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# Effect of Friction Factor on Wrinkling and Fracture Limits in Deep Drawing of Cylindrical Cup

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**Abstract**

Wrinkling and fracture are the important defects in deep drawing operation, which can be prevented using blank holding force (BHF) which has to be optimized as lower BHF promotes wrinkles formation and higher BHF promotes fracturing. Hence the limits of wrinkling and fracture have to be established. These limits depend on various tooling and process parameters. In this work the effect of tooling parameters like die corner radius and punch corner radius on wrinkling and fracture limits are investigated using a finite element explicit solver LS-DYNA. Constant BHF is considered for analysis.

**Key Words:** Deep drawing, BHF, friction factor, Drawing Ratio (DR), wrinkling limit, fracture limit, LS-DYNA.

## 1. Introduction

In the deep drawing process, a punch pushes a sheet metal blank into a die cavity, resulting in a contoured part. A part is said to be deep drawn if the depth of the part is at more than half of its diameter. Otherwise, it is simply called shallow drawing [1].
One of the primary defects that occur in deep drawing operations is the wrinkling of sheet metal material, generally in the wall or flange of the part. The flange of the blank undergoes radial drawing stress and tangential compressive stress during the stamping process, which sometimes results in wrinkles. Wrinkling is preventable if the deep drawing system and stamped part are designed properly.

Wrinkling in the flange occurs due to compressive buckling in the circumferential direction. Fracturing occurs because of high tensile stresses that cause thinning and failure of the metal in the cup wall. The blank holder, as the name implies, holds the edges of the sheet metal blank in place against the top of the die while the punch forces the sheet metal into the die cavity the sheet metal deforms into the proper shape, instead of simply being pulled into the die cavity.

The blank holder, however, does not hold the edges of the blank rigidly in place. If this were the case, tearing could occur in the cup wall. The blank holder allows the blank to slide somewhat by providing frictional force between the blank holder and the blank itself. Blank holder force can be applied hydraulically with pressure feedback, by using an air or nitrogen cushion, or a numerically controlled hydraulic cushion.

The greater the die cavity depth, the more blank material has to be pulled down into the die cavity and the greater the risk of wrinkling in the walls and flange of the part. The maximum die cavity depth is a balance between the onset of wrinkling and the onset of fracture, neither of which is desirable. The radii degrees of the punch and die cavity edges control the flow of blank material into the die cavity. Wrinkling in the cup wall can occur if the radii of the punch and die cavity edges are too large. If the radii are too small, the blank is prone to tearing because of the high stresses.

## 2. Finite Element Modeling

The FE Model of forming a cylindrical cup of 25mm diameter and 13mm deep is shown in Fig.

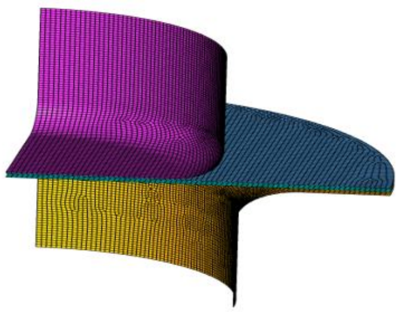


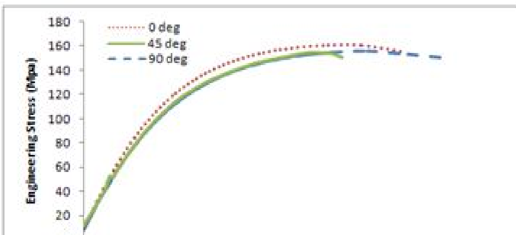
Fig .1 Finite Element Model

Based on the symmetry boundary condition a quarter of the geometry is modeled. In sheet metal forming, generally, membrane element or continuum element or shell element are employed [1]. Since membrane elements lack the bending stiffness and the continuum element takes higher computation time, the blank is modeled with shell elements at the mid plane with Belytschko formulation and with five through thickness integration points. Punch, die and blank holder are taken as rigid materials. Commercially pure Aluminum of 99.5% (AA- 1100) is chosen as blank material. The element size is decided by the convergence of punch load as done by Jamal Hematian [2].

