

# Investigation of the Deep Drawability of Aluminium Sheets by Finite Element Numerical Simulation

Aruna Jyothi Anumula<sup>1</sup>

Assistant Professor, Department of Mechanical Engineering, Malla Reddy Engineering College, Telangana, India<sup>1</sup>

**ABSTRACT:** All sheet metal forming processes occur after permanent plastic deformation resulting in the material properties changing and therefore it is necessary to determine the extent to which a material can further be deformed for subsequent forming operations. The aim of the present work is to evaluate the formability of TWBs made of two dissimilar Al alloys sheets through deep drawing process. The different aluminium alloy sheets AA 6061 and AA 5052 are considered. The modelling of these two sheets is modelled in different length ratios to know the effect of sheets length. The sheet length ratios like 30-70, 40-60, 50-50, 60-40 and 70-30 are considered. The numerical simulations are performed for deep drawing of square cups on sheet width of 75x150, 100x200 and 200x200 mm strain paths at three different punch forces (10, 15 and 20kN) and blank holding forces (60, 70, 80kN). For numerical simulation a commercial FEM dynamic explicit code in which Holloman's power law and Hills 1948 yield's criterion is used. Failure initiation, major limit strains and dome heights are evaluated for all conditions. From the overall results, it has been noted that by increasing the punch force major stain is improved. Failure initiation is happened in AA6061 alloy irrespective of the punch force and blank holding force in strain path.

**KEYWORDS:** Deep Drawing, TWBs, Forming limit diagram, speed of welding.

## I. INTRODUCTION

In the modern development of manufacturing processes, sheet metal forming is one of the major processes. Among conventional sheet metal forming processes, deep drawing processes give distinct results by various materials. A part is said to be deep drawn when its depth is one and half times the diameter of the part. Deep drawing process is an efficient automated process for large productions having the advantage of lowering wastage of the material. Thus reducing cost besides yielding stronger finished products than that are manufactured by casting or machining. It also reduces the cost of assembling by providing combined assembly parts in a single deep drawing process.

Deep drawing is used extensively in the forming of sheet metal into cup or box like structures under tensile and compressive conditions, without altering the sheet thickness. Products of various shapes and sizes such as pots and pans for cooking, containers, sinks, automobile parts like panels and gas tanks are among a few of the applications manufactured by sheet metal deep drawing.

The formability of sheet material during the deep drawing depends on the parameters like blank holder force, lubrication, punch radius, die radius, die-punch clearance, in addition to mechanical properties and thickness of the sheet metal and part's geometry. The proper selection of these variables helps to reduce the defects in the deep drawing process like fracture, wrinkling etc and helps to implement optimum results out of the forming behaviour of the materials used in the process.

## II. RELATED WORK

Rodrigues et al [1](2007) compared the formability behavior of friction stir welded aluminum blanks with wide weld beads and Laser steel welded blanks with narrow weld beads. A tailor-welded blank of 1mm thick is made by considering similar and dissimilar combinations of the two steel alloys (DC06 and DP600) and two aluminum alloys (AA 5182-H111 and AA 6016-T4). The formability tests of the AA 5182-H111 and AA 6016-T4 base materials and its similar welds show that they suffer strong wrinkling associated with severe changes in microstructure of the material, thickness of the weld relative to the base material, which induces non-homogenous behavior of the blank and surface finishing. Reza et al.[10] (2012) studied the effects of punch and die temperature on the formability of a cup shaped AA3003 aluminum alloy sheet. The formability improves as the temperature difference between the punch and the die increases. Also the forming speed does not affect localized necking for the given punch velocities in their study

Recently Mostafapur et al[11](2013) conducted investigation to examine the effect on the formability and drawing depth of Al 1050 alloy using the new pulsating blank holder system. When compared with static holder, there was an increase in the depth, strength, formability and accuracy of the final product by using pulsating blank holder.

III. METHODOLOGY

III .a. Mechanical properties of base materials

The sheet material was considered as aluminum and the properties of AA 6061 and AA 5052 alloy were applied to the blanks. The properties of AA 6061 and AA 5052 aluminum sheet are shown in the Table 3.1 and Table 3.2 and also Table 3.3 shows Blank holding force, blank ratios, and Punch force and sheet metal blanks in three levels.

