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Influence of the Process Parameters in Deep Drawing

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Abstract:

Deep drawing process is a sheet metal forming process where a punch is utilized to force a flat sheet metal to flow into the gap between the punch and die surfaces. As a result, the sheet metal or blank will deformed into desired shape like cylindrical, conic, or boxed shaped part and also complex parts which normally require redrawing processes by using progressive dies. One of the most common outcomes in deep drawing process is the defects that occur in the cup shell. These defects are caused by many parameters like blank holder force (BHF), Die Radius, Punch Radius, Blank diameter, friction between punch and blank and Die, normal anisotropy of material, blank thickness and many more. The main objectives of the present study are to determine the most critical process parameters that cause defects and thinning in the blanks. The effect of various process parameters will be determined by using Statistical as well as Experimental methods.

Keywords: Sheet Metal Forming, Deep Drawing, Design of Experiments, ANOVA

I. INTRODUCTION

FORMING

Forming is a process in which force is applied to metal to modify its geometry instead of removing of material. The applied force stresses the metal beyond its yield strength, causing the material to plastically deform, but not to fail. The stresses induced during the process are greater than yield strength, but less than fracture strength, of the material. The type of loading may be tensile, compressive, bending or combination of these. This is very economical process as the desired shape, size and surface finish can be obtained without any significant loss of material.

This kind of process is required very fine control over the material properties, because to obtain desired shape and size of formed part it is required to maintain ability of material to flow plastically in solid state without deterioration of their properties.

In case of plastic deformation the forces applied to material is above the elastic limit. Basically this process is done at room temperature (in cold state) and in this state the material is more rigid than in hot state. Thus, to deform the metal greater pressure is needed in cold state then in hot state. The amount of deformation is depended on the ductility of material.

Sheet metal forming is one of the most widely used manufacturing processes for the fabrication of a wide range of products in many industries. The reason behind sheet metal industry gaining a lot of attention in modern technology is due to the ease with which metal may be formed into useful shapes by plastic deformation processes in which the mass and volume of metal are conserved and metal is displaced from one location to another.

II. SHHET METAL FORMING

In a large measure the importance of sheet forming is due to the ability of high quality and relatively low cost flat-rolled metal strip. Typically, sheet metal is produced by high speed cold rolling of coils, which may weigh from several kilograms to several thousand tones. The subsequent localized deformation of the cold rolled sheet by sheet metal working techniques produces many useful parts such as household utensils, car body parts, food or beverage containers, window screen frames and countless other products.

The sheet metal operations done on a press may be grouped into two categories cutting or shearing operations and forming operations.

The cutting operation includes:

- Punching
- Blanking
- Cutting off and parting
- Notching
- Lancing
- shaving
- Trimming
- Perforating

The forming operation includes:

- Bending

- Drawing
- Roll forming
- Deep drawing

2.1 Deep drawing

Deep drawing is process to produce cups, shells, boxes and similar parts from metal blank. It is a sheet metal forming process in which a sheet metal blank is radially drawn into forming die by the mechanical movement of the punch. It is thus a shape transformation process with material retention.

A simple drawing operation is shown in fig 1.1. A round blank is first cut from flat stock. The blank is then placed in the draw die, where the punch pushes the blank through the die. On the return stock the cup is stick with punch, to avoid this blank holder is used. Generally, a drawing operation is referred to as shallow drawing when the depth of cup is less than the diameter of cup and drawing of cup is deeper than half its diameter then it is called deep drawing.

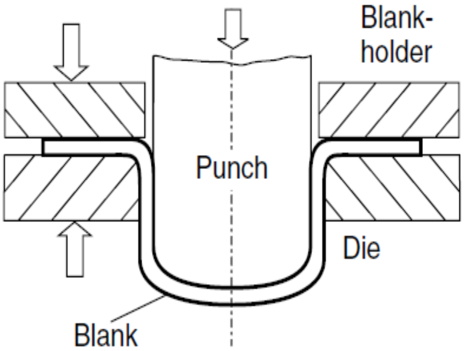

Fig 1.1 A typical Deep drawing operation

III. WORK HARDENIG

When metal is strained beyond its yield point an increasing stress is required to additional plastic deformation and the metal apparently becomes stronger and more difficult to deform this phenomenon is known as work hardening. Metal becomes stronger because of straining the metal so it is also known as strain hardening. This phenomenon is generated in cold working operation. Simply we can says that strain hardening, is the strengthening of a metal by plastic deformation. This strengthening occurs because of dislocation movements within the crystal structure of the material. Discontinuities in the crystal structure, present in all metals is known as dislocations. Grain size will also influence strain hardening. A material with small grain size will strain harden more rapidly than same material with large grain size.

