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Improving the Bending Quality of SUS 201 1B Material by Optimization of the Processing Parameters using Taguchi Method

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ABSTRACT

Sheet metal bending was a type of sheet metal forming process that produced sheet metal bending according to a certain angle and length using a die. The formed process caused elastic and plastic deformation, resulting in springback and sheet metal elongation. The research analysed used the Taguchi method to find the best arrangement of bending parameters that produced the best bending angle and side length. The bending parameters selected in the study were material cutting orientation factor, punch velocity, and holding time. The ANOVA method would follow the tested results to determine the contribution of each parameter tested. The results stated that the material cutting orientation 0-degree, punched velocity of 10 mm/s, and holding time of 5 seconds was the best parameter arrangement that produced the best bending angle with the smallest springback angle. The bending parameter arrangement for the best-bending side length was a material cutting orientation of 0 degrees, pressing speed of 15 mm/s, and holding time of 5 sec, it minimize springback, significantly optimizing the deformation process for SUS 201 1B materials. The studied results concluded that the material cutting orientation factor had the largest contribution to the angle and length of the bending side, with a percentage contribution of 98.105% and 98.499%.

1. INTRODUCTION

Sheet metal forming is one of the world's oldest types of metal manufacturing. Sheet metal forming aims to transform sheet metal into a product shape according to the mould design by applying pressure until it reaches the point of plastic deformation [1,2]. Bending is a sheet metal forming process that produces sheet metal bending according to a certain angle and length using moulds (dies). The bending process requires several appropriate parameters to create angles and side lengths that meet the demands and tolerances. Material thickness, material type, and product geometric design determine bending parameter variations [3].

Sheet metal forming, especially bending, cannot be separated from elastic and plastic deformation. The resulting deformation results in spring back and elongation. Springback is the return force that arises due to the elastic deformation of a material when the compressive load is removed [2,4,5]; on the other hand, elongation is the ability of sheet metal material to stretch without necking and other form failures [6]. In addition, elongation occurs due to the stress on the outer side of the sheet metal caused by the force during the bending process [7–9]. Some 5 mm thick SUS 201 1B products have non-uniform bending angles and side lengths. However, the non-uniformity of product dimensions arises due to variations in material cutting orientation and different bending machine parameter settings for each operator. The bending machine parameters in question are punch velocity and holding time. Material cutting orientation is a significant factor that affects the springback value in the v-bending process [10]. Material cutting orientation in the sheet metal manufacturing industry can be divided into longitudinal (0°), transverse (90°), and diagonal (45°) [11]. Punch velocity affects the springback value but has a different influence on each material [5,12,13]. Holding time is one of the bending parameters that majorly impact spring back in the v-bending process [5,14]. Bend allowance and bend deduction define the length increase in the bending process [15].

Research is needed to find the best arrangement of cutting material orientation, punch velocity, and holding time factors that produce the best bending angle and bending side length in accordance with applicable tolerances. Research was also conducted to find the percentage contribution for each parameter used. The research methods used in the test are the Taguchi Method and ANOVA.

2. METHODS

2.1 Taguchi Method

The Taguchi method is one of the research methods introduced by Dr Genichi Taguchi to improve or enhance a product's quality and production process by combining controlled factors. The advantage of the Taguchi method is that it can minimise the causes of production variability and reduce the number of experimental variations, thereby saving time and costs [16,17]. The information obtained makes it possible to arrange a parameter variation of the optimally controlled factor so that the resulting product has the best quality.

2.1.1 Orthogonal Array

The process of determining the combination of factors and levels in the Taguchi method uses an orthogonal array. The orthogonal array produces a minimum combination variation depending on the number of factors and levels used. The research results are information from the combination of all factors and levels affecting the responses.

The most essential step in preparing an orthogonal array is determining the level combination of factors used for each experiment [18]. The choice of level for each independent variable is determined from the development of the situation that occurred during the bending process of PT Dempo Laser Metalindo. The cutting orientation factor is divided into three levels, including longitudinal (0°), diagonal (45°), and transverse (90°). Parameter variation in the pressing speed and holding time used are the results of the development of the default settings for each bending operator. Variable free pressing speed is divided into three levels, namely five mm/s, ten mm/s, and 15 mm/s. The holding time variable is divided into three levels, namely 1 second, 3 second, and 5 seconds. Table 1 shows the $L_9\,(3^3)$ orthogonal array used in the study, with three factors and three levels.