To identify the Material model and find out the material properties, tensile test specimens of ASTM Standard size, shown in Fig 2, are prepared from the sheet. The pieces are cut in the rolling direction, $45^0$ to rolling direction and transverse to the rolling direction. The pieces are tested on universal testing machine (INSTRAN 4507 MODEL).

Fig. 2 Tensile test Pieces of AA -1100

From the figures 3 and 4, it is observed that there is no significant variation in properties with the direction of rolling. So one of the curves, the one in the rolling direction is chosen as material property input. For the selected stress-strain curve, the log-log graph is plotted and presented in figure 5. From the figure it is observed that the plot is a straight line indicating that the material follows power law plasticity model, $\sigma = K \varepsilon n$ , Where $\sigma$ is the true stress K is strength coefficient (exponent of Y-intercept in Fig. 5), $\varepsilon$ is the true strain and n is the strain hardening index (the slope of the line in Fig 5.)
Strain rate dependency is not considered, since Aluminum alloys are strain rate sensitive only at high temperatures. The properties obtained from the tensile test that are input to LS-DYNA are listed in table 1[3].
The Engineering stress-strain and true stress-strain curves are presented in Fig. 3 and Fig. 4 respectively.



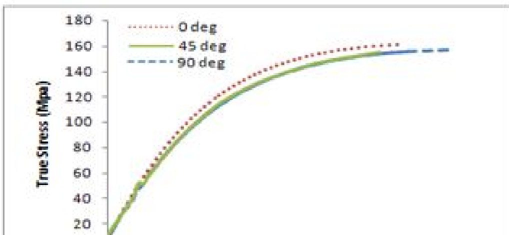




Fig.3& Fig.4:-Engg. stress-strain and true stress-strain

## 3. Experimental Validation

Validation of the FE model is carried out by comparing the force obtained from the experiment with that in simulation. The experimental setup, as shown in Fig.5, consists of a 15Ton hydraulic press interfaced to the computer with the load cells through digital force indicator.

The blank holding schema obtained from the experiment (operating the press without blank), shown Fig.6, is applied in the simulation. Since spring loaded blank holder is used, the schema should be linear. The same is evident from the graph with little variation due to experimental error. The force obtained from the experiment is shown in Fig.7 and by simulation in Fig.8.

Fig 5: Experimental set up

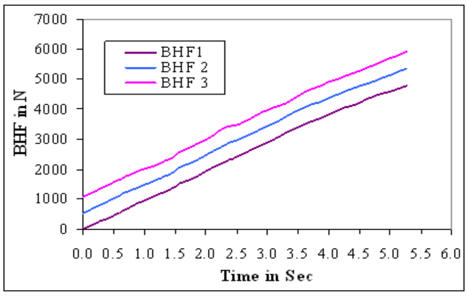



Fig 6 BHF obtained from the experiment

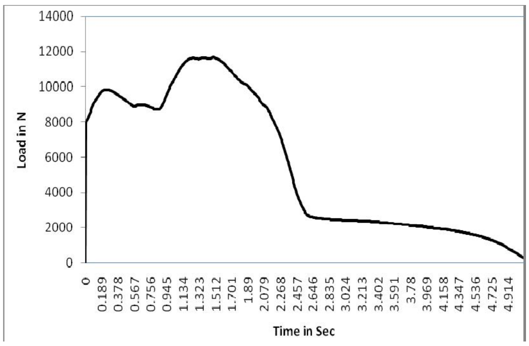



Fig 7 :Transient load v/s time diagram obtained from the experiment

The maximum force obtained from the experiment is 11.58 kN and from the simulation, it is found to be 2.698kN..

