Modelling & Simulation of Die Compaction Process Using Modified Drucker-Prager Cap Model

Tafzeelul Kamal and M. Arif Siddiqui

Abstract—This paper presents the results of simulation of die compaction process that has been carried out with the help of ABAQUS software using the modified Drucker-Prager cap model. Aluminium powder is the main constituent used to model the die compaction process in this study. The results obtained from simulation have been compared with the manufactured components to validate the study.

Index Terms— Die compaction; Abaqus; Drucker-Prager; Aluminium

1 INTRODUCTION

DIE compaction is one of the key operations involved in the powder metallurgy process. It is of considerable economic importance for a variety of industries such as ceramic, food, pharmaceutical, refractory etc. In order to achieve the desired properties and to improve the efficiency of the process it is very much important to know the mechanical behavior of materials such as density and stress distributions. Galen and Zavaliangos [1] have shown through their investigations that the strength of compacts produced by the process of die compaction is anisotropic.The die compaction process is highly nonlinear because of material response, large deformations produced and strains induced, contact boundary conditions and friction behavior. During compaction, the powder friction at the die wall induces non-uniform axial stress and produces density gradients within the compact. The frictioneffect could be quantified by the wall friction coefficient during compaction. Drucker et al. (1957)[2] first of all introduced Drucker Prager Cap (DPC) model.The DPC plasticity model was modified and extended by efforts of many researchers (Chen and Mizuno, 1990[3]; Sandler, 2002,[4]). The modified Drucker Prager Cap (DPC) model although intended for geological materials, is very much suitable for representing the behavior of powder material when subjected to the compaction process. The modified DPC model is shown in fig.1 and it is assumed to be isotropic. It has yield surface consisting of three parts: a shear failure surface in which shear flow is predominant, a “cap” which provides a mechanism of inelastic hardening to express plastic compaction model and a transition region in between the two segments introduced in order to provide smooth surface for facilitation of numerical implementation. The Modified Drucker Prager Cap model can be considered as a multi-surface elastic-plasticity model that has the capability to represent densification hardening and inter-particle friction involved in the process of compaction.

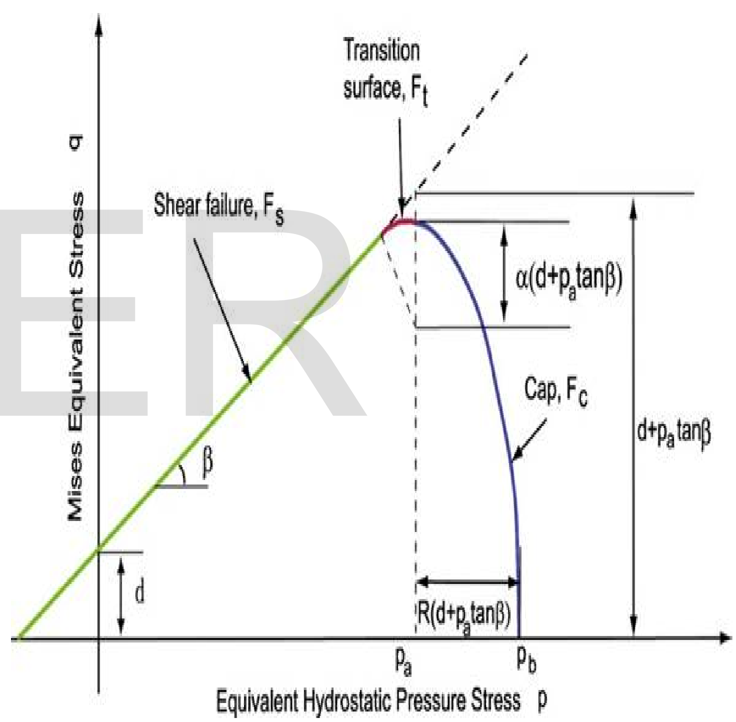

Fig.1. Modified Drucker Prager Cap Model(ABAQUS, 2006).

