Finite Element Study on Pattern of Pins Supporting an Elastic Blankholder Used for Stamping Irregular Shaped Sheet Metal Parts

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Abstract. Working with individual in-process controllable elements to support an elastic blankholder is the state-of-the-art for stamping irregular shaped sheet metal parts without wrinkles and cracks. It is thus needed to carefully determine the position for each expensive device. This study is therefore aimed to appraise a feasible approach with finite element analysis, in that the blankholder is first modelled as a rigid object instead of an elastic one to evaluate the contact pressure of the blankholder to the blank during the forming process. The sites showing a locally relative high contact pressure, which are usually induced by local thickening of material, can be regarded as the locations of the supporting elements to intently form a local high pressure to control the material flow and thus to eliminate the local thickening there. As a result, since the blankholder force can be efficiently delivered from the supporting elements directly to the blankholder as well as to the blank, it is not only applied to the rectangular box-shaped part but also to a fender-like irregular sheet metal part. Furthermore, the initiated contact pressure can be maintained at locations during the whole stamping process. This is also experimentally validated by stamping a sound fender-like irregular sheet metal part with an elastic blankholder supported by elements located accordingly at those sites suggested by this study.

1. Introduction
In the last few decades, a tremendous amount of research has been involved in overcoming the failures, such as wrinkles and cracks, presented on irregular shaped sheet metal parts during the stamping process [1]. Especially when working with an elastic blankholder supported by individual in-process force-controllable cylinders, which is based on the monitoring of part wall stresses, a sound stamped part can be easily carried out [2]. However, this achievement is investment-intensive, because lots of expensive hydraulic proportional valves are needed to realize such robust stamping process. Therefore, it has been alternatively proposed by [3] to transfer the achievement to the press shops, where the presses are usually equipped with a die cushion, by implementing length-adjustable thermal pins as die cushion pins, with which no more expensive hydraulic valve is needed. However, it is still unclear whether the available pin pattern is appropriate for forming irregular shaped parts using an elastic blankholder. If not, it is still required to figure out another approach to support the elastic blankholder in properly building up the localized contact pressure to control the material flow. Based on this idea, this study is thus initiated to
investigate how well the layout of the cushion pins works for locating the thermal pins to support the elastic blankholder, as well as to further figure out a preliminary layout of the thermal pin supports if the pin pattern is not appropriate to build up a localized contact pressure on the elastic blankholder. Actually, even in the phase working with individual cylinders for stamping irregular shaped sheet metal parts, it is still required to specify the locations of the individual cylinders.

On this basis, this study starts with the process of forming a rectangular box-shaped sheet metal part with round corners, which can be considered as a basic irregular shape, to investigate how well the accessible pattern of the cushion pins works with an elastic blankholder to stamp the box, as shown in Figure 1 (a). If it does not work well, the layout of supporting elements, which stand on an intermediate plate raised by the cushion pins and then support the elastic blankholder to deliver the cushion force to the blankholder as shown in Figure 1 (b), is then investigated. At the same time, an approach should be proposed to preliminarily specify a layout to individually position each supporting element. Once the layout of the supporting elements is specified for forming irregular shaped sheet metal part, the optimization of the process parameters can then be further conducted. In comparison to direct using robust design optimization approaches, it can benefit the engineers by eliminating the design parameters, such as number and locations of the supporting pins, and thus reducing lots of trials while developing the process by using the approach proposed by this study. The approach suggested by this study will be further validated in this study by forming a fender-like irregular sheet metal part stamped with an elastic blankholder supported by such elements.

![Figure 1](image_url)

**Figure 1.** Illustration of layout for an elastic blankholder supported (a) directly by the cushion pins and (b) by the supporting elements standing on the intermediate plate raised by the cushion pins

### 2. Deep Drawing of Rectangular Box-Shaped Sheet Metal Part

A rectangular sheet with a width of 210 mm and a length of 260 mm is approximately determined for drawing a rectangular box-shaped sheet metal part having dimensions of 100 mm wide, 150 mm long, and 50 mm high according to the handbook [4]. The punch for stamping has a corner radius of 20 mm and a top radius of 7.5 mm, while the die has a radius of 5 mm.

