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Evaluating the Parameters Affecting the Distribution of Thickness in Cup Deep drawing of ST14 Sheet

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Abstract

Production of cylindrical cups is one of the most important deep drawing processes. However, the process has some noticeable defects such as wrinkling, tearing, spring back, and thickness variation in different locations of produced cups. In this research the parameters of interest are punch/die shoulder radius, blank holder force, friction between sheet and die/punch/holder. To make the simulations ABAQUS finite element software, and to study the effects of these parameters, Taguchi method are used. To verify the study's simulation results, experimental tests have been carried out. Studied locations include flange, die radius shoulder, wall thickness, punch radius shoulder, punch radius, the bottom of the cups. Also By applying Analysis of Variance (ANOVA) method the significance and magnitude of each parameter in determining the thickness in previously given locations are calculated in percentage. Finally, to get the initial blank thickness in different locations the optimum level of parameters is calculated.

Keywords: **Deep drawing, Wrinkling, ANOVA, Taguchi method**.

1. Introduction

Heat metal forming is one of the most important production processes which is applied massively in different industries such as production of industrial parts, home and office appliances, automotive body, aircraft parts and etc. Deep drawing is one of the compressive-tensile sheet metal forming processes. Thickness variation is a common defect of this process. This defect is caused by increase of sheet thickness in compressed locations and sheet thickness decrease in locations under tensile stress. Lots of parameters such as punch/die shoulder radius, blank holder force, friction between sheet and die/punch/holder affect this process and finding the optimum value of these parameters is both expensive and time consuming by trial and error methods; therefore, recently developed finite element and numerical method are used to shorten the time and cost of optimization process (Colgan. and Monaghan, 2003; Ibrahim et al., 2008; Pegada et al., 2002). In this study Taguchi method has been applied to evaluate the effect of each parameter mentioned above on thickness of different locations of produced cup and also by using ANOVA (Analysis of Variance) method significance level and percentage of effectiveness of each parameter is calculated (Browne and Hillery, 2002).

2. Material and Experimental Procedure

Material used for experimental test is one-millimeter thick ST14 steel sheet. Diameter of initial blank is 138 mm. To achieve mechanical properties of the material, uniaxial tensile test with ASTM8 standard in rolling direction of the sheet was carried out. The same test was done in two directions 45 and 90 degrees from rolling direction in order to get R-value. Test results are shown in Table. I. Moreover, Table II shows the chemical properties of the sheet.

Table 1: Mechanical Property

Ultimate tensile strength/MPA	yield Strength/ MPA	Work hardening coefficient	Strength coefficient/MPA	R0	R45	R90
320	180	0.262	541	2.05	1.48	1.76

Table 2 Chemical Element

C	Cu	Si	V	Mn	W	P	Co	S	Al	Ni	Sn	Mo	Pb
0.04	0.03	0.01	0.002	0.23	0.003	0.007	0.004	0.006	0.055	0.03	0.007	0.01	0.003

Geometry of die is presented in the Fig 1. Experimental tests were carried out using a hydraulic press on 138mm diameter blank. Then the produced cups were split in half using a wire cut machine. The die has been designed with an adjustable shoulder radius. Fig 2 shows produced cups and the hydraulic press used, and Fig3 shows the split cups.

