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Parametric Optimization & Simulation of Mild Steel Cup In Deep-Drawing Using LS-Dyna

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Abstract

Parametric optimizations widely needed for mass production of cup shapes in aerospace,automobile, and packaging industries. Cup drawing, besides its importance as forming process, also serves as a basic test for the formability of sheet metal. The friction between the coating punch and mild steel sheet was based on a Coulomb formulation. The combination of input parameters and residual stresses were defined as tied with failure contact during operations. The results of the L-S Dyna simulation has been tabulated that the steel sheet and the coating punch do not delaminate at the interface. The stress field of the mild steel will be more complicated depending on the different coating materials used in punches. Furthermore, it is found that the punch-nose radius is the most unsubstantial part for the intensity of the entire deep-drawing part and the thinnest part; it is a dangerous zone for the break. At this zone, the thickness thinning of the steel sheet are up to 4.82% with respected to overall thinning.

Key words: deep drawing; mild steel sheet; thickness distribution; signal to noise ratio; L-S Dyna, coated punch.

Introduction

The deep drawing is the metal forming process through which materials sheet can form in to the desire shape and size having good surface finish. Deep drawing process is being optimized by controlled parametric combination but drawbacks also occur and associate in terms of residual stresses after forming. Curve of the variable blank holder force (VBHF) designed can improve the formability of sheet.The coated steel sheet is an important type of structural-function material; it can be prepared by bilaterally electrodepositing nickel on the low carbon steel sheet. It is found that this material has good corrosion resistant, attractive toughness and excellent plasticity which offers the potential for advanced structure applications. With the development of this material, the process technique that nickel is firstly electrodeposited on the steel substrate, and then the coating and substrate are wholly formed instead of the process technique that the steel is firstly formed and then the production surface is electrodeposited nickel coating. Therefore, the formality of sheet with coating is an important process technology [1−3]

Deformation of sheet materials in the stamping process is classified by the four deformation modes, i.e. deep drawing, stretching, stretch flanging and bending[1]. Deep drawing is one of the widely used sheet metal working processes in the industries, to produce cup shaped components at a very high rate. Cup drawing, besides its importance as forming process, also serves as a basic test for the sheet metal formability.

During the course of deep drawing, the following five processes take place[2]. They are: 1) pure radial drawing between the die and blank holder, 2) bending and sliding over the die profile, 3) stretching between the die and the punch, 4) bending and sliding over the punch profile radius, and 5) stretching and sliding over the punch face.

Thus, the deep drawing process involves complex deformation Mechanisms. The parameters that affect the success or failure of a deep drawing operation are the punch and die radii, the punch and die clearance, the press speed, the lubrication and the type and the extent of restraint to metal flow material in deep-drawn shapes. Among these, the die shoulder radius [6], punch nose radius [5] and the blank holder force are considered to be the significant parameters in deep-drawing processes [7−8].

Noticeable differences in forming behaviour on the stamping have been observed in the aluminium alloys.

The relationship between the material, die design parameters and test parameters versus the deep drawing ability has not been well defined[9]. The quality characteristics chosen for the experiment should reflect as accurately as possible the design parameters under study. Thickness is one of the major qualitiescharacteristics in sheet metal formed part [6].

In the present work, the deep drawing process of the nickel-coated punch was simulated by LS-DYNA software using solid elements. An attempt has been made to investigate the rules of the residual stresses field and material flow of the sheet. Moreover, the effect of blankholder force (BHF) was also studied and a VBHF curve was designed to improve the formability of sheet. The selection of appropriate process parameters and their combination results in high quality parts. In this work, a statistical approach based on LS-DYNA deviation was adopted to determine the degree of importance of the parameters such as die shoulder radius, punch nose radius and the blank holder force on the thickness distribution of the deep drawn cup of mild steel sheet and to determine the optimum combination of these factors for the most even wall thickness distribution.

