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Optimization of Blank Holding Force in Deep Drawing of Cylindrical Cups Using Taguchi Approach

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Abstract: Wrinkling is an undesirable phenomenon occurring in deep drawing. It occurs at flange as well as the sidewalls of a deep drawn cup. The main reason for wrinkles is inadequate Blank holding force. However excessive blank holding force results in fracture.. The aim of this work is to arrive at optimum Blank holding force in order to produce wrinkle free products. In this work Numerical simulation is conducted by considering five different parameters namely Punch radius, Die radius, clearance, Coefficient of friction and Punch diameter using finite element explicit solver LSDYNA3D. 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.

Index Terms- **Deep Drawing, Blank Holding Force, Wrinkling, Fracture Limit, LSDYNA.**

I. INTRODUCTION

Deep drawing is one of the extensively used sheet metal forming processes in the industries to have mass production of cup shaped components in a very short time. In deep drawing, a flat blank of sheet metal is shaped by the action of a punch forcing the metal into a die cavity. Deep drawing products in modern industries usually have a complicated shape, so these have to undergo several successive operations to obtain a final desired shape. It is used to manufacture complicated parts from sheet metal and in many industries such as automobile, aerospace, appliance and so on. 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 Tearing occurs because of high tensile stresses that cause thinning and failure of the metal in the cup wall. Other factors, such as die temperature and the metal alloy of the blank, can also affect the drawing process. A variation in any of these factors influences the potential for wrinkling or cracking in the deep-drawn part. 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. In this work tooling parameters die profile, punch profile are investigated and the wrinkling limit in deep drawing process is determined.

II. FINITE ELEMENT MODELING

The FE Model of forming a cylindrical cup of 25mm diameter and 13mm deep is shown in Fig. 1. 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].

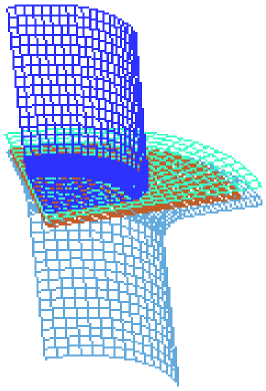


Fig .1 Finite Element Model

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 (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). The Engineering stress-strain and true stress-strain curves are presented in Fig. 3 and Fig. 4 respectively.

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 σ is the true stress K is strength coefficient (exponent of Y-intercept in Fig. 5), ε 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 [3]. The properties obtained from the tensile test that are input to LSDYNA are listed in table 1.

III. 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.5, 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.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.

