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INFLUENCE OF LUBRICATION AND BLANK HOLDER FORCE IN DOME WRINKLING DEFECT ON CUP DRAWING PROCESS

Agus Dwi Anggono, Wahyu Ahmad Sharif, Agung Trianto and Muhammad Yahya Darmawan
Department of Mechanical Engineering, Universitas Muhammadiyah Surakarta, Pabelan, Surakarta, Jawa Tengah, Indonesia
E-Mail: agus.d.anggono@ums.ac.id

ABSTRACT

In sheet metal forming operations, the most deleterious defect are wrinkling, tearing, necking and springback. Wrinkling of cups drawing was simulated using the finite element method (FEM). The fem code Autoform was used in numerical analysis. Wrinkling phenomenon is affected by the mechanical properties of the blank sheet material, contact conditions, blank holder force (BHF) and the geometry of the punch and dies. The wrinkling prediction is difficult to perform due to the highly sensitivity of the parameters. The effect of parameters of BHF and friction coefficient in the cup drawing process are studied. The small variations of the parameters can result in widely different wrinkling behaviours. The objectives of this paper are to investigate the effects of lubrication and blank holder force on a dome wrinkling behaviour. The experiment was conducted in lubricated condition, without lubrication and BHF variations of 1, 3, 5 and 8 kN. Two different blank sheets of Aluminum and Steel have been selected. The result shows that the dome wrinkling generation was influenced by blank holder force, while the lubrication did not give different result.

Keywords: sheet metal forming, cup drawing, wrinkling, finite element method.

INTRODUCTION

Deep drawing is a process to form a cylindrical, cup or box shape from flat sheet metal. The blank sheet is held by blank holder and employed by a certain force. When the punch moves down, radial tensile stress is acting on the bottom face of blank holder. Compressive hood stresses is caused by radial tensile stresses. During drawing process, it may cause wrinkling of the flange. Wrinkling, thinning and wall fracture are predominant failure modes in deep drawing. It can increase the wastage of sheet metal.

Wrinkling is a fold of plate at the drawing process. It usually occured on the flange of drawn part. Not enough pressure to restrain the sheet plate can be one of factors causing wrinkling. It also can be occured in wall area as called wall wrinkling and part wrinkling. To avoid this, the sufficient amount of blank holder force (BHF) should be applied to the binder (blank holder). However, excessive BHF can cause thinning and even cracking or splitting (Lee *et al*, 2007). Thus, the BHF optimization is become crucial issues in sheet metal forming (SMF) industries. Drawing process, BHF and wrinkling are illustrated in Figure-1. Another way to control wrinkling is increase pressure and maintenance of tooling surface condition. Increasing pressure of BHF to control wrinkling may lead to increased thinning and fracture.

Finite element method (FEM) for numerical analysis and simulation has become an important tool in predicting material behavior, collapse, cracking, fracture and fatigue (Anggono and Riyadi, 2014). In SMF, it able to predict the defects such as thinning, earring, wrinkling, cracking and splitting. Furthermore, developing analytical models sometimes can be assisted by finite element results. Anggono and Siswanto, (2014) has successfully decreased the earing defect by using ironing process in the simulation of SMF. The optimization of BHF can be conducted by using FEM as well, to find the BHF which minimum of wrinkling and thinning. Thus, the method is becoming popular. The parameters of finite element analysis (FEA) such as element type, mesh density, and analysis type are highly affect to the reliability of the results.

Wang *et al*., (2007) proposed a method to control BHF varied with the time by using algorithm as called response surface methodology (RMS). Using the method, a wrinkle free-product can be acquired through regulating the BHF profile. The aims of this work is to study the influence of lubrication and BHF in generating wrinkling defect.

