The Effect of Hole Size and Location on Spring-back Phenomenon in Sheet Metal Bending

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Abstract

Due to the sheet metal bending process, the sheet of metal is forced to take the shape of the die cavity by a rigid punch to fit it with that cavity dimensions, but when the punch is removed, the elastic deformation will be released and only the plastic deformation will be remained, this release of the elastic deformation caused the phenomenon which is called springback defect. The springback is one of the defects that happen in the forming of sheet metal and its effect appears clearly in the assembly processes because of the change in final product dimensions. More researches were done to reduce the effect of this phenomenon on the uniform and symmetry sheets, but in reality, the products which are made by bending the sheet metal may contain holes before its forming. Therefore, in this research, the effect of the hole size and its center locations on the springback behavior and its value was specified for carbon steel material with (200 x 50 x0.75) mm, which and was drilled with different holes diameters (5, 10, 15, 20, 25) mm, and then the location of each hole was changed about the perpendicular centerline of each sheet . Design of Experiment Software DOE was used to predict the value of springback for two V-shaped dies with forming depth of 12 and 19 mm by conducting 78 experimental tests and feeding its results as an input to DOE to select the perfect mix between hole size and its position which gives the minimum springback effect. Two mathematical quadratic models were built for the two die depths in terms of use input parameters. It was found that both hole size and its location had great impact on the springback. The optimum values of springback were obtained for the two die depths. Good agreement was found between the experimental and theoretical springback with a maximum error of 0.286 % for 12 mm die depth and 0.037 % for 19 mm die depth. Finally, it was concluded that the springback value was reduced by 6.47 % when using 19 mm die depth in comparison with 12 mm depth.

Keywords: Sheet Metal Forming, Die depth, Rigid punch, Spring-back phenomenon, Hole size, Hole location, V shape dies, Design of Experiment Software DOE .

Symbol	English Symbol Description
ANOVA	Analysis of Variance
DOE	Design of Experiment
L1, L2	Parameters Levels
RP	Reference Point for levels

1- Introduction

One of the most widely applied metal forming operation is bending. Materials with various cross– sections can be processed by this technology: sheet metal, bars, rods, pipes, wires. However, bending of sheet metal is most frequently used in industrial practice, first of all in car and ship building industry. There are different types of metal bending operations such as air bending, V – and U – die bending, roll bending, roll forming, and press brake forming. [8]

Springback is the geometric change made to a part at the end of the forming process when the part has been released from the forces of the forming tool, as shown in fig (1). Upon completion of sheet metal forming, deep-drawn and stretch-drawn parts spring back and thereby affect the dimensional accuracy of a finished part. Therefore the final form of a part is changed by springback, which makes it difficult to produce. As a result, the manufacturing industry is faced with some practical problems: Firstly, prediction of the final part geometry after springback and secondly, appropriate tools must be designed to compensate for these effects. [4]

In this paper Experimental works and analytical Design of Experiment Software DOE was used to predict the value of springback to established the effect of the hole size and hole location on this value.

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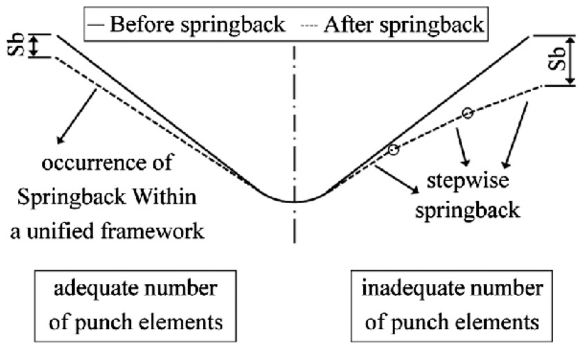

Fig (1): The bent sheet metal before and after springback occurring [9]

Bogdan ChirIta presented an experimental work to investigate the influence of the blankholder force upon spring-back parameters. Two methods were investigated: one that uses a constant blankholder force and the other that uses variable blankholder forces. The material tested is aluminum alloy, and the strips used are 220×30 mm and 1 mm thick. The results were revealed that the increase of blank holder force reduced the spring-back value [1].

