-die bending is used to analyse compensation for v-dies bending. The study revealed that spring-back deformation is a serious issue, particularly for HSS steels with complex geometries (Gautam and Kumar, 2018). More research on spring-back materials was conducted by (Kan and Hailing, 2011). B210P1 was used in the study, and it had thicknesses, yield strengths, tensile strengths, and elongations of 1.6 mm, 249 MPa, 413 MPa, and 38.23%, respectively. The results demonstrated that spring-back was concentrated in the bending area (Kan and Hailing, 2011).

Phanitwong (Phanitwong, Sontamino and Thipprakmas, 2013) studied the effect of section geometry on spring-back and pinch-go features in the U-bending process. The research was conducted by performing a FEM simulation using A1100-O aluminum material. The bending allowance zone's bending characteristics improve as the die radius and punch increase. However, a decrease in the bending characteristics also occurs in the straight section of the bottom of the workpiece. Spring-back material increases as the die and punch radius increase. The thickness of the workpiece results in a decrease in the punch radius's bending characteristics and a decrease in the reverse bending characteristics of the workpiece under the punch. In general, the spring-back material will increase as the thickness of the workpiece decreases. The results of the FEM simulation, which were validated by experimental, showed that the curvature U error compared to the results of laboratory experiments was about 2% (Phanitwong, Sontamino and Thipprakmas, 2013).

Wahed (Wahed *et al.*, 2020) researched further by optimizing V-die bending using Ti-6Al-4V alloy steel. The research is focused on getting the optimum spring back by optimizing the process parameters, namely temperature, punch speed, and holding time. The research was conducted using an orthogonal Taguchi array (L9), simulating the finite element method on V-bending, and validated by experiment. Simultaneously, a full factorial simulation (L27) was performed, and the response surface method was conducted to study the impact of the process parameters, which were then optimized using a genetic algorithm. ANOVA was applied to assign the effect of individual process parameters in minimizing spring-back based on the experimental results. In addition, the finite element simulation results were found to match the experimental results. From the ANOVA results, the percentage contribution of each process variables shows that temperature is the most dominant process parameter, followed by holding time and punch speed to obtain minimum spring-back. When the temperature increases, the yield strength decreases; therefore, the springbok decreases drastically (Wahed *et al.*, 2020).

The spring-back phenomenon occurs when the angle shift is greater than the angle prior to the release of the bending force. In contrast, the spring-go phenomenon occurs when the angle shift is less than the angle prior to the release of the bending force.

This research focuses on the occurrence of two bending phenomena simultaneously, a topic that has received slight prior attention. This investigation focuses on the analysis of spring-back and spring-go on the bending process of electro-galvanized steel (SECC) material with a thickness of 0.8 mm. The method of bending employs V-die bending, where the punch angle, depth, and opening of the V-dies vary. This research used an experimental method using four input variables, including v-die opening, punch angle, punch speed, and bending force, which were selected randomly. This study aims to analyze the effect of the input variable on the output variable, namely the phenomenon of the spring-back angle.

2. METHODOLOGY

2.1. Material & Equipment

This study uses SECC material with a thickness of 0.8 mm. PT POSCO Malaysia produces SECC material with coil number C9AA6511B. The mechanical characteristics and chemical composition of SECC materials refer to the JIS G-3313 standard (JAS, 1998). The mechanical properties and chemical composition of the SECC materials used are presented in Table 1.

In sample preparation, an SECC steel sheet with a thickness of 0.8 mm measuring 1219 mm x 2438 mm was cut using a shearing machine with a length and width of 64 x 24 mm, respectively. Each parameter is made up of 2 units each. It is to determine the consistency of the expected output variable. The sample geometry shape and dimensions are shown in Figure 1.

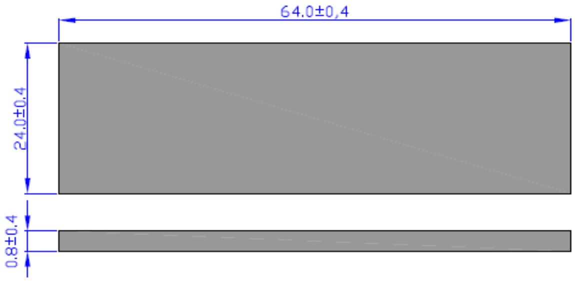


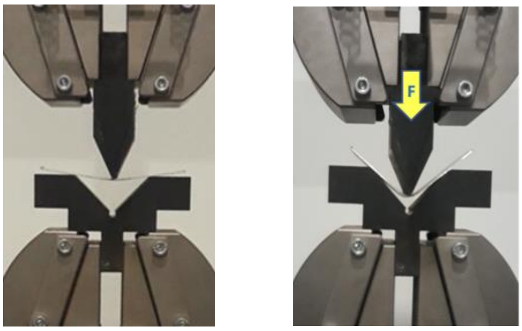
Figure 1. The geometry and dimensions of the test sample