Table 1. Orthogonal array $L_9\,(3^3)$

Experiment	Material Cutting Orientation (°)	Punch Velocity (mm/s)	Holding Time (sec)
1	90	5	1
2	90	10	3
3	90	15	5
4	45	10	1
5	45	15	3
6	45	5	5
7	0	15	1
8	0	5	3
9	0	10	5

2.1.2 Signal to Noise Ratio

Signal to Noise Ratio is a method to find the contribution of each factor listed in the orthogonal array to the response that occurs. The signal-to-noise ratio selects factors that reduce variation in the combination of response factors [19,20]. The characteristics of the signal-to-noise ratio method are divided into three including:

a) Smaller is Better

The quality characteristic sought has a smaller value, or the closer to zero, the better, with the limitation that the value must be non-negative.

$$S/N\ Ratio\ = -10 \times \log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \tag{1}$$

Explanation of the formula:
n = number of repetitions of each experiment
y_i = value of each run

b) Nominal is Better

The quality characteristic sought has a specific value as the ideal value.

$$S/N\ Ratio\ = 10 \times \log\left[\frac{y^2}{s^2}\right] \tag{2}$$

Explanation of the formula:
y = average of each run
s = deviation of each run

c) Larger is Better

The sought-after quality characteristic has the greater the value, the better with the limitation of non-negative values.

$$S/N\ Ratio\ = -10 \times \log\left[\frac{1}{n}\sum_{i=1}^{n} \frac{1}{{y_i}^2}\right] \tag{3}$$

Explanation of the formula:
n = number of repetitions of each experiment
y_i = value of each run

In this research, calculating the S/N spring back angle ratio using smaller is better; meanwhile, for the bending side length, using the nominal is better, with a target of 64.50 mm.

2.2 ANOVA (Analysis of Variance)

Analysis of variance (ANOVA) is a statistical calculation technique used to quantitatively calculate each factor's effect or role on a particular response [21,22]. ANOVA allows a researcher to know the percentage of influence of each factor and the optimal arrangement of factors on a response. ANOVA used in parameter design research is useful for determining the effect of a parameter on the specified response model.

2.3 Specimen of Experiment

The research specimen uses SUS 201 1B sheet metal material. The specimen has actual dimensions of 120.0 mm long, 40.0 mm wide, and 4.8 mm thick. The form of the research specimen can be seen in Figure 1. Stainless steel (SUS) is widely used in the manufacturing world, ranging from the oil and gas industry to the needs of home industries [23]. The description of the chemical composition and mechanical properties of SUS 201 1B according to ASTM-A240 is presented in Table 2 and Table 3 [24].

Table 2. Chemical properties of SUS 201 1B

Properties	C	Mn	P	S	Si	Cr	Ni	N
Percentage (%)	0.15	5.50 – 7.50	0.06	0.03	1.00	16.0 – 18.0	3.50 – 5.50	0.25

Table 3. Mechanical properties of SUS 201 1B

Yield Strength (MPa)	≥ 260
Tensile Strength (MPa)	≥ 515
Elongation, in 50 mm (%)	≥ 40
Hardness (HRB; Brinell)	≤ 217; ≤ 95

Figure 1. Specimen of experiment

2.4 Measurements and Testing

Each experiment produced three measurement results for each response. Measurements were made according to ABBE Principal [25]. The springback angle and bending side length measurement results will be averaged and calculated using the S/N ratio. The characteristic of calculating the S/N ratio of the springback angle is that it is minor, which is better, while for the bending side length, using nominal is better with a target of 64.50 mm. The target side length is determined from the sum of the bending line distance from the edge of the specimen with half the bend deduction value set at 9 mm. The measurement results are written in the measurement result sheet, as shown in Table 4.

Table 4. Measurement results sheet

E	Factor			Springback Angle (°)					Side Length (mm)				
	CO (°)	PV (mm/s)	HT (sec)	1	2	3	Avg.	S/N Ratio	1	2	3	Avg.	S/N Ratio
1	90	5	1										
2	90	10	3										
3	90	15	5										
4	45	10	1										
5	45	15	3										
6	45	5	5										
7	0	15	1										
8	0	5	3										
9	0	10	5										

2.1.2 Springback Angle

The angle measurement process is carried out in the Measuring Tool Work Unit of PT ATMI SOLO, with a room temperature of ± 20° Celsius. The measuring instrument used for the measurement is the bevel protractor brand Etalon Switzerland by Roch, as shown in Figure 2. The springback angle is obtained by subtracting the actual bending angle from the desired bending angle (90 degrees).

