Modeling of Springback During Ejection of Hardmetal PM Parts Following Compaction

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Abstract

Springback during ejection following compaction of hardmetal PM parts is a significant consideration for the tool and part designer. By modeling the elastic recovery in the constitutive behavior, the springback during the decompression cycle was estimated. A modeling procedure was developed and implemented using a general-purpose non-linear FEM based compaction simulation. Model constants were fine tuned and validated by experimental data. The inputs to such a model are the geometries of compact, tooling, press kinematics, and material parameters. The powder material system was characterized for its densification behavior during compaction. Once developed and validated, such a model can be used as a virtual tool to develop tool and process designs.

Introduction

Sintered carbide inserts are increasingly being made of intricate geometrical shapes. These are made by compaction and sintering. Quality of powder, press, tooling, compaction process, etc. all play an important role in yielding a precision pressed and sintered part. Simulation of this entire process through a model has been an objective of many investigators. However, due to the complexity of such a model, the present work is aimed at developing and validating a model to simulate only the compaction process and resulting springback as the part comes out of the die. Powder compaction is a critical step in this process, especially while fabricating precision parts requiring tight pressed and sintered tolerances with variable shrinkage and without cracks. During compaction, a non-homogeneous density profile is generated in the green compact. Therefore, during ejection, the elastic recovery will be non-uniform as well. These non-uniformities result in an irregular sintering rate and distortion. As a result, the sintered shape has significant deviation from the design, which needs to be corrected by expensive post processing operations, such as grinding. Still other solutions may require repair or re-design of dies, or significant development of the compaction process through trial and error.

Die tooling and the development of the compaction process are both expensive and time consuming. Thus, development of such a model should create value through reduction of tooling cost and help develop better methods to compact complex parts.

Compaction Model

Finite element analysis based process modeling of compaction and ejection has been used to estimate the green density at different pressures in the die, and the extent of elastic recovery or springback on ejection of the part from the die. One of the key issues in development of such model is the material models to be used for the particular grade or hard metal powder. In this work, experimental data from compaction and ejection experiments has been used to estimate the material constitutive model and yield behavior of hardmetal powder. In the formulation developed, the porosity of the powder mass is treated as an evolving internal variable. Although there is theoretical possibility of porosity going to zero (fully dense compact), the current compaction model is developed in the relative density range up to 55% since the intended application is limited only to green parts.

FEM simulation tool ABAQUS is used to model compaction in which the material parameters are incorporated. The parameters that are needed to define these yield surfaces for Cam Clay model are given below.

1. Slope of the critical state line, **M**
2. Logarithmic elastic bulk modulus, **k**
3. Logarithmic plastic bulk modulus, **λ**

The model is based on the yield surface as given by equation 1 and depicted in Figure 1.

$$(\varepsilon/a-1)^2+(\sigma/Ma)^2-1=0 \qquad (1)$$

The slope M of the critical state line helps to define the critical shear surface.
The logarithmic elastic bulk modulus κ defines the elastic behavior of the material The logarithmic plastic bulk modulus λ defines the plastic hardening (densification) behavior of the material or the cap surface. These material parameters are derived from an iterative loop of model runs as shown in Figure 2. For this purpose, powder materials are compacted to different extents to yield different densities of the green compact. Load on the press, geometries after compaction and ejection, are measured. One batch of experimental data is used for generating the material model.