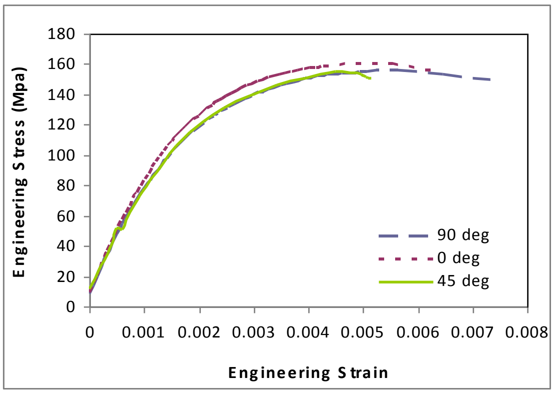


Fig. 3 Engg. Stress Strain Curve of AA1100

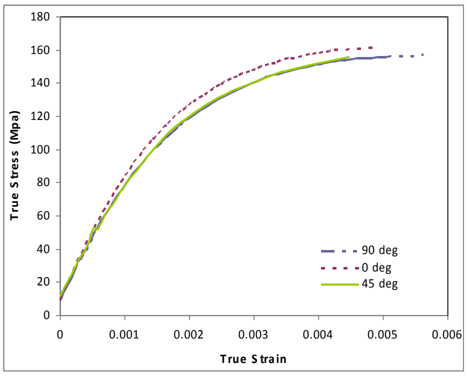


Fig. 4 True Stress Strain Curve of

Fig 5: Experimental set up

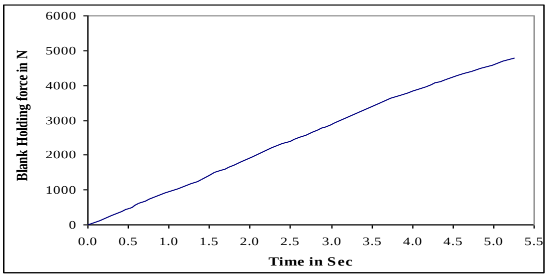


Fig 6 BHF Schema Obtained from the experiment

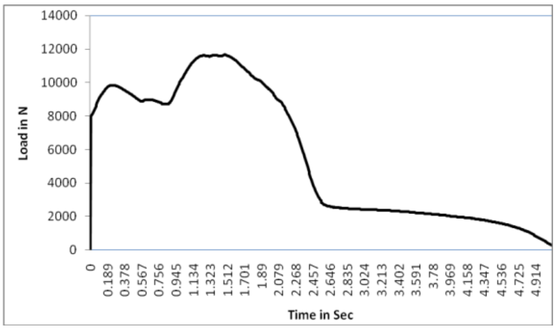


Fig 7: Transient Load V/S Time Diagram Obtained From the Experiment

The maximum force obtained from the experiment is 11.58 kN and from the simulation, it is found to be 2.698 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 10.79 kN. The deviation from the experimental result is 7%. Since the power law model underestimates the punch load[4], 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

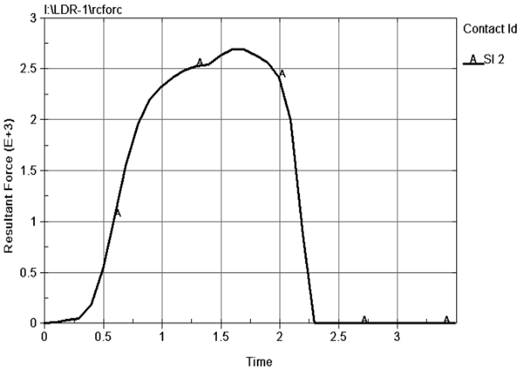


Fig. 8: Load V/S Time Diagram Obtained in Simulation

Here five parameters viz Punch radius, Die radius, Clearance, Coefficient of friction & Punch Diameter are selected for the analysis of significant parameters standard L-27 orthogonal array is selected. The range of the Parameters is fixed based on literature. Level 1 and level 3 are chosen from minimum and maximum of the range and level 2 is approximately taken as mean value of the two ranges. The levels of the Parameters chosen are presented in table. I

Table – I: Levels of Parameters

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
5	Punch diameter (mm)	30	90	150

The Parameters are assigned to orthogonal array and simulations are conducted accordingly. Wrinkling limit is identified iteratively. For wrinkling limit initially some blank holding force is randomly chosen and a simulation is carried out. If wrinkles, appear the blank holding force is increased else it is decreased. The same is carried out till the minimum blank holding force is arrived where wrinkles do not appear. The minimum blank holding force thus found out is the wrinkling limit. A sample of the same is presented in figure 9 to 11 from which it is observed that wrinkling appears at BHF 1500N hence the BHF is increased to 2000N and it is observed that there are no wrinkles. So wrinkling limit is in between 1500N and 2000N. Further the BHF is reduced to 1700N and it is observed that wrinkles do not appear. Hence, 1700N can be taken as wrinkling limit with reasonable accuracy

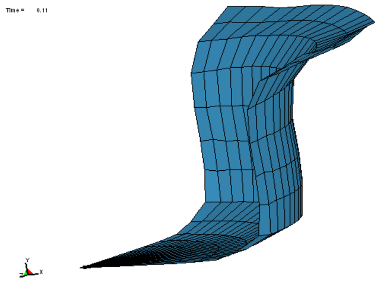


Fig 9. Cup drawn with bhf-1500N (Wrinkled Cup)

