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Finite Element Analysis for Material and Geometrical Nonlinearity in Powder Compact Components

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Abstract

Metal powder compaction is an important process in powder metallurgy (PM) industry, and it is widely applied in the manufacturing of key component in different fields. The numerical simulation based on the Finite Element Method (FEM) provides a flexible and efficient approach for the researchers of this process and its complicated mechanical behaviours. Die compaction of powder is a process which involves filling of dying with powder, compressing of the powder using rigid punches to form a dense, compact and ejection from the die. In this work, the modified Drunker-Prager Cap Model, a plasticity model for granular materials, is applied to represent the behaviour of metal powder during the compaction process. The model contains a number of material parameters which affect the accuracy of the Finite Element (FE) prediction. Methodology for parameter determination as described herein. The model has been validated by comparing the computed results with experimental results available in the literature survey. The predictive capability of the model has been demonstrated through the simulation of both compaction and ejection stages of the cylindrical specimen with various tooling motion. The tooling motion considering here include the top pressing and holding load features of a commercial pressing machine. Here ABAQUS solver was used to simulating the powder compaction process, and the results obtained from that are compared with the literature. Here we are going to consider material and geometrical nonlinearity of the powder compaction components.

Keywords: *Powder Compaction, Relative Density, Abaqus, Void Ratio, Modified Drunker-Prager Cap Model*

I. INTRODUCTION

Powder Metallurgy (PM) has many advantages both in technology and economy over the conventional processes. It has got a wide application in the manufacturing of high-performance Components in different fields. The powder compaction procedure is of great importance in PM production. Powder compaction is important in many aspects of the industry, including the flow and storage of agricultural products, the forming of ceramic components, powder Metallurgy parts, and pharmaceutical tablets, road and dam construction, subway and Tunnel excavation, mine and oil-well locating, and rock slides and avalanches. For example, it is estimated that more than 80% of all medication doses are administered as tablets, that is, in unit dosage forms prepared by compacting powders indies.

Density gradients are often presented in green part due to the complicated powder deformation mechanism during compaction. These gradients could lead to part fracture during the ejection stage and induce distortion in subsequent processes. Green

parts with uniformly-distributed and high density are there for preferable manufacturing process for the industry. It is of great significance because this will bring more economic effects to the industry, and engineers can control the particle compaction. In modelling of powder compaction, constitutive relation and numerical methods are developed for simulating the response of powder during compaction. A good model should be able to predict the state of stress, strain and the displacements everywhere in a powder sample subjected to some external and internal forces. Traditional soil mechanics and rock mechanics concepts and theories are introduced and adopted into the constitutive models for the powders.

At the same time, Finite Element Methods (FEM) has become the most important numerical methods because they can accurately predict the density variation in a compaction procedure and can provide information on defect detection. More and more scientists are engaged in the work of combining classical or promising constitutive models with FEM and compare with the results from the experiments and improve them. This shows great potential in the research work of powder materials. Many theoretical models have been issued for understanding the constitutive relations of powders.

II. OBJECTIVES

To study the variation of relative density properties of powder compaction process qualitatively and quantitatively. To build a model by using ABAQUS solver.
To compare the results derived from analysis with the numerical model results taken from the literature survey [6].

A. Aim

Is to study the variation of the properties qualitatively and quantitatively for the powder compaction process. This study can be made either experimentally or by building a Numerical model. In this project work, it is proposed to build a Numerical model and validate the numerical model with the experimental results available in the literature. Once the Numerical model is validated, the same model can be used for different load condition as well as for different geometries. The model is built using software package ABAQUS which is widely used for such studies

a) Problem Definition

Powder compaction usually results in variation in physical and mechanical properties along with the height and as well as across the radius. It is essential to produce components using powder compaction process where properties are as close as possible to cast or rolled or forged components.

b) Material Model Used

The modified Drucker-Prager cap model, which is considered to be an appropriate one to represent the behaviour of metal powders during the compaction process, is used. As shown in Figure 1. Figure 2,3,4 shows the Boundary Condition.