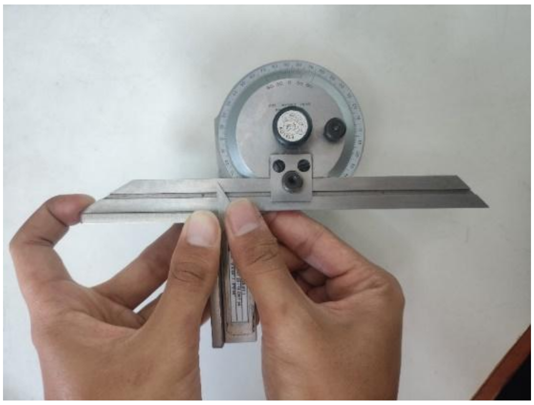

Figure 2. Measurement of bending angle

2.1.2 Bending Side Length

The bending side length measurement is carried out in the Measuring Tool Work Unit of PT ATMI SOLO at a room temperature of ± 20° Celsius. The measuring instrument used for the measurement is a Mitutoyo 192-664-10 height gauge, as shown in Figure 3. Measurement data was obtained by measuring the highest point of the bending side from the surface of the magnet box.

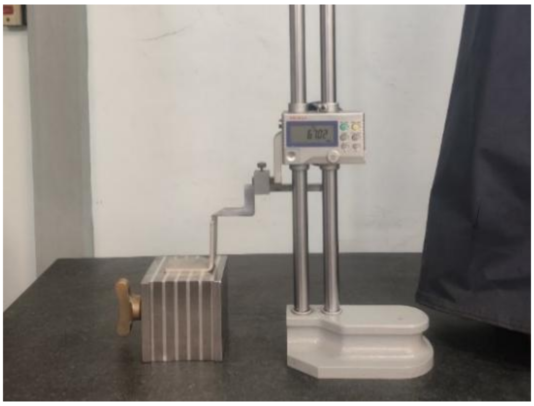

Figure 3. Measurement of bending side length

3. RESULT AND DISCUSSION

3.1 Taguchi Analysis of Springback Angle

The angle measurement data of each specimen were summed and averaged to produce the experimental bending angle. The springback angle measurement results of each experiment are presented in Table 5.

Table 5. Measurement results of springback angle

E	Parameter			Springback Angle (°)					
	CO (°)	PV (mm/s)	HT (sec)	1	2	3	Avg.	SB	S/N Ratio
1	90	5	1	92,583	92,583	92,500	92,556	2,556	-8,150
2	90	10	3	92,167	92,333	92,250	92,250	2,250	-7,044
3	90	15	5	91,917	92,833	92,750	92,500	2,500	-7,959
4	45	10	1	91,417	91,250	91,333	91,333	1,333	-2,499
5	45	15	3	91,167	91,167	91,083	91,139	1,139	-1,130
6	45	5	5	90,917	91,000	91,000	90,972	0,972	0,245

E	Parameter			Springback Angle (°)					
	CO (°)	PV (mm/s)	HT (sec)	1	2	3	Avg.	SB	S/N Ratio
7	0	15	1	90,250	90,333	90,250	90,278	0,278	11,126
8	0	5	3	90,083	90,000	90,083	90,056	0,056	25,105
9	0	10	5	90,083	90,000	90,000	90,028	0,028	31,126

The data processed using the S/N Ratio Smaller Is Better character is used to calculate the variability value of each parameter used in the experiment. Table 6 shows the results of calculating parameter variability values for the springback angle. The data describes the optimal arrangement of parameters that results in the smallest springback angle.

Table 6. Data of springback angle variability values

S/N Ratio Springback Angle			
Level	Parameter		
	Cutting Orientation	Punch Velocity	Holding Time
1	-7,717	5,733	0,159
2	-1,128	7,195	5,644
3	22,453	0,679	7,804

A level's most considerable S/N Ratio determines the best parameter value. The optimal arrangement of parameter values based on the Smaller Is Better S/N Ratio calculation to produce the smallest springback angle includes cutting orientation level 3 (0°), punch velocity level 2 (10 mm/s), and holding time level 3 (5 sec).

The orientation greatly influenced the elastic recovery for the AISI1045 sheet, and 90^0 orientation displays more excellent springback when compared to 0^0 orientation. Elastic recovery angle is a purpose of yield strength to modulus of elasticity ratio.The springback angle is more significant for the transverse direction when compared to the rolling direction [5].

A graphic depiction of the best parameter arrangement based on the S/N Ratio Smaller Is Better calculation can be seen in Figure 4.

