Analysis of the Effect of AISI 1005 Grain Structure and Cutting Angle on Springback Using the V-Bending Method

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Keywords: Springback, V-Bending, Direction Bending.

Abstract: Many considerations exist in a process of bending, plate material (product) will change the angle and radius bend dimension called springback. As a result, the process of forming the product experiences a mismatch/change in terms of dimensions. The direction of cutting the rolling plate for the product is often ignored by the operator in the manufacturing process. However, the use of grain structure parameters in the direction of cutting the rolling plate may have an effect to minimize the amount of springback. Springback itself occurs in almost all forming processes (bending, forming, deep drawing, etc.) on sheet metal. The analysis was carried out by v -bending using the test using a test specimen that has dimensions of 1.87 × 35 × 150, bending angle of 90°, bending radius of R8.465 mm, and clearance between punch bending and die bending is equal to the plate thickness (1.87 mm), and with plate material AISI 1005, and tested with variable cutting angles from the direction of rolling the plates using the machine press AIDA direct servo formers DSF-C1-A series. The results of the analysis state that the amount of springback due to the variable cutting angle from the rolling direction of the plate affects the amount of springback. The amount of springback from the direction parallel to the rolling angle of the plate gets a positive value of 1.148°, then the perpendicular angle with a value of negative 1.431°, and the springback largest is 45° from rolling with a value of negative 1.716°.

1 INTRODUCTION

In the manufacturing industry, technology is growing rapidly. One of them is the development in the field of sheet metal. The manufacture of sheet metal products has now penetrated almost all fields, and the results of the output are very varied, ranging from simple shapes to complex shapes, from low accuracy to high accuracy. The achievement of the product in any way is the main goal of manufacturers in producing their products. To maintain product achievement in terms of form, the technology press is a tool used by manufacturers to produce their products. A press tool is a tool for shaping, cutting, or both by applying an emphasis to the material in the form of tool shapes sheet metal, the press can produce objects from simple shapes to complex.

Many considerations exist in plate manufacture or formation, one of which is the parameter of the plate rolling grain structure. The direction of cutting the rolling plate for the product is often ignored by the operator in the manufacturing process. However, the use of grain structure parameters in the direction of cutting the rolling plate may have an effect to minimize the amount of springback. Springback is a reverse force caused by the effect of the elasticity of the plate material undergoing the forming process. Springback itself occurs in almost all forming processes (bending, forming, deep drawing, etc.) on sheet metal.

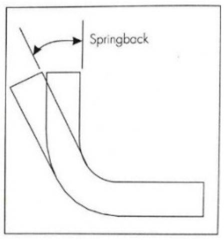

Figure 1: Springback.

Therefore, knowledge about springback and analysis of springback is needed to determine the behavior of springback. One of the methods used to analyze the springback is by testing the bending by paying attention to the grain structure variable towards the cutting direction of the plate rolling. The results of this trial will produce varied data so that it

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can find out the amount of deviation that occurs by springback with predetermined variables and is used as a reference or reference for grain structure settings and the direction of cutting the rolling plate in plate formation.

2 METHODOLOGY

2.1 Bending Material Specifications

The material that is used for this v-test *bending* is AISI 1005, with plate dimensions 150 × 35 × 1.87 (mm). The specimen is bent at 90° with an inner radius of R8.465 and an outer radius of R10.32 and the rolling direction is transverse, perpendicular and 45° with the direction of rolling as in Figure 2 and Figure 3, and its mechanical properties are known as follows.

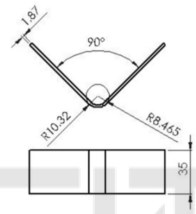


Figure 2: Specimen specifications.

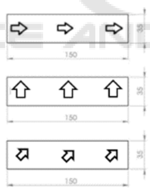


Figure 3: Direction of cutting the rolling plate of the bending specimen.

Table 1: Data plate material with the direction of rolling.