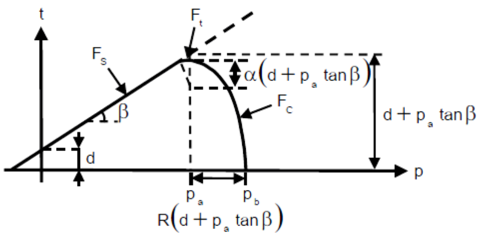


Figure 1 Shows the Modified Drucker-Prager cap model

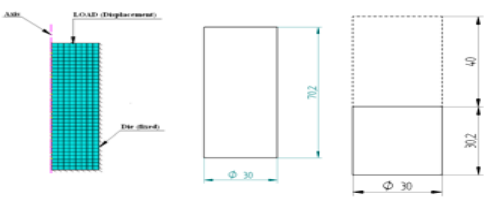


Figure 2 Boundary condition Figure 3 Before Compaction Figure 4 After Compaction

c) Geometrical and Material Details

Initial Height =70.2mm No of Elements=282

Initial Diameter=30mm No of Nodes=326

Compaction Height=40mm

Initial Relative Density=0.40

Element Type= Axi-symmetry Four Node Bilinear

d) Results

To validate the model parameter, the uniaxial compactions of 316L cylindrical specimen were simulated. During the compaction process, the dense specimen with symmetric density distributions about the central axis (axis of rotation) in the direction of the applied load. The cylindrical specimens were compacted with filling height (initial height) of 70.2mm and an initial relative density of 0.4 as determined from the apparent filled density.

The 247-element mesh with axi-symmetric four-node bilinear element was used to simulate the axi-symmetric behaviour of the specimen. The die wall and the upper punch were modelled as rigid surfaces because they are much harder than powder.

Validation of the simulation work with the given literature survey is as shown in Figure 5

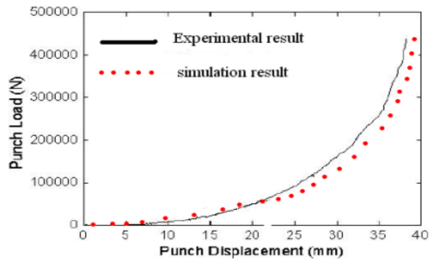


Figure 5 The load vs. Displacement of the simulation and the experimental given in the literature are matching

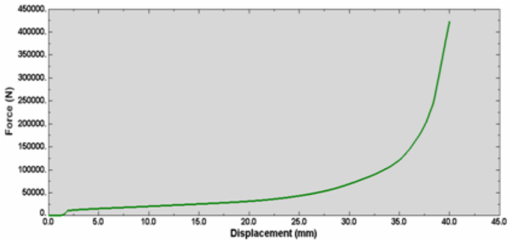


Figure 6 The punch load vs. displacement results of the simulation

From the above Figure 5, it is noted that the compaction of the powder will start after 5mm compaction before that the particle rearrangement, elastic deformation of the particle, plastic deformation of the particle, fragmentation of the particle, the formation of inter particulate bonds, elastic recovery of compacts. After that, the compaction begins, and the load vs. displacement graph looks like the above Figure 6. And the compaction process takes place up to 40mm compaction the above concept can be validated by the literature survey [6].

e) Variation of Relative Density along with the Height and across the Radius for Different Displacement and Relative Density

Case 1 Assumed Relative Density as 0.4

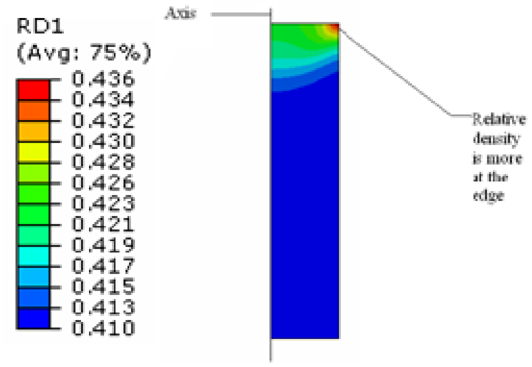
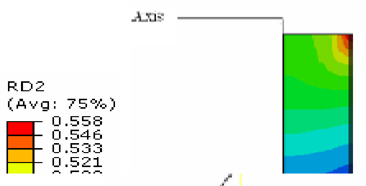


