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Plastic Behaviour of Green Powder Metallurgical Compacts

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Abstract

The results of monotonic and cyclic uniaxial compression tests, in which the deviatoric component of the stress is predominant, carried out on green and recrystallized iron compacts with different levels of density are presented and discussed in order to analyse the macro and micro-mechanisms governing the mechanical behaviour of non-sintered PM materials. The plastic deformation of the particles, especially at the contact areas between neighbouring grains, produces an internal friction responsible for the main features observed in the behaviour of green metallic compacts.
These results show important discrepancies with the plasticity models, Cam-Clay and Drucker-Prager Cap.

Keywords: mechanical behaviour, plastic behaviour, granular materials, powder metallurgy

1. Introduction

The computer simulation of the processes involved in Powder Metallurgy is in an initial developing stage due to the lack of knowledge of an elasto-plastic model able to explain the mechanical behaviour of the porous sintered components. The lack of mechanical models is even greater when the initial stage of powder die compaction is the one to be simulated. For this reason geological models such as Cam-Clay and Cap [1,2] have initially been used to represent the plastic behaviour of the metal particles inside the die during compaction. The validity of these models, in spite of giving good qualitative results in certain cases, is inevitably limited due to the different nature and, consequently, mechanical behaviour of the geological and metal particles. Most of the experimental results already existing consist mainly in triaxial compression tests [3] because they correspond to isotropic or nearly isotropic stress states giving information on the behaviour of these powders during die compaction. However, very little work can be found in literature on uniaxial compression tests [4] in which the deviatoric component of the stress state is predominant. In this work the behaviour of green metal powder compacts under uniaxial compression tests has been investigated with the aim to contribute to the understanding of their dilatation and failure mechanisms.

2. Experimental Procedure

The compacted material contains a 99.2% of *ASC 100.29* (an atomised, iron powder manufactured by Höganäs) and a 0.8% of Kenolube as an internal lubricant. The bulk density of this mixture is 7.45 Mg/m^3. 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. Monotonic and cyclic uniaxial compression tests were carried out on non-sintered samples. 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: $\varepsilon_{ax} + 2\,\varepsilon_r = \varepsilon_v$.
During the cyclic tests the axial load is increased by a fixed amount (500 N) in each cycle. Compression tests were also carried out on samples recrystallized by thermal treatment at 550 ^{0}C. At this temperature, no sintering occurs but particle ductility is completely restored.

3. Results and Discussion

The cyclic volumetric compression curve for a sample of 6.86 Mg/m^3 (Fig.1) shows that different plastic mechanisms are acting in each stage. Several theories have been proposed to explain the plastic densification taking place in the initial foot of the compression curves, both axial and volumetric, being the most generally accepted theory the one which proposes the closure of internal microcracks developed during the elastic spring-back occurring when the specimen is ejected from the die. Additionally, new contact areas between particles can be formed because the state of stress during die compaction is, mainly in the final part, quite hydrostatic, meanwhile in uniaxial compression a strong shear stress exists. In any case, it can be considered as a stage of accommodation to a new state of stress. In the final stage (region III), irreversible plastic dilatation occurs from the moment in which $2\Delta\varepsilon_r$ becomes greater than $|\Delta\varepsilon_{ax}|$. An important, and to some extent surprising, aspect of the mechanical behaviour of this material during this final stage is that dilatation occurs under increasing applied stress. This behaviour differs from the one observed in other granular materials such as clay and sand in which dilatation takes place under constant stress; this situation is known as the "critical state". The simultaneity between hardening and dilatation can be understood if friction among metal particles is taken into account. In the contact areas between neighbouring grains two forces are acting, a normal and a shear force, over the contact surface; both of them increase when the external applied stress also increases. Dilatation occurs when the localshear stress τ becomes greater than the shear yield limit *mk* of the interface, in which *m* is a parameter, which varies between 0 and 1 depending on the severity of the friction, and *k* is the shear yield limit of the bulk metal. In metal powder compacts, the value of *m*, particularly in specimens of high density, can be sufficiently close to 1 because microwelding, in the contact surface between grains, can take place during compaction. When $\tau > mk$ neighbouring grains can slide along their contact surface and the distance between the centres of the two grains increases, therefore dilatation occurs. The sliding between the two grains under a multiaxial state of stress, normal and shear stresses, can produce an increase of the shear limit, *mk*, of the interface mainly due to a local increase of *k*. Further sliding between grains, and therefore dilatation, can only be continued if a higher external stress is applied. Finally, stage II, corresponding to that part of the compression curve showing little or no volumetric change, is clearly a transition between the compaction occurring in the initial "foot" of the curve and the dilatation taken place in the final stage. Therefore, no characteristic plastic deformation mechanism seems to be acting in this stage.

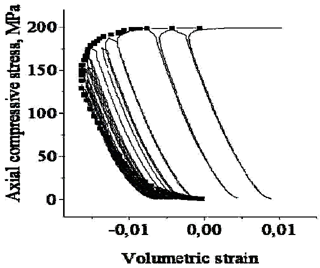

Fig. 1. Axial cyclic strain. Density 6.86Mg/m^3

More information can be derived when comparing this latter uniaxial compression curve with that obtained on similarly compacted samples and having undergone a thermal treatment of static recrystallization at 550 ºC. The volumetric compression curve for a sample with similar density to the one previously studied is shown in Fig.2, the non-recrystallized curves are also included. The three deformation stages already defined exist also in these new curves. The initial plastic "foot" (stage I) is now less marked than in the as compacted sample, what contradicts the theory that this stage is due to the closure of the microcracks developed during the ejection of the sample from the die because they will not disappear by only thermal treatment. This behaviour can be better understood as the effect of local residual stresses in the plastified region below the contact areas between grains.

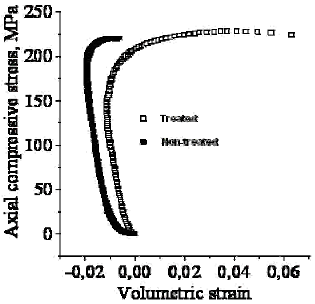

Fig. 2. Axial stress versus volumetric strain for the treated and non-treated samples

The coexistence of mechanical strain hardening and volumetric softening is even more marked than in the non-thermally treated samples. This is the consequence of the decrease in the value of the shear yield limit undergone by the metal powder grains during recrystallization. The consequence of the results obtained in uniaxial compression tests is that the yield locus in metal powder compacts expands even when the sample is undergoing dilatation because the mechanical hardening compensates the geometrical softening. This is not the behaviour observed in geological materials and reflected in plasticity models like Cam-clay and Cap.

4. Conclusions

The curves show three well-marked stages. In stage I plastic compaction takes place under low applied external stresses. Stage II is characterised by a small change in shape with constant volume; while in Stage III sample dilation takes place but needs increasing amounts of applied stress. Internal friction deriving from the plastic deformation of the metal particles, mainly at the contact surfaces between neighbouring grains, explains the characteristic behaviour of these compacts.

5. References

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