Table 3.1 Mechanical Properties of AA 6061 sheet

Base	E(GPa)	$\nu$	$\sigma$ (MPa)	K(MPa)	n	R <sub>0</sub>	R <sub>45</sub>	R <sub>90</sub>	t (mm)
AA 6061	69	0.33	277	392	0.08	0.81	0.9	0.71	2

Table 3.2 Mechanical Properties of AA 5052 sheet

Base	E(GPa)	$\nu$	$\sigma$ (MPa)	K(MPa)	n	R <sub>0</sub>	R <sub>45</sub>	R <sub>90</sub>	t (mm)
AA 5052	69	0.33	174	350	0.14	0.92	0.93	0.85	2

Table 3.3 Blank holding force, blank ratios, and Punch force and sheet metal blanks in three levels

Blank Holding Force (kN)	60, 70, 80
Blank length ratios	30-70, 40-60, 50-50, 60-40 and 70-30
Punch force (KN)	10, 15, 20
Sheet metal blank (mm)	75x150, 100x200 and 200x200

III .b. Forming Limit Diagram (FLD)

The forming limit diagram (FLD) is a crucial tool for characterizing the formability of sheet metal. For a given material the FLD depends on the shape of the yield function. But from the experimental and numerical results the FLD was strongly strain path dependent. The experimental method for determining the FLD was introduced by Keeler (1965,1968). The maximum strains that the sheet materials can sustain prior to the onset of localized necking are referred as the forming limit strains. A FLD is the plot of the major and minor limit strains in the principal strain space. But in all the sheet metal forming processes, experimental determination of the FLD has been tedious and expensive as the strain paths of different materials were non-linear and vary from each other. The simulation results when compared with FLD, focuses the problematic areas such as wrinkling, tearing etc of the component. They were then subjected to redesign of the component or the tool. A typical forming limit diagram is as shown in Figure 1.

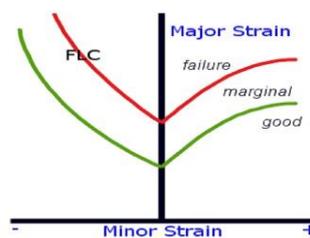


Fig 1. Forming limit diagram (FLD)

III .c. Simulations Using PAMSTAMP 2G

III .c. i. Finite Element Method and PAM STAMP 2G

Finite element method was mainly used for numerical analysis of sheet metal forming operations. Nowadays there were numerous commercial finite element codes. The simulations of two or three dimensional deep drawing operations mostly use the explicit finite element codes though there were weaknesses in the calculation of various stresses. The explicit finite element code PAM STAMP 2G was chosen for the simulations in this study. PAM STAMP 2G was an integrated solution for carrying out various stamping processes. It works as a unique graphical user interface that imports a CAD file, rework the geometry, mesh different parts, generation of the tools, launch the calculations by specifying the stamping process and finally post-process the results.

In CAD modelling, the tools required for the test, blank, punch, blank holder and die were generated. Simulations of deep drawing process were simulated using a finite element code, PAM STAMP 2G. The sheet comprised of quadrilateral shell elements with five through thickness integration points of Belytschko-Tsay formulation. The strain hardening law and the plasticity model considered were the Holloman's power law and the Hill's 1948 isotropic hardening yield criterion respectively. Two base material sheets each of size 150x150mm and 200x200mm were taken for all the conditions. The punch radius considered was 8mm and 6mm. A uniform meshing of size 1mm was used throughout the simulations. The yield strength was kept constant and the friction coefficients taken were 0.1, 0.15 and 0.2. The blank holder forces considered were 10kN, 15kN and 20kN. Downward stroke to the punch is given with a velocity of 10mm/min and a total of 18 simulations were performed by varying the friction coefficient and blank holder force. From the simulation results the thickness distribution, punch force, and dome height were evaluated.

