GAS BLOW FORMING OF AZ31 MAGNESIUM ALLOY IN BOX SHAPED DIES

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Abstract

This paper presents the numerical and experimental results obtained from the finite element analysis of superplastic forming of AZ31 alloy sheet in box shaped die. The FEM models are used to optimize the process and predict the forming times in terms of deformed shapes, stress-strain distributions and the thickness distribution of the formed parts. Marc/standard a commercial FEA package is used to simulate the SPF process. In order to obtain the required performance. At the same co-relative experimental investigations also were carried out in order that demonstrates the validity of the finite element analysis.

Keywords: SPF, Magnesium alloys, FE Simulations, box shaped die, AZ31 B,

INTRODUCTION

The use of the light weight components is inevitable issue for the protection of global environment. Superplastic forming is a advanced forming technology, which is extremely important to fabricate the lightweight components. Knowledge and understanding of this advanced forming technology can lead to the development of the ultralight weight structural and non-structural components in simple and complex shapes. Magnesium (Mg) has a density of 1.74 g/cm^2 and is the lightest of all structural metals. The term “superplasticity” was introduced by A.A. Bochvar to describe the unusual behavior of the two-phase alloy Zn–22% Al [1]. This phenomenon is studied by Pearson in 1934, he was the first scientist who described the main features of superplasticity [2]. Superplasticity is the ability of high elongation (usually higher than 200% for metallic alloys) without necking with high strain rate sensitivity of flow stress [3]. Strain rate sensitivity index m ($m=lg(ds/d\varepsilon)$) is higher than 0.3. Superplastic deformation (SPD) is a kind of hot deformation that usually occurs at temperatures more than 0.5 T *melt* [4]. Superplasticity is a result of three possible mechanisms: grain boundary sliding (GBS), diffusion and dislocation creep [4].SPF is a sheet metal forming process used to deform such materials under controlled conditions of temperature and strain rate. Magnesium with a density of merely 1.74 g/cm3 forms the lightest structural alloys that are currently available for engineering applications. Therefore, the greatest advantage of choosing magnesium alloys for engineering design lies in its low density, which translates into higher specific strength and stiffness. Besides being lightweight, magnesium also has high torsion strain resistance and toughness. Despite these advantages, the limited use of magnesium alloys is due to their relatively low ductility and high degree of anisotropy in mechanical properties [5]. This is attributed to their hexagonal close-packed (HCP) crystal structures with very few active slip systems at low temperature. Therefore, the formed products of magnesium and its alloys are very limited. The deformability of wrought magnesium alloys at room temperature is limited and a way to overcome this limit is to carry out forming operations in warm or hot conditions. The most studied Mg alloy is the AZ31 alloy and has been found that the ductility of wrought AZ31 alloy can be significantly improved by deforming it under superplastic state instead of resorting to conventional hot forming techniques. In general, AZ31 attains greater elongation at higher temperature and lower strain rates , for these alloys with grain sizes of about 10 microns, superplastic properties are generally obtained between 350°C and 400°C for strain rates typically ranging from 10^{-4}s-1 to 10^{-3}s-1 [6,7].Elevated temperature deformation such as superplastic deformation and creep can be characterized by the constitutive equation:

$$\sigma = k\dot{\varepsilon}^{m} \quad (1)$$

where σ is the true flow stress, *k* is a constant and $\dot{\varepsilon}$ is the true strain rate. Most metals and alloys exhibit *m<0.2* whereas superplastic alloys typically have values of m>0.3 [8].The deformation Mechanism of the commercial AZ31 mg alloy at different conditions is dissimilar. The deformation mechanism at high temperature and low strain rate is mainly GBS controlled by grain boundry diffusion. While at low temperature and high strain rate, the mechanism is the mix of GBS and plastic or/and creep deformation controlled by lattice diffusion Several studies showed that the AZ31 Mg alloy does not exhibit significant initial anisotropy at elevated temperatures [9,11]. However, many superplastic materials may develop deformation-induced anisotropy due to large deformation [9, 10].For AZ31 alloy, the values of m of about 0.5 are frequently obtained and activation energies slightly less than 100 kJ/mol were reported, suggesting that intergranular diffusion would be predominant over lattice diffusion in the control of GBS for this alloy. For the AZ31 alloy, the results correspond roughly to what is generally measured for fine grained alloys: for a given temperature, m decreased when the strain rate was increased and for a given strain rate, m increased with temperature (in particular in the low strain rate interval). For such low strain rates, values between 0.2 and 0.8 were measured depending on the temperature. Values of m □□0.5 could be reached at high temperature and moderate strain rates (typically less than $10^{-3}s^{-1}$) confirming that superplastic properties could be obtained for this alloy. The AZ31 magnesium alloy possesses many attributes that make it particularly attractive for sheet metal applications, and for that it is considered in this study. Detailed uniaxial tensile tests covering a wide range of temperatures and strain rates indicated optimum superplastic behavior in the vicinity of 400 °C [12, 9].

