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Numerical Analysis On The Effect Of Various Parameters On Fracture Limit For Deep Drawn Cups ☆

B.V.S.Rao[1], G. Chandra Mohan Reddy[2], G. Krishna Mohana Rao[3], P.V.R.Ravindra Reddy[4],

1,2 & 4, Department of Mechanical Engineering, CBIT, Gandipet, Hyderabad-75.
Ph: 9290545750, email: balivadarao@gmail.com
3. Department of Mechanical Engineering, JNTU College of Engg., Hyderabad

Abstract

Deep drawing is the process of converting a blank into cup shaped articles like kitchen sinks, cooking pans, automobile panels, gas tanks, fountain pen caps etc. Wrinkles and fractures are the major defects in deep drawn products. Fracture is the separation or fragmentation of a solid body into two or more parts under the action of stress. In deep drawn cups tearing is usually an open crack in the vertical wall which occurs near the base due to high tensile stress that causes thinning and fracture of the metals at this location. During this process the punch force acting on the bottom of the cup is transferred to the side of the cup. The narrow ring of metal just above the bottom of the cup is subjected to plane strain condition. As a result, failure of the cup easily happens in this zone due to necking induced by the tensile stress, leading to tearing. This type of failure can also occur on the flange as the metal is pulled over the sharp die corner. In addition to this sharp corner on the punch could also cause fracture of the cup along the corner. The objective of this work is to predict the fracture limit of deep drawn cups. This would help in preventing rejections in deep drawing industry. This can be achieved by setting the blank holder force appropriately. Also it would save material and reduce the total cost. In this work numerical simulations are conducted by considering five different parameters namely punch radius, die radius, clearance, coefficient of friction and punch diameter using finite element explicit solver LSDYNA. Modeling of the set up is done using hyper mesh. In this work simulations are carried out as per L-27 orthogonal array suggested by Taguchi. A combination of finite element method and Taguchi analysis is used to determine the influence of process parameters on fracture limit in deep drawing process. During analysis the value of optimum BHF is arrived by performing a number of trial runs. Also Column effect method and plotting methods are used for finding out the most influencing parameters and their interactions respectively for analysis. The studies reveal that punch diameter is most significant parameter for deciding fracture limit followed by die corner radius and clearance. In addition to this regression analysis is carried out for developing an empirical model using Minitab 17 for predicting fracture limit.

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Keywords: deep drawing, blank holding force, wrinkling, Taguchi approach, LSDYNA.

1.0 Introduction: Deep drawing is the process of converting a blank into cup shaped articles like kitchen sinks, cooking pans, automobile panels, gas tanks, fountain pen caps etc. Wrinkles and fracture are the major defects in deep drawn products. Fracture is the separation or fragmentation of a solid body into two or more parts under the action of stress. [1]. In deep drawn cups tearing is usually an open crack in the vertical wall which occurs near the base due to high tensile stress that causes thinning and fracture of the metals at this location. This type of failure can also occur on the flange as the metal is pulled over the sharp die corner. In addition to this sharp corner on the punch could also cause fracture of the cup along the corner.

In deep drawn parts the region just above the bottom of the punch is subjected to circumferential tensile stress and longitudinal tensile stress. Punch force acting on the bottom of the cup is transferred to the side of the cup. The narrow ring of metal just above the bottom of the cup is subjected to plane strain condition. As a result, failure of the cup easily happens in this zone due to necking induced by the tensile stress, leading to tearing. The maximum tensile force on the cup which causes tearing can be estimated from the plane strain condition as:

$F_{max} = 2/\sqrt{3}\ UTS\ \pi\ D_p t$ [1], [2] ----------------------------------(1)

Where UTS = ultimate tensile stress, Dp = Punch diameter, t = sheet thickness.

Fig.1 Fractured cup

It can be seen from the above formula that the parameters which influence the tearing process or facture limit are punch diameter, sheet thickness and UTS. The other parameters which influence the fracture limit are die corner radius, punch corner radius, clearance between die and punch, friction and blank holder force. The objective of this work is to predict the fracture limit of deep drawn cups through numerical simulations by considering five different parameters namely punch radius, die radius, clearance, coefficient of friction and punch diameter using finite element explicit solver LSDYNA. Modeling of the set up is done using Hyper mesh. In this work simulations are carried out as per L-27 orthogonal array suggested by Taguchi. A combination of finite element method and Taguchi analysis is used to determine the influence of process parameters on fracture limit in deep drawing process. Predicting fracture limit would help in preventing rejections in deep drawing industry. This can be achieved by setting the blank holder force appropriately. Also it would save material and reduce the total cost.

Nomenclature

Rp	Punch corner radius	BHF	Blank Holder force
Rd	Die corner radius	μ	Coefficient of friction
C	Clearance	Dp	Punch diameter
UTS	Ultimate Tensile Steam		

2.0 LITERATURE REVIEW ON FRACTURE LIMIT:

Investigation of damage behaviour for prediction of fracture initiation in deep drawing was carried by Saxena et.al.[3] In the research work carried out by them a parametric study has been proposed to investigate the effect of material, geometric and other process parameters on maximum cup height (i.e., the cup height at which the fracture occurs) in deep drawing. It was suggested that the maximum cup height (i.e., the height of cup at which the fracture initiates) increases with the sheet thickness, die profile radius and punch profile radius. In this study it was found that the plastic properties of material affect fracture initiation. In case of square cup fracture initiation is effected more by the plastic deformation in the corner regions and less by the triaxiality. Lou Yanshan et.al.[4] have investigated fracture mechanisms for determining fracture forming limits. In their research a new criterion was proposed considering damage accumulation induced by nucleation, growth and shear coalescence of voids. The equivalent plastic strain, the stress triaxiality, and the normalized maximal shear stress have been considered as a function of nucleation, growth and shear coalescence of void to represent a fracture model. In their research work fracture forming limit diagram has been suggested for dual phase steel sheets. The model suggested by them can predict ductile fracture in a stress triaxiality ranging from -1/3 to 2/3. A model based on anisotropic elasto-plastic and isotropic ductile damage for the prediction of damage in work-piece during stamping or forming of square cup of steel was proposed by Khelifa et.al.[5]. In their work a coupled approach was suggested in which the damage evolution equation is incorporated and coupled with the constitutive equations. The results obtained by numerical simulations have been compared with experimental results. The model proposed by them also predicts the elastic, plastic, and hardening behaviours. Ali et.al.[6] have investigated the deep drawing process to identify the region of punch stroke within which tear occurs. In case of components with light weight and with complex shapes it shows a small operating window. Also identification of critical tearing region enabled to develop strategy to produce parts without defects. Further this study revealed that if blank holder force is applied at an ultra- low frequency and synchronized with the punch force then BHF can be maintained within the process limits for the entire critical width of the critical tearing window and complex shapes may be produced. Tests have been conducted with blanks of steel and aluminium over a range of draw ratios. These tests have been conducted with different blank diameters in the range of 220-250mm, with frequencies, in the range of 1-10 Hz and amplitudes between 10 and 50 kN. Ravindra et.al [7] has investigated the effect of tooling parameters like punch profile and die profile using a finite element explicit solver LSDYNA. These studies were performed for AA1100. It was concluded by them that the fracture limit slightly increases with die radius and punch radius. Venkat Reddy et.al [8] have performed a study on the formability of rectangular or cylindrical parts from Extra Deep Draw (EDD) steels. In the work carried out by them wrinkling, fracture limits have been determined and BHF control methods have been developed to eliminate defects, improve part quality, and increase the draw depth. From all the above research works it is quite clear that determination of fracture limit by considering five parameters Punch corner radius (Rp), Die radius (Rd), Clearance (C), Coefficient of friction (μ) & Punch Diameter (Dp) for brass material is yet to be investigated completely. Hence this becomes potential area for studies to be carried out. In this work an attempt is made in this direction.