Z. Damián-Noriega, R. Pérez-Moreno *et.al.*, presented a new equation to predict the springback in the bending and rolling processes of metallic sheet. This equation was experimentally applied in the design of a wood truncated cone to form an aluminum sheet truncated cone. Kalpakjian’s equation was also applied, but Damian’s equation gave the best performance [2].

M. A. Osman *et.al.*, developed a theoretical model conducted for the air-bending process and V-die bending experiments are conducted. Based on comparisons between springback ratios predicted using the developed theoretical air bending model and the V-die bending experiments, a semi-empirical formula for predicting springback ratio in V-die bending process was suggested. The validity of this formula was verified using finite element simulations as well as comparisons with the results of two other independent sets of experiments [3].

Mohammad A. Farsi and Behrooz Arezoo, studied experimentally the influence of the area of the holes, die angles, die widths and punch radius on the value of the springback for a low carbon steel material. Two thicknesses of material (0.95 and 0.75 mm) were applied. It was found that all these parameters affect the springback and the bending forces, but not in the same way. A new equation was suggested in this paper to predict the bending forces in V-shaped dies for parts with oblong holes on the bending surfaces [4].

Hani Aziz Ameen studied the effect of springback on the bending operation. Three types of alloys were used; aluminum alloy 7020 T6, copper alloy and lead alloy. These alloys have different sheet thicknesses (2 and 4) mm. It was concluded that the aluminum sheets have the biggest springback factor, the hardness of the sheet increased, and the springback back factor increased too. Also in the aluminum and copper sheets when the thickness increased, the springback factor increased, while in the lead alloy when the thickness increased the springback factor decreased [5].

Yongde Zhang *et.al.*, proposed a theoretical model to predict the springback in archwire bending. This model, which considering the neutral line does not coincide with the center. The experimental results indicated that the proposed theoretical model could accurately predict the springback angle. Furthermore, the formed angle showed a general increase with the bend angle [6].

Karem M.Younis and Aseel Hamad, investigated the optimum parameters that reduce the springback by using the commercially [SPSS] program to analyze data and find the best parameters that give the lowest springback in the U-die bending. For commercial aluminum alloy [AL-1050] with sheet thickness (0.9 mm) that found that when the punch speed increased, the springback increased, when the rolling direction angle is 90°, springback reduced, and the increase of the dwell time decreased the springback [7].

M.S. Buang *et.al.*, focused on the effect of the die and punch radii on the springback in the air V-die free bending process of stainless steel sheet metal. The experiment was performed using various die and punch radius values, and their springback behavior was observed. The design of experiment approach showed that the die and punch radius parameters are significant factors contributing to the springback effect in the V-die bending. The springback values can be decreased by decreasing the values of the die and punch radii in the air V- die bending process [10].

The difference between this research and the other researches in that the previous researches has been interested in studying the springback phenomenon due to the bending of the sheet metal , which does not contain holes, while in this research has been studied the effect of the hole diameter and its location on the springback value by bending of sheets Metal which is containers on precast holes with diameters and different locations.

2- Experimental Work

In this paper, the DOE program was selected as a tool to predict the effect of both the size of the hole and its location on the value of springback of the occurred due to bending process of the low carbon steel sheets. This program is statistical program that helps in predicting the effect of the parameters on the process and builds an empirical equation depend on the used levels of input parameters.

2-1 Parameter Selection

To use the DOE program, it must be fed it firstly by the selected levels (L1) and (L2) of holes diameters and their center locations. The levels are limited by (-1) and (+1), as shown in table (1). This level refers to the working area that the DOE program will work to cover all suggested values of the hole sizes and holes locations for two die depths of 12 and 19 mm. The Reference point (RP) was selected according to the previous practical experience.

