Investigation of Superplastic Forming Process through FEA to Minimize the Forming Defects: A Literature Review

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***Abstract* - Superplastic forming is the ability of certain alloys, to undergo very large elongations, prior to fracture without neck formation. Material with more than 200% elongation during hot tensile testing are said to have superplastic forming capability. The low flow stresses and high sensitivity of flow stress to strain rate are the main aspects of superplastic deformation. Superplastic forming mainly used in aerospace and automobile sector where complex shapes required for fine and thin material without any damage. Quality of superplastic formed material mainly depend on Forming pressure, Dome height Sensitivity index, Effective strain at the dome apex and Annealing time. Purpose of this study is to minimizing the forming defects with balancing the factors having more influence on it.**

***Keyword* - Superplastic forming, Strain rate sensitivity, Finite element analysis, Forming defects, Cavity formation**

I. INTRODUCTION

Superplastic forming is the ability of certain alloys, to undergo very large elongations, prior to fracture without neck formation. It allows the forming of complex to very thin parts which are not possible under normal forming condition. Working principle of Superplastic forming are as the other forming process as: the sheet metal is firmly clamped between the die halves and is blow by gas pressure. The initial requirement for Superplastic forming are as:

i. The average grain size of less than 10µm,
ii. Forming temperature for superplastic forming is more than one half the melting temperature of the material,
iii. Superplastic forming is usually formed between the strain-rate of 10-1 to 10-5 s-1. The alloys are formed at slow strain rate superplastic forming of 10-3 to 10-5 s-1.

Schematic diagram of Superplastic forming has been shown as:

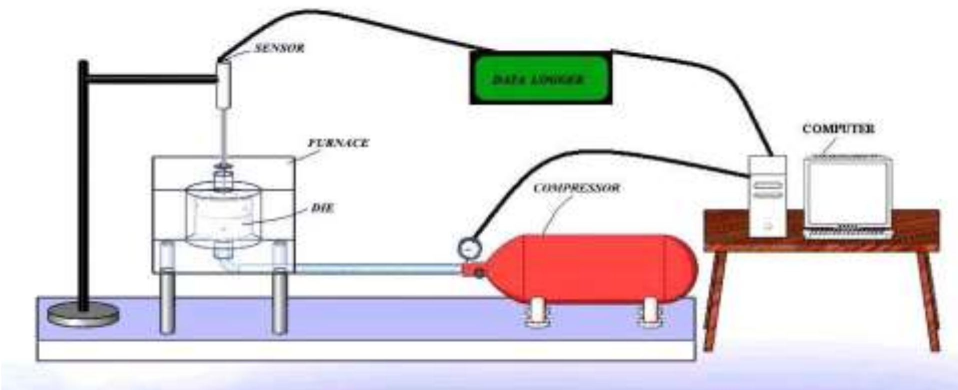

Fig 1 Schematic representation of the experimental Setup

II. FORMING DEFECTS

In this study observed that the main factors which influence the acceptability of forming parts are as;

1. Forming pressure
2. Dome height
3. Sensitivity index and
4. Effective strain at the dome apex
5. Annealing time

From literature it's found that in Superplastic forming some major problems occurred due to either variation in pressure/temperature/forming time or strain rate. Failure of superplastic forming material counted due to:

1. Premature fracture
2. Minimum thinning

3. Long forming time
4. Cavity formation

III. LITERATURE SURVEY

Jens Kappes et al.[1] designed the SPF of Aluminium alloy with the help of pneumatic bulge test and FE-simulation using PAM-STAMP 2G as tool code. For both pneumatic and FEA strain rate kept warring while pressure and temperature both constant respectively 0.3Mpa and 5150 C and observed strain rate control. Jens Kappes et al. (2010)[1] designed the SPF of Aluminium alloy with the help of pneumatic bulge test and FE-simulation using PAM-STAMP 2G as tool code. For both pneumatic and FEA strain rate kept warring while pressure and temperature both constant respectively 0.3Mpa and 5150 C and observed strain rate control. They also noted that Forming mechanism for 5xxx Aluminium alloy heavily dependent on grain size and the movement of their grains.