#### 2.1. Finite element analysis with a rigid blankholder

A stamping process of sheet metal parts can be efficiently and robustly simulated with an explicit finite element code [5]. In this study, the finite element analysis for stamping is then carried out by the commercial explicit code LS-DYNA. Normally, the steel tools around the sheet metal blank can be modelled as rigid parts in shell elements for further efficient computation [6]. Thus, the drawing process of this rectangular box-shaped sheet metal part is firstly checked with a finite element model, in which the blankholder is regarded as rigid. Figure 2 (a) depicts the thickness distribution on the sheet metal parts stamped with a blankholder force of 75 kN, which is determined according to the handbook [4] with the blankholder pressure of 2.0 MPa for a deep-drawing steel DC04 used in this study. It can be observed that the whole sheet metal part has at least a thickness of 0.84 mm from the initial thickness of 1 mm. However, a bulge can be found on the long side wall of the part, as shown the dark blue fringed area in Figure 2 (b). This can be attributed to that the part suffers a compression stress in the length (Y) direction there as shown in Figure 2 (b), which should be reduced in a reasonably acceptable range.
2.2. Finite element analysis with an elastic blankholder directly carried by cushion pins

To minimize the bulge on the side wall of the part, which might be considered as a possible drawback of the part, an elastic steel blankholder is used in this study to provide localized contact pressure to depress the potential origin, the compressive stress in the length direction. The blankholder used in the common design has a dimension of 600 mm each in length and width to enclose the four guide pins and bushings at the corners as well as 8 cushion pins around the die cavity. The 8 cushion pins are modelled as rigid parts, which have a diameter of 50 mm each and are positioned according to the pin hole pattern centered on the press bed with a distance of 150 mm to each other in the directions of front-back and left-right. The blankholder has a thickness of 25 mm, which might be reasonably considered as a compliant one to sensibly bring a specific contact pressure to the blank. Most of the keywords used for finite element modelling the stamping process with the elastic blankholder are the same as with the rigid blankholder, except that the elastic steel blankholder is modelled with the selective reduced integrated solid elements. Either solid elements or shell elements that are used for the blankholder have an average mesh size of 8 mm, while the other rigid tools modelled in shell elements have a finer mesh with at least 11 elements around the 90° corners to keep the curvature detail there. The plastic behaviour of the DC04 sheet is formulated with three parameter Barlat material model. The penalty surface-to-surface contact was taken between the blank and the tools as well as between the cushion pins and the blankholder. The coefficient of friction is set as 0.125 to reduce the potential of wrinkling formations.

![Figure 2](image1.jpg)

**Figure 2.** (a) Thickness and (b) stress in the length (Y) direction on the sheet part stamped with a blankholder force of 75 kN

In comparison to the results as shown in Figure 2, the thickness and the stress obtained with the elastic blankholder shown in Figure 3 depict no significant difference to those computed with the rigid blankholder. It means that an elastic blankholder directly supported by the cushion pins might not provide localized contact pressure to adequately depress the bulge on the side wall of the part. It needs thus to explore another measurement.

![Figure 3](image2.jpg)

**Figure 3.** (a) Thickness and (b) stress in the length (Y) direction on the sheet part stamped with an elastic blankholder having a thickness of 25 mm supported by 8 cushion pins under a force of totally 75 kN
Because there is no reaction force provided for the results computed with the rigid blankholder via the current available postprocessor LS-PrePost, to expose potential inducement, the contact pressure of the blank to the blankholder is shown alternatively in Figure 4 and 5 for the results computed with each kind of blankholder. It can be observed in Figure 4 (a) that even with the rigid blankholder the pressure is not homogeneously distributed. There already exist sites having high pressure far away from the designed one of 2.0 MPa that are concentrated around the middle of each side of the outer edge of the blank at the very beginning of the forming process as the die stroke just reaches 10 mm. Actually, the material at these sites accumulates and becomes thicker there. It means that, other than the typical sites in deep drawing around the corners, the material there suffers a compressive stress in the circumferential direction along the edge of the die cavity as well. Especially, the contact pressure around the corners is measured to be significantly lower than the expected value. Around the edge of the die cavity, a contact pressure about the designed value is present. This might be attributed to that the material there is bent and tilts a little bit over the die corner radius. For the further die stroke to 40 mm, the contact pressure around the outer edge middles and around the corners of the blank stays high and closer to the die cavity as shown in Figure 4 (b), because the thickness there becomes thicker. Around the die cavity, small amount of contact pressure still can be found due to bending over the die radius.

