Vol.2, No.1 ISSN Number (online): 2454-9614

Proceedings of International Conference on Recent Trends in Mechanical Engineering-2K15(NECICRTME-2K15), 20th – 21st November,2015

FINITE ELEMENT ANALYSIS OF SUPERPLASTIC FORMING OF TITANIUM ALLOYS

J.Kandasamy*
S.V.Narsimha Rao*
M. Lokeshwari*
*MVSR Engineering College, Nadergul – 501510

Abstract

Super Plastic Forming is the process of undergoing large uniform elongation prior to necking and fracture tension. Super Plasticity is the ability of a polycrystalline material to exhibit, in a generally isotropic manner though there are some works reported on anisotropic behavior also, very large elongations without necking prior to failure. Super Plasticity in sheet metals offers advantages for forming complex shapes easily in high strength alloys, as a regular production process. The focus of the present work is to generate pressure-time diagram and stress strain curve for Titanium alloys. The sheets are formed in single and double (Diffusion bonding) with different thickness. The results obtained from the FE analysis is used as input to experimental analysis. The formed shapes are in accordance with the FE results.

Keywords: Superplastic forming, FE Analysis, Titanium Alloys

Introduction

The computational analysis is performed on a conical shaped die. The analysis is carried out in MARC MENTAT 2010. Analysis is done for single sheet and for double sheet (SPF/DB) [1]. The die is modeled in 3D and represents a quarter of die. (Axisymmetric analysis).Titanium alloy flat sheet of 1.65 mm thickness is formed into a rigid die by pressure[2-5]. The work piece material is assumed to be rigid-plastic material with no elasticity and the flow stress is only function of the strain rate [6]. As the sheet contacts the die, friction causes the thickness of the sheet to vary. In addition the pressure must be adjusted to keep this strain rate sensitive material within a certain target range. This is necessary to maintain the proper flow of the superplastic material. Prediction of thinning of the sheet is important since the sheet may become too thin for its application. The SPF pressure control in load case is used to automatically adjust the pressure on the sheet to keep within the target strain rate [7-11]. The inputs to the analysis are strength coefficient of the material and the strain rate sensitivity. The software performs the FE analysis using the superplastic forming loading scheme that keeps adjusting the applied pressure to maintain an average target strain rate in the material. From the analysis, pressure-time profile, thickness variation of the sheet, and stress strain diagram are obtained as output.

The model of the die and sheet is generated by creating the curves in MARC. Boundary conditions involves in fixing the edges of the sheet with respect to die around the symmetry of sheet and applying the pressure on the face of the sheet. Material properties k and m values are given as input. The thickness of the membrane, geometric property is provided to the software. The type of contact between the mating bodies are defined i.e., the sheet is defined as deformable body and the die is defined as rigid body. The maximum possible input pressure, target strain rate, load case time are defined. The problem is set to run with Coulomb frictions using the membrane elements. Analysis is carried out at large strain with follower force. A maximum pressure of 2MPa, with different load case times of 4500s, 5400s and 7500 s at a target strain rate $0.0002 sec^{-1}$ is applied. For SPF/DB, an attempt is made where a superplastic material is used to form a non-superplastic material. The non superplastic material is non-grade AA5083 alloy. The procedure for SPF/DB is different at contact between two sheets. A contact table is mentioned such that during forming the superplastic material comes in contact with non-superplastic material and hence the superplastic forming continues.

Superplastic material: Ti-6Al-4V Alloy

Table.1 Composition of Ti-6Al-4V alloy

Material	Ti	Al	V	Fe	Al
Composition (%)	91	5.5	3.8	0.2	0.2

Table.2 Mechanical Properties

Elastic Modulus	Ultimate tensile strength	Yield tensile strength	Poisson's ratio
113.8GPa	993MPa	924 MPa	0.342

Table.3 Thermal Properties

Linear coefficient of Thermal Expansion,	Thermal conductivity	Specific heat capacity
8.6µm/m-°C	6.7W/m-K	0.5263 J/g-°C