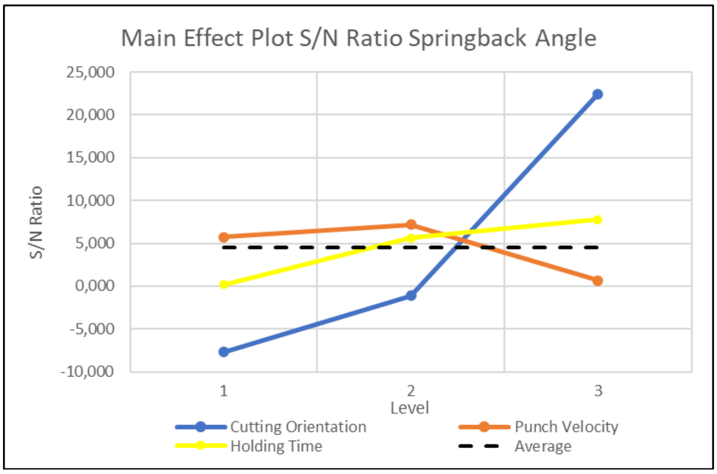

Figure 4. S/N Ratio graph of springback angle

3.2 Taguchi Analysis of Bending Side Length

The measurement data obtained from the calculations are averaged to produce the bending side length of each experiment. The bending side length measurement results are presented in Table 7.

Table 7. Measurement results of bending side length.

E	Parameter			Bending side length (mm)					
	CO (°)	PV (mm/s)	HT (sec)	1	2	3	Avg.	*S*^2	S/N Ratio
1	90	5	1	64,160	64,150	64,060	64,123	0,003033	61,321
2	90	10	3	64,153	64,140	64,125	64,139	0,000201	73,112
3	90	15	5	64,097	64,068	64,087	64,084	0,000206	72,986
4	45	10	1	64,335	64,355	64,328	64,339	0,000193	73,323
5	45	15	3	64,370	64,387	64,380	64,379	0,000070	77,701
6	45	5	5	64,392	64,397	64,397	64,395	0,000008	86,969
7	0	15	1	64,493	64,490	64,490	64,491	0,000004	90,504
8	0	5	3	64,522	64,512	64,512	64,515	0,000033	80,964
9	0	10	5	64,507	64,515	64,508	64,510	0,000019	83,305

The data processed using the S/N Ratio Nominal Is Better character is used to calculate the variability value of each parameter used in the experiment. Table 8 shows the results of the calculation of parameter variability values for the bending side length. The data describes the optimal arrangement of parameters that produces the best-bending side length.

Table 8. Data of bending side length variability values

S/N Ratio Bending Side Length			
Level	Parameter		
	Cutting Orientation	Punch Velocity	Holding Time
1	69,140	76,418	75,049
2	79,331	76,580	77,259
3	84,924	80,397	81,087

A level's most considerable S/N Ratio determines the best parameter value. The optimal arrangement of parameter values based on the Nominal Is Better S/N Ratio calculation to produce the best-bending side length includes cutting orientation level 3 (0°), punch velocity level 3 (15 mm/s), and holding time level 3 (5 sec). A graphic depiction of the best parameter arrangement based on the calculation of the S/N Ratio Nominal Is Better can be seen in Figure 5.

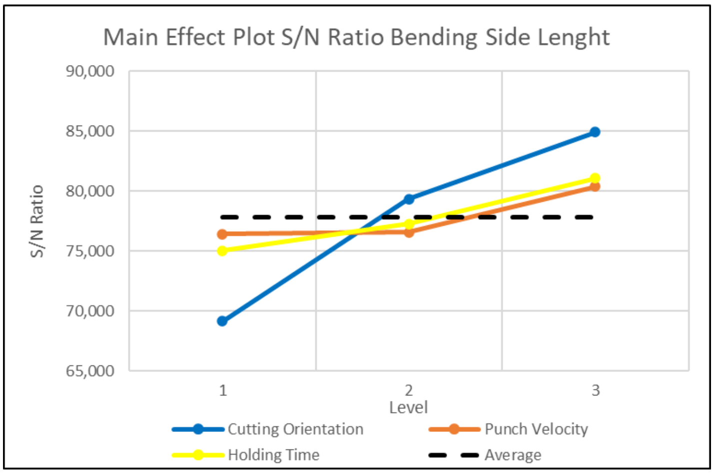

Figure 5. S/N Ratio graph of bending side length

3.3 ANOVA of Springback Angle

The ANOVA method analysis process was carried out with the help of MiniTab21 software as a reference for the final results. The calculation by MiniTab21 is shown in Table 9. The results of the ANOVA method calculation of each parameter and error factor on the springback angle can be concluded as follows:

