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Deformation And Crack Analysis in Metal Powder Compaction

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ABSTRACT:- *This paper presents a preliminary assessment and qualitative analysis on fracture criterion and crack growth in metal powder compact during the cold compaction process. Based on the fracture criterion of granular materials in compression a displacement based finite element model has been developed to analyze fracture initiation and crack growth in metal powder compact. Approximate estimation of fracture toughness variation with relative density is established in order to provide the fracture parameter as compaction proceed. A single crack initiated from the boundary of a multi-level component made of iron powder is considered in this work. The finite element simulation of the crack propagation indicates that shear crack grows during the compaction process and propagates in the direction of higher shear stress and higher relative density. This also implies that the crack grows in the direction where the compaction pressure is much higher, which is in line with the conclusion made by previous researchers on shear crack growth in materials under compression. In agreement with reported work by previous researchers, high stress concentration and high density gradient at the inner corner in multi-level component results in fracture of the component during preparation.*
Powder metallurgy (PM) is widely applied to produce mainly automotive parts such as bearings, cams, and toothed components.
Manufacturing parts using PM involves four major steps: *powder and lubricant mixing, compacting powders into appropriate shapes in closed dies to produce green compacts, sintering the green compacts at elevated temperature and finally, post-sintering secondary operations.*
In modeling the compaction process, the macro-mechanical modeling approach is used in this work, which provides information on the macroscopic behavior of the powder assembly such as powder movement, density distribution, stress state and the shape of the compact during and after compaction.

I. INTRODUCTION

Powder compaction is a production method commonly used in the manufacturing industry today such as those in the ceramic forming, pharmaceutical and detergent industries. The granulated material is consolidated by the application of pressure. Artifacts of the granule structure often persist as pores and laminations after compaction, and may persist as defects in the sintered microstructure. Such defects can be detrimental to the properties of the final part called "green body". The fracture and deformation behavior of particles under impact loading is important in many industrial processes. For example, impact commination is widely used to modify the size distribution of a population of particles. On the other hand, unintentional attrition by impact can degrade particles, and the resulting fragments may cause serious problems elsewhere in the system. Thus, it is desirable to eliminate the granule structure as completely as possible during the compaction.

In cold uniaxial powder compaction, the powder is formed into a desired shape with rigid tools and a die. A critical property in the powder pressing process is the mechanical properties of the formed piece. Beyond a defect-free green body, the desired properties are high strength and a uniform density. The compression induces a tensile stress perpendicular to the compressed diameter. Understanding breakage in granulation could lead to a better control of product quality and improved manufacturing efficiency. In either case, it is important to under-stand the mechanisms of failure under impact conditions so that these attrition and commination processes can be appropriately controlled.

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In modeling the compaction process, the macro-mechanical modeling approach is used in this work, which provides information on the macroscopic behaviour of the powder assembly such as powder movement, density distribution, stress state and the shape of the compact during and after compaction. Thus the powder medium is considered as a continuum that undergoes large elastic–plastic deformation. In order to describe the effect of loading state on the response of the powder, constitutive model based on granular material is used since it was found in the literature that powder behaves similarly to a frictional granular material with regard to militancy and densification behavior. Details on cold compaction process can be found, where the numerical modeling of the compaction, relaxation, ejectionand emergence phases have been developed, and validated by experiments.

II. LITERATURE REVIEW

A. *Review of Papers*

S.M. Tahir , A.K. Ariffininvestigated thata preliminary assessment and qualitative analysis on fracture criterion and crack growth in metal powder compact during the cold compaction process. Based on the fracture criterion of granular materials in compression, a displacement based finite element model has been developed to analyse fracture initiation and crack growth in metal powder compact. Approximate estimation of fracture toughness variation with relative density is established in order to provide the fracture parameter as compaction proceed. A single crack initiated from the boundary of a multi-level component made of iron powder is considered in this work. The finite element simulation of the crack propagation indicates that shear crack grows during the compaction process and propagates in the direction of higher shear stress and higher relative density. This also implies that the crack grows in the direction where the compaction pressure is much higher, which is in line with the conclusion made by previous researchers on shear crack growth in materials under compression. In agreement with reported work by previous researchers, high stress concentration and high density gradient at the inner corner in multi-level component results in fracture of the component during preparation.