MATERIALS AND METHODS

The magnesium alloy, AZ31 B, has various industrial applications because of its special characteristics such as light weight, high stiffness. A sheet of Mg alloy of 1.2 mm thickness is used in this study. The constitutive model proposed as power law by Backofen. et al. is the widely applied model that relates the effective strain, strain rate, stress and flow stress through power law. The chemical composition and the mechanical properties of the alloy Magnesium AZ31B is shown in Table.1 and 2 respectively. The alloy is characterized for a temperature range of 450^0C and a strain rate of 0.001 s^{-1}. The material property values are experimentally found to be K = 254 MPa (Constant), strain rate sensitivity index m = 0.518, strain hardening index n = 0.87.

Table.1 Chemical Composition of AZ31B

Alloy	Al	Zn	Mn	Si	Cu	Ni	Mg
% by weight	2.9	1.1	0.49	1.0	0.1	0.03	Balance

Table.2 Mechanical Properties of AZ31B

Property	Yield Strength	Ultimate Strength	Melting Point	Modulus of Elasticity	Poisson ratio
Value	220 MPa	290 MPa	630^0 C	45 GPa	0.35

COMPUTATIONAL ANALYSIS

The main objective on superplastic sheet metal forming applications is to complete the forming process as quickly as possible while maintaining a uniform thickness distribution and a minimum amount of accumulated interval damage. For the production of components with complicated geometrics the optimum leading schemes are currently determined by time consuming trial and error experimental techniques. More recently, FEM is on increase to simulate the SPF process without any shape assumption. With the help of FEM, it is also possible to see the influence of in value on bulging shape by its graphic ability, and to obtain some deformation parameters easily such as strain rate, stress-strain distribution and thinning of the shape. Using the commercial finite element software MSC Marc, rigid-plastic flow formation was applied to the superplastic forming analysis. (13) Several papers are available got superplastic analysis using MARC-MENTAT codes. First, Rebelo and Wertheimer [14] showed general description of superplasticity on the same commercial code (MARC) analyzing a two-step pan. Later Sadeghi and Purcel[15] modelled an aircraft door using the same code. When deformation is done at constant pressure, very low strain rates are necessary, which will result lower value of 'm' and longer deformation time. By using P-T diagram obtain through FEM code, which can be effectively used to reduce the deformation pressure and as well as minimize the deformation time with successful forming.

The mesh is composed of four node iso-parametric elements used or axisymmetric applications. The stiffness of this element is formed using four node point Gaussian integration. The element has two coordinates in the global Z and r-direction and two degrees of freedom for node (16) An integration scheme which imposes a constant dilatational strain constraint on the element was used. The deformable body correspondingly to the metal sheet was divided with four rows of 188 continuum elements with 4-nodes. The die was considered as a perfectly rigid body. Contact pressure is applied as distributed load.

In superplastic gas bulging process, it is determined by the pressure, whether the final shape and distribution of thickness is reasonable or not, by superplastic gas bulging forming appropriate pressure gets part which thickness distribution meet the requirements in the shortest possible time. In essence, the controlling pressure at per second is control material necking, yet controlled necking is best way to control the strain rate of the material. Through the MSC Marc, we can obtain the appropriate pressure that make bulging forming part of the minimum thickness thinning rate. Therefore, this simulation offers necessary reference for later productive process.