Table 9. ANOVA of springback angle

Source	DF	Adj SS	Adj MS	F-Value	P-Value
OS	2	8,07116	4,03558	318,05	0,003
HT	2	0,10768	0,05384	4,24	0,191
PV	2	0,002281	0,01140	0,90	0,527
Error	2	0,02538	0,01269		
Total	8	8,22702			

- $\mathbf{P_A}$ is the percentage contribution of the material cutting orientation variable in testing the springback angle with a value of $\mathbf{98,105}$ **%.**
- $\mathbf{P_B}$ is the percentage contribution of the punch velocity variable in springback angle testing with a value of $\mathbf{0,277}$ **%.**
- $\mathbf{P_C}$ is the percentage contribution of variable holding time in springback angle testing with a value of $\mathbf{1,309}$ **%.**
- $\mathbf{P_E}$ is the percentage contribution of the error factor in testing the springback angle with a value of $\mathbf{0,308}$ **%.**

3.4 ANOVA of Bending Side Length

The ANOVA method analysis process was carried out with the help of MiniTab21 software as a reference for the final results. The calculation by MiniTab21 is shown in Table 10. The results of the ANOVA method calculation of each parameter and error factor on the bending side length can be concluded as follows:

Table 10. ANOVA of bending side length

Source	DF	Adj SS	Adj MS	F-Value	P-Value
OS	2	0,235290	0,117645	159,88	0,006
HT	2	0,001057	0,000528	0,72	0,582
PV	2	0,001057	0,000528	0,72	0,582
Error	2	0,001472	0,000736		
Total	8	0,238875			

- $\boldsymbol{P_A}$ is the percentage contribution of cutting orientation material variables in testing the length of the bending side with a value of **98,499 %**
- $\boldsymbol{P_B}$ is the percentage contribution of punch velocity variables in testing the length of the bending side with a value of $\mathbf{0,442}$ **%**
- $\boldsymbol{P_C}$ ais the percentage contribution of variable holding time in testing the length of the bending side with a value of $\mathbf{0,442}$ **%**
- $\boldsymbol{P_E}$ is the percentage contribution of error factors in testing the length of the bending side with a value of $\mathbf{0,616}$ **%**

3.5 Other Result

Bending specimens with a material cutting orientation of 90 degrees (transverse) experienced cracks on the outer radius of the specimen, as shown in Figure 8. Crack that occurs due to reduced material ductility for transverse cutting orientation material [6].

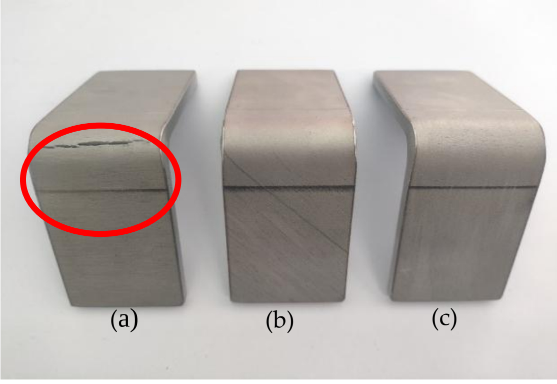

Figure 8. (a) Transverse bending specimen (b) Diagonal bending specimen
(c) Longitudinal bending specimen

4. CONCLUSION

The main objective of the research conducted was to obtain the optimal arrangement and percentage of influence of material cutting orientation factors and bending machine parameters on the bending angle and bending side length of 5 mm thick SUS 201 1B material. The results of the research and testing carried out resulted in the following conclusions:

- The arrangement of material cutting orientation factors and bending machine parameters that produces the best bending angle (smallest springback angle) is material cutting orientation of 0 degrees, punch velocity of 10 mm/s, and holding time of 5 sec.
- The arrangement of material cutting orientation and bending machine parameters that produce the best bending side length is a material cutting orientation of 0 degrees, punch velocity of 15 mm/s, and holding time of 5 sec.
- The percentage contribution of each parameter to the bending angle includes 98.105% material cutting orientation, 0.277% punch velocity, 1.309% holding time, and an error factor of 0.308%.
- The percentage contribution of each parameter to the bending side length includes 98.499% material cutting orientation, 0.442% punch velocity, 0.442% holding time, and an error factor of 0.616%.

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