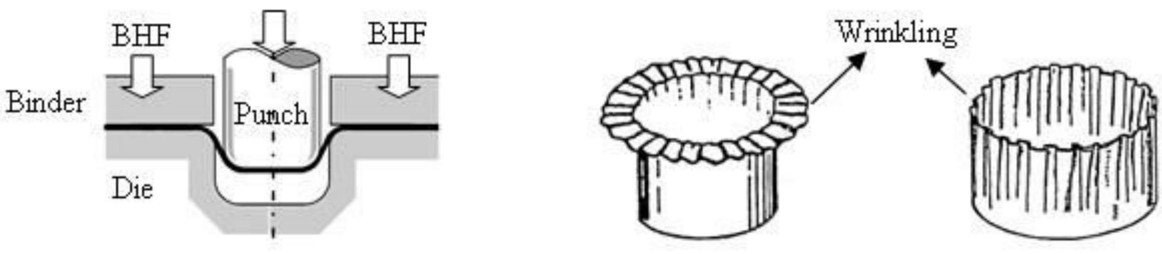

Figure-1. BHF in deep drawing process and wrinkling.

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EXPERIMENTAL PROCEDURE

The wrinkling analysis problem was selected from the benchmark 4 problems of Numisheet 2013. The dimension of die, punch, blank holder and blank sheet of cup drawing that will be used in the experiment are described in Table-1 and the schematic of tools are described in Figure-2. Tools material is Steel to manufacture of punch, die, and blank holder. According to the figure and dimensions, the models are then build by using CATIA V5. All models are created in surface design and then save as IGES files. The files are common use to change ability.

Two materials of Aluminum and Steel are selected for the blank sheet. Aluminum sheet with the thickness 0.2 mm and IF Steel of 0.3 mm thickness are considered in the investigation. Four equally space bolts were prepared for blank holder force (BHF), and BHF was set 3, 5 and 8 kN by means of an accurate torque meter. For experimental test, the tools are set up and mounted on a double action press machine as shown in Figure-3. The machine has hydraulic press of 1500 kN capacity. Two types of contact condition will be applied i.e using lubrication and without lubrication.

Table-1. Dimensions for the drawing process tools, in milimeters.

Parameter	D1	D2	D3	D4	D5	D6
A	15.24	31.75	45.72	45.72	46.74	64.77
C	15.24	31.75	45.72	45.72	46.74	64.77
Parameter	R1	R2	R3	T1	H1	H2
A	1.016	3.81	1.905	T	5.207	34.29
B	1.016	3.81	1.905	t	3.429	34.29

The wrinkle wave amplitude used to determine the initial of wrinkling. (Liu *et al*., 2014) have reported different threshold values for the maximum wrinkle wave amplitudes. In this research, eliminate wrinkle is conducted by reducing the compressive stress on unsupported region, and increasing the area of sheet attached to the punch surface.

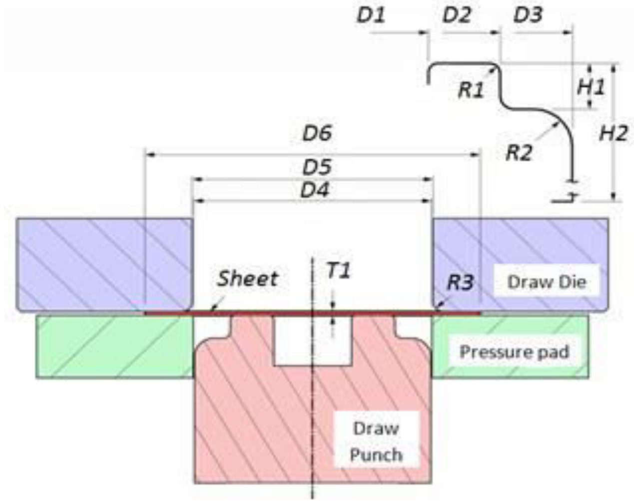

Figure-2. Schematic view of tools for the drawing process.

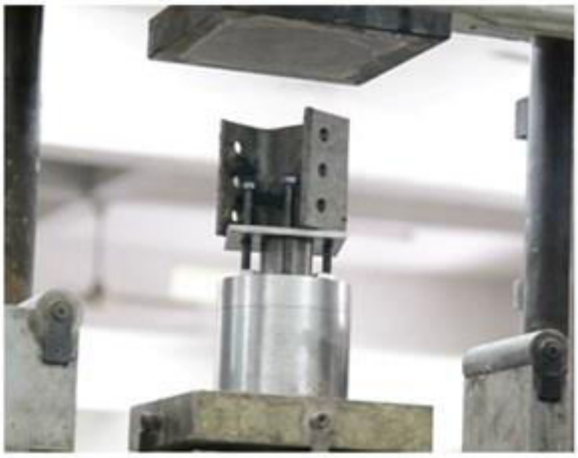

Figure-3. Tools set up and mounted on the press machine.

