

Article

Micro Cup Drawing without Wrinkles Using a Bulged Punch

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Abstract. A novel Bulged Punch (BP) was successfully performed for wrinkle elimination in micro cup drawings of AA1235 foils. BP was used to create a specific enlarged gradual punch profile before wrinkles began to occur until the end of the stroke, with fully annealing of AA1235 occurring before accumulative roll bonding (ARB), asymmetric rolling (AR), and stress relieving of a rolled blank, and deep drawing. The research purpose is to create a micro cup without wrinkles. The method was studied via experimentally deep drawing a blank thickness of 300 μm with pairs of dies-BPs supported by a press tool. Blanks were processed under (a) ARB 4 and 6 cycles, (b) combined ARB with AR and (c) post-heat-treatment. The process was selected when a force (F) from the simulation matched with the measured value. The results showed that BP can simultaneously eliminate the occurrence of wrinkles at the cup edge, reduce the earing occurrence, increase cup corner thickness, and decrease the edge thickness. Simulation models were built using the finite element method software LS Dyna, which supports experimental evidence. The findings imply that BP can successfully eliminate wrinkles at the cup edge.

Keywords: Wrinkle elimination, cup drawing, AA1235 foils, bulged punch, simulation.

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1. Introduction

Deep drawing is one of the most needed microforms. In deep drawing, product defects often occur in the form of tearing and wrinkling. Sridhar et al. [1] mentioned that wrinkling is a major type of deep drawing failure. Bell et al. [2] stated that hydroforming technology can reduce wrinkling and can make components lighter, stiffer, and cheaper with less waste. Rejection of the components of the deep-drawing results needs to be predicted such as by Takalkar and Chinnapandi [3] from thinning, wrinkling and spring back. Progressive micro forming techniques, especially size effect deformation in materials, dimensional accuracy, deformation load, failure analysis, the roughness of micro components (deep drawing, extrusion, forging, incremental forming, and stamping) which are the research issues of micro mass production and industrial complexity require extensive attention according to Srinivasan, Rajenthirakumar and Sridhar [4].

Wrinkling was investigated in the cone cup wall area with simulation and hydrodynamic experiments through radial pressure with an inward flowing fluid which showed a reduction in wrinkling according to Khademi et al. [5] but did not eliminate wrinkling.

In cases of cup wall wrinkles, tearing in the radius of punch (RP), cup edge earing, tears beginning to occur at RP, the cup edge thickening compared to the initial thickness of blank (TB), and difficulty of ejecting the cup is due to cup edge thickening frequently occurs in a micro cup drawing. Research regarding wrinkle elimination in micro drawings using a BP (bulged punch) is significant since cup wrinkles always occur in a micro drawing. Producers of micro part products will there derive the benefits of the research.

The effect of the initial foil thickness and reduced blank form was investigated by Mahmood, Irthia and Ahmed [6] for deep drawing on SS304 square cups which showed that results without flanges.

Preparation made by Lubis and Ristiawan [7] in blank materials was reached a good higher value for a 2.5% clearance (between die and punch) which over a 50% shear zone, compared to a 5% clearance that reached a 20 to 48% shear zone.

Residual stresses in blank sheets are generally removed through annealing or stress relief so that residual stresses do not cause tearing during deep drawing. Another method was researched by Pan et al. [8] with 1.5% cold rolling on AA7xxx T-section panels to eliminate residual stresses in the quenched core components up to < 83 MPa. An AC8H Aluminum alloy was observed by Akhtar et al. [9], who found that after quenching from 530 to 60°C, the alloy was heated to an aging temperature when heated at 150 and 175°C, and the maximum strength was reached but decreased when heated at 200°C.

The manufacturing of aluminum foil lamination by a combination of accumulative roll bonding (ARB) followed by asymmetric rolling (AR) can increase the strength and ductility because the microstructure is not

homogeneous with nanoscale granules and abnormal hardening of some grains occurs during AR according to Yu et al. [10].

Several studies related to deep drawing have been conducted by Hadi et al. [11], Hadi [12], Mahmood, Irthia and Abed [13], Dhal, Panigrahi and Shunmugam [14], Takalkar and Babu [15], Luo et al. [16], Wang et al. [17], Sato et al. [18], and Thanh et al. [19] regarding cup form-ability, wrinkles, reducing earing, thickening, flexible deep drawing, hydromechanical deep drawing, forming limit diagram (FLD) and limiting drawing ratio (LDR) which have shown progress. The AA1235-H14 flow stress with a thickness of 16-300 μm is significantly reduced by thinning as a function of the thickness and grain size of the material. An LDR of 2.003 can be achieved via ARB followed by stress releasing (SR) which increases the cup form-ability due to planar anisotropy being reduced and normal anisotropy increasing in the research of Hadi et al. [11]. Simulations using LS Dyna without wrinkles were achieved with a 300 μm blank thickness, and 14 and 15 mm blank diameters. Wrinkles began to appear at the cup edge for a 130 μm blank thickness, with increasingly wrinkles for a 70 μm blank thickness. The results of the experiments and simulations using BP for the first time by showed advantages: prevention of wrinkles, reducing earing, thickening the wall thickness at the cup corner radius which reduces tears, and thinning the thickness of cup edge based on research results from Hadi [12]. Floating rings drawing deep on SS304 micro cups as a flexible pad on a flexible die placed between a blank sheet and a rubber pad are worth adopting in the research of Mahmood, Irthia and Abed [13]. To overcome the abnormal stress-strain of the material, refined grains were used by Dhal, Panigrahi and Shunmugam [14] in the deformation zone with cryogenic rolling followed by annealing to a fully recrystallized, equiaxed, strain-free refined microstructure to increase the limits of microforming capabilities. Multistage deep drawing sequences for the first stage with a flat bottom and the second stage with a bulge bottom were simulated by Takalkar and Babu [15], who used that the strain distribution is used to produce FLD to predict thinning and wrinkling. Micro-hydro-mechanical deep drawing (MHDD), demonstrated by Luo et al. [16], revealed that the wrinkled area causes significant wear on the cup wall due to heavy contact between the blank and die. Experiments on a micro deep drawing of annealed of T2 copper foils were reached a maximum LDR of 2.2 with a 50 μm thickness of blank and a 0.5 mm diameter of the punch according to the research by Wang et al. [17]. Sato et al. [18] stated that MHDD requires a high counter pressure of ≥ 100 MPa. Intarakumthornchai et al. [19], through hydromechanical deep drawing (HDD) have obtained optimal results of BHF and linear pressure profiles of a parabolic cup with the response surface method (RSM) in minimizing part thinning of the cup without cracks and wrinkles.