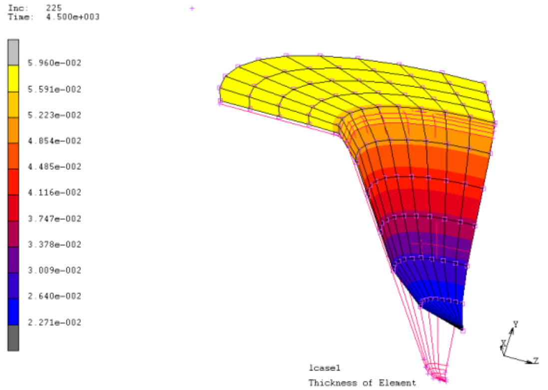

Fig.1 Thickness variation of Ti alloy in conical die at t=4500s

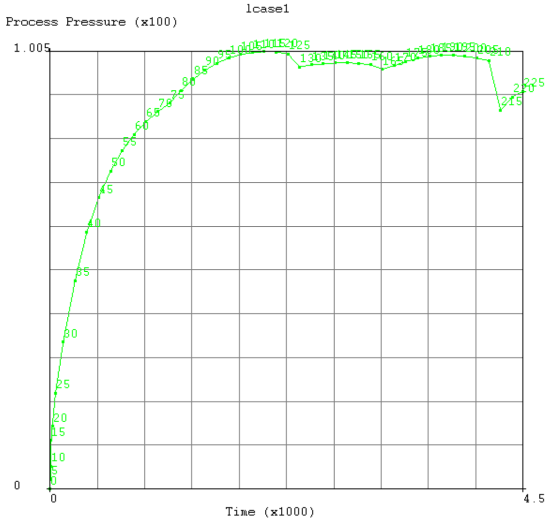

Fig.2 Pressure-Time profile of Ti alloy in conical die at t=4500s

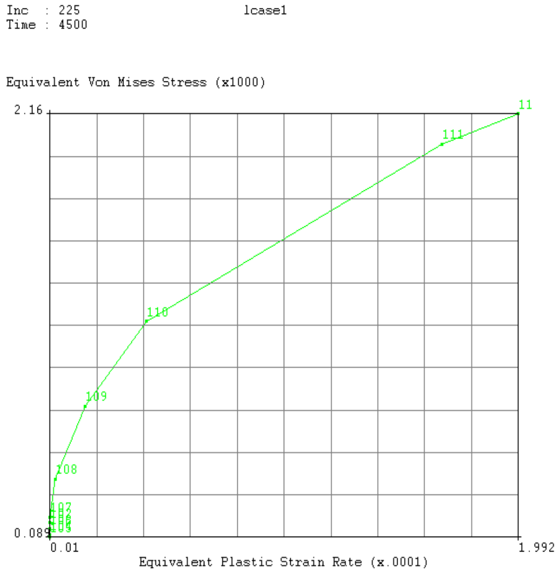

Fig.3 Stress- strain diagram of Ti alloy in conical die at t=4500s

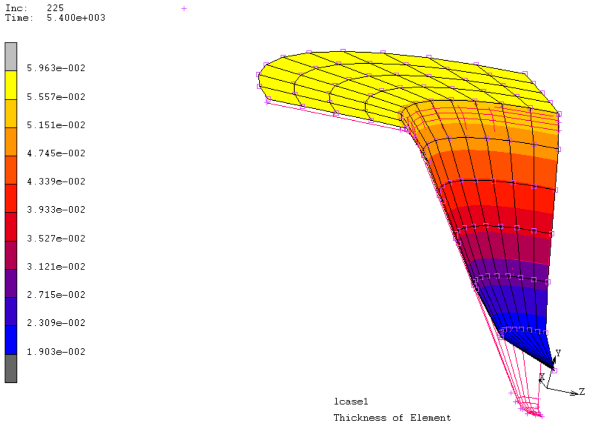

Fig.4 Thickness variation of Ti alloy in conical die at t=5400s

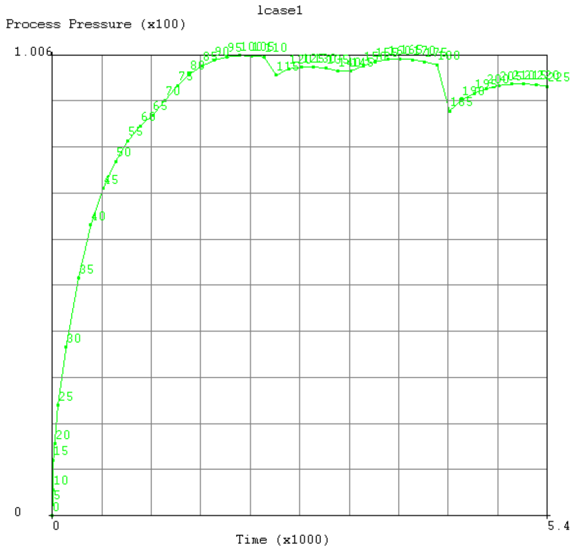

Fig.5 Pressure-Time profile of Ti alloy in conical die at t=5400s

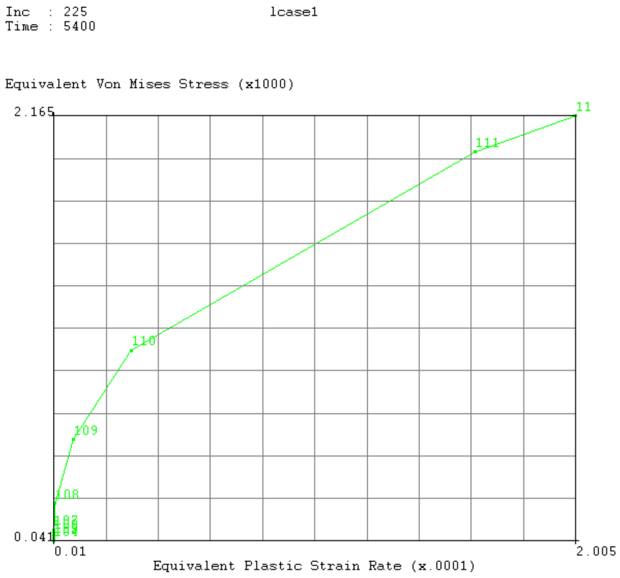

Fig.6 Stress- strain diagram of Ti alloy in conical die at t=5400s

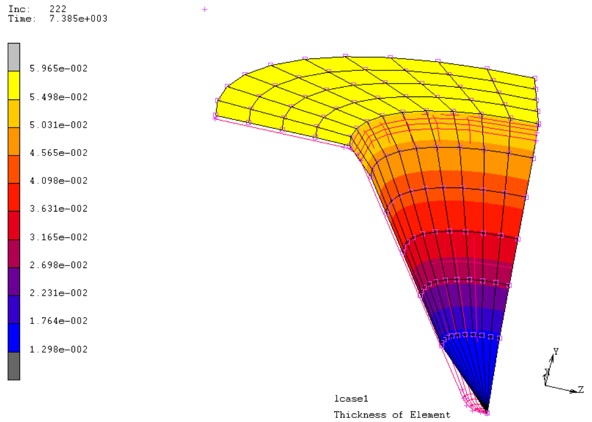

Fig.7 Thickness variation for cone at t=7400s,Ti alloy

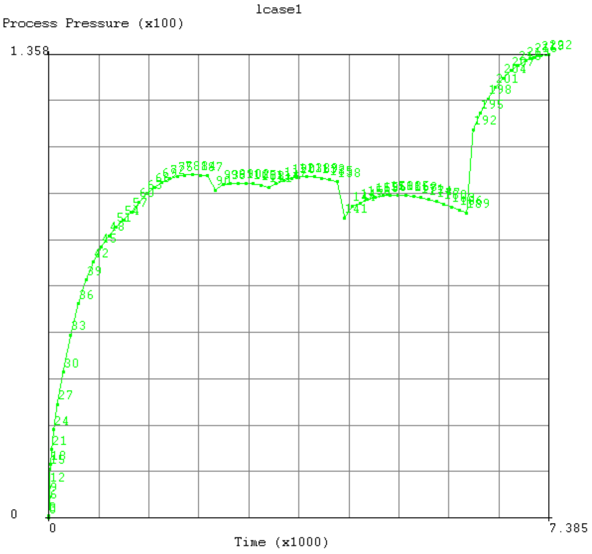

Fig.8 Pressure-Time profile for cone at t=7400 s, Ti alloy