Nomenclature

DDP	–	*Deep Drawing Process*
LS-Dyna	-	*Simulation Software*
BHF	-	*Blank Holder Force*
R_p	-	*Punch nose radius*
R_D	-	*Die shoulder radius*
F_B	-	*Blank holder force*
R_a	–	*Surface Roughness*
VBHF	-	*Variable blank holder force*
MSE	-	*Mean Square Error*
RMSE	–	*Root Mean Square Error*

Experimental Setup

Parameters and levels

The fractional factorial design of experiment was used to conducting the experiment considering residual stress influencing five input parameters. The punch diameter, Radius of curvature at the punch,blank holder diameter, Die diameter and Ni coating thickness on punchwere considered to be the predominant parameters which influencing on residual stresses. In deep drawing, the quality of the formed parts is affected by the amount of the metal drawn into the die cavity. Excessive metal flow will cause wrinkles in the part while insufficient metal flow will result in tears or splits. The blank holder force plays a key role in regulating the metal flow [7]. The geometry of the punch and the die[4−7] also influences the deep drawing processes. It has been shown that for a punch nose radius (*R*P) that is less than twice the thickness of the blank (*t*), the cup fails due to tearing, whilst for *R*P greater than 10*t*, stretching may be introduced. In addition, within region $4t<RP<10t$, the radius does not significantly affect the limiting draw ratio (LDR)[2]. Therefore, according to the thickness of the blank, the most suitable shoulder radii for the die and punches were found to be 3, 5.5 and 8 mm with a constant punch stem diameter of 100 mm and a die cavity of 102.5 mm[10]. Proper tool steel with appropriate mechanical properties and hardening treatment was used for the materials for the punches and dies. The tools were ground to finish and final hardness of HRC 64. The amount of blank holder force required to prevent wrinkles is largely determined by trial and error.

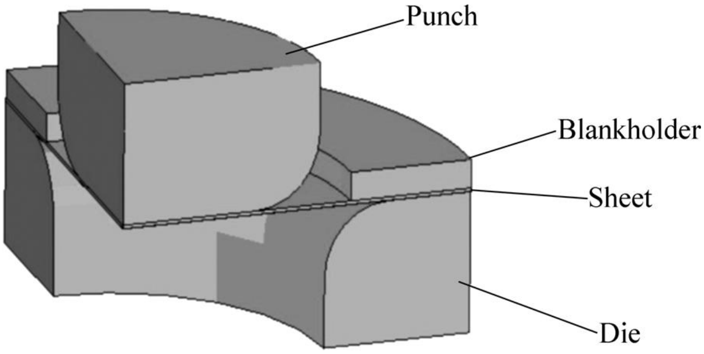

Figure 1: Schematic Diagram of One Quarter Profile of Problem Model (Thomson J.N; et al, 2006.)

Table 1: Material properties of MS sheet metal

Blank Material	DC04
Yield strength	188.9 N/mm2
Tensile strength	298.4 N/mm2
Elastic module	210000 N/mm2
Strength coefficient	384.98 N/mm2
Hardening exponent	0.21
Coefficient of Anisotropy (90°)	2.079

Design of Experiments:

Five different sets under 1/4th fractional factorial design of experiments ($2^{5-2} = 8$) have been selected at two levels so that 40 rows of experimental data have been taken at three levels of replication on mild steel using deep drawing process with influence of Ni coated punch.

Table 2: 1st set of DOE for screening test (IP- Input)

IP-1	IP-2	IP-3	IP-4	IP-5
1	-1	1	-1	1
1	-1	-1	-1	-1
-1	-1	-1	1	1
-1	-1	1	1	-1
-1	1	-1	-1	1
1	1	-1	1	-1
-1	1	1	-1	-1
1	1	1	1	1

Screening test on mild steel has been performed.

Table 3: Factors for screening test

Factors/Three Levels(Coding)	**1**	**2**	**3**
Punch diameter: (mm)	30	40	50
Radius of curvature at the punch: (mm)	5	10	15
Blank holder diameters (Inner): (mm)	26	30	34
Die diameter: (mm)	22	25	28
Ni coating thickness on punch:(µm)	6	12	18

In the deep drawing processes of this material, the coating/substrate composite may delaminate or crack in the interface. The combination of coating with substrate was considered a contact in the simulation, defined as"tied with failure contact", that is, before it arrives the deterioration, the contact surface or node ties with the target, and after the arrived deterioration, contact surface or node separate from the target and may slide each other.