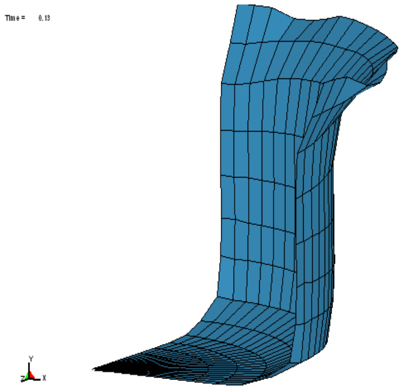


Fig 10. Cup drawn with bhf-1600N (Wrinkled Cup)

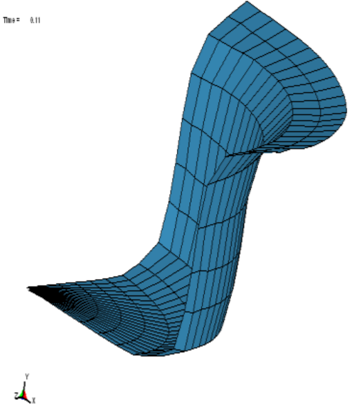


Fig 11.Cup drawn with bhf1700N (Wrinkled free Cup)

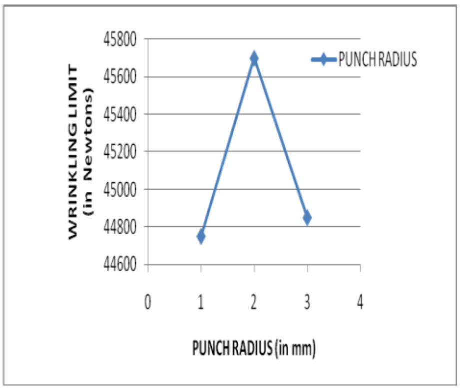
IV. RESULTS & DISCUSSION

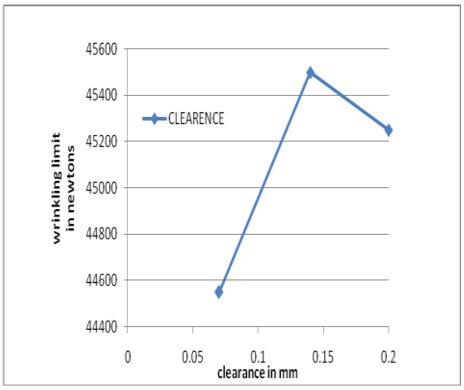
The wrinkling limits are identified as per the procedure stated in previous section for each trail and presented in table II. Column effect method is used for analysis. In column effect method the values at various levels are summed up and the range is calculated. Higher range indicates higher influence of the parameter. From table II it is noted that the range for punch diameter is highest hence punch diameter is the most significant parameter for deciding wrinkling limit. For a given cup 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. The variation of wrinkling limit with the variation of punch radius is shown in figure 12(a). Too low value 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 wrinkling limit with the variation of die radius is shown in figure 12(b). As the die radius increases the wrinkling limit first decreases and then increases. If the die radius is low tearing occurs so it is made as large as possible. But higher the die radius higher will be the metal flow so wrinkles occur Hence the wrinkling limit increases. The variation of wrinkling limit with the variation of clearance is as shown in figure 12(c). As the clearance increases wrinkling limit increases and then decreases slightly. Because when clearance increases the metal will flow easily so wrinkles occur up to certain limit and then decreases due to lesser influence of punch. The variation of wrinkling limit with the variation of coefficient of friction is as shown in figure 12(d). As the coefficient of friction increases the wrinkling limit decreases. This may be because if coefficient of friction increases then the metal will not flow easily, so the accumulation of material at the flange is less. Hence wrinkles are reduced. The increase in coefficient of friction causes the wrinkles to reduce, but high values of the coefficient of friction can cause cracks and material failure. The variation of wrinkling limit with the variation of punch diameter is as shown in figure 12(e). As the punch diameter increases the wrinkling limit increases due to increase in contact area between punch and blank.

