EFFECT OF A THERMAL ANNEALING ON THE MECHANICAL BEHAVIOUR OF GREEN PM COMPACTS

M. D. Riera and J. M. Prado

Abstract. Cold die compaction can produce different effects on the dimensional and mechanical behaviour of green PM compacts. They can be due to different causes, such as residual stresses, microcracks and others. Residual stresses should be relieved by means of applying thermal annealing treatments. In this work, the authors present the results obtained from uniaxial compression tests applied on green specimens of an atomised iron based powder, compacted to different densities and having undergone thermal annealings at several temperatures, always below the sintering one. The stress-strain compression curves obtained are compared with those corresponding to as compacted samples. The results seem indicate the existence of residual stresses that could act at different levels: microscopically, in the contact among particles, and macroscopically, in the overall specimen resistance.

1. INTRODUCTION

In Powder Metallurgy the knowledge of the mechanisms governing the deformation behaviour of the material during its processing is in an initial stage due to the lack of an elasto-plastic model that could explain the mechanical behaviour, specially when the initial stage of powder die compaction is the one to be considered. For this reason geological models such as *Cam-clay* and *Cap* [1, 2, 3, 4] have initially been used to represent the plastic behaviour of the metallic particles inside the die during their compaction. The validity of these models are inevitably limited due to the different nature and, consequently, mechanical behaviour of the geological and metallic particles.

Most of the experimental results already existing consist mainly in triaxial compression tests [5, 6] because they correspond to isotropic or nearly isotropic stress states giving information on the behaviour of these powders during the process. However, very little work can be found in literature on uniaxial compression tests [7, 8], in which the deviatoric component of the stress is predominant. Dilatation of the powder compacts followed by the failure of the specimen is the behaviour normally observed in this kind of tests, but some of the micro-mechanisms taken place are not yet well established.

In bulk metals, the mechanical behaviour during uniaxial compression tests is thoroughly described by means of representing the variation of the axial true strain with the applied axial true stress (σ_{ax}-ε_{ax} *curve*). This is not the case with porous materials in which density variations take place during compression; in such situation, at least two curves are necessary, namely the evolution of axial and volumetric true strains with the applied true stress. The monotonic axial and volumetric compression curves obtained by the authors of the present paper by testing iron compacts with several levels of density [8], are presented in Figs. 1 and 2. The specimens were obtained by pressing loose *ASC-100.29*, an atomised iron powder manufactured by *Höganäs* [9].

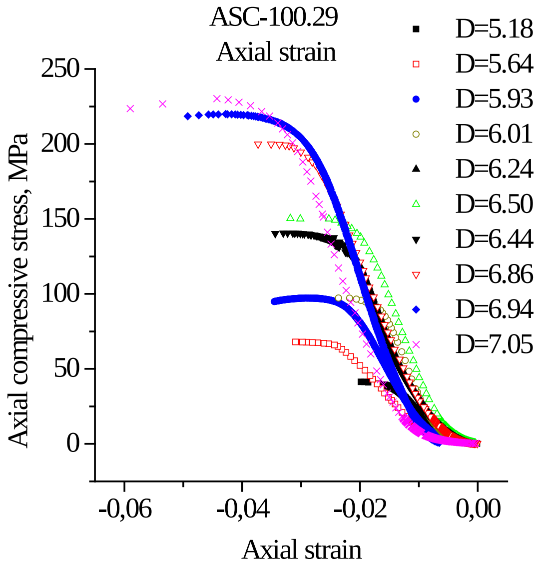


Fig 1.- Evolution of the axial true strain during the compression test. After [8]. The values of density are in Mg/m^3.