A penalty-based contact model is considered in the computations where the friction effects are described via the Coulomb law. Similar lubrication conditions between the sheet and different tools were considered in the simulations. Therefore, for simplicity, a constant friction coefficient was used in the simulations. Moreover, to prevent wrinkling in the sheet drawing process, a blank holder force (BHF) during the forming process is assumed for each case, in these analyses, the substrate and coating are discredited with 8-node 'brick' solid elements from the element library of DYNA 3D code, which presents the macroscopic mesh distortion in a better way, while different tools are only meshed with surface elements on their contours since they are assumed to be rigid.

ANN Modelling:

The Artificial Neural Network concept has been implemented in WEDM process because of its supervised learning condition. It can be explained theoretically as considering five input factors which affects output on the basis of transfer functions and learning criterion.

$$\sum = w_1P_1 + w_2P_2 + w_3P_3 + w_4P_4 + w_5P_5 + b_1 \quad [1]$$

P_1, P_2, P_3, P_4, P_5 is the input variables or parameters of the problem. The first function is a linear combination of the input variables, P_1, P_2, P_3, P_4, P_5 multiplied with the weight coefficients, w_1, w_2, w_3, w_4, w_5 (called weights) while the second function serves as a transfer function. b_1 is the bias value. fIs transfer function and y indicates output of the function.

The weights w_1, w_2, w_3, w_4, w_5, in the artificial neurons are analogous to the real neural synapse strengths between axons firing the signals and the dendrites receiving those signals. Synapses strength between an axon and a dendrite decides what proportion of the incoming signal is transmitted into the neuron body.

Results

LS-DYNA Simulation

Eight node brick points residual stress simulating software has been used to validation of predicted and observed (FEM) residual stresses. In present investigations LS-DYNA deviation have been pointed out, so that the most influencing parametric combination on residual stress may find out.

Stress field and thickness distribution

The equivalent stresses distribution of the substrate and the coating with drawing depth of 13 mm ware shown in Fig.2 (a)& (b) respectively. The maximum equivalent stress of the substrateand Ni coated punchare found at the die radius, up to 604 MPa& 514 MPa.

