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# Optimization of the blank holder force in cup drawing

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**Analysis and modelling**

## ABSTRACT

**Purpose:** Develop an optimization strategy for the cup drawing process in order to produce a defect free deep drawn cup.
**Design/methodology/approach:** An optimization strategy for the blank holder force (BHF) scheme is proposed which searches for the BHF scheme that minimizes the maximum punch force and avoids process limits. This strategy is applied to the linearly varying BHF scheme and compared to the constant BHF.
**Findings:** The optimized linear BHF scheme resulted in an improved cup forming when compared to that produced by the constant BHF scheme. The BHF scheme is optimized for different cases of drawing ratios and die coefficients of friction in order to analyze the nature of the optimum linear BHF scheme. It was found that the slope of the linear BHF scheme increases with the increase in the drawing ratio in a linear manner. Also, the intercept of the function showed a nearly linear variation with the drawing ratio. A general equation is deduced for the optimum blank holder force at any drawing ratio for the cup under study.
**Research limitations/implications:** The proposed optimization strategy can be applied to BHF schemes other than the linear one, and with different objectives. In this scheme, the objective has been the minimization of the maximum punch load. Other objectives like minimum punch work may be implemented.
**Practical implications:** The proposed optimization strategy can be applied to any deep drawn part if an analytical or numerical model is available for this part.
**Originality/value:** The research presented in this paper offers a new optimization strategy which can be useful in controlling the process parameters to produce a defect free deep drawn part using optimum process conditions.
**Keywords:** Numerical techniques; Computational mechanics; Plastic forming; Cup drawing; Blank holder force optimization

## 1. Introduction

The main concern of the deep drawing industry is to optimize the process parameters in order to get a complete deep drawn product with least defects and high limiting drawing ratio (LDR). In order to achieve this optimization objective, a large number of solution runs need to be performed in order to search for the optimum or near optimum solution. Most researchers have been using experimental design or finite elements for process optimization [1-8].

Carrying out the optimization process through experimental design approach would require many runs in order to fit a proper objective function depending on the number of variables and the degree of fitting. Also, the use of finite elements to evaluate the function will require a lot of time which would reach one hour for one function evaluation on a 2.5GHz computer processor. This time can vary depending on the part geometry, material properties, loading conditions, and FE model. At some cases it will need months to satisfy an optimization objective. Therefore, a less time consuming approach is more reasonable and practical if optimization or process design is the objective. An appropriate and less time consuming solution approach is the analytical one. However, there has been no complete closed form solution for the simple problem of deep-drawing a cylindrical cup. Still, a complete analytical solution of the problem requires the use of numerical analysis.

In part I of this work [9], an analytical model was developed for the cup drawing process to solve for the induced stresses and strains over the deforming sheet at any stage of deformation until a full cup is formed. The model is established on the solution of force equilibrium and plasticity relations using finite difference method.

The aim of the present study is to develop an optimization system to be used in determining the optimum BHF scheme that minimizes punch force without running into any of the two process limits; wrinkling and tearing. The optimization process utilizes the recently developed analytical/numerical solution [9, 10].

## 2. Methodology

Blank holder force (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.

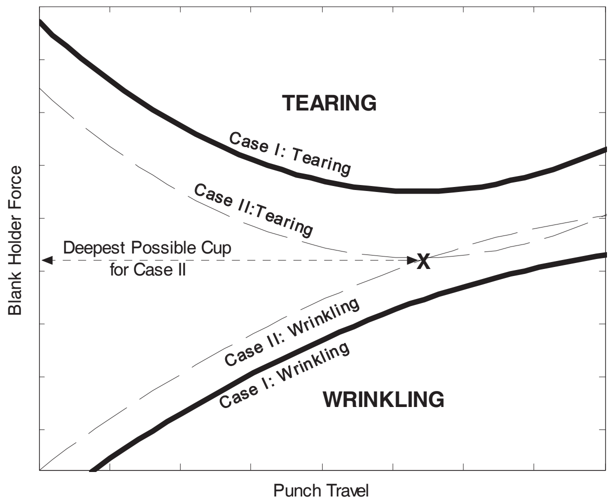


Fig. 1: Forming Process Window

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. The range of suitable values is called the process window which can be shown in Fig. 1, which is shown for two cases. The first case (bold lines) has a large range of values for the BHF that gives a complete cup without hitting any of the two limits. The second case (dashed lines) has overlapping process limits, which limits the maximum possible punch stroke above which wrinkling and/or tearing would occur.

