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OPTIMISATION OF THE BLANK SHAPE AND DIMENSIONS IN ORDER TO REDUCE MATERIAL SCRAP FROM DEEP DRAWING PROCESSES

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Abstract: The final part of deep drawing process is affected by multiple interdependent factors. Some of these factors are: process parameters (forming speed, blank holder force, tool clearance, friction coefficient), mechanical properties of the blank material, and shape and dimensions of the initial blank (blank prior the forming process). This paper presents a study regarding optimization of the blank shape and dimensions in order to obtain a final forming product which will not require multiple trimming operations. Additional operation after the forming process is over, are costly even we quantify time or money. For this reason the producer objective is to cut all the supplementary work that will delay him to reach the market. The optimisation is having as a second goal maximization of the material utilization. Generally, deep drawing operation generate important quantities of scrap material, which must be collected, transported and finally reinstated in the production chain; all of this with additional costs for the end user and with sever harms of the planet environment. The work presented in this paper is using as a starting point the final product requested to be made. The forming tools are designed in order to obtain the desired part and the forming process is simulated using Dynaform software. As expected the obtained part differs from the desired one. All the process parameters, tools dimensions, and blank shape and dimensions are optimised in order to obtain the requested part and to reduce material scrap. Multiple simulations are required in order to understand and to quantify the influence of each parameter (factorial design) and numerical optimisation is done to obtain the best value for each factor. The gained knowledge is used to generate the objective function required by the numerical optimization method. With the optimized process parameters a new simulation is made and the final shape of the part is compared with the ideal geometry. The shape of the part obtained with the optimized parameters is proving the capability of the proposed method. Also a comparison it is done between the material scrap obtained initially and after optimisation. In the final part of this paper conclusions regarding the optimisation results are presented.

Key words: deep drawing, blank shape, blank dimensions, optimization, scrap.

1. INTRODUCTION

The blank material, shape and thickness are the principal elements in deciding the direction of the forces and metal flow. All the deforming tools and process parameters relating to the deep drawing method can have a variable influence on the final part. Blank sheets must be tested in order to identify the formability behaviour. The blank is marked with a net composed by squares having circles inside. The print from the blank top, deform during the forming process, and their deformation deliver important information regarding material flow and material deformation. After the drawing process is over, the sheets metal and the printed network it must be studied in order to establish sheet thinning along part profile, distortion in critical areas and how the metal flow during the fabrication process. Using this information, a process designer can adjust the process parameters in order to avoid tearing or wrinkles. Forming limit diagrams are very valuable, and widely used in this kind of problems, [1].

In our days more and more complex formed parts are required by the customers. The initial shape and dimension of the blank makes the difference between a good part and a failure. If the blank is to large, will decrease the material flow in the forming process, increase the required punch force and break or damage the part. In order to optimize the blank shape and dimension, the material flow during the deforming process must be identified.

For example, let's consider a common known case of a square box forming. Due to its shape, when the part is drawn from a square blank it is obvious that the material will not flow uniformly in the die cavity from all directions. The material flows easier and faster into the forming process on the side areas of the blank and with difficulties in the corner area. The most often problem for manufacturers are the part corners. This problem is solved if is possible to reduce material flow and wrinkling in that specific area. In conclusion, less metal is required in these sections, [2]. Diminution of the material from those areas will decrease the internal forces and improve material flow. It is not possible to stipulate a rule that is generable valuable for different parts shape and materials, nerveless the optimal sheet shape will be different. But at the present time, specific programs have been developed in order to predict such shapes and dimensions. Even like that, there are situation where trial and error is the only method with good results for establish the optimal initial blank contour and dimensions.