In metal working operations strain hardening is desirable, because in this process we required permanent shape change after plastic deformation. Work hardening improves tensile strength, yield strength and hardness at the expense of reduced ductility. These effects can only be removed by annealing or normalizing.

Mathematical descriptions of the work hardening phenomenon are expressed by; Hollomon's equation, is a power law relationship between the stress and the amount of plastic strain:

$$\sigma = K\,{\varepsilon_p}^n$$

Where σ is the stress, K is the strength index, ε_p is the plastic strain and n is the strain hardening exponent.

IV. EFFECTS OF PROCESS PARAMETER DURING DRAWING

Radius on Punch: There is no set rule for the size of the radius on the punch. A sharper radius will require higher forces when the metal is folded around the punch nose and may result in excessive thinning or tearing at the bottom of the cup. A general rule to reduce the thinning is to design the punch with a radius of from 4-10 times the metal thickness.

Radius on Die: Theoretically, the radius on the draw die (draw ring) should be as large as possible to permit full freedom of metal flow as it passes over the radius. The draw ring causes the metal to begin flowing plastically and side in compressing and thickening the outer portion of the blank. However, if the draw radius is too large, the metal will be release by the blank holder too soon and wrinkling will result. Too sharp a radius will hinder the normal flow of the metal and cause uneven thinning of the cup wall, with resultant ering.

Friction: The force of static friction between the work piece blank and draw die surfaces must be overcome in a drawing operation. The force of the blank holder adds significantly to the force of static friction.

Material to be drawn: The characteristics of the material to be drawn have a great influence on the success of a drawing operation. Ductility and yield strength are the most important. Low yield strength is desirable so that metal flow can begin easily without tearing near the punch radius. Drawing quality is generally specified for severe draws because, with a nominal extra cost, required drawability is guaranteed.

Blank holding force: A deep drawn part's quality is affected significantly by the flow of metal into the die cavity .The force exerted by the blank holder on the sheet supplies a restraining force which controls the metal flow. This restraining action is largely applied through friction. Blank holding force is small at beginning, which is good for the flow of material towards die cavity. But if blank holding force is less than the chances of wrinkling is more and if blank holding force is higher than chances of tearing is higher.

Percent reduction and depth of draw: The percent reduction in drawing cylindrical shells is expressed in terms of the diameters of the blank D and the drawn shell d as shown in eq 2.8, where D is blank diameter and d equals to the internal diameter of shell.

Percentage reduction is calculated as: P= (1-d/D) x 100 ……………... (1.1)

Die clearance: Die clearance is the gap left between the punch and die to allow for the flow of the work material. Generally enough clearance is left to allow for thickening of the material. This allowance is depended upon the type of operation and the metal. When clearance is equal to the metal thickness or less, ironing and burnishing of the metal will occur near the top of the cup.

V. DEFECTS IN DEEP DRAWING PROCESS

Wrinkling in the flange: This defect occurs due to compressive buckling in the circumferential direction. Due to less blank holding force this defect may occur. Because of the material flow is not restricted and more material is trying to flow inside the die cavity.

Wrinkling in the wall: This defect takes place when wrinkled flange is drawn into cup or if the clearance is very large, which results in large unsupported region. Wrinkling is avoided by applying a blank holder force through a blank holder. This increases friction and hence the required punch load increases. The edges of punch and die are rounded for the easy and smooth flow of metal.

Tearing: This defect occurs because of high tensile stresses that cause thinning and failure of the metal in the cup wall. Tearing can also occur in a drawing process if the die has a sharp corner radius. If die radius is too small because of that, more restriction to flow of material. If punch radius too small because of that more thinning of material is occur at that corner of formed part.