**IV. EXPERIMENTAL RESULTS**

The present study observed the variation of the blank holding force and the blank ratio at three different varying levels while simulating the whole process. The blank holding force and the lubrication condition are effectively evaluated by comparing the punch force and the thickness distribution from the results obtained from the deep drawing process simulations of the AA 6061 and AA5052 sheet by calculating the major strain and minor strain values at each condition of different strain paths.

**IV.I. FAILURE INITIATION**

Figure 2 (a),(b) and (c) shows deformed strain paths of width 75x150mm, 100x200mm and 200x200mm at punch force of 10kN. In all Figures failure is happened in the AA 6061 sheet whereas failure location is same in all the strain paths. In 75x150mm and 100x200mm the stain paths failure is in the width direction. Initial failure is seen in the AA 6061, it is due to variation in the mechanical properties as compared to AA 5052 alloy. Strain hardening coefficient (n) which is one the effectible formability parameters during the deformation and also play a vital role during the strain localization. If the n value is more the strain localization will be uniform and vice versa. From the Table 1and 2, n value of AA 6061alloy is less compared to AA5052 alloy which lead the faster failure in AA 6061 alloy than AA 5052 alloy. Similar failure phenomenon has seen at punch forces of 15kN and 20kN.

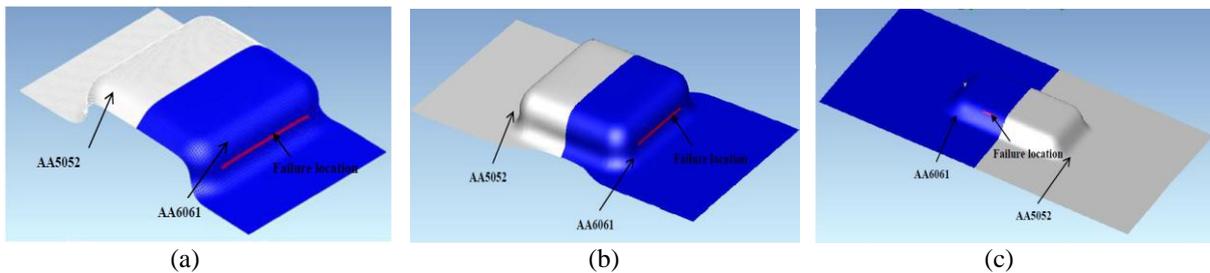


Fig. 2 (a)Failure location at 10kN punch force in 75x150 mm sheet (b) Failure location at 10kN punch force in 100x200 mm sheet (c) Failure location at 10kN punch force in 200x200 mm sheet

**IV.II. Failure Locations**

Below is the table showing the failure point, also considered as the punch force for the applied blank holding force along with the different blank ratios. The different strain paths are also mentioned.

Blank holding force (kN)	Blank ratio	Punch Force (kN)	Failure Initiation
60, 70, 80	30-70, 40-60, 50-50, 60-40, 70-30	10, 15, 20	AA 6061

**Table 4. 1 Failure locations at different parameters**

It is observed from the above Table 4.1 that all the time base material AA 6061 is undergoing into failure which shows that base material AA 5052 has got high forming when compare to base material AA6061 to undergo forming into any considered strain paths for the given blank holder force and punch force in considered blank ratios.

Finally it is concluded that among five different blank ratios as 30-70, 40-60, 50-50, 60-40, 70-30 for the blank holding force (60, 70, 80), punch force (10, 20, 30), strain paths (75x150, 100x200, 200x200) shows the best

forming in 70-30 blank ratio which indicates that at blank ratio 70-30, AA 6061 base material has got the highest forming limit.

