Re-entrant Formation on Superplastic Forming Process by Mechatronics Approach in 5083 Al Alloy

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Abstract. Superplastic materials are attributed viscous in behavior which exhibit very narrow and steady grain formation at half of the melting point temperature of given components. Superplastic deformation characteristics are carried out in different pressure control with constant strain rate conditions. In different alloy, the maximum (optimum) strain rate changes from 0.001 to 0.00001s\(^{-1}\). The objective of this research work is to predict the pressure requirements (optimize) to obtain smooth (uniform) profile in a re-entrant shape formation of 5083 Aluminium alloy by using mechatronics approach of Programming Logic Control method. The effect of various forming parameter such as, forming pressure, bulge forming time and thickness distribution of the sheet in a re-entrant shape product. Finite Element analysis is a powerful tool to evaluate the superplastic forming processes (SPF) with accurate prediction of the deformation characteristics.

1. Introduction
industrialized of multifaceted lightweight automotive structure that meet high cost and preferred manufactured goods target is a competitive challenge which is faced by the industry. Today superplastic forming is a process for manufacturing of multifaceted and assembly parts which is used in the aerospace and automobile application. Superplasticity is the capability of certain materials which undergoes extreme elongation at an prominent temperature and low stain rate. Some alloys such
as 5xxx,7xxx,8xxx series aluminum alloy [1-7] undergo viscoplastic deformation (creep behaviour) prior to failure at high elevated temperature.

Hwang et al. [8] have taken circular die for examined to optimize the pressure profile and evaluated uniform and non-uniform thickness distribution in the free bulge region. Jovane, et al. [9] have considered as a circular diaphragm for demonstrating the optimum thickness during the blow forming process. Ghosh and Hamilton [10] experimentally illustrated to optimized the pressurization profile during blow forming into a rectangular die. SenthilKumar, et al. [11] has examined in hemispherical profile during superplastic forming process (SPF) in AA7475 alloy with help of FEA. Balasubramanian et.al [12] have considered analytical and FEA simulation to evaluate the thickness formation, processing time and forming pressure in a long single step rectangular die. In this research an attempt is made to minimize the forming duration, minimize the forming pressure and optimize the thickness formation in a re-entrant dome profile.

2. Material selection

AA 5083 alloy material has been taken for this investigation process. 1.5 mm thickness material has been considered for experimental process with other SPF parameters are taken such as 1 x 10^{-3} s^{-1} strain rate, 450°C temperature, \( m \) (Strain rate sensitivity index ) value of 0.39 [13] and \( k \) (material constant) value of 159.5 MPa s^{m}. The chemical composition [12] are given in Table 1.

| Table 1. Composition of 5083 Al Alloy |
|-----------------|--------|-----|-----|-----|-----|-----|-----|
| Si   | Fe   | Cu  | Mn  | Mg  | Cr  | Zn  | Ti  |
| 0.128 | 0.185 | 0.001 | 0.171 | 2.96 | 0.052 | 0.051 | 0.102 |
| Al   |       |     |     |     |     |     | 96.35 |

3. Experimental modeling

The 1.5 mm thick and 30 mm diameter specimen has heated to the superplastic forming temperature inside sealed die during superplastic forming process. The specimen to obtain the contour of the dome profile after applying inert gas pressure. The blow forming in a dome before and after applying of pressure as shown in figure 1. In SPF, the constitute formula has been adopted, in order to attain thickness formation, period of formation and smooth pressure curve. The equation (1) represent the flow stress during SPF process.

\[ \sigma = k\dot{\varepsilon}^m \]  