Parameters Measurement Average	Average
0.2% Y.S. [N/mm^2]	221.967
Yield Strength (γ) [N/mm^2]	223.697
Tensile Strength (σ) [N/mm^2]	299.347
Elongation (ε) [%]	52.97
Parameters Measurement	Average
0.2% Y.S. [N/mm^2]	268.413
Yield Strength (γ) [N/mm^2]	270.35
Tensile Strength (σ) [N/mm^2]	324.11
Elongation (ε) [%]	51.593
Parameters Measurement	Average
0.2% Y.S. [N/mm^2]	253.543
Yield Strength (γ) [N/mm^2]	259.226
Tensile Strength (σ) [N/mm^2]	317.306
Elongation (ε) [%]	56.453

2.2 Making Tools

Tools made are vbending tools consisting of the 4 main components, namely, upper late with DIN 1.0037 material, punch bending with DIN 1.2510 material, die bending with DIN 1.2510 material, and DIN 1.0037 bottom plate. Tools that made were divided into 2 main parts, namely the bottom of the tools and the top of the tools. The lower part of the tools consists of the base plate, die bending an, and d pin locator and the upper part consists of the upper plate and the bending punch. The tools were made as follows:

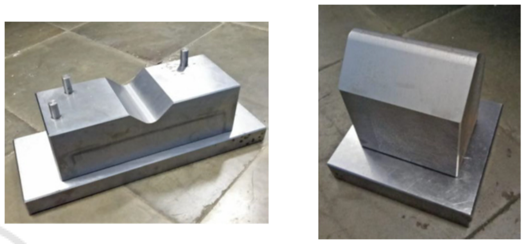


Figure 4: (a) The bottom of the tools, (b) The top of the tools.

2.3 Testing and Measurement

Testing was carried out on the machine AIDA press direct servo formers DSF-C1-A series Manufacturing Engineering Laboratory Manufacturing Bandung. This machine press uses a servo motor main drive so that it allows for large presses and stable pressing speeds

In the testing process, the engine speed used was 56 strokes/minute, and the holding time was 0 seconds. Furthermore, the angle formed in the specimen is measured using a CMM (Coordinate Measuring Machine) machine in the measurement laboratory, in Manufacture Engineering Department.

3 CALCULATION AND ANALYSIS

3.1 Prediction of Springback with Formulas

The first step is using the formula of springback to calculate the modulus of elasticity of the specimens bending, for the calculation of elongation is used the comparison formula between elongation peak before breaking plates and elongation after plate breaks. The calculations are as follows.

- Parallel

$$\varepsilon=\frac{\varepsilon\text{before the plate breaks}}{\varepsilon\text{after the plate breaks}}=\frac{52.97\%}{38.867\%}=1.33\% \quad (1)$$

- Perpendicular

$$\varepsilon=\frac{\varepsilon\text{before the plate breaks}}{\varepsilon\text{after the plate breaks}}=\frac{51.593\%}{37.533\%}=1.37\% \quad (2)$$

- 45°

$$\varepsilon=\frac{\varepsilon\text{before the plate breaks}}{\varepsilon\text{after the plate breaks}}=\frac{56.453\%}{41\%}=1.38\% \quad (3)$$

So that the modulus of elasticity obtained is as follows.

- Parallel

$$E=\frac{\sigma}{\varepsilon}=\frac{221.967}{1.33\%}=16689.25\ N/mm^2 \quad (4)$$

- Perpendicular

$$E=\frac{\sigma}{\varepsilon}=\frac{268.413}{1.37\%}=19592.19\ N/mm^2 \quad (5)$$

- 45°

$$E=\frac{\sigma}{\varepsilon}=\frac{253.543}{1.38\%}=18372.68\ N/mm^2 \quad (6)$$

Next is calculating elastic modulus by entered the formula springback to predict the final radius. Here is the calculation of the springback final radius:

- Parallel

$$\frac{\text{Ri}}{\text{Rf}}=4\left(\frac{\text{Ri.Y}}{\text{E.t}}\right)^3-3\left(\frac{\text{Ri.Y}}{\text{E.t}}\right)+1 \quad (7)$$

$$\frac{8.465}{\text{Rf}}=4\left(\frac{8.465\times223.697}{16689.25\times1.87}\right)^3-3\left(\frac{8.465\times223.697}{16689.25\times1.87}\right)+1$$

$$\frac{8.465}{\text{Rf}}=0.819$$

$$Rf=10.317$$

- Perpendicular

$$\frac{\text{Ri}}{\text{Rf}}=4\left(\frac{\text{Ri.Y}}{\text{E.t}}\right)^3-3\left(\frac{\text{Ri.Y}}{\text{E.t}}\right)+1 \quad (8)$$

$$\frac{8.465}{\text{Rf}}=4\left(\frac{8.465\times270.35}{19592.19\times1.87}\right)^3-3\left(\frac{8.465\times270.35}{19592.19\times1.87}\right)+1$$

