APPLICATION OF RKPM IN NUMERICAL SIMULATION OF POWDER FORMING PROCESSES USING CAP PLASTICITY MODEL

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Summary. *In this paper, an application of the Reproducing Kernel Particle Method is presented in numerical simulation of powder forming processes using a cap plasticity model. A double-surface cap plasticity is developed within the framework of large deformation analysis in order to predict the non-uniform relative density distribution during powder die pressing. The RKPM technique is employed in the analysis of 2D compaction simulation. Numerical examples are presented to illustrate the applicability of the algorithm in modelling of powder forming processes.*

1 INTRODUCTION

As yielding of powder material is pressure-sensitive, the yield criterion needs to capture the influence of hydrostatic pressure. Development of constitutive stress-strain models that can provide adequate physical representation of observed mechanical behaviour in such materials is a challenging problem. The most practical yield functions, employed for powders are the critical state, cam–clay and cap models. A double-surface plasticity model based on a combination of a distortion surface, i.e. a Mohr–Coulomb criterion, and hardening cap was employed by Gu et al. [1] and Lewis and Khoei [2] to describe the behavior of powder material in cold compaction processes.

Modelling of solid mechanics problems has been performed using appropriate methods in computational mechanics. During last two decades, considerable effort has been devoted to the development of meshfree or gridfree methods [3]. In these methods, the interpolation functions are established by enforcing certain continuity requirements around a set of points. In addition, if the interpolation methods, such as finite element and finite difference methods, require a mesh or a grid, the distorted mesh can terminate the calculation due to mesh entanglement problems.

In the present paper, an application of a two invariant cap model for granular material is presented. The meshfree algorithms based on the reproducing kernel particle method is employed to the analysis of two-dimensional problems involving powder material. Several numerical examples are solved to demonstrate the applicability of the RKPM algorithm in modelling of metal forming processes.

2 REPRODUCING KERNEL PARTICLE METHOD

One of the original approaches in meshfree methods is the SPH technique. A rationale for this method is provided by invoking the notion of a kernel approximation for $f(x)$ on domain Ω by the following equation:

$$f^R(x) = \int_\Omega \varphi_a(x-s) f(s) ds \tag{1}$$

where $f^R(x)$ is the approximation, Ω is the domain of interest, and $\varphi_a(x-s)$ is a kernel function. $f^R(x)$ depends only on the values of f at nodes which are in the subdomain for which $\varphi_a(x-s)$ is nonzero. The domain over which $\varphi_a(x-s)$ is nonzero has been called the support of the kernel function and a is the dilation parameter that determines its size. The discretization of the kernel estimate in SPH assures neither zeroth nor first order consistency in a finite domain, unless the lumped volume is carefully selected, which is a very difficult task with irregular boundaries and arbitrary particle distributions.

The basic idea of the RKPM is to formulate the discrete consistency that is lacking in SPH. It modifies the kernel by introducing a correction function (C) to enhance its accuracy near, or on the boundary of the problem domain. Due to this correction function, the RKPM kernel function obtains the consistency conditions throughout the domain of the problem [4]. The reproduced kernel estimate of a function $f(x)$ can be written as:

$$f^R(x) = \int_\Omega C(x, x-s) \varphi_a(x-s) f(s) ds \tag{2}$$

3 CAP PLASTICITY MODEL

A two-invariant cap model developed by Hofstetter et. al.[5] formulated within a framework of associative multi-surface plasticity theory is employed as the constitutive model. This cap constitutive model that serves as an example for nonsmooth cap plasticity, is defined by a convex yield surface consisting of a failure envelop, an elliptical cap which closes the open space between the failure surface and the hydrostatic axis and can expand in the stress space according to a specified hardening rule, and a tension cutoff surface; as shown in Figure 1. The functional forms for the three sufaces are as follows:

$$f_1 = \sqrt{J_{2D}} - \theta J_1 + \gamma e^{-\beta J_1} - \alpha = 0 \tag{3}$$

$$f_2 = R^2 J_{2D} + (J_1 - L)^2 - R^2 b^2 = 0 \tag{4}$$

$$f_3 = J_1 - T = 0 \tag{5}$$

where J_1 and J_{2D} are the first invariant of stress and second invariant of deviatoric stress, respectively. α, β, γ and θ are the parameters of fixed yield surface f_1.