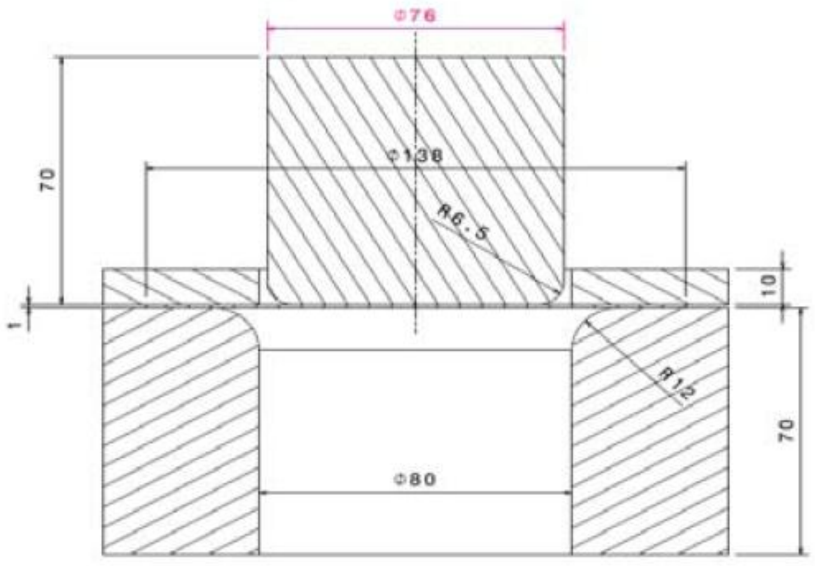

Fig. 1 Geometry of die

Fig. 2 Produced cups and the hydraulic press

Fig. 3 The split cup

3. Simulation

All parts were modeled in ABAQUS software using 3D explicit method. To model the sheet material, elastic-plastic conditions were considered using results taken from tensile test properties (Table 1.) e.g. Y.S, and R-values. To solve the problem four steps were taken place. They are: 1) exercising blank holder force, 2) punch movement, 3) the blank holder force release, and 4) moving the punch up. The sheet model was meshed with 1332 nodes and 1260 S4R elements. Die, punch, and holder were simulated in Discrete Rigid form and meshed with R3D4 elements (Gunnarsson, 2001; Wei et al., 2006).

4. Taguchi Method

The method to define and evaluate every possible condition in a test with multiple factors is called design of experiment. In a full factorial method possible number of experiments is calculated, as in:

$$N=L^m \tag{1}$$

In which L is the number of levels chosen for each factor and m is the number of evaluating factors. Taguchi determined special groups of orthogonal arrays to carry out his experiments. Understanding the individual contribution of each factor helps us to decide more precisely about the process. ANOVA is the most common statistical operation acting on the results to determine the percentage share of each factor. Studying and evaluating the ANOVA table for any defined analysis helps a lot to determine which factors must be controlled and which one does not (Jaisingh, et al., 2004; Padmanabhan et al., 2007).

To proceed the research we study the degree of effectiveness of six parameters (punch/die shoulder radius, blank holder force, friction between sheet and die/punch/holder) on the thickness of different locations of the sheet. Due to the fact that effect of each parameter on thickness of different locations of the produced cup is nonlinear, each parameter is evaluated in 3 levels. Based on (1) 36=729 tests were needed. However, Taguchi method design of experiment effectively reduces the number of tests to 27 (Raju et al 2010).

The die shoulder radius depends on the work piece size and thickness of the sheet. Increasing die shoulder radius increases both LDR (Limit Drawing Ratio) and drawing force. On the other hand, above mentioned increase of die shoulder radius decreases the contact surface between sheet and blank holder causing higher possibility of wrinkling. In this study

3 levels (6, 9, and 12 mm) were considered for die shoulder radius. In deep drawing process the tearing starts from the upper edge of the punch radius. The larger the punch radius, the larger the shoulder of punch and the lower the risk of tearing. But the main constraint in a deep drawing die is the final product geometric shape. The relation used to determine punch shoulder radius is $0.1D < P_r < 0.3D$ in which D is punch diameter. In this study the punch shoulder radius is taken 6.5, 9.5, and 12.5. mm, moreover, based on try and error method, blank holder force magnitude is 10, 14, and 18 KN (Hosford 1966; Schnakovszky, 2007; Kawkaa et al., 2001). Finally chosen levels for 6 parameters are shown in Table 3 (Schuler, 1988; Oheler, Kaiser, 1973; Hosford 1966)