Since, it is a quarter model, the actual force obtained from the simulation is four times of the value given by the simulation i.e 10.79 kN. The deviation from the experimental result is 7% [4]. Since the power law model underestimates the punch load4, the deviation is acceptable and thus model is assumed to be validated. Another reason for this discrepancy may be due to non-isotropic hardening during forming operation

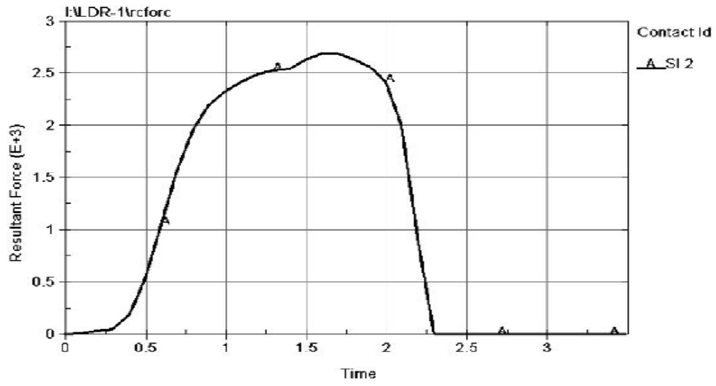



Fig. 8: Load v/s time diagram obtained in simulation

## 4. Results and Discussion

Simulations are carried out to find out the wrinkling and fracture limits for various process parameters i.e., friction factor are presented following the section.

After validation, the further simulations are carried out to find wrinkling and fracture limits at various friction factor values.

For wrinkling limit initially some BHF is orbiterly chosen and a simulation is carried out. If wrinkling, appear the BHF is increased else it is decreased. The same is carried out till the minimum BHF where a wrinkle does not appear. The minimum BHF thus find out is the wrinkling limit. Similarly at the BHF orbiterly chosen it is observed whether the fracture occurs. If fracture occurs the BHF is reduced else it is increased. This iterative process is carried out till the maximum BHF where fracture does not occur found out. The maximum BHF thus find out is the fracture limit. Fracture is estimated from Von Mise’s stress based on the fact that, if Von_Mise’s stress is more than ultimate tensile stress of the material, there will be fracture.

**Effect of friction factor on wrinkling limit**

By using LS-DYNA wrinkling limit in the circular cups can be studied. The LS-DYNA in deep drawing process besides depending on the material, process parameters and also depends on the contact boundary conditions. Wrinkling analysis is performed using only the flange region in the cup. The objective is to study of the wrinkling defect in a circular cup, for the given set of process parameter i.e., friction factor, when the full blank is analyzed.

**Simulations for friction factor=0.015**

After validation, further simulations are carried out to find out the wrinkling limits at various drawing ratios, friction factors and blank thickness. A sample simulation for each case is presented. Results at drawing ratios 1.8 and 2, friction factor values are from 0.015 to 0.18 and blank thickness values 1 mm and 1.5 mm are also presented.

The friction factor has an important factor, influences on the onset of wrinkling in deep drawing. Effect of BHF is one of the important process parameters controlling the wrinkling in deep drawing. The change in the onset of wrinkling is studied for various values of the BHF. The analysis is performed with the values of BHF 60N,80N and 100N, blank thickness is 1mm, friction factor 0.015, the tooling geometry also remain the same i.e., die corner radius is 3mm and punch corner radius is 2mm and drawing ratio is 1.8. The material is AA-1100. As a sample of simulation, the wrinkling limit is presented from fig. no's 4.23 to 4.25.

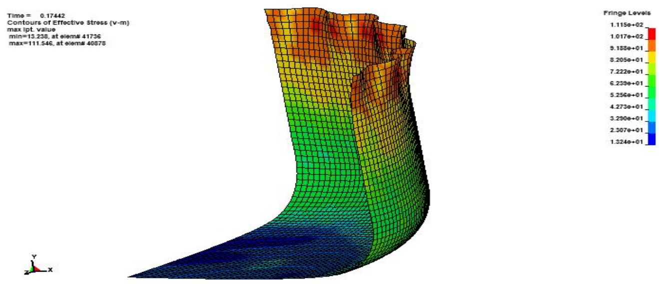


Fig. 9 Cup drawn with BHF = 60N (wrinkles appeared)

From the fig.9 it is observed that, wrinkles are formed at the BHF 60N. So the BHF is increased to 100N and simulation is carried out and cup drawn is presented in fig.10 and it shows the no wrinkles are forming. In between the BHF value 60N and 100N, no. of iterations are performed to determine the wrinkling limit. The BHF is reduced to 80N and simulations are carried out is as shown in fig.11, wrinkles are not appeared at BHF 80N also .Therefore the BHF 80N is the wrinkling limit.