$$\frac{8.465}{\text{Rf}}=0.813$$

$$Rf=10.412$$

- 45°

$$\frac{\text{Ri}}{\text{Rf}}=4\left(\frac{\text{Ri.Y}}{\text{E.t}}\right)^3-3\left(\frac{\text{Ri.Y}}{\text{E.t}}\right)+1 \quad (9)$$

$$\frac{8.465}{\text{Rf}}=4\left(\frac{8.465\times259.226}{18372.68\times1.87}\right)^3-3\left(\frac{8.465\times259.226}{18372.68\times1.87}\right)+1$$

$$\frac{8.465}{\text{Rf}}=0.809$$

$$Rf=10.458$$

The next step is to calculate the amount of springback using the formula for the k factor equation of springback. Where it is known that the initial bend angle (α_i) is 180° minus the bending angle (89.98°) so that the initial bend angle (αi) is 90.02° or 1,571 radians, so the calculation is as follows.

- Parallel

$$Ks=\frac{\alpha f}{\alpha i}=\frac{\left(\frac{2Ri}{t}\right)+1}{\left(\frac{2Rf}{t}\right)+1} \quad (10)$$

$$\alpha f=1.571\ x\ \frac{\left(\frac{2\times8.465}{1.87}\right)+1}{\left(\frac{2\times10.317}{1.87}\right)+1}$$

$$\alpha f=1.312\approx75.172°$$

- Perpendicular

$$Ks=\frac{\alpha f}{\alpha i}=\frac{\left(\frac{2Ri}{t}\right)+1}{\left(\frac{2Rf}{t}\right)+1} \quad (11)$$

$$\alpha f=1.571\ x\ \frac{\left(\frac{2\times8.465}{1.87}\right)+1}{\left(\frac{2\times10.412}{1.87}\right)+1}$$

$$\alpha f=1.301\approx74.542°$$

- 45°

$$Ks=\frac{\alpha f}{\alpha i}=\frac{\left(\frac{2Ri}{t}\right)+1}{\left(\frac{2Rf}{t}\right)+1} \quad (12)$$

$$\alpha f=1.571\ x\ \frac{\left(\frac{2\times8.465}{1.87}\right)+1}{\left(\frac{2\times10.458}{1.87}\right)+1}$$

$$\alpha f=1.296\approx74.255°$$

So that the magnitude of the prediction springback is the difference between α_i and α_f.

- *Springback* Parallel = $\alpha i-\alpha f$=90.02°− 75.172° = 14.848°
- Perpendicular=$\alpha i-\alpha f$=90.02°−74.542°= 15.478°
- *Springback* 45° = $\alpha i-\alpha f$ = 90.02° − 74.255° =15.765°

The initial and final radius and the magnitudes of the bend angle known as initial(α_i) and bend angle final (α_f) can be used to calculate the k size of the springback factor. The following is the calculation of the k factor of springback.

- Parallel

$$Ks=\frac{\alpha f}{\alpha i}=\frac{\left(\frac{2Ri}{t}\right)+1}{\left(\frac{2Rf}{t}\right)+1} \quad (13)$$

$$Ks=\frac{\alpha f}{\alpha i}=\frac{1.312}{1.571}=0.835$$

- Perpendicular

$$Ks=\frac{\alpha f}{\alpha i}=\frac{\left(\frac{2Ri}{t}\right)+1}{\left(\frac{2Rf}{t}\right)+1} \quad (14)$$

$$Ks=\frac{\alpha f}{\alpha i}=\frac{1.301}{1.571}=0.828$$

- 45°

$$Ks=\frac{\alpha f}{\alpha i}=\frac{\left(\frac{2Ri}{t}\right)+1}{\left(\frac{2Rf}{t}\right)+1} \quad (15)$$

$$Ks=\frac{\alpha f}{\alpha i}=\frac{1.296}{1.571}=0.825$$

3.2 Prediction of Springback with Tables

Figure 5 and table 2 below is a table to predict the amount of springback with the influence of plate material, radius punch and thickness of the plate.

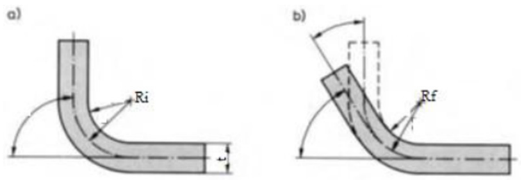


Figure 5: Springback on bending (a) Before springback, (b) After Springback.