The optimum pressure time cycle for square die is generated by using Marc Mentat fem software (as shown in fig (1) at constant pressure 0.2 MPa and its arc thickness in fig (4)

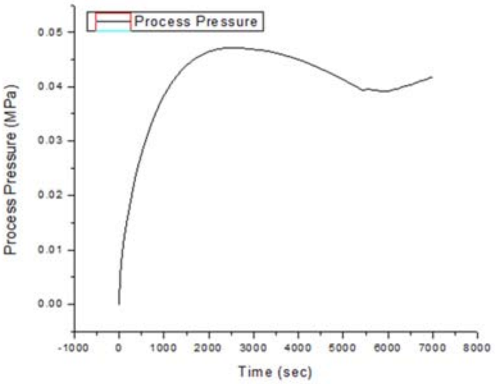

Figure 1 Optimum pressure time cycle of square die

It has been found that load case time of 7000 secs is giving optimum results for forming square die with in less time with less thickness variation. The same load case time has been divided into four stages for forming of square shaped components as shown in table(3). When sheet forming begin, in the first stage, deformation zone is not contact with the die, with the increasing pressure. In the second stage the sheet is gradually thinning and attaching to the mold, in the third stage , the sheet touches the bottom of the die. In the fourth stage, last forming area is at the bottom of the mold fillet.