Table 1: Used input design parameters levels in DOE

Parameters	Levels			
	Unit	**L1**	**RP**	**L2**
Hole diameter	mm	10	15	20
Hole location	mm	35	50	65

2-2 Specimens Preparation

After the values of parameters were selected, then they were used as inputs to the DOE program. The output achieved was a two set of randomly selected tests, one of them consist of (13) suggested test which they must be done experimentally by the V-bending die of 12 mm in depth, and the second set of (13) suggested tests too but for the depth of 19mm. Therefore, (78) specimen of low carbon steel was cut by (200, 50, and 0.75) mm to prepare them for testing during V-bending. The mid-span of each strip was defined by a perpendicular mid- line of B-B at its length as shown in fig (2), because of the drilled holes locations was on one side of strips only at a distance of (20, 35, 50, 65 and 80) mm from the mid-line B-B.

2-3 Bending Test

The bending test was carried out to low carbon steel sheets that consist of holes with different diameters by used of two depths of V-bending die in the strength of material laboratory of the Mechanical Engineering Department / University of Technology / Baghdad by using the tensile device type H50KT by installing the punch of angle with 90° instead of the upper grip of the device while the v-bending die was placed on the base of the tensile device, as shown in fig (3).

(78) bending test were done because each specimen was tested with the two parameters and was repeated for three times to get an accurate average value in all 13 tests suggested by DOE program for two depths of bending type 12 mm and 19 mm. The springback of each bending test was measured, and all the results are listed for each bending die depth (12 mm) and (19 mm) in Tables (2) and (3), respectively.

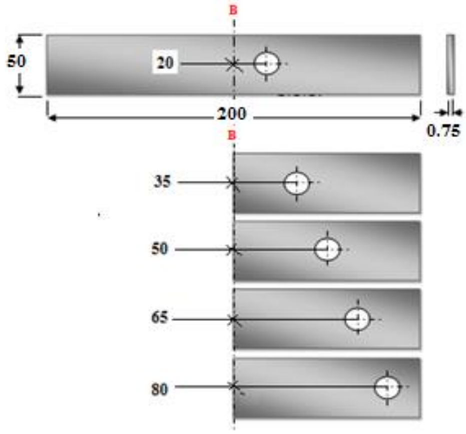

Fig (2): The holes arrangement on sheet metal before bending test.

Fig (3): The V-bending test

Table 2: Parameter design matrix for input and output factors for die depth = 12 mm

Std. No.	Run No.	Hole diameter (mm)	Hole location (mm)	Average of measured angle (degree)	Springback Value (degree)
1	7	10	35	108.20	18.2
2	6	20	35	107.20	17.2
3	2	10	65	107.00	17
4	8	20	65	106.00	16
5	3	5	50	107.42	17.42
6	1	25	50	105.50	15.5
7	9	15	20	106.50	16.5
8	11	15	80	104.65	14.65
9	4	15	50	108.00	18
10	10	15	50	109.00	19
11	5	15	50	109.25	19.25
12	12	15	50	108.22	18.22
13	13	15	50	109.07	19.07

Table 3: Parameter design matrix for input and output factors for die depth = 19mm

Std. No.	Run No.	Hole diameter (mm)	Hole location (mm)	Average of measured angle (degree)	Springback Value (degree)
1	7	10	35	99.58	9.58
2	6	20	35	99.54	9.54
3	2	10	65	99.41	9.41
4	8	20	65	99.14	9.14
5	3	5	50	100.14	10.14
6	1	25	50	99.35	9.35
7	9	15	20	99.00	9
8	11	15	80	98.37	8.37
9	4	15	50	99.35	9.35
10	10	15	50	99.48	9.48
11	5	15	50	99.52	9.52
12	12	15	50	99.45	9.45
13	13	15	50	99.58	9.58

