

Optimization of Blank Holder Force to Control Wrinkling and Fracture of Cylindrical Cups in Deep Drawing

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Abstract

The Predominant failure modes in sheet metal parts (deep drawing process) are wrinkling, fracture. In many cases these defects may be eliminated by appropriate control of the blank holding force (BHF). This paper summarizes the results of a resent study on the formability of rectangular or cylindrical parts from Extra Deep Draw (EDD) steels. Wrinkling, fracture limits have been determined and BHF control methods have been developed to eliminate defects, improve part quality, and increase the draw depth.

The prediction and prevention of wrinkling and fracture are extremely important in the design of tooling and process parameters in deep drawing process. Forming process of Extra Deep Draw (EDD) Steel alloy sheets can be investigated by using deep drawing process. When the BHF is 70-80 N/mm² the steel sheets with a thickness 5mm can be produced in the cups without any defects such as wrinkling, tearing.

A 3-D explicit-finite element analysis is used to investigate the influence of various BHF schemes on sheet metal formability limits especially wrinkling, and fracture. The role of relevant parameters of each blank holding technique is also investigated. Experiments were conducted using a die block of 250 mm diameter and punch 240 mm on EDD steel alloys of blank size is 165mm and thickness 5 mm.

Keywords: Blank Holder Force, Deep Drawing, EDD steel alloy, Wrinkling, Fracture.

1. Introduction

During deep drawing process, blank under the blank holder was drawn into the deformation by the punch. The main concern of the deep drawing industry is to optimize the various process parameters in order to get a complete deep drawn product with least defects. Failure of deep drawing parts during deep drawing processes usually take place in the form of wrinkling, tearing or fracture.

In this study, a cylindrical cup geometry and an low carbon steels, namely EDD steels, were selected to develop methods for evaluating and improving the final part quality. The effect of the blank shape and the blank holder force on wrinkling, fracture were investigated. Wrinkling, fracture limits have been determined under the current process conditions, and BHF control methods have been developed to improve formability and to increase the attainable cup height.

Wrinkling defect generally occurs at the flange and is generated by excessive compressive stress that causes the sheet to buckle. [1].

Wrinkling and tearing or rupture thus define the deep drawing process limits [8-10].For this problem, many variables affect the deep drawing process, these include material properties, die design, friction conditions, drawing ratio, BHF, punch corner radius, die corner radius and punch speed.

Among these process and design variables, the BHF is greatly influence the growth and development of part defects. Studies have shown that a deep drawn parts

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 blank holding force which controls the metal flow. This restraining action is largely applied through friction. Excessive flow may lead to wrinkles within the part, while an insufficient flow can result in tearing or fracture.

A properly chosen BHF can prevent wrinkling and delay fracture in drawn part [3]. The rate of metal flow into die cavity must be controlled so that a better quality was maintained for the strip and defects of wrinkling and tearing or fracture are prevented.

In the past, the demand for this alloy as a structural material was not high because of its less availability commercially as well as limited manufacturing methods. In recent years, EDD steel alloys have been prevailing method for making parts in the refrigeration industry. However this process is not ideal in making thin walled EDD steel alloy structures because of excess amount of waste materials. So sheet metal forming processes such as deep drawing [5] are developed to make thin-walled parts with good mechanical property and surface quality to avoid the defects. The cup drawing process has been used for years as a measure of sheet formability.

Closely coupled with the BHF is the material thickness an increase in the material thickness has the beneficial advantage of increasing its resistance to wrinkling. However, increase in material thickness also results in increased material weight and cost of the component. Increased thickness has also been shown to have the effect of increasing the formability of the material. BHF's act to suppress wrinkling of the sheet and to apply the surface tractions, through friction. Increases in the BHF will result in increased thinning in addition to decreasing the wrinkling in the sheet. A BHF level exists above which the formation of wrinkles in the component can be kept below an acceptable level.