Thanh et al. [20], conducted a study on a deep-drawing using a double-action hydraulic press for SPCC steel (JIS G3141) fuel-filter cup with first-second punches and the dies were examined to optimize the geometric parameters (BHF/blank holder force, die-shoulder radius, and clearance) to ensure thickness uniformity. The die-shoulder radius was the most influential parameter in the occurrence of wrinkling and tearing.

Some research by Reddy and Rajesham [21], Shinge and Debadre [22], Sudarsan et al. [23], Sheng and Mallick [24], and Woo et al. [25] has been conducted regarding LDR and FLD in the deep drawing, which shows that the prediction between the experiment and the simulation is close enough, the safe working zone and fracture zone, change in strains, and the ductile failure criterion (DFC) is met. Research related to LDR has been conducted on two undersize blanks and one of the oversize blanks with experiments and simulation, and the results are in good agreement with the 5.4% variation which is likely due to lubrication conditions specified by Reddy and Rajesham [21]. Shinge and Debadre [22] have manufactured FLD from HCHCr steel (ASTM E 2218-02) with a 5 mm diameter grid, and showed that the area below the FLD was the safe working zone, and the above FLD was a fracture zone with a major strain of 13.1-36.78% and minor strain 1.06-6.64%. Sudarsan et al. [23] evaluated of SS304 sheets with a 200 μm thickness for FLD through limiting dome height (LDH) tests with different widths of the rectangular specimens using a hemispherical punch of 30 mm and found that the change in marginal in limiting strains attributable to the change in the diameter of the punch from 30 to 50 mm, FLD_0 (at 0 degrees of rolling direction) changed by approximately 7.5% in the punch diameter and 6.8% changed in the stretching direction, and the change in the diameter of the circular grid from 2.5 to 2.0 mm resulted an increased in FLD_0 by 15%. DFC treats decentralized necking as a critical and failure damage as a function of the thickness of the initial sheet and strain path to predict FLD by validating 16 different steel and aluminum sheets, whose formulation shows sufficiently matching in most empirical cases, as proved by Sheng and Mallick [24]. The FLD for the Al 6061-T6 sheet improved the form-ability at a high-speed forming and the experimental FLD results for the electro-hydraulic forming (EHF) free-bulging test were shown to be in good agreement with the theoretical FLD according to the research of Woo et al. [25]. An experimental-theoretical investigation was conducted by Zhalehfar, Hashemi and Hosseinipour [26] on the effect of the strain path change on the FLD of AA5083 sheets on the form-ability with a hemispherical punch. There was a good agreements between the theoretical results and experimental observations. An evaluation was conducted by Rahmatabadi and Hashemi [7] on AA1050 on the elongation and FLD values after annealing at 380°C for 60 minutes is decreasing from 34% and 23% to 3.5% and 5% in 1 cycle of ARB, respectively. However, when increasing up to 7 cycles ARB, the

elongation and FLD values were increased to 7.8% and 14.5%, respectively, and when compared to the annealed samples the values were decreased to 77% and 37%, respectively. Alisaraci et al. [28] experimentally studied AA 1050 from 200 μm x 300 mm x 80 mm samples for 5 cycles of ARB and obtained an ultimate tensile strength (UTS) 393 MPa or 5.9x larger than that of the initial sample which was influenced by 2 mechanisms of strain hardening and grain refinement.

Micro deep drawing simulations with various eccentric distances and thicknesses were conducted: if the thickness was almost the same as the punch and die gap, it tended to experience fractures at the cup corner on the bottom side; if the gap was much wider than the thickness, wrinkling appeared; if the thickness was decreased, the wrinkles approached the bending zone; and if the die-punch eccentricity increased, the press resulted in a faulty product. The results can be compared to fit with the results of experiments by Hadi et al. [29]. Simulations for ironing in flanging of DC04 sheets with a thickness of 1.75 mm were used to predict the spring-back effect in the element formulation in new thick shell showing that an increase in the element can acquire a high accuracy material flow with maximum errors from thickness or cup heights is < 5%, but errors in hard ironing cases reach 45%, the results are in agreement with the experiment based on the results of the investigation by Güner et al. [30].