Table 1. Mechanical properties and chemical compositions of SECC material

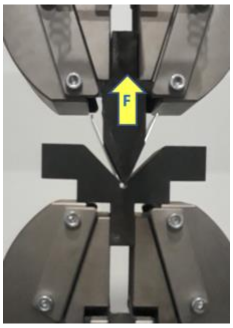
Specifications	Material Standard	
	JIS G-3313*	C9AA6511A**
Mechanical properties		
T. S. (N/mm^2)	≥ 270	311
Y. P. (N/mm^2)	≤ 205	164
El. (%)	≥ 80.0	47
Coating Thick (μm)	≥ 11.2	12.75
Chemical composition (%)		
C	≤ 0.15	0.0206
Mn	≤ 0.60	0.187
P	≤ 0.04	0.007
S	≤ 0.05	0.0097

*JIS Specifications (JAS, 1998) and **certificate of analysis (Rahardja *et al.*, 2020).

V-dies are manufactured using a wire-cut EDM process with SKD-11 material that has been heated treatment with a hardness range achieved about 55-65 HRC. The punch-dies design is provided in 3 bending angles, including 40°, 50°, and 60°, respectively. These use a bending radius of R1.0 mm. On different sides, the V-die bending design is made in two types with different die openings. Figure 2 shows the testing of the bending process using V-die bending.



(a). Pre V-bending processing (b). Loading processes



(c). Unloading processes

Figure 2. The process of V-bending in SECC galvanized material

The bending radius of a punch affects the final dimensions of the workpiece and the quality of the bending results. A bending radius that is too small will cause the workpiece for cracking, while if it is too large, it will impact wasting material and the final dimensions of the workpiece (Altan, 1998; Khoirudin *et al.*, 2021). The punch and V-die bending are designed with a radius of 1.0 mm.

Determination of the bending radius must pay attention to the mechanical properties and thickness of the material to be used. Table 2 references the use of a minimum radius of V-dies on materials with tensile strength up to 490 N/m^2 for bending angles below 120^o (Khoirudin *et al.*, 2022).

Table 2. Minimum V-dies bending radius for angles below 120^o

Tensile strength in N/mm^2	Material thickness (t) in mm					Bending direction
	1.0	**> 1.0 - 1.5**	**> 1.5 - 2.5**	**> 2.5 - 3.0**	**> 3.0 - 4.0**	
≤ 390	1.0	1.6	2.5	3.0	5.0	Transverse
	1.0	1.6	2.5	3.0	6.0	Longitudinal
>390 - 490	1.2	2.0	3.0	4.0	5.0	Transverse
	1.2	2.0	3.0	4.0	6.0	longitudinal

Table 3. Four bending parameters in V-dies bending samples that provided by statistical software

Bending Parameters	The sample and parameter of V-bending processes					
	S-1	S-2	S-3	S-4	S-5	S-6
Die opening L (mm) and high, *h* (mm)	30.0 & 15.00	30.0 & 15.00	30.0 & 15.00	35.00 & 17.10	35.00 & 17.10	35.00 & 17.10
Punch angel ø (^{o})	40.00	50.00	60.00	40.00	50.00	60.00
Punch speed V_b (mm/minutes)	30.00	40.00	50.00	30.00	40.00	50.00
Bending Force (kN)	6.50	7.00	6.50	7.50	7.50	7.00

2.2. Calculation of Bending Force (Fb) and Bending Work (Wb)

Bending force (Fb) calculations are required to establish the tonnage need of the bending machine and to set the bending force in the production process. It is employed in this study to calculate the minimal bending force in the testing process. Equation 1 calculates the minimum bending force for ratios of width and thickness higher than 10, whereas equation 2 calculates it for ratios less than 10 (Altan, 1998; Khoirudin *et al.*, 2021). Calculation of bending force for a w/t ratio ≥ 10:

$$F_b = \frac{b_s t^2 R_m}{w} \qquad (1)$$

Calculation of bending force for a w/t ratio less than 10:

$$F_b = \left(1 + \frac{4,t}{w}\right)\frac{b_s t^2 R_m}{w} \qquad (2)$$

This experiment used bending forces with variations of 6.50 kN, 7.00 kN, and 7.50 kN. Calculation of bending work, Wb (Joule), is carried out using equation 3 (Altan, 1998; Khoirudin *et al.*, 2021).

$$W_b = x.F_b.h \qquad (3)$$

Where b_s is the width of the workpiece on the bending line (mm), t is the thickness of the material (mm), R_m is the tensile strength (N/mm^2), w is the width of the V-dies (mm), and x is the force unevenness constant between 0.3 and 0.6 provided by Altan (Altan, 1998), the value of the unevenness constant is affected by bending requirements and bending machine settings. The variable h represents the displacement of the bending point induced by force provided to the bending process until the v-dies punch stopped in units of m (meters).