During deep drawing process, blank under the blank holder was drawn into the deformation zone by the punch as a result; compressive hoop stress and thus wrinkling can be developed in the sheet metal under

the holder (flange wrinkling) as well as those in the side wall as wrinkling [2]. The rate of metal flow into die cavity must be controlled so that better quality was maintained for the part and defects of wrinkling, thinning and tearing are prevented. Defects due to wrinkles and excessive localized thinning after the product geometry from the designed one causing difficulties in joining and assembly of sheet products.

1.1 Research Objective

The main objective of the proposed research paper is to eliminate the various defects like wrinkling and tearing or fracture in deep drawing process to produce a cylindrical cup of required shape and size. For general deep drawing, operations, most people define the defects as that block which can be deformed into a cylindrical cup with either a uniform flange or cup free from ears.

However it is not easy to an eliminate the defects because of complexity of deformation behavior and there are couple of process parameters like die radius, punch radius, punch speed BHF and amount of friction which affects the result of the process, i.e., tearing, wrinkling and thinning. Even a slight variation in one of these parameters can result in defects.

2. Equipment and tooling

The deep drawing experiments were performed on a 200 ton hydraulic press installed at the Penner Steels Ltd. The clamping pressure is applied by means of a hydraulic die cushion. Die cushion force can be kept constant or varied as a function of stroke, with a maximum load of 100 tons.

The punch and die is made of high carbon high chromium steel and a radius of 4mm and 10mm respectively. The die block was made from oil hardened D2 steels or HCHCR steels. The outer and inner diameter of the die block was taken as 250 mm and 102.2 mm respectively. Thickness of the die block is 40 mm.

2.1 Experimental Work

A set of deep drawing experimental facilities were designed to analyze formability of the EDD steel alloy sheets. The arrangement tool dies setup is shown in fig. No. 1. The deep drawing experiments were carried out using the double action hydraulic press with the capacity of 200 ton made of Bemco Hydraulics limited and installed at Pennar Industries Limited, Hyderabad.



Fig. No. 1 Experimental set up

Materials used in the experiments are EDD alloy sheets. The initial diameter of blanks is 164.5 mm and 166 mm with a sheet thickness 5 mm and 3.65mm respectively. The dimensions of the different types of tools used deep drawing experiments is shown in Table no.1

Table.1. Dimensions of main tool for deep drawing experiments

Punch Shoulder Radius (mm)	3	2
Blank holder dimension(mm)	164.5	166
Die shoulder radius (mm)	23	23
Clearance between punch and die block(mm)	10	7.2
Punch diameter(mm)	103	103
Sheet metal thickness(mm)	5	3.65

The chemical compositions are shown in Table.2.

Table.2.Chemical composition of EDD steel alloy

C	Mn	S	P	A1	Si
0.080	0.400	0.050	0.030	0.033	0.019

Process parameters include the speed, lubricant of tools such as coconut oil or white dramate coolant oil which was uniformly spread over the surfaces of tools and blank. Polythene paper is placed at top of blank for improving the life of the punch and die.

The ram speed of the press was 600 mm/ min. in forward stroke and 8100 mm/min in return stroke. The size of the table was 1000mm x 1000mm. The ram plate had the maximum stroke distance 150 mm. The maximum working pressure of the press was 500 N/mm² with motor capacity of 20 h.p

The tooling setup is arranged in hydraulic press to measure the loads and stroke during the deformation. The punch load or force is measured with the help of a load cell [5]. The Blank Holder plate is supported by 8 cushion pins which are transfer the load from the die cushion to the Blank Holder supporting plate. The BHF was measured by providing load cells at sides of the rectangular blank holder.

To produce a cylindrical cup of 112.4mm diameter and 42.5mm height from a flat sheet of 164.5mm diameter of blank and 5mm of thickness. The required tools like die, punch, blank holder and clamping devices were designed and fabricated to suit the hydraulic press specifications. The drawing force required to convert the blank of diameter 164.5mm with thickness 5 mm into a cylindrical shape of cup was 9.0 ton [4]. Additional force 20 to 40% was added to take into account the rapid change in the structure.