The Drucker Prager shear failure surface function can be represented as

$$F_s = q - p\tan\beta - d = 0$$

Where β represents material friction angle, d is material cohesion, p is the hydrostatic pressure stress and q is the Mises equivalent stress, which are given by the following relationships:

$$p = -\frac{(\sigma_z + 2\sigma_r)}{3}$$

$$q = |\sigma_z - \sigma_r|$$

- Tafzeelul Kamal is currently pursuing Master's degree program in Industrial & Production engineering in Aligarh Muslim University E-mail: tafzeelulkamal@gmail.com
- M. ArifSiddiqui is currently Associate Professor in the Department of Mechanical Engineering, Aligarh Muslim University

Where σ_z and σ_r denote axial and radial stresses respectively, which are developed during powder compaction process in the die.The cap yield surface function is given as

$$F_c = \sqrt{[p - p_a]^2 + \left[\frac{\mathrm{Rt}}{1 + \alpha - \frac{\alpha}{\cos\beta}}\right]^2} - R(d + p_a \tan\beta) = 0$$

Transition yield surface function is given by

$$F_t = \sqrt{[p - p_a]^2 + \left[t - \left(1 - \frac{\alpha}{\cos\beta}\right)(d + p_a \tan\beta)\right]^2} - \alpha(d + p_a \tan\beta) = 0$$

Where β is the angle of friction, d is the material cohesion, t is known as the deviatoric stress measure, p is the equivalent pressure stress. R represents the ratio of horizontal axis to the vertical axis of the elliptic cap, p_a shows the volumetric inelastic-strain driven hardening and α is the ratio of horizontal axis to the vertical axis of the elliptic cap in the p-t plane.Evolution parameter p_a is given by

$$p_a = \frac{p_b - Rd}{(1 + R\tan\beta)}$$

Where, p_b is the yield stress.The volumetric plastic strain can be represented by following relationship (Chtourou et al., 2002) [8]:

$$\varepsilon_v^p = \ln\left(\frac{\rho}{\rho_o}\right) \text{------------} \quad (1)$$

ρ is the final density and ρ_o is the initial filling density.

2. EXPERIMENRAL SETUP

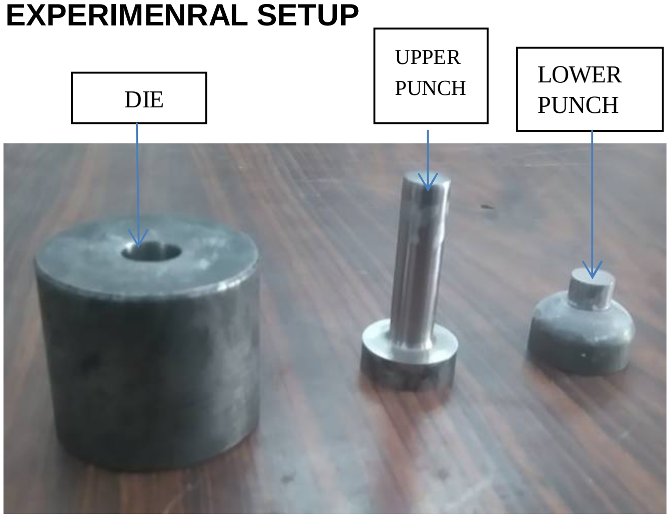

Fig.2. Die and Punch for Compaction

In order to define the actual behavior of powder during compaction process uniaxial die compaction was performed using hydraulic pellet press.

3. Hydraulic Pellet Press

Powder used in compaction consists of Aluminum powder (95%) of 200mesh size and Boron Carbide powder (5%) of 220mesh size. Hand mixing is done followed by ball milling so that a uniform mixture is obtained. A sample of this powder weighing 2gm is filled into the cylindrical die and tapped with the upper punch. Initial tapped height is recorded using vernier caliper. After this powder compaction is done using hydraulic pellet press and final height of the compact is recorded.