M. Balaguruswamy et al.[2] analysed superplastic blow forming on composition of Ti-6Al-4V alloy sheet having stepped rectangular die. They observed forming characteristic for given material such as thickness distribution, optimum pressure, forming time, with or without die entry radius, friction coefficient by theoretical as well as numerical simulation.

Based on their observation they noted that,

i. For maintaining the constant strain rate deformation increased die radius decrease the pressure requirement.
ii. At 9270C temperature thickness distribution directly proportional to die entry radius.

Sujanth M[3] conducted experimental work on Aluminium alloy with using pulse current where sheet metal directly heated by pulse current and deformed with gas pressure. Where gas pressure forced the sheet metal into die cavity for obtaining the desired shape of form.

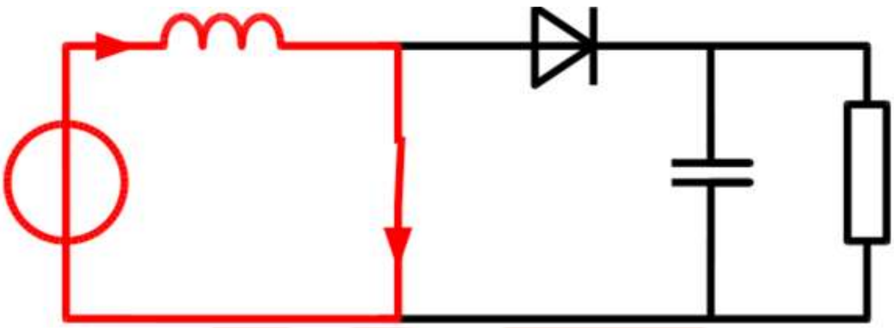

Figure.2- Close Switch Booster Convertor [3]

Jens Kappes et al.[4] observed process parameters during superplastic sheet metal forming operation of magnesium alloys (AZ31 and ZE10) were initial sheet thickness 1.6 mm, forming temperature 400°C determined by using the pneumatic warm bulge test with circular and elliptical dies.

Jens Kappes and Mathias Liewold [5] evaluated forming experiment based on bulge test and corresponding FEA. They performed experiment on AA5083 aluminium alloy. During process temperature was taken constant at 5000 C., and pressure warring from 0.2 to 0.33 Mpa for obtaining different strain rate. Calculations were conducted using Minitab.

Equal-channel angular pressing (ECAP) were performed on5052-O, Aluminium allow to check the forming capability at 9560 C temperature in presence of unconstrained die. Based on experimental data **Michael J. O'Brien et al.[6]** generated constitutive relationship between stress and strain in FEA, using ABAQUS as tool code.

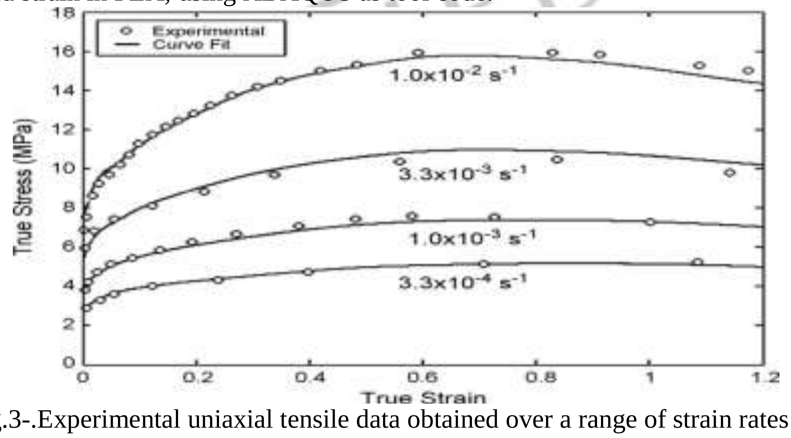

Fig.3-.Experimental uniaxial tensile data obtained over a range of strain rates [6]

Horng- yu wu et al.[7] concluded that the evolution of cavity could be related to the thinning behaviour of the deformed sheet. Thickness at the bottom corner of the deformed sheet kept on decreasing with forming time, and increasing in cavity volume fraction continued during forming. The cavity volume fraction increased with decreasing thickness at the central region, but decreased when the thickness of the sheet remained constant. Decrease in cavity volume fraction at the central region in the later stage of forming could be related to the cavity shrinkage as a result of sintering effect at elevated temperature under pressure.