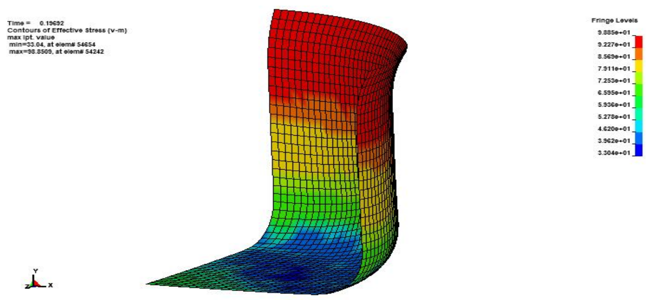


Fig. 10 Cup drawn with BHF= 100N (wrinkles not appeared)

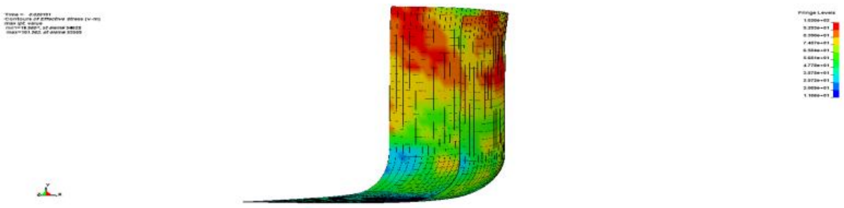


Fig. 11 Cup drawn with BHF= 80N (wrinkles not appeared)

It is observed from fig. no's from 9 to 10 for friction factor is 0.015 and thickness 1mm, that the onset of wrinkling gets delayed with an increase in the BHF. The onset of wrinkling occurs at a higher cup height if the BHF is increased. This is the confirmation with the fact that the higher BHF delays the wrinkling. Similarly no. of simulations is performed of varying friction factor. Variation of the wrinkling limits with friction factor from 0.015 to 0.18 is presented.

**Effect of friction factor on fracture limit**

By using LS-DYNA fracture limit in the circular cups can be studied. The LS-DYNA in deep drawing process besides depending on the material, process parameters and also depends on the contact boundary conditions. Fracture analysis is performed only the flange region and in the cup respectively. The objective is to study the fracture defect in a circular cup, for the given set of process parameter i.e., friction factor, when the full blank is analyzed.

**Simulations for friction factor=0.015**

After validation, the further simulations are carried out to find out the fracture limits at various drawing ratios, friction factors and blank thickness. A sample simulation for each case is presented. Results at drawing ratios 1.8 and 2, friction factor values are from 0.015 to 0.18 and blank thickness values are 1 mm and 1.5 mm are also presented. The friction factor has an important parameter, which influences on the fracture in deep drawing. Effect of BHF is one of the important process parameters controlling the fracture in deep drawing. The change in the fracture is studied for various values of the BHF. The analysis is performed with the values of BHF, blank thickness is 1mm, friction factor 0.015,the tooling geometry also remains the same i.e., die corner radius is 3mm and punch corner radius is 2mm and drawing ratio is 1.8. The material is AA-1100.

A sample to find out the fracture limit is presented from fig. no's 12 to17. Fracture is estimated from Von- Mise's stress. If the Von-Mise's stress is more than ultimate tensile strength of the material i.e., 110MPa, it is known as the cup fractures. From the fig.12 it is observed that, the fracture is appeared at BHF 4800N. So the BHF is reduced to 4400N and simulation was carried out, fracture is appeared is as shown in fig.13. In between 4800N and 4400N no. of iterations performed to find out the fracture limit. At BHF 4700N, 4600N and 4500N fracture appeared. Therefore the

BHF value is again reduced to 4000N and simulation is carried out. Fracture does not appear at this BHF value is as shown in fig.14. Therefore the BHF 4000N is the fracture limit.

