Modeling Studies on Formability of Al-Mg-Si Alloy -Computational Solid Mechanics Approach

M.Prabhu Teja, K.Veeranjaneyulu,

Abstract— The most common terms used in the formability tests are Stretch and deep forming. In the case of stretch forming and deep forming the former process results in thinning and increase in surface area due to the biaxial stretching the later process includes the drawing of the complete blank without changing the thickness. In the present study the a coupled thermo-mechanical finite element simulation software based on the computational solid mechanics(CSM) approach, Deform-3D was used to simulate the real time experimental values with the Numerical simulation. It was also observed that the error percentage between the experimental and predicted (Numerical model) is minimum. The effect of the process parameters such as the blank diameter, nose radius of punch, thickness of sheet and their ability on the formability of aluminum alloy was also simulated using Deform-3D

Index Terms— Forability, Strech Forming, Deep Forming, Thermo-mechanical, Deform-3D, Nose Radius, CSM.

1 INTRODUCTION

IN the Modern industry currently, deep drawing is used because of its promising methodology[1]. The plain strain formability analysis which evaluates automobile panels formability at early design phases, before initializing the design and production tool commitments can save time and cost [2]. Deep drawing is a sheet metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch. It is thus a shape transformation process with material retention. The flange region experiences a radial drawing stress and a tangential compressive stress due to wrinkles. Wrinkles can be prevented by using a blank holder, the function of which is to facilitate controlled material flow into the die radius. Stretch Forming is an operation to produce a dome-shaped part. The edges of the blank are securely clamped with a lock bead. A section through a stretch-forming die producing a dome-shaped part, the edges of the blank are securely clamped with a lock-bead, and the metal in the punch area is deformed by biaxial stretch.

Lightweight construction is crucial where mass is critical to enable the product function like in aeronautical applications. In case of masses subject to acceleration, lightweight components can increase the product performance e.g. allows higher revolutions with lighter crankshafts. Driving comfort and safety can be increased when unsprung masses are reduced like in a car chassis. At least, reducing masses improves the fuel consumption. Much effort is being put into the development of lightweight components and structures in automotive applications. Firstly, lightweight construction deals with the use of lightweight materials [4].

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For example, the tail gate of the Volkswagen consists of a magnesium cast inner part with an aluminum outer panel although severe corrosion issues have to be considered. Secondly, lightweight construction deals with different design strategies. For example, the chassis design possibilities providing different levels of suspension comfort, costs and weight. Concerning the body structure of cars and buses, frame and shell structures can be differentiated. Both design strategies are commonly linked to a specific material; aluminum in the case of frame structures, steel in the case of shell structures. Therefore, different manufacturing demands arise using different design strategies. Design, choice of material, and manufacturing technology are closely related as can be show by wheel productions, for example; weight reduction at wheels is important due to its unsprung mass and the associated reduction of fuel consumption and the better ride and handling comfort. Especially in the front of the car, a weight reduction is necessary to ease the critical mass distribution at the front axle and therefore increase driving safety. Forming technology can substantially contribute to lightweight construction.

The problem at early design phases, however is that the designs are not complete and are rapidly changing. For these reasons, there is a need for fast formability evaluation tool that requires minimum geometric definitions with minimum simulation time and modeling effort [3]. To reduce the time and cost involved in extensive experimental research, different analytical and numerical methods are being developed in order to analyze the best combination of them.

Simulation based on finite element method is one of the most frequently used methods being adopted by several researchers in mental forming processes recently. The advent of simulation tools for sheet metal forming analysis has enabled precise prediction of forming strains and other process parameters during sheet metal forming.[3]-[5]

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2 Materials and Methods

2.1 Materials

The Aluminum AA 6061-T6, was chosen as the sheet material because of its numerous applications in the field of the automotive industry the thickness of the sheet is 3.0mm.

The chemical composition and material properties of the AA6061-T6 are given in below tables 1&2.