Wang et a[8] concluded the FSP 7075 Al with a grain size of 6.2 μm exhibited good thermal stability up to incipient melting temperature, and a maximum elongation of 3250% was obtained at 5350C and 1×10-2s-1, with a very low cavitation level until fracture.

Process design and accuracy of die for superplastic forming process has been obtained based on modelling strategy. Modelling strategy established by **S.G. Luckey et al**.[9] when they compared predictive accuracy of design parameter.
Using two different FEA tool codes ABAQUS/Standard (implicit) and LS-DYNA (explicit) and established of correlation between SPF industrial trial and simulation result.

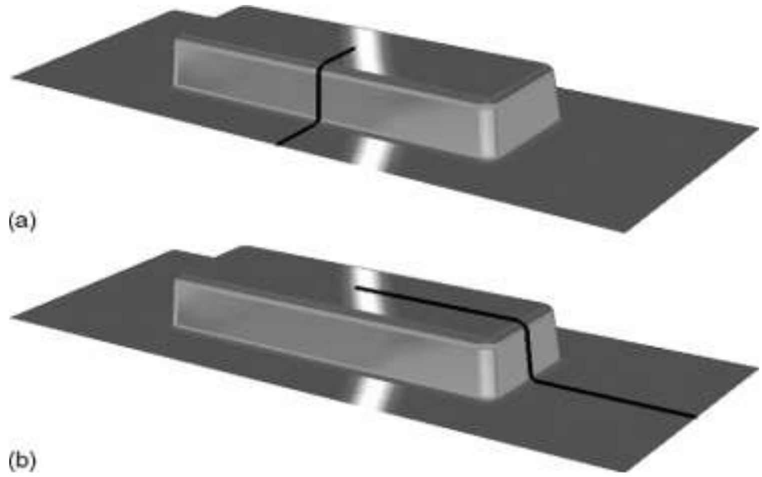

Fig.4- Thickness profiles measured experimentally and in FEA along sections perpendicular (a) and parallel (b) to the length of the part. [9]

Shih-Tsung TSENG and Hsuan-Teh HU[10] developed constitute low based on stress-strain relationship regard curve fitting tensile test. Material taken for study was AZ31B-H24 Mg alloy within a strain rate range from 10-5 to 10-2 s-1 at a temperature of 400 °C for constant strain-rate uniaxial tensile test.
Mary-Anne Kulas et al.[11] established forming limit diagram for AA5083 Aluminium sheet under superplastic and quick plastic forming condition.

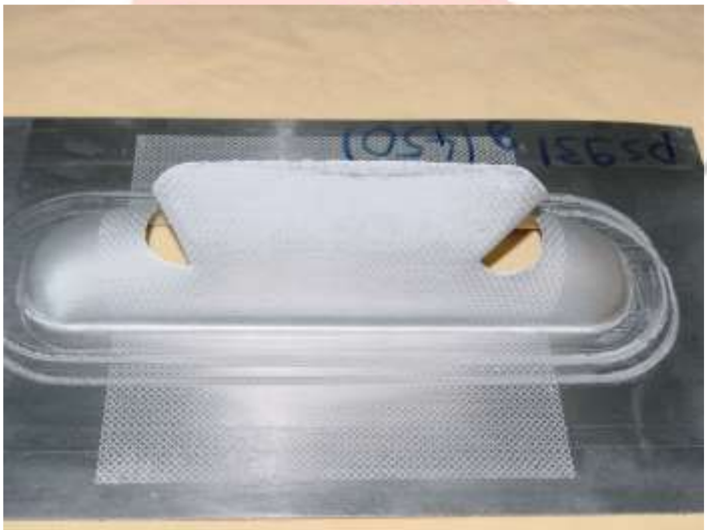

Fig.5-plane strain bulge samples [11]

O.F. Yenihayat et al.(2005)[12]developed an approach to control thickness of product at constant strain rate and 5250 C temperature on 7075 Aluminium alloy sheet at different cross-head. Analysis were performed an ANSYS and approach was to develop the Parametric Design Language (PDL) for constant pressure.