Initial tap density of the powder, $\rho_o = 1.48$ g/cm^3

Compaction pressure was varied from 180 MPa to 315 MPa and corresponding density of the tablet obtained after compaction was calculated, which has been used to verify the results obtained from simulation

Fig.4. Tablet obtained after compaction

3. SIMULATION OF DIE COMPACTION PROCESS

In order to simulate the process of die compaction process, an axis symmetric finite element model has been adopted because of the symmetry of the cylindrical tablet specimen. The element chosen is a four node bilinear axisymmetric quadrilateral as shown in the fig.5. The simulation was performed in ABAQUS (Dynamic Explicit mode). The die and punch walls have been assumed to be rigid. Interaction between die wall, punch and deforming powder has been modeled using contact elements available in ABAQUS. Coefficient of friction between the contact surfaces has been taken as 0.12 [7].The lower punch is kept fixed, while upper punch is moved to compact the powder. Diameter of die is 13mm.Initial filling height of powder is 12mm, which is tapped properly by using upper punch. Compaction pressure applied is 210MPa. In this simulation the Young's Modulus and Poisson's ratio have been assumed to be constant because of the small size and simple geometry of the compact.

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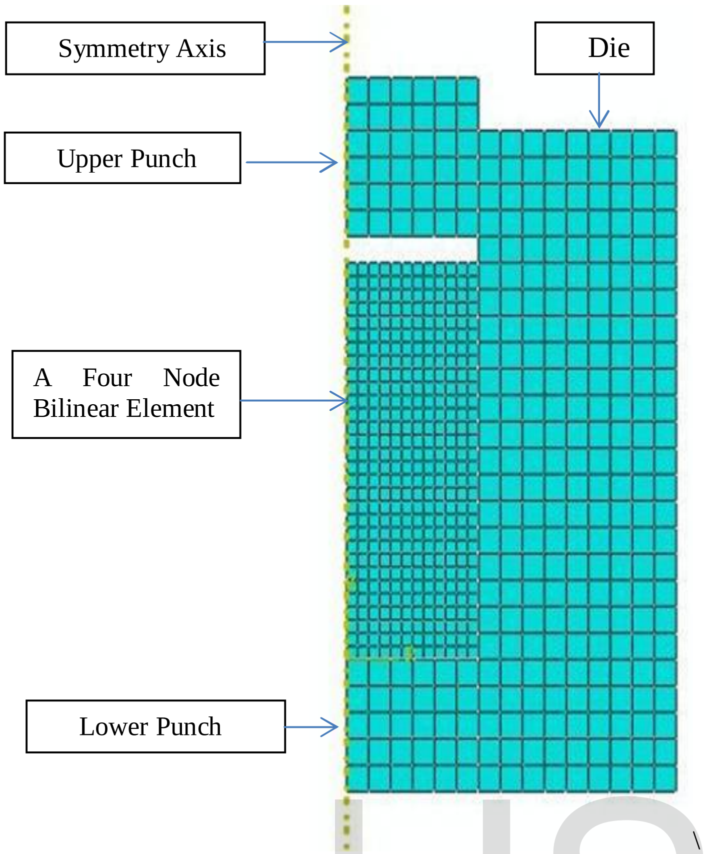


Fig.5. Finite Element Model for Die Compaction Simulation

Value of Young's modulus obtained from the uniaxial compression test of the powder is taken as 23GPa while Poisson's ratio is 0.3.Parameters used to implement DPC model are listed below and have been taken from the previous experimental investigations of researchers.

Cohesion, d = 18.64 MPa [5]

Friction angle, $\beta = 69^{o}$[5]

Cap Eccentricity, R = 0.558 [10]

Transition yield surface parameter, $\alpha = 0.03$ [7]

4. RESULT & DISCUSSION

Stress distribution obtained in the compact after the compaction process has been shown in the figure 6. Simulation of the die compaction process for Aluminum Boron Carbide composite shows how the stresses are developed within the tablet as well as the strain distributions in different regions of compact due to the die compaction process. The stress distribution is more severe near the top and side regions while bottom region has lower stresses. High stress distribution reflects chipping possibilities of chipping failure in these regions. Non uniformity in stress distributions near the top and side regions may be attributed to friction due to wall as well as elastic recovery of material in radial direction causing large shear stresses as other regionsof the compact were still being constrained due to die walls and hence resulted in the development of greater stress concentrations at the top of the compact. Such type of stress concentration in the tablet can lead to capping and lamination.