3.0 Methodology: As described in section 1.0 in this work five parameters are considered viz., Punch corner radius (Rp), Die radius (Rd), Clearance (C), Coefficient of friction (μ) & Punch Diameter (Dp) for the analysis of significant parameters. The methodology for carrying out the present work consists of: (i) Selection of parameters, (ii) Selection of their levels, (iii) The selection of suitable Orthogonal array (OA), (iv) Assignment of parameters to OA, (v) Simulations as per OA and (vi) Analysis of results.

3.1 FINITE ELEMENT MODELING

The FE Model of forming a cylindrical cup of 25mm diameter and 13mm deep is shown in Fig.2.

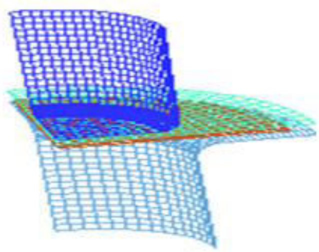

Fig. 2 Finite Element Model

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[2]. 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. Brass (IS:410, Grade CuZn40) is chosen as blank material. The chemical composition of the blank material chosen is indicated in table 1. The element size is decided by the convergence of punch load as done by Jamal Hematian[10].

Table 1: Chemical composition of blank material
(Brass IS:410 :1977 Grade-CuZn40)

Material	Cu	Pb	Fe	Mn	Si	Ni	Zn
Percentage	59.5	0.28	0.098	0.0001	0.0001	0.13	Rem

To identify the Material model and find out the material properties, tensile test specimens of ASTM Standard size, shown in Fig 3, are prepared from the Brass sheet. The pieces are cut in the rolling direction, 45^0 to rolling direction and transverse to the rolling direction as shown in Fig.4 using wire cut EDM. The pieces are tested on universal testing machine (INSTRON 4507 MODEL) shown in Fig.5 at AMTL Lab, a subsidiary of Midhani, Hyderabad.

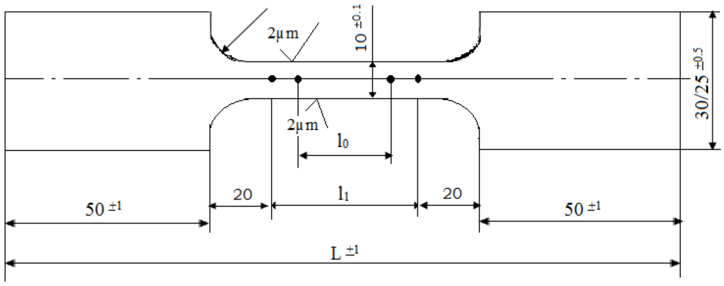

Fig. 3 Dimensions of tensile test specimen (in mm)

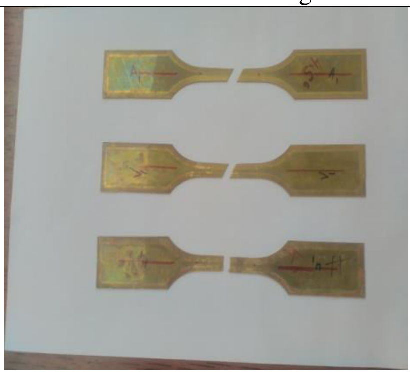

Fig. 4 Tensile test specimen of Brass

Fig. 5 Specimen after fracture on universal testing machine (INSTRON 4507)

The Engineering stress-strain and true stress-strain curves are presented in Fig. 6 and Fig. 7 respectively.

From the figures 6 and 7, 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. The plastic strain is computed ($\varepsilon^p = \varepsilon - \sigma/E$) and the flow curve is plotted and shown in Fig.8. The values of flow curve are given as input by choosing piece wise linear plasticity model.

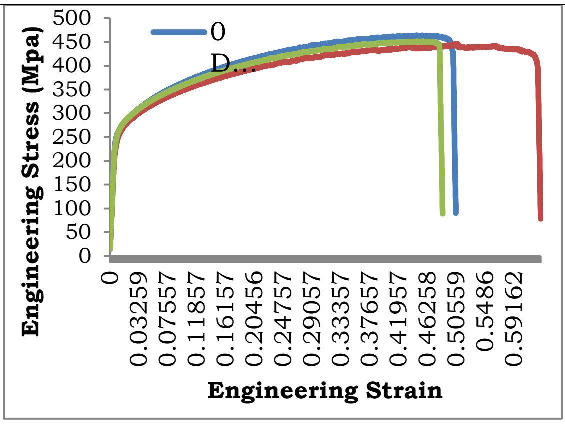

Fig. 6 Engg. Stress Strain Curve of Brass (IS:410)

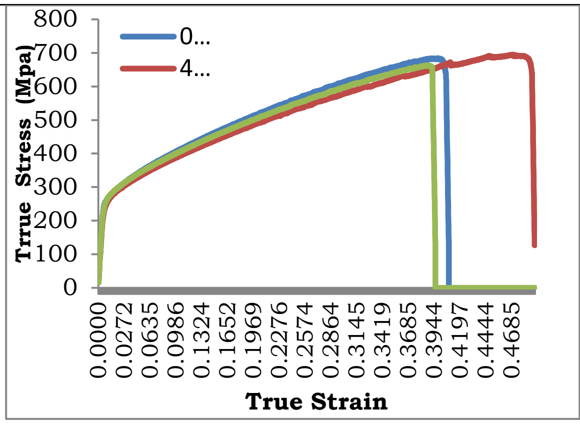

Fig. 7 True Stress Strain Curve of Brass (IS:410)

Strain rate dependency is not considered, since brass alloy is strain rate sensitive only at high temperatures.