Weight (%)	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
AA6061	97.9	0.8	0.65	0.40	0.15	1.0	0.2	0.1	0.15

Table 1: Chemical Compostion of AA6061-T6

Youngs Modulus	70-80Gpa
Tensile Strength	115Mpa
Yield Strength	48Mpa
% Elongation	22
Poissons Ratio	0.33

Table 2: Mechanical Properties of AA6061-T6

2.2 Cup Drawing Method.

The most common method used for the analysis of formability is Ericsson cupping test as shown in the figure.1 a blank is rigidly clamped and the die is forced towards the sheet. The sheet is deformed and it breaks at particular time where the yield stress of material is less than that of the applied stress.

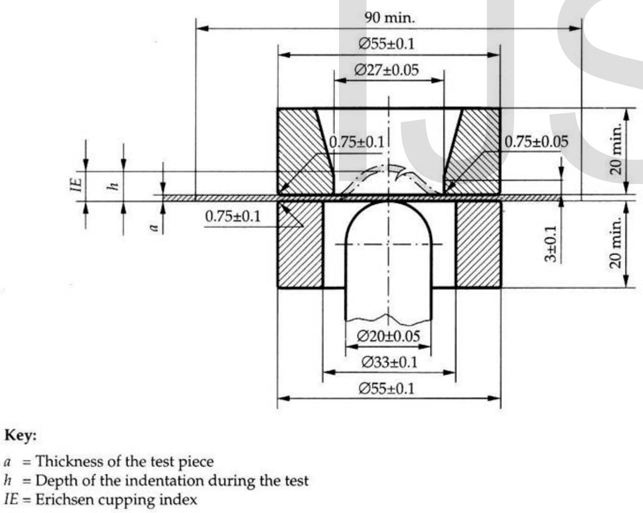

Figure 1: Ericsson cupping test [7]

The limiting dome height ratio is calculated in order to explore the formability of particular material.

The basic layout for an axi-symmetrical cup drawing is shown in the figure 2.

A cylindrical solid punch of radius Rp and nose radius Rn is used where Rn< Rp implies a flat bottomed punch and Rn=Rp implies a hemispherical punch. The clearance between the punch and the throat die is 0.3

A full cup is formed when the outer rim of the blank is drwn completely into the die throat, the drawing ratio is Rb/Rp

Where, R_n-Radius of the nose, R_p-Radius of the punch, R_r-Radius of the rim, R_b-Radius of the blank, H-Height of the cup, t-Thickness of the work.

2.3 Process Parameters

The combination of process parameters such as nose radius, Rn , Balnk Radius Rb and blank thick ness, t were used to analyze the deep drawing process

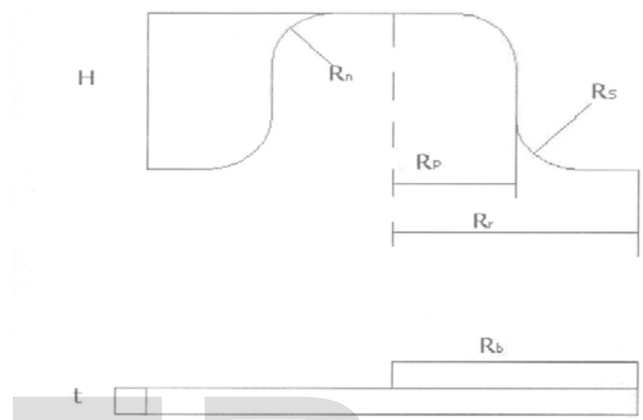

Figure 2: Basic layout for an axi-symmetrical cup drawing

t	Rn	Rb
3	5	50
3	10	50
3	15	50
3	20	50

Table 3: Case-1 sheet thickness 3mm

t	Rn	Rb
1	5	50
1	10	50
1	15	50
1	20	50

Table 3: Case-2 Sheet thickness 1.0mm

$$\Psi = \log_e (Ab/Ar) = 2\log_e (R_b/R_r)$$

$$\xi = \log_e (A/A_b) = \log_e (tb/t)$$

$$\chi=\xi/\psi$$

If $\psi = 0$, pure stretching.