A 90 μm brass sheet was used to plot FLD using the LDH test according to ASTM E2218-02, and the results of hemispherical punch with a 15 mm diameter were plotted. Research and analytical approaches showed that the research was more accurate and had a safe zone with a higher accuracy than the analytical approach as proven by Mashalkar, Kakandikar and Nandedkar [31].

Micro deep drawing of Fe-30Mn-3Si-2Al-0.11C steel for domed-bottom cups with different grain sizes and thicknesses showed that earing easily occurs with the larger grain sizes and smaller thickness in the cups of good-formed domed-bottom. If the fraction of the grain boundaries increases with a smaller grain size, than the deformation load will increase. The case were earing becoming intense of a larger grain size is a result of characterization by Guo, Sun and Fu [32].

Micro deep drawing simulation on SUS304 sheets in which friction and contact significantly impact microsheet forming and its homogeneity cannot be simplified, since they show different roughening behavior at three areas (wall, radius, bottom) on the drawn cup, as observed by Luo, Jiang and Wei [33]. Cylindrical cups with an 8 mm inner diameter were formed with a rigid punch and polymer powder flexible forming (PPFF) deep drawing. An annealed blank thickness of 0.4 mm at 450°C for 1 h from Copper C1100 was produced well-formed cups using PVC powder to obtained an LDR = 2.1, which was higher than the rigid punch observed by Zhang and Gong [34]. Deep drawing DC04 sheets (EN 10130:2009) were used in pulling off a sheet on the draw bead, in which the effectiveness of reducing the friction

coefficient depends not only on the lubricant but also on the level of deformation on the middle roll displacement. An increase in the specimen width causes an increase in the friction coefficient, which is the result of the evaluation by Trzepiecinski, Fejkiel and Kubit [35].

The influence of the draw bead geometry utilized on the mechanical properties shows that the TS is enhanced by approximately 25% for materials of DC04 and 4% for DP800 when the fracture strain is decreased by > 70% for DC04 and 40% for DP800, which is the experimental result of Schmid and Merklein [36]. The DC04 after tensile testing has a 25% increase in TS, but the fracture strain can reach > 70% which shows a weakness compared to DP800 whose fracture strain is 40%, so with similar forming conditions between the draw bead and deep drawing can indicate that the form-ability of DP800 is better than that of DC04. The restraining force increases slightly when the DC04 sheet thickness increases as a consequence that of the material flowing through the draw bead which results in the sheet metal experiencing work hardening and wall thinning for higher restraining forces, these results are the experimental results of Bassoli et al. [37]. DC04 and DP800 with a thickness of 1.0 mm were subjected to tensile tests with a TS of 314.4 MPa and 817.9 MPa, respectively. Schmid, Suttner and Merklein have analyzed a draw bead that has a radius of 6.5 mm given a pressure of 5 MPa, where the strip (700 mm long and 50 mm wide) was pulled through the draw bead with a velocity of 10 mm/s which shows microhardness values on the upper and lower layers of the sheet as a visualized for both sheet steels which overall increases of the hardness and strain [38].

2. Materials and Methods

The material used in aluminum alloy research is foil from serial AA1235 which has properties soft and ductile properties with a silver white luster and temper of H14.

Research methods consisting of the AA1235 with TB = 300 μ m were used to form cups through micro deep drawing. Experiments were supported by a 3D FEM simulation. The mechanical properties of AA1235 were characterized through tensile tests after annealing with TB = 70 \div 300 μ m to account for variation due to these size effects. Blanks were processed under (a) ARB 4 and 6 cycles, (b) combined ARB with AR and (c) post-heat-treatment. The process was selected when a force (F) from the simulation matched with the measured value.

ARB is a serial rolling that bonds some sheets due to a high thickness reduction. ARB is a cyclical rolling stack of sheet metals; a stack is sectioned into 2 halves, piled, and rolled again. Thickness reduction of the next rolling at least 50%. The interface between the 2 surfaces was brushed by a steel brush, cleaned by Acetone, preheated at 200°C for 3 minutes and rolled immediately with a **reduction of 65%**, which **resulted in good bonding**. A rolls speed of 10 rpm for ARB was selected. ARB started with 9 sheets, resulting in $9 \times 2 \times 2 \times 2 = 72$ layers for 4 cycles, and started with 13 sheets for 6 cycles, which

yielded $13 \times 2 \times 2 \times 2 \times 2 = 416$ layers. The purpose of ARB in this work is to obtain a reduction in the grain size of the material so that the forming of the material can be conducted at a thinner thickness.

AR is a process caused by modified rolling mills with different roll velocities, which creates a friction region between pairs of rolls. The speed ratio was set to 1:1.2, which corresponds to the highest true stress and true strain from Hadi [12]. The experimental apparatus consisted of an Instron machine and press tool for a cutting blank and a drawing cup, and is shown in Fig. 1. F (force) and S (stroke) data were recorded by a machine.

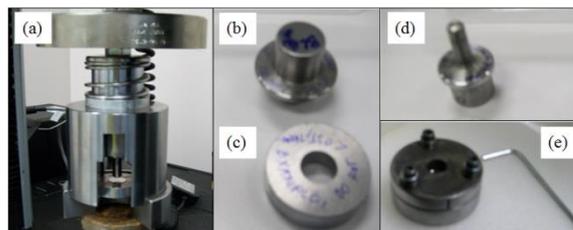


Fig. 1. A tool set of deep drawing: (a) a press tool mounted on an Instron testing machine, (b) a blanking punch, (c) a die block, (d) a drawing punch, and (e) a die set, for which the blank holder included 3 L bolts and 3 compressive springs.