Mohamed Bouaziz1, Said Abid, HatemKsibiinvestigated thatThe compaction of granulated powder is a common forming process used in ceramic and pharmaceutical industries. Argillaceous particles are used as a model system to investigate granule failure during cold compaction. In this work both experimental and numerical investigations have been focused on the fracture in powder compacts. This includes studies of crack propagation and determination of operating conditions to avoid the green body fracture. In fact, axial compaction tests have been performed to determine material parameters for hardening. The numerical modeling is implemented using a finite element method based on the Von Mises criterion. Simulation examples are presented to dem- onstrate the ability of the model to compute the distribution of the relative stresses in porous media.

Sydney H. Luk, Frank Y. Chan, Alan B. Davala, Thomas F. Murphy Hoeganaes Corporation investigated thatGreen strength enhanced material systems have been developed for iron and Low alloy as well as stainless powder metallurgy applications. Relative to normal processing, the increase in green strength is 50-100%. The nature of green strength with respect to both materials and processing conditions is reviewed. The processing variations designed to meet target properties such as apparent density, flow and compressibility are compared with conventional material systems. Manufacturing experience with a mechanical press is presented.

Thomos F. Murphy and Bruce Lindsleyinvestigated thatpreliminary assessment and qualitative analysis on fracture criterion and crack growth in metal powder compact during the cold compaction process. Based on the fracture criterion of granular materials in compression, a displacement based finite element model has been developed to analyse fracture initiation and crack growth in metal powder compact. Approximate estimation of fracture toughness variation with relative density is established in order to provide the fracture parameter as compaction proceed. A single crack initiated from the boundary of a multi-level component made of iron powder is considered in this work. The finite element simulation of the crack propagation indicates that shear crack grows during the compaction process and propagates in the direction of higher shear stress and higher relative density. This also implies that the crack grows in the direction where the compaction pressure is much higher, which is in line with the conclusion made by previous researchers on shear crack growth in materials under compression. In agreement with reported work by previous researchers, high stress concentration and high density gradient at the inner corner in multi-level component results in fracture of the component during preparation.

Young-Sam Kwon and Suk-Hwan Chung .Seonjin-ri, Yonghyeon-myon, Sacheon, Kyongnam, investigated that

The optimization program is developed to analyze and optimize the powder compaction.
The optimization program has the capability to predict
(1) The formation of cracks in the green compact,
(2) The density distribution in the compact and
(3) The tooling forces required to achieve these densities and

(4) provide the optimum processing variables during powder compaction.

The optimization program is applied to predict the density distribution and tooling forces. Based on the verification of the program, loading schedule is optimized to achieve uniform density distribution in the Hub shaped green part during die compaction. This part had been previously analyzed by several compaction simulation models through the European consortium MODNET. A new concept to predict crack formation during powder compaction is proposed. The numerical simulation results show excellent agreement with experimental data and the process conditions obtained by the optimization procedure remarkably improve the quality of product.

Joaqu´ın A. Hern´andez Ortega, Xavier Oliver Olivella, Juan Carlos investigated that Powder metallurgy (P/M) is an important technique of manufacturing metal parts from metal in powdered form. Traditionally, P/M processes and products have been designed and developed on the basis of practical rules and trial-and-error experience. However, this trend is progressively changing. In recent years, the growing efficiencies of computers, together with the recognition of numerical simulation techniques, and more specifically, the finite element method, as powerful alternatives to these costly trial-and-error procedures, have fueled the interest of the P/M industry in this modeling technology. Research efforts have been devoted mainly to the analysis of the pressing stage and, as a result, considerable progress has been made in the field of density predictions. However, the numerical simulation of the ejection stage, and in particular, the study of the formation of *cracks* caused by elastic expansion and/or interaction with the tool set during this phase, has received less attention, notwithstanding its extreme relevance in the quality of the final product. The primary objective of this work is precisely to fill this gap by developing a constitutive model that attempts to describe the mechanical behavior of the powder during both pressing and ejection phases, with special emphasis on the representation of the cracking phenomenon. The constitutive relationships are derived within the general framework of rate-independent, isotropic, finite strain elasto plasticity. The yield function is defined in stress space by three surfaces intersecting non smoothly, namely, an elliptical cap and two classical Von Mises and Drucker-Prager yield surfaces. The distinct irreversible processes occurring at the microscopic level are macroscopically described in terms of two internal variables: an internal hardening variable, associated with accumulated compressive (plastic) strains, and an internal softening variable, linked with accumulated (plastic) shear strains. The innovative part of our modeling approach is connected mainly with the characterization of the latter phenomenological aspect: strain softening. Incorporation of a softening law permits the representation of macroscopic cracks as high gradients of inelastic strains (strain localization). Motivated by both numerical and physical reasons, a parabolic plastic potential functionis introduced to describe the plastic flow on the linear Drucker-Prager failure surface.

