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Three method comparison used for calibration of Drucker-Prager Cap constitutive model for ceramic powder compaction

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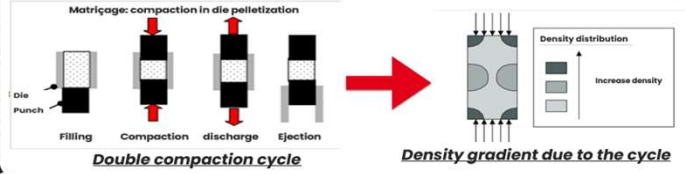
*jean-philippe.bayle@cea.fr



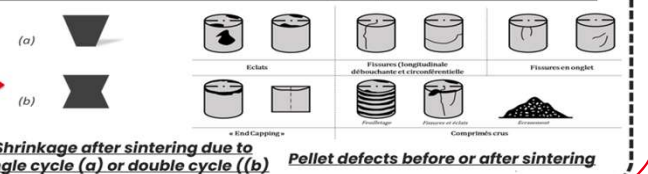
Contents

Manufacturing fuel pellets in nuclear industry is composed of three main steps : Powder grinding, Pressing and Sintering. Powder during uniaxial pressing step is stressed with a lot of stages such filling, compaction, discharge in die and pellet ejection with a springback. Multiple phases occurs in the powder during the compaction stage and the agglomerates inside the powder undergo successively rearrangement, strain and breakage. Ceal/Sec is conducting research to control manufacturing processes in order to minimise defects and rejects in the pellet, and to take into account the history of the powder and its rheology when shaping a pellet, with control of the density card that precedes the final sintering stage. In addition, the characteristics of powders are constantly evolving in order to improve the quality of the product in the reactor for greater efficiency. So, combined with the multi-scale approach, a great deal of research is aimed at characterising the laws of behaviour of powders for the numerical simulation of the fuel manufacture for predicting. In the present work, three methods for calibrating the elastic and porous plastic model of the Drucker Prager cap are tested in order to reduce the amount of powder used. The first method is the reference method and has the disadvantage of using the pellet after ejection to characterise shear failure by means of an axial and radial fracture tests. The second method uses less powder and proposes replacing the fracture test with a shear test, but extrapolation of the cohesion and friction angle is not easy at high consolidation pressure. The third method is a numerical method that uses a minimum amount of powder and enables to show that the accuracy of the model is preserved.

Stress gradient in the pellet due to the internal and contact friction



Crack due to the springback during ejection step or after sintering step



Modelling : Porous elastic-plastic material behaviour

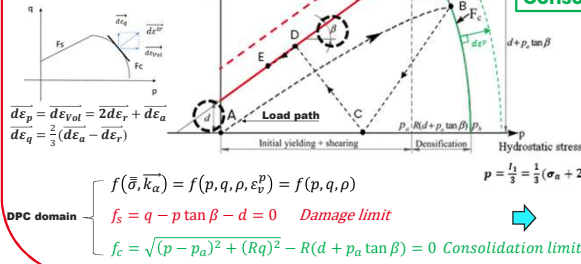
$$q = \sqrt{3} \tau_2 = |\sigma_a - \sigma_r|$$

Drucker-Prager Cap (DPC) load surfaces in (p, q) plan:

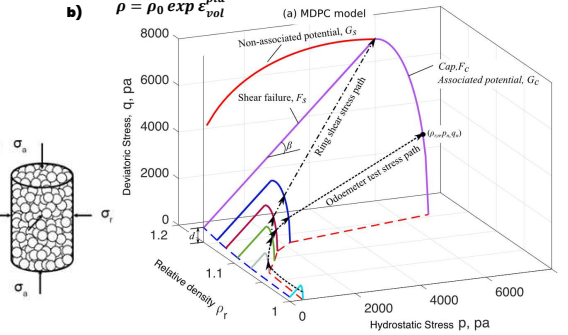
a) For one relative density [7], b) For the evolution of relative density [8]

$$\rho = \rho_0 \exp \frac{\epsilon_p \lambda}{\nu_{vol}}$$

- Consolidation depends on :
- $\epsilon_p \lambda > 0$
 - The direction of the surface normal
 - The plastic factor value