Earing: Ears are often wavy projections or unevenness formed along the edge of the flange or end of the wall of the cup. These are formed due to uneven metal flow in different directions, which is primarily due to presence of the planar anisotropy in the sheet.

Localized necking: The appearance of any local neck that leads to tearing and failure will obviously terminate the forming process. This can be considered as local instability that that can be analyzed by considering a local element.

Fracture: it is possible for a plastically deforming element to fracture in almost a brittle manner. This is not common for sheet used for forming and is often preceded by some local instability.

Basically the quality of deep drawn parts is depended on the better control over metal flow during process. A blank holder is used to prevent the formation of wrinkle. There should enough forces on the blank holder to prevent the wrinkles because after winkle is started, the blank holder is raised from surface of the metal and allow other wrinkles. The force created by the blank holder also increase frictional forces. Too much blank holder pressure may tear the side wall of the drawn cup, and also increases tonnage capacity of press tool. Both the condition is not advisable. So, one another method is used and it is a use of draw bead on die or on blank holder surface.

VI. TAGUCHI'S DESIGN OF EXPERIMENTS

Taguchi orthogonal array (L4) is used to perform experimental runs so that no parameter is left out and hence unnecessary experimentation is reduced. Another important reason to use Taguchi method is that it is straight forward and easy to use.L27 orthogonal array is also used as 2 levels will not be enough to justify the results obtained.

Response Variable:

In deep drawing thin blank sheet is deformed to obtain the desired shape of the product. All the parts produced through this process undergo plastic deformation. This process is generally used to manufacture automobile parts and hence the thickness of the formed part should be within the limits. Formed parts get thickening at the flange area and thinning occurs at the bottom and nose of the punch due to stretching of the blank sheet. The final objective of deep drawing process in particular or of any sheet metal forming process in general is to produce good quality product, hence uniform thickness should be obtained throughout.

The original thickness of the blank considered in this study is 1 mm.

It is decided to select L27 orthogonal array since it best suits purpose required in this present study. L27 orthogonal array can check for 13 different parameters at 3 levels.. In the present study only 3 parameters are considered so it is required to reduce the L27 orthogonal array to present requirements. So it is required to reduce the number of columns of L27 orthogonal array. To perform this task L27 orthogonal array was reduced to L27' orthogonal array. The Process parameters and their values is as shown in Table 1.1

Table 1.1 Process parameters and their values

	PARAMETERS		
LEVEL	Die radius (mm)	Punch Nose Radius (mm)	BHF (N)
1	2	2	100
2	5	5	300
3	8	8	500

MATERIAL SELECTION:
- Stainless Steel 304L.
- Thickness of Material 1mm

Chemical Composition of Material
The chemical composition of material is as shown in table 1.2

Composition	% Wt
C	Max 0.03
Cr	18-20
Mn	Max 2
Ni	8-12
P	Max 0.045
S	Max 0.03
Si	Max 1

Physical Properties of Material
The physical properties of material is as shown in table 1.3

Hardness, Rockwell B	80	
Tensile Strength, Ultimate	586 MPa	
Tensile Strength, Yield	241 MPa	0.2% YS
Elongation at Break	55 %	in 2 inches
Modulus of Elasticity	193 GPa	Tension

VII. EXPERIMENTAL SET UP:

The experimental set up used for performing various experiments as per the data mentioned in research methodology is as shown in Fig 1.3

Fig 1.3 Experimental set up for performing Deep Drawing operations

The hydraulic press with 25 ton capacity was used to perform the Deep Drawing experiments.
Different parts such as Die, Punch and guide plate for Blank holding force which can also be used as guide way for punch to travel deep inside the die was also manufactured for performing various Deep Drawing operations. Dies and Punches used for the experimental purpose is as shown in Fig. 1.4.

Fig 1.4 Sets of Dies and Punches with 2mm, 5mm, and 8mm radius respectively

Fig 1.5 Blank with 82 mm Diameter

Fig 1.5 shows the blank with 82mm diameter used for performing Deep Drawing operations.

VIII. RESULTS

As discussed earlier, the results of L4 orthogonal array are not sufficient to define the safest conditions necessary for performing deep drawing operation and to check whether the defects can occur more consistently with the experiments, L27 orthogonal array is used by introducing one more level and thereby to define more safer limits with three levels.

