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Die compaction of copper powder designed for material parameter identification

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Abstract

This article presents uniaxial compaction experiments of a fine copper powder in a cylindrical die. The compaction process consists of monotonic loading and of loading paths with inserted unloading and reloading cycles. An experimental setup that has been developed for determining the axial and radial stresses during the compaction is described and the calibration of the new device using highly accurate p-finite element simulations of the dies response to internal pressure is shown. The experimental results were subsequently used for the identification of the material parameters of a constitutive model for granular materials recently proposed by Bier and Hartmann [A finite strain constitutive model for metal powder compaction using a unique and convex single surface yield function. accepted for publication by European Journal of Mechanics, Series A/Solids 2006.]. The identification of the elasticity parameters was treated with special attention.

Keywords: Metal powder; Die compaction; Material parameter identification; Elastoplasticity

1. Introduction

One objective in powder compaction technology is concerned with a realistic prediction of the stress and density distribution in a compaction process. In order to achieve this goal, several tasks have to be completed. These include the design of well-defined experiments, the development of a constitutive model, the identification of the material parameters and the numerical treatment of complicated boundary value problems (for example, by finite elements). The mathematical modeling of such compaction processes requires the development of experimental devices that provide maximum information and ensure fully defined process conditions in order that the stress and deformation state inside a specimen be known.

One of the major difficulties is the determination of the radial stress in the powder specimen inside the die. The determination of the radial stress on the basis of strain–gauge measurements of the circumferential strains has been described in Carnavas [1] and Geindreau et al. [2]. These authors made use of hoop strains of the outer die surface in order to estimate the radial stress inside the die. The determination of the material parameters of new or established constitutive models for powder compaction on the basis of experimental data was considered by several authors [3–6]. Often experimental data from the literature were utilized, e.g. Khoei and Azami [7] used the data of an iron and copper powder mixture published by Doremus et al. [8] for the identification of the material parameters of their new cone–cap plasticity model. Chtourou et al. [9] presented a detailed description of the parameter identification for their own cap model for a steel powder. They derived their material parameters from a variety of tests consisting of resonant frequency measurements, hydrostatic compaction, triaxial compaction and uniaxial compression tests. Such detailed test data is desirable to gain maximum of information about the considered material, unfortunately such a detailed examination is not always realizable.

In the present work a new method for measuring the axial and radial stresses during a die compaction process is

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Nomenclature

A_1	abbreviation used in the yield function, see Eq. (15)
A_2	abbreviation used in the yield function, see Eq. (16)
B_{axial}	initial slope of unloading curve of axial stress σ_{axial} over axial stretch λ
B_{radial}	initial slope of unloading curve of radial stress σ_{radial} over axial stretch
$\mathbf{C}$	right Cauchy–Green tensor
$\mathbf{C}_p$	plastic part of right Cauchy–Green tensor
E	Young's modulus
F	yield function
$\mathbf{F}$	deformation gradient
$\mathbf{F}_e$	elastic part of deformation gradient
$\mathbf{F}_p$	plastic part of deformation gradient
Grad	gradient operator with respect to material coordinates
H	position of radial expansion sensor
I_0	material parameter influencing shape of yield function
I_1	first invariant of the Mandel stress tensor, see Eq. (13)
J_2	second invariant of the Mandel stress tensors deviator, see Eq. (14)
K	compression modulus
L_0	reference length of the setup for correction of axial displacements
$\mathbf{P}$	Mandel stress tensor, $\mathbf{P} = \mathbf{F}_p\tilde{\mathbf{T}}\mathbf{C}\mathbf{F}_p^{-1}$
$\mathbf{T}$	Cauchy stress tensor
$\tilde{\mathbf{T}}$	second Piola–Kirchhoff stress tensor
$\mathbf{X}$	material or reference coordinates
a	measure for the length of yield function along the I_1 axis
a_1	material parameter in relation between ξ and r_k
a_2	material parameter in relation between ξ and r_k
b_d	material parameter in evolution equation of α
c	material parameter influencing shape of yield function
c_d	material parameters in evolution equation of α
c_k	material parameter in relation between ξ and r_k
$\vec{e}_r$, $\vec{e}_\vartheta$, $\vec{e}_z$	basis vectors of cylindrical coordinates
g_1, g_2	simple yield functions, constituents of F
h	current height of powder inside the die
h_0	initial powder height
i	individual number of experiment with inserted unloading cycle
j	individual number of unloading cycle in each experiment
k	abbreviation used in the yield function, see Eq. (15)
n_{exp}	total number of experiments with inserted unloading cycles
n_{up}	total number of unloading cycles in each experiment
q	proportionality factor for the calculation of radial stresses
$q(h)$	dependence of proportionality factor q upon current powder height h
r_k	measure of volumetric plastic strain, see Eq. $(18)_2$
r	material parameter used in the yield function
t	time
u_{axial}	measured axial displacement
u_{axial}^{pow}	axial displacement at the top of the powder
u_{axial}^{sys}	part of measured axial displacement due to compliance of the setup
$\mathbf{x}$	position of material point $\mathbf{X}$ at time t
Δd	radial expansion of the die
Λ	elasticity parameter
$\bar{\Lambda}$	mean value of Λ
α	internal variable of elastoplasticity model
α_0	initial value of internal variable α
γ	plastic multiplier
λ	stretch λ of the powder
λ_0^j	initial stretch λ_0^j of jth unloading
λ_p	axial plastic stretch of powder
λ_{pq}	radial plastic stretch of powder
μ	elasticity parameter
$\bar{\mu}$	mean value of μ
ν	Poisson's ratio
ξ	material function to model hardening, depending on $\mathbf{C}_p$, see Eq. (18)
ρ_{rel}	relative density
$\rho_{rel,0}$	initial relative density
σ_Y	yield strength of punches and die
σ_{axial}	axial Cauchy stresses inside the powder
σ_{radial}	radial Cauchy stresses inside the powder
χ	abbreviation in evolution equation of α, see Eq. (21)
$\boldsymbol{\chi}_R(\mathbf{X}, t)$	mapping of material points into current configuration

proposed. From the simultaneous measurement of axial displacements, axial stress and (indirectly) radial stress of a cylindrical specimen the stress–stretch behavior is determined. In the experimental setup, a Hall effect sensor has been used to measure the radial expansion of the die. This approach allows the simultaneous determination of both the axial displacements as well as the axial and radial stress in real time. The computation of the radial stresses from the measured expansion of the die is based on a finite element calculation of the dies expansion under internal pressure and under isothermal conditions. The data regarding the axial displacements and stresses as well as