Table(3): FEM predicted values of Square die

Stages	1	2	3	4
Height from pole	24	30	40	40
Processing time	1000	2820	5470	7000

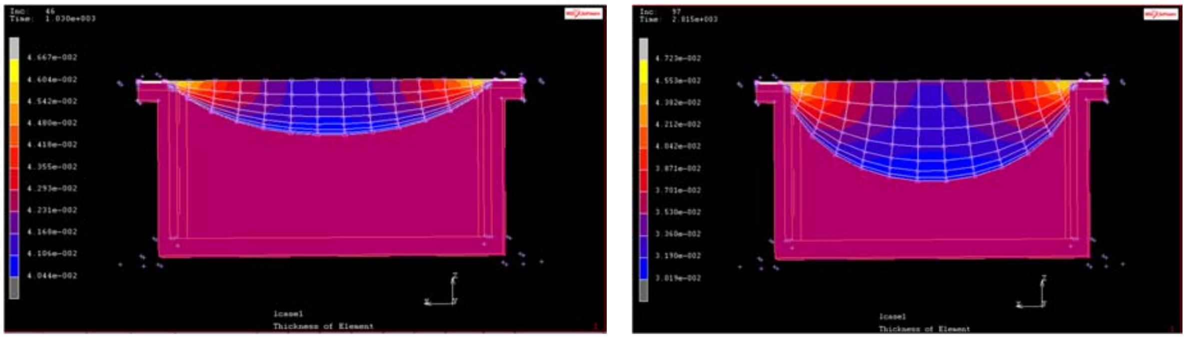

Fig:aThe contours of thickness distributions of stage 1

Fig:b:The contours of thickness distributions of stage 2

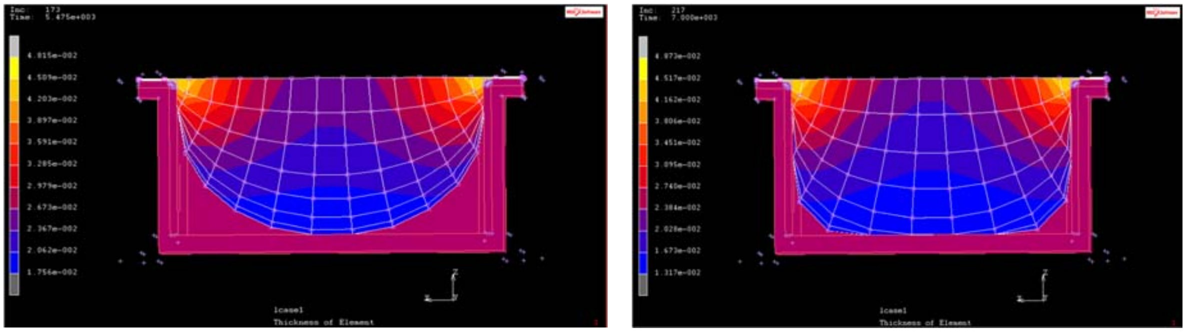

Fig c:The contours of thickness distributions of stage 3

Fig d:The contours of thickness distributions of stage 4

Fig 3 (a) (b)(c) and (d): Stages of forming sheet material in Square die

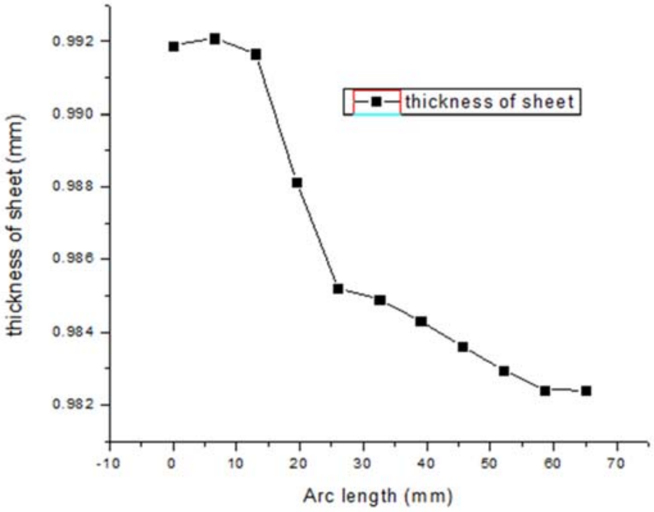

Figure :4 Arc length vs thickness of square die

Table(4): FEM predicted values of Square die

S.No	1	2	3	4	5	6	7	8	9	10
Arc Length mm	0	6.499	12.99	19.49	25.99	32.49	38.99	45.49	51.99	58.49
Sheet thickness mm	1	0.992	0.991	0.988	0.985	0.984	0.984	0.983	0.982	0.982

Experimental Investigations

.The Superplastic Forming experiments have been performed in an indigenously built-in laboratory scale equipment embedded in the cylindrical split furnace connected to computer controlled system. The equipment consists in: (i) a blank-holder, (ii) a male and female die with different die cavity shapes for superplastic forming of the blank different forming conditions, (iii) a pneumatic circuit for gas supply with an argon cylinder, proportional electronic valves, steel tubes in proximity of the forming chamber and flexible polyurethane tubes in colder zones, (iv) an electric furnace with its electronic controller (v) thermocouples to monitor thermal condition on the furnace as shown in Fig.5. The workpiece specimens are sheared from the same material lot. The specimen with a blank size of 160 mm diameter and 1.2 mm thickness with rolling direction perpendicular to the longitudinal axis is used for forming. The forming experiments are conducted at 4000C. In heating stage the sheet in die setup is heated upto its 0.5Tm of melting temperature using electric heater. Argon gas pressure is introduced into the male die thus forming the sheet into the female die. The dynamic control of the pressure with respect to time during experimentation is the prime variable in manufacturing of components with uniform thickness. The pressure is computer controlled with time according to the better load case P-T graph obtained from the simulation results.

Fig.5 (a) Square die (b) Die assembly (c) Experimental set up

More important are the clamping loads and thermal stresses encountered during heat-up and cool-down and the environmental conditions. The thermal stresses can cause permanent distortions in the die, and this is controlled by selection of a material that has good strength and creep resistance at the forming temperature. Slow heating and cooling of the tooling can reduce the thermal stresses. Material with a low coefficient of thermal expansion and those that do not undergo a phase transformation during heating and cooling are preferred for the high temperature SPF processes. Oxidation can alter the surface condition of the tooling, thus affecting the surface quality of the SPF part produced and eventually affecting dimensional characteristics, hence argon gas is used to apply gas pressure load. To successfully form the near net shape of the component, the cavity must be sealed so that pressure applied to side of the blank is not dissipated. The seal is normally established by providing a seal bead on the tooling that engages the periphery of the sheet metal. The FE simulation results obtained from MSC.Marc software are compared with the experimentation outcomes. The results, Process Time Vs Height from pole are tabulated in Table.5 and Arc length Vs Sheet thickness in Table. 6 respectively.

Fig.6.Formed box shaped component

Fig.7. Sectional view of Formed box shaped component

Table 5. Formed component Experiment values of Square die

Stages	1	2	3	4
Height from pole	24	30	38	38
Processing time	1000	2820	5470	7000

Table.6: Experimentation results for Arc length Vs Sheet thickness

S.No	1	2	3	4	5	6	7	8	9	10
Arc Length mm	0	6.499	12.99	19.49	25.99	32.49	38.99	45.49	51.99	58.49
Sheet hickness mm	1	0.952	0.951	0.948	0.945	0.944	0.943	0.943	0.942	0.942