2.3. Parameters for Bending Testing

The bending test aims to evaluate the effect of bending parameters on the spring-back material of the tested SECC material. The bending process was tested experimentally utilizing the SHIMADZU Universal Testing Machine with UTM AGS-X model 10 kN STD E200V, which has a 10 kN capacity. The test room is controlled at a maximum temperature of 25ºC. The test is stopped after passing the predetermined bending force. This study uses four input parameters whose values are arranged randomly. The four input parameters used in this study are: V-die opening L (mm), punch angel (Ø), punch speed Vb (mm/min), and bending force (N). The values of the v-die opening used are 30.0 mm and 35.0 mm. For the punch angle input parameters, we used values of 30º, 45º, and 60º; punch speed of 30 mm/minute, 40 mm/minute, and 50 mm/minute; bending force with input values. of 6.50 kN, 7.00 kN, and 7.50 kN. Details of the four V-die bending parameters for this test are presented in Table 3.

2.4. Phenomenon of Spring-back Material

The spring-back phenomenon occurs in forming materials using cold methods such as bending, roll forming, and roll bending (Altan, 1998; Khoirudin *et al.*, 2021). The elasticity of the material during forming causes the spring-back phenomenon. The type of workpiece material influences the spring-back characteristics. The spring-back phenomenon occurs when the angle change is greater than the angle before the bending force is released. In comparison, the spring-go phenomenon occurs when a minor angle changes after the bending force is released. These two bending phenomena significantly affect the workpiece's dimensional precision and geometric shape.

The phenomenon of spring-back and spring-go is a critical factor that determines the quality of elasticity, increases product costs, and reduces the efficiency of the manufacturing process (Su *et al.*, 2017). Figure 3 shows the spring-back factor, kR, which is the ratio the bending angle of the workpiece after spring-back(α_1) or after spring-go (α_3) and between the bending angle of the dies (α_2). The amount of spring-back and spring-go factors are calculated using equations 4 and 5.

$$k_R = \frac{\alpha_1}{\alpha_2} = \frac{r_{i1}+0{,}5t}{r_{i2}+0{,}5t} \tag{4}$$

$$k_R = \frac{\alpha_3}{\alpha_2} = \frac{r_{i1}+0{,}5t}{r_{i2}+0{,}5t} \tag{5}$$

Where r_{i1} and r_{i2} are the radius of dies and workpieces, respectively, the spring-back and spring-go factor values are between 0 and 1 (0≤kR ≤1). The value of k_R = 1 indicates that there is perfect rigid material with no spring-back or spring-go on the workpiece. In contrast, k_R = 0 indicates that the workpiece has perfect elasticity (Ahmed *et al.*, 2014; Khoirudin *et al.*, 2022).

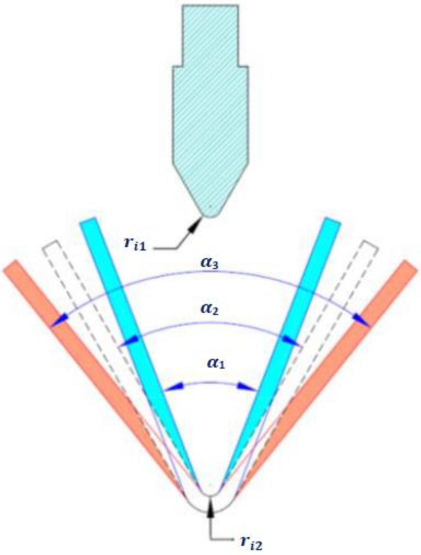


Figure 3. The spring-back and spring-go phenomena of the V-bending process

3. RESULTS AND DISCUSSION

3.1. Analysis of Force and Work Bending

The minimum bending force calculation is carried out using equations 1 and 2. The width of the bending side in this study is 24 mm and uses SECC material (JIS G 3313) with a material thickness of 0.8 mm. The bending process was done longitudinally with V-bending dies with a radius of 1.0 mm and a V-die width of 30 mm. The minimal bending force is derived using equation 1 for SECC electro galvanized steel (JIS G 3313) with a tensile strength of 337 N/mm^2.

