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Bending Force and Spring-Back in V-Die-Bending of Perforated Sheet-Metal Components

Sheet metal bending is one of the most widely applied sheet metal operations. The bending operations present several technical problems in production, such as prediction of spring-back and the punch load. In this paper, the value of the spring-back and bending forces are investigated for a low carbon steel material. Two thicknesses of material (0.95 and 0.75 mm) are applied. Sheet metal components, which are used in the experiments, have oblong holes on their bending surfaces. The influence of the area of the holes, die angles, die widths and punch radius on the value of the spring-back and the bending forces in V-die bending is studied. It is found that all these parameters affect the spring-back and the bending forces, but not in the same way. A new equation is suggested in this paper to predict the bending forces in V-shaped dies for parts with holes on the bending surfaces.

Keywords: *V bending dies, holes on bending, bending force, spring-back*

Introduction

One of the most common processes in sheet metal forming is bending. Although the process is simple, it can cause several technical problems in production such as prediction of spring-back, punch load and fracture in stretched surfaces (Farsi and Arezoo, 2007).

Bending consists of uniformly straining flat sheet metals around a linear axis (bending line). The bending operations can be done in several ways. The V-shaped dies are frequently used because they are simpler and cheaper to manufacture.

In industry, the value of the spring-back and the bending forces are usually obtained from empirical equations or from handbook tables. They are not constant and can vary with bending conditions. Several equations have been suggested by researchers in this regard. These equations, and even the handbook tables, are only suitable for those components with no holes on their bending surfaces; they cannot be used for parts with any kind of hole on their bending surfaces. As will be discussed later, no such equations or tables are available for these kinds of components and a detailed study in this field seems relevant.

Nomenclature

R = *initial bend radius, mm*
R' = *final bend radius, mm*
t = *thickness, mm*
E' = *elastic modulus corrected for the case of plane strain, MPa*
M = *bending moment, N-M*
R_p = *punch radius, mm*
R_m = *die radius, mm*
l_k = *die opening, mm*
F = *bending force, N*
K = *die opening factor*
S = *ultimate tensile strength, MPa*
W = *sheet metal width, mm*
L = *die opening, mm*
Rh = *hole radius, mm*
W_e = *effective width of the part (the difference between the width of the part and the hole), mm*
$F_{perfect}$ = *bending force for the part without holes where k = 1.33 in Eq. (3), N*

Greek Symbols

α = *angle factor (0.7 to 1.0)*
θ = *bend angle, Degree*
σ_0 = *flow stress, MPa*

Related Works

Weinmann and Shippell (1978) presented the experimental results on the V-die bending of a hot-rolled, high-strength low-alloy steel sheet; both the maximum air bending force and the elastic unloading state in coining were assessed as functions of punch radius, die width, and sheet thickness.

Magnusson and Tan (1990) used the elementary bending theory with pure moment bending (without transverse stresses) to analyze V-die bending. They suggested an integral form equation to determine the spring-back angle.

Tekiner (2004) experimentally studied the spring-back of sheet metals with several thicknesses and properties in bending dies. Özgur Tekaslan et al. (2006, 2007) used modular V-shaped dies to experimentally determine the spring-back of stainless steel sheet metals. They concluded that holding the punch longer on the material reduces the spring-back, whereas an increase in the thickness of the material and bending angle increases the spring-back values (Özgur Tekaslan et al., 2007).

Other researchers studied the influence of different parameters such as: blank profile (You-Min Huang, 2005) and Bauschinger effect (Chun, Jinn and Lee, 2002) on the final angle of bent components.

A study of the literature showed that although the field of sheet-metal bending has been extensively researched, V-bending has received little attention. Additionally, the bending components used in the literature did not have holes or any kind of cuttings on the bending surfaces. Many components found in industry have some kind of cuttings (circle, oblong…) on the bending surfaces. The amount of the spring-back and bending forces in these components (with cuttings) is different from those without. So the amount of the spring-back and the bending forces which are found in the handbooks, etc. are not valid for the parts with holes and they should be treated separately. In the present work, the spring-back and bending forces for low carbon steel

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sheet metal components with oblong cutting holes on their bending surfaces for V-shaped dies are studied. The influence of die angle, die width, punch radius, material thickness and the amount of cutting is examined experimentally on the final bending angle and bending forces. Using the experimental data, an equation is suggested for the calculation of the bending forces.