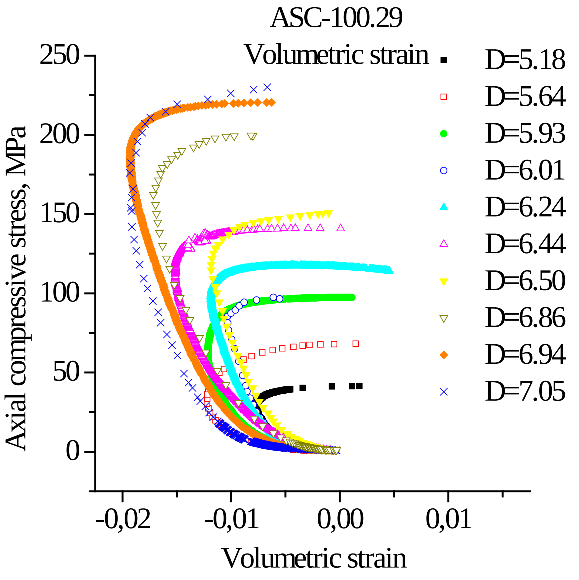


Fig. 2.- Volumetric true strain against the applied axial stress, after [8].

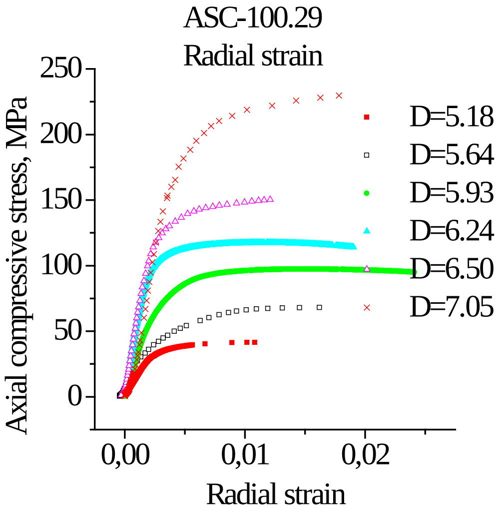


Fig. 3.- Radial true strain against the applied axial stress, after [8].

Both, axial and volumetric curves show an initial *foot* in which appreciable strain occurs under a small increasing applied stress. Another region in which the relationship between strain and stress is rather linear follows this initial stage. In the final part, deformation takes place under a decreasing rate of applied stress. Finally, a saturation stress is reached and the failure of the specimens follows immediately after. During the two initial stages the volume decreases, but in the final one, the volumetric curve show a strong *dilatation*, in spite of the fact that axial curves indicate a continuous decrease in the height of the specimen. This behaviour is understood by looking at the variation of radial strain (Fig. 3) during the loading; the diameter of the specimens increases along the test and in the last stage more than compensates the decrease in height.

The type of deformation occurring in each of these stages has been described by these same authors from the results corresponding to cyclic compression tests [7, 8]. Nevertheless, the *dilatation* phenomenon and the initial plastic part are not yet well known mechanisms.

The present work pretends to be a contribution to the better understanding of the mechanical behaviour of PM compacts. In this case, the interest of the authors has been centred on the mechanisms governing the first plastic stage observed during the compression test.

Several theories have been proposed to explain the plastic densification taking place in the initial *foot* of the compression curves, 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 [6]. Moreover, new contact areas between particles [10] 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.

More information can be derived when comparing the behaviour under uniaxial compression of the as compacted samples with that observed on similarly prepared compacts but having undergone a thermal treatment of static recrystallization.

2. EXPERIMENTAL PROCEDURE

The material used in this work is the *ASC* – 100.29; an atomised iron powder manufactured by *Höganäs,* with 0.002% of carbon. Its apparent density [9] is of 2.96 Mg/m^3. The compacted material contains a 99.2% of this type of powder and a 0.8% of Kenolube as an internal lubricant. The bulk density of this mixture is 7.45 Mg/m^3.