Equation 1 is used to calculate the minimum force when the ratio of the width of the bending line with the thickness (w/s) of the material more than 10 (w/s > 10). Whereas Equation 2 is used to calculate the minimum bending force when the ratio of the width of the bending side to the thickness of the material is up to 10 (10 w/s) (Altan, 1998; Suchy, 2006). Based on equation 1, the minimum required bending force is 160 N. In its implementation, the bending forces used are 6.50 kN, 7.00 kN, and 7.50 kN so that it meets the criteria in equation 1. Next, the bending work is calculated using equation 3. S-1 to S-3 samples have a bending depth of 15.00 mm, and S-4 to S-6 samples have a die depth of 17.1 mm. The unevenness constant of x was set at 1/3, so the work bending value for sample 1 is 32.2 N.m (≈32.2 Joule). The results of the work bending calculation for all samples are presented in Figure 4. The largest *Kr* is close to 1. The Kr value is calculated using equation 4 or 5. The measurement of the bending angle results shows the value of α_1 of $K_r = \frac{\alpha_1}{\alpha_2} = \frac{40}{40{,}42} = 0.99$. Figure 5 shows the spring back/spring-go factor data for the six parameters of the tested V-dies bending test sample. The obtained spring-back or spring-go factor is between 0.94 and 0.98. This indicates that the material is not perfectly rigid, so the material has a spring-back or spring-go phenomenon (Altan and Tekkaya, 2012). The result has been follow previous studied conducted by Khoirudin et al. (Khoirudin *et al.*, 2022).

3.2. Analysis of the spring-back and spring-go phenomenon

The result of the V-bending process in sample one shows the emergence of a spring-back material phenomenon. The results of the spring-back and spring-go analysis are shown in Figure 6. The sample in the 1st iteration uses a die opening parameter of 30 mm, a punch angle of 40°, a punch speed of 30 mm/minute and a bending force of 6.50 kN. The spring-back phenomenon occurs in the fourth sample iteration when the die-opening of 40 mm, the punch angle of 40°, the punch speed of 30 mm/minute, and the bending force of 7.50 kN. The spring-go phenomenon occurs in four other samples in the third, fifth, and sixth sample iterations. This experimental data shows that all samples processed using punch angles of 50° and 60° experienced a spring-go phenomenon.