In Figure 1 an industrial component is shown:

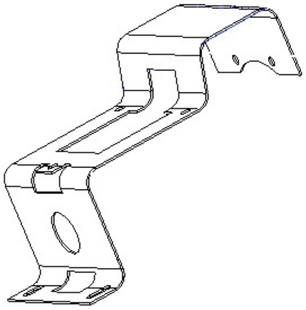


Figure 1. Industrial component.

Spring-back and Bending Force

Variations in bending stresses cause spring-back after bending. The stress changes from tensile stress on the outside surface to compressive stress on the inside surface of the material at the bend. The largest tensile stress occurs on the outside surface of the material at the bend. The tensile stress decreases towards the center of the sheet thickness and becomes zero at the neutral axis. The neutral axis has been stressed to values below the elastic limit. This metal creates a narrow elastic band on both sides of the neutral axis. The metal farther away from the axis has been stressed beyond the yield strength and has been plastically or permanently deformed. When the die opens, the elastic band tries to return to the original flat condition but cannot, due to restriction placed on it by the plastic deformation zones. Some slight return does occur as the elastic and plastic zones reach equilibrium, and this return is known as spring-back (Semiatin, 2006).

Researchers have tried for many years to determine the amount of spring-back in bending operations. Equation (1) (Vukota, 2004) is one of the mathematical formulas used to determine the spring-back ratio and final shape of the components.

$$S.B.\ Ratio = R/R' \approx 1 + 4\left(\frac{R\sigma_0}{E't}\right)^3 - 3\left(\frac{R\sigma_0}{E't}\right) \tag{1}$$

Some researchers have suggested neural networks or other AI approaches to determine the amount of spring-back (Garcia-Romeu and Ciurana, 2006; Inamdar et al., 2000). However, these systems are limited and cannot be applied in all conditions.

Another important factor to be considered in die design and press selection is the bending force. The bending force can be determined by Eq. (2) (Vukota, 2004).

$$F = \frac{4M.\cos^2\dfrac{\theta}{2}}{l_k - 2(R_m + R_p + t)\sin\theta/2} \tag{2}$$

This equation shows that the force depends on the bending moment. Many parameters such as material properties and die profile affect the bending moment. An analytical approach cannot correctly describe the amount of moment in the bending process (Carden et al., 2002; Vukota, 2004; Marciniak, Duncan and Hu, 2002). Thus, die designers use simple equations such as Eq. (3) (Suchy, 2006) to determine the bending force.

$$F = KSwt^2/L \tag{3}$$

In this equation, the die opening factor, K, is not constant and varies according to the bending conditions. Also, errors in the calculation are increased when the component has any kind of hole or cutting on the bending surfaces because the stress pattern is not normal. The stress concentration on the edges of the holes will result in more complexity and hence will make determination of the bending force and the spring-back more difficult with analytical approaches. Therefore, experimental studies need to be carried out.

Material and Procedure in Experiments

The material used for the experiments is of a low carbon type, which is frequently used in industry. Figure 2 shows the result of a tensile test for this material and Table 1 shows the material data. Tensile tests were carried out according to ASTM standards.

A universal test machine (Zwick machine) was used in the experiments. This machine can record the force and the displacement (accuracy = 0.01 mm) making it suitable for the experiments. The schematic of the sample used in the tests is shown in Fig. 3.

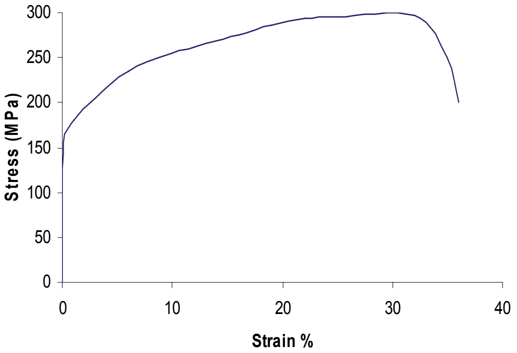


Figure 2. Result of tensile test (ASTM E08).