FINITE ELEMENT ANALYSIS

In this paper, FEA of dome wrinkling on cup drawing was conducted by using Autoform software. That is commonly used for solving sheet metal forming processes and its problems. Wrinkling on the dome area will be investigated by using this software. All CAD (Computer Aided Design) data were prepared by using CATIA V5 such as blank sheet, punch, dies, and blank holder. All models are imported into Autoform to be set up as assembly models as illustrated in Figure-4.

The yield criterion used in the analysis is Gotoh Yield Criterion. Gotoh proposed a polynomial yield function of fourth degree for orthotropic rolled sheet metals by writing the yield function in the form given by Hill Criterion.

$$f = \sum_{i,j,k} A_{ijk}\sigma_{11}^{i}\sigma_{22}^{j}\sigma_{12}^{2k} \quad (1)$$

The wrinkling conditions of blank in axisymmetric deep drawing necessitate to write for the function *f*.

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$$f = A_0(\sigma_{11} + \sigma_{22})^2 + \left[\begin{array}{l} A_1\sigma_{11}^4 + A_2\sigma_{11}^3\sigma_{22} + A_3\sigma_{11}^2\sigma_{22}^2 + A_4\sigma_{11}^{\square}\sigma_{22}^3 + \\ A_5\sigma_{22}^4 + \left(A_6\sigma_{11}^2 + A_7\sigma_{11}^{\square}\sigma_{22}^{\square} + A_8\sigma_{22}^2\right)\sigma_{12}^2 + A_9\sigma_{12}^4 \end{array}\right] \quad (2)$$

The first term can be considered as the mean normal pressure function, assuming an incompressible material, A_0 is obtained. The condition to avoid wrinkling.

$$cos\alpha \; sin\alpha F(c) = 0$$
$$c = cos^2\alpha$$
$$F(c) = 4Ac^3 + 3Bc^2 + 2Cc + D \quad (3)$$

A ... D are coefficients depending on A_1 ... A_9 :

$$A = (A_1+A_3+A_5+A_7+A_9) - (A_2+A_4+A_6+A_8)$$
$$B = (A_2+3A_4+A_6+3A_8) - 2(A_3+2A_5+A_7+A_9)$$
$$C = (A_3+6A_5+A_7+A_9) - 3(A_4+A_8) \quad (4)$$
$$D = A_4+A_8-4A_5$$

The materials used in this research were IF Steel and Aluminum with the material properties described in Table-2.

Table-2. Material properties.

Material	Young's modulus (GPa)	Initial Yield stress (MPa)	Work hardening	Poisson's ratio	K value (MPa)
IF Steel	210	167.9	0.223	0.3	550
Aluminum	70	97	0.22	0.3	250

The mesh quality in Autoform depends on the sets of values of parameters i.e: radius penetration, maximum element angle, maximum displacement and maximum bending angle. The adaptive discretization or refinement is carried out by dividing and combining element, as well-known the h-method (Logan, 2007). The mesh refinement is varied from rough, standard and fine. The details are shown in Table-3.

Table-3. Properties of mesh refinement.

Accuracy	Radius penetration (mm)	Maximum element angle (deg)	Maximum displacement (mm)
Rough	0.32	45	3.2
Standard	0.22	30	2.2
Fine	0.16	22.5	1.6

The simulation is carried out in three stages globally. At the first step, the blank holder is pushed onto the blank with a prescribed displacement to establish contact. At the second step, the boundary condition is removed and replaced by the applied force (BHF) of 1kN on the binder. Another analysis is conducted in different value of BHF to investigate the effect of BHF. At the third step, the punch is moved toward the blank.