A simulated deep drawing of the cup was performed used FEM software, LS Dyna. The model consists of an AA1235 blank, a die, a punch, and a blank holder. The AA1235 model has a yield strength of 38 MPa and a tensile strength (TS) of 74.2 MPa from Hadi et al. [11] with a diameter of blank (DB) = 14 mm and TB = 300 μ m containing 28561 elements and 34693 nodes. The elements number in the 4 parts was 28561, which consisted of 10800 elements for the shell part and 17761 elements for the 3 solid tools. The number of integration points used in the deep drawing model is 8 points in the deformation area, namely between the contact surface of the bottom blank and the inner diameter surface of the die, and the integration points are from the edge of the blank to the punch corner radius.

Punch speed (V) = 100 mm/s and FA (full annealing) conditions for all simulations by Hadi et al. [25].

The friction force (F) and normal force (N) on two contact areas on a sheet moving at a certain velocity were measured. The coefficient of friction was then calculated using the formula [39-40]:

$$\mu = F / (2N) \quad (1)$$

The strip drawing test is used to measure the friction coefficient of AA1235 with lubrication on the sample surfaces, as shown in Fig. 2.



Fig. 2. The strip drawing test to measure the friction coefficient of AA1235.

The basics of the forming process, especially rolling and deep drawing, are discussed in the following description. Plates can be transformed into other shapes if a force is applied that exceeds the yield strength of a material. The yield strength is obtained from the tensile test results of a material that is achieved from the lowest load to the elastic limit that meets the requirements of Hooke's law. Formation in the case of rolling must be given a force that exceeds the yield strength of a material or enters the plastic region of a material. Hot rolling above the recrystallization temperature can be performed indefinitely, but cold rolling can only be conducted with a limited thickness reduction, if the reduction exceeds the formability limit, the material will crack or fracture. As a result of the rolling process, the strength of the material increases due to the strain hardening of the material. To anticipate that the material does not crack, an annealing process is required to eliminate residual stress due to the previous process. In the ARB process, preheating is needed to help reduce the occurrence of side cracks in the rolling results. Similarly, for the deep drawing process, the stress-relieving process is conducted to reduce the possibility of cracks in the resulting cup, and with the stress relieving process the chance of cracking can be avoided, resulting in a cup without cracks or tears. Especially for micro deep drawing, the chance of wrinkling on the cup wall is very large. Generally, in the deep drawing process, the wrinkle is overcome by an advanced process, namely the ironing process. However, in this study, this process can be overcome by using a bulged punch where the size of the punch is made to start becoming larger when the wrinkle begins to occur, so that only one stroke in deep drawing can produce a cup without a wrinkle.

The method of eliminating wrinkles on the edge of the cup walls in the deep drawing process was granted for a patent on August 18, 2020, to the Ministry of Law and Human Rights of the Republic of Indonesia with the Number of Certificates of IDS000003125 for claims: the use of bulged punch in deep drawing can eliminate the occurrence of wrinkles in the cup wall, there is a thickening of the cup in the punch corner radius, and there is a reduction in the occurrence of earing on the edge of the cup wall.

3. Results and Discussion

Using ARB 6 cycles, TB = 338 μm and DB = 14 mm can form a cup with few wrinkles, but ARB 4 cycles failed, because it only reached a depth of ~ 2.0 mm. This means that ARB 6 cycles had a better form-ability than ARB 4 cycles. This was surprising because more ARB cycles produce materials with a lower ductility, but a higher strength according to Hadi et al. [11].

Cup drawing with ARB 6 cycles and AR 1 cycle with a speed ratio of 1:1.2 and an SR formed a cup without a tear but produced some wrinkles. The parameters were: clearance, $c = 0.057$ mm, $\left(\frac{8.26-7.54}{2}\right) - 0.303 = 0.057$ mm, DB/TB = 14 mm/303 μm , and diameter of die (DD)/DP = 8.26/7.54 mm. For DB = 14 mm, TB = 303 μm , the cup had edge wrinkles. A free $c = 0.057$ mm is likely to produce a cup with wrinkles, but the material strength and ductility are adequate for deep drawing; then a minimum c is needed to produce a good cup and reduce wrinkles. The value of c relative to TB was $(0.057)/0.303 = 19\%$.

Some micro cups formed with ARB 6 cycles and AR 2 cycles from TB = 45 μm were produced according to Yu et al. [10].

Most deep drawings cause thickening of the cup edge if NP (normal punch) is used. The NP process used TB = 0.05 \div 2 mm, and the cup wall edge thickness was 0.105 \div 2.13 mm, as a result, cup edge thickening was 5.2 \div 56% from Hadi [12].

Using AA1235 with NP resulted in a thickening of 25.7%, whereas BP resulted in 8.7%; hence, BP was used to prevent wrinkles. Hadi [12] have researched deep drawing with thickening in the cup wall edge.

BP is a novel punch that was specifically designed (Fig. 3) by Hadi [12]. Novel BP exhibits a gradual curve from DP = 7.59 mm to DP = 7.70 mm, which was used with DD = 8.25 mm to draw a blank with TB = 300 μm .