Table 1. Material Data

E (MPa)	Yield stress (MPa)	U.T.S (MPa)	ν	Final strain
193.000	155	298	0.3	0.36

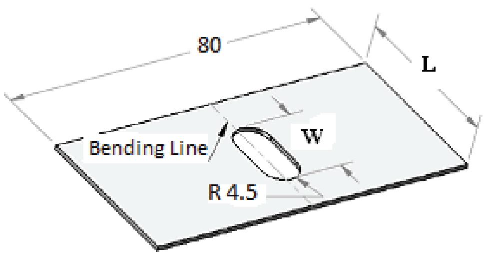


Figure 3. Schematic of the sample.

In this investigation, V-shaped dies with three different angles (90, 120 and 135 degrees) and sheet metals with two different thicknesses (0.95 and 0.75 mm) were used. First, the effects of different sizes of punched holes in the bending area on the spring-back and the bending forces were studied. Second, using a 90 degree V-shaped die, the effect of four different die widths on the spring-back and the bending forces was studied. The punch radius effect was also studied in this work. The punched holes were of an oblong shape placed in the centre of the bending area. For the sake of accuracy, the holes and the blanking of the parts were produced by a CNC punch machine.

Figure 4 shows a sketch of the bending test and Table 2 gives more information regarding the test conditions.

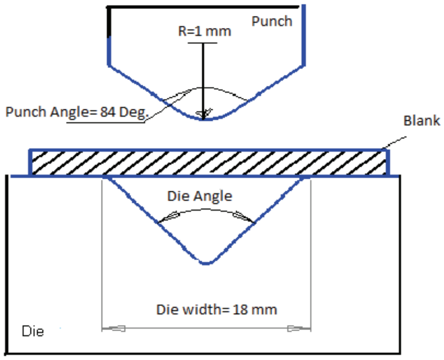


Figure 4. A sketch of the bending test.

Table 2. Die, Punch and Material parameters.

Material	Die	Punch
Type = low carbon steel	Width = 18 mm	Angle = 84 degrees
t = 0.95, 0.75 mm	Angle = 90-120-135 degrees	R = 1mm

The bending tests comprised of the following steps:

1- Aligning the die and punch in the test machine;
2- Replacing the part on the die bringing the punch down far enough to just touch the part;
3- Punch moves down with a constant speed and bends the component;
4- Punch moves up;
5- The part is replaced and its angle measured by a profile projector (Fig. 5).

Figure 5. Profile projector machine.

In the test procedure, the bending angles were controlled by punch displacement. The angles of the parts after loading and unloading were measured by a profile projector (accuracy =1 min).

Results and Discussion

Altogether 41 tests were carried out to study the influence of sheet metal thickness, die angle, die width, punch radius and the hole's cutting percentage on the bending forces and spring-back. It should be noted that the hole's cutting percentage here and throughout this paper refers to the ratio of width to length (W/L) in Fig. 3.

Final Angle Determination

Figure 6 shows the parts which are bent. Experiments showed that when the hole's cutting percentage increases, the final angle of the parts and, hence, the values of the spring-back, decrease. The results obtained for both thicknesses are the same (Fig. 7, Table 3, 4). These results also show that the punched holes on bending surfaces and their sizes affect the spring-back in a non-linear manner. This relation depends on the die angle and sheet metal thickness.