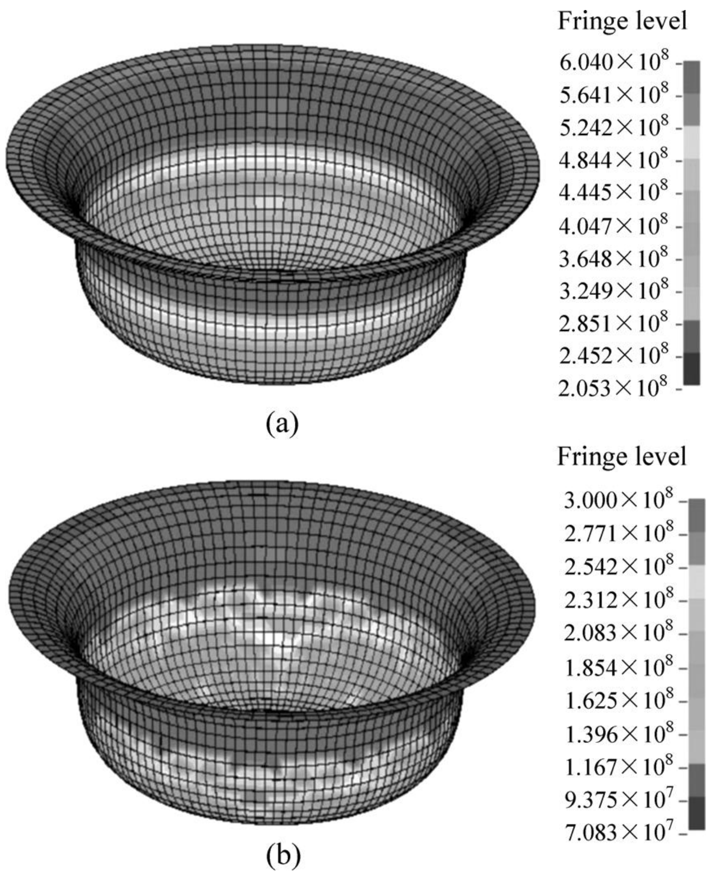

Figure 2: FEM analysis of residual stress on cup forming

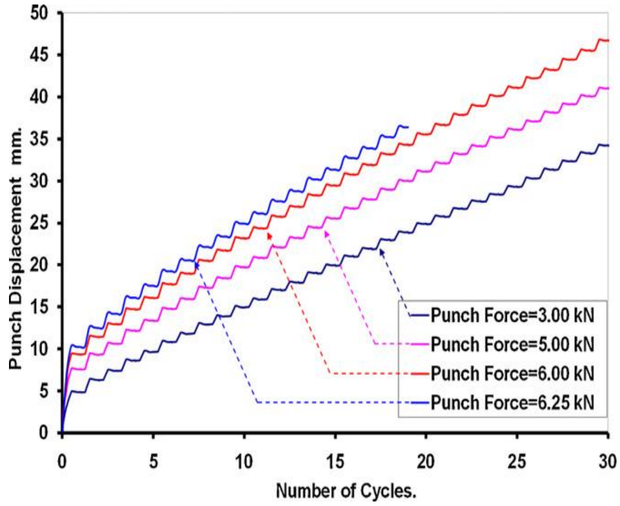

Figure 3: Punch force analysis corresponding to displacement and cycles

In above Fig. 3, theeffect of the punch load on cup height and punch displacement (P1 = 170 kN, dx = 1 mm, DR = 3.2 and R = 4.2 mm.) has been analyzed and drawn for the number of cycles.

The BHF is set to 0.5 kN. Because the VBHF technique can improve the formability of sheet, forming precision and surface quality, how to implement the VBHF technology has become one of the research emphases in the field of sheet metal forming [10−11].

The result of residual stresses of the mils steel cup has been observed using FEM analysis is being tabulated in Table 4. Using the same input parameters of the individual row of experiments artificial neural network (ANN) modelling were also carried out and best correlation coefficient 0.9008 as given in Fig. 6. Also Probability plot (Fig.7) of the error been drawn and P- value lies less than 0.005, which implies to data is validated by using LS-DYNA as Fig. 5.

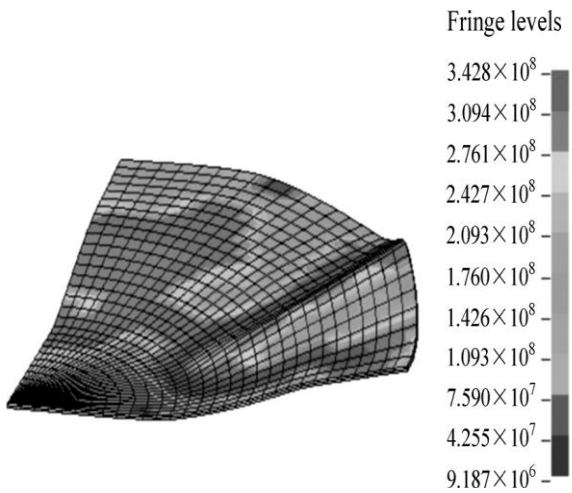

Figure 4: Distribution of equivalent stress at BHF=0.5 kN

Table 4: Residual stresses of the deep drawing MS Cup

Exp. No	FEM Stress (10^7)	ANN stress (10^7)	Error	$(\text{Error})^2$	LS-Dyna Deviations %
8	34.28	34.398	-0.00344	1.1849E-05	-0.01001
10	30.94	35.543	-0.14877	0.02213305	-0.41857
5	27.61	24.810	0.101413	0.0102845	0.408757
4	24.27	25.992	-0.07095	0.00503416	-0.27298
3	20.93	28.147	-0.34482	0.11889811	-1.22505
11	17.61	22.711	-0.28966	0.08390579	-1.27544
7	14.26	18.441	-0.2932	0.08596492	-1.58992
1	10.93	10.027	0.082617	0.00682551	0.823942
9	07.59	07.572	0.002372	5.6242E-06	0.03132
2	04.25	12.502	-1.94165	3.7699933	-15.5307
6	00.91	4.524	-3.97143	15.7722449	-87.7858