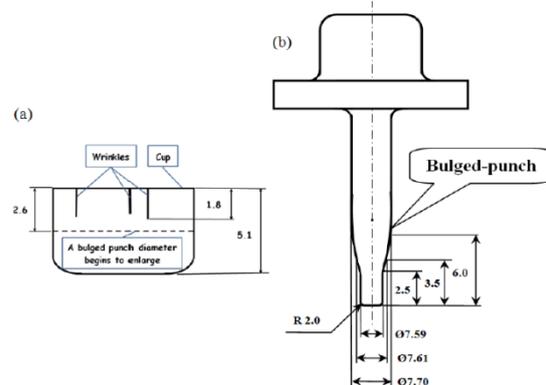


Fig. 3. Details of (a) a cup wrinkle depth, 1.8 mm, and (b) the shape and size of a novel bulged punch for a blank of thickness 300 μm and a die diameter of 8.25 mm.

The friction coefficient of AA1235 with lubrication on the sample surfaces under full annealing (FA) conditions with a thickness of 300 μm is shown in Fig. 4.

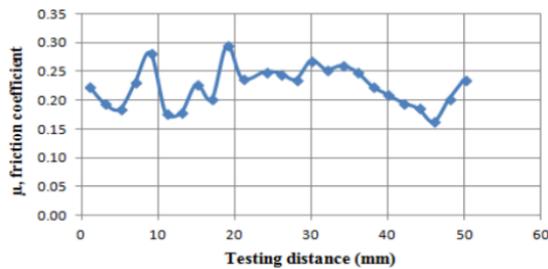


Fig. 4. The result of friction coefficient of the AA1235 with lubrication on the sample surfaces.

Friction coefficients (μ) of $0.10 \div 0.30$ were used for $TB = 300 \mu\text{m}$ simulations, as shown in Fig. 5 from Hadi [12]. The range of F was $F_{\text{max.sim,(0.10)}} = 724 \text{ N}$ to $F_{\text{max.sim,(0.30)}} = 1803 \text{ N}$ and $F_{\text{max.exp}} = 1640 \text{ N}$, which was 9% less than the simulated value. This discrepancy was due to ironing which affects the prevention of sidewall wrinkles according to Khademi et al. [5].

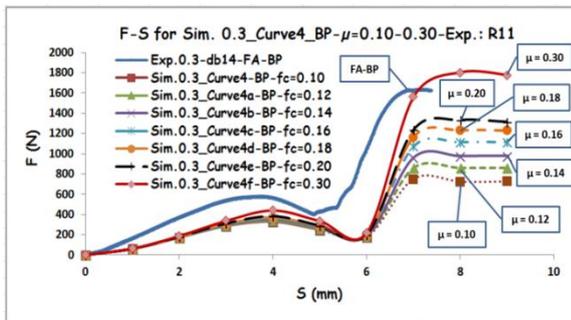


Fig. 5. The punch force (F)-punch stroke (S) for using a bulged punch with a coefficient of friction ranging from 0.10-0.30 for simulations with a blank thickness of $300 \mu\text{m}$ and FA condition.

The simulation result of AA1235 with $DB = 14 \text{ mm}$, $TB = 0.3 \text{ mm}$, $\mu = 0.18$, $RP = 2.5 \text{ mm}$, $RD = 1.2 \text{ mm}$, $DP = 7.54 \text{ mm}$, and $DD = 8.35 \text{ mm}$ are shown in Fig. 6 by Hadi [12]. $F_{\text{max.exp}}$ was 420 N , 17.3% greater than F in simulation with $\mu = 0.18$ was found that $F_{\text{max.sim}} = 358 \text{ N}$; hence, a better prediction was obtained for $\mu = 0.2$.

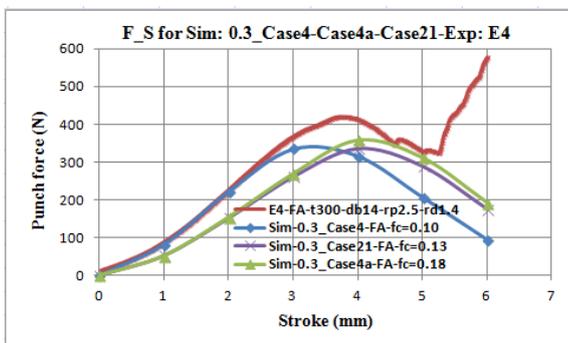


Fig. 6. The simulation results of deep drawing in the FA condition for a $TB = 0.3 \text{ mm}$.

The simulation result of AA1235 with $DB = 14 \text{ mm}$, $TB = 0.13 \text{ mm}$, $\mu = 0.15$, $RP = 1.2 \text{ mm}$, $RD = 1.2 \text{ mm}$, $DP = 7.54 \text{ mm}$, and $DD = 8.35 \text{ mm}$ were compared to an $F_{\text{max.exp}}$ of 440 N , which was 20.23% greater than the

F simulation with $\mu = 0.15$, which yielded $F_{\text{max.sim}} = 351 \text{ N}$; hence, a better prediction was obtained if $\mu = 0.2$ was used, but the value was still $\sim 20\%$ greater. F was lower because c at the cup top was wider for $TB = 0.13 \text{ mm}$ than for $TB = 0.3 \text{ mm}$, even though wrinkles occurred from Hadi [12].