2-4 Modeling of Springback for 12 mm Die Depth

The Analysis of Variance (ANOVA) for response surface quadratic model for this die depth was performed statistically according to design matrix shown in Table (2) by using response surface methodology (RSM) technique. The purpose of this analysis is to determine the significant parameters that effect on springback. RSM technique was used to build the prediction model for springback in form of mathematical equation in terms of input parameters. The final empirical quadratic equation for springback in terms of hole diameter (A) and hole size (B) for 12 mm die depth was developed by using DOE software, as follows:

$$\text{Sipringback} = 97.93808 + 0.5825 * A + 0.31624 * B - 0.022661\, A^2 - 3.50125.10^{-3} * B^2 \quad \ldots\ldots\ldots (1)$$

2-5 Modeling of Springback for 19 mm Die Depth

Similarly, the analysis of variance (ANOVA) for response surface quadratic model was conducted according to design matrix given in Table (3) by using RSM technique in order to obtain the significant input factors. Also, RSM technique was employed to establish the prediction mathematical model. The final empirical quadratic equation for springback in terms of hole diameter (A) and hole size (B) for 19 mm die depth was developed by using DOE software, as follows:

$$\text{Springback} = 98.90969 - 0.11369 * A + 0.07717 * B + 2.73966.10^{-3} * A^2 - 8.73372.10\text{-}4 * B^2 \quad \ldots (2)$$

3- Results and Discussion

By comparing the experimental results of bending tests for the two depths in tables (2) and table (3) , it can be seen that in general the springback value of the 19mm die depth are less than those of in the depth of 12 mm because the plastic deformation developed in low carbon steel during bending by depth of 19 mm is greater than the plastic deformation in depth of 12 mm , that means the value of elastic deformation which is responsible for the springback phenomenon decreased if the die depth increased.

This result is confirmed by figs (4) and (5) for 12 mm and 19 mm die depths showing that the springback values are less than those for 12 mm depth over the used level of input parameters.

Numerical optimization by RSM technique was carried out for the input and springback data for the two die depths the optimum value of predicted springback is (106.286) deg at (20) mm hole diameter and (65) mm hole location center using 12 mm die depths as shown in figs (6) and (7) where as the optimum predicted springback is (99.3728)mm deg at (10) mm hole diameter and (65) mm hole location center as shown in figs (8) and (9) .

Accordingly, confirmation tests were then conduced at these optimum values of input parameters in order to check the validity of two models as shown in figs (10). The value of measured springback for 12 mm depth is (106.00) deg while it is (99.44) deg for 19 mm depth. Thus, the maximum error between the predicted and experimental is (0.27%) and (0.04%) for two depth, respectively as shown in table (4) indicating a good agreement between the predicted and experimental results. Finally, it can be concluded that the value of springback when using 19 mm die depth was reduced by (6.47 %) and (6.25%) for both experimental and predicted works respectively in comparison with that 12 mm die depth.

Conclusions

The value of springback due to bending process depended on the depth of the bending dies, this value decreased when the die depth increased, therefore this value for the sheet of low carbon steel of 0.75 mm decreased by 6.47 % for the die depth of 19 mm in comparison with the depth of 12 mm experimentally.

The value of springback affected by the hole size more than the location of this hole when the die depth was 12 mm in comparison with the depth of 19 mm, and this affect is governed by the equation (1).

The location of hole center has more effect on the springback value than the effect of the hole size when the die depth was 19 mm in comparison with the depth of 12 mm, and this affect was governed by equation (2).

Good agreement was found between the experimental and theoretical springback with a maximum error of 0.27 % for 12 mm die depth and 0.037 % for 19 mm die depth.