If $\xi = 0$, pure deep drawing.

According to the above fromulae, finding the values of ξ, ψ and χ by using simulation, here analyzing the x values for combination of different process parameters as mentioned in the previous section.

To get the value of ξ, we need to know the average thickness value of the blank after deep drawing. For that we have to considr thickness of the blank at different locations.

3 Finite element simulation

A coupled thermo-mechanical simulation software Deform-3D uses lagrangian implicit method for solving the metal forming problems, it follows the most promising computational solid mechanics principles.
The capabilities of the deform includes Coupled modeling of deformation and heat transfer for simulation of cold, warm, or hot forging processes, Extensive material database for many common alloys including steels, aluminums, titanium's, and super-alloys.

The model has been developed with assumptions of the die as a rigid member and workpiece as the visco-plastic member Which is presented in the figure 3. The dies are represented with the arrow marks

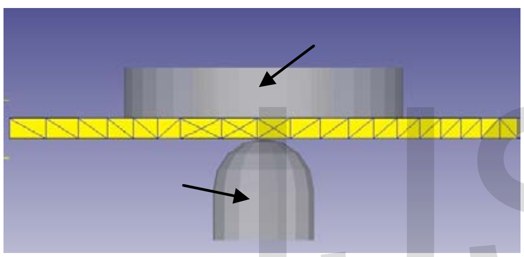

Figure 3: Meshed Dies-Tool Steel and Material-6061

The model is meshed with tetra element shape which gives the accurate results.

4 Results & Discussions

According to the above results, the noce radius with 5,10,15,20 mm are treated as the bottomed punches and nose radius with 25mm is equal to the punch radius than that is the hemispherical punch. Thus the curve is linear for all the values of the flat bottomed punch. It is slightly varied incase of the hemispherical punch.

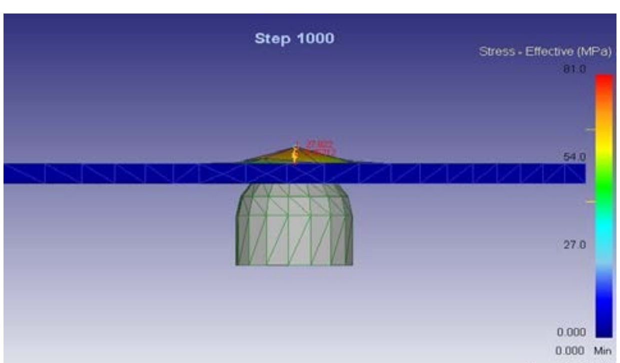

Figure 4: Progress of die and LDH Max at 1000th Step

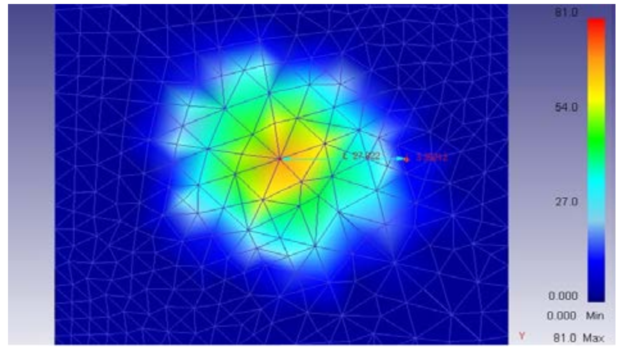

Figure 5: Un-uniform Distribution of Stress around the Punch

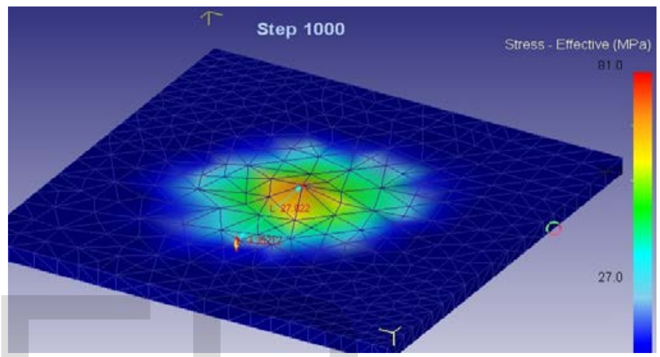

Figure 6: Stress Effective at 1000th Step during simulation.