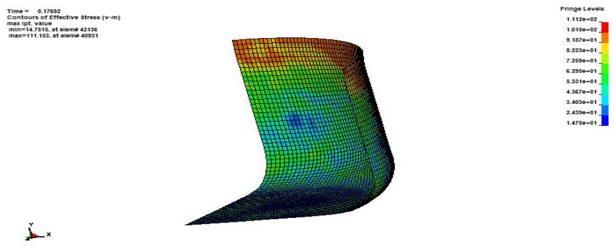


Fig. 12 Cup drawn with BHF= 4800N (fracture appeared)

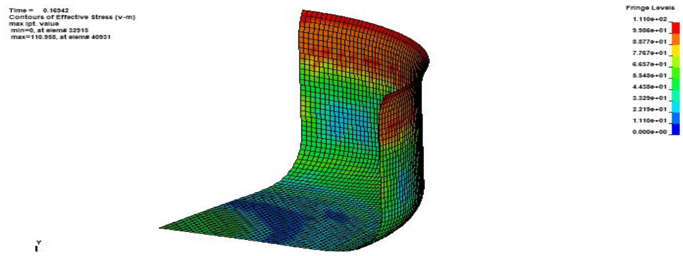


Fig. 13 Cup drawn with BHF= 4400N (fracture appeared)

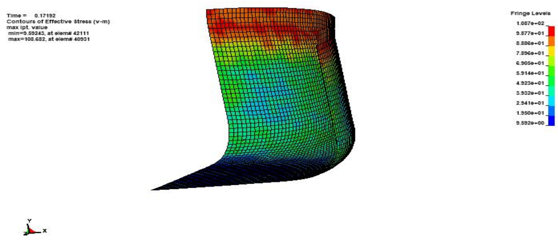


Fig. 14 Cup drawn with BHF= 4000N (fracture not appeared)

It is observed from fig. no's from 12 to 14, for friction factor 0.015, thickness 1mm and fig. no's from 15 to 17 for friction factor 0.015, thickness 1.5mm that the fracture gets delayed with an increase in the BHF. That is the fracture occurs at a higher cup height if the BHF is decreased. This is in confirmation with the fact that the lower BHF delays the fracture.

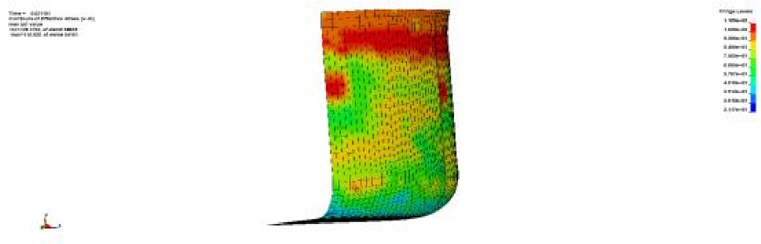


Fig. 15 Cup drawn with BHF= 4700N (fracture appeared)

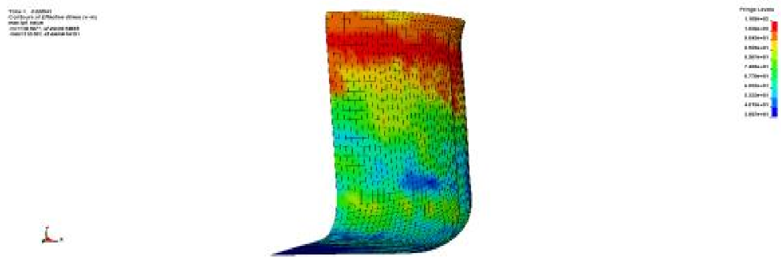


Fig. 16 Cup drawn with BHF= 4600N (fracture appeared)