B. Outcome of Review papers

Generally, crack can grow in three different manners:

i) Under low pressure, crack grows via incipient kink byopening mode, at an angle from the original crack plane,

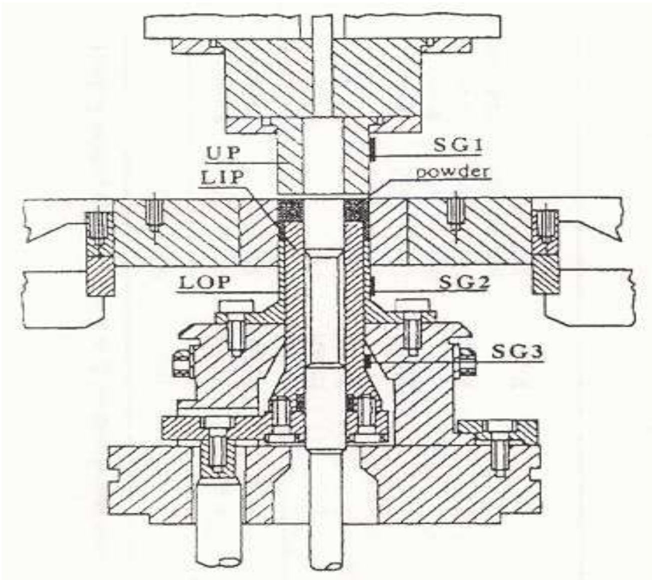
ii) Under increasing pressure, crack grows as a combination of open (mode I) and shear (mode II) crack,

iii) Under substantially high pressure, crack grows as a shear (mode II) crack, straight ahead or at a small angle from the original crack plane.

III. BASIC THEORY

A. Working procedure of Metal powder compaction.

The tooling equipment consists of the upper punch, the lower outer punch, the lower inner punch and die. Even though the lower outer punch was the fixed component, three process parameters such as the upper punch, the lower inner punch and die have to be controlled. They used five different conditions for the upper punch, the lower inner punch and die. But, there can be a number of processing conditions since the three independent process parameters make many combinations. Recently, developed the optimization program to provide the optimum process conditions to achieve the most uniform density distribution inside the powder compact.



Die set of a general compaction machine

The metal powders are placed in a die cavity and compressed to form a componentshaped to the contour of the die. The pressure used for producing green compact of the component vary from 80 Mpa to 1400 Mpa, depending upon the material and the characteristics of the powder used. Mechanical presses are used for compacting objects at low pressure. Hydraulic presses are for compacting objects at high pressure.

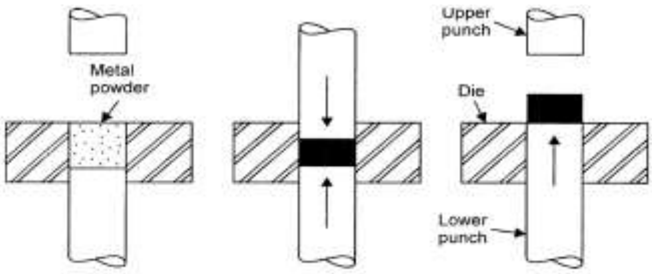


Fig. 4.2 Steps in Pressing Operations

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B. Causes of Cracks in green P/M Compaction.

Inter particle Shifting.

Another mechanism of cracks is inter particle side shifting. The inter particle bonds are formed primarily by plastic deformation and bulk movement of the powders. In an ideal condition, densification is bilateral, symmetrical and simultaneous, and inter particle side shifting does not take place. This particle motion after the onset of densification can prevent the inter particle bonds from forming and generate a crack.

Improper Elastic Strain Release.

Improper elastic strain release is another mechanism of crack formation. During compaction an unrecoverable plastic deformation of the particles occurs. Additionally a recoverable elastic deformation is also present. When the tooling elements reach their final required positions, the related pressures are reduced and during ejection will eventually go to zero. At the moment of release from compaction pressures, the compressive stresses relax and the green compact will change abruptly from a plastic to a purely elastic stage. If the internal stresses are beyond the compact's strength Limit, cracks will form.