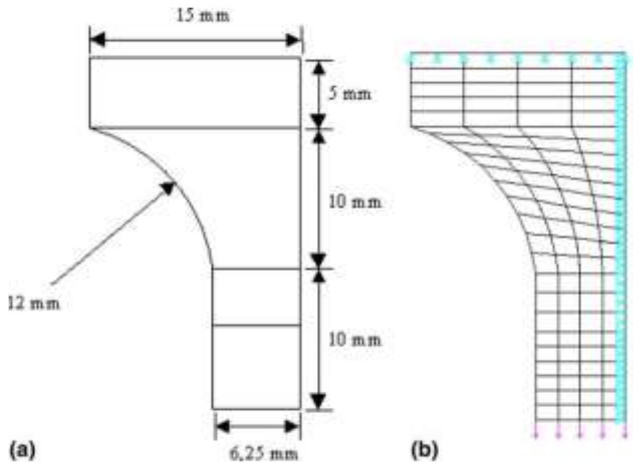

Fig.6- Tensile Sample. (a) Experimental sample quarter, (b) finite element model [12]

L. Carrino et al.[13] presents an algorithm, with a finite-element interface capability that can calculate load curve to be applied during forming, for superplastic forming processes. Main purpose for employing algorithm was to maintain strain rate by reducing the forming time, which can predict the optimum pressure value to be applied for each time step.

Theory of creep analysed and elaborated by **R.A. Vasin et al.[14]** analytically and experimental work performed using ABAQUS as tool code on Ti–6Al–4V titanium sheet alloy at constant pressure of 1.0 mm into the rectangular die for validation. Based on all three results they noted that, the accuracy of FEM modelling is found to be < 3% with respect to the time intervals of constant gas pressure forming and < 13% with respect to the duration of constant strain rate forming.

W. Guofeng et al[15] performed the experiment on side wall outer panel of metro vehicle to increase the efficiency of production with lover cost and flexibility of design. Material used for design was 5083 aluminium alloy sheet, the operation performed in two way as superplastic forming and quick superplastic. For the traditional superplastic forming, yield is 70%, for quick superplastic forming, yield can reach 90%; at the same time, during the process of forming experiment, the gas needed is reduced, forming time has shortened, it can be reduced about 40%. They suggested that quick superplastic forming have great development prospects.

Superplastic bulging process had been simulated on SP-700 Titanium alloy using MARC as tool code. MARC code employed to analyse whole deformation by incremental approach. **Nihat Akkus et al[16]** carried a simulation process under two kind of pressure control: Constant pressure and nearly constant apex strain rate

Leo et al.[17] reported during hot deformation the alloy exhibits cavitation which increases with temperature. The analysis of these phenomena has shown that cavity growth is mainly controlled by plastic strain.

Luo et al.[18] studied the influence of different forming process parameters by comparing the simulation results of final thickness distribution. This novel hot draw mechanical pre-forming technology can deliver a superior thickness profile and significantly decrease forming time as compared to conventional SPF for high aspect ratio, deep draw panels.

Chin-hui Shen[19] obtained the heat treatment process using Taguchi's robust design method the optimal heat treatment conditions for Al-Mg-Si wrought alloys. He noted that the important factors influencing the optimization criteria are solution temperature, solution time, pre-aging temperature, and pre-aging time.

Yogesha et al.[20] studied the superplastic forming operation - hemispherical bulge forming of Ti-Al-Mn alloy. Superplastic forming were carried out with different temperature between 8250C to 9500C and pressure between 0.2 to 0.8 MPa. After conducting series of experiment they observed that: Increase in pressure reduces the forming time. .No change in grain size before and after Superplastic forming process was noted.