Table 2: Table Springback (β).

t(mm)	Ri(mm)	β (°)
0.5 s.d. 0.7	1t s.d. 5t	5
0.8 s.d. 1.9	1t s.d. 5t	3
2 s.d. 4	1t s.d. 5t	1

So, to predict the amount of springback with this analysis design, we can refer to the previous table 2. Here is a prediction using table springback. It is known:

AISI 1005 material parallel = 299,347 N / mm^2 (σ)

Perpendicular AISI 1005 material = 324.11 N / mm^2 (σ)

AISI 1005 material 45 ° = 317,306 N / mm^2 (σ)

Material thickness (t) = 1.87 mm.

Bending radius (radius punch) = R8.465 mm.

So that:

- Predict the size using the table, springback which is 3°. Furthermore, to determine the magnitude of the influence of the prediction springback using table springback this, the next step is to calculate the k factor of springback. The following is a calculation of the k factor for springback using the table springback.

$$Springback = 3° \approx 0.052\ radian \qquad (16)$$

- So that the magnitude of the bend angle final (αf) is the difference between the bendsangel initial (αi) and magnitude springback, with magnitude αi = 90.02 ° or 1,571 radians. Here is a calculation to find the size of αf and k factor springback.

$$springback = \alpha i - \alpha f \qquad (17)$$

$$\alpha f = \alpha i - springback = 1.571 - 0.052 = 1.519\ radian$$

$$Ks = \frac{\alpha f}{\alpha i} = \frac{1.519}{1.571} = 0.967$$

3.3 Analysis of Measurement Results

Table 3: The results of measurements.

No	Cutting direction	Average
1	Parallel	1.148
2	Perpendicular	-1.431
3	45°	-1.716
		-0.666

Next, the calculation of the k factor of springback from the total average springback using v-bending with the bend angle initial(αi) = 90.02 ° or 1,571 radians. Here is the calculation of the k factor for springback.

$$Total \text{ average } springback = -0.666° \approx -0.0116\ rad$$

$$springback = \alpha_i - \alpha_f \qquad (18)$$

$$\alpha_f = \alpha i - springback = 1.571 - (-0.0116) = 1.583\ radian$$

$$Ks = \frac{\alpha f}{\alpha i} = \frac{1.583}{1.571} = 1.007$$

So that the results of the trials carried out are different from the results using the formula springback and the table springback as shown in table 4.1 above and can also be seen in the k factor of springback. So that the magnitude of the value of springback with the difference in the cutting angle of the plate is quite influencing on the amount of springback,

3.4 Calculation of Metal Microstructure

After obtaining AISI 1005 metallographic data, then quantitative metallographic analysis was carried out to determine the average grain size of the 500x magnification microstructure using the Planimetry (Jeffries) method according to the ASTM E112 standard. As for below, the results of the calculation of the grain size using the Planimetry method (Jeffries).

Table 4: Microstructure before the test bending and after the test bending.

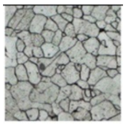
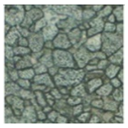
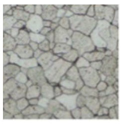
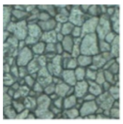
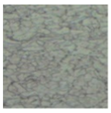
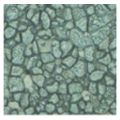
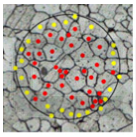
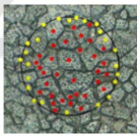
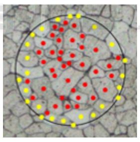
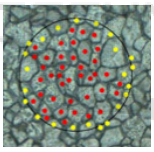
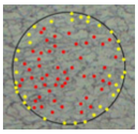
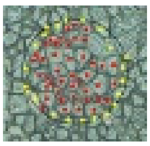
Before the test	Visual	After the test	Visual
Parallel		Parallel	
Perpendicular		Perpendicular	
45^0		45^0	

Table 5: The results of the calculation of the grain size before the test grain bending and after the test bending.

Before the test	Visual	After the test	Visual
Parallel		Parallel	
Perpendicular		Perpendicular	
45^0		45^0	
Information: ● = Whole grain ● = Clipped grain			

(EXAMPLE)

Before bending the

parallel cutting It is known: Whole(n_1) = 36

clipped grains (n_2) = 24

Magnification (M) = 500x

Asked: ……… d?

$$f = \frac{M^2}{5000} = \frac{500^2}{5000} = 50$$

$$N_A = f\left[n_1 + \left(\frac{n_2}{2}\right)\right] = 50\left[36 + \left(\frac{24}{2}\right)\right]$$

$= 50\ (48) = 2400/\text{mm}^2$

$G = [3{,}322 \log N_A] - 2{,}95$

$= [3{,}322 \log 2400] - 2{,}95$

$= 11{,}23 - 2{,}95 = 8{,}28$

Then from this G value is compared with the existing standard in ASTM 112-12 for know the average grain diameter size.