Figure 7 The variation of Relative Density for 5mm Compaction



for 10 mm

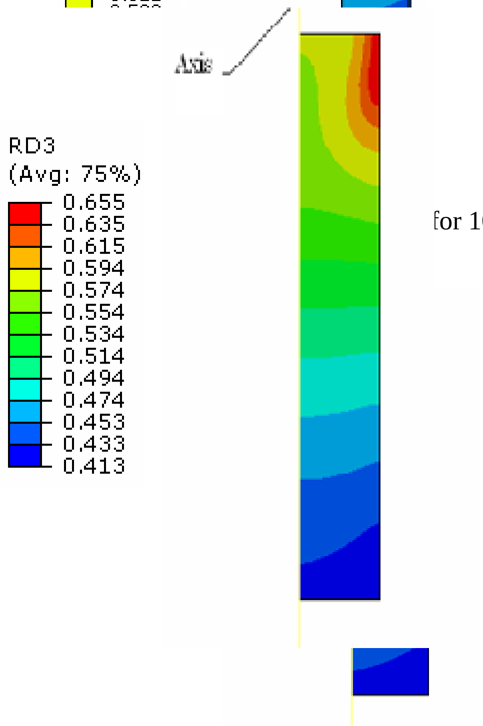


Figure 9 The variation of Relative Density for 15 mm Compaction

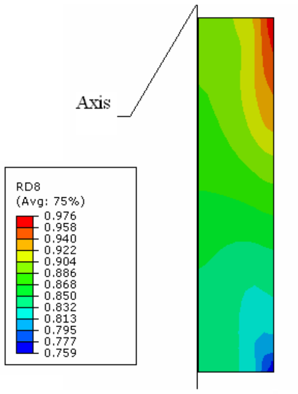


Figure 10 The variation of Relative Density for 40 mm Compaction

f) Graphs of Relative Density Ratio vs. z/hi ratio

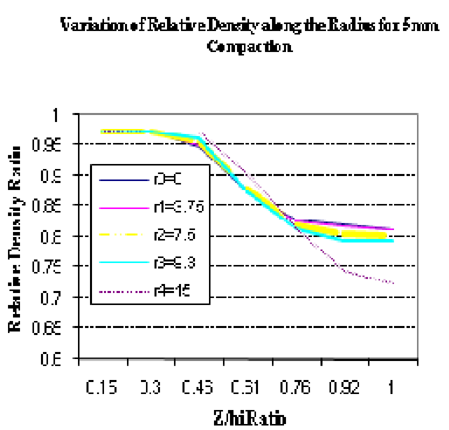


Figure 11 The graph of relative density ratio vs. Z/hi for

5mm compaction

In the above Graph Z_i represent 5 10 15 20 ……. Up to 40 mm compaction or reduction in height and h_i represent 70.2, and these terms are no dimensional no, and these are the Ratio, and the relative density ratio is also the same for all the graph. It is clear from the Fig 11, that Ratio of z/h_i increases Relative density ratio decreases for all the condition, i.e. r_0=0mm, r_1=3.75mm, r_2=7.5mm, r_3=9.3mm, r_4=15mm, for 5mm compaction. There is no appreciable dropping, showing a drastic reduction in density as expected because up to a certain length of movement of the Ram there is a readjustment of the particle to particle contact. In other words, there will be the beginning of all the point of contact from particle to particle will transfer to line contact. Eventually, deformation will lead to surface contact from there, and there will be an appreciable reduction in density. This phenomenal will continue until individual particles deformation begins when there is intimate contact leaving no voids availability situation. Another point of inflection is expected towards theoretical density. Perhaps the particles will be sinking into the available voids space in the initial movement of the Ram. Because of which there is no decrease in density. Since near the die wall, particles deformation is restricted by the die wall, and also friction being more at the die wall the density is expected to be relatively higher. At the certain became all the particles are surrounded at the available extend of voids being more, compaction will be less making the relative density lower than at the die wall. Because of the friction at the die wall, the particle deformation also will be higher, making the density higher. As the Ram comes down, more particles will experience the pressure gradient maximum just below the Ram and least at the bottom.

g) Theoretical validation for the above plots

Relative density assumed as 0.4

Initial relative density =0.4

Fill density =0.4 × sintered density of the Material (steel granular powder)

=0.4 × 7800

=3120 kg/m^3

Fill Density=mass / volume

Mass=Density × volume

=3120 × 49.62×10^{-6}

=0.1548 kg/m^3

Calculating the density after 40mm compaction

Density=mass / volume

Density=0.1548 / 28.274.33×10^{-6}

=5474.99 kg/m^3

Theoretical Relative Density = Density/sintered material density

=70%

III. CONCLUSION

The modified Drucker-Prager cap constitutive model was used to model the metal powder compaction of a cylindrical specimen. The model predictions have shown good agreement with the experimental results given in the literature. FEM modelling can be a useful tool for process design and optimization of powder compaction modelling process. Virtual process development and tool design using FEM can significantly reduce the development time, effort and cost. With the advance in the computing power, compacting of complex 3D shapes can now be simulated by using FEM Material constitutive behaviour, and yield function can be incorporated in the user subroutines and the models available in ABAQUS.

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