Study of Springback Behavior on U-bending Part Using Die Shoulder Patterning Method (DSPM)

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Abstract. U-bending is increasingly used in the sheet metal industry for the manufacturing of car door pillars and beams. However, the springback phenomenon that occurs after removing the sheet metal from the fixtures leads to altered product accuracy, rejection, and increased manufacturing costs. Thus, minimizing springback in the bending of sheet metal is vital to maintain close geometric tolerances in the deformed parts of the metal. Many studies have been performed on the prediction of springback occurrence based on various experiments and simulations. Nevertheless, no study has been performed to reduce springback occurrence, especially during the hat-shaped fabrication process. In this study, the hat-shaped part is deformed using the die shoulder patterning method (DSPM) and validated using three-way ANOVA. It was shown that all the DSPM models improved the accuracy of the deformed parts by exhibiting greater contact area during the bending process, thus reducing the springback of the deformed parts. The DSPM with a radius of 5 mm and rib size of 0.4 mm successfully minimized springback as the contact area and sliding stress between the die shoulder and surface of the blank were optimized for AISI 1030.

INTRODUCTION

U-bending of sheet metal has been increasingly used in the manufacture of beams and car fenders [1-2]. Most manufacturers agree that this forming process is the easiest and most useful method in forming the hat-shaped parts of the metal. It also facilitates mass production as it has the potential to manufacture the same item at a remarkably high pace at low costs and with outstanding quality. The U-bending process involves three main steps, namely bending, forming, and unloading as shown in Figure 1.

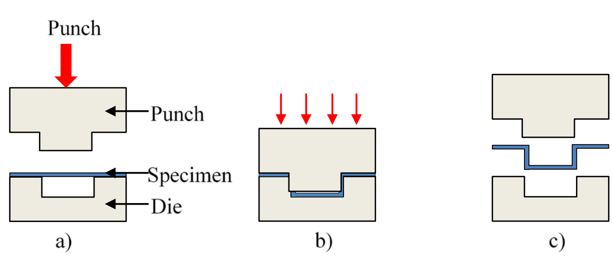


FIGURE 1 Schematic diagram of U-bending

Generally, the deformation of the metal using the U-bending mechanism involves the force of a punch to the blank with constant speed and pressure in the downward direction according to the dimension of the die. However, the springback phenomenon has become a growing concern for manufacturers as they rely on various sheet metals such as low-carbon steel and advanced high—strength steel (AHSS). Sheet metal is low carbon steel that is likely to return to its original form after its removal from the fixture grips. The springback phenomenon is described as the elastically driven changes in the shape of a part upon unloading after the forming process. Hence, the occurrence of springback tends to appear after bending the parts, thus affecting product accuracy, increasing rejection as well as manufacturing costs.

Springback reduction is necessary during the die design to obtain definite final shapes. Numerous techniques have been performed by manufacturers and researchers to minimize springback correction during the forming process. For example, numerical predictions based on fundamental theories or assumptions of engineering beams in U-bending were developed in previous studies on springback behavior [3]. The authors modified the tool curves for bending the sheet metal under minimal tension. However, these assumptions can only be implemented for a small springback in pure bending cases [6].

In this study, a new method of springback correction was performed using a set of inserts that was patterned on the corner shoulder to produce the best final hat-shaped parts in the U-bending process. Specifically, the U-bending process was performed utilizing the hydraulic pressing machine as it is commonly used in the manufacture of hat-shaped parts. The machine includes a press holding time in seconds for a pre-set period which acts as one of the bending condition parameters [8–10]. The forming process of U-bending requires several critical parameters for sheet metal to bend into the desired shape with the assistance of a pair of tools known as the punch and die that is attached to the body of the hydraulic press machine.

DIE SHOULDER PATTERNING METHOD

Die shoulder patterning method (DSPM) is a new approach to improve the structural integrity of U-bending components like hat-shaped. Over the years, surface patterning has been widely recognized for its crucial role in the structural integrity of engineering components [11]. Eight blocks of AISI H13 insert will undergo this process with three different type of patterning, size, pattern distance and position as mentioned in Table 1. The surface patterning was selected based on others journal and simulations. Next, the surface patterning was performed using EDM die sinking (MITSUBISHI, EA12D). The patterning procedure was followed and resulted in an accurate pattern as shown in Figure 2.