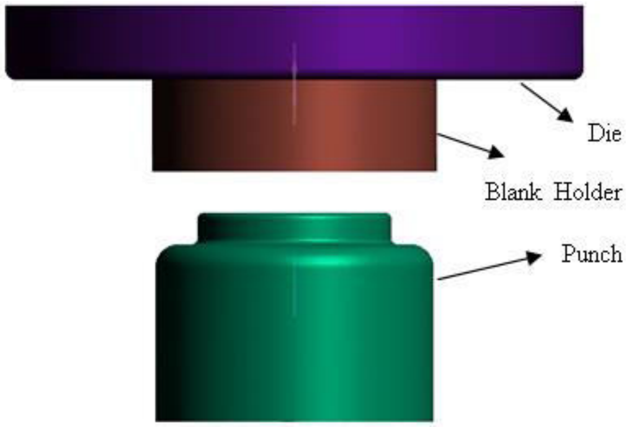

Figure-4. Tools assebly of punch, die and blank holder.

RESULTS AND DISCUSSION

In the experimental, the workpieces are deformed by press machine. Drawing occurs continuously during one punch stroke, and the punch speed is 140.0 mm/sec. The experiment is started by using Steel blank sheet and using a lubricant. For the use of 1 kN BHF, the dome wrinkling is seen clearly in the formed product. Figure-5 was given illustration of the wrinkling in variation of BHF starting from 1, 3, 5 and 8 kN. In the increasing of BHF, it can be seen that the dome wrinkling is decreased. At the last BHF of 8 kN, the dome wrinkling still occur although it is small value but it can be seen. The use of lubrication on the surface between punch-blank, binder-blank and die-blank does not give the significant difference in the dome wrinkling generation.

The cup drawing of Aluminum sheet is shown in Figure-6 for the use of 1 kN BHF. From the figure, it can be seen clearly that the wrinklings are arise in the dome area and side wall. Then the BHF is increase to the 3 kN, but the cup drawing of Aluminum sheet was failed and cracked. The failur of the drawing of Aluminum sheet can be seen in the Figure-7. The fracture of the blank can be caused by the material properties of Aluminum. As described before, that the Young's modulus of Aluminum is 70 GPa. It is lower than the Steel blank sheet. For the design aspect, it could be caused by the unused of drawbead model. In drawing process, drawbead model can provide material restraining action. So, it can control the material flow during punch moving.

In order to investigate the impact of lubrication on dome wrinkling, a numerical analysis was generated. Lubrication condition are taken into account for the friction in the analysis. In Autoform, Coulomb model with stick slip modeling was used. A braking force is applied on sheet during sliding, which is proportional to the contact pressure and to the coefficient of friction.

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The influence of friction coefficient to the wrinkle generation can be seen in Figure-8. From the figure, it can be said that the increasing of friction coefficient can decrease the dome wrinkling. But the increase of BHF should use the lower friction coefficient, so the blank material is able to flow during punch moving. As shown in the Figure-8, the increase of BHF to 8 kN, the drawing was failed at the increase of friction coefficient to 0.4. All BHF of 1, 3 and 5 kN were successfully formed a cup drawing by using variation of friction coefficient. The lowest wrinkling was 0.028, 0.013 mm for 1 and 3 kN BHF. The best result was delivered by 5 kN BHF and 0.8 coefficient of friction which is no wrinkling appear in this condition. Therefore, base on this analysis, it can be said that the ideal condition to form the cup drawing is using 5 kN BHF and 0.8 coefficient of friction.

(a) 1 kN BHF (b) 3 kN BHF

(c) 5 kN BHF (d) 8 kN BHF

Figure-5. Dome wrinkling of steel sheet.

Figure-6. Dome wrinkling of 1 kN BHF of aluminum sheet.

Figure-7. Failure drawing of 3 kN BHF of aluminum sheet.

Wrinkling measurement can be done in Autoform by using wrinkle results. Surface defect height shows the height of wrinkles with respect to the configuration of wrinkle free sheet. Surface defect height is calculated using eigenvalue analysis. The result value is shown as independent color shaded result variable, as shown in Figure-9. It results from the comparison of the configuration containing wrinkles and the configuration containing no wrinkles. It is before and after the eigenvalue analysis.

