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MODELLING OF FRACTURE IN METAL POWDER COMPACTION PROCESS

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Summary. *This paper presents analysis on the prediction of crack initiation and propagation during the cold compaction process of metal powder. Based on the fracture criterion of granular material in compression, a displacement based finite element model with adaptive remeshing technique has been developed to analyse crack growth in iron powder compact. Friction between crack faces is modelled using the six nodes isoparametric interface elements, incorporating a constitutive model of friction based on plasticity. Simulations of the predicted crack growth are presented and discussed in terms of the effects of shear stress and relative density distributions as the compaction proceeds.*

1 INTRODUCTION

Even though the modelling of powder compaction process can now be regarded as well established, numerical simulations on powder compaction which focused on the stress and density distributions is insufficient in order to produce a crack free component since cracks still formed in some green components and cause fracture especially in multi-level components[1,2]. Therefore, prediction of crack growth in metal powder compact during the cold compaction process is needed in order to provide a more useful simulation to produce crack free components, while saving time and cost due to trial and error approach. Based on the cohesive frictional behaviour of metal powder during the compaction process in a closed die, a fracture criterion based on granular material in compression is incorporated in this work. A displacement based finite element procedures has been developed to simulate the powder compaction and fracture process. Mohr-Coulomb yield criterion is used in this work, and FORTRAN programming language is utilised in developing the finite element procedures.

2 FRACTURE CRITERIA

Extensive literature review on fracture in materials under compression reveals that experimental and numerical simulation results on crack growth in brittle, ductile and granular materials under compression indicate the same trend of crack propagation. Generally, crack can grows in three different manners: under low pressure, crack grows via incipient kink by opening mode, at an angle from the original crack plane. Under increasing pressure, crack grows as a combination of open (mode I) and shear (mode II) crack, while under substantially high pressure, crack grows as a shear (mode II) crack, straight ahead or at a small angle from the original crack plane. However, mode II fracture is more likely to occur in granular materials due to their cohesive frictional behaviour during compression[4] as in metal powder during the compaction process. Hence, a fracture criterion based on granular materials in compression[4] is incorporated in this work, which covers the possibilities of the occurrence of both mode I and mode II crack. This criterion stated that for mode I and mode II respectively to occur:

$$1 < \frac{K_{II\max}}{K_{I\max}} < \frac{K_{IIC}}{K_{IC}}, \quad K_{I\max} = K_{IC} \quad at \quad \theta_{IC} \tag{1}$$

$$\frac{K_{II\max}}{K_{I\max}} > \frac{K_{IIC}}{K_{IC}}, \quad K_{II\max} = K_{IIC} \quad at \quad \theta_{IIC} \tag{2}$$

where $K_{I\ max}$ and $K_{II\ max}$ are the maximum stress intensity factors of mode I and mode II respectively, while K_{IC} and K_{IIC} are the critical stress intensity factors of mode I and mode II.

3 FINITE ELEMENT MODELLING

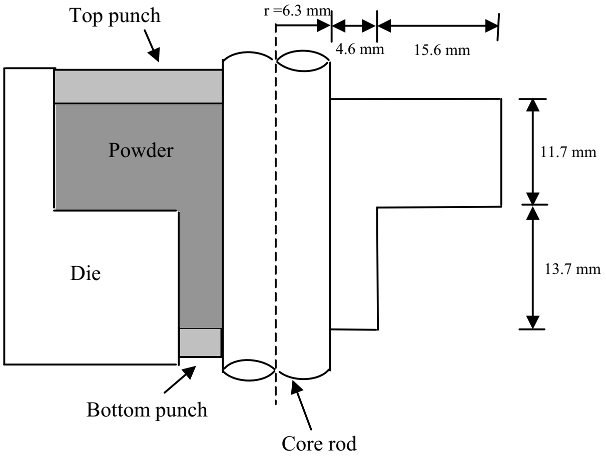

Figure 1: Initial geometry and boundary conditions of a rotational flanged component

In modelling the compaction process, the macro-mechanical modelling approach with constitutive model based on granular materials[3] is used in this work, where the powder medium is considered as a continuum that undergoes large elastic-plastic deformation. An adaptive finite element mesh[5] is applied to accommodate large displacement changes in geometry of the domain during the compaction and fracture process. Hence crack initiation and propagation have been inserted automatically in the model, without having to predefine the direction of crack. Crack is modelled to propagate inter-element in the mesh, while the node release mechanism[6] is used to provide two adjacent crack faces when the criteria is fulfilled. Constitutive model of friction based on analogy with plasticity[3] is incorporated into the six nodes isoparametric interface elements in modelling the friction between the powder material and the die wall during the compaction process, as well as friction on the crack faces in contact.