Where \( \sigma \) - Stress (N/mm²), \( k \) - Material constant, \( \dot{\varepsilon} \) - Strain Rate (per sec) and \( m \) - Strain rate sensitivity index. The re-entrant circular shape of die design is very significant role. It consists of two part such as top (male) and bottom (female) part. The re-entrant die of female die has two different stages. The first stage dimensions are 30 mm top diameter and 15 mm depth. 3 mm radius and 2 mm depth are kept in four cups in second stage of re-entrant dome. At the end, 2.5 mm and 0.5 mm are
considered as a die entry radii at first and second stage respectively. The re-entrant shape model as shown in figure 2. Gas pressure forming of SPF grade AA 5083 alloy into Re-entrant circular die was performed at a temperature of 450°C with variable pressure and different constant gas pressures techniques. Also due to thermal losses, defects in sheet metal, hardening of sheet metal, clearance between contacts dies, due to misalignment of work piece are to prevent during SPF process. The main intention of this work is to reduced forming time, find out the optimum forming pressure and thickness distribution.

**Figure 2.** Illustration of re-entrant shape model

**Figure 3.** PLC signal processing of pressure control

The experimental setup is performing the blow forming process, it consists of hydraulic press, specially designed re-entrant die, argon gas, cylinders, gas regulation, pipe linings with controlling of PLC circuit [13]. The press unit available has a hydraulic power press and a main motor of 5 horse power. The fixture is bolted on to the top die using alien screws. The top die is made to seat on top of the bottom die with the help of the grooves provided. A stainless steel rod is attached to the L-shaped hole in the top die. On to the top die, a circular pipe for the passage of argon is welded and the other end is connected to the argon gas hose pipe. The compressed argon gas is controlled by PLC circuit and passed into the top die. The complete structure of the experimental setup process is shown in figure 3.

**4. Finite element modeling**

Large deformation, material non linearity and more strain are involved during superplastic blow forming process. The initial and boundary conditions are important role during superplastic deformation. In a large non-linear process are solved by computational techniques of some numerical methods. In non-linear process, blow materials are considered as a rigid visco-plastic [14]. The finite element techniques (Abaqus) have been taken on during superplastic formation with creep strain control scheme. The stress distribution and thickness distribution of quarter part of re-entrant simulation model is shown in figure 4 a, b.
The geometric FEM model for the first stage circular has 30 mm diameter and 15 mm depth and second stage is 4 cups with 6 mm diameter and 2 mm depth with a fillet radius of 2.5 mm and 0.5 mm in first and second stage respectively. In finite element modeling, SAR element are chosen during pre-processor. In blank, the circumferential edges are clamped rigidly. Assume, blank is axially deformable and die is rigid. For solving non-linear equation in abaqus, the modified Newton-Raphson method \[12\] has been implemented. All direction (all degree of freedom) of the movement of die surface nodes have been arrested. On the top surface of the blank in Y direction the pressure has been applied by constant pressure technique as well as variable pressure technique method. An accurate simulation process has been carried by implementing mechatronics coding system during variable pressure technique condition.

5. Results and discussion
Experimental and the finite element modeling has been carry out to obtain the uniform thickness formation, minimum time formation and optimum (minimum) pressure requirements by using constant pressure technique and programme logic control (PLC) approach of variable pressure technique.

5.1. Predict the best pressure control method with respect to forming time and dome depth under different pressure control techniques.

![Figure 5. Illustration of forming time with a function of die cavity depth and different pressure control techniques at a temperature of 450°C.](image)
The superplastic blow forming process were carried out numerically and experimentally by using constant pressure of 0.4 MPa, 0.5 MPa, 0.6 MPa and variable pressure by Programming Logic Control approach. Superplastic blow forming time with a function of die cavity depth as shown in figure 5. From figure 5, it is observed that, the constant pressure increases from low to high the blow forming duration decreases, further blow forming duration highly decreases by using variable pressure technique with adopting PLC method. In constant pressure technique, time required to fill the die cavity is 2993 sec, 2272 sec and 1982 sec in 0.4 MPa, 0.5 MPa and 0.6 MPa respectively. But, by using programming logic control approach method, by filling the die cavity smoothly and thereby eliminating the defects [13] by slow filling with minimum time of 1264 sec and minimum pressure range of 0.0 to 0.52 MPa.