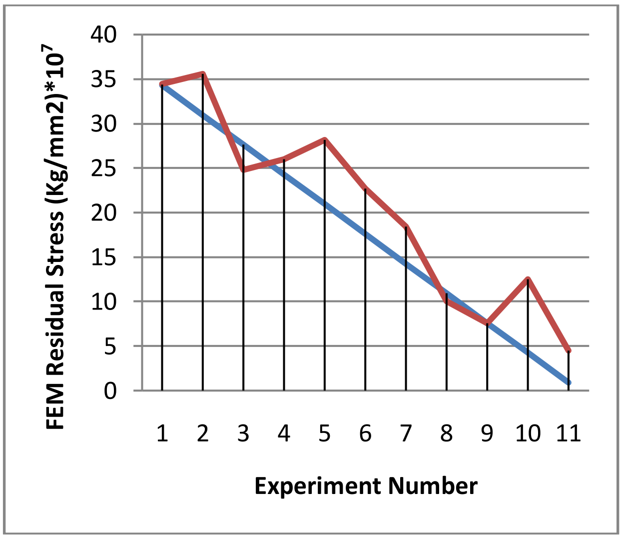

Figure 5: Observed residual stress corresponding to experiment numbers.

In this Fig. 5, experiment number 1 & 9 are the best opted to which they are very close to standard lines.