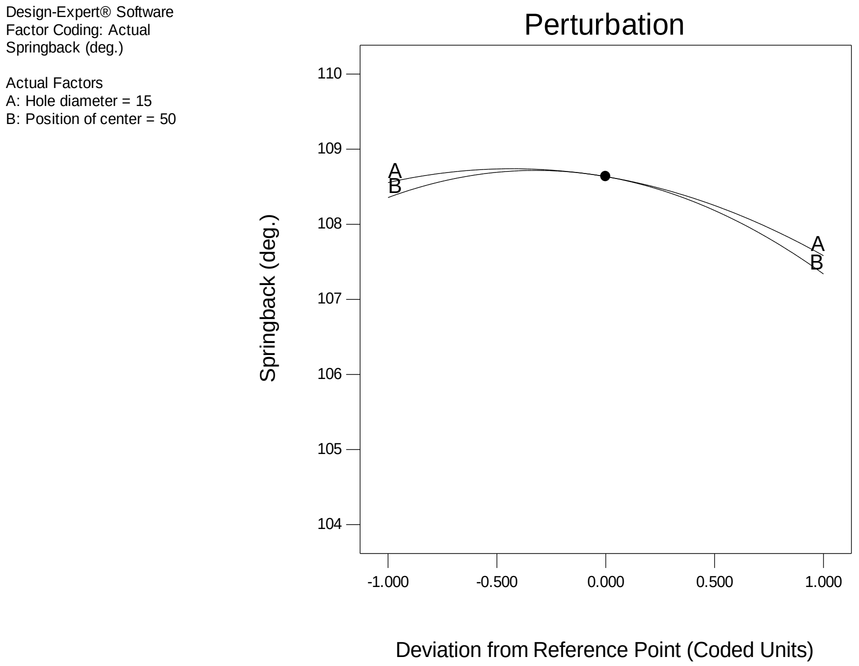

Fig. 4: Showing the effect of each parameter on springback for 12mm depth

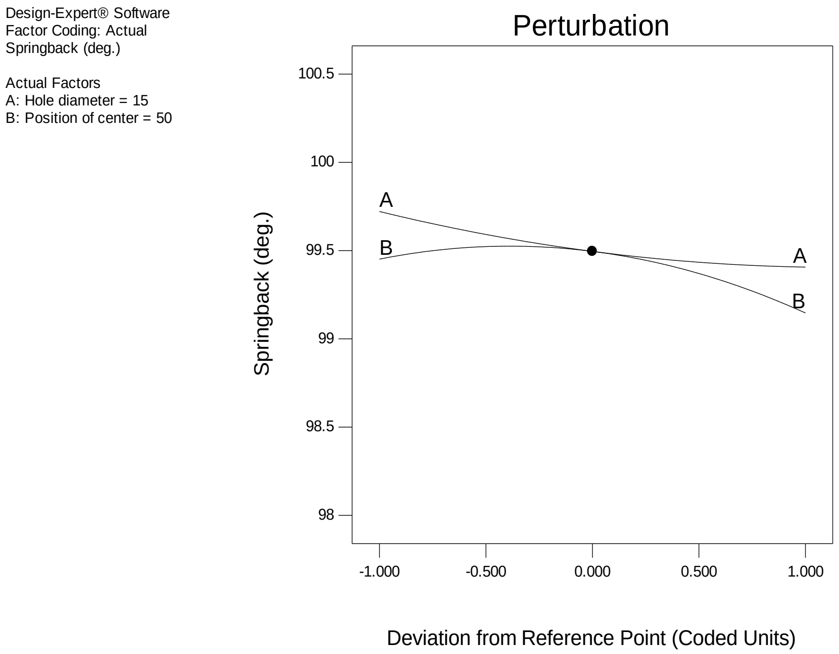

Fig.5: Showing the effect of each parameter on springback for 19 mm depth

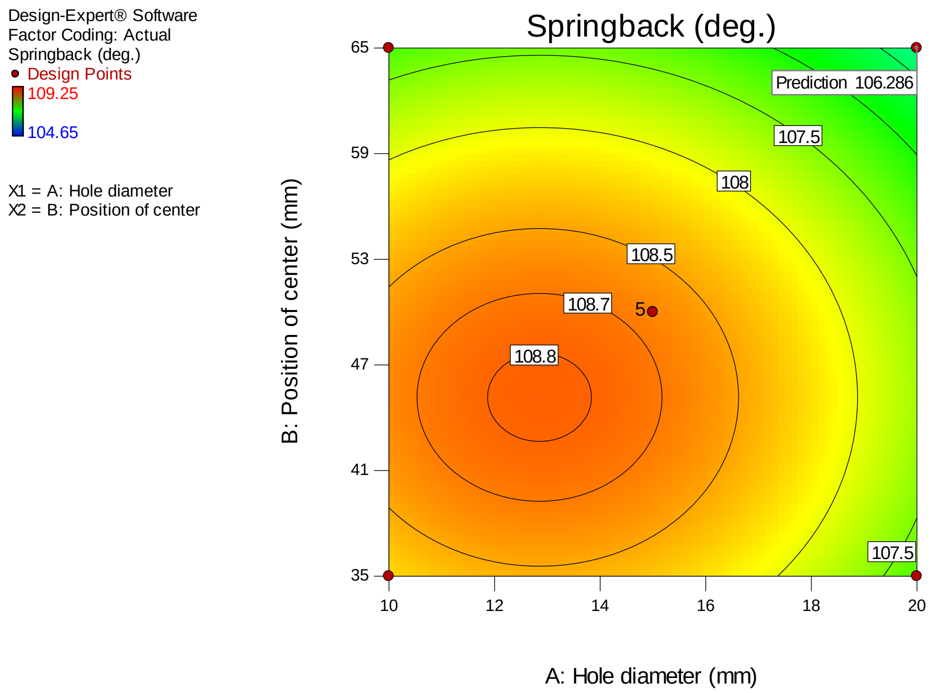

