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Material Flow Analysis of Super Plastically formed AZ31B Magnesium Alloy into a Conical Shape

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***Abstract*—The aim of the project is to study the MATERIAL FLOW BEHAVIOUR OF SUPER PLASTICALLY FORMED AZ31B MAGNESIUM ALLOY INTO CONICAL DIE SHAPE. Super plastic forming has become a viable process in manufacturing aircraft and automobile parts. The super plastic forming process offers many advantages over conventional forming operations including low forming pressure due to low flow stress, low die cost, greater design flexibility and the ability to shape hard metals and form complex shapes. However, low production rate due to slow forming process and limited predictive capabilities due to lack of accurate constitutive models and strength to weight ratio for super plastic deformations are the main obstacles to the widespread use of super plastic forming. Super plasticity is a property of certain metallic materials which enable them to achieve very high elongations (100% and above) without necking under certain conditions.**

In this work, the forming behaviour of a commercial sheet of AZ31B magnesium alloy at elevated temperatures is estimated and reported using bulging test. The experimental activity has been carried out to determine the material flow behaviour of magnesium alloy by changing it into a conical die shape. The process involves applying different pressure and temperature levels. In free bulging tests, the specimen dome height is used as characterizing parameter; the strain rate sensitivity index is calculated using theoretical and analytical approach by ABAQUS. Thus, appropriate forming parameters, such as temperature and pressure, are individuated and used for subsequent forming tests. Then the forming parameters are applied to determine the strain rate sensitivity of magnesium alloy. The influence of relevant process parameters concerning forming results in terms of cavity filling, fillet radii on the final specimen profile are analyzed. Closed die forming tests put in evidence how the examined commercial magnesium sheet can successfully be formed in complicated geometries if process parameters are adequately chosen.

***Keywords*—Superplastic Forming;Magnesium Alloy; Superplasticity, Formability, AZ31B Magnesium Alloy, Temperature, Pressure, Forming Time, Thickness Distribution .**

I. INTRODUCTION

1.1. Superplasticity

Superplasticity is a characteristic of some fine-grained (3–5 lm) alloys and ceramics to exhibit, under certain process conditions, very high ductility resulting in large tensile deformation before fracture. Such materials are formed at high temperatures,typically of the order of half the absolute melting temperature, and at specific strain rates or flow stresses. Since the material behaviour during forming is viscoplastic high dimensional precision can be achieved with little or no springback associated with cold forming. Superplastic forming (SPF) is widely used in aerospace industries to form a variety of complex, very light, structurally strong thin sheet components often very resistant to adverse in-service conditions. In particular the popular titanium aluminium vanadium alloy,Ti–6Al–4V, is able to diffusion bond (SPF-DB), whereby material coming into contact during SPF fuses together to form abond having the strength of the parent alloy. Consequently a single SPF manufacturing process can produce complex cellular structural components without the need for welding or rivetting parts together. SPF can also be used to forge solid components such as turbine disks and hybrid solid and thin shell components such as fan blades. Although originally pioneered by the aircraft industry SPF is increasingly used in the automotive industry and more recently for the construction of dental and medical prostheses where high precision is paramount.relationship between volume and surface area of the casting, and shape of the mould.

1.2 *Strain rate*

The quality of the final forming is mainly depending upon the flow pattern of the metal and rate of strain. Hence it is an important factor in the forming process. As the strain rate influence the quality of the final forming if it can be controlled the quality of the forming can also controlled to very good level. The scope of this project also mainly deals with the control of strain rate of the forming to produce a quality forming material. The strain rate is found in terms of curve which is drawn the stress strain curve.The general strain rate curve for magesium is shown in the fig 1.

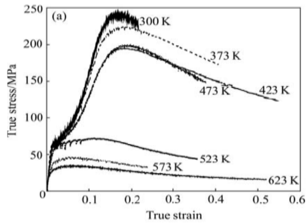

Fig 1 Compressive true stress-strain curves at different temperatures and at strain rates of $10^{-3}s^{-1}$

2.EXPERIMENTAL SETUP:

2.1. Construction

The machine system consists of a press clamp to hold the die, a thermocouple to measure the temperature, a band heater to heat the work piece and a temperature controller to maintain the temperature. The pressure cylinder containing pressure of 2bar has been applied to the system for gas blowing. The base temperature for magnesium alloy is 350oc in order to maintain the strain rate and pressure cycle of it. A die made of stainless steel with the shape of conical has been used for the experiment.