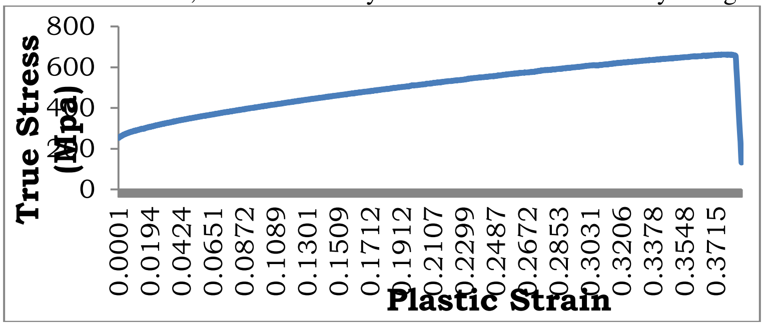

Fig. 8 Flow curve of the material

3.2 EXPERIMENTAL VALIDATION

Validation of the finite element model is carried out by comparing the force obtained from the experiment with that in simulation. The experimental setup, as shown in Fig.9, consists of a 25T 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.10, 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.11 and by simulation in Fig.12.

Fig. 9 Experimental setup

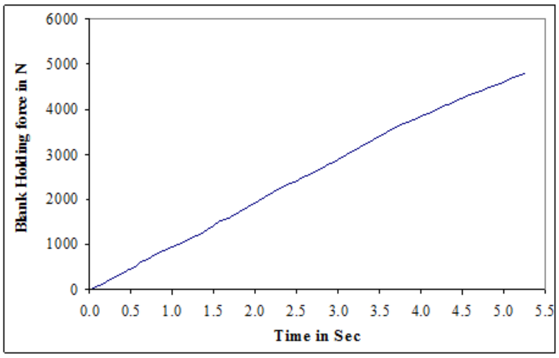

Fig. 10 BHF Schema Obtained from the experiment

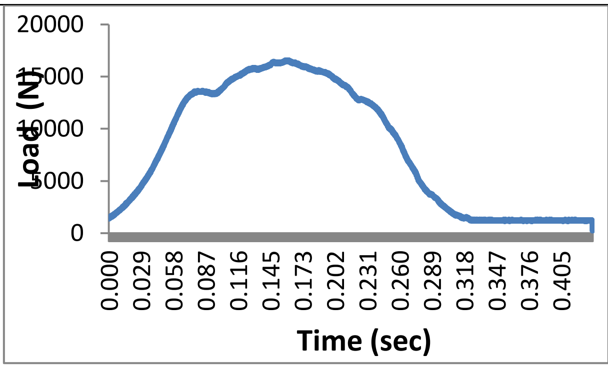

Fig. 11 Transient load v/s time diagram obtained from the experiment

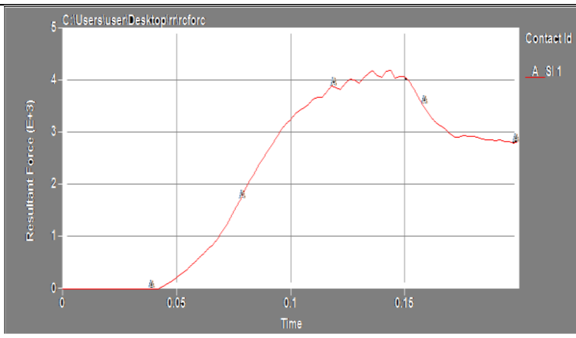

Fig.12: Load v/s time diagram obtained in simulation

The maximum force obtained from the experiment is 16.2 kN and from the simulation, it is found to be 4.2 kN. Since, it is a quarter models, the actual force obtained from the simulation is four times of the value given by the simulation i.e 16.8 kN. The deviation from the experimental result is 4%.

After selecting the five input parameters viz., Rp, Rd, C, μ and Dp, the range of the Parameters is selected based on literature study. Level 1 and level 3 are chosen from minimum and maximum of the range and level 2 is taken approximately as mean value of the two ranges. The levels of the parameters fixed are shown in Table 2.

Table 2: Parameters selected for study & their levels

S.No.	Parameter	Level 1	Level 2	Level 3
1	Punch radius (mm)	1	2.5	5
2	Die radius (mm)	3	7	10
3	Clearance	7	14	20
4	Coefficient of friction	0.015	0.2	0.45

As the 3 level experimentation takes the nonlinearity into account, 3 levels are chosen for each parameter. As for three levels with four parameters a full factorial experimentation requires 81 (3^4) trials. But to reduce the no. of experiments L-27 is selected for the study with a reasonable accuracy. L-27 Orthogonal array(OA) consists of 27 trails with five parameters. The level selected for the parameters are assigned to L-27. Then simulations are carried out as per the designed table shown in table 3. During analysis the value of optimum BHF is arrived by performing a number of trial runs.

The modelling of die set i.e., punch, die, blank and blank holder is done using Hypermesh software .Then based on L27 Orthogonal array for each trial analysis is carried out on deep drawn cups using LS Dyna software. For trial 1**:**punch radius of 1mm,die radius of 3mm, clearance of 0.07mm,friction factor of 0.015 and punch diameter of 30mm are considered. These values are used in modelling using Hypermesh software. This model was exported to LSDYNA software for analysis. Using LS Dyna the exact blank holding force is obtained by observing the point at which the maximum Von Mises stress just exceeds the UTS of the material. This procedure is repeated for 27 trials.

3.4 Method of determining Fracture limit:

For determining fracture limit initially some blank holding force is randomly chosen and a simulation is carried out. If the maximum stress does not exceed ultimate tensile strength (UTS) the BHF is increased or else it is decreased. The same is carried out till the maximum stress exceeds UTS. A sample to find out the fracture limit is presented in figures 13(a) to 13(f). From figure 13(a) it is observed that when BHF is set at 1000N, maximum stress value is < the ultimate tensile strength (UTS) which is 453. Hence the BHF value is increased to 2000N. Again it is seen from figure 13(b) that the maximum stress value is less than ultimate tensile strength which is 453. So once again it is increased to 3000N as shown in 13(c). Now it is seen that the maximum stress value which 470.727

exceeds ultimate tensile strength which is 453. Hence it may be treated that the cup has fractured. Further when BHF is reduced to 2900N as shown in figure 13(e) and 2850N as shown figure 13(f) the maximum stress values are found to be slightly more than the UTS. As it is desirable to have lower value of BHF hence 2850N can be treated as the fracture limit with reasonable accuracy.