#### V. CONCLUSION

The results obtained by varying all the above parameters are evaluated for the punch force and also for the thickness distribution. And it is concluded that:

- As the blank holding force increases from 10kN to 20kN, the punch force decreases with slight variation for the strain path 200x200mm. The punch force is noticed to increase with increase in the blank holding force for the strain path 150x150mm.
- The thickness distribution is evaluated from the graphs drawn by comparing the thickness with the distance, both calculated in mm. The observations show variation in the thickness distribution for the strain path 150x150mm for variations in the process parameters. But there is no change in the thickness distribution for the strain path 200x200mm.
- The dome height decreased as the coefficient of friction increased from 0.1 to 0.2. The maximum dome height is noted as 23mm for the strain path 150x150mm and as 13mm for 200x200mm strain path. But the variation in the dome height in each of the simulations is very minimum

#### REFERENCES

- 1) Rodrigues, BM Chaparro, C Leita, AJ Baptista, ALoureiro, P Vilaca Formability of Steel and Aluminium tailor welded blanks 2007.
- 2) R. Padmanabhan, M.C. Oliveira, J.L. Alves, L.F. Menezes Numerical simulation and analysis on the deep drawing of LPG bottles journal of materials processing technology 200 (2008) 416–423.
- 3) Cebeli Özek, Muhammet Bal The effect of die/blank holder and punch radiuses on limit drawing ratio in angular deep-drawing dies Int J Adv Manuf Technol (2009) 40:1077–1083.
- 4) R. Boissière, P. Vacher, J.J. Blandin Influence Of The Punch Geometry And Sample Size On The Deep-Drawing Limits In Expansion Of An Aluminium Alloy Int J Mater Form (2010) Vol. 3 Suppl 1:135 138.
- 5) D. Ghaffari Tari, M. J. Worswick, J. Mckinley, R. Bagherias Az31 Magnesium Deep Drawing Experiments And Finite Element Simulation Int J Mater Form (2010) Vol. 3 Suppl 1:159 162.
- 6) Mohammad Reza Morovvati & Afshin Fatemi & Mojtaba Sadighi Experimental and finite element investigation on wrinkling of circular single layer and two-layer sheet metals in deep drawing process Int J Adv Manuf Technol (2011) 54:113–121.
- 7) Ravindra K. Saxena, P.M. Dixit Numerical analysis of damage for prediction of fracture initiation in deep drawing Finite Elements in Analysis and Design 47 (2011) 1104–1117.
- 8) WEN Tong, GAO Rui, CHEN Xia Influence of High Frequency Vibration on Deep Drawing Process of AZ31 Sheet at Room Temperature J. Shanghai Jiaotong Univ. (Sci.), 2012, 17(4): 456-460 2012
- 9) Nguyen Duc-Toan, Kim Young-suk, Jung Dong-Won Formability Predictions of Deep drawing Process for Aluminum Alloy A1100-O Sheets by Using Combination FEM with ANN Advanced Materials Research Vols. 472-475 (2012) pp 781-786.
- 10) Reza Bagheriasl, Kamyar Ghavam, Michael J. Worswick Formability improvement with independent die and punch temperature control Int J Mater Form 2012
- 11) Amir Mostafapur & Sattar Ahangar & Reza Dadkhah Numerical and experimental investigation of pulsating blank holder effect on drawing of cylindrical part of aluminum alloy in deep drawing process Int J Adv Manuf Technol (2013) 69:1113–1121 2012
- 12) F. Javier Ramírez, Rosario Domingo Miguel A. Sebastián, Michael S. Packianather The development of competencies in manufacturing engineering by means of a deep-drawing tool J Intell Manuf (2015) 24:457–472 2012
- 13) Lade Jayahari, P.V. Sasidhar, P. Prudvi Reddy, B. BaluNaik, A.K. Gupta, Swadesh Kumar Singh. Formability studies of ASS 304 and evaluation of friction for Al in deep drawing setup at elevated temperatures using LS-DYNA Journal of King Saud University – Engineering Sciences (2013)
- 14) Farhang Pourboghrat, Senthilkumar Venkatesan, John E. Carsley LDR and hydro forming limit for deep drawing of AA5754 aluminum sheet Journal of Manufacturing Processes xxx (2017) xxx–xxx 2013
- 15) U. Pranavi, P. Venkateshwar Reddy, K. Lavanya, NV Narasimha Charyulu and Perumalla Janaki Ramulu, E-ISSN 2277 – 4106, P-ISSN 2347 – 5161, 2013
- 16) U. Pranavi, P. Venkateshwar reddy, Perumalla Janaki Ramulu Formability studies on Aluminum Alloy Sheets through Deep Drawing Process 2014