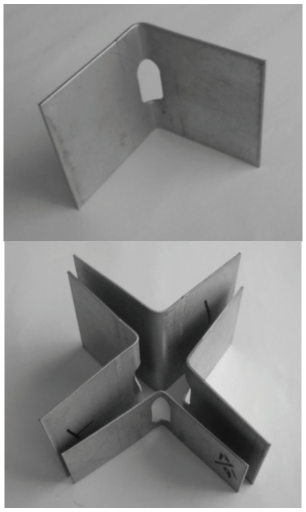
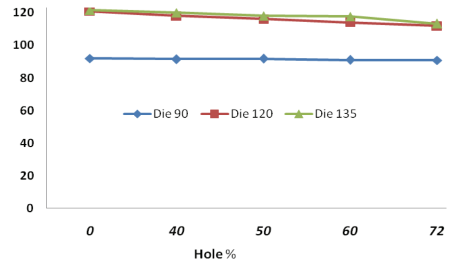


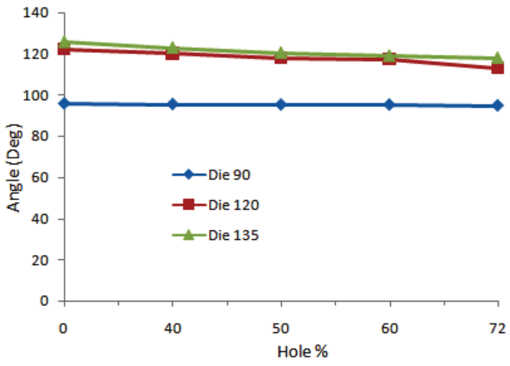
Figure 6. Parts after bending.

Results of the experiments show that under the same conditions, in dies of 120 and 135 degrees, the difference between the spring-back of the part with and without holes is more noticeable than the 90-degree die since the punch angle in these cases is very small and the difference between the die and punch angle is greater. Thus, it can be suggested that for a perforated component, the punch angle should be made close to the die angle to decrease the influence of the hole on the spring-back.

To study the influence of the punch radius on the spring-back in 90 and 120 -degree dies, eleven tests were performed. These tests were performed using parts without holes and with holes (60%) and of 0.95 mm thickness. Figure 8 shows the results of these tests. When the punch radius is increased, the final angle is increased. The effect is more pronounced in the 120-degree die. Thus, it can be said that when the ratio of the punch radius to the value of the thickness increases, the region under plastic deformation becomes smaller and the spring-back is decreased. This effect is similar in parts with and without holes in both dies.



a) sheet metal thickness = 0.95 mm;



b) sheet metal thickness = 0.75 mm.

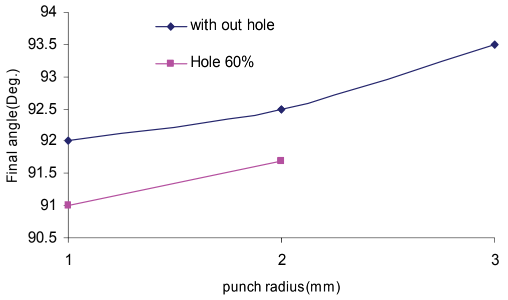
Figure 7. The influence of cutting on the spring-back.

Table 3. Final angle for part with t = 0.95.

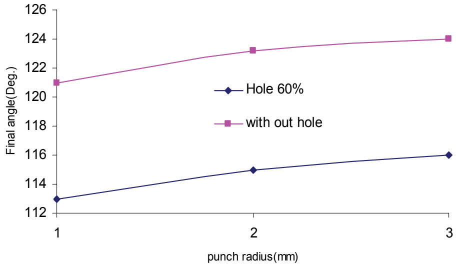
Hole %	Die 90	Die 120	Die 135
0	92	121	121.6
40	91.5	118	119.95
50	91.7	116.22	116.65
60	91	114	117.7
72	90.8	112	113.3

Table 4. Final angle for part with t = 0.75.

Hole %	Die 90	Die120	Die 135
0	95.7	122	125.8
40	95.4	120	123
50	95.2	118	120.5
60	95.15	117	119
72	94.75	113	118



a) 90- degree die;



b) 120- degree die.

Figure 8. Influence of the punch radius on the final angle.

The influence of the die width on the final angle in 90 and 120-degree dies is also studied in this work. Eight tests were performed using parts which were 0.95 mm thick and had holes (50%). Figure 9 shows the results of these tests. As can be seen, the influence of the die width is very important. When the die width is increased, the final angle is decreased in a linear manner. In the 90-degree die, the influence of die width is lower than the 120-degree die.