Then blank was etched by OLEPHOS-XL and Tonato crystal white powder in 15-20 minutes and then quenching is done by air cooling. After

etching clean the blank with wood flour for removing the scales. The clamping pressure is applied by means of a hydraulic die cushion. Die cushion pressure can be kept constant (120 N/mm^2) or varied as a function of stroke, with a maximum load of 100 tons.

The blanks used in the experiments were made of EDD steels whose material properties are given below..

Material properties

Initially, the metal sheet used is a disc having 164.5 mm in diameter and the thickness 5 mm. The material used is a EDD steel with the following characteristics.

Hardness	=49 RB/VBN
Young's Modulus	= 245 N/mm^2
Ultimate Tensile Strength	= 3010.30 N/mm^2
Elongation	= 43mm

3. Deep Drawing of cylindrical cups

A cylindrical cup was produced with 112.4mm diameter and 42.5 mm from a 164.5 mm circular shape of blank. In this deep drawing process, a flat blank holder and oil based lubricant namely coconut oil or White Dramate was used, and the BHF was kept constant at 40 tons during the stroke. Since the nature of the deformation is close to axis symmetric at the corners of the cylindrical cup, due to some extra blank holding forces, retards the metal flow, and causes the largest thinning will be occur at this area.

To reduce the forming severity at the corners of the cylindrical cup and to prevent wrinkling on the sides, the metal flow must be uniform.

The following methods are adopted for this purpose.

1. The blank shape must be modified for providing the smaller contact surface at the corners.
2. More space for sheet thickening should be provided.
3. Draw beads must be used on the sides of the circular blank.

4. Multipoint pressurized system will be used to control Blank Holding pressure [6, 7].

A circular pan was formed to 50 mm height from an oblong shaped blank. In this experiment, a flat blank holder and oil based lubricant was used, and the BHF was kept constant at 25 tons during the stroke.

5. Deep Drawing Defects

5.1 Fracture:

This defect can be detected by using UT/MPI method or sometimes by visual Method or by using some chemical solution defects, can be easily traced out. For this first heat the cup and then apply the liquids namely PMC flow check PP-5011B penetrant after identifying the defect, clean the cup with PMC flow check PP-5021B cleaner. For minimizing or eliminating the fractures using lubricant namely coconut oil or coolant oil (white dramate) servo and the placing the polythene paper on the top surface of the blank before applying the punch force.



Fig.No.2 (a): Fracture at the bottom of the cup

The objective of the present study is to develop an optimizations strategy for determining the optimum BHF scheme for a certain cup model that minimizes the punch force without causing wrinkling and tearing in the cup materials. This objective is applied to the linear BHF scheme, so, the objective can be formulated as an optimization problem in the following manner.

The wrinkling criterion used in this analysis is based on a semi – empirical work carried out by kawai (7) as for the fracture criterion, it is based on that necking is assumed to occur at the point, where maximum uniaxial stress occurs.

All BHF schemes for the different drawing ratios are passing just above the wrinkling limit. This is expected since the optimization objective is to minimize the maximum punch force, which is directly proportional to the BHF. Thus, the minimum possible BHF, which passes just above the wrinkling limit, corresponds to the minimum maximum punch force. The case of drawing ratio of 2.1 is shown in Fig.2 (b).



Fig.No.2 (b): Fracture at the side walls

Where the optimized BHF scheme is passing just above the wrinkling limit for the die coefficient of friction. For the low drawing ratio of 1.9, the optimum BHF scheme has a negative slope. However, for the drawing ratio of 2.2, the slope is positive. This study that there exists a break even point at which the optimum BHF scheme shifts from a negative slope to a positive slope. Also, this suggests that no general recommendation can be declared about which slope is better. In other words, the slope depends on the drawing ratio, where negative slope can be favorable for some drawing ratios and the positive be favorable for others.

From these results of the optimized cup, some relations are reduced for the intercept (V_0) and slope (V_1) of the BHF function. There is a general trend for the slope to increase with increasing the

drawing ratio in a linear manner. Thus, it is possible to reduce a general linear relation between the drawing ratio (B_0) and the BHF function slope (V_1) for all coefficient of friction.