Figure 4. Resultant contact pressure of the blank on the blankholder under a force of totally 75 kN computed with a rigid blankholder at the stroke (a) 10 mm and (b) 40 mm of the die

The contour of the blank that reveals a relative high contact pressure to the blankholder computed in elastic model at the die stroke of 10 mm can somehow reflect the rectangular shape of the blank as shown in Figure 5 (a), which is complete different to that computed in rigid model as shown in Figure 4 (a). Only the area of the blankholder underneath the die projection is shown in Figure 5, because the area out of the projection of the die face has no contact to the blank and it is thus ignored for easy comparison to the results computed with the rigid blankholder. Part of the 8 yellow rings shown in Figure 5 is the outer contour of the 8 cushion pins used to demonstrate where the 8 cushion pins are located. The highest contact pressure is present in front of the short side wall, where there two cushion pins are located. It means that the force delivered from the cushion can directly act on the blankholder as shown in Figure 6 (pin #4 and #8). The pressure is thus dominant there. Furthermore, even the four cushion pins located at the corners do not contribute any of the contact pressure on the blankholder, because there is no resultant force on them as shown in Figure 6 (the remaining pins). However, the high contact pressure presents around the corners can be attributed to the material becoming thicker there because of the compressive stress existing in the circumferential direction. In contrast to the contact pressure around the corners, there is no significant pressure appearing on the area in front of the long side wall, even there is a resultant force on the cushion pins there as shown in Figure 6 (pin #2 and #6). In general, the elastic blankholder having the thickness of 25 mm can efficiently deliver the cushion force as the localized contact pressure of the blankholder, if the thickness of the blank on the blankholder is relatively homogeneous. However, as the die increases its stroke, the thickness of the blank becomes inhomogeneous and more material accumulates around the outer edge middles of the blank and around
the corners of the die cavity, the elastic blankholder losses its function to build up the localized contact pressure on the area above the cushion pins. It can be observed that the contact pressure shown in Figure 5 (b) is more or less similar to those shown in Figure 4 (b).

Figure 5. Resultant contact pressure of the blank on the blankholder under a force of totally 75 kN computed with an elastic blankholder having a thickness of 25 mm supported by 8 cushion pins at the stroke (a) 10 mm and (b) 40 mm of the die

Figure 6. Resultant force acting on the 8 cushion pins supporting the elastic blankholder having a thickness of 25 mm in comparison to the cushion force over the die stroke

2.3. Finite element analysis with an elastic blankholder carried by supporting elements

Based on the above earned results that the localized contact pressure of the blankholder to the blank can be built up directly by the supporting elements and can be maintained to the end of the forming process, it is thus meaningful to select the sites that have the relative higher contact pressure at the beginning as well as at the end of the forming process as the locations for the supporting elements. It is easily done by executing a simulation with a rigid modelled blankholder. For the above investigated rectangular box-shaped sheet metal part, eight sites are accordingly chosen, four at the corners and four at the side middles, to position the supporting elements. Each of the supporting elements is a cylindrical rod having a diameter of 50 mm standing on a disc base. All the elements are located such that there is a small gap of 3.5 mm to the die cavity of the blankholder and that they are completely underneath the blank, as indicated by the gold rings shown in Figure 7. Figure 7 depicts the contact pressure of the blankholder to the blank. Around the location of the supporting elements a relative higher pressure is maintained as intended through the process. The resultant force on each supporting element is then plotted in Figure 8. In comparison to the results with the blankholder supported by the cushion pins as shown in Figure 6, all the elements can provide the blankholder force, which actually is the main idea behind using the elastic blankholder. With this layout of the supporting elements, it is easily to have another resultant force diagram for each element for each length. Figure 9 depicts the results for the setup, in that the elements closest to the long side walls (pin #2 and #6) have a length only 0.01 mm longer than the
remaining elements. The resultant force on those elements is raised about 14.5 kN. Therefore, an optimization of the process can be carried out to eliminate the bulge on the long side wall by this approach, which is not conducted in this study.