Fig. 6: Minimum springback for hole diameter 20 mm and hole location 65 mm for 12 mm depth

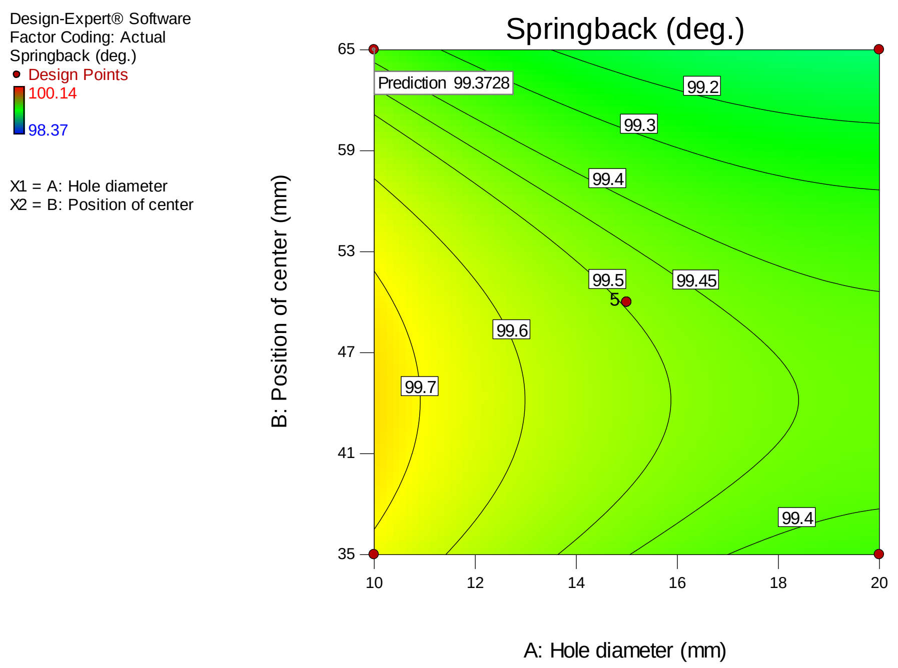

Fig. 7: showing the minimum springback for hole diameter 10 mm and hole location 65 mm for 12 mm depth