High Tensile/Shear Stress.

In the green P/M state, if the tensile/shear stress which can be generated by external or internal factors in a compact exceeds its green strength, which usually ranges between 10- 30 MPa for most P/M green compacts, then a crack could be formed.

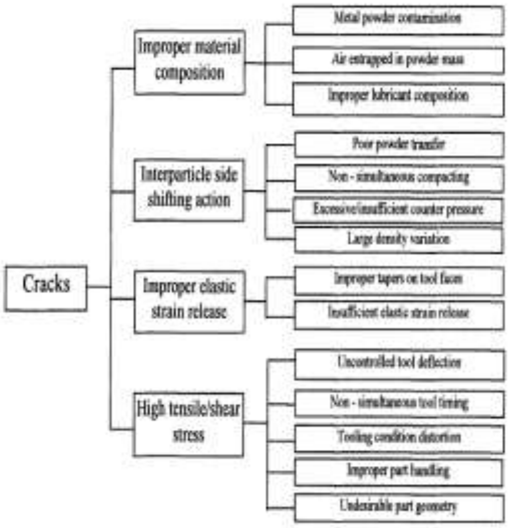


Figure 1. General causes of cracks in green P/M compacts and some example conditions.

IV. FINITE ELEMENT ANALYSIS

A.Fracture criteria.

Even though it is believed that failure in metal powder compaction is due to shear fracture (mode II), the fracture criterion in need must not neglect the possibility of fracture due to opening mode (mode I). Classical mixed mode fracture criteria have always been used to find the crack initiation angle (or direction) where crack extension depends on a specific fracture parameter. However, based on three basic criteria, namely the maximum circumferential stress criterion (rh-criterion), the maximum strain energy release rate criterion (G-criterion) and the minimum strain energy density criterion (S-criterion) reveals that these criteria fail to predict the occurrence of mode II fracture even when pure shear load is applied. The crack initiation angle obtained from all three criteria is between 70 and 80 from the original crack plane when pure shear load is applied, while the true mode II crack should be in the direction of the maximum shear stress intensity factor, that is in the original crack plane or at a small angle from the original crack plane. In other words, the analysis proved that a more robust fracture criterion is needed to predict the occurrence of mode II crack.

B. Adaptive mesh and crack mechanism.

An adaptive finite element mesh is applied to accommodate large displacement changes in geometry of the domain. Error estimator based on stress error norm is used, where automatic re meshing is calculated at each step during the compaction process. Crack initiation and propagation havebeen developed and implemented in the model, without having to predefine the direction of crack. Initially, a three nodes triangle element is used. After the first stage of re meshing, the three nodes elements are automatically converted into six nodes triangle elements.

In finite element modeling using advanced re meshing technique, crack propagation can be modeled by inter-element or intra-element in the mesh. while the node release mechanism is used to provide two adjacent crack faces when the criteria is fulfilled. Using an adaptive mesh, the maximum and minimum element size can always be chosen such that the smallest element will be generated around the crack tip. As crack propagates, elements with appropriate size are generated around the crack tip, while the mid node of an element will become a new crack tip in order to ensure that the crack extension is within the process zone.

C. Geometry and boundary conditions of finite element model.

A multi-level component, in this case a rotational flanged component, is modelled by an axisymmetric representation as shown in. Iron powder with material properties obtained from experimental work inas listed in, is compacted by bottom and top punch movements. Total displacement of the bottom punch, db = 7.69 mm while the top punch displacement, dt = 6.06 mm at the end of compaction process. In this work, the compaction is performed in 20 steps movement of bottom and top punch, respectively, band in turn as shown in. This mean that a total displacement of 7.69 mm is first achieved when the bottom punch had finished a 20 steps movement, followed by a total displacement of 6.06 mm by the top punch after a 20 steps movement.

Material properties	
Young_s modulus, E	40 MPa
Poisson ratio,	0.35
Cohesion, C	2.5
Angle of internal friction	33
Coulombs friction coefficient	0.3332
Initial relative density	0.327

Material properties of iron powder

D. Fracture toughness.

The fracture criterions require values of the critical stress intensity factors, KIC and KIIC which are the material parameters and also called fracture toughness. Standard procedures exist for determination of fracture toughness for solids, such as three point bending test or four point bending test. However, the fracture toughness of the powder compact during the compaction process is not as simple as fully dense solids due to continuous rapid change of density and other material properties at each compaction step. Hence variation of fracture toughness with relative density must be obtained in order to provide these fractureparameters as compaction proceeds.

