The Elastic Behaviour of Metal Powder Compacts

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Abstract

Cylindrical specimens with different levels of density have been submitted to uniaxial compression tests with loading and unloading cycles. The analysis of the elastic loadings shows a non linear elasticity which can be mathematically represented by means of a potential law. Results are explained by assuming that the total elastic strain is the contribution of two terms one deriving from the hertzian deformation of the contacts among particles and another that takes into account the linear elastic deformation of the powder skeleton. A simple model based in an one pore unit cell is presented to support the mathematical model.

Keywords: **Mechanical Behaviour; Elastic Behaviour; Granular Materials; Powder Metallurgy**

1. Introduction

The interest on the elastic behaviour of green compacts is recent and is mainly due to the increasing use of computer simulation of the compacting stage of the PM industrial process. In order to be able to carry out this type of simulation and predict important phenomena like the spring back it is necessary to dispose of the corresponding elastic constitutive equations of the material. The theoretical and experimental results found by Walton (1) and Prado et al. (2) respectively show that the elastic behaviour follows a non-linear behaviour of potential type.

$$\sigma = K\,\varepsilon^{3/2}. \qquad (1)$$

$$E = d\sigma/d\varepsilon = (3/2)\,K\,\varepsilon^{1/2} = (3/2)\,K^{2/3}\,\sigma^{1/3} \qquad (2)$$

However, authors working in continuum mechanics (3) tend to consider the elastic moduli as linear depending only on the part density. .In this work both behaviours are conciliated by means of a elastic model in which both contributions linear and non-linear are taken into account.

2. Experimental and Results

The metal powder used in this work was the DISTALOY AE. The samples tested were cylinders with a 10 mm diameter and a height of 15 mm; they were die compacted to different densities ranging from 5.18 and 7.05 Mg/m^3. Axial strain, ε_{ax}, was measured by monitoring the displacement of the movable crosshead of the testing machine, whereas for the radial strain, ε_r, a diametrical extensometer was used. The volumetric strain, ε_v, has been calculated by using the expression: $\varepsilon_{ax} + 2\,\varepsilon_r = \varepsilon_v$.

Sintering was done at 1050 ^{0}C during 30 minutes .
The type of curves obtained when the applied axial true stress, σ, is represented as a function of ε_{ax} is shown in Fig.1 for the case of a sample compacted to a density of 6.75 Mg/m^3. An important feature of the elastic loading-unloading cycles that can be observed in this figure is the non-linear dependence between the applied true stress and the axial true strain.

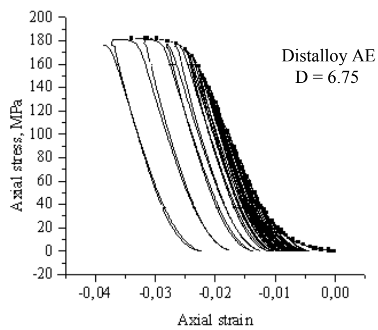

Fig. 1. Axial strain during cyclic compression.

When a double logarithmic representation of the elastic loading curves for the axial elastic deformation is used, a linear relationship between the stress and the elastic strain turns up. A potential expression of the type:

$$\sigma = K_{ax}\,(\varepsilon_{ax}^{el})^{n_{ax}}$$

describe the behaviour found in this work for the elastic part of the loading cycles. In these equations, K and n are two parameters of the material. Results in which a linear elastic behaviour is observed correspond to unloadings from compacting triaxial cells[4]. In this type of test the state of stress is very different from that of the uniaxial compression tests. In the former case higher hydrostatic stresses can be reached while in the latter case the sample breaks before high hydrostatic stresses are reached. In order to be able to carry out uniaxial compression tests up to higher level of applied stresses sintered samples were prepared. Curves obtained are shown in Fig.2.

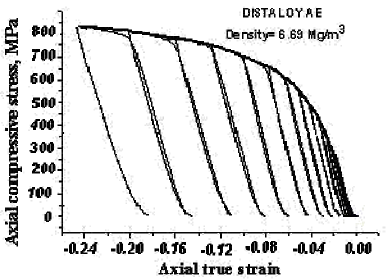

Fig. 2. Axial true strain during cyclic compression.

The relationship between ln σ_{ax} and ln $\varepsilon^{el}_{ax,}$ hold for all the densities studied and follows a behaviour such as that showed in Fig. 3.

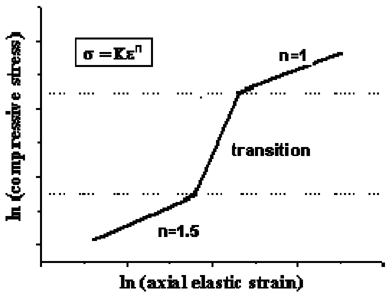

Fig. 3. Scheme of the evolution of the axial strain

During the first stages of the compression test, pore closing dominates the deformation of the material; the contact between the original particles (the necks) increase, and a model of herztian contact [5] among particles would be adequate to describe the elastic behaviour of the material in this stage; a power law ($\sigma = K \{\varepsilon^{el}\}^n$) with an exponent n of about 1.5 is fulfilled by all the experimental results.

In the stage of the highest compressive stresses the pores are more closed and rounded. Contact areas among particles can not increase and the elastic deformation is absorbed by the metal skeleton. Hence, the linear elasticity of the metallic material is now the main mechanism governing the mechanical behaviour; therefore, the part of the curve in Fig.3, which corresponds to high stresses, has a slope of 1. A schematic representation of how the pore geometry can change during loading is shown in Fig.4.

A model that takes into account both behaviours should consider that to the elastic deformation contributes both the

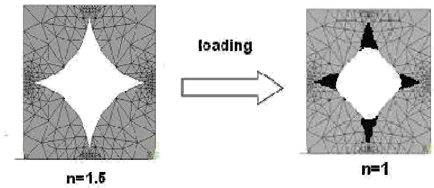

Fig. 4. Variation of the pore geometry during loading

local hertzian deformation of the contacts and also the whole linear elastic deformation of the metallic skeleton. According to this criterion the total elastic deformation, ε_t^e, is the addition of the non-linear and linear contributions.

$\varepsilon_t^e = \varepsilon_n^e + \varepsilon_l^e$. (1)

$\varepsilon_t^e = a\,(\rho,\sigma)\,(\sigma/k\,(\rho))^{2/3} + (1\text{-}a)\,(\sigma/E(\rho))$ (2)

Where a is a parameter that weights the contribution of the non-linear elasticity. It is a function of density and state of stress. At low densities necks among particles are only incipiently developed and great local stresses exist at them, however they remain small in the rest of the material. The elastic behaviour under these circumstances is mainly non-linear. At high densities necks among particles are well developed and stresses are more homogeneously distributed throughout the bulk material favouring linear elasticity. The state of stress also influences the type of elastic behaviour encountered because hydrostatic stresses are more efficient in closing pores than deviatoric ones. Deviatoric stresses change mainly the pore shape. Hence, in close die compaction with a high hydrostatic stress component the elastic behaviour will tend to be predominantly linear from early stages. The character strongly deviatoric of the uniaxial compression tests makes them more adequate to determine the non-linear elastic behaviour.

3. Summary

The amount of porosity and the shape of the pores are responsible for the complex elasticity showed by these materials. During compression uniaxial tests non-linear and linear elastic behaviour has been observed.

4. References

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