2.2. Working

The given work piece has been placed on the die which was get clamped, the die has been pre-heated to a certain temperature with the help of band heater in order to make the material hot at early stage, after that the work piece has been mounted on it and are heated by the band heater throughout its surroundings.

Fig 2.1.a.Experimental setup

The thermocouple has been used for controlling the temperature. With the temperature of 350oc has been kept as base temperature and a pressure of 2 bar was applied for gas blowing. With the applied constant pressure and varying temperature the strain rate and elongation has been calculated with respect to the time, the pole height of the cone formed at different temperatures with constant pressure has been shown in table.1.

Fig 2.1.b. Cone height at different temperature

Fig 2.1.c.Cone height at different pressure

2.3. Modelling of conical die:

A conical model was created with the dimensions as shown in fig.2.2. A simple model is assumed for this project with basic dimensions.

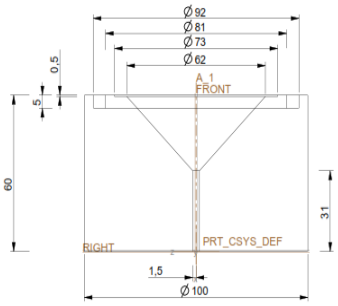

Fig 2.2 Model of conical die

Initially it is assumed that the circular magnesium alloy sheet has been mounted on die and the constant pressure has been applied to it. And also the temperature has been maintained by temperature controller.

3 .EXPERIMENTAL PROCESS

Commercial AZ31B Mg Sheets have been tested in the as received conditions. No mechanical or thermal treatment has been carried out on the material; sheet has been purchased in the annealed conditions with an average thickness of 1.5mm. In superplastic material characterization, usually tensile tests at different temperatures and strain rates are performed in order to get optimal conditions in which material has the best performances with the highest elongation to failure.This can be done by measuring the elongation to failure in standard tensile tests and the strain rate sensitivity index in jump strain rate tests . Some authors have demonstrated that, when grain boundary sliding (GBS) is the predominant deformation mechanism, the stress and strain condition has a marginal role in the material characterization .Some other authors have demonstrated also that uni-axial tensile stress and strain conditions are not effective for obtaining material parameters due to the fact that during a forming process the sheet, interacting with the die, undergoes to a stress and strain condition that is completely different. Moreover, Mg alloys have a great tendency to grain coarsening and in several cases

GBS cannot be considered as the predominant deformation mechanism . Furthermore, testing setup and specimen geometry for uni-axial tensile tests in superplastic conditions have to be properly designed. Some standards exists, such as ISO 20032 and ASTM E2448, giving indications on the best test procedures and equipments. In superplastic conditions, the great advantage of tensile tests is the possibility of controlling in a sufficiently accurate way the strain rate during the test.

In this work, the material has been characterized with blow forming tests: constant pressure bulge tests at different temperatures and different pressure levels have been performed using the aforementioned laboratory equipment.Tests have been performed ranging pressure from 0.3 MPa to 0.5 MPa and temperature from 350°C to 450°C, according to material physical properties and to the equipment capabilities. Pressure has been kept constant during the whole test until rupture occurred. For each test, the dome height has been acquired during the whole test using fixture. Final height of the specimen has also been measured after the test.Tested specimens are shown,inspite of the use of an inert forming gas, the formed specimen, after a forming time of 2825 s, appear markedly oxidised. Good results, in terms of dome height at failure, can be found also at 450°C, especially for low pressure levels, with a less evident grade of oxidation on the formed sheet. Another result that can be highlighted is that, reducing the temperature, the height of the specimen at which the material fails, is less influenced by the forming pressure. Value of the thickness distribution during the test can be calculated by the following expression:

$$h/h_0 = 1/(1+\delta Y_p/b_0^2)$$

where,

h = instantaneous thickness of sheet

h_0 = initial thickness of sheet

Y_p= height of bulge during free bulging

b_0 = die aperture radius

$$Y_p = b_0(1-\sin\theta)/\cos\theta$$

θ = semi angle of cone, where $2\theta = 90^0$

It can be seen that the forming time needed to get the same dome height, has a more than linear decrease when pressure level increases.Analogous behaviour can be seen also at other temperatures. One of the most important parameters in the hot forming process is the strain sensitivity index, m, which can be easily calculated from tensile tests at different strain rates. In bulge forming Jovane and then other authors, like Enikeev and Kruglov , proposed analytical approaches to estimate constitutive parameters from bulge tests. For instance, measuring the height during two bulge tests at two different pressure levels, the strain sensitivity index and the forming time of the material can be found by the following expression:

$$m = \log(\sigma_2/\sigma_1)/\log(\varepsilon_2/\varepsilon_1)$$

m=strain rate sensitivity

$$T = \int_0^Y (2Y)^{1+1/m} (1+Y^2)^{-1-2/m}\, dY$$

$$Y = Y_p/b_0$$

$$T = (Pb_0/2\sigma_0 h_0)^{1/m}\, t_1$$

Where,

P = forming pressure

t_1 = forming time to end of free bulging stage of forming

As mentioned before, Mg alloys during forming at elevated temperatures, is subjected to microstructural changes that influences also the m value. Thus, the m value calculated by equation (2) is a mean value but it can be considered a good starting parameter to analyse how pressure influences the forming behaviour of the material. The highest m values can be found both for the low pressure levels (between 0.3 and 0.5 MPa) and for high pressure levels at the highest temperatures . Confirming the importance of this index, the highest dome heights to failure correspond to the highest values of m. Using elevated forming temperature can bring to a coarse grain size in post-forming conditions; in addition, considering also the oxidation of the sheet, reducing the temperature of the process brings to a better quality of the final component. Thus, according to experimental results and these considerations, the best temperature, among those that have been examined, for this alloy can be considered 450°C at which a good compromise between equivalent elongation to failure and estimated material post forming is achieved.

Temp(^{0}C)	Pressure(MPa)	Pole height(mm)	Time(min)
350	0.4	2.5	280
	0.5	24	182
400	0.3	27	80
	0.4	27	35
	0.5	27	23
450	0.3	27	252.5
	0.4	27	85
	0.5	27	59.5

TABLE.I. POLE HEIGHT AT DIFFERENT TEMPERATURE

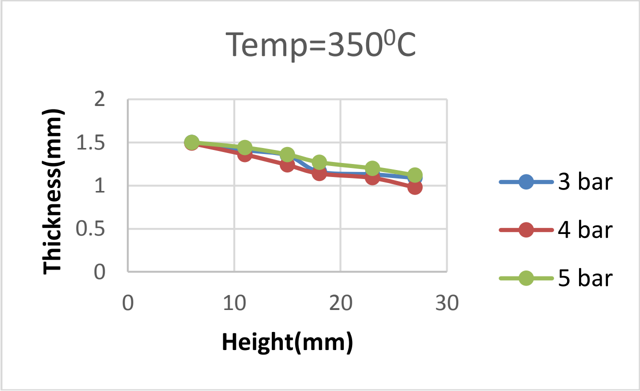

Fig .3.1.a Thickness of cone at different height at 350^{0}c

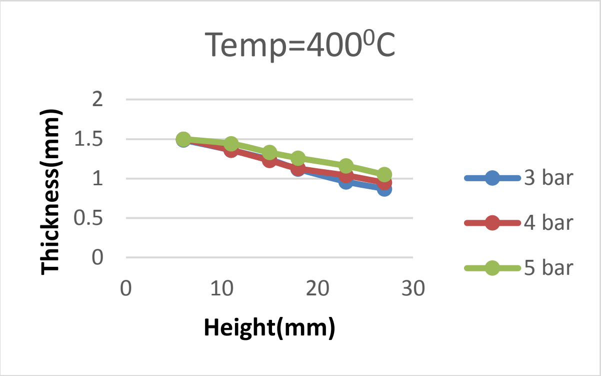

Fig.3.1.b.Thickness of cone at different height at 400^0c

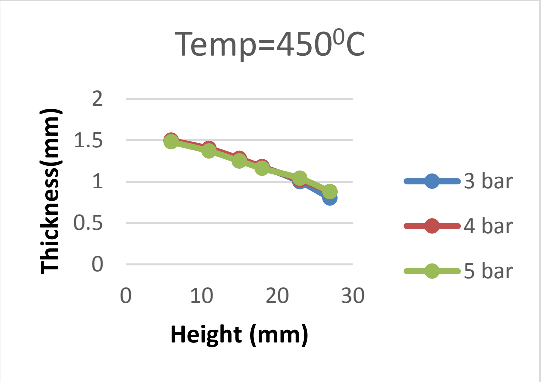

Fig.3.1.c.Thickness of cone at different height at 450^0c

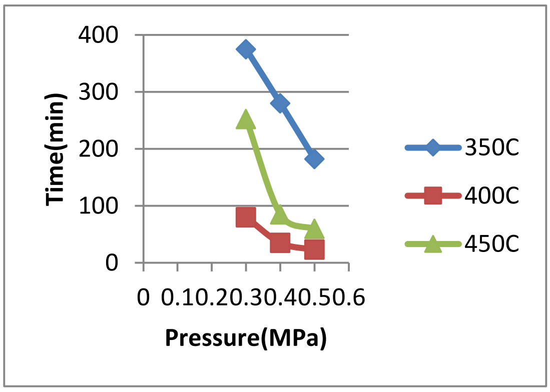

Fig.3.1.d. Height of cone at different temperature with respect to time and pressure