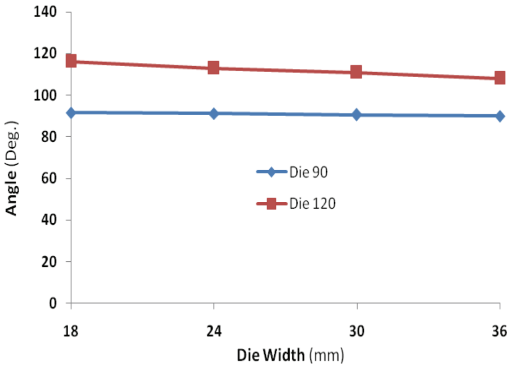


Figure 9. Influence of die width on the final angle.

The Determination of Bending Forces

In V-die coining bending processes, the bending force graph has four stages. The first stage is the elastic deformation where the force is increased suddenly. In the second stage, the force is mostly constant. In the third, the force decreases because of material slip in the die. In the fourth stage, the force increases very rapidly because the material is pressed between the die and the punch. Figure 10 shows the relationship between bending force and the punch traverse in the experiments (t = 0.75 mm).

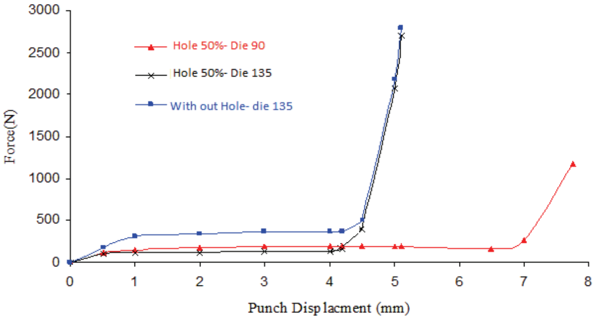
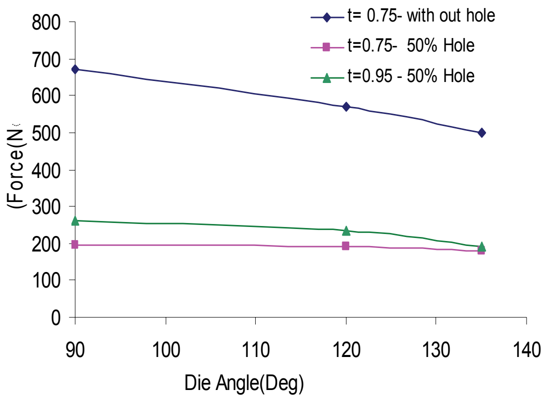


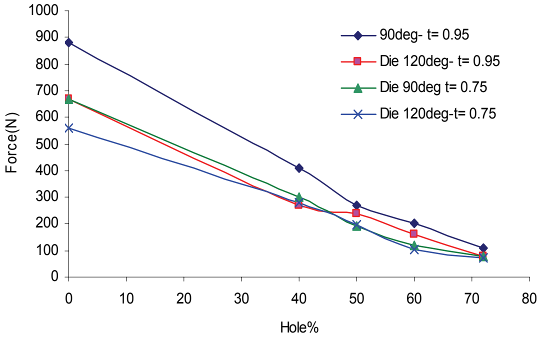
Figure 10. Relationship between the bending force and the punch traverse.

Figure 11 shows the influence of the die angle and the amount of the cutting area on the bending forces. In these charts an average of the bending forces in the second stage (air bending force) is used. Figure 11(a) shows that when the die angle increases, the forces decrease.

Figure 11(b) shows that with the decrease of material in the bending area, the force is also decreased. This relation is in a nonlinear manner.



a) Influence of the die angle (hole 50%);



b) Influence of the hole percentage.

Figure 11. Average of the bending forces in stage 2.

The punch radius is another parameter which is studied in this work (Fig. 12). Results show when punch radius in the 120-degree die is increased from 1 to 3 mm, the bending force increases from 880 to 910 N. The influence of this parameter on bending force is low and can be ignored.