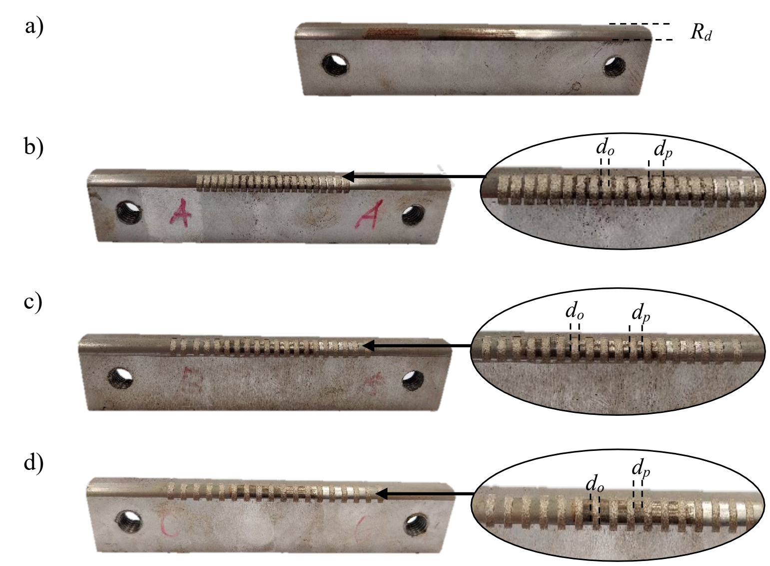


FIGURE 2 The (a) non-pattern, (b) pattern 1, (c) pattern 2, (d) pattern 3

TABLE 1. Selected DSPM with variable parameters.

Pattern	Type	Radius corner, R_d (mm)	Rib size, d_o (mm)	Pitch distance, d_p (mm)	Factors	
					Press holding time, t (s)	Blank width, w (mm)
No pattern, P_0	Non-vertical	5	0	0	1, 3, 5	20, 25, 30
Pattern 1, P_1	Vertical		2	0.2		
Pattern 2, P_2	Vertical		2	0.4		
Pattern 3, P_3	Vertical		2	1		

Design of Experiment Setup

In this study, the u-bending process are conducted using the hydraulic press machine that are available as shown in Figure 3. Generally, the press forming process performed where the designed punch compressed the sheet blanks in downward direction as the bottom die fixed. Two parameters used are press holding time, t in seconds and blank width, w in millimeters have been chosen as variables parameters that influencing warpage in the u-bending process. The selected variable parameters range were defined according to the variability of the press hydraulic machine used. Then, full factorial design was selected as a DOE in order to predict the interactions of the variable parameter and the type of DSPM of the deformed part. The punch force (*Pf*) and punch speed (*Ps*) were kept constant throughout the test as these conditions cannot be controlled by the machine. Besides, the three different blank widths of 20 mm, 25 mm, and 30 mm acted as variable parameters. The thickness and length of the blank were also kept as constant parameters. A hat-shaped part was formed using the experimental setup displayed in Figure 3. The punch had a width of 50 mm and a punch profile radius of 2 mm. The die clearance required for punching mild steel was calculated using the following formula:

$$\text{Clearance, } C = 20\% \times t \qquad (1)$$

For 1 mm,

$$1 \text{ mm} \times 0.2 = 0.2 \text{ mm}$$

From the above calculation, the clearance between the punch and the die was 0.2 mm per side. The hat-shaped part was drawn over the radius at a constant velocity of 40 mm/s and the final punch displacement was limited to 31 mm. The blank holder was not used in this process. There was no use of lubrication or other mediums throughout the experiments. After the bending and removal of the final parts, measurements were taken for the springback reduction analysis. In the end of the experiment, this will help to find the optimum setting parameters of the cold embossing process. Finally, the final components of each experiment that obtained from this process are measured and analysed.