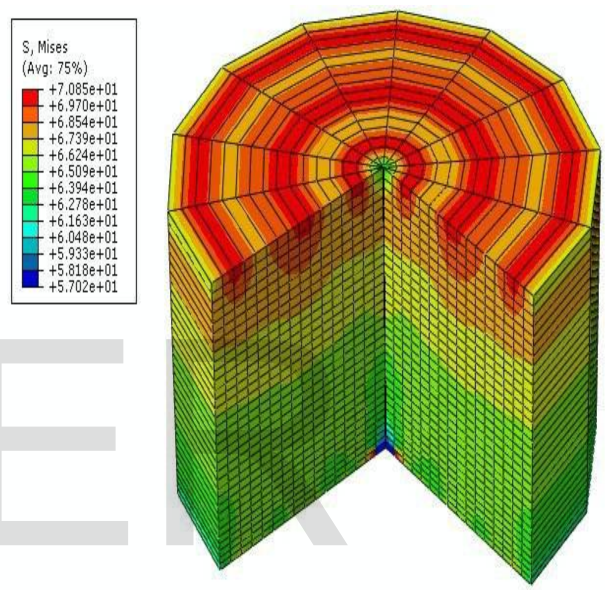
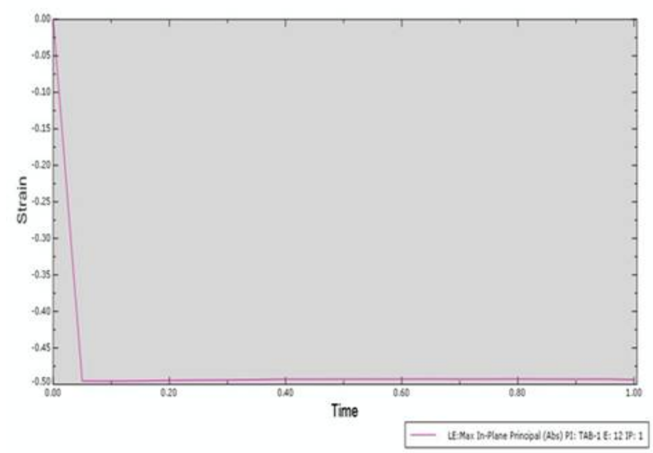


Fig.6. Stress Distribution in Tablet after Compaction

Fig.7. Strain variation with time



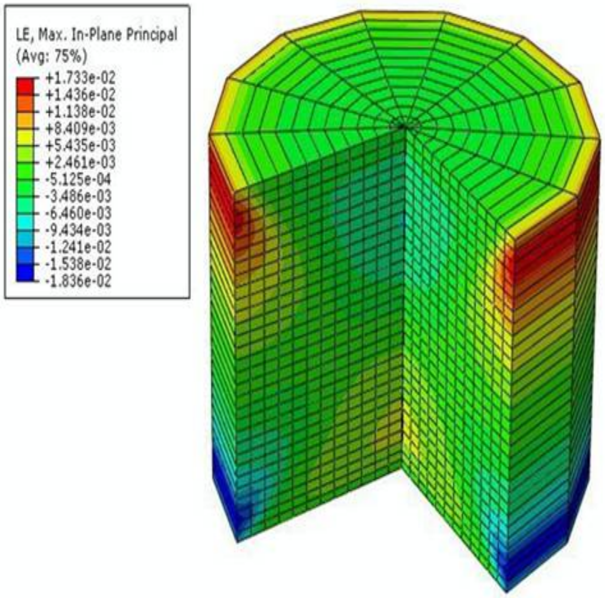


Fig.8. Strain induced in tablet after compaction

Also the true strain is directly linked with the density as depicted in relationship (1). Variation in the true strain distribution throughout the tablet suggests non-uniform density distribution within the tablet and is depicted in fig.8. High density regions are visible in the upper corner of the tablet while low density region is near the bottom corner which is in agreement with the experimental findings (Eiliazadeh et al.,2003) [10].

