

# MATERIAL PARAMETERS FOR A NUMERICAL SIMULATION OF A COMPACTION PROCESS FOR SINTERED DOUBLE-HEIGHT GEARS

## MATERIALNI PARAMETRI ZA NUMERIČNO SIMULACIJO POSTOPKA STISKANJA SINTRANIH DVOVIŠINSKIH ZOBNIKOV

**Tomaž Verlak<sup>1</sup>, Marko Šori<sup>2</sup>, Srečko Glodež<sup>1</sup>**

<sup>1</sup>University of Maribor, Faculty for Mechanical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia  
<sup>2</sup>University of Maribor, Faculty of Natural Sciences and Mathematics, Koroška cesta 160, 2000 Maribor, Slovenia  
tomaz.verlak@gmail.com

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This paper presents the initial material parameters for the Ecka Alumix 231 aluminum-powdered metal required for a successful numerical simulation of a compaction process for sintered components with a proper software package. Experimental work was used to obtain Drucker-Prager-cap (DPC) model material parameters with the help of a Brazilian disc test and a uniaxial compression test for the linear part of the DPC model in the equivalent pressure stress/deviatoric stress (p-q) plane. The specimens used for this test were cylindrical probes (greens) that were compacted with a mechanical press and then compressed to the failure point in the axial and radial directions.

Keywords: aluminum-based powder, compaction process, Drucker-Prager cap model, numerical simulation, Ecka Alumix 231

V članku so predstavljeni začetni materialni parametri za aluminijev prah Ecka Alumix 231, ki so potrebni za uspešno izvedbo numerične simulacije stiskanja sintranih komponent s primerno programsko opremo. S porušitvenimi preizkusi in pridobljenimi eksperimentalnimi rezultati je bilo mogoče določiti potrebne parametre materiala z Drucker-Prager-jevim cap (DPC) modelom, ki določajo linearno območje DPC modela v grafu ekvivalentne tlačne obremenitve v odvisnosti od deviatorične obremenitve. Uporabljeni so bili cilindrični preizkušanci (zelenci), ki so bili stisnjeni z mehansko stiskalnico in kasneje obremenjeni do porušitve v osni in radialni smeri.

Ključne besede: aluminijev prah, stiskanje, Drucker-Prager-jev cap model, numerična simulacija, Ecka Alumix 231

## 1 INTRODUCTION

Sintering is a densification process of powder compacts based on the atomic diffusion of powder components. These mechanical compacts (products), especially gears (**Figure 1**), are widely used in numerous fields of mechanical engineering because they can be made into near-net-shaped objects with minimum or no machining after the sintering. The equipment for sintering is quite expensive and, for that reason, the sintering process required for manufacturing different, small, complex components is economical for larger production series.

The process of sintering can be divided into multiple steps, of which one of the most important is the compaction process. When a powder is being compacted with mechanically or hydraulically operated presses, the density distribution is changing.

The density magnitude and the density distribution within a component have large impacts on the mechanical properties of finished product<sup>1,2</sup> so it is crucial that the achieved density after the compaction process is as close as possible to 100 % of the theoretical density of the material and that the density distribution is uniform. To achieve a higher density and a uniform density distribution throughout the whole component after the

compaction process, the press operator must have a great deal of experience to optimize the compaction parameters (the movement of the press components).

When optimizing compaction parameters based on experience, there is a great chance that damages occur to the press tools. To avoid high costs for repairing damaged tools and spending the time for optimizing the compaction parameters on a press, numerical simulations can be applied to resolve these situations. Using a numerical simulation in ABAQUS with a build-in Drucker-Prager cap model, it is possible to eliminate the trial-and-error process and numerically optimize press-compaction parameters, thus saving time and money.<sup>2</sup> The



**Figure 1:** Double-height gear  
**Slika 1:** Dvovišinski zobnik

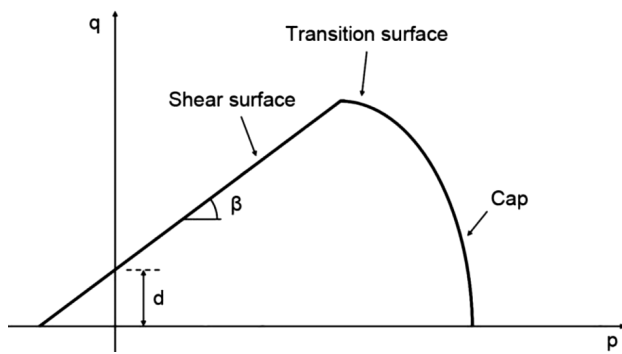


Figure 2: Drucker-Prager-cap-model chart  
Slika 2: Graf Drucker-Pragerjevega cap modela

results of this kind of simulation show the local density distribution over the entire model. By optimizing the movement of the punches in a numerical simulation, the simulation can be restarted again and again with different compaction parameters and this way the results of the final density distributions can be compared. When the results of a numerical simulation are satisfactory, the compaction parameters can be transferred onto the press.