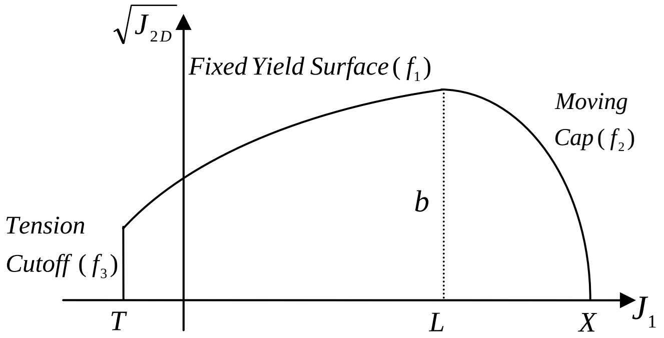


Figure 1: The cap plasticity model

4 NUMERICAL RESULTS

In order to illustrate the efficiency and accuracy of the material model and numerical schemes, the compaction process of a rotational flanged component is simulated, as presented in Figure 2. The model parameters for iron powder are listed in Table 1. The FEM and RKPM models and associated boundary conditions for this component are shown in Figure 3. The compaction is employed by means of the action of top and bottom punches. The relative density contours at the half and final stages of compaction are presented in Figure 4.

Moving cap surface	**Fixed yield surface**	**Tension cutoff**
$R = 1.75$	$\alpha = 255.0MPa$	$T = -0.3MPa$
$D = 0.005MPa^{-1}$	$\beta = 0.002MPa^{-1}$	
$W = 0.34$	$\gamma = 200.0MPa$	
$Z = 1.0MPa$	$\theta = 0.008$	

Table 1 : Material model parameters for iron powder

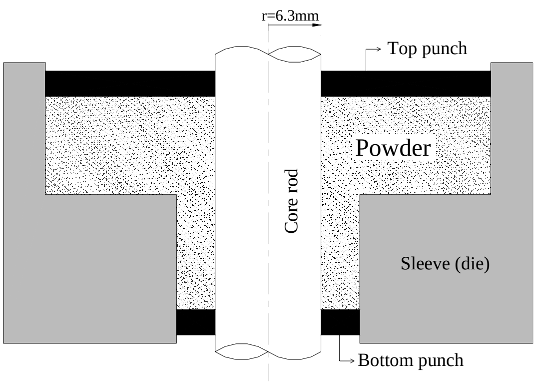


Figure 2: Rotational flanged component

The results show that the proposed method with linear basis functions provided higher solution accuracy than the classical bilinear finite element method. Although good accuracy was obtained here, the high computational cost and the use of integration cells for Gauss integration presented the major bottlenecks in applying the meshfree method.

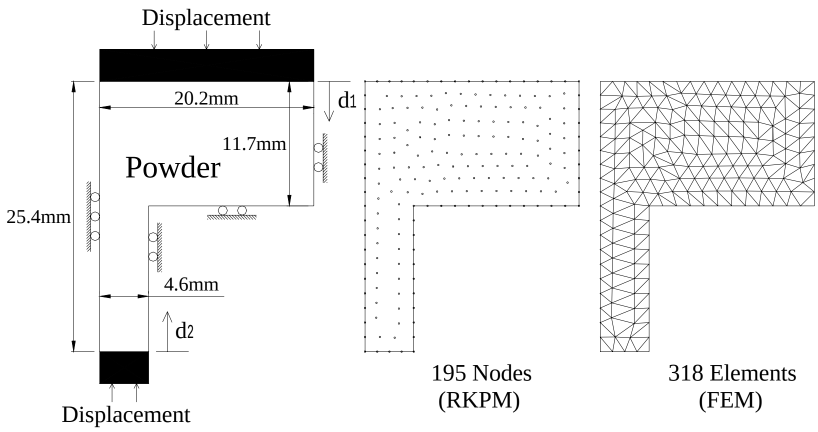
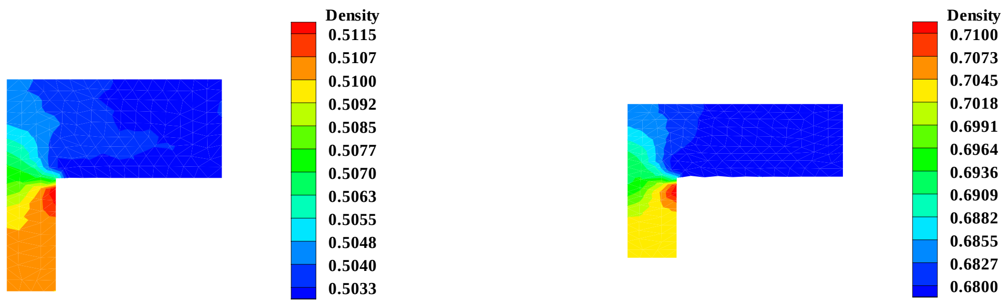


Figure 3: Rotational flanged component; Geometry, boundary conditions and the FEM and RKPM models



a) $d_1 = 2.4mm \quad , \quad d_2 = 3.0mm$ b) $d_1 = 4.8mm \quad , \quad d_2 = 6.0mm$

Figure 4: Relative density contours at the half and final stages of powder compaction

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