The cross section investigation of wrinkling is conducted as well. There are three section i.e 0^o, 45^o and 90^o from the center of cup product. For Steel material, the section investigation is provided in Figure-10. From the figure, the highest wrinkling was on 90^o direction, then the 0^o direction and the lowest was on 45^o direction. Figure-11 is shown the section investigation for Aluminum material. From the figure, it can be seen that the highest value of wrinkling was delivered by 45^o direction. The second is at 90^o direction and the third is the lowest wrinkling which is delivered by 0^o direction. Actually, wrinkling is occur not only on the dome area but also on the side wall. But in this paper, the focus is on the dome wrinkling. Wall wrinkling can be decrease by adding a process called ironing. The process is effective for the blank thickness more than 0.5 mm because it will be thinning.

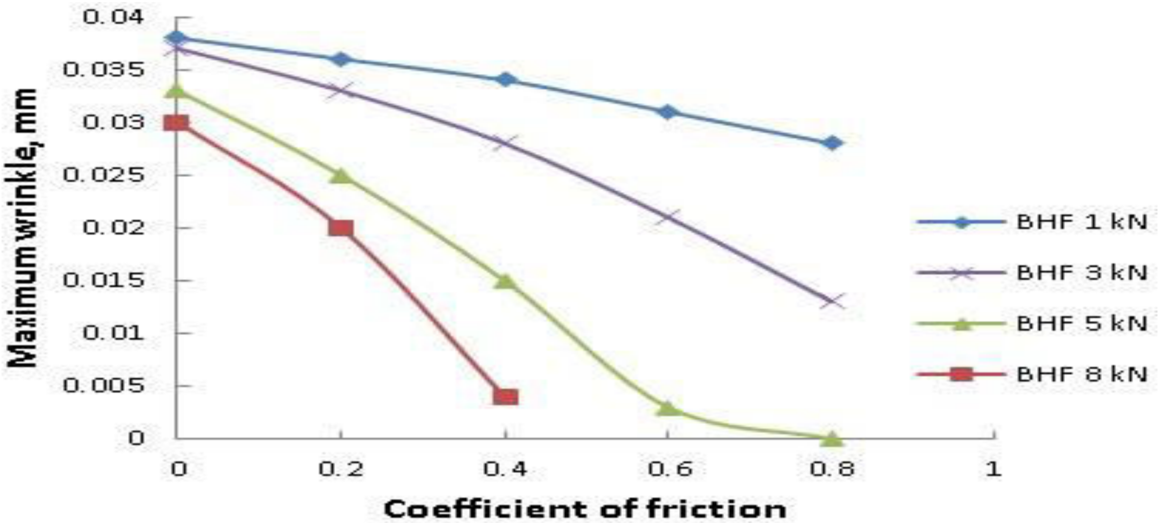

Figure-8. Influence of friction coefficient to the wrinkle generation.