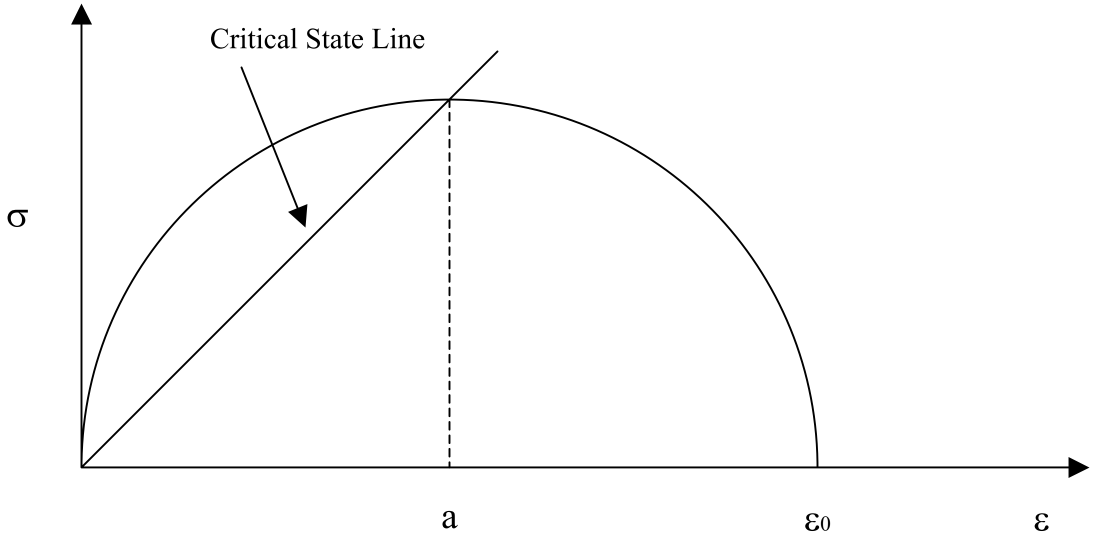


Figure 1: Cam-Clay model depicting the yield surface.

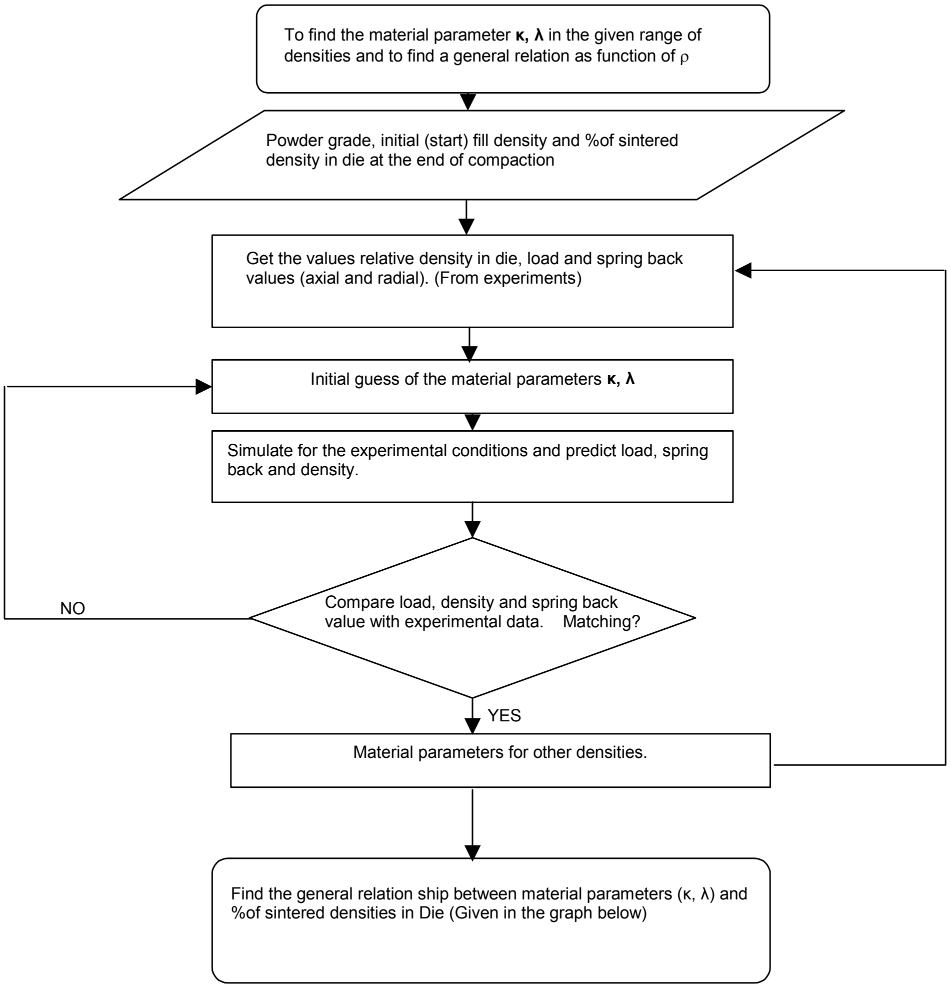


Figure 2: Iterative scheme to estimate material parameters from experimental pressing data.