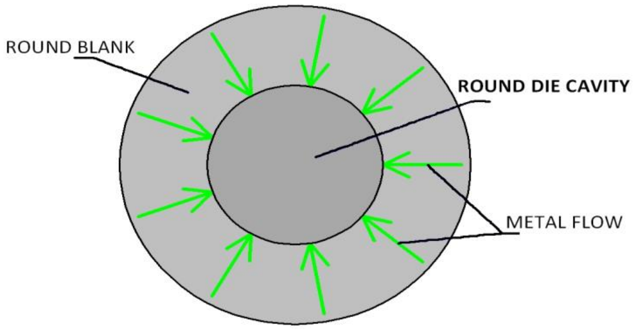


Fig. 1. Metal flow during forming process, [6]

2. QUANTIFICATION OF THE DRAWING AMOUNT

The drawing ratio evaluates the amount of forming which is taken by a sheet of material. If the drawing ratio is forced to the maximum values, there are multiple problems that can occur. Due to multiple factors as: part geometry, properties of the material, process parameters, forming temperature, there are limits regarding deep drawing in a single operation [3]. Drawing ratios are used to establish the maximum forming depth that can be achieved.

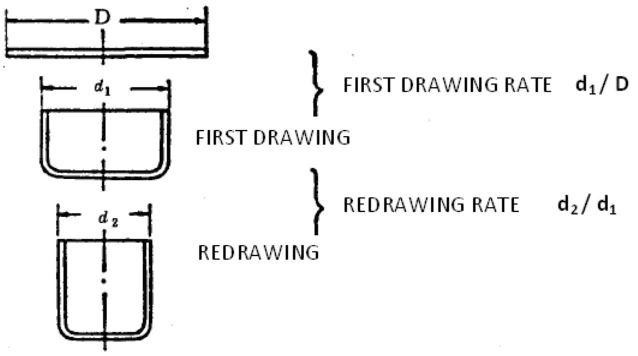


Fig.2. Redrawing rate, [7]

The drawing ratio is calculated as a raport between diameter of the blank and the punch diameter:

$$DR = D_b / D_p \tag{1}$$

where the blank diameter is noted with D_b and D_p is the diameter of the punch. In case of geometries which are noncircular, it is possible to use surface areas in order to calculate the drawing ratio. The maximal drawing ratio is 2, but rarely used in practical work. But in fact, the drawing ratio limits depend upon sheet material, depth of the part, die radius, punch radius, blank holder force, punch speed, friction coefficient between sheet and die radius and punch radius.

A different possibility to quantify the drawing ration is to use de reduction indicator (r). In this study, identical variables as forming ratio, is used to evaluate the reduction, and is described as:

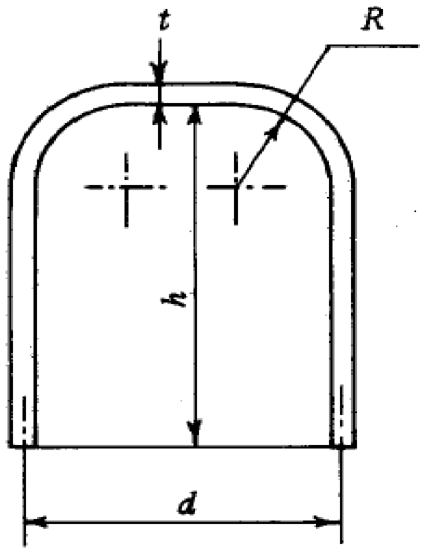
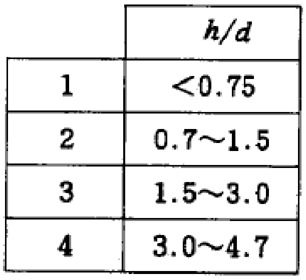


Fig. 3. Redrawing parameters, [10]



	h/d
1	<0.75
2	0.7~1.5
3	1.5~3.0
4	3.0~4.7

Fig. 4. Number of processes needed in sheet metal drawing, [10]

A different possibility to quantify the drawing ration is to use de reduction indicator (r). In this study, identical variables as forming ratio, is used to evaluate the reduction, and is described as:

$$r = (D_b - D_p) / (D_b) \tag{2}$$

where, the blank diameter is D_b and the punch diameter is D_p. Generally, the reduction factor it should be at the maximum value around 0.5.