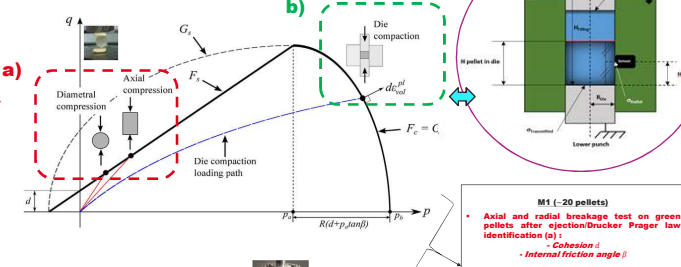
- Parameters to be defined :
- Poro-Elasticity:
 - Log Bulk modulus k
 - Poisson's coefficient ν
 - Tensile Limit
 - Initial void ratio e_0
 - Drucker-Prager:
 - Cohesion d
 - Friction angle β
 - Transition surface radius R
 - Cap Eccentricity
 - Hardening/densification law
 - $P_b = f(\epsilon_p^{\text{pl}})$



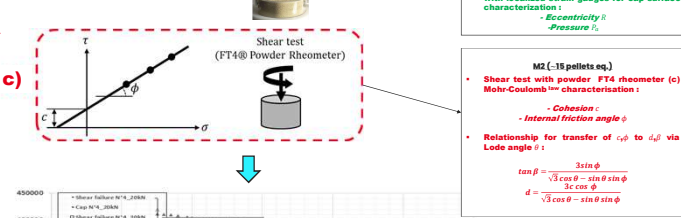
[7] Sinha, T., Curtis, J. S., Hancock, B. C., & Wassgren, C. (2010). A study on the sensitivity of Drucker-Prager Cap model parameters during the decompression phase of powder compaction simulations. Powder Technology, 198(3), 315-324.
 [8] Jin, W., Klingner, A. L., Westover, T. L., & Huang, H. (2020). A density-dependent Drucker-Prager-Cap model for ring shear simulation of ground loblolly pine. Powder technology, 368, 45-58.

Model calibration and partial results

Method 1 (M1) :

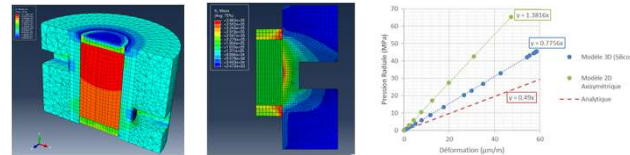


Method 2 (M2) :



Method 3 (M3) :

Medium low strain gauge location for calibration (Silicon):



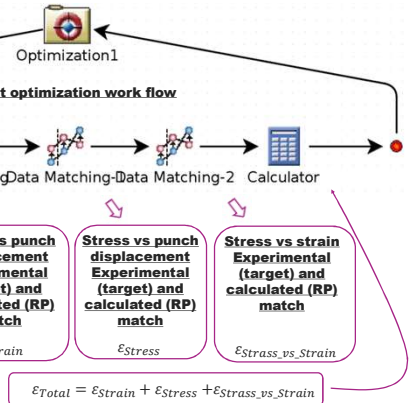
Axisymmetric 2D model/Powder Material/Isight optimisation:

For each parameters, the error is:

$$\epsilon_x = \sum_i (X_i - x_i)^2$$

With
 i = the density level
 X = the experimental value to i point
 x = the calculated value to i point

Law component	Parameters	Symbol	Min value	Max value
Poro-Elasticity	Log bulk modulus	k	0.01	0.03
	Poisson's coefficient ν	ν	0.20	0.25
	Tensile limit	-	0.5	0.3
	Initial void ratio	e_0	0.25	0.45
Drucker-Prager (Cap plasticity)	Cohesion	d	26	2180
	Friction angle	β	10	40
	Eccentricity	R	0.5	1
Cap hardening	P_b	-	-	-
Friction	Friction coefficient μ	μ	0.1	0.3



Conclusion/Outlook

As the conclusion of this study, three calibration methods of the Drucker Prager cap porous elastic and plastic model have been challenged in order to reduce the powder quantity engaged. The third numerical method has a great interest because ten pellets for ten densities are enough with the conservation of the model representativity. The Hooke-Jeeves optimization algorithm was used and other optimization methods are available in the Isight code for the future investigations. The interest of the numerical method is data matching between Abaqus and Isight, and the future goal will be to achieve a meta model or simplify it for press digital twin include in the main numerical manufacturing chain. Furthermore, we plan to use numerical tools like AI associated to the large nuclear material data base.

2D Axisymmetric model

[9] Spaus, B., Bayle, J.-P., Socie A., Helfer T., Bernard-Granger G., Extrapolation du modèle élasto-plastique poreux de Drucker prager Cap à des pressions de consolidation faible et élevée, FPG colloque, Montpellier xx may 2024.
 [10] Ledrappier, F., Moutte, A., Bayle, J.-P., Identification and optimization of the constitutive model for die-formed expanded graphite for sealing applications. In EMMC18 - 18th European Mechanics of Materials Conference, Oxford, United Kingdom, avril 2022.