Besides avoiding both process limits (wrinkling and tearing), it is desirable to have a deep drawn component with uniform thickness, which means less thinning. A direct link to the sheet thinning is the punch force. For higher values of the punch force, more thinning is expected. This is due to the fact that the punch force is directly related to the radial stress in the sheet. Therefore, in order to have less thinning in the drawn part, the maximum punch force must be reduced. This can be achieved by controlling the value of the BHF throughout the process.

## 3. Approach for optimizing the blank holder force

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

- **Objective function:** Minimize the maximum punch force in the cup deep drawing process. The maximum punch force, $(F_P)_{max}$, is determined as the maximum value obtained from the following equation (referring to Fig.2.)

$$F_P = 2\pi r_1 t_1 (\sigma_r)_1 \sin\theta \tag{1}$$

where,
$r_1$ = radial position of sheet at point (1) (die lip)
$t_1$ = thickness of sheet metal at point (1)
$\sigma_r$ = radial stress at point (1)
$\theta$ = angle of contact between the sheet and the die profile

Then, $(F_P)_{max} = \max(F_P)$

- **Design Variables:**

1. Initial value (intercept) of the BHF function ($v_0$)
2. Slope of the BHF function ($v_1$) (either positive or negative slope)

Such that the function is:

$$F_{BH} = v_0 + v_1 L \tag{2}$$

where,
$v_0$ = Initial value (intercept) of the BHF function
$v_1$ = Slope of the BHF function
L = Punch travel

- **Constraints:** Avoid wrinkling and tearing such that at each punch travel (L) increment, the following relations must be satisfied: $F_{BH} > F_{wrinkling}$ and $F_{BH} < F_{tearing}$

The wrinkling criterion used in this analysis is based on a semi-empirical work carried out by Kawai [11]. As for the fracture criterion, it is based on the notion that necking is assumed to occur at the point where maximum uniaxial stress occurs in the material. This point is usually located at the punch nose, i.e. at radial position $r_2$. This criterion was discussed by Marciniak [12] and applied by Ahmetoglu et al [13].

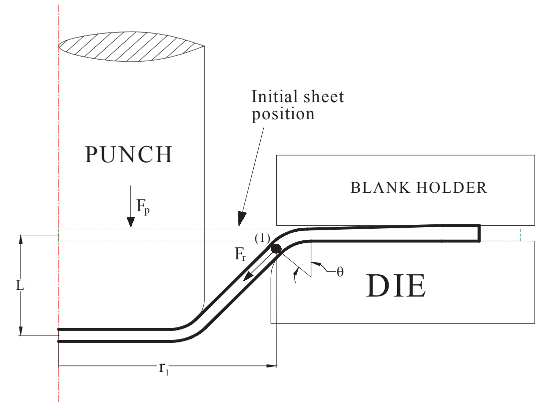


Fig. 2: Punch force in cup drawing

## 4. Optimization search method

In order to achieve the optimization objective, genetic algorithms (GAs) are used. This global search method is found to be most suitable due to the multi-modal nature of the objective function at hand. If a local search method is used, it usually fails to find the global minimum of the function by falling into a local minimum. Genetic algorithms are known to be able to search through all of the function space, thus it can detect the global minimum of the function[14].

## 5. Results and discussion

Optimization of the BHF scheme is attempted for two cup models. The first is used to compare the optimized BHF scheme with the constant BHF scheme, while the second is used to analyze the nature of the optimized BHF scheme. The following is a description of the two cases investigated.

### 5.1. Cup drawing with constant BHF versus linear BHF scheme

The optimized scheme is compared with a constant BHF of 100kN given by the experimental results of Saran et al. [15]. It was recognized that the use of the linear BHF scheme decreased the punch force over all stages with a maximum of 6%.