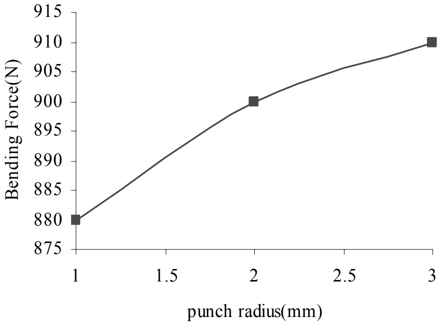


Figure 12. Punch radius effect on the bending force.

To study the influence of the die width on the bending forces, eight tests were performed. Four different die widths with 90 and 120- degree dies and parts with 50% holes and a thickness of 0.95 mm were used. Figure 13 shows the results of these tests. It can be seen that when the die width is increased, the bending forces are decreased. It is noted that for both dies these results are also in agreement with the theoretical formulas shown as Eq. (3).

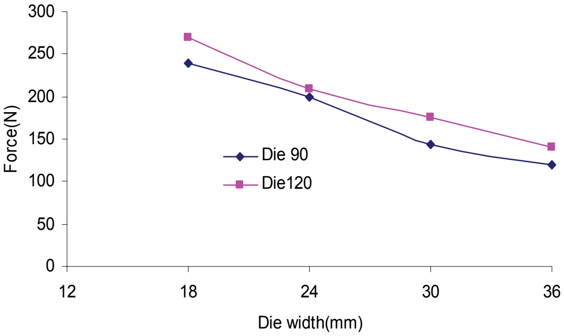


Figure 13. Influence of the die width on bending force (t = 0.95mm).

Prediction of the Bending Forces for Parts with Holes

Experimental observations show that given the same conditions, those parts with holes on their bending surfaces need smaller bending forces than the parts without holes. The relationship between the bending forces for the parts with and without holes is of a non-linear nature. As demonstrated in previous sections, amongst all the parameters which affect the bending forces, the size of the holes, die angle, the effective width and the thickness of the parts are the most important factors. Therefore, in order to determine the bending forces for parts with holes on the bending surfaces, Eq. (4) is suggested in the present work.

$$F = F_{perfect} \times \alpha \times \left(\frac{t}{Rh}\right)^{\frac{t}{we}} \qquad (4)$$

Angle factor (α) in Eq. (4) denotes the influence of the difference between die angle and punch angle. When this difference is increased, angle factor is decreased. Also this factor is increased in thicker parts. In other words, the angle factor is a function of the sheet metal thickness and the difference between die angle and punch angle. The experiments in the present work show the angle factor value varies between 0.7 and 1.0. The angle factor = 1 is used when difference between die and punch angles are closer to zero. The angle factor = 0.7 is used when the difference between die and punch angles is clear and sheet metal thickness is less than 1 mm.

The authors are studying this subject in more depth to try and present a mathematical formula for calculating the angle factor in the next study.

Table 5 (a, b, c) and Figs. 14 and 15 compare the calculated results using Eq. (4) with the experiments. To compare the difference between calculated forces and experiments, the mean errors are used. As can be seen in Table 5, the mean errors of the forces which are calculated using Eq. (4) are less than 10 N.

When the average force is calculated by this equation and compared with the average experimental force, in the worst case, 3.3% error can be seen. Using Eq. (4), a great improvement in the accuracy of the prediction of the bending forces for parts can be seen.

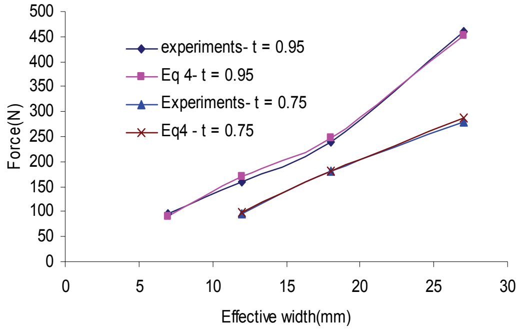


Figure 14. Bending forces, 120- degree die.