The simulation results of AA1235 with $DB = 14 \text{ mm}$, $TB = 0.07 \text{ mm}$, $\mu = 0.1$, $RP = 1.2 \text{ mm}$, $RD = 1.2 \text{ mm}$, $DP = 7.54 \text{ mm}$, and $DD = 8.35 \text{ mm}$ were $F_{\text{max.sim}} = 67 \text{ N}$. The curve decreased but then started to increase, due to the occurrence of wrinkles from Hadi [12].

μ can be estimated by matching F with the experimental results, but this is not simple because deep drawing is a complex process in which various parts of the blank experience tension, compression, and bending by RP and RD , and the blank holder presses onto the flange area to reduce the bending effect by Güner et al. [30].

SEM microstructural photos from annealing and AA1235 processed ARB for up to 4 cycles followed by stress relief at 200°C for 8 h which shows the deep drawing success of increasing the LDR of 1.869 to 2.003 which was never achieved by the AA1235 material, as shown in Fig. 7.

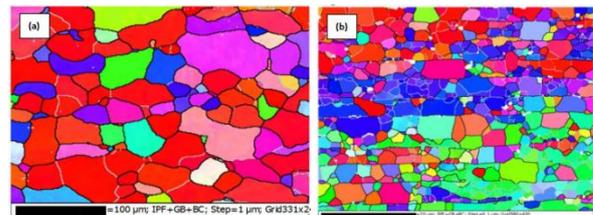


Fig. 7 The SEM of AA1235 for the electron back scatter diffraction (EBSD) images on the cross-section in the RD (a) of a FA material and (b) of an ARB 4 cycles material subsequent stress relieved at 200°C for 8 h.

The effect of the annealing process is indicated by the results of the tensile test which represent its mechanical properties which show an increase from the AA1235 material which is only annealed with the tensile stress from 90 MPa to 110 MPa for the AA1235 material which is processed by ARB to 4 cycles followed by stress relief at 200°C for 8 h.

The size effect of the SEM results on the annealing results of the AA1235 material with a grain size (d) of $25.09 \mu\text{m}$ and the AA1235 material from the results of which were processed by an ARB up to 2 cycles producing d of $1.76 \mu\text{m}$, followed by the ARB 4 cycle process producing d of $1.75 \mu\text{m}$. With the continued stress-relieving process at 175°C for 8 h, d was coarsened to $1.77 \mu\text{m}$, and for the stress-relieving process at 200°C for 8 h, d was coarsened to $2.15 \mu\text{m}$, as shown in Table 1.

Table 1. The result of average grain size (d) of the AA1235 from the SEM images.

| No. | Treatment/process | True Stress (MPa) | Strain (%) | d (μm) | d _{min} (μm) | d _{max} (μm) | Number of grains |
|-----|-------------------|-------------------|------------|---------------------|------------------------------------|------------------------------------|------------------|
| 1 | FA | 92 | 21 | 25.0 | 1.95 | 75.7 | 68 |
| 2 | ARB1c | 140 | 2.53 | 9 | | 5 | |
| 3 | ARB2c | 134 | 2.65 | 1.76 | 0.2 | 9.48 | 303 |
| 4 | ARB3c | 134 | 2.65 | | | | |
| 5 | ARB4c | 138 | 2.49 | 1.75 | 0.11 | 7.25 | 565 |
| 6 | ARB4cSR175 | 85 | 3.6 | 1.77 | 0.2 | 9.20 | 535 |
| 7 | ARB4cSR200 | 105 | 13.5 | 2.15 | 0.2 | 7.29 | 274 |

In cup deep drawing, the grain orientation is uniformly formed around the cup circle, so that the orientation in all directions changes shape, the raw material is AA1235 after the ARB process is conducted for several cycles, followed by a stress-relieving process for up to 8 h at a temperature of 200°C, so that after the blank is changed into a cup, there is no crack or tear in the cup corner, which means that the direction of rolling or grain orientation can be anticipated with further heat treatment after rolling. Components that are deep drawing processed include electronic component containers, e.g. capacitors and transistors, which are generally small in size and the material tends to be thinner.

The novelties of the present work are: (1) in overcoming the occurrence of a wrinkle, which is generally conducted in two steps, namely, the first process is deep drawing and the second process is ironing process, but by using a bulged punch, wrinkle can be eliminated in just one step from the deep drawing process, (2) in the cup corner, the result of deep drawing generally is that the thickness become thinner and the cup corner tends to tear, while in the present work with a one-step process using a bulged punch, the thickness of the cup corner become thicker, (3) the cup wall thickness resulting from the deep drawing process using a normal punch become thicker and the results from the use of a bulged punch show thinning that can facilitate the ejection of a product against the tools used, and (4) earing that occurs in the results of deep drawing of materials that were only fully annealed was greater than the earing that occurred in materials that were processed by ARB 4 cycles followed by stress relieving at 200°C for 8 h, as shown in Fig. 8.

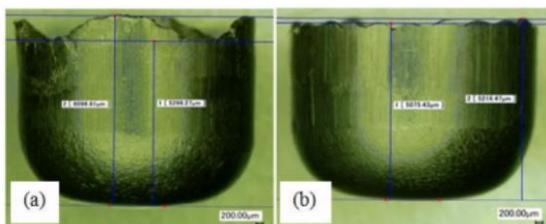


Fig. 8. The drawn cups by (a) a Normal Punch (14.1% earing), and (b) a Bulged Punch (2.7% earing).