Frequently calculated as the percent reduction has the following formula:

$$r = (D_b - D_p) / (D_b) \text{ X } 100\% \qquad (3)$$

In this study case the reduction percentage it must be 50% or less. The deformation of the blank is performed by a complex combination of compressive forces and traction. However, the thickness and the volume are constant, [10].

3. CALCULATING THE DIMENSIONS OF THE INITIAL SHAPE

Mainly, the general starting idea is that the initial blank surface will correspond to the development of the final piece. This is not true at 100% because the deformation of the material hadn't been considered, [6].

Generally, we proceed to remove the cur edges (flanges) after the deep drawing. So it is necessary to take into account in the calculation of the initial blank dimensions, the additional material needed in these areas.

The basic idea of the size of the shape is that the silhouette surface should be equal that the drawn sheet and the weight of both should be the same indeed.

The size of the silhouette obtained from the theoretical calculation is not always optimum, even appropriate. You should consider information and data from similar products that have worked before and make the operation form in physical to determine the final size of the silhouette.

In case of the cylindrical cup, the area of the initial sheet metal is equal to the sum of the areas of the geometric elements forming the cup (circle cylinder bottom and side walls), therefore, [9]:

- Ac = surface of the cup

$$Ac = (\prod \text{ x } d^2) / 4 + (\prod \text{ x } d \text{ x } h) \qquad (4)$$

where d = diameter of the cup h = height of the cup.

- As = surface of the silhouette

$$As = (\prod \text{ x } D^2) / 4 \qquad (5)$$

where D = diameter of the silhouette.

$$D = \sqrt{d^2 + (4 \times d \times h)} \qquad (6)$$

Getting the surface and the diameter of the profile of a cylindrical cup

- A = external surface of the final part,
- D = diameter of the part.

$$A = \frac{\pi d_1}{4} + \pi d_1 h + \frac{\pi}{4}\left(d_2^2 - d_1^2\right)$$
$$D = \sqrt{d_2^2 + 4 d_1 h} \qquad (7)$$

Applying the formulas presented above, it is possible to obtain:

$D = \sqrt{170^2 + 4 \text{ x } 150 \text{ x } 70} = 266.27$ mm, part diameter;

A = ($\prod$xD^2) / 4 = 55.684mm^2, part area;

V = A x t0 = 55.684mm^3, part volume.

Knowing the diameter of the required part, it is possible to obtain the Drawing Ratio, representing the quantity of measurement of the amount of drawing performed on a sheet metal blank.

$$DR = D_{blank} / D_{punch} \qquad (8)$$
$$DR = D / D_1 = 266{,}27 / 150 = 1{,}78$$

About forces in cylindrical deep drawing:

$$P = \prod \text{ x d x t x } \delta b \text{ x Kd} \qquad (9)$$

where P: Drawing force (kgf); d: Punch diameter (mm) = D1; t: Silhouette thickness (mm); δb: Ultimate tensile strength of the material (kg/mm^2); Kd: correction coefficient shown in the following table for mild steel (kgf).

Applying the formulas, we obtain:

P = ∏ x d x t x δb x Kd = ∏ x 150 x 1 x 320 x 1 = 150.796 kgf = Drawing Force

With the Drawing Force, we can calculate the workload required (energy) for the cylindrical deep drawing. As we saw:

$$E = (P + Pb) \text{ x h x Cd} \qquad (10)$$

where E: Energy required for drawing work (kg x m); P: Drawing force (t); Pb: Blank holder pressure (t); h: Drawing depth (mm); Cd: correction coefficient shown in the following table for mild steel; (Db / dp): Drawing ratio = 1.78 in our example; Cd = 0.80;
Pb: Blank Holder pressure (t):

$$Pb = A \times hs \quad Pb = (\prod \times (D2 - D1)^2 / 4) \times hs \qquad (11)$$

where Pb: pressure of the blank holder in cylindrical drawing; A: Area of the blank holder that is holding the silhouette; hs: pressure of the blank holder by area.

$$Pb = (\prod \times (D2 - D1)^2 / 4) \times h = (\prod \times (170 - 150)^2 / 4) \times 0.18 = 56.55 \qquad (12)$$