Fig. 8: showing the two bent plate with optimal hole size and center location

Table 4: Percentages of springback reduction of experimental and predicted values at different die depths

Die depth (mm)	Hole diameter (mm)	Position of hole center (mm)	Experimental Springback (deg.)	Predicted springback (deg.)	Maximum Error (%)
12	20	65	106.286	106.00	0.286
19	10	65	99.41	99.373	0.073
Percentage of springback reduction			6.47 %	6.25 %	

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تأثير حجم وموقع الثقب على ظاهرة الرجوعية في الصفائح المعدنية خلال عملية الحنى

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الخلاصة

في عملية تشكيل الصفائح المعدنية يتم إجبار المشغولة على إتخاذ شكل وأبعاد الفجوة الموجوده في القالب وذلك عن طريق مكبس صلد وبعد ان تتم عملية التشكيل وإزالة المكبس يلاحظ حدوث رجوع نسبي للابعاد عن الابعاد الحقيقية لفجوة القالب وقيمة هذا الرجوع تعتمد على كلا من نسبة التشويه المرن ونسبة التشويه اللدن، وتسمى ظاهرة التخلص من التشويه بظاهرة الرجوعية. تعتبر الرجوعية واحده من أهم العيوب في عمليات التشكيل ويظهر ذلك التأثير واضحا عندما يرداد تجميع تلك الصفائح مع الاجزاء الاخرى وذلك لعدم دقة الابعاد النهائية. وقد تم انجاز الكثير من البحوث العلمية لتقليل من تأثير تكلك الظاهره خللا عملية حني الصفائح المعدنية المتماثلة في الشكل والمتناظره في الابعاد والغير حاويه على تجاويف او ثقوب، في حين إن واقع الحال هنالك الكثير من المنتجات يتم خلالها حني صفائحا حاويةً على ثقوب مسبقة. ولمعرفة تأثير كل من حجم الثقب وموقعه تم في هذا البحث اجراء عمليات الحني على صفائح معدنية من معدن الحديد المنخفض الكاربون بالابعاد (200 x 50 x 0.75) ملم وقد تم عمل ثقب نافذ في كل صفيحه وحسب الاقطار (5 ، 10 ، 15 ،20 ، 25) ملم ثم تم تغيير موقع كل ثقب حول خط عمودي على طول كل صفيحة. وقد تم إستخدام برنامج تصميم التجارب (DOE) لمعرفة قيمة الرجوعية عند حني الصفائح المثقوبه في قالب على شكل حرف V بعمق 12mm و19mm عن طريق إجراء (78) إختباراً عمليا وتغذية نتائج تلك الاختبارات كمدخلات لبرنامج (DOE)لكي يتم تحديد التاثير المثالي بين حجم الثقب وموقعه الذي يعطي الحد الأدنى من تأثير الرجوعية. وقد تم بناء نموذجين تربيعيين للقالب بعمقين كمدخلات. وقد تبين أن كلا من حجم الثقب وموقعه كان لهما تأثير كبير على قيمة الرجوعيه. تم الحصول على القيم المثلى من الرجوعيه لكلا العمقين. تم التوصل إلى توافق جيد مابين قيمة الرجوعيه التجريبية وقيمتها النظرية مع نسبة خطأ 0.286 .% لعمق القالب 12 mm و0.037 % للعمق 19mm. وأخيرا، تم التوصل إلى أن قيمة الرجوعيه قد انخفضت بنسبة 6.47 % عند استخدام القالب ذو عمق 19mm بالمقارنة مع عمق القالب 12 mm.

الكلمات المفتاحية: تشكيل الصفائح المعدنية، ابعاد الفجوة، تصميم برنامج التجربة DOE.