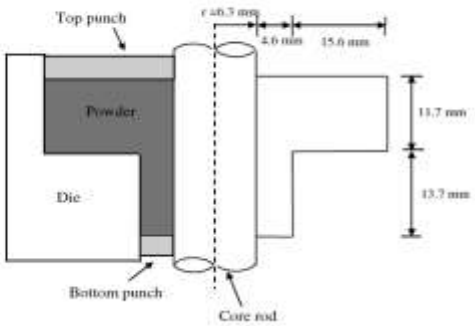


Fig. 4. Geometry and boundary conditions of a rotational flanged component.

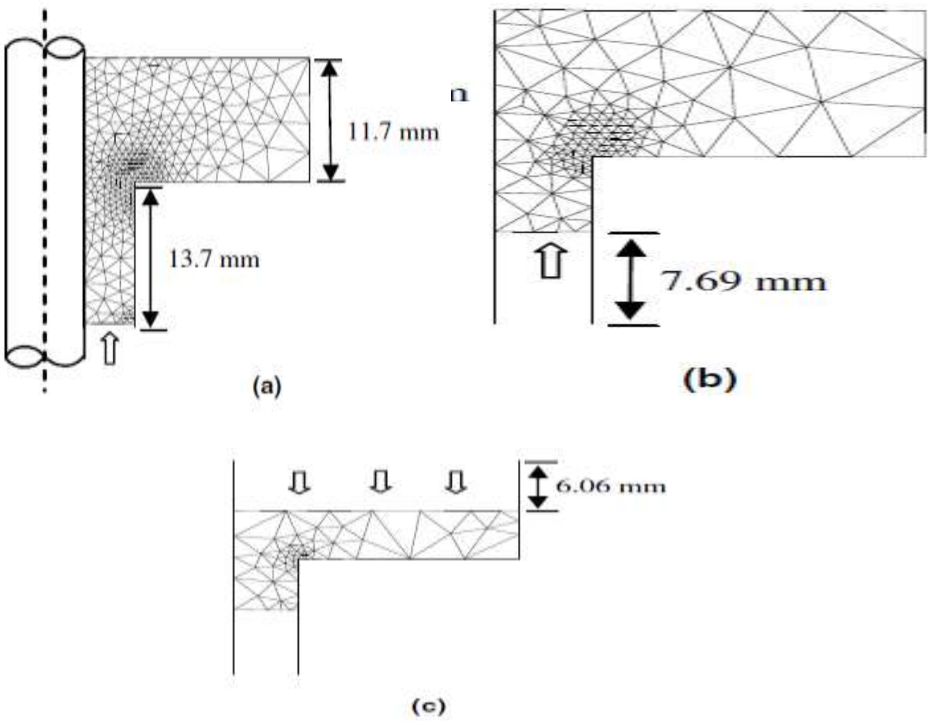


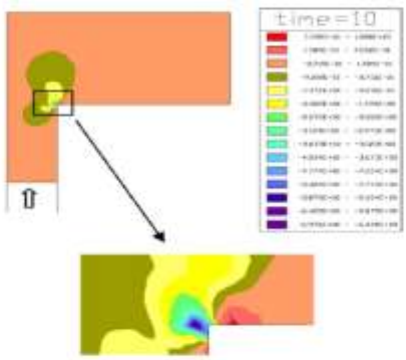
Figure Axisymmetric representation of compaction process with tool path and position during compaction process. (a) Step begins, (b) end of step and (c) end of final step

V. RESULT AND DISCUSSION

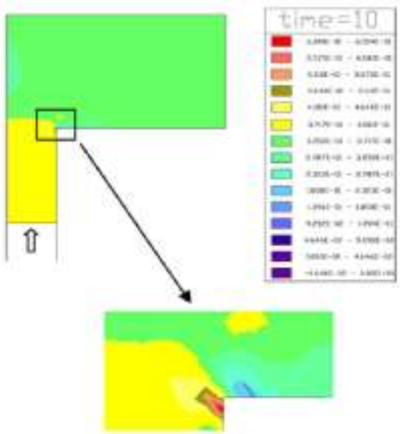
A. Crack initiation

Since no pre-crack is present in this case, the direction of maximum shear stress is used as the original crack direction, in the calculation of KI(h) and KII(h) for the first crack formation. This is acceptable because the same conclusions regarding the crack path are achieved in materials under compression, by assuming that crack grows along the plane of maximum shear stress as by assuming that crack follows the direction of maximum KII. Without pre crack in this work, the point with maximum shear stress is taken as the point where the crack starts.