The simulation value given in the table below is for a blank thickness of 3mm and blank radius is 50 mm.

SNO	Rn	Rr	Rb	t	ψ	ξ
1	5	33.791	50	2.5	0.7505	0.0155
2	10	32.745	50	2.9	0.8618	0.01065
3	15	31.75	50	2.97	1.0368	0.0108
4	20	30.35	50	2.93	0.884	0.06568
5	25	36.678	50	2. 8	1.1034	0.02668

χ	DAMAGE	HEIGHT	R_P	DRAW RATIO
0.02439	0.151	25.1	25	2.2
0.01266	0.144	30	25	2.2
0.00571	0.256	35	25	2.2
0.00368	0.144	40.1	25	2.2
0.00406	0.140	50	25	2.2

The thickness of the object is taken at different locations and the average thickness value is 2.97mm, damage value is found to be 0.318 and the displacement is 25.1. The rim radius is measred as 45.807mm.
According to the simulation results different graphs are plotted etween

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1. Nose radius and X
2. Punch nose radius and full cup height.

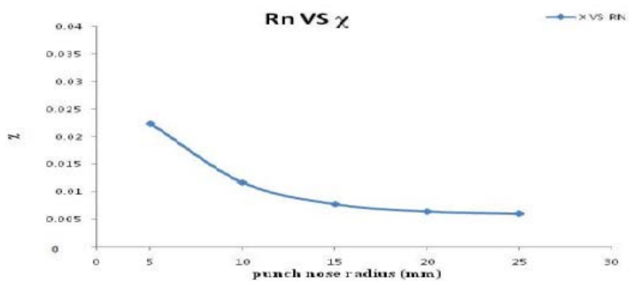

Figure 6: Plot of draw parameter vs. Rn

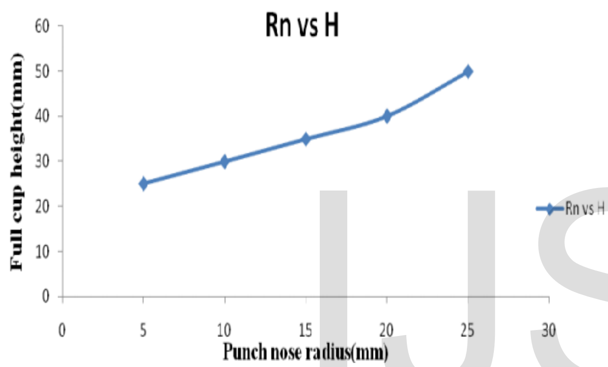

Figure 7: Plot of Cup height vs. Punch Nose radius.

The drawn cup with thickness at various locations with nose radius of 5 mm. The average thickness value is at this condition the thickness of the object is taken at different locations and the average thickness value is 0.9997mm, damage value is found to be 0.0835 and the displacement is 25.1. The rim radius is measured as 35.597 mm.

At this condition the thickness of the object is taken at different locations and the average thickness value is nearly 1mm, damage value is found to be 0.0562 and the displacement is 30. The rim radius is measured as 33.07 mm.

5 Conclusions

The result shows that the full cup height (H) increases not only with χ but also with the nose radius. For all the cases the nose radius is less than the punch radius except in case of 25mm.

The nose radius with 5, 10, 15, 20mm are treated as flat bottomed punches and nose radius with 25mm is equal to the punch radius than that is the hemispherical punch. Thus the curve is linear for all the values of the flat bottomed punch. It is slightly varied in case of the hemispherical punch

From the results it is very clear that for a thickness of 1mm the value of ξ = 0 or tending towards zero showing that it is a case of pure drawing.

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