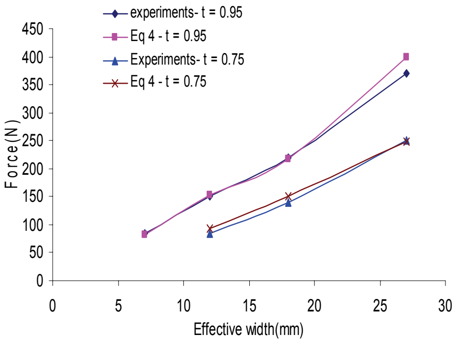


Figure 15. Bending forces, 135- degree die.

Table 5. Comparison of the experiments and prediction of the bending forces:

a) Bending forces in a 90- degree die;

t(mm)	Effective width(mm)	Experiments	α	Equation 4	Error
0.95	50	950	Without hole	-	
0.95	27	510	1	504	6
0.95	18	270	0.9	296	26
0.95	12	180	0.9	190	10
0.95	7	110	0.9	102	8
0.75	50	660	Without hole	-	
0.75	27	300	0.95	302	2
0.75	18	180	0.88	182	2
0.75	12	120	0.88	116.5	3.5
Main error (N)					8.21
Average error					1.34%

b) Bending forces in a 120- degree die;

t(mm)	Effective width(mm)	Experiments	α	Equation 4	Error
0.95	50	880	Without hole	-	
0.95	27	460	0.9	453	7
0.95	18	240	0.85	248	8
0.95	12	160	0.8	169	9
0.95	7	95	0.8	91	4
0.75	50	510	Without hole	-	
0.75	27	280	0.9	286	6
0.75	18	180	0.88	182	2
0.75	12	95	0.75	99	4
Main error (N)					5.71
Average error					1.19%

c) Bending forces in a 135- degree die.

t(mm)	Effective width(mm)	Experiments	α	Equation 4	Error
0.95	50	580	Without hole	-	
0.95	27	370	0.8	400	30
0.95	18	220	0.75	218	2
0.95	12	150	0.73	154	4
0.95	7	85	0.71	81	4
0.75	50	375	Without hole	-	

0.75	27	250	0.78	248	2
0.75	18	140	0.73	150	10
0.75	12	85	0.7	92	7
Main error (N)					8.42
Average error					3.3%

Conclusions

According to the results obtained from the experiments, the following conclusions can be drawn:

- The spring-back is a function of material thickness, die and punch angle, punch radius, die width and the size of the punched hole.
- The size of the hole on the bending surface has an effect on the bending angle. When the size of the hole is increased, the final angle of the part is decreased.
- The influence of the size of the hole on the bending force in the 135-degree die is greater than that in the 120-degree die, and the influence of the 120-degree die is greater than that in the 90-degree die.
- The difference between the die and punch angle is important in perforated components bending operations. When that is increased, the spring-back is increased too.
- Under the same conditions, the spring-back for the parts with less thickness is greater than the parts with more thickness.
- When the material in the bending area decreases, the bending force also decreases. This means that under the same conditions, the parts with holes always need less bending forces compared to the parts without holes.
- When the die width increases, the bending force decreases. As the die width increases, the bending force decreases in a non-linear manner.
- When the die width increases, the final angle of the part decreases.
- When the punch radius increases, the final angle of the part and the bending force increases. This increase for the final angle is large, but for the bending force it is small and can be ignored.
- How the difference between the punch and die angle influences the bending force is very important. When it is increased, the bending force is decreased. This effect is greater in thinner material and material with a larger hole percentage.
- Bending forces in sheet metal components with holes on bending surfaces can be determined by Eq. (4).

The results of this study show that the components which have any kind of holes on the bending surfaces behave in a way which is different from the ones without holes. Among all other factors, the spring-back is the most important, since the final shape of the component depends on it. This factor becomes even more important when the component has closer tolerances. Also the bending forces in the parts with and without holes are not similar. Using the experimental results of the current work, an empirical equation is arrived at. This equation predicts the bending forces with 1.35% average error compared to experimental results.

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