A multi-level component, in this case a rotational flanged component with initial geometry and boundary conditions as shown in Figure 1 is considered in this work. Iron powder with material properties as listed in Tran et al.[7] is compacted by the top and bottom punch movements. A total displacement of d_b=7.69 mm is first achieved when the bottom punch moves upward in 20 steps movement (step 1 to 20), followed by a total displacement of d_t=6.06 mm by the downward movement of the top punch in another 20 steps movement (step 21 to 40).

4 RESULTS AND DISCUSSION

Referring to Table 1, simulation shows that crack starts at the end of step 9, and propagates at steps 17, 18 and 20. Crack propagation direction is measured from the original or previous crack plane, where θ^{O} is defined as positive in the anticlockwise direction. No further crack propagation occurs after step 20, until compaction is completed at step 40. Referring to the fracture criterion used in this work, results of the simulation indicate that shear crack (mode II) propagates in the compact during the compaction process. Analysis on the shear stress and relative density distributions within the compact shows that crack starts at the inner corner of the component, in the region of high shear stress but low relative density distributions.

Compaction Step	Crack propagation from original crack direction, θ^{o}
9	0 (Crack starts)
17	+22.7883
18	+5.34889
20	+13.74237

Table 1: Crack propagation direction

As compaction proceeds, crack propagates towards the region of high shear stress as shown in figure 2(a). Due to the movement of the bottom punch in the first 20 steps, high density gradient is formed around the inner corner, causes the crack to propagate towards the region of high relative density as illustrated in figure 2(b). This is in line with reported fracture in multi-level component during preparation, expected to be caused by high stress concentration and high density gradient at inner corner[1,2].

5 CONCLUSIONS

- A displacement based finite element model has been developed incorporating a fracture criterion based on granular materials in compression to simulate the fracture process in iron compact during the cold compaction process, which shows that fracture results from shear crack growth in the compact.

- Crack propagation in a multi level component has been successfully simulated compared to prediction of fracture by previous researchers, which is only based on stress and density distributions within the compact.

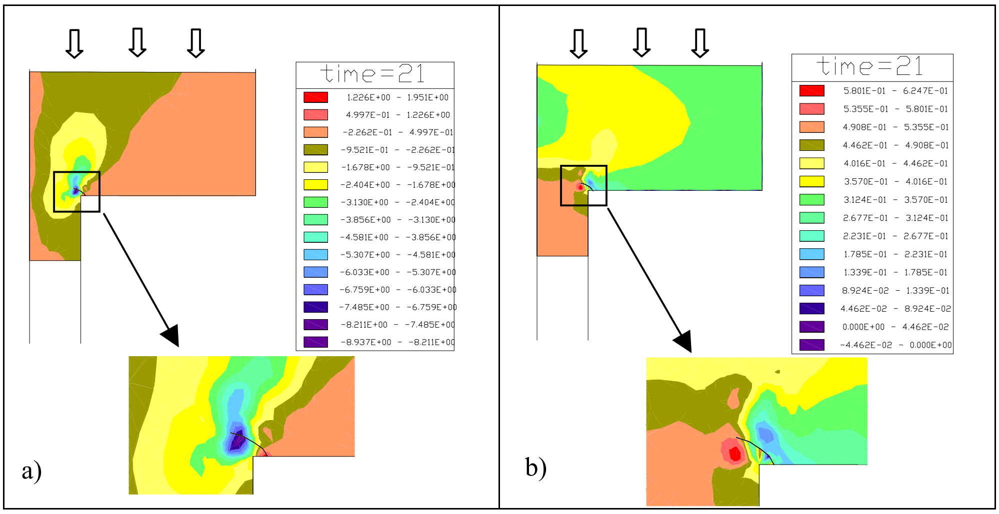

Figure 2: (a) Shear stress distribution at step 21
(b) Relative density distribution at step 21

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