The thickness strain distribution for the two cases of constant and optimized linear BHF schemes showed that the maximum thinning has decreased by 22% using the optimized linear BHF scheme. This decrease in thickness strain provides a more uniform thickness at the punch bottom which is a major requirement in the cup forming process.

### 5.2. Nature of the optimized BHF scheme

It is of interest to investigate the nature of the optimized BHF scheme and how it is affected by varying the process and die parameters. Two parameters seem to be most influential here namely the drawing ratio ($B_0$) and the die coefficient of friction ($\mu_D$). Five drawing ratios are investigated with $B_0$ equals 1.9, 1.95, 2.0, 2.1, and 2.2. For each drawing ratio, four die coefficients of friction (0.045, 0.06, 0.1, and 0.13) are considered. The details of the investigated cup are as follows:

**Geometry**

$t_o = 0.89mm$
$R_a = 50mm$
$\rho_d = 10mm$
$\rho_p = 5mm$
$r_d = 26.068mm$
$r_e = 25mm$

**Loading**

$F_{BH} = 17KN$
$\mu_{BH} = \mu_{DP} = \mu_{PP} = 0.13$

**Material: AL7075-T6**

Based on the flow equation:

$\bar{\sigma} = C\bar{\varepsilon}^n$
$C = 756.6MPa$
$n = 0.0782$
$E = 65GPa$
$\nu = 0.33$
Density = 2796 $Kg/m^3$

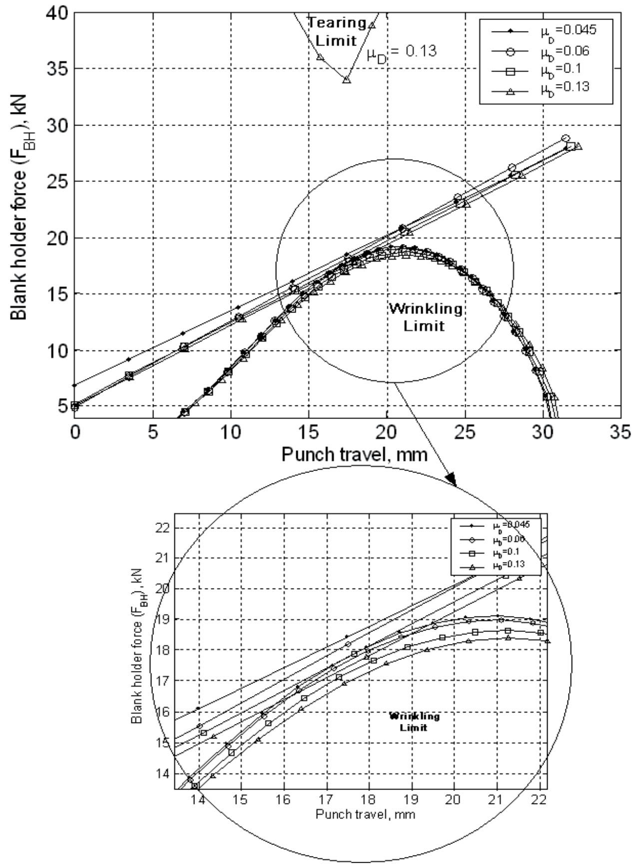


Fig. 3. BHF scheme for a drawing ratio of 2.1

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. 3, where the optimized BHF scheme is passing just above the wrinkling limit for the four die coefficient of frictions.

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 shows 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 the results of the optimized cup, some relations are deduced for the intercept ($v_0$) and slope ($v_1$) of the blank holder force 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 deduce a general linear relation between the drawing ratio ($B_0$) and the BHF function slope ($v_1$) for all coefficients 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 (2), a general relation between the BHF and the drawing ratio and the punch travel can be concluded as follows.

$$F_{BH} = 68.544 - 29.660B_0 - 8.143L + 4.189B_0L \quad (3)$$

## 6. Conclusion

The suggested incremental analytical model has been successfully implemented into a genetic algorithm to optimize the blank holder force 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.

Optimization of the BHF scheme needs to be carried out on other cup models in order to determine the validity of the linear relation between the BHF function slope and intercept with the drawing ratio. Optimization can be carried out for other BHF functions to determine if there are other types of functions that can give better results than the linear function.

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