Table 3: level of parameters

Parameter	Level 1	Level 2	Level 3
Dr	6	9	12
Pr	6.5	9.5	12.5
BHF	10	14	18
M1	0.04	0.13	0.22
M2	0.1	0.19	0.28
M3	0.04	0.13	0.22

Then the effect of each parameter has been evaluated in 6 different locations shown in Fig 4. As shown in Fig 4. Location 1 is in flange area (5 millimeter from edge of flange), 2 is in die shoulder radius, 3 in the wall area (5 millimeter lower than the bottom edge of die shoulder radius), 4 upper edge of punch shoulder radius, 5 punch shoulder radius, and 6 bottom surface of the cup.

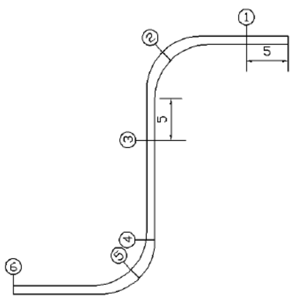

Fig. 4 Thickness evaluation locations

As the thickness of each direction varies in simulations, mid thickness has been calculated in three directions (OX, OY, and OZ).

5. Result

5.1 Experimental tests and simulations

It is known that under a definite blank holder force wrinkling occurs (Schnakovszky, 2007; Kawkaa et al., 2001) and in this study as shown Fig. 5(a) and Fig. 5(b) for 8KN blank holder force wrinkling appears both in experimental and simulation tests respectively in the flange area.

Fig. 5 (a) wrinkling in experimental test

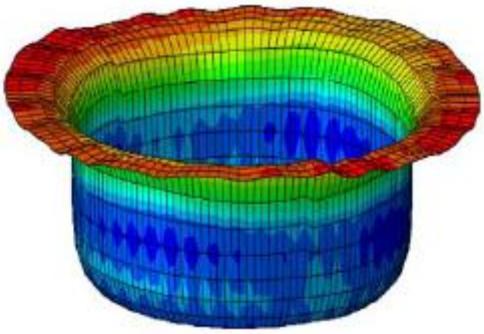

Fig. 5 (b) Wrinkling in simulation test

However, when blank holder force exceeds a special limit tearing happens and in this study in 22KN force tearing appeared in both tests. See Fig. 6(a) and Fig. 6(b)

Fig. 6 (a) Tearing in Experimental test

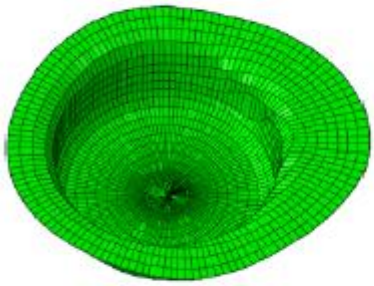

Fig. 6 (b) Tearing in simulation test

Experimental and simulation tests within 10 to 20KN confirm that this is a safe range of blank holder force without any wrinkling or tearing for 1 mm thick sheet. Fig 7(a) and 7(b) show a perfect cup produced in experimental and simulation tests respectively.

Fig. 7 (a) Perfect cup in experimental test

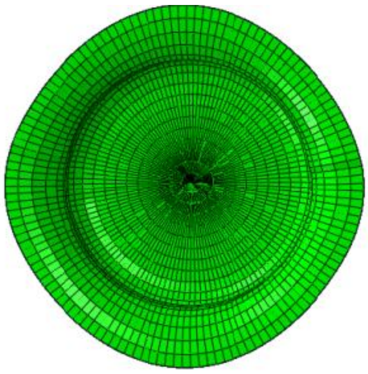

Fig. 7 (b) Perfect cup in simulation test

5.2 ANOVA

Taguchi method results for 27 tests in different locations are shown in Table IV. To keep the parsimony simultaneous comparison of means is carried out instead of making a lot of pair wise comparisons.