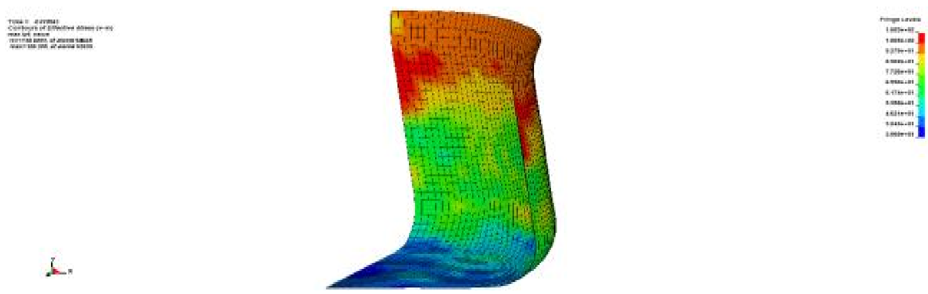


Fig. 17 Cup drawn with BHF= 4500N ( fracture not appeared )

Similarly no. of simulations is performed of varying friction factor. Variation of the fracture limits with friction factor from 0.015 to 0.18 is presented.

## 5. Variation of the wrinkling and fracture limits with the values of variation of friction factor with DR (β) = 1.8 and blank thickness is 1mm

The effect of friction factor for drawing ratio (β)= 1.8 and blank thickness is 1mm on wrinkling and fracture limits are studied and presented in fig. 18.

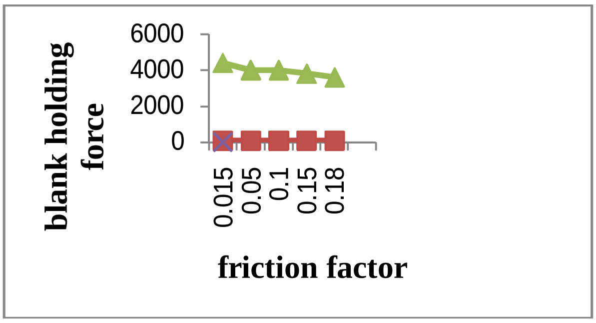



Fig.18 DR (β) 1.8 and blank thickness =1mm

From the above fig.18 it is observed that, wrinkling limit almost remain constant at BHF 10N with the variation of friction factor, but the fracture limit decreases with the increasing of friction factor, and it is varying from the BHF 4400N to 3600N. It may be due to the increase of the punch force on the side wall.

**DR (β) =2 and blank thickness =1mm**

Similarly the variation of the wrinkling and fracture limits with the friction coefficient for the drawing ratio 2 is presented in figure no. 6.4. In the below mentioned figure, the friction coefficient is taken on horizontal axis and blank holding force is taken on vertical axis.

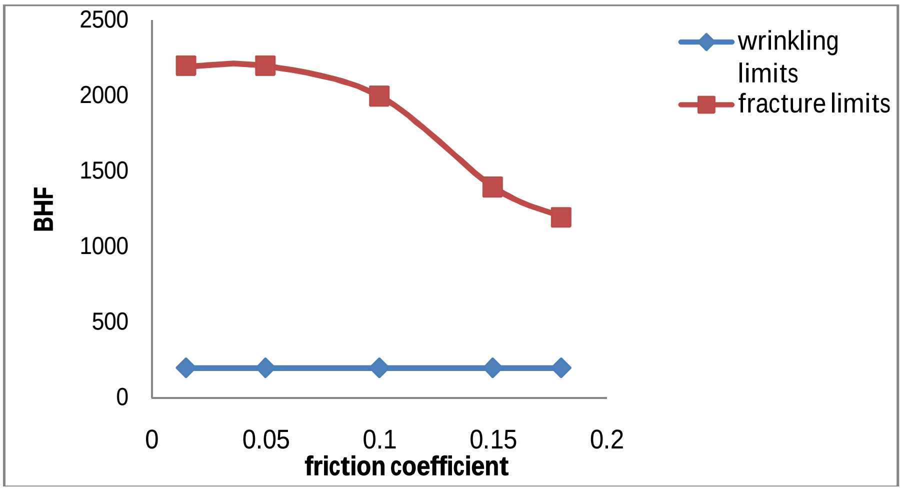



Fig.19 DR (β) 2, blank thickness = 1mm

From the above fig.19, it is observed that wrinkling limit is constant at 200N with the friction coefficient and fracture limit decreases with the increasing of friction coefficient, it is varying from 2200N to 1200N. By comparing the two figures i.e., fig.18 and fig.19 of variation of wrinkling limits with friction coefficient for drawing ratios 1.8 and 2. The fracture limit is varying from 4400N to 3600 N for the drawing ratio 1.8. Hence the same is varying from 2200 N to 1200 N for the drawing ratio 2.