In Fig. 9 from Hadi [12], the maximum Mises for NP and BP were quite different; the maximum stress on

RP of NP was 69 MPa (Fig. 9(a)), compared to 63 MPa for BP (Fig. 9(b)). This means that BP was lower, and hence the possibility of tearing was also lower. In the middle of the cup wall, stress with NP was the lowest (55 MPa), which means that this region experienced less F than when BP was used (76 MPa); the latter requires a high F to eliminate the wrinkles once they are initiated. The cup edge for NP showed a Mises = 85 MPa (Fig. 9(a)) and only 55 MPa (Fig. 9(b)) for BP. This means that BP was lower, and the cup edge was not thickened.

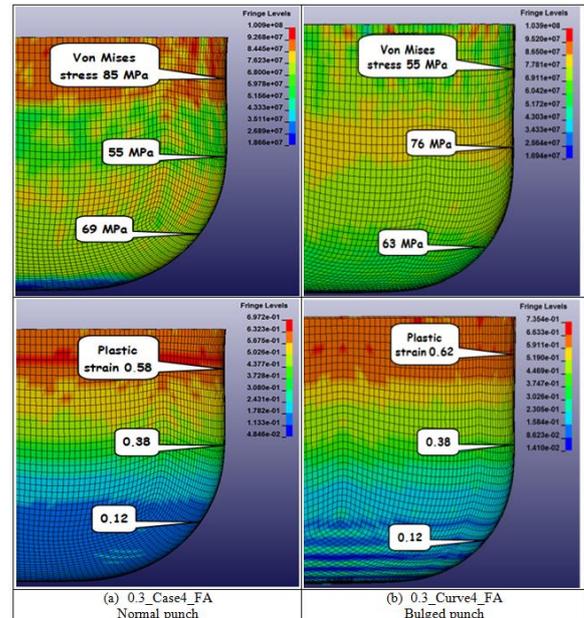


Fig. 9. The Von Mises stress (top figures) and a plastic strain (bottom figures) on AA1235 in the FA conditions for a TB = 300 μm and a DB = 14 mm: (a) a NP and (b) a BP.

A comparison of the cup wall thickness in the experiment and simulation is shown in Fig. 10 from Hadi [12]. An experiment of AA1235 with TB = 300 μm and DB = 14 mm exhibits a concave curve for NP (Exp.FA_20_NP) and a convex curve for BP (Exp.R11_BP). The simulation results reveal a concave curve for NP (Sim.0.3_Case1_FA_NP) and a concave curve for BP (Sim.0.3_Curve4_FA_BP). The limits of microforming capabilities can be neutralized by increasing the number of grains in the deformation zone, according to Dhal, Panigrahi and Shunmugam [14].

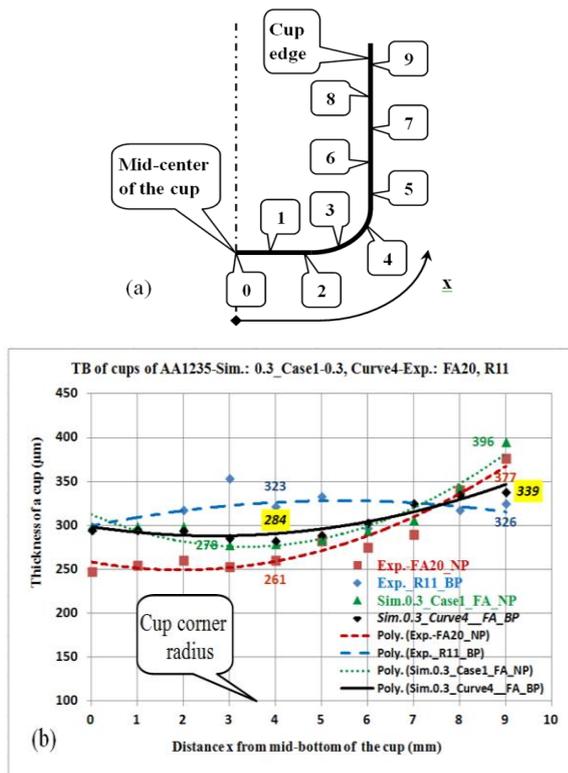


Fig. 10. A comparison of the distribution of the cup wall thickness in the experiment and the simulation results for the use of a NP and a BP for a blank thickness of 300 μm and the FA condition.

From the results of the experiment, the thickness at RP using NP was 261 μm , and it was 323 μm when using BP; this indicates a significant thickening of 62 μm (23.8%). Thickening in this region is an advantage because it can reduce tearing. The cup edge thickness using NP was 377 μm , and it was 326 μm when using BP which indicated a significant thickness reduction of 51 μm (13.5%).

The best value for the punch and die sizes is in the range of 4-15% c to TB to avoid wrinkles. For AA1235, NP resulted in a thickening of 25.7%, and thickening of 8.7% when BP was used; therefore, BP was used to avoid wrinkles.

Simulations demonstrated that cup corner radius thickness was 270 μm when NP was used and 284 μm when BP was used; this finding indicated a thickening of 14 μm (5.2%). The cup edge thickness for using NP was 396 μm , whereas it was 339 μm when using BP; this indicated a thinning of 57 μm (14.4%), which helps the cup to be ejected from tools more easily. Predictions were made on thinning, wrinkling, and spring-back defects in deep drawing by Takalkar and Chinnapandi [3]. Multistage deep drawing can predict thinning and wrinkling by Takalkar and Babu [15].