Before a numerical simulation can begin, the material parameters for the chosen metal powder must be known. These parameters are hard to come by or, in some cases, they do not even exist, which is specially the case with most aluminum powders.<sup>3</sup> To obtain the material parameters for a successful simulation, suitable tests must be done. These tests include a Brazilian disc test, a uniaxial compression test and a triaxial compression test. With these tests, it is possible to obtain the parameters that are needed for drawing a Drucker-Prager-cap-model chart and start a numerical simulation. The Drucker-Prager-cap-model chart, shown in Figure 2, is presented with the equivalent pressure stress/deviatoric stress (p-q) plane. It consists of three surfaces.<sup>4,5</sup> The first is the shear surface, the second is the transition surface and the third is the cap surface. This paper focuses on gathering the Drucker-Prager-cap-model parameters for the linear part, presented with the shear surface, and the tests required to

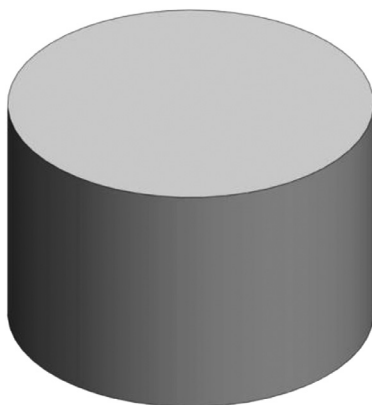


Figure 3: Specimen – a cylindrical disc  
Slika 3: Vzorec – cilindrični plošček

gather proper information include a Brazilian disc test and a uniaxial compression test.

## 2 EXPERIMENTAL WORK

For the experimental work, the Ecka Alumix 231 aluminum powder was used. The basic powder specifications can be found in Table 1 where  $\rho_A$  is the apparent density,  $\rho_G$  is the green density and  $\sigma_{CP}$  is the recommended compaction pressure. The testing can be divided into two parts. The first part involves the preparation of the samples and the second part involves the testing of the samples to the failure point and the reading of the failure-point load. The specimens used in this experimental work were cylindrical discs (Figure 3) prepared with a DORST TPA 45 mechanical press (Figure 4) that is capable of a compaction force of 440 kN. A total of 24 samples were prepared. Each compacted specimen was measured and the values are presented in Table 2 where  $D$  is the diameter of a specimen,  $L$  is the height of a specimen,  $m$  is the mass and  $\rho_G$  is the green density of a specimen.

Table 1: Basic properties of aluminum powder Ecka Alumix 231  
Tabela 1: Osnovne lastnosti aluminijevega prahu Ecka Alumix 231

Physical characteristics			Chemical compositions, w/%		
$\rho_A/(g/cm^3)$	$\rho_G/(g/cm^3)$	$\sigma_{CP}/MPa$	Si	Cu	Mg
1.05 – 1.25	2.56	620	14–16	2.4–2.8	0.5–0.8

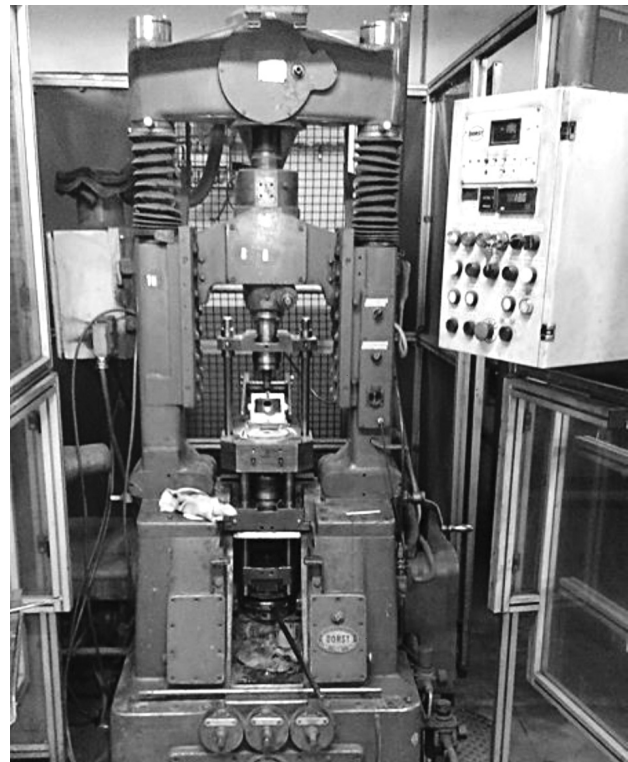


Figure 4: Dorst TPA 45 mechanical press  
Slika 4: Mehanska stiskalnica Dorst TPA 45