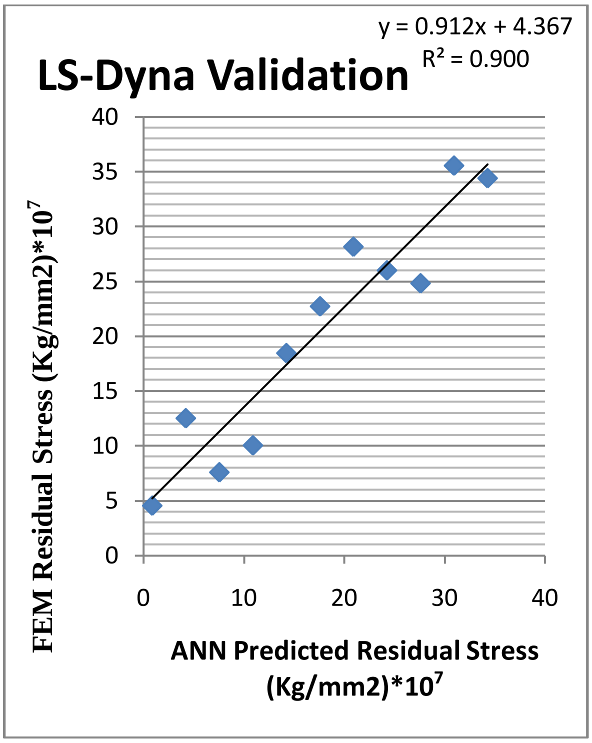

Figure 6: Correlation Between Observed And Predicted Stresses

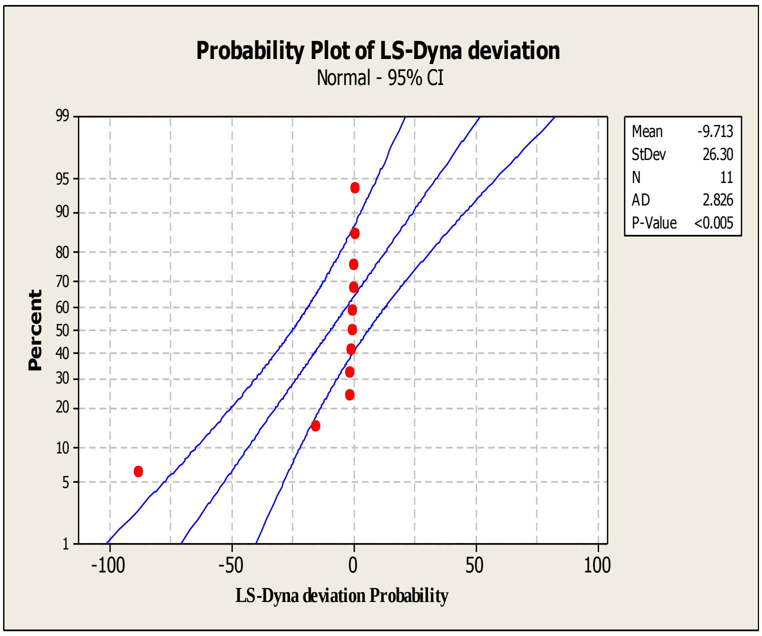

Figure 7: Probability plot of LS-DYNA deviations

Conclusions

1. The thinnest part of the mild sheet is at the fillet of lower part of the cup and the thickness thinning ratio of the mild steel sheet and the nickel coating punch are 4.82 % and 6.71%, respectively.
2. The LS- DYNA able to validate the FEM observed and ANN predicted residual stresses.
3. 26% of the residual stress may be minimized by applying the combined technique FEM analysis and ANN modelling.
4. The VBHF technology can improve the formability of sheet, a curve of the VBHF designed can be used in the deep drawing process, which can decrease the maximum tensile stress along the punch direction and the danger for breaking.

References

[1] LONG S G, ZHOU Y C, PAN Y. Computation of deformation-induced textures in electrodeposited nickel coating[J]. Trans Nonferrous Met Soc China, 2006, Pg 232−Pg. 238.

[2] ZHOU L Q, ZHOU Y C, PAN Y. Coating thickness variation during multistep drawing processes[J]. Journal of Materials Science letter, 2004, 39(2): 757−760.

[3] ZHOU L Q, LI Y P, ZHOU Y C. Forming limit of electrodeposited nickel coating in the left region[J]. Journal of Materials Engineering and Performance, 2006, 15(3): 287−294.

[4] BROWNE M T, HILLERY M T. optimising the variables when deep-drawing CRI cups [J]. Journal of Material Processing Technology, 2003, 136: 64−71.

[5] BRABLE G, NANU N, RADU E M. Deep drawing tools and process optimization based on Taguchi and L-Mec. A-Taguchi methods for the compensation of errors generated by springback [C]//Proceedings of National Conference on Excellence Research−A way to Innovation. Brasov, 2008: 27−29.

[6] PADMANABAN R, OLIVEIRA M, ALVES J L, MENEZES L F. Influence of process parameters on the deep drawing of stainless steel [J]. Finite Elements in Analysis and Design, 2007, 43: 1062−1067.

[7] SHENG Z Q, JERATHEARANAT S, ALTAN T. Adaptive FEM simulation for prediction of variable blank holder force in conical cup drawing [J]. International Journal of Machine Tools and Manufacturing, 2004, 44: 487−494.

[8] LEU D K. The limiting drawing ratio for plastic instability of the cup drawing process [J]. Journal of Material Processing Technology, 1999, 86: 168−176.

[9] JAIN M, ALLIN J, BULL M J. Deep drawing characteristics of automotive aluminium alloys [J]. Material Science and Engineering A, 1998, 256: 69−82.

[10] DOEGE E, SOMMER N. Blank-holder pressure and blank-holder layout in deep drawing of thin sheet metal[J]. Advanced Technology of Plasticity, 1987, 11(10): 1305−1314.

[11] SHENG Z Q, JIRATHEARANAT S, ALTAN T. Adaptive FEM simulation for prediction of variable blank holder force in conical cup drawing[J]. International Journal of Machine Tools & manufacture, 2004, 44(3): 487−494.