Also, a second linear relation between the drawing ratio and the BHF function intercept (V_0) is observed. There is a tendency for the intercept value to decrease with the increase in the drawing ratio. From those two linear relations and the BHF equation a general relation between the BHF and the drawing ratio and the punch travel can be conducted as follows.

$$F_{BH} = 68.544 - 29.660 B_0 - 8.143L + 4.189 B_0L$$

5.2 Wrinkling

Wrinkling usually occurred on the flange at the sides of the rectangle (Figure 3). Since most of the BHF is concentrated on the corners where the metal thickness more, the sides of the rectangle cannot get enough pressure to restrain the metal and prevent wrinkling increasing the blank holder pressure at the sides of the rectangular blank using a multipoint pressure control system may improve the formability of rectangular pans.

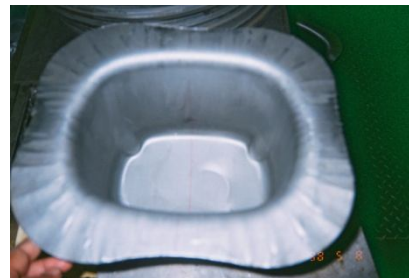


Figure 3: Wrinkling

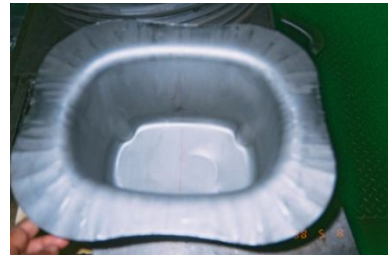
The wrinkling amplitude and the wavelength were measured on the selected pans using the Coordinate Measurement Machine (CMM). A sample measurement is shown in Figure6, where the flange locations are as indicated in Figure 1. A computer code was used to find the peaks and valleys in the surface profile measurements, and to calculate the wrinkling amplitudes and wave lengths. These calculations are used as the basis for the following discussion.

To determine the formability limits, a method has to be developed to quantify both wrinkling and fracture. For this purpose, a number of pans were formed to different heights using each blank shape with various BHF's. Measurements of wrinkling amplitudes on such experiments using oval blanks are shown in Figure 7. By visual inspection, the upper and lower control limits for the wrinkling amplitude are set at 0.08 mm and 0.08 mm and 0.05 mm, respectively.

These limits depend upon the application, material, and process conditions. The effect of blank shape on wrinkling is shown in Figure 8. In this figure, wrinkling amplitude measurements on three pans formed to 32 mm depth less than 30 tons BHF are plotted together. Due to the non-symmetry in the tooling, the wrinkling amplitude measurements vary at different locations on the pan as illustrated by Figures 1 and 5. Wrinkling and fracture limits for rectangular pans formed from different blank shapes are shown in Figure 9. These limits are determined for a wrinkling amplitude of 0.08 mm. As shown in Figure 9. The rectangular blanks showed higher wrinkling and fracture limits. Wrinkling was also predicted in the process simulations using FEA.

Fracture was predicted by means of a sudden drop in the punch force measurements during the experiments, and extensive localized stretching during the simulations. This type of defect usually occurs on the flange at the sides (flange wrinkling). The BHF is sides of wall (side wrinkling). The BHF is concentrated on the corners, where the metal thickness more, the sides of the cup cannot get enough pressure to restrain the metal and prevent wrinkling. Increasing the blank holder pressure at the sides of the circular blank using multipoint pressurized control systems is to improve the formability and drawability of cylindrical cups.

The wrinkling defects were measured on the selected cups by using a coordinate measurement machine (CMM) or flexible arm illuminated magnified which magnification is 110 X.



a



b

Fig No.5. Wrinkling defects
(a) Flange wrinkling (b). Side wrinkling

Wrinkling was also predicted in the process simulations using FEA. The deformed cup with severe wrinkling as predicted by using a BHF of 70 N/mm².