4.MODEL USING ABAQUS

4.A)Forming time of cone:

Pressure : 0.6 MPa

1)For 6mm depth:

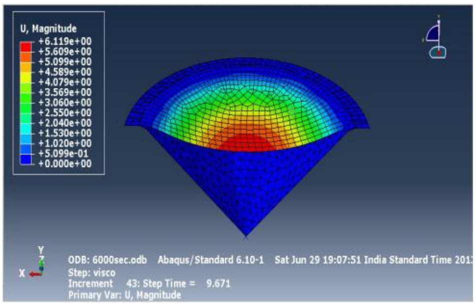

Fig 4.1a Numerical analysis of forming time of cone for 9.67 sec

2)For 11mm depth:

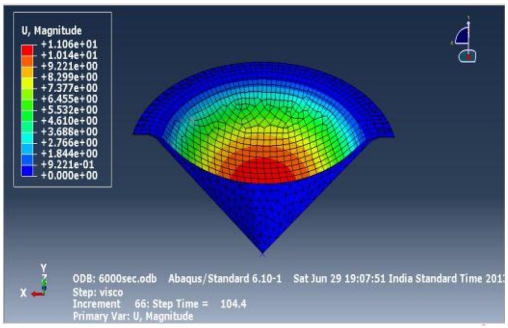

Fig 4.2a Numerical analysis of forming time of cone for 104.4 sec

3)For 15mm height:

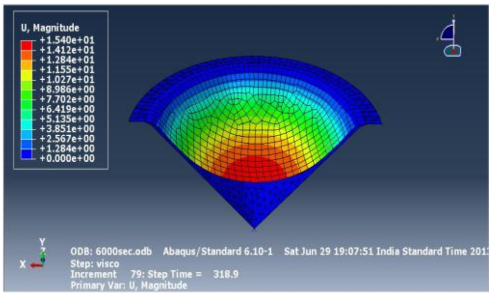

Fig 4.3a Numerical analysis of forming time of cone 318.9 sec

4)For 18mm height:

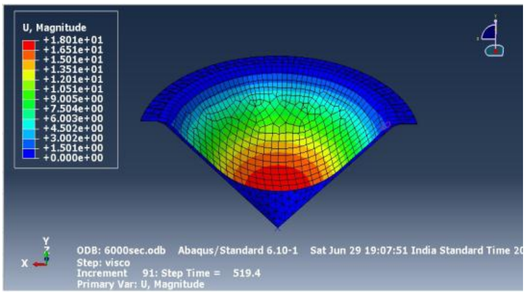

Fig 4.4a Numerical analysis of forming time of cone for 519.4 sec

5)For 23mm height:

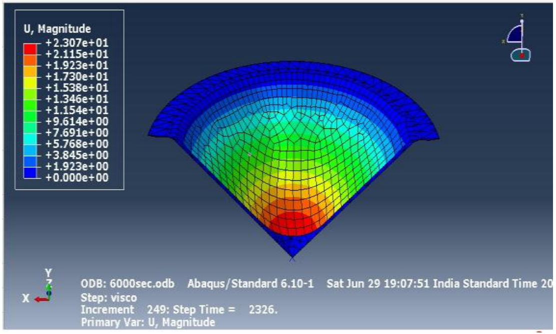

Fig 4.5a Numerical analysis of forming time of cone for 2326 sec

4.B.Thickness distribution of cone:

1)For 6mm depth:

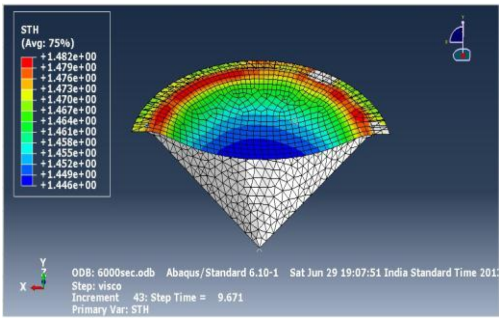

Fig 4.1b Numerical analysis of thickness of cone for 9.67 sec

2)For 11mm depth:

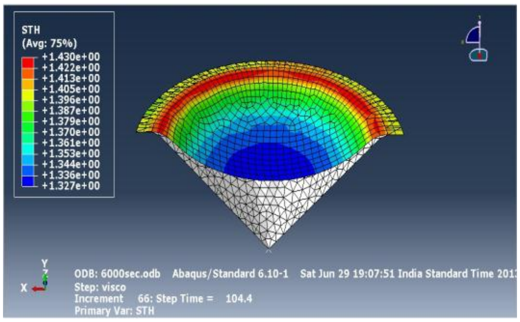

Fig 4.2b Numerical analysis of thickness of cone for 104.4 sec

3)For 15mm depth:

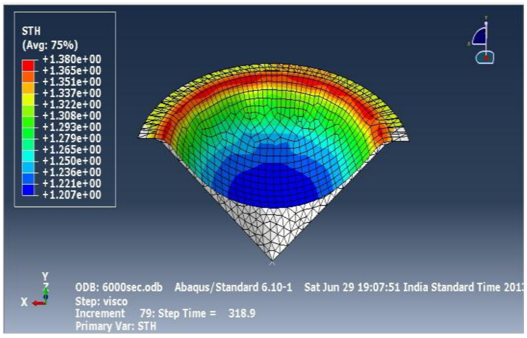

Fig 4.3b Numerical analysis of thickness of cone for 318.9 sec

4)For 18mm depth:

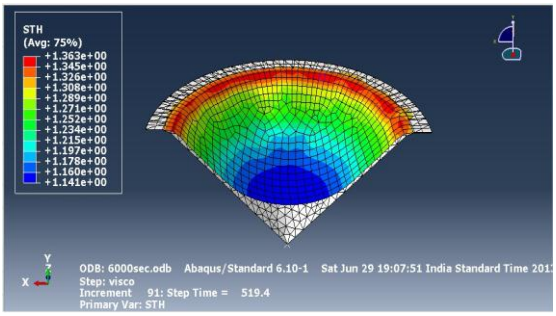

Fig 4.4b Numerical analysis of thickness of cone for 519.4 sec

5)For 23mm depth:

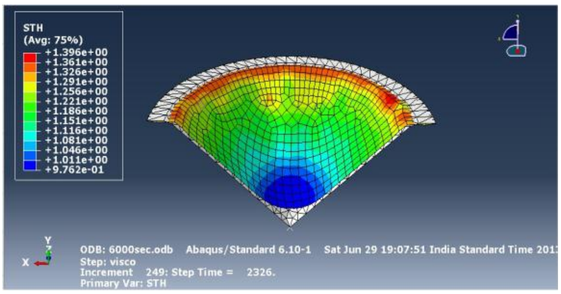

Fig 4.5b Numerical analysis of thickness of cone for 232.6 sec

5.COMPARISON OF ABAQUS RESULTS WITH EXPERIMENTAL

Table 5.1. Thickness distribution(mm):

Bulge height(mm)	Experimental thickness(mm)	Numerical thickness(mm)
6	1.48	1.44
11	1.42	1.327
15	1.27	1.207
18	1.10	1.141
23	0.83	0.762

Table 5.2. Forming time(Sec)

Bulge height(mm)	Experimental forming time(Sec)	Numerical forming time(Sec)
6	9	9.67
11	98	104.4
15	300	318.9
18	480	519.4
23	2370	2326

6. CONCLUSION

The forming behaviour of a commercial AZ31B Mg alloy sheet has been analyzed at elevated temperature both in closed die tests. Results from the experimental activities highlighted that:

- even if the material is not pre-treated in order to have a super plastic behaviour, it shows large equivalent elongation to failure in the as-received conditions;
- the biggest elongation to failure can be recorded for the highest temperature and the lowest pressure; among temperature levels that have been explored, at 450°C a good compromise between elongation to failure.
- decreasing the forming temperature the influence of pressure on the dome height to failure is reduced; strong non linearities can be found when analyzing the strain rate as a function of pressure, at a constant temperature, or as a function of temperature, at a constant pressure;
- in closed die forming, the material can achieve very small fillet radii, denoting a big ductility at elevated temperature;
- in the examined range of temperature and pressure, the die filling increases more than linearly with pressure and less than linearly with forming time.
- Further investigations are needed to better understand the effectiveness of forming Mg alloys at elevated temperature with the BF technique. Forming characteristics, due to microstructural changes and cavitation have to be deeper analyzed. Considering that pressure can be managed during the process to speed up the forming cycle and to optimize thickness distribution along the sheet, the BF process can be considered a good competitor in manufacturing thin walled Mg alloys component with complex shapes.

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