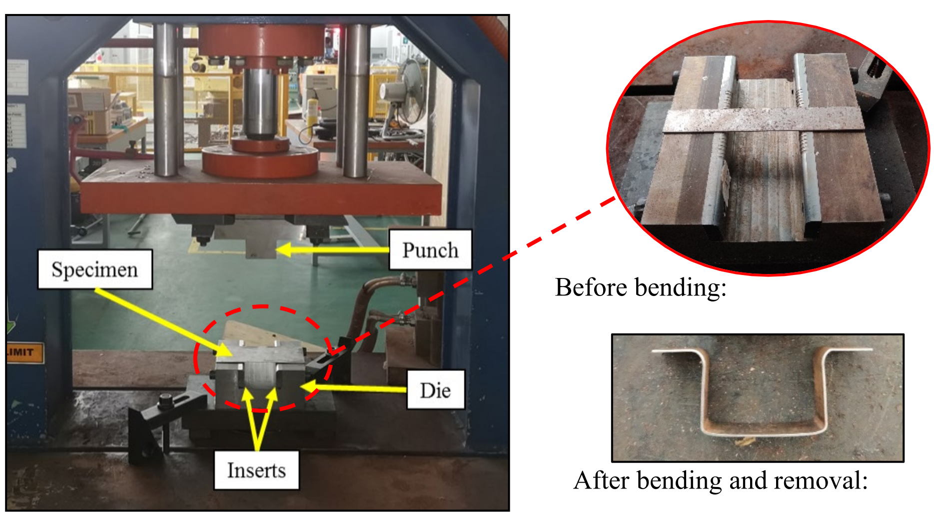


FIGURE 3 The experimental setup of U-bending process

RESULTS AND DISCUSSIONS

Results

The results tabulate the warpage value for each run at the flange-wall region of $\theta_{I,\,L}$ with the specified variable parameters condition which obtained from the three-way of Analysis of Variance (ANOVA). The specified variable parameters condition was set and tabulated in the Excel 2016 software.

Parameters Results

Warpage value obtained from ANOVA analysis was shown in Table 3. The results tabulate the warpage value for each run at the flange-wall region of $\theta_{I,\,L}$ with the specified variable parameters condition which obtained from the three-way ANOVA. The specified variable parameters condition was chosen and analysed in the Excel 2016 software.

In this study, the three-way ANOVA analysis was used, three hypotheses consisting of hypotheses 1 (H1), hypotheses 2 (H2), and hypotheses 3 (H3) were proposed and applied to all three-region cases.

H1: The mean values of the measurement variable are equal for different values of the non-DSPM. (2)
H2: The mean values of the measurement variable are equal for different values of the DSPM. (3)
H3: The mean values of the measurement variable are equal for different values of the blank width, b. (4)
H4: There is no interaction between DSPM and press holding time in springback effect (5)

For H1, H2 and H3, the F-value to FCrit-value (F critical) was compared and these hypotheses were rejected when F > FCrit, thus indicating that the mean values of the springback angle were not equal for different values of the DSPM and vice versa. On the other hand, the H4 hypothesis was rejected when F > FCrit, thus indicating an interaction between DSPM and press holding time in the springback effect. The P-value of ANOVA produced an alpha value of 0.9 that was used for comparison. When the P-value obtained is smaller than 0.9, the hypothesis is rejected. The results of both cases were analysed and discussed in the following section.

For Case 1, the comparison of F-value to F-critical value as well as P-value to alpha value 1 for the flange-wall region of $\theta_{I,\,L}$ are shown in Table 2. The F-value of non-DSPM was higher than FCrit. These findings indicate that the non-DSPM was an impractical model to investigate the springback effect as no effect was observed between the die shoulder since there was no patterning. However, the P-value of non-DSPM was larger than 0.9 due to higher plastic occurrence after removing the parts from the jigs.

On the other hand, the F-value of DSPM was indicated by other prominent factors since it was smaller than the F-crit value. Therefore, the H1 for DSPM was not rejected. This observation was also supported as the P-value was higher than the alpha value of 0.9. Therefore, DSPM had a significant influence on the springback effect for the flange-wall region at $\theta_{I,\,L}$.

In contrast, the F-value was higher than F-critical value for the source of variation for blank width, b and thus, H2 was rejected. This indicates that the factors for blank widths, b, does not significantly affect springback. Lastly, the values shown in Table 2 indicate that there was an interaction between DSPM and press holding time in the springback effect.