A single crack propagating inward from the boundary surface is considered in this work. It is found that the point with the maximum shear stress is always generated around the sharp corner. Shear crack starts at the end of compaction step 9, and the shear stress distributions as well as the relative density distributions at step 10 are shown in respectively. These two figures indicate that crack starts in the region with high shear stress but low relative density.



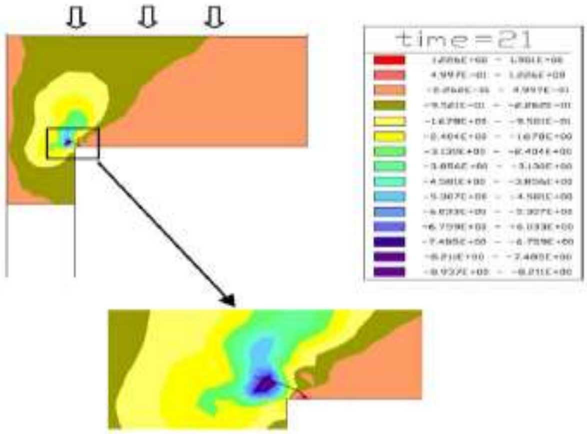
Shear stress distribution



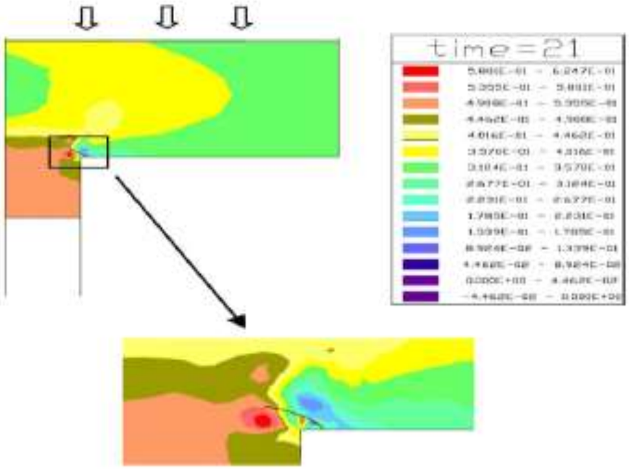
Relative Density distribution

B. Crack propagation

As compaction proceeds, the crack propagates as shear crack at step 17, 18 and 20, where the crack propagation directions, h. No further propagation occurs after step 20, until compaction is completed at step 40. The shear stress distributions and relative density distributions at step 21 are shown in. Due to the small angle of propagation direction, a smooth curve of crack propagation is formed at the inner corner, showing the behaviour of shear crack growth. Neglecting the sign convention that indicates the direction of stresses, it can be seen from that the crack propagates towards the region with higher shear stresses. that the crack also propagates in the direction where the relative density is much higher. Since relative density increases as compaction pressure increases, it can be deduced that the crack grows in the direction of higher compaction pressure. This is in linewith the conclusion made byarguing that crack grows in the direction of higher confininghydrostatic pressure, which is equivalent to the compaction pressure in this case.



Shear stress distribution



Shear stress distribution

VI. CONCLUSION

- A displacement based finite element model has been developed to simulate the crack initiation and propagation in a rotational flanged component made of iron powder.
- A fracture criterion based on fracture of granular materials in compression has been successfully used to model the crack propagation process.
- Simulation of the crack propagation process in the iron compact shows that shear crack starts in the region with the highest shear stress and the lowest relative density distributions.
- As compaction proceeds, the crack propagates in shear mode in the direction where the shear stress and the relative density are much higher.
- Propagation of the crack towards the region of much higher relative density distribution also implies that the crack grows in the direction of higher compaction pressure, which is in line with the conclusion made by previous researchers on crack growth in materials under compression.
- In addition, simulation of crack growth at inner corner in multi-level component due to high stress concentration and high density gradient around the corner is indeed in line with reported fracture in multi-level component during preparation by previous researchers.
- This useful preliminary assessment on fracture behavior in metal powder during the compaction process can be further developed for prediction of crack growth in multi-level components with more complex geometrical shape and by using more accurate material fracture parameters.

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