Figure 7. Resultant contact pressure of the blankholder to the blank under a force of totally 75 kN computed with an elastic blankholder having a thickness of 25 mm supported by 8 elements at the stroke (a) 10 mm and (b) 40 mm of the die

Figure 8. Resultant force acting on the 8 elements directly underneath the blank to support the elastic blankholder

Figure 9. Resultant force acting on the 8 supporting elements, in that element #2 and #6 are longer than the others

3. Deep Drawing of Fender-Like Sheet Metal Part
To validate the procedure proposed by this paper, a fender-like irregular sheet metal part is used, which is based on [7] and has a slender right trapezoid on its top face and also on its bottom projection with different radii at the corners. There exists an inclined wall on each side, in that the radii and size on the bottom projection are larger than those on the top face. Figure 10 depicts the thickness of the sheet metal
part stamped to the die stroke of 70 mm under a cushion force of 650 kN with an initial DC04 blank in octagonal shape having a thickness of 1 mm and the contact pressure of the blank to the blankholder modelled as a rigid part. It confirms the above mentioned approval that the material at the sites having a relative high contact pressure accumulates and becomes thicker there. Because the existing layout of 20 cushion pins for the die set to stamp such an irregularly shaped part [8] cannot provide a promised contact pressure when the blankholder is modelled as an elastic part [9], the ten sites shown in Figure 10 (b) are thus accordingly applied to set up the layout of the elements supporting the blankholder.

![Figure 10](image1.png)

**Figure 10.** (a) Thickness of the fender-like sheet metal part stamped with a blankholder force of 650 kN and (b) contact pressure on the blankholder modelled as a rigid part

Figure 11 depicts the contact pressure of the blankholder to the blank with the layout of the supporting elements, which are suggested by this study for stamping the fender-like sheet metal part and shown as black rings. There is a gap of 20 mm between each supporting element and the die cavity. It can be observed that around the location of the supporting elements a relative higher pressure could be maintained through the stamping process. This layout is actually similar to the 10 hydraulic individual cylinders as the multipoint cushion system built by [10] to apply the blankholder force on the blankholder for forming such fender-like irregular sheet metal parts. The blankholder force for stamping the part with the multipoint cushion system has been optimized by the previous study [7]. Figure 12 depicts the fender-like part having a height of 70 mm stamped from a DC04 sheet in thickness of 1 mm with the above-developed setup under the approximation of the optimized blankholder force by adding the height of the supporting element with feeler gauges, which was determined in [9], and with the compensation of the backlash presenting in the die set, which is detailed in [11].

![Figure 11](image2.png)

**Figure 11.** Resultant contact pressure of the elastic-modelled blankholder to the blank stamped with a blankholder force of 650 kN supported by 10 elements at the die stroke of (a) 20 mm and (b) 70 mm

4. **Conclusion and Prospects**

Based on the fact that the blankholder directly supported by the available cushion pins might not work properly for stamping irregular shaped sheet metal parts, using separate supporting elements instead of directly using the cushion pins is one of the ways to build up a localized contact pressure of an elastic blankholder to the blank in order to efficiently control the material flowing into the die cavity and thus
produce a sound part. To effortlessly find a suitable layout of the supporting elements out of unlimited combinations, this study proposed an easy approach to determine the layout with finite element analysis, in which all the tools involved in the stamping process are modelled rigid. The sites, where a relative higher contact pressure appears on the blankholder to the blank at the beginning as well as at the end of the stamping process, can be considered as candidate locations for the supporting elements. In the study, a rectangular box-shaped sheet metal part, which can be regarded as a basic irregular shape, is used to demonstrate this procedure. As a result, it has been proven that the blankholder force can be more efficiently delivered from the supporting elements directly to the blankholder as well as to the blank, if the elements are located at the sites suggested by this study. A fender-like irregular sheet metal part is further used to demonstrate and validate the procedure to layout the supporting elements with experiment as well. It seems that the procedure proposed by this study works well for stamping irregular shaped sheet metal part, in this study, a quadrilateral box-shaped part with round corners. Thus, for the future works, it is worth to conduct further studies involving different materials, different anisotropy, different shape and dimension of initial blank and so on, so that the procedure proposed by this study can benefit most of applications.

Figure 12. The stamped fender-like sheet metal part on the blankholder supported by 10 elements

Acknowledgements
The per diem for the first author working on this research was supported by the Ministry of Science and Technology of the Republic of China with the grant coded MOST 108-2918-I-005-008.

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