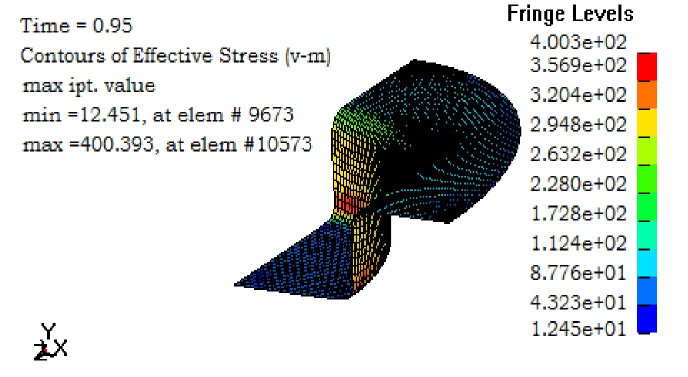

Fig.13(a) Cup drawn with BHF 1000N

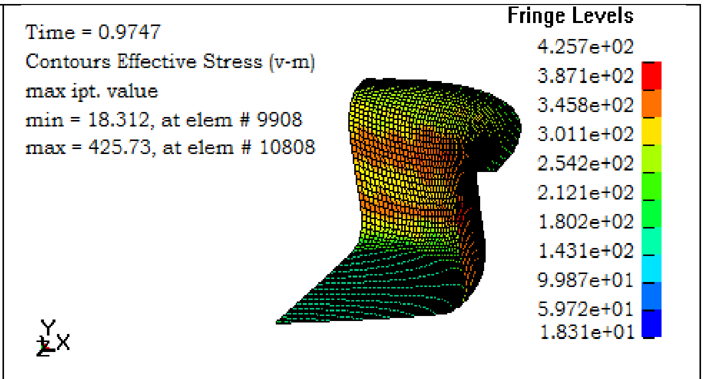

Fig. 13(b) Cup drawn with BHF 2000N

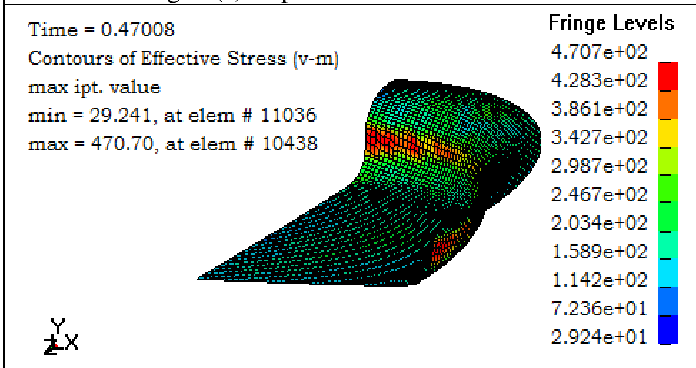

Fig. 13(c) Cup drawn with BHF 3000N

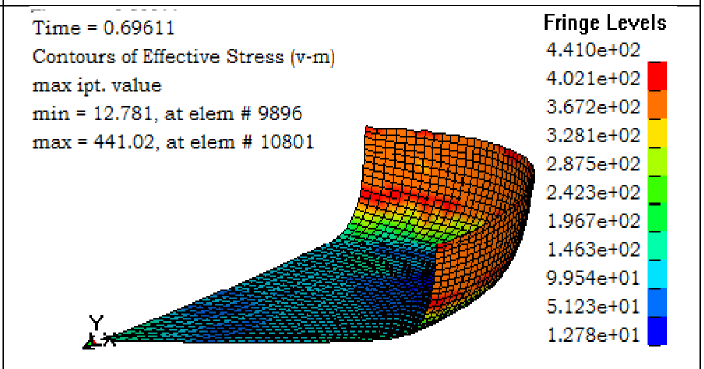

Fig. 13(d) Cup drawn with BHF 2500N

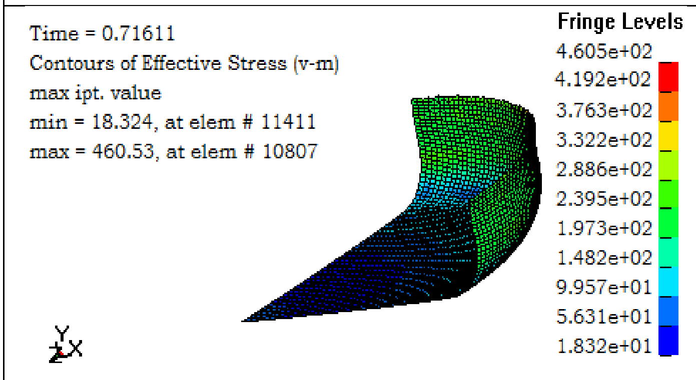

Fig.13(e) Cup drawn with BHF 2900N

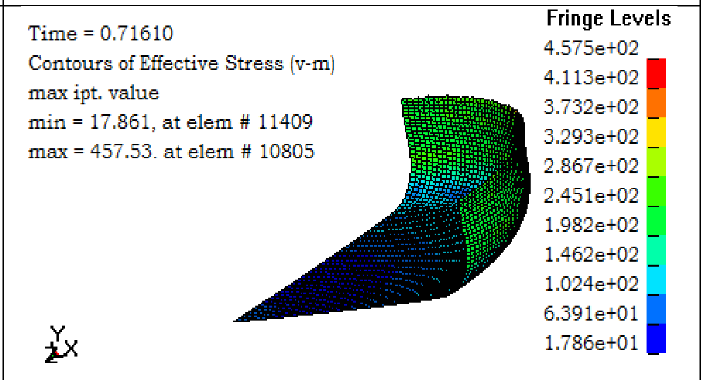

Fig. 13(f) Cup drawn with BHF 2850N

Fig.13 Cups drawn with various BHF values

4.0 Results and discussions:

The fracture limits are identified as per the procedure stated in the previous section for each trail and presented in table 3. Column effect method and plotting methods are used for finding out the most influencing parameters and their interactions respectively for analysis. From table 3 it is noted the maximum range of BHF is for punch diameter. Hence punch diameter is most significant parameter for deciding fracture limit. For a given diameter punch diameter is fixed and there is no liberty to change it. Out of coefficient of friction, punch corner radius, die corner radius and clearance the die radius is the most influencing parameter followed by clearance. Clearance, punch corner radius and coefficient of friction have less influence on fracture limit.