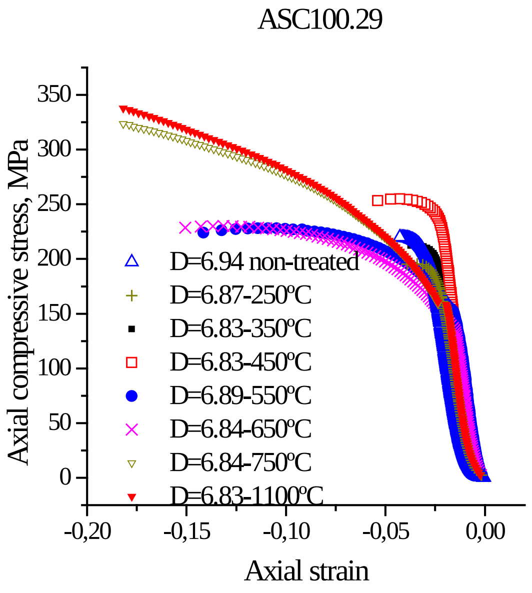
Cylinders with a 100 mm diameter and a height of 15 mm have been compacted to densities ranging from 5.18 and 7.05 Mg/m^3.

After compaction, the samples (except one group of them) have been thermally treated at temperatures from 250ºC to 1100ºC.

All the compacts, thermally treated and as compacted, have been submitted to monotonic uniaxial compression tests by means of using an *INSTRON 4507* device. 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 component of the strain has been calculated with the following expression: $\varepsilon_v = \varepsilon_{ax} + 2\varepsilon_r$.

3. RESULTS AND DISCUSSION

As an example, Fig. 4 shows the results corresponding to the uniaxial compression of samples with an average level of density of 6.85 Mg/m^3 and thermally treated at different temperatures. Fig. 5 presents a detail corresponding to the initial stage of the test. Clearly, the intensity of this *foot* varies with the treatment; the lowest temperatures, however, give only a stress relieve (and the burning off of the lubricant, which can also contribute to change the state of residual stresses). The results for the samples treated at 550ºC show that these compacts have been statically recrystallized. Then, this has been taken in this work as the best condition to analyse the mechanisms governing the behaviour of the compacts.



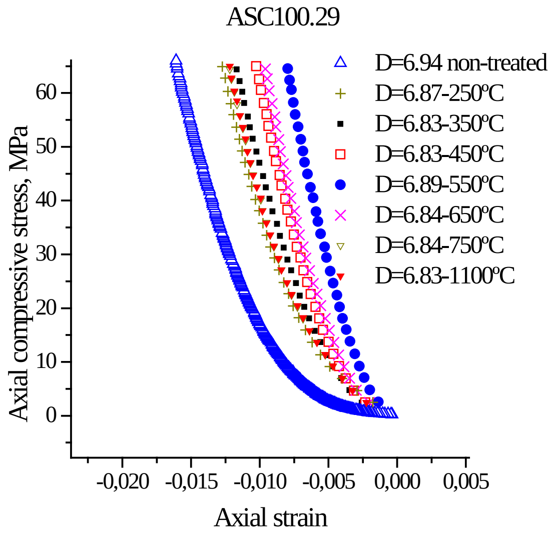
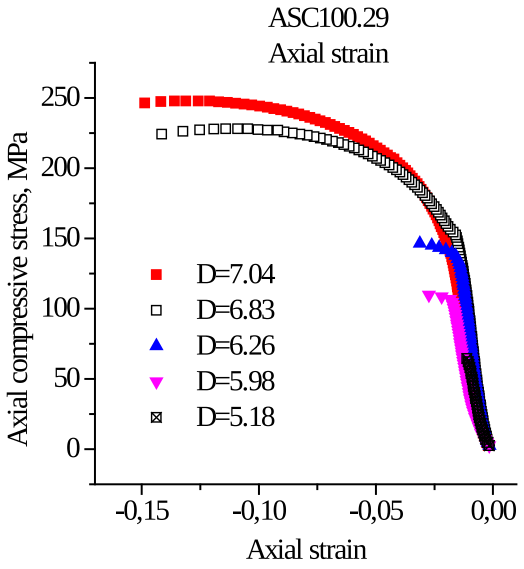


Fig. 4.- Axial true strain