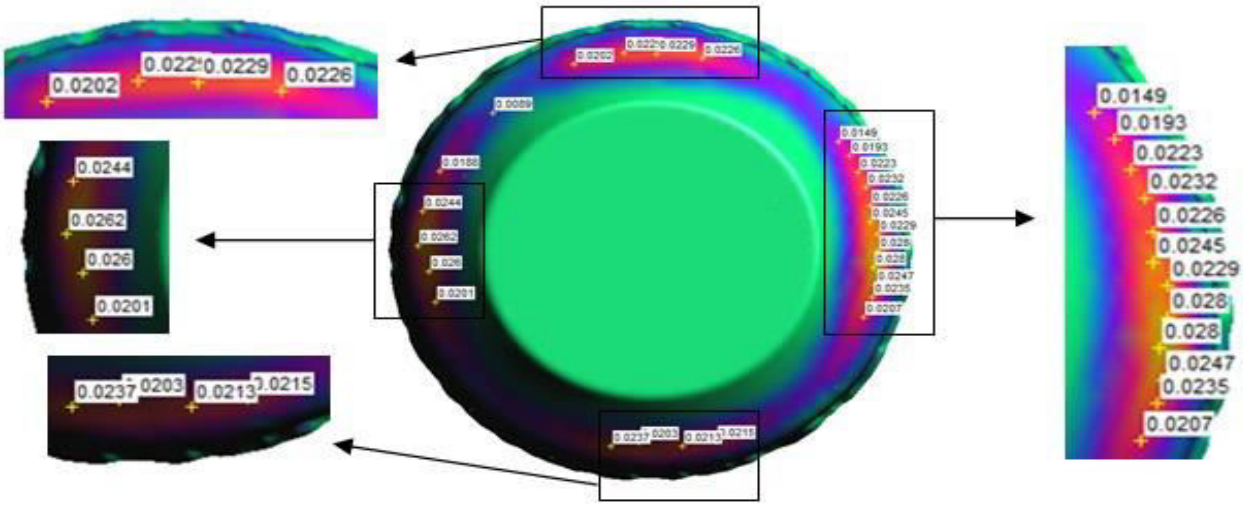

Figure-9. Wrinkling measurement.

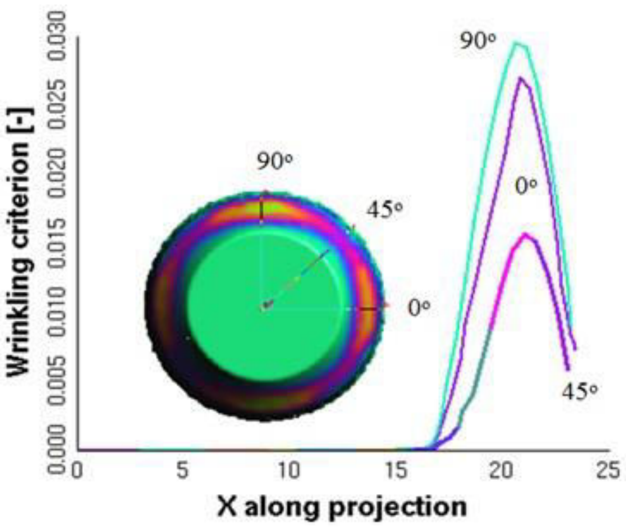

Figure-10. Section investigation of wrinkling of steel material.

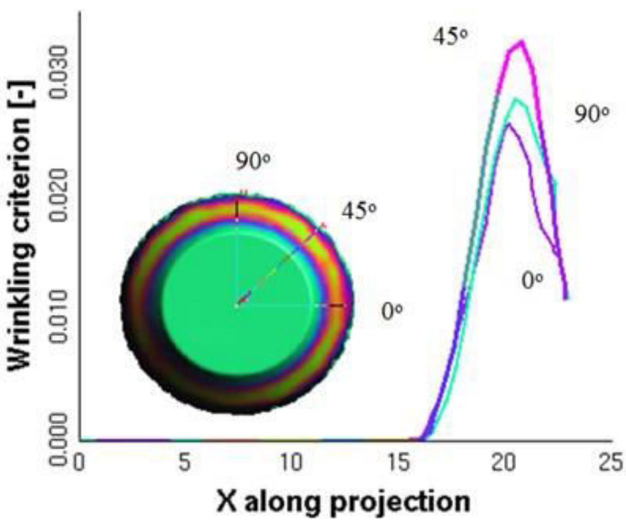

Figure-11. Section investigation of wrinkling of aluminum material.

CONCLUSIONS

The dome wrinkling phenomenon investigation of cup drawing has been done. Dom wrinkling in the chamfer area of cup was considered numerically and experimentally. The dom wrinkling of Aluminum blank sheet was shown higher compared to the Steel blank sheet. Blank holder force can decrease the wrinkling for Steel sheet but for Aluminum sheet, the increasing of BHF can cause failure during forming. The wave of dom wrinkling is clearly seen on the cup drawing of Steel blank sheet. For the future research, optimization of punch tool and simulation parameters can be conducted to reduce the dom wrinkling

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