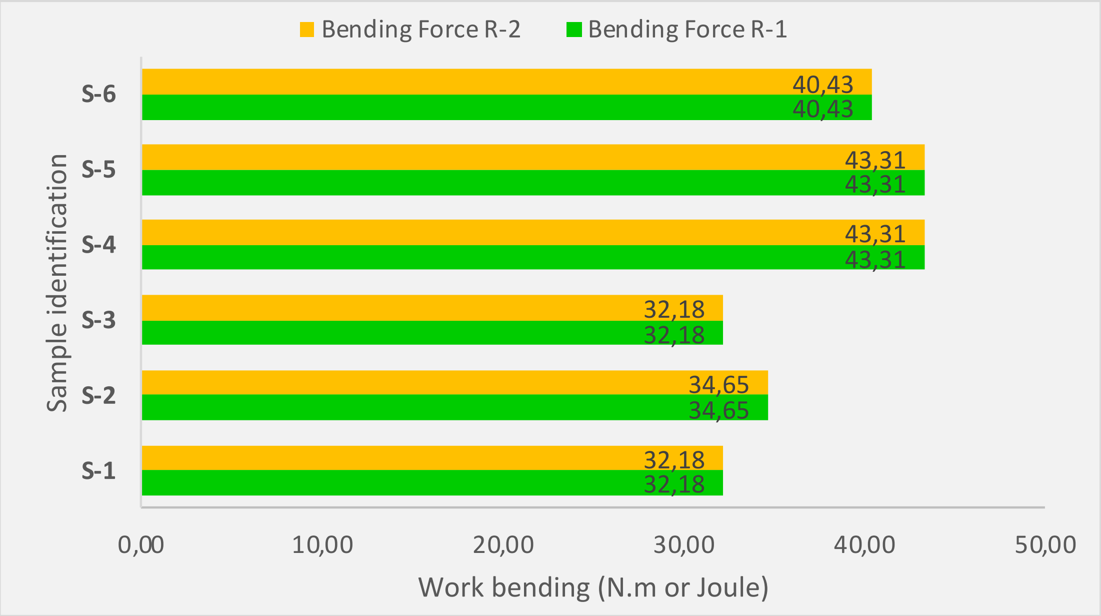


Figure 4. The work-bending calculation results for all samples

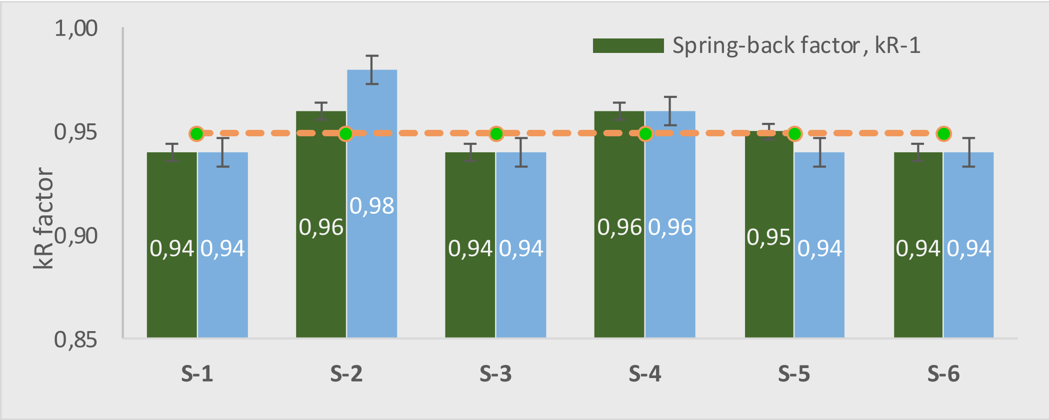


Figure 5. The spring back and spring-go factor data for the tested V-dies bending test sample's six parameters

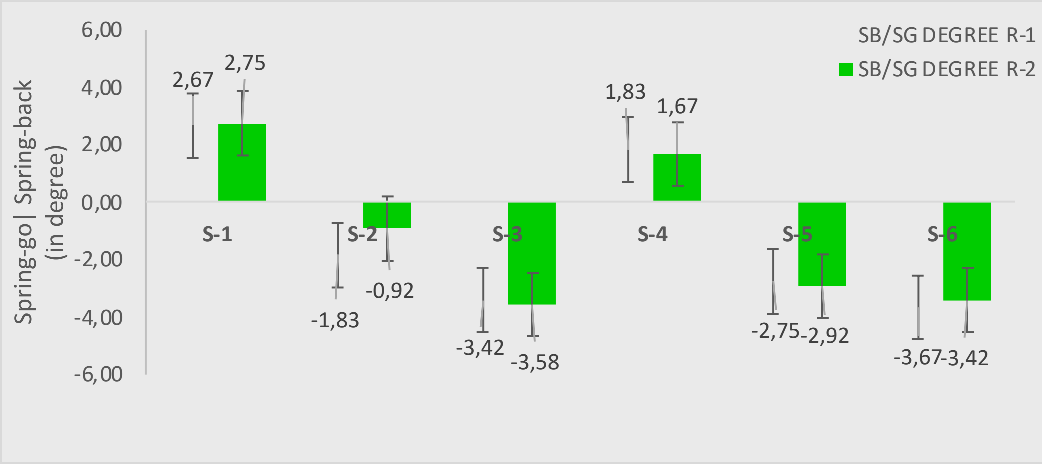


Figure 6. The spring-back and spring-go analysis of the tested V-die bending test sample

Furthermore, punch speed as an input variable can be analyzed that the spring-back phenomenon occurs at a 30 mm/minute punch speed setting. In contrast, there is a spring-go phenomenon at the punch speed setting of 40 mm/minute and 50 mm/minute. These two occurrences follow the analysis of the spring-back and spring-go phenomena undertaken by (Özdin *et al.*, 2014), which states that as the bending angle (punch angle) increases, so does the spring-go. In the other two input variables, namely dies opening and bending force, spring-back and spring-go phenomena occur at all given values. This phenomenon also follows previous studied conducted by (Khoirudin *et al.*, 2022). In the other two input variables, namely dies opening and bending force, spring-back and spring-go phenomena occur at all given values. This phenomenon also follows previous studies conducted by Thipprakmas (Thipprakmas, 2020).

4. CONCLUSION

The following is a summary of research results regarding spring-back and spring-go on variations in the v-bending angle using electrolytic zinc-coated steel sheet (SECC/JIS G 3313). The spring-back phenomenon occurs at bending angles below 45°. In contrast, the spring-go phenomenon occurs at V-die bending angles above 45°. In the V-die bending test with angles of 40°, 50°, and 60°, the spring-back value is directly proportional to the magnitude of the V-die bending angle. A similar phenomenon occurs in the V-dies bending test using bending speeds of 30, 40, and 50 mm/minute.

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