We are now going to study if there are truly significant differences between means of different groups, parameters of deep drawing process, or the perceived differences are just errors. ANOVA is applied to perform statistical procedures. Now using ANOVA method, effectiveness percentage each parameter on thickness variation in different locations are given. In this method SST (Sum of Square Total) is given by
(2):

$$SST=\sum_{i=1}^{k}\sum_{j=1}^{n} x_{ij}^2 - \frac{1}{kn}.T^2 \quad (2)$$

In which k is the number of each parameter level (in this study for every parameter k=3), n is the number of experiments carried out in each level (in this study for every parameter n=9) x_ij is the thickness of row number i and column number j and T.. sum of total n*k tests. Sum of Square treatment is, as in:

$$SS(Tr)=\frac{1}{n}.\sum_{i=1}^{k} T_i^2 - \frac{1}{kn}.T^2 \quad (3)$$

In which T_i is the sum of ith level thickness Moreover, Sum of square error is calculated by (4):

$$SSE=SST-SS(Tr) \quad (4)$$

Using (2), (3), and (4) percentage of effectiveness of each parameter is given in 6 already mentioned locations in Table 4

Table 4: Effective percentage of parameters

Parameter / Location	Dr	Pr	BHF	M1	M2	M3
Location 1	27.5	62.8	3.7	4.9	0.2	0.9
Location 2	10.2	40	9	36	0.1	4.3
Location 3	5.2	12.7	29.4	46	0	6.2
Location 4	39.2	0.7	8.9	47.6	0.1	2.9
Location 5	31.3	5	9.1	49.6	0.1	3.9
Location 6	1.2	53.7	6.7	13.6	4.9	2.2

Table 5 concluded the taguchi results

Table 5: Taguchi results

Dr	Pr	BHF	M1	M2	M3	1	2	3	4	5	6
6	6.5	10	0.04	0.1	0.04	0.00110	0.00107	9.92E-04	9.77E-04	9.77E-04	9.97E-04
6	6.5	10	0.04	0.19	0.13	0.00110	0.00107	9.90E-04	9.74E-04	9.75E-04	1.03E-03
6	6.5	10	0.04	0.28	0.22	0.00110	0.00107	9.88E-04	9.72E-04	9.74E-04	9.96E-04
6	9.5	14	0.13	0.1	0.04	0.00109	0.00105	1.01E-03	9.63E-04	9.72E-04	9.89E-04
6	9.5	14	0.13	0.19	0.13	0.00109	0.00105	1.01E-03	9.59E-04	9.69E-04	9.89E-04
6	9.5	14	0.13	0.28	0.22	0.00109	0.00105	1.01E-03	9.56E-04	9.66E-04	9.89E-04
6	12.5	18	0.22	0.1	0.04	0.00108	0.00103	9.87E-04	9.46E-04	9.58E-04	9.66E-04
6	12.5	18	0.22	0.19	0.13	0.00108	0.00103	9.83E-04	9.39E-04	9.52E-04	9.73E-04
6	12.5	18	0.22	0.28	0.22	0.00107	0.00102	9.78E-04	9.31E-04	9.47E-04	9.75E-04
9	6.5	14	0.22	0.1	0.13	0.00109	0.00105	9.93E-04	9.58E-04	9.60E-04	9.89E-04
9	6.5	14	0.22	0.19	0.22	0.00109	0.00104	9.89E-04	9.55E-04	9.56E-04	9.95E-04
9	6.5	14	0.22	0.28	0.04	0.00109	0.00105	9.97E-04	9.62E-04	9.63E-04	9.96E-04
9	9.5	18	0.04	0.1	0.13	0.00108	0.00105	1.01E-03	9.85E-04	9.84E-04	9.93E-04
9	9.5	18	0.04	0.19	0.22	0.00108	0.00105	1.01E-03	9.81E-04	9.81E-04	9.93E-04
9	9.5	18	0.04	0.28	0.04	0.00108	0.00105	1.02E-03	9.87E-04	9.86E-04	9.94E-04
9	12.5	10	0.13	0.1	0.13	0.00108	0.00104	1.00E-03	9.84E-04	9.81E-04	9.82E-04
9	12.5	10	0.13	0.19	0.22	0.00108	0.00104	9.97E-04	9.82E-04	9.80E-04	9.82E-04
9	12.5	10	0.13	0.28	0.04	0.00108	0.00104	1.00E-03	9.86E-04	9.83E-04	9.83E-04
12	6.5	18	0.13	0.1	0.22	0.00108	0.00104	9.90E-04	9.72E-04	9.75E-04	9.96E-04
12	6.5	18	0.13	0.19	0.04	0.00108	0.00105	9.99E-04	9.79E-04	9.81E-04	9.98E-04
12	6.5	18	0.13	0.28	0.13	0.00108	0.00105	9.94E-04	9.75E-04	9.78E-04	9.98E-04
12	9.5	10	0.22	0.1	0.22	0.00108	0.00103	9.83E-04	9.72E-04	9.76E-04	9.90E-04
12	9.5	10	0.22	0.19	0.04	0.00108	0.00104	9.88E-04	9.76E-04	9.79E-04	9.94E-04
12	9.5	10	0.22	0.28	0.13	0.00108	0.00104	9.86E-04	9.74E-04	9.78E-04	9.94E-04
12	12.5	14	0.04	0.1	0.22	0.00107	0.00103	1.01E-03	9.90E-04	9.83E-04	9.85E-04
12	12.5	14	0.04	0.19	0.04	0.00107	0.00104	1.02E-03	9.94E-04	9.86E-04	9.87E-04
12	12.5	14	0.04	0.28	0.13	0.00107	0.00104	1.02E-03	9.92E-04	9.85E-04	9.86E-04