Results and Discussion

The Process Time Vs Height formed and Arc length Vs. Sheet thickness graphs and the manufactured components are shown in Fig. 7 and 8 respectively. In superplastic forming using gas, the pressure is to be controlled continuously since the instantaneous magnitude influences the flow stress on the material during forming, following equilibrium mechanics. The stress induced during forming drives the material to cause the plastic deformation and subsequently the rate of strain. The pressure applied determines the time of formation. The simulated pressure time diagrams, induced better pressure control and maintained the strain rate distribution over the entire deformed surface. This has led to maximum stretching of the surface at the processed temperature. This could be substantiated by the basic theory of grain boundary sliding that takes place in fine grained superplastic materials. It is observed from Fig.7 that the superplastic forming of AZ31B depends on the gas pressure and time. For regular prismatic surfaces as shown in Fig.7 the rate of change in pressure increases gradually in a quadratic manner. This could be due to the rate of change of the thickness which is comparatively lesser than rate of change of the radius. This continues till the free bulge forming of the sheet. In this region, the rate of change of thickness increases as the radius decrease. Once the sheet contacts the die surface, the rate of change of the radius again dominates in both the stages, and an increase in pressure is observed.

Table.7 Comparison of FE with Experimentation Results for Process Time Vs Height from pole

Stages	1	2	3	4
Processing time	1000	2820	5470	7000
Height from pole (FEM)	24	30	40	40
Height from pole (EXPT)	24	30	38	38
% error	3.3	2.98	5	5

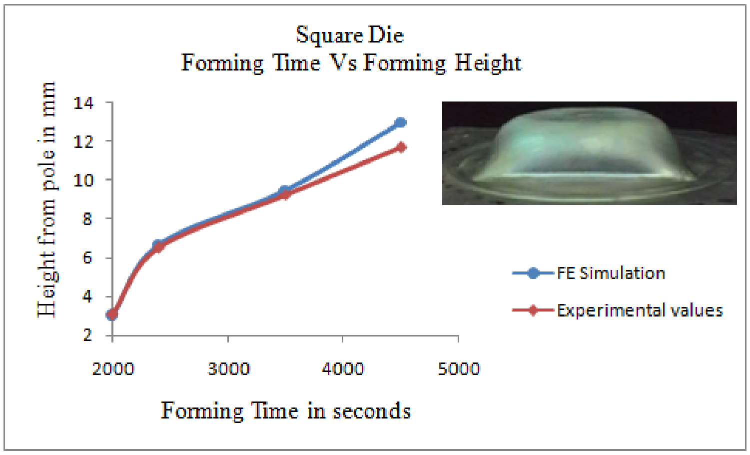

Fig. 7 Square Die: Forming Time Vs. Forming Height

Table.8 Comparison of FE with Experimentation results for Arc length Vs. Sheet thickness

S.No	1	2	3	4	5	6	7	8	9	10
Arc Length mm	0	6.499	12.99	19.49	25.99	32.49	38.99	45.49	51.99	58.49
Sheet Thickness mm (FEM)	1	0.992	0.991	0.988	0.985	0.984	0.984	0.983	0.982	0.982
Sheet Thickness mm (EXPT)	1	0.952	0.951	0.948	0.945	0.944	0.943	0.943	0.942	0.942

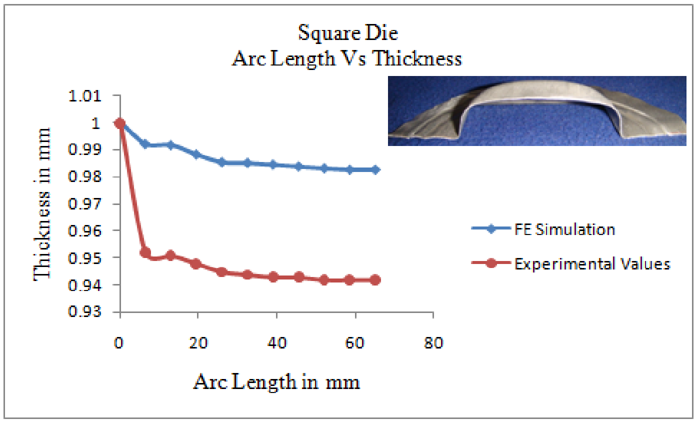

Fig. 8 Square Die: Arc Length Vs Thickness

CONCLUSIONS

1. Simulation results executed from the 3D FEA software MSC MARC are in good agreement with the experimental results.. It also facilitates the understanding of forming behavior of the AZ31B material by SPF.
2. The thickness distribution in the manufactured component is uneven in intricate shapes due to stick friction between the die and sheet leading to resistance to grain boundary sliding, and thus irregular stretching of the surface.
3. Less deep the shape of the components with fewer intricacies better the strain rate and stretching with less thinning and uniform thickness distribution.

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