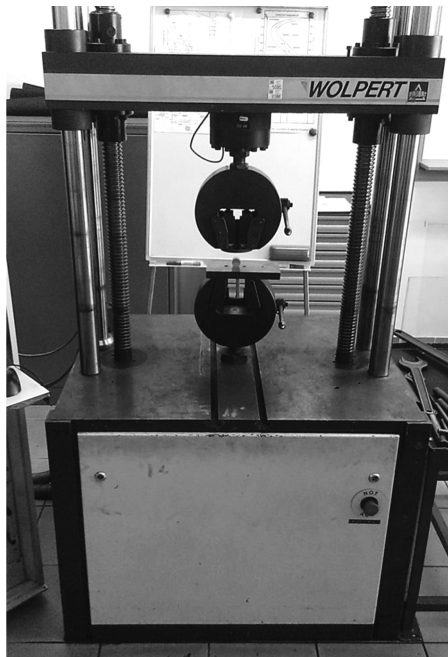


Figure 5: Wolpert TZZ 100 material-testing machine  
Slika 5: Stroj za preizkušanje materialov Wolpert TZZ 100

Table 2: Average numerical values of specimens  
Tabela 2: Povprečne numerične vrednosti vzorcev

Specimens	D/mm	L/mm	m/g	$\rho_G/(g/cm^3)$
1–6	24.15	16.19	18.73	2.53
7–12	24.15	16.21	18.79	2.53
13–18	24.14	16.27	17.28	2.32
19–24	24.15	16.28	17.30	2.32

For the second part of the experimental work, specimens were tested to the failure point with a WOLPERT TZZ 100 material-testing machine (Figure 5) that is capable of measuring compression and tension forces of up to 100 kN. The specimens were placed between two metal plates and then tested.<sup>6</sup> 12 cylindrical discs were

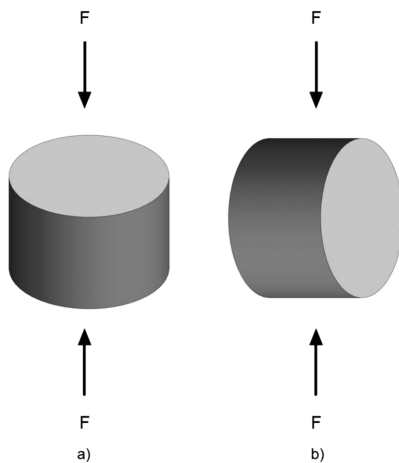


Figure 6: a) Axial and b) radial load directions  
Slika 6: a) Osna in b) radialna obremenitev

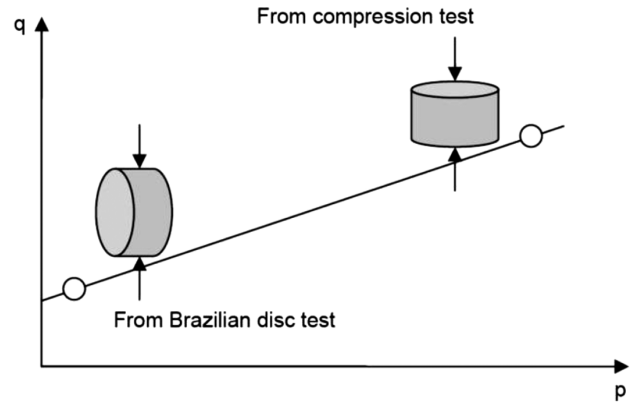


Figure 7: Linear part of the Drucker-Prager-cap model  
Slika 7: Linearni del Drucker-Pragerjevega cap modela

tested to the failure point in the axial direction (Figure 6a) using a testing speed of 5 mm/min and another 12 in the radial direction (Figure 6b) using a testing speed of 2.5 mm/min.

### 3 RESULTS AND DISCUSSION

In order to obtain the linear part of the Drucker-Prager-cap model (Figure 7) parameters  $p$  and  $q$  for the compression test and Brazilian disc test must be calculated from the gathered data, where  $p$  is the hydrostatic-pressure stress and  $q$  is the deviatoric stress. For the compression test, parameter  $p$  can be calculated using Equation (1) and parameter  $q$  is calculated using Equation (2). For the Brazilian disc test, parameter  $p$  can be calculated using Equation (3), and parameter  $q$  is calculated using Equation (4):