G. Kumaresan and K. Kalaichelvan[21] developed technique to assess the strain rate sensitivity of a 7075 Al alloy sheet by a multi-dome forming test, under different forming pressures, temperatures and annealing times. They mainly focused on the thickness at dome apex, cavity volume fraction and assessment of the strain-rate sensitivity index. From above observations they concluded that the strain rate sensitivity heavily influenced by process parameters of temperature and pressure while annealing time variation have negligible impact.

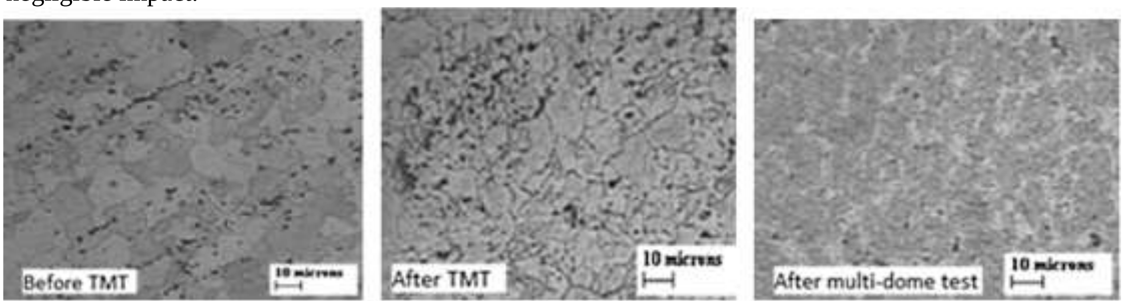

Fig. 7- Microstructure of the specimen [21]

G. Kumaresan and K. Kalaichelvan[22] investigated experimentally the formability of 7075 fine grain Aluminium alloy at different variable parameters such as sheet thickness of 1.75 and 1.5 mm and the temperature of 520˚C and 530˚C during deformation and the time taken for forming process was considered as 1 hour. Based on experimental result they noted that: 1) Good formability can achieve at 520-5300 C temperature for the taken thickness of material. 2) When thickness increased correspondingly the forming time also increases, it affects the formability.

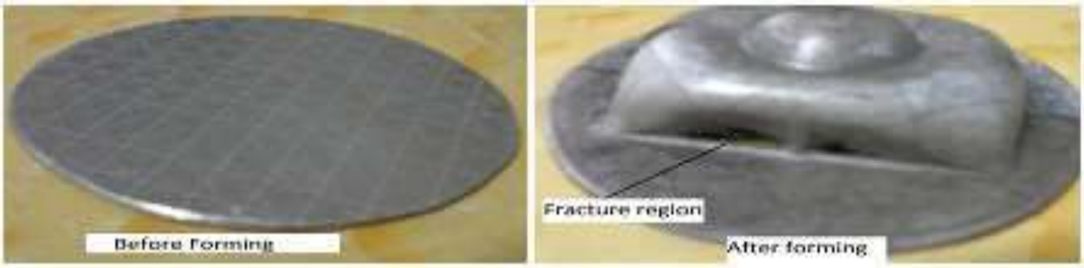

Fig-8- Formed component [23]

For obtaining the complex shape of an object through superplastic forming it essential to maintain low strain rate and large tensile elongation within the certain temperature range. **G. Kumaresan and K. Kalaichelvan[23].** They suggested that 7075 Aluminium alloy can give the best formability at 5300 C temperature having 1.5mm thickness and pressure of 0.4 Mpa, because optimal strain rate achieved at mentioned parameters.

Further increased in pressure decrease the formability. To determine strain rate after forming circle grid of 5mm dia. marked to employed sheet to measure strain level in each test. During operation marked circle either enlarged or formed into ellipse. Principle stress determine by measuring minor and major dia. of formed entity.

III CONCLUSION

The review of contemporary literature suggests that a good amount of work has been performed in the area of Superplastic forming process and the rejection of forming part due to several defects such as premature fracture, minimum thinning, cavity formation, and long forming time.

For this the best combination of variation in pressure/temperature/forming time or strain rate required to be identified. The further work will focus on identifying the main factors having influence on forming defects and their best combination to minimize defects.

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