Applied Main Effects plot gives the best level of each parameter to reach 1mm thickness in every location of produced cup as an example this plot for location four is Shown in Fig. 8.

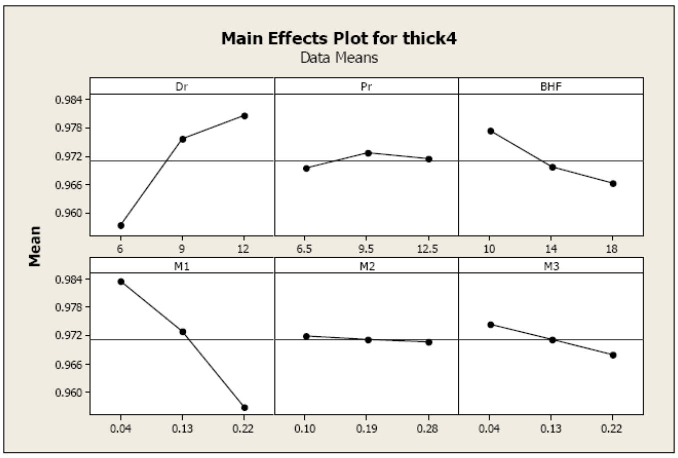

Fig. 8 Main effects plot for location 4

Table 6 shows the best level of each parameter for every location of the product

Table 6: Optimum Level Of Parameters

Parameter / Location	Dr	Pr	BHF	M1	M2	M3
Location 1	12	12.5	18	0.22	0.1	0.22
Location 2	12	12.5	18	0.22	0.1	0.22
Location 3	9	12.5	18	0.13	-	0.04
Location 4	12	9.5	10	0.04	0.1	0.04
Location 5	12	9.5	10	0.04	0.1	0.04
Location 6	12	6.5	10	0.04	0.19	0.13

6. Conclusion

Percentage of effectiveness of each 6 parameter (punch/die shoulder radius, blank holder force, friction between sheet and die/punch/holder) in 6 locations of the produced cup has been calculated by ANOVA method and the best level for them has been given. Using resulted data can help to determine desired thickness in different locations. Considering the results shows the nonlinearity of this process more than ever.

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