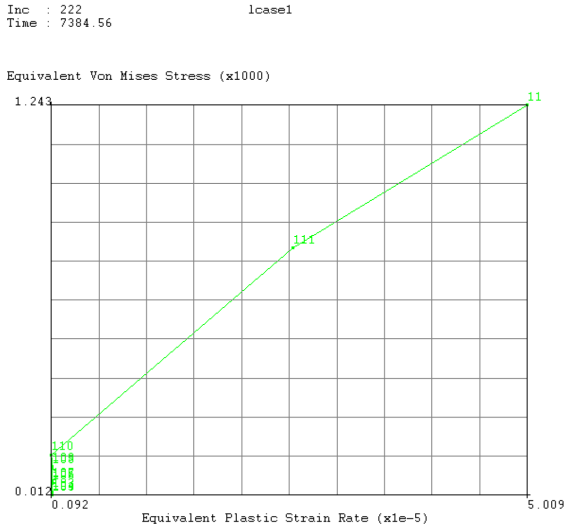

Fig.9 Stress- strain diagram of Ti alloy in conical die at t=7400s

The summarized forming pressure and forming time for conical die are tabulated in table for single sheet and its corresponding graph in Fig. The values obtained from the FE analysis are compared with the values obtained by analytical approach by Dutta's model [7].

Table.4 Analytical and FEA forming pressure and time values for conical die for Al-Li Alloy

Time, s	Pressure, MPa	
	Analytical	FEA
500	0.140	0.149
1000	0.179	0.189
1500	0.209	0.206
2000	0.214	0.212
2500	0.212	0.209
3000	0.220	0.211
3500	0.230	0.219
4000	0.235	0.194
4500	0.240	0.211
5000	0.260	0.214
5500	0.280	0.201
6000	0.290	0.260
6500	0.321	0.311
7000	0.350	0.327

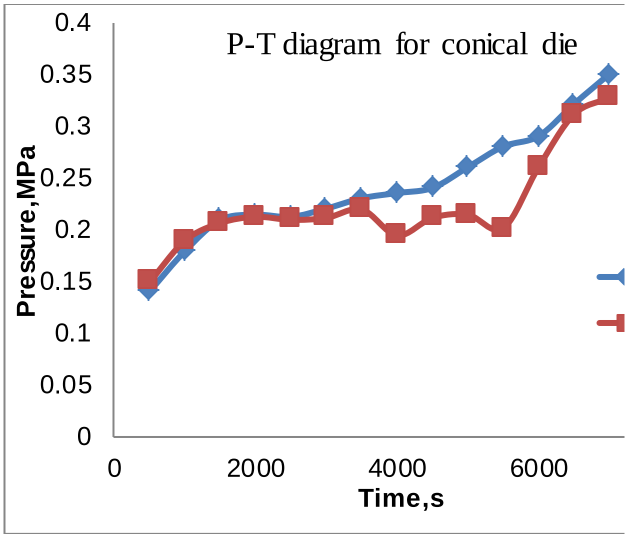

Fig.10 Comparison of P-T diagram of analytical and FEA values for conical die

Table. 5 Maximum forming Pressure and time values single sheet superplastic forming

Die	Ti alloy		
	Cone	Sphere	Rectangle
Forming time, s	7348	5011	5453
Forming pressure, MPa	0.93	0.625	1.51

Table.6 Maximum Pressure and time values for superplastic forming with diffusion bonding

Die	Ti alloy	
	Sphere	Rectangle
Forming time, s	5500	5143
Forming pressure, MPa	0.35	4.07

Table.7 List of maximum equivalent plastic strain rate and equivalent von-mises stress values of different alloys and die shapes from FE analysis

Die	Ti alloy		
	Cone	Sphere	Rectangle
Equivalent plastic strain rate, s^{-1}	5.01E-05	3.66E-05	0.0002
Equivalent von-mises stress, MPa	8.57274	7.562656	14.7849

Table.8 List of maximum equivalent plastic strain rate and equivalent vonmises stress values of different alloys and die shapes, SPF/DB from FE analysis