$$p = \frac{\sigma_c}{3} \quad (1)$$

$$q = \sigma_c \quad (2)$$

$$p = \frac{2\sigma_t}{3} \quad (3)$$

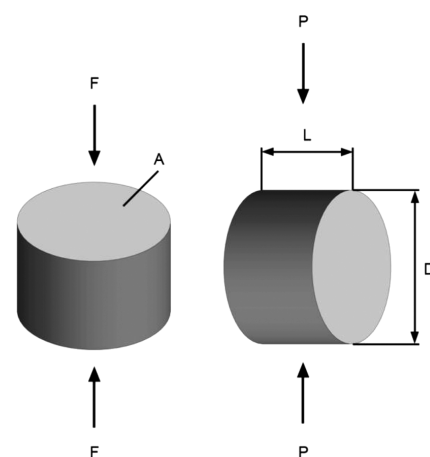


Figure 8: Parameters for calculation  
Slika 8: Parametri za preračun

$$q = \sqrt{13}\sigma_t \quad (4)$$

where  $\sigma_c$  represents the compression strength expressed with Equation (5) and  $\sigma_t$  represents the splitting tensile strength expressed with Equation (6):

$$\sigma_c = \frac{F}{A} \quad (5)$$

$$\sigma_t = \frac{2P}{\pi LD} \quad (6)$$

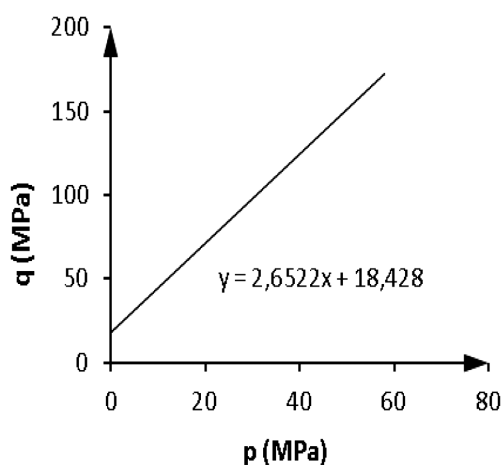
where  $F$  is the maximum load applied during the uniaxial compression test,  $A$  is the surface area of a specimen,  $P$  is the maximum load applied during the Brazilian disc test,  $L$  is the thickness of a specimen and  $D$  is the diameter of a specimen. All the parameters mentioned above are presented in **Figure 8**. **Table 3** presents the average values gathered during the experimental work, where  $F$  is the maximum load applied in the axial direction and  $P$  is the maximum load applied in the radial direction. As expected, the values of the maximum load applied during the Brazilian disc test are smaller because of a greater notch factor and a smaller surface. With the help of Equations (1) to (6) and the added trend line, the linear part of the Drucker-Prager-cap model was plotted and it is presented in **Figure 9**.

**Table 3:** Average values of applied loads

**Tabela 3:** Povprečne vrednosti uporabljene sile

Specimens	Load direction	$F/N$	$P/N$
1–6	axial	77145	/
7–12	radial	/	8405
13–18	axial	64394	/
19–24	radial	/	4275

Using Microsoft Excel and its feature "display equation", the equation for the linear part of the Drucker-Prager-cap model of the Ecka Alumix 231 aluminum-powder metal can be displayed (Equation (7)):



**Figure 9:** Linear part of the Drucker-Prager-cap model for powder Ecka Alumix 231

**Slika 9:** Linearni del Drucker-Prager-jevega cap modela za prah Ecka Alumix 231

$$y = 2.65x + 18.43 \quad (7)$$

In order to successfully complete the numerical simulation in ABAQUS, parameters  $d$  and  $\beta$  must be obtained.<sup>2,7</sup> Parameter  $d$  represents the material cohesion and parameter  $\beta$  represents the angle of friction. Both of these parameters can be obtained from Equation (7). Parameter  $d$  is the point on the p-q plane where the line intersects the y axis (**Figure 2**) and it has a value of 18.43 MPa. Parameter  $\beta$  represents the slope of the linear part (**Figure 2**) and can be calculated using Equation (8):

$$\beta = \tan^{-1} 2.65 \quad (8)$$

Using Equation (8), the angle of friction was calculated, having a value of 69 °.

## 4 CONCLUSIONS

Both the Brazilian disc test and the compression test are very popular testing methods for gathering material data for the linear part of a Drucker-Prager-cap model.<sup>2</sup> They are both inexpensive methods because individual specimens do not have to have exactly the same dimensions and the testing equipment is widely accessible. Dimensions are then taken into account with the use of appropriate equations. Lower-density specimens result in a lower applied failure load due to a lower diffusion of dust particles and a greater notch factor. On the other hand, higher-density specimens result in a higher applied failure load. The present study shows that there is a linear relationship for the specimens with different densities and that the specimens with higher densities are much more resistant to higher loads.

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