For a given grade of powder and given cross section, a relation can be developed to correlate the springback (S) with the axial load (L) through eqation 2, where a and b are constants derived from the model

$$S = a + b\,L \tag{2}$$

Material models have been developed for three different grades of powder (1) WC-11.5% Co, (2) WC-10% Co and (3) WC-6% Co.

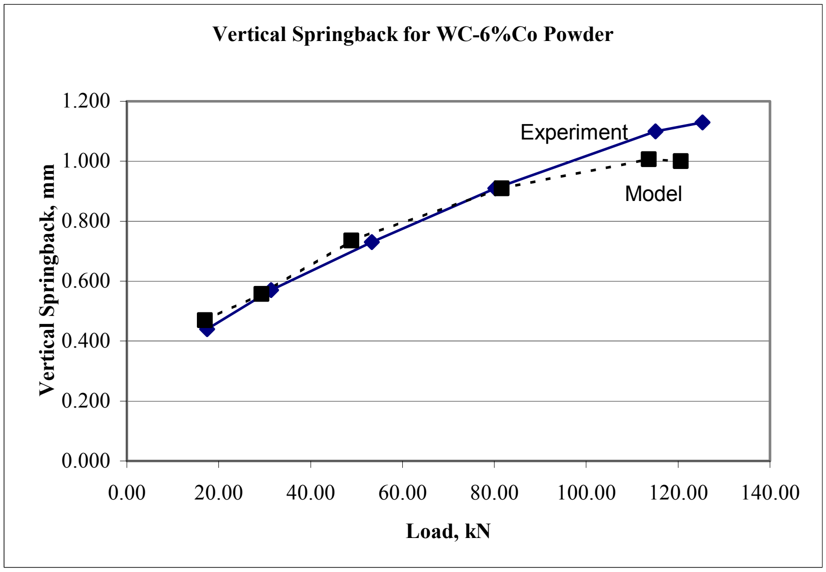
The value of a and b for the three powders used were estimated using the model and are listed in Table 1:

Table 1: Values of constants a and b estimated from the iterative

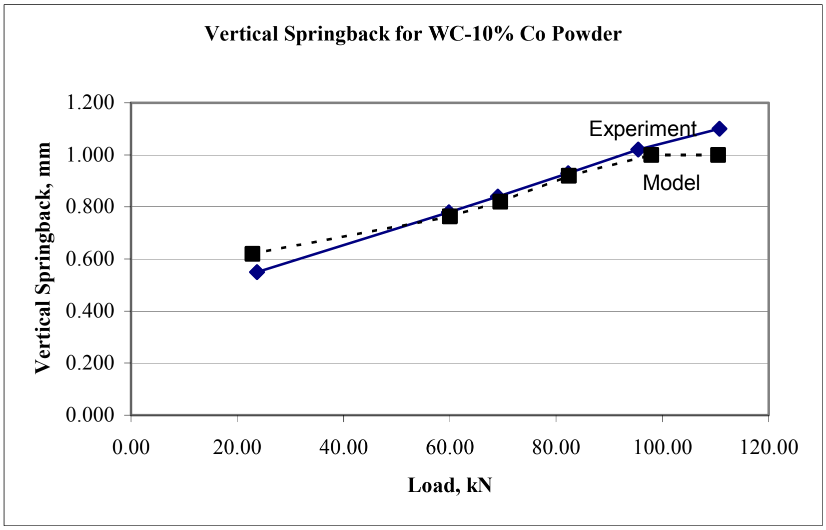
Powder	a	b
WC-6% Co	$3.652\text{x}10^{-1}$	$6.358\text{x}10^{-3}$
WC-10% Co	$3.989\text{x}10^{-1}$	$6.409\text{x}10^{-3}$
WC-11.5% Co	$3.944\text{x}10^{-1}$	$6.223\text{x}10^{-3}$