Results of L4 orthogonal array is as shown in fig 1.6 (a), (b), (c) and (d) respectively.

(a)

(b)

(c)

(d)

Fig 1.6 (a),(b), (c), (d)

Results of L4 Orthogonal Array

(a) Wrinkling in the cup

(b) Safe Component

(c) Tearing in the cup

Fig 1.7 Results of L27 Orthogonal Array

Fig. 1.7 (a) shows the wrinkling in the part. This is caused due to the less blank holding force during the experiments. This defect is quite often seen during the experiment. Fig 1.7 (b) shows the safe component which is formed due to proper amount of die radius, punch radius and blank holding force. Fig 1.7 (c) shows the tearing in the component which is formed at the punch radius due to lower punch radius. Strain hardening exponent is a limiting strain value, each material can withstand before neck formation. For any material based on the power law material behavior, strain hardening (n) can be equal to strain at the ultimate point of tensile instability. At this point strain in the material becomes unstable resulting into necking. Hence in the present work it is assumed that maximum safe zone for the forming will be when strain in thickness direction is less than or equal to strain hardening exponent. Hence, the material can be drawn until the strain reaches the ultimate strain value.

Initial blank thickness (to) = 1 mm.

Strain hardening exponent (n) = 0.22

At onset of tensile instability ,

n =εu= ln(to/ti) Or n= ln(to/ti)

$t_0/t_i = e^n$

Hence, instantaneous thickness of sheet (ti) =0.806 mm. From this value of thickness, we can find out value of percentage thinning for present experimentation, and for this thickness value, percentage thinning is 19 %. So from this point of percent thinning if parts are further drawn than it will come under failure zone and finally the material gets cracked at the critical point of component. By observing the results obtained from the experiments that critical region is just above punch nose radius.

From the experimental results, percentage thinning of formed part is explained. These results are of 4 experiments based on L4 array as explained in previous section. The value of percentage thinning for experiment 1, 2, 3, and 4 are 19%, 36%, 23% and 24% respectively. Similarly for all the 4 experiments the values of minimum thickness are 0.80 mm, 0.64mm, 0.77 mm and 0.76 mm respectively.

As explained earlier from strain hardening exponent calculations that 0.806 mm is an instantaneous thickness for this present work, and at this value of limiting thickness, the limiting value for percentage thinning 19 %. Above this value of percentage thinning parts are failed due to plastic instability. By comparing all the 4 experiments results of percentage thinning and minimum thickness from table 4.4 with this limiting value, it is observed that experiment 1 is safe. In experiment 2,3 and 4 the value of percentage thinning is 36% ,23% and 24% respectively which is above the value of percentage thinning, and value of minimum thickness is 0.80 mm, 0.64 mm, 0.77 mm and 0.76 mm respectively, which is below the value of minimum thickness. So in experiment 3 parts are failed. From the experimental results it was observed that the results are failed from Experimental run 1 to 9, 13, 14, 15, 19, 20, 21.

ANOVA

There is a standard statistical technique called analysis of variance (ANOVA) which is routinely used to provide a measure of confidence. The technique does not directly analyze the data but rather determines the variance of data. The analysis of variance

(ANOVA) is the statistical treatment most commonly applied to the results of the experiments to determine the percentage contribution of each factors. Study of ANOVA table for a given analysis helps to determine which of the factors need control and which do not. Once the optimum condition is determined, it is usually good practice to run a confirmation experiments. In case of fractional factorial some of the tests of full factorial are conducted. The analysis of the partial experiment must include an analysis of confidence that can be placed in the results. So analysis of variance is used to provide a measure of confidence.

ANOVA analysis shows the percentage contribution of individual parameters on Deep Drawing. The percentage contribution of Die radius is 36.44 %, Punch nose radius is 8.48 % and Blank holding force is 53.39 % and the error is of 1.69 %. This error is due to human ineffectiveness.

IX. CONCLUSION

From the above experiments and the parametric analysis carried out during this project, following things were concluded.

- The blank holding force has the major influence in the deep drawing process.
- The die radius also has an influence in the process which is followed by punch nose radius.
- The failure in the component i.e. tearing in the cup was observed due to less punch nose radius.
- Wrinkling in the formed part was also seen during the experiments which occurred due to less blank holding force.

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