Figure 6 shows the simulation results that more c resulted in more wrinkles; for thinner blank, the wave of wrinkles was consequently higher.

An improvement was attempted by SR, and the material was then deeply drawn, resulting in a very good

cup when DB = 15 mm was used with an LDR was 2.003. This finding is extraordinary for a one-step deep-drawing because the most successful one-step deep drawing has LDR < 2, such as a fully drawn cup of AA6111 with an LDR of 1.752 by Reddy and Rajesham [21]. ARB 6 cycles and AR 2 cycles with TB = 45 μm and SR can form cups without tears, even though it had some wrinkles. The advantages of using BP compared with using NP are shown in Table 2.

Table 2. The advantages of using a BP compared with a NP for the deep drawing process.

| No. | Advantages | In experiment | In simulation |
|-----|--------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Preventing the formation of cup wrinkles | No wrinkles on blank thickness 300 μm of blank of 4 cycles ARB followed by SR at 200°C for 8 h. | No wrinkles for blank thickness of 300 μm due to have changed to the thickening on the cup edge. Half part (~50%) wrinkles on wall height were occurred at the cup wall edge for blank thickness 130 μm , and whole wrinkle of the cup wall for blank thickness 70 μm . |
| 2 | Reducing the occurrence of cup earing | About 80% lower earing of blank of 4 cycles ABR followed by SR at 200°C for 8 h than FA condition. | Not considered |
| 3 | Increasing the cup wall thickness of the punch corner radius | The significant thickening of 62 μm (23.8%) of thickness on the cup corner radius when using a BP was 323 μm than 261 μm thick when using a NP. | The quite thickening of 14 μm (5.2%) when using a BP, the thickness on the cup corner radius when using a BP was 284 μm than 270 μm thick when using a NP. |
| 4 | Reducing the cup edge thickness | The significant reduction in thickness on the cup edge of 51 μm (13.5%) was 326 μm when using a BP than 377 μm thick when using a NP. | The significant thinning on the cup edge of 57 μm (14.4%) was 339 μm when using a BP than was 396 μm thick when using a NP. |

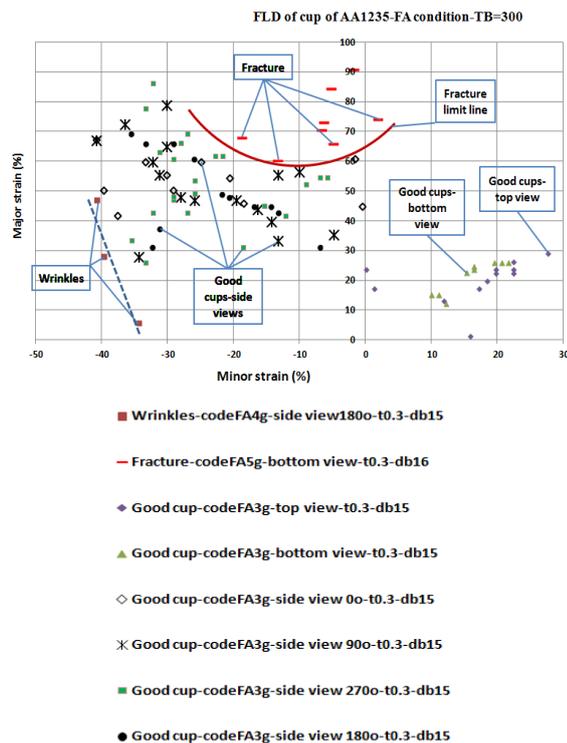


Fig. 10. The forming limit diagram (FLD) of an AA1235 deep drawn cup.

FLD of a deep-drawn cup from AA1235 was analyzed (Fig. 10) by Hadi [12]. Good cups were obtained under the fracture limit line, and the fracture cups were obtained above the fracture limit line.

Verification of the model in this paper is by experimenting in deep drawing using a bulged punch on AA1235 material with a heat treatment process only with full annealing conditions compared to AA1235 material which was conducted by the ARB process followed by stress relieving at a temperature of 200°C for 8 h. The proof that only one stroke in deep drawing can eliminate the occurrence of wrinkle is shown from the measurement results of the experiment with thinning of the wall thickness and thickening of the cup corner was supported by the simulation results.

4. Conclusions

Experimental and simulation results of AA1235 for TB = 300 μm yielded the following conclusions:

- 1) BP can eliminate wrinkles by ironing in the latter part of the stroke. This proposed BP can produce a good cup without wrinkles. Other benefits of the BP method compared to NP include (a) thickening of the cup corner radius, (b) thinning of the cup edge, and (c) reduced earing.
- 2) Earing can be reduced by ARB 4 cycles following SR before deep drawing. For FA conditions, using BP on TB = 300 μm may decrease earing on a cup, but F on BP is 181% greater than on NP, due to ironing.
- 3) Cup thickness at RP thickened when BP was followed by NP. The cup edge was thicker when NP was used,

but it decreased almost to initial TB when BP was used. A cup edge thickness reduction of 13.5% due to ironing when BP was used is significant for facilitating cup removal from tools.

- 4) Values of $\mu = 0.18 \div 0.23$ in micro cup drawing can be estimated by matching F between theory and experiment.
- 5) In the simulations of TB = 300 μm for AA1235, all cups were perfect, without tears/wrinkles; however, for TB \leq 130 μm , the cup wall exhibited a greater tendency to wrinkle.

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