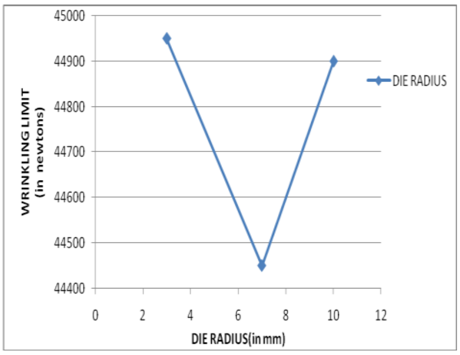
Table II. Wrinkling Limits for Various Trials

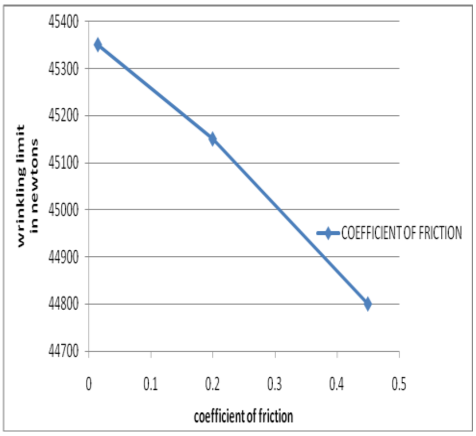
Trial no	Rp in mm	Rd in mm	Clearance in mm	Coefficient of friction μ	Dp In mm	BHF for wrinkle free cups
1.	1	3	0.07	0.015	30	1700
2.	1	3	0.07	0.015	90	5050
3.	1	3	0.07	0.015	150	8350
4.	1	7	0.14	0.2	30	1650
5.	1	7	0.14	0.2	90	5000
6.	1	7	0.14	0.2	150	8200
7.	1	10	0.2	0.45	30	1600
8.	1	10	0.2	0.45	90	5150
9.	2.5	10	0.2	0.45	150	8050
10.	2.5	3	0.14	0.45	30	1750
11.	2.5	3	0.14	0.45	90	5350
12.	2.5	3	0.14	0.45	150	8450
13.	2.5	7	0.2	0.015	30	1700
14.	2.5	7	0.2	0.015	90	5250
15.	2.5	7	0.2	0.015	150	8200
16.	2.5	10	0.07	0.2	30	1650
17.	2.5	10	0.07	0.2	90	5200
18.	2.5	10	0.07	0.2	150	8150
19.	5	3	0.2	0.2	30	1850

20.	5	3	0.2	0.2	90	5050
21.	5	3	0.2	0.2	150	8400
22.	5	7	0.07	0.45	30	1550
23.	5	7	0.07	0.45	90	4950
24.	5	7	0.07	0.45	150	7950
25.	5	10	0.14	0.015	30	1700
26.	5	10	0.14	0.015	90	5150
27.	5	10	0.14	0.015	150	8250
S1	44750	45950	44450	45350	15150	
S2	45700	44450	45500	45150	46150	
S3	44850	44900	45250	44800	74000	
RANGE	950	1500	1050	550	58850	









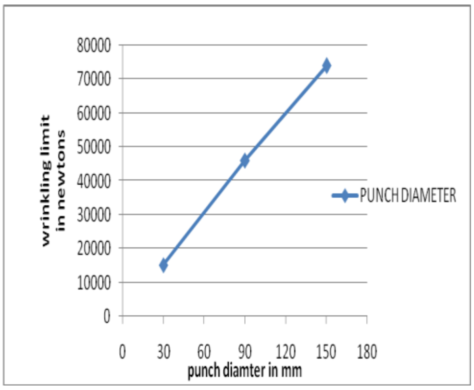


Fig 12: The variation of wrinkling limit with variation of following parameters is shown in figure 12. Figure (a) Punch Radius, (b) Die Radius, (c) Clearance, (d) Co-efficient of friction, (e) Punch Diameter.

From figure 12.it is observed that the optimum condition to eliminate wrinkling is die corner radius at level 2,clearance at level 1, coefficient of friction at level 3, punch diameter at level 1 and punch corner radius at level 2.

V. CONCLUSION

The following conclusions were drawn from this work:

- Optimum blank holding force for producing wrinkle free component was found.
- It is observed that punch diameter is most influencing parameter followed by die radius, punch radius, clearance and coefficient of friction.
- It is also observed that wrinkling limit is minimum at the die radius of 7mm, punch radius of 1mm, clearance of 7% and coefficient of friction of 0.45.

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