Model Validation

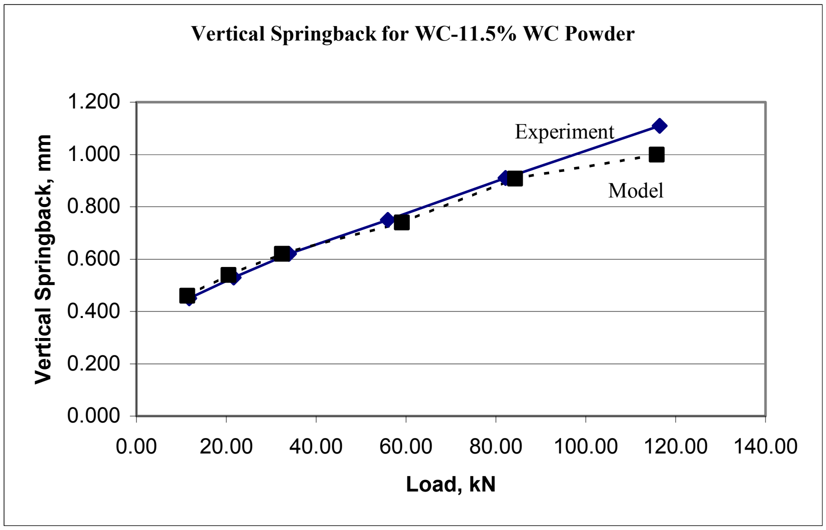
A comparison of experimental and modeled values of vertical sprigback as a function of pressing load for the three powder grades is presented in Figures 3a, 3b and 3c. The model underestimates the vertical springback at high load for all powder grades. Figure 4 shows a comparison between the experiment and the model for the horizontal springback for the 6% Co powder. The model predicts this parameter fairly well at high loads but overestimates it at low loads. However, the absolute values of horizontal springback are smaller than the vertical springback, and the latter is generally of greater interest due to its impact on crack generation in green parts on ejection from the die.



(a)



(b)



(c)

Figure 3: Experimental and modeled vertical springback as a function of pressing load for (a) WC-6% Co, (b) WC-10% Co and (c) WC-11.5% Co powders.

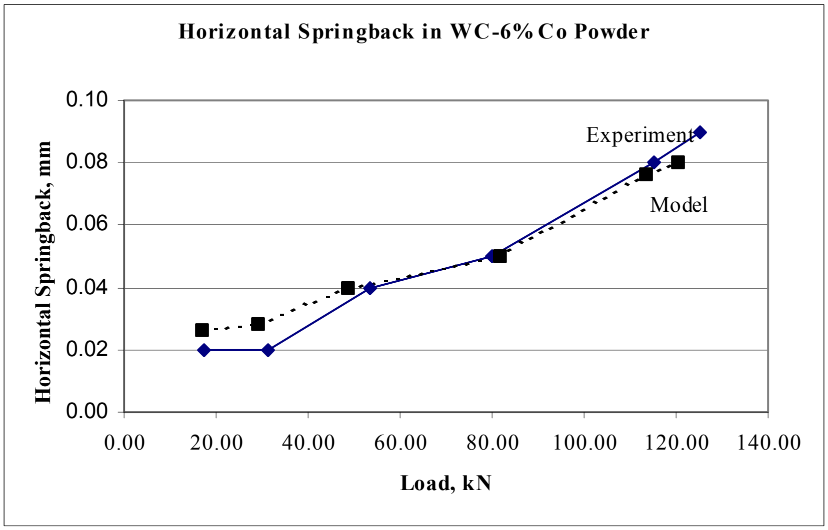


Figure 4: A comparison of experimental and modeled horizontal springback as a function of pressing load for WC-6% Co powder.

Discussion

In order to understand the reasons for poor predictability of vertical springback at high loads, the ability of the model to predict out-of-die green density was evaluated. Figure 5 shows the dependence of out-of-die green density, as a % of theoretical density, on pressing load, and figure 6 shows the relation ship between vertical springback and out-of-die green density for the 6% Co composition. Figure 5 shows that the model overestimates the green density, which could result in an underestimation of vertical springback. Similarly, underestimation of vertical springback in figure 6 by green density could also be due to overestimation of green density as a function of pressing load.