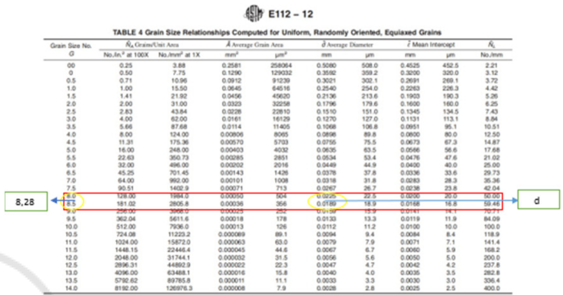


Figure 6: Grain Size Relationship Computed for Uniform, Randomly Oriented, Equalaxed Grains in ASTM 112-12.

$$\frac{8{,}28-8{,}0}{8{,}5-8{,}28} = \frac{0{,}0225-d}{d-0{,}0189}$$

$$\frac{0{,}28}{0{,}22} = \frac{0{,}0225-d}{d-0{,}0189}$$

$0{,}28d - 0.005292 = 0.00495 - 0{,}22d$

$0{,}5d = 0.010242$

$d = 0{,}0205$ mm

From the ASTM E112-12 table for the value of G = 8.28, the average grain diameter is obtained of 0.0205 mm.

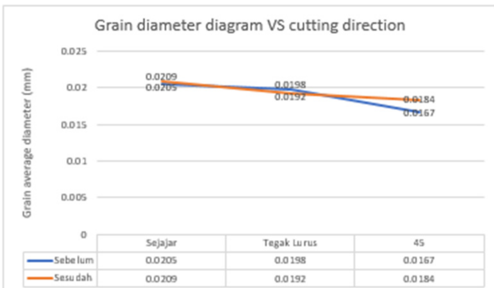


Figure 7: The effect of cutting direction on grain diameter.

From the results of the diagram above shows that different cutting directions greatly affect the grain size. In the AISI 1005 specimen before bending, it shows that the grain with the largest diameter is indicated by the grain with a parallel cutting direction of 0.0205 mm, and the smallest grain is 0.0167 mm with 45° cutting. Then the AISI 1005 specimen after bending shows that the grain with the largest diameter is shown by the grain with a parallel cutting direction of 0.0209 mm, and the smallest grain is 0.0184 mm with 45° cutting.

The effect of bending also affects grain size and grain roughness. When the specimen is bent it will make the average grain size larger. It can be seen that in the parallel cutting direction, the grain size before bending was 0.0205 mm, while the size after bending was 0.0209 mm, there was an increase even though the deviation was very slight by 4×10^{-4} mm. At the direction of cutting 45° is also the same, before dibending grain size of 0.0167 mm while the size after dibending of 0.0184 mm, an increase although the deviation is very small at 17×10^{-4} mm. However, in the perpendicular cutting direction, there was an increase in the average grain size, before bending by 0.0198 mm, while the size after bending was 0.0192 mm, there was a reduction even though the deviation was very little by 6×10^{-4} mm.

4 CONCLUSIONS

Based on the results of the analysis in the previous chapter, there are several conclusions including:

1. The cutting angle that produces springback with the smallest deviation is parallel to the plate rolling angle with a positive value of 1.148°, then the perpendicular angle with a negative value of 1.431° and the largest is 45° rolling with a negative value of 1.716°.

Table 6: Comparison of springback result.

No	Cutting direction	Average
1	Parallel	1.148
2	Perpendicular	-1.431
3	45°	-1.716
		-0.666

So that the bending process is better to use a plate with an angle in the direction of rolling between the three angles that are used as a reference for the study.

2. The microstructure result is in Table 4.4 shows that after doing bending all results in all directions cutting have relatively the same grain shape, the direction of cutting 45° deformed original grains become relatively flat irregularly rounded. In the results before bending, the grain boundaries are still tight, the items between the items are still not stretched. However, after bending, the grain experiences a strain. The grain surface also undergoes roughening.

3. The grain with the largest grain diameter is indicated by the grain with a parallel cutting direction of 0.0205 mm, and the smallest grain is 0.0167 mm with 45° cut. Then the AISI 1005 specimen after bending shows that the grain with the largest grain size is shown by the grain with a parallel cutting direction of 0.0209 mm, and the smallest grain is 0.0184 mm with 45°cutting.

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