Fracture was predicted by means of a sudden drop in the punch force measurements during the experiments, and extensive localized stretching during the simulations [8]. BHF control to prevent wrinkling, fracture and thinning.

A set of experiments was performed to show the effects of the BHF control on the fracture, wrinkling cylindrical cups. In these experiments circular blanks from EDD steels were formed.

Initial experiments were done using a constant BHF of 50 N/mm², 60 N/mm², 70 N/mm², 80 N/mm², 90 N/mm² and 100. N/mm². Fracture occurred at 34 mm. diameter, a BHF of 50 N/mm² minor wrinkles occurred. Therefore, in order to prevent wrinkling and fracture at the same time, a BHF as a function a time was developed. The BHF is high initially when wrinkling is more critical. However, the BHF is reduced towards the end of the stroke to ease the metal flow and to prevent fracture.

The punch force measurements using three different BHF values and variable BHF are shown in Fig.12. Starting

with a large BHF causes the punch force to increase steeply, at the same time it suppresses wrinkling initiation. The BHF was reduced at a punch travel of 18 mm and was dropped down to 70 N/mm². At a punch travels of 38 mm. The wrinkling a height was significantly reduced by controlling the BHF as a function of stroke.

6. Results and Discussion

6.1 Effect of BHF on the formability

BHF determines the work pieces of the EDD steel alloy can be formed without defects. BHF's are selected 50 N/mm², 60 N/mm², 70 N/mm², and 80 N/mm², 90 N/mm² and 100. N/mm².

When BHF's are lower, the blank is difficult to be formed because of wrinkling on the flange. A cup can be drawn successfully using a drawing ratio of 1.68 with a BHF of 70 kg/cm² and cushioning pressure =120 kg/cm². Blank with diameter of 164.5 mm with different BHF's.. BHF is an important parameter in the deep drawing process. It is used to suppress the formation of wrinkles that can appear in the flange of the drawn part. When increasing the BHF, stress normal to the thickness increases which restrains any formation of wrinkles. However, the large value of the BHF will cause fracture at the cup wall and punch profile. So, the BHF must be set to a value that avoids both process limits of wrinkling and fracture.

7. Summary and conclusions

(i) Circular pans have been formed from the EDD steel alloys. The effect of process parameters such as initial blank shape and the blank holding force on the final part quality (i.e., wrinkling, fracture) has been investigated. During the initial experiments, it was found the oval blank shape had the worst formability, from a fracture point of view, among the three blank shapes (i.e.; oval, oblong, and rectangle). The oval shapes reduced the fracture limit of EDD steel alloys. However, it caused smaller wrinkling heights in the flange along the sides of the conclusion about the

optimum blank shape, more experiments are necessary.

- (ii) The defect of wrinkling occurs easily in this process of EDD steel alloy sheets. It is to avoid wrinkling of blank by selecting the correct BHF's, decreasing friction, increasing the tool edge radius and reducing the deep drawing depth all together in one operation.
- (iii) EDD steel alloys drawn work pieces show strong anisotropic deformation behavior on the flanges.
- (iv) The suggested incremental analytical model has been successfully implemented into a genetic algorithm to optimize the BHF scheme that minimizes the punch drawing force. The linear optimized BHF scheme of equation (3) can be useful in industry if it is required to determine the optimum linear BHF scheme for any drawing ratio. It is worth noting that this relation is only applicable to the cup under study. Further analysis will need to be carried out for other cups in order to determine if the BHF slope and intercept vary linearly with the drawing ratio for any cup.
- (v) Fracture defect is eliminated with proper chosen BHF, increasing the punch radius, decreasing friction.
- (vi) Control of the (BHF) as a function of time improves the formability and the quality of the final part. However, BHF control in time is not enough by itself. Since the deformation characteristics are not uniform around the periphery of the rectangle, the BHF has to be controlled as a function of location, too. Metal flow can be controlled by using draw beads on the sides of the rectangle. However, blank holding pressure may still be necessary to eliminate the wrinkles completely [5]. Additional experiments will be performed at the Pennar Industries Limited.

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