The fracture limit of drawing ratio 2 is nearly half of the fracture limit of drawing ratio of 1.8. Similarly the variation of wrinkling and fracture limits with friction factor for blank thickness 1.5mm with the drawing ratio 1.8 are carried out, is as shown in fig. 20. The below mentioned fig. friction factor is taken on horizontal axis and blank holding force is taken on vertical axis.

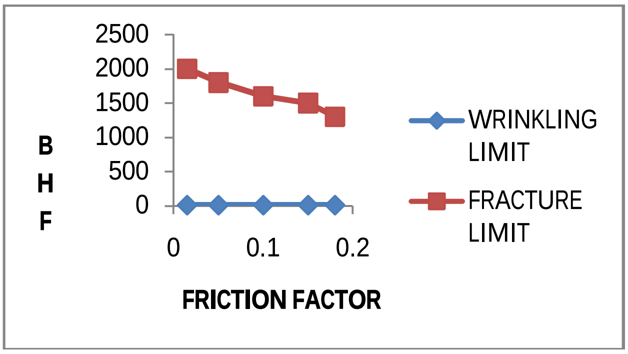



Fig. 20 DR (β) 1.8, blank thickness 1.5 mm

**Variation of the wrinkling and fracture limits with the values variation of blank thickness**

Similarly the variation of wrinkling and fracture limits with the friction coefficient for blank thickness 1.5 mm and drawing ratio 2.0 is as shown in fig.21. The below mentioned fig. the friction factor is taken on horizontal axis and the blank holding force is taken on vertical axis.

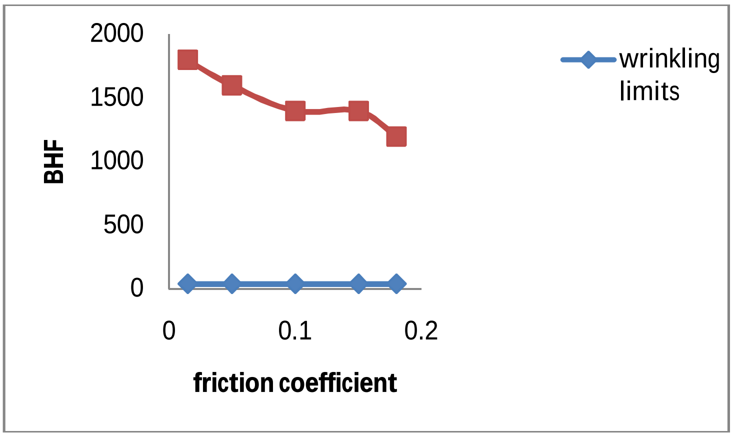



Fig. 21 DR = 2.0 and blank thickness 1.5 mm

From the fig.21 it is observed that, wrinkling limit is remain constant at BHF 10N. The fracture limits decreases with the friction coefficient for blank thickness. It may be due to the increase of the punch force on the side wall.

By comparing the two figures i.e., fig.21 and fig.20, variation of the wrinkling and fracture limits with friction factor or friction coefficient for blank thickness 1.5mm.

The fracture limit is varying from 2000N to 1300N for drawing ratio = 1.8, the blank thickness 1.5 mm and drawing ratio = 2.0. The same is varying from 1800N to 1300N for drawing ratio 2 and the blank thickness 1.5 mm. The fracture limit of drawing ratio = 1.8for 1.5 mm blank thickness is 10 to12 % more than the fracture limit of the 1.5 mm blank thickness.

## Conclusions

It is found that while the process parameter i.e., friction factor in the interfaces of blank holder-blank and blank-die has less significant affect on wrinkling limit, it has very significant effect on fracture limit.

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