Die	Ti alloy	
	Sphere	Rectangle
Equivalent plastic strain rate, s^{-1}	0.0002	0.0002
Equivalent von-mises stress, MPa	14.9756	14.8357

Conclusions

From the above superplastic forming of single sheet and superplastic forming with diffusion bonding (SPF/DB) FE Analysis it can be concluded that,

1. The forming time increases with the height of the die, the time taken for conical forming is more compared to that of other dies, considering the same height for all other dies.
2. The forming pressure is more for SPF/DB for spherical die when compared to the others.
3. The forming pressure for the double sheet i.e., SPF/DB is more when compared to single sheet superplastic forming because of the initial contact between the sheets.
4. More thinning of sheet is observed in conical die when compared to other dies because of increase in forming time.
5. The forming time for Ti alloys is more as strain rate sensitivity decreases and also thickness distribution of Ti alloys also increases.
6. The stress induced in Ti alloy is more as strength of coefficient increases. The stresses obtained with SPF/DB are more than the single sheet forming

References

1. S. Hori, M. Tokizane, “Superplasticity in Advanced Materials”, The Japan Society of Research on Superplasticity, Osaka, Japan (1991).
2. Namas Chandra, “Constitutive Behavior of Superplastic Materials” International Journal of Non-Linear Mechanics, Vol. 37 (2002), 461-484.
3. G.J. Davies,”Superplasticity: A Review”, Journal of Material Science, Vol. 5, (1970), 1091-1102.
4. A. K. Ghosh and C. H. Hamilton “Influence of Material properties and microstructure on

Superplastic forming" Metallurgical Transactions A (1982), 733-745.

5. MSC MARC 2013, Volume A- Theory and User information.
6. L.Carrino, G.Giuliano, "A posteriori optimisation of the forming pressure in superplastic forming processes by the finite element method", Finite Elements in Analysis and Design, Vol. 39, Issue 11, (2003), 1083–1093.
7. Abhijit Dutta, Amita K. Mukherjee, "Superplastic forming: an analytical approach" Materials Science and Engineering A, (1992), 9-13.
8. Hambli R and Kobi S, "Optimization of superplastic forming using the finite element method" IEEE (2002).
9. G.Y. Li, M.J. Tan K.M. Liew, "Three dimensional modeling and simulating of superplastic forming" Journal of Materials Processing Technology 150, (2004), 76-83.
10. GAO Chong-yang and FANG You tong, "Investigation on the factors influencing the thickness distribution of superplastic formed components" Journal of Zhejiang University Science 6A (7), (2005), 711-715.
11. Mohammad A. Nazzal et al., "Finite Element Simulation of Superplastic Forming using a Microstructure Based Constitutive Model" ABAQUS Users Conference (2005).
12. L.Filice et al., "FE simulation and experimental considerations on Ti alloy superplastic forming for aerospace
21. g, A157 (1992), 9-13

applications", International Journal for Material Forum, (2010), 41-46.

13. L. M. Tang et al., "Comparative Study of Element Formulation on Simulation of Superplastic Forming", Materials Science Forum Vols. 551-552 (2007), 281-286
14. Pushkarraj Vasant Deshmukh, "Study of Superplastic forming using finite element analysis" Thesis.
15. F.U. Enikeev, "Strain rate sensitivity index m:definition, determination, narrowness", Materials science forum, Vol 243-245 (1997), 77-82
16. Dr. P. V. R. Ravindra Reddy "A Review on Finite Element Simulations in Metal Forming", International Journal of Modern Engineering Research Vol.2, Issue.4, (2012) 2326-2330.
17. B. Yogesha and S.S. Bhattacharya, "Superplstic forming of Ti-Al-Mn alloy", International Symposium of Research Students on Materials Science and Engineering (2004)
18. O.C. Zienkiewicz and R.L. Taylor, "The Finite Element Method", Volume 1 and 2, 5th Edition, Butterworth-Heinemann, 2000.
19. R.H.Wagoner and J.L.Chenot, "Metal Forming Analysis", Cambridge University Press, 2001.
20. Abhijit Dutta, Material science and engineerin