TABLE 2. Results of the three-way ANOVA for the flange-wall region of $\theta_{I,\,L.}$

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F-crit*
Non-DSPM	9597.817	4	2399.454	140.3848	9.23E-07	4.120312
DSPM	0.876949	2	0.438474	0.065847	0.936443	3.402826
b	29447.42	3	9815.807	1474.063	2.46E-27	3.008787
Interaction	1.497391	6	0.249565	0.037478	0.99973	2.508189
Within	159.8164	24	6.659016			
Total	39207.427	39				

TABLE 3. Result Summary of ANOVA

Null Hypotheses	Comparison of F-value to F_{Crit}-value	Comparison of P-value to 0.05	Status
Case 1: Flange-wall region			
H1: non-DSPM	$F > F_{Crit}$	Larger	Reject
H2: DSPM	$F < F_{Crit}$	Smaller	Do not reject
H3: *b*	$F > F_{Crit}$	Larger	Reject
H4: Interaction	F < FCrit	Smaller	Do not reject

The ANOVA results are shown in Table 3. In conclusion, the hypotheses that were accepted for all three cases were H1 and H3. Therefore, DSPM has a substantial influence on the springback effect and there is no interaction between DSPM and press holding time in the springback effect. In contrast, the H2 hypothesis was rejected in all three cases, in which the factors of blank width, b, did not affect springback limitations for DSPM.

Figure 4 depicts the relationship between four different DSPM models with different press holding time intervals at the top flange-wall of the hat-shaped parts and their respective schematic diagrams. Figure 4 (a) showed that the obtained angles of $\theta_{I,\,L}$ for P2 and P3 were close to the optimum line throughout the three selected press holding time intervals. On the other hand, the P0 or non-DSPM for the 20 mm blank width was further apart from the optimum line during the press holding time of 1 second and 3 seconds. One of the contributing factors for this observation was that there was no die patterning involved. Thus, the P0 was rejected as it did not have enough contact area, especially for the flange-wall regions during the 1-second and 3-seconds press holding time intervals to produce the optimal angles. However, the P0 during the 5-second press holding time was back to normal as the press holding time was longer despite being exposed to the sidewall warping. Sidewall warping is known as one of the major failures in sheet metal forming [12]. The surface contact area of the hat-shaped parts is shown in Formulas 6 and 7.

The surface contact area of the hat-shaped part = The surface area of DSPM - Surface area of the hat-shaped part

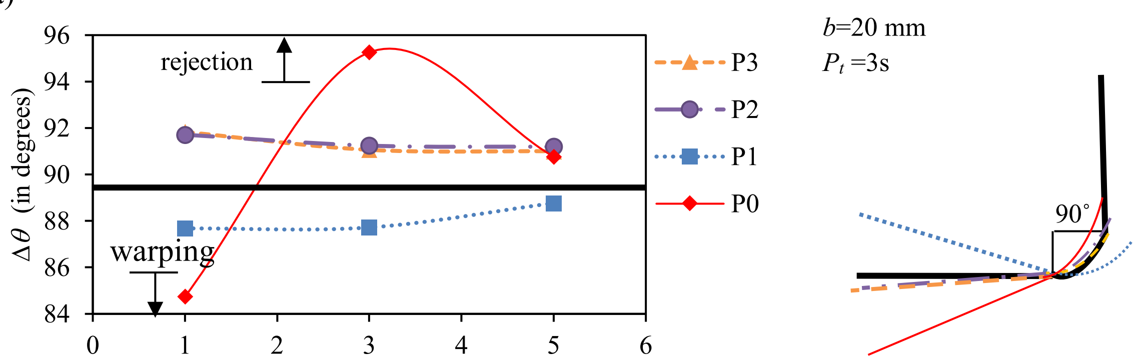
Sum of the surface contact area of the hat-shaped part = Sum of the surface area of DSPM - Sum of the surface area of the hat-shaped part

$$A = (2\pi rh + \pi r^2) - (2\pi rh + \pi r^2) \times \text{Rib slots} \quad (6)$$

$$\Sigma A = \Sigma\,[(2\pi rh + \pi r^2)] - \Sigma\,[(2\pi rh + \pi r^2) \times \text{Rib slots}] \quad (7)$$

The formulas above were generated based on the surface area of the curved surface formula, $2\pi rh + \pi r^2$. Both formulas were multiplied by the number of the rib slots that touched the surface of the blank.