Compaction Pressure (MPa)	Volumetric Plastic Strain Induced (ε_v^p)	Final Density of Compact (g/cm³)
180	0.41	2.167
210	0.49	2.259
255	0.54	2.495
285	0.60	2.746
315	0.68	2.948

Table 1: Density variations Predicted from Simulation

Volumetric plastic strain induced in tablet has been recorded in table 1 after running a series of simulation by varying compaction pressure and the final density has been calculated using the relation (1) give earlier. I t is evident from table 1 that density of the compact increases as the compaction pressure increases. As the density increases strength of the compact also increases. Fig.9 shows the variation of strain energy with the passage of time. Initially it increases as powder gets compressed and reaches a maximum value and then after a slight decrease it remains constant.

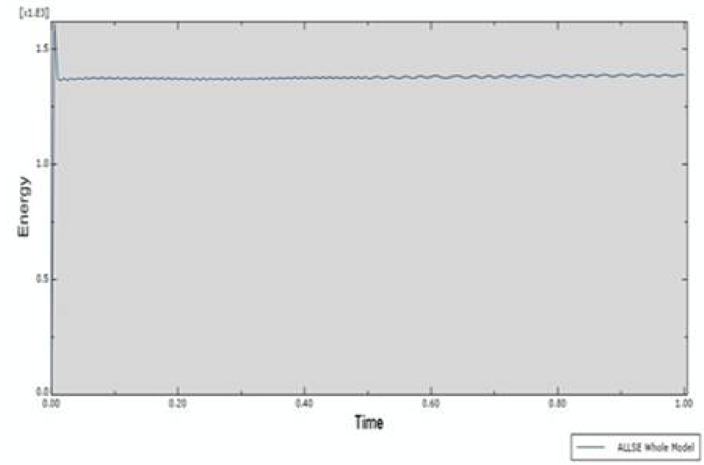


Fig.9.Variation of Strain Energy with Time

Compaction Pressure (MPa)	Predicted Density (g/cm³)	Actual Density (g/cm³)	Percentage Error
180	2.167	2.243	3.39
210	2.259	2.324	2.79
255	2.495	2.552	2.23
285	2.746	2.701	1.67
315	2.948	2.902	1.59

Table2: Validation of Simulation Data

Also the results obtained from the simulation have been compared with the actual density as shown in table 2 obtained after performing the die compaction in laboratory. It is clear that the actual data is in good agreement with the simulation results and the corresponding errors are also less, thus validating the simulation results.

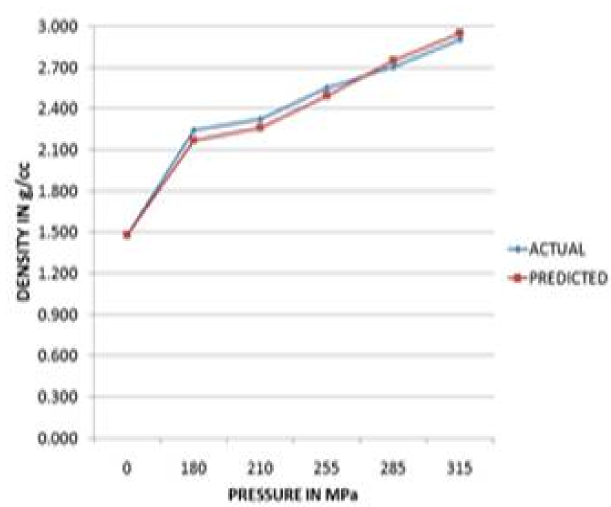


Fig.10. Comparison of Simulation Results with Actual One

5. RESULT

In spite of the fact that complex parts can be made using die compaction process, it is evident that a homogenous green density cannot be obtained by die compaction. Compaction pressure and friction between powder and die wall play a significant role in inhomogeneity in density. In summary simulation can be an effective tool in optimization of the process parameters in order to improve the final properties of the compact, saving the cost involved in tool design and testing and the time lost, thus reducing the overall production cost.

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