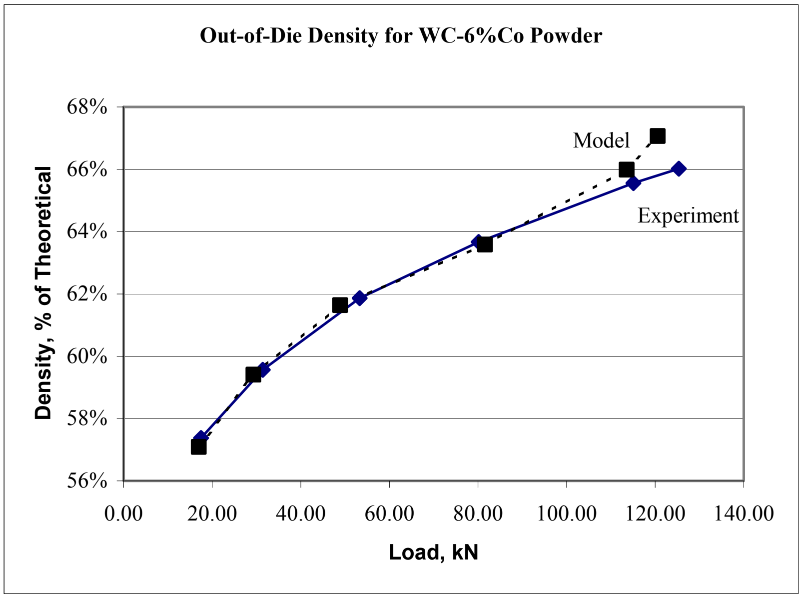


Figure 5: A comparison of experimental and modeled out-of-die green density as a function of pressing load for WC-6% Co powder.

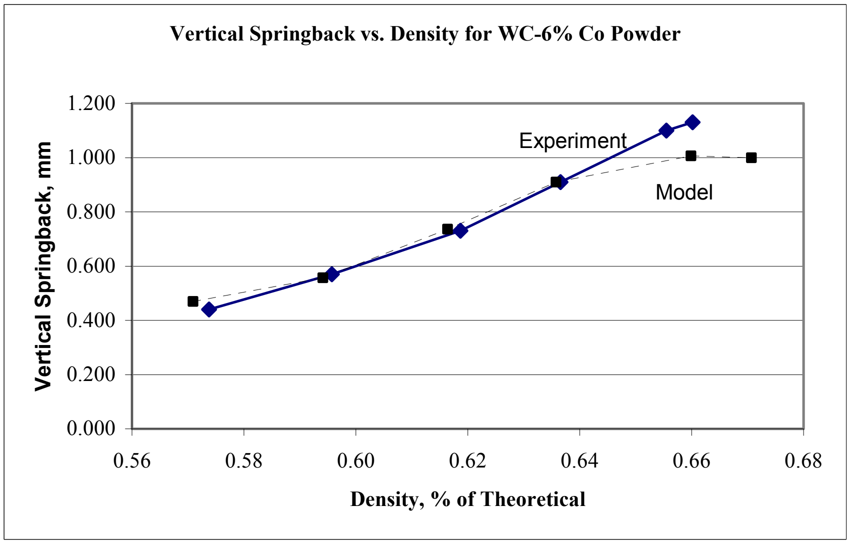


Figure 6: Experimental and modeled vertical springback vs. out-of-die green density for WC-6% Co powder.

Since the poor prediction of vertical springback occurs at high pressing loads, it is also possible that at sufficiently high green densities, yield mechanism, and therefore, the yield criteria is no longer described adequately by equation 1.

Conclusion

A predictive model for springabck of green compacts of WC-Co powders has been developed using a commercially available FEM package. A Cam-Clay model has been used to define the functional yield criteria, and, using experimental data, an iterative method has been used to estimate both elastic and plastic deformation moduli. A comparison of experimental and modeled data shows that the model underestimates vertical springback at high pressing loads, which could be due to an overestimation of green density by the model. Another reason could be a change in the yield criteria at high green densities.

References