(a)



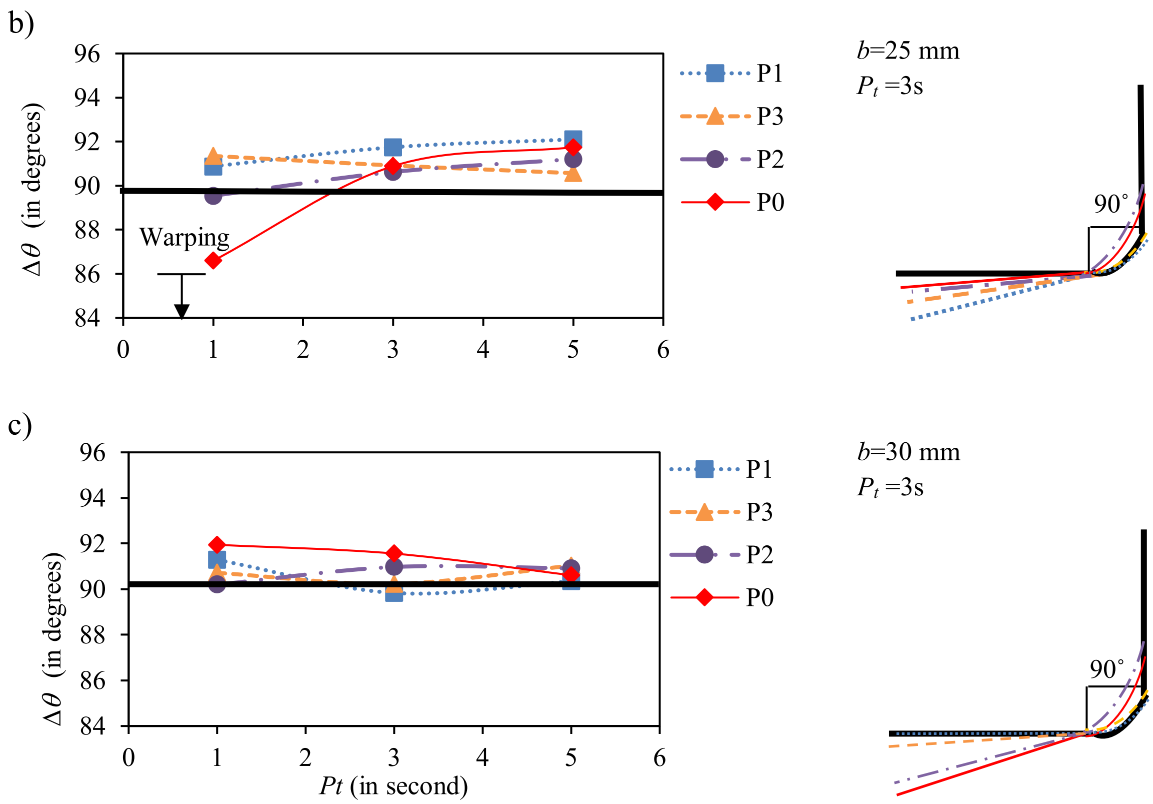


Figure 4 The graph of DSPM versus press holding time (P_t) at the left flange-wall region ($\theta_{I,\,L}$).

The flange-wall springback angle for P2 using a 25 mm blank width with 0.2 vertical pitch distance patterned at 3 seconds of P_t had the highest close rate to the optimal line compared to P1 and P3 [Figure 4 (b)]. However, the P0 or non-DSPM was closer to the optimal line than P1 but experienced warping at a P_t of 1 second. On the other hand, P1 using a 30 mm blank width was more optimal than P0 and P2 as shown in Figure 4 (c). Hence, the nearest angles of DSPM to the optimal line at the flange-wall region on the top-left angle were P1, P2, and P3 but the farthest was P0 or non-DSPM. These results indicate that DSPM reduces the springback effect for press forming of hat-shaped parts.

CONCLUSIONS

Four novel DSPM models for U-bending of hat-shaped parts were proposed and assessed in this study to identify the characteristics of typical process variables on springback such as pattern type, blank width, and press holding time. Three parameters – type of DSPM, sample width and press holding time were used in a laboratory experiment to investigate the effect on springback of U-bending process.

Based on the result obtained, each of DSPM provides different friction stress condition between the die and the blank in U-bending or press-forming process, which gives different impact on springback amount. The springback was recorded higher with a small parameter of sample width, while lower at parameters of press holding time.

It is concluded that when the surface of the die is smooth (without surface treatment), the springback amount is larger, as compared to the surface of die of DSPM (with surface treatment). From these findings, it is shown that a DSPM can be considered as a promising technique in overcoming a springback.

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