5.2. Formation pressure profile with a function of forming time
Superplastic profile formation depends upon the different technique of applied pressure and forming duration. The forming pressure with a function of forming time as shown in figure 6. In this profile the pressure constantly increases and further rapidly increases as evidence in figure 6. Because of, this pressure changes is, the sheet first reaches the first stage of bottom surface and the sheet moves towards corners and re-entrant shapes four cups in simultaneously in the second stage. As the bulge envelope contact the corner of the die cavity, rapid increase in pressure is noticed which could be attributed to the dominant change in radius in a both stages.

![Figure 6. Effect of forming pressure as a function of forming time](image)

The relationship between pressure and forming time at different pressure levels is shown in figure 6. The finite element values are very closed to the actual experimental value, with maximum error of 2.65 %, 4.68 %, 5.17 % and 4.91 % in PLC approach and constant pressure of 0.4 MPa, 0.5 MPa and 0.6 MPa respectively. In PLC method, 2.65 % error only accruce in FEA results when compare to experimental value.

5.3. The thickness distribution and different pressure control method to optimize the thickness variation
The figure 7 represent, the re-entrant formation profile can be split into IX regions in order to predict the thickness variations. Region I, region II, region III and region IV are represent die entry contact, side wall contact, free bulged region and bottom contact regions respectively during first stage formation. similarly, the region V, region VI, region VII, region VIII and IX are represent die entry
contact, side wall contact, opposite side wall contact, die entry contact and bottom contact regions during second stage.

![Figure 7. Schematic view of the different contact mode during blow forming](image)

Thickness distributions for re-entrant shape forming have been shown in figure 8 along the dome profile for a temperature of 450°C using constant and variable pressure control of PLC for the results obtained from experimental. From figure 8, it is observed that, in constant pressure control method, more thickness variation are obtained in different regions, however PLC method very minimum (optimum) thickness variations and smooth profile has been obtained. Because, the pressure has controlled by in PLC technique. The control circuit to regulate the pressure flow in order to filling corner regions, side wall regions slowly, thereby eliminating the premature fracture and oscillations.

The thinning factor [15] is a very important key factor for determination of uniformity of thickness profile. The greater value represent the more uniform thickness profile. The Table 2 represent the average corner thickness, average thickness and thinning factor values at different pressure condition methods.

![Figure 8. Thickness distribution along the dome profile in experimental at a temperature of 450°C.](image)
Table 2. Average corner thickness, average thickness and thinning factor values at different pressure conditions

| Parameters                      | Variable Pressure method | Constant pressure (MPa) (PLC approach) | 0.4 | 0.5 | 0.6 | (Range 0.0 to 0.52 MPa) |
|---------------------------------|--------------------------|---------------------------------------|-----|-----|-----|------------------------|
| Average corner thickness (mm)   |                           | 0.72                                  | 0.5 | 0.66| 0.8466                 |
| Average Thickness (mm)          |                           | 0.8153                                 | 0.789| 0.7393| 0.8823                 |
| Thinning factor (%)             |                           | 88.3                                  | 88.71| 89.26| 95.95                  |

Table 2 shows that the PLC approach has a higher thinning factor of 95.95 %, when compared to constant pressure of 0.6MPa (thinning factor 89.26 %), 0.5 MPa (thinning factor 88.71 %) and 0.4 MPa (thinning factor 88.3 %). From figure 8 and Table 2, observed that the PLC process has obtained optimum thickness variation when compared to constant pressure control method.

6. Conclusion
The experimental method and FEM simulation has been made for superplastic forming of 5083 Al alloy sheet in to a re-entrant dome shape. The following conclusion have been made from the observation.

- The programming logic control approach method, by filling the die cavity smoothly and thereby eliminating the defects by slow filling with minimum time of 1264 sec and minimum pressure range of 0.0 to 0.52 MPa.
- Smooth dome profile obtained in PLC method at a maximum pressure range up to 0.52 MPa.
- The variation in thickness distribution is found to be uniform in PLC approach.

7. References
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