Applying the workload required formula, we obtain:

$$E = (P+Pb) \times h \times Cd = (150.8 + 56.55) \times 70 \times 0.80 = 11.611.6 \text{ kgxm} = \text{Energy required}$$

4. SIMULATION RESULTS

Please The Process apart is going to be very important for our results because in this apart we set how is made the depth drawn process. Mainly we have two stages, closing where the die is displaced until the binder, and the drawing where the punch go into the die and deform the blank. In the closing stage we set only the die movement until the binder with a slow speed of 200mm/s, leaving the others tools in stationary position and the rest of values by default. In the drawing stage we set the following values: *Die*: -150.800N, the value that we obtained theoretically by ecuation, [7] *Punch force*: Stationary. *Binder force*: 56.500N, the value that we obtained theoretically by ecuation, [2].

We select the die as the tool that is going to travel trough the die in order to deform the blank, we put the depth of the draw, 70mm. Last, in the process window we have chosen 10 total frames. These frames can be edited and we can choose the type, for instance, time, distance from start or distance to end.

Once we have fixed all the simulation parameters we want to study, we can check if the process is right watching the stages with the animation tool in the preview menu. Now, we are be able to run the LS-DYNA Jobs Submitter as we saw in the section *4-Dynaform.* The solver process takes about 10 hours for each simulation, because we chose really slow speeds of the die to avoid problems when the blank comes into contact with the tools. After the process is finished the eta/LS-DYNA Jobs Submitter software saves the D3PLOT and ASCII data files. Then we can continue working in the eta/Post-Processor software. In the Post-Processor, the first sequence that we can see is a video frame by frame of the full process.

The starting thickness of the blank was 1mm and in the final drawn cup, removing the flanges, we can check that the thickness variation will be between 0.95 and 1.03mm. So, we can confirm that the deep drawn process has been executed correctly, and the obtained results are correct. In addition to checking that the theoretical values calculated were right because the simulation was successful, the simulator gives to us more important information about the process, like forces, energy required, mean stress diagrams, Von Mises, etc.

5. CONCLUSIONS

After both calculations, we are going to compare and extract some conclusions. We started supposing a certain cylindrical drawing process which concrete dimensions. We solved it theoretically, and the result was that the initial dimension of the sheet metal blank would be of 226mm at least. We also obtained more parameters of the process like the Punch force or the Blank holder force.

After that, we pass to the simulator part. We know that the desire depth of the cup for our case is 70mm. So, we have to check if the simulator confirms that this depth is possible with our initial sheet metal blank of 226mm diameter. We entered all the parameters that we have calculated before in the theoretical part (like punch and blank holder forces) and run the simulation.

With the Forming Limit Diagram study, the thickness plot, the Main Stress Diagrams and the Von Mises Stress criterion, we confirmed that the deep drawn process was executed correctly, and the obtained results were correct. The blank has no evidence of cracks or damage in any site.

By numerical simulation has been verified that, removing the according flanges, the depth of the final drawn cup exceeds the 70mm that were the maximum that we got by the theoretically method with the 266 mm diameter initial metal sheet.

Now we are going to compare the Drawing Force value that we have calculated theoretically by equation [7] with the simulator results. Theoretically we obtained a value of: P = 150.796kgf.

By the simulator, we can difference two important areas. At first contact between the punch and the blank, we have a peak force of 100.000 kgf. After the sheet starts deforming, the punch forces in momentarily reduced to then reach another peak of 175.000 Kgf, which is the maximum drawing force.

So, we can conclude that the theoretical approximation is good enough to get an idea of the value of the forces that are going to be holding the sheet. Concerning the workload or energy required in the process, theoretically the obtained values of E is 11.611,6 kgxm. By the simulator, the value of the maximum energy required is 10.800 Kgxm. Once more, we can take for good the theoretical approximation.

After all these findings, we can conclude that the simulator optimization explained perfectly all the results that we obtained by the theoretical method and moreover it gives to us lot of extra information about the sheet metal behaviour during the process.

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