Table 3: Orthogonal array showing Fracture limits for various trails

INPUT PARAMETERS						OUTPUT
Trial no	Rp in mm	Rd in mm	Clearance in mm	Coefficient of friction μ	Dp in mm	BHF for fracture limit values in Newtons
1	1	3	0.07	0.015	30	2850
2	1	3	0.07	0.015	90	8500
3	1	3	0.07	0.015	150	14150
4	1	7	0.14	0.2	30	2750
5	1	7	0.14	0.2	90	8425
6	1	7	0.14	0.2	150	13900
7	1	10	0.2	0.45	30	2660
8	1	10	0.2	0.45	90	8650
9	1	10	0.2	0.45	150	13650
10	2.5	3	0.14	0.45	30	2900
11	2.5	3	0.14	0.45	90	9000
12	2.5	3	0.14	0.45	150	14325
13	2.5	7	0.2	0.015	30	2850
14	2.5	7	0.2	0.015	90	8850
15	2.5	7	0.2	0.015	150	13900
16	2.5	10	0.07	0.2	30	2750
17	2.5	10	0.07	0.2	90	8750
18	2.5	10	0.07	0.2	150	13800
19	5	3	0.2	0.2	30	3100
20	5	3	0.2	0.2	90	8500
21	5	3	0.2	0.2	150	14250
22	5	7	0.07	0.45	30	2550
23	5	7	0.07	0.45	90	8350
24	5	7	0.07	0.45	150	13450
25	5	10	0.14	0.015	30	2850
26	5	10	0.14	0.015	90	8650
27	5	10	0.14	0.015	150	14000
S1	75525	77575	75150	76600	25250	
S2	77125	75025	76800	76225	77675	
S3	75700	75750	76400	75525	125425	
Range	1600	2550	1650	1075	100175	

The interaction plot between Rp and Rd is shown in figure 14 it is observed that the slopes of the lines are highly different so it can be stated that there is consistence and a good interaction between Rp and Rd on fracture limit so the variation of fracture limit with Rp and Rd should be combinedly studied.

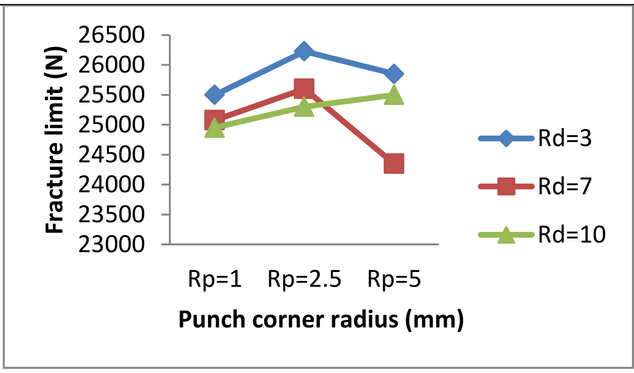

Fig.14 Interaction graph between punch corner radius and die corner radius

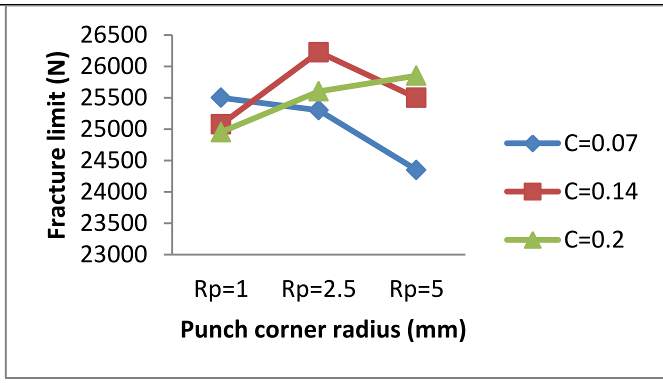

Fig.15 Interaction graph between Punch corner radius and clearance

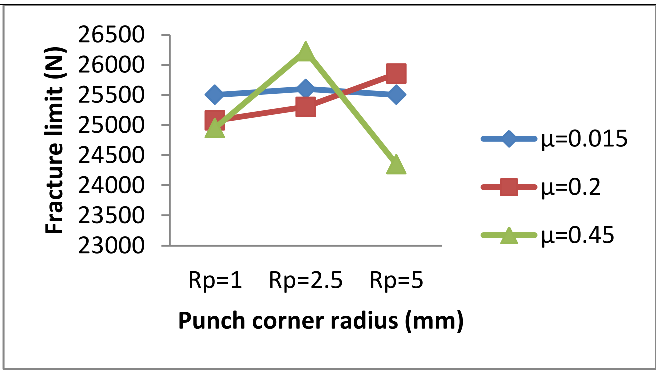

Fig.16 Interaction graph between punch corner radius and Coefficient of friction

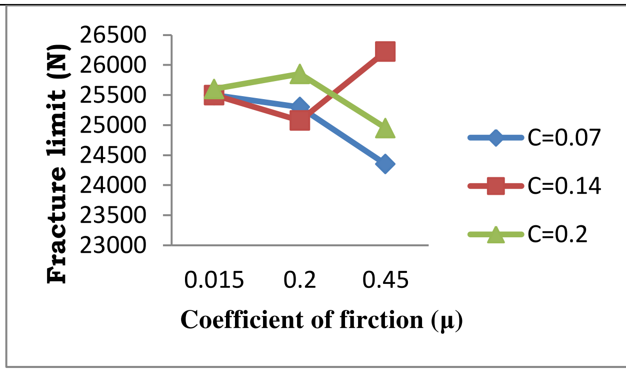

Fig.17 Interaction graph between Coefficient of friction and Clearance

The interaction plot of punch corner radius and clearance is plotted in Fig.15. From the figure 15 it is observed that there is lot of variation in the slopes of line so it can be stated that there is consistence and a good interaction between punch radius and clearance on fracture limit so the variation of fracture limit with punch radius and clearance should be studied together.

The interaction plot between Rp and coefficient of friction is shown in Fig.16. From the Fig.16 it is observed that the slopes of the lines are highly different so it can be stated that there is consistence and a good interaction between Rd and coefficient of friction on fracture limit so the variation of fracture limit with Rd and coefficient of friction should be studied together.

The graphical relationship between Clearance and coefficient of friction is shown in Fig.17. From the Fig.17 it is observed that the slopes of the lines are highly different so it can be stated that there is consistence and a good interaction between Clearance and coefficient of friction on fracture limit so the variation of fracture limit with Clearance and coefficient of friction should be combinedly studied.

The interaction plot between punch corner radius and punch diameter is shown in Fig.18. From the Fig.18 it is observed that the slopes of the lines vary very little so it can be stated that punch diameter independently effects fracture limit.

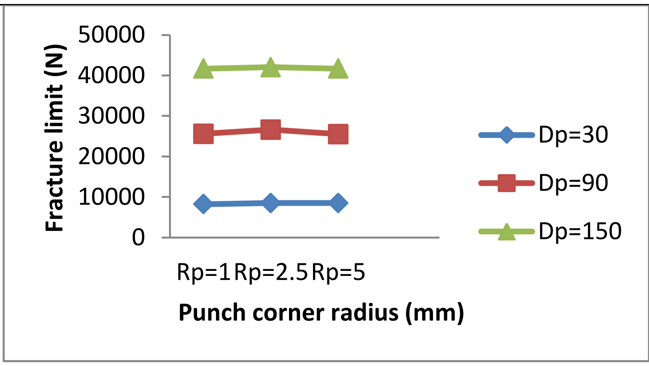

Fig.18 Interaction graph between punch corner radius and punch diameter

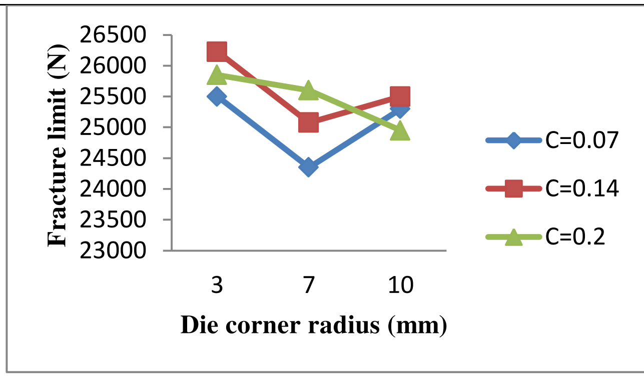

Fig.19 Interaction graph between Die corner radius and Clearance

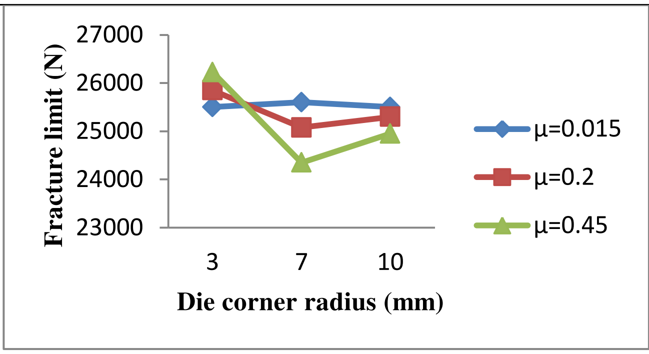

Fig.20 Interaction graph between Die corner radius and Coefficient of friction

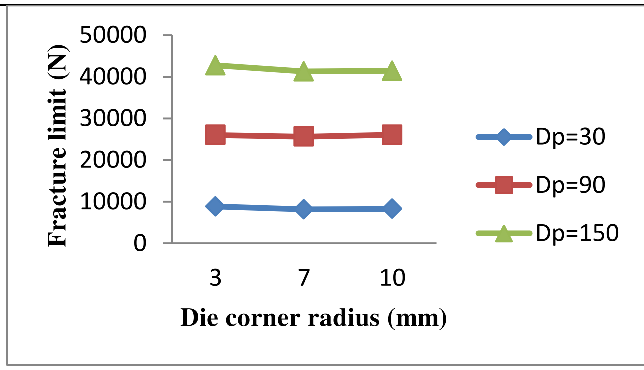

Fig.21 Interaction graph between Die corner radius and Punch diameter

The interaction plot between Clearance and die corner radius is shown in Fig.19. From the Fig.19 it is observed that the slopes of the lines are highly different so it can be stated that there is consistence and a good interaction between Clearance and die corner radius on fracture limit. So the variation of fracture limit with Clearance and die corner radius should be combinedly studied.

The interaction plot between Coefficient of friction and die corner radius is shown in Fig.20. From the Fig.20 it is observed that the slopes of the lines are highly different .so it can be stated that there is consistence and a good interaction between Coefficient of friction and die corner radius on fracture limit so the variation of fracture limit with Coefficient of friction and die corner radius should be combinedly studied.

The interaction plot between Punch diameter and die corner radius is shown in Fig.21. From the Fig.21 it is observed that the slopes of the lines vary little so once again it can be said that punch diameter independently effects fracture limit.

4.1 Results of column effect method: After getting the output parameter i.e., fracture limit with the variation of the input parameters viz., punch corner radius, die radius, clearance, co-efficient of friction and punch diameter, using column effect method with the three levels the results are presented in the form of graphs for knowing their influence. These graphs are shown from figures 22 to 27. The variation of fracture limit with the variation of punch corner radius at various die corner radius is shown in graphical form in fig. 22. From figure 22 it is noted that the fracture limit first increases and then decreases with the variation of punch radius. Too low values of punch radius causes tearing of cup. As the punch radius increases the metal will flow easily so that blank holding force increases up to certain limit after that it decreases.

The variation of fracture limit with the variation of punch corner radius at various clearances is presented in figure 23. From figure 23 it is noted that as the punch corner radius increases the fracture limit first increases and then decreases. If the punch radius is low tearing occurs so it is made as large as possible. But with higher punch corner radius higher will be the metal flow. Hence the fracture limit increases.

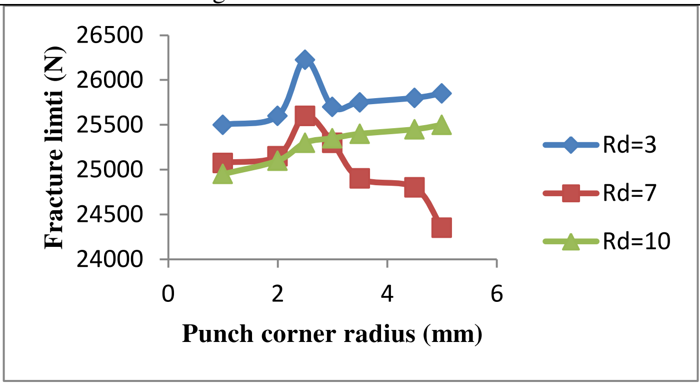

Fig. 22 Variation of Fracture limit with Punch corner radius at various Die corner radius

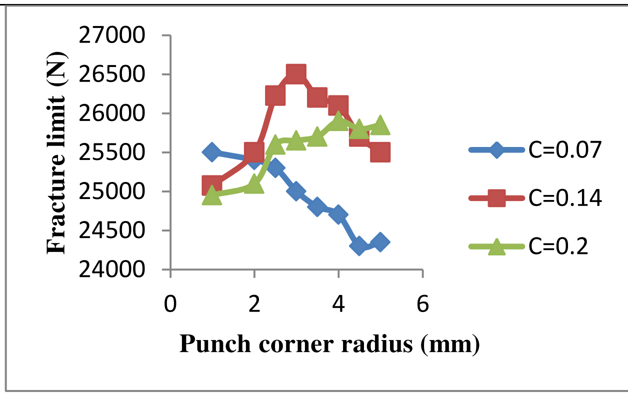

Fig. 23 Variation of Fracture limit with Punch corner radius at various Clearance values (%)

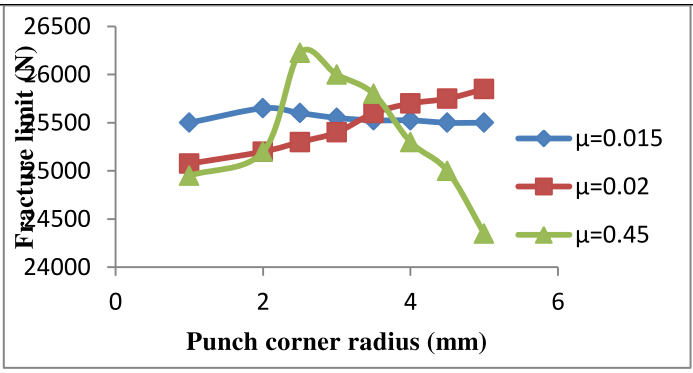

Fig. 24 Variation of Fracture limit with Punch corner radius at various Coefficient of friction values

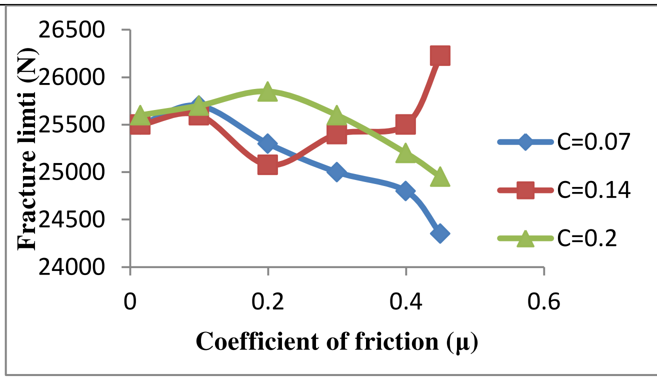

Fig. 25 Variation of Fracture limit with Coefficient of friction at various Clearances

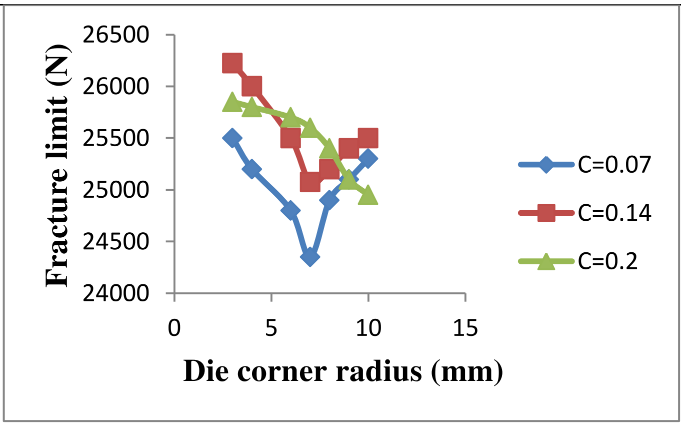

Fig. 26 Variation of Fracture limit with die corner radius at various Clearances

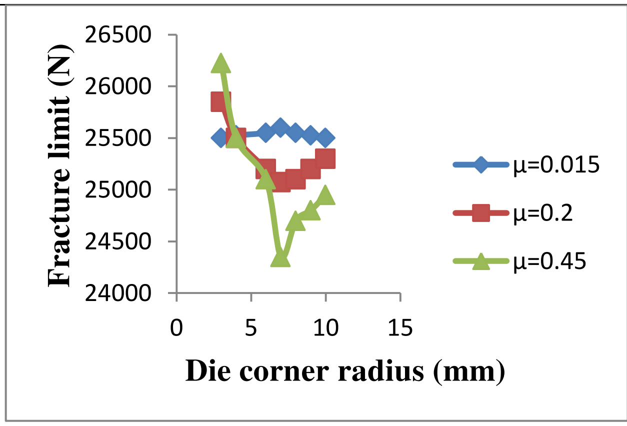

Fig. 27 Variation of Fracture limit with die corner radius at various Coefficient of friction

The variation of fracture limit with variation of punch corner radius at different coefficient of friction values is shown in figure 24. From figure 24 it is noted that as coefficient of friction increases the fracture limit slightly increases and then decreases. This is because if the coefficient of friction increases then the metal will not flow easily, so accumulation of material at flange is less. The increase of the coefficient of friction causes the fracture limit to reduce, but high values of coefficient of friction can cause cracks and material-breakage.

The relationship between coefficient of friction and clearance is as shown in figure 25. It can be seen that as clearance increases the fracture limit also increases and then decreases. It may be due smooth flow of metal initially due to increase in gap between die and punch, but with further increase in clearance chances of fracture formation increases.

The variation of fracture limit with the variation of die corner radius at various clearances is as shown in figure 26. It can be seen that as die corner radius increases fracture limit first decreases and then increases. It may due to lesser flow of metal due to lesser gap between punch and die initially and then higher subsequently due to increase in the gap.

The variation of fracture limit with the variation of die corner radius at various coefficient of friction is as shown in figure 27. It can be seen that as die corner radius increases fracture limit first decreases and then increases. It may due to lesser flow of metal due to smaller die radius initially and then higher subsequently due to increase in die corner radius.

4.2 Regression Analysis For Determining Fracture Limit In Deep Drawn Cups

After carrying out interaction studies between different parameters it is important to develop a model or an equation which can readily give us the required value of fracture limit. This can be achieved by performing Regression analysis. To carry out regression analysis the blank holding force is modeled by means of the equation : $Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5$ - - [2]. Here x_1 = punch corner radius x_2 = die corner radius x_3 = clearance x_4 = coefficient of friction x_5 = punch diameter and b_0, b_1 ………..b_5 are constants. Minitab 17 was used to perform regression analysis. The summary of results shown by Minitab software is as given below.

Regression Analysis: BHP versus Rp, Rd, C, µ, Dp

Table 4 : Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	557765156	111553031	1921.40	0.000
Rp	1	405	405	0.01	0.934
Rd	1	214459	214459	3.70	0.068
C	1	95487	95487	1.65	0.213
µ	1	64403	64403	1.11	0.304
Dp	1	557390401	557390401	9625.50	0.000
Error	21	1216061	57908		
Total	26	55981217			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
240.640	99.78%	99.73%	99.65%

Coefficients

Table 5 :

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	232	212	1.10	0.285	
Rp	-2.3	28.1	-0.08	0.934	1.00
Rd	-31.1	11.2	-1.92	0.068	1.00
C	1119	872	-1.28	0.213	1.00
µ	-274	260	-1.05	0.304	1.00
Dp	92.745	0.945	98.11	0.000	1.00

Regression Equation

$BHF = 232 - 2.3\,Rp - 31.1\,Rd + 1119\,c - 274\,\mu + 92.745\,Dp$---------------(3)

Fits and Diagnostics for Unusual Observations

Obs	BHP	Fit	Resid	Std Resid	
11	9000	8514	486	2.21	R
17	8750	8286	464	2.09	R
24	13450	13870	-420	-2.05	R

R Large residual

After calculation of regression coefficients the values of coefficients are as given below:

b_0=232, b_1= -2.3, b_2 = -31.1, b_3 = +1119, b_4= -274, b_5 = +92.745

On the basis of the calculated coefficients the obtained mathematical model is as follows.

BHF = 232 - 2.3 Rp - 31.1 Rd + 1119 C - 274 μ + 92.745 Dp ………………..(4)

Evaluation of significance of regression coefficient is done using t criteria and it is found that all parameters are significant. Hence the final mathematical model for blank holder force is :

BHF = 232 - 2.3 Rp - 31.1 Rd + 1119 C - 274 μ + 92.745 Dp …………. (5)

since Fa < Ft the mathematical model describes well the blank holder force (BHF) which depends on tool geometry, clearance, coefficient of friction and punch diameter. The multiple regression coefficient R = 0.966 so it shows a good inter dependency of the variables xi and yi (BHF).

Fig 28 shows the area graph indicating the contribution of various parameters of the total on fracture limit. It is clear that punch diameter has maximum influence on fracture limit as it occupies maximum area which is followed by die corner radius.

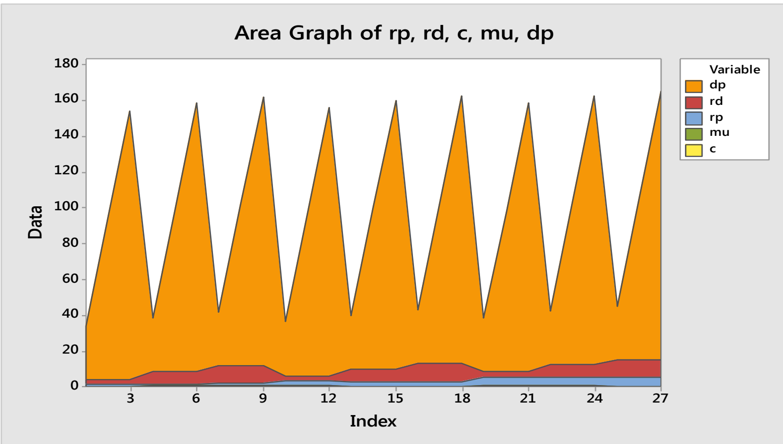

Fig.28: Impact of Rp, Rd, C, μ, Dp on Fracture Limit

Fig 29 and 30 show probability plot of punch corner radius and die corner radius indicating the degree to which the data points follow fitted lines.

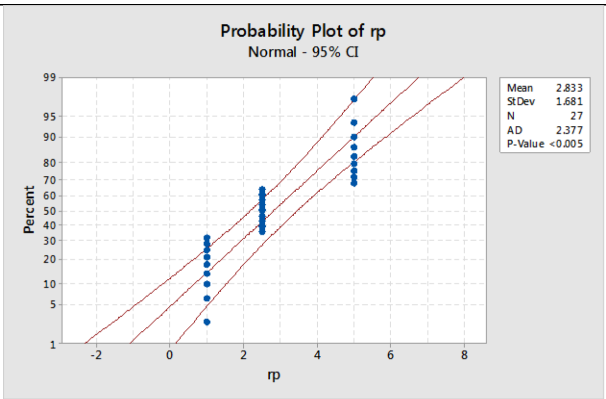

Fig 29: Probability plot of Punch Corner Radius

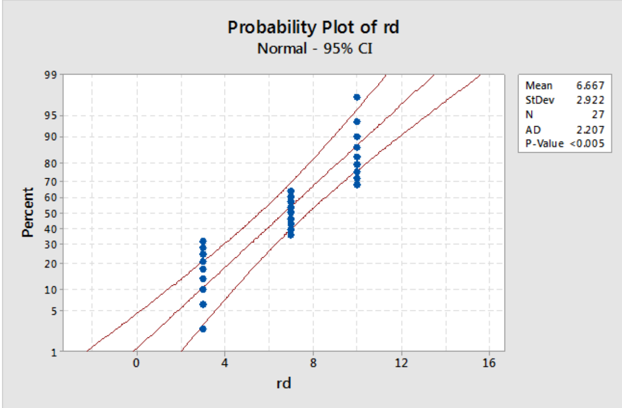

Fig.30: Probability plot of Die corner radius

5.0 Conclusions

The following conclusions are made:

- Optimum blank holding force for determining fracture limit in deep drawn cups was found.
- It is observed that punch diameter is most influencing parameter followed by die corner radius, punch corner radius, clearance and coefficient of friction.
- It is also observed that fracture limit is minimum at the die corner radius of 7 mm, punch corner radius of 5mm, clearance of 7% and coefficient of friction of 0.45.
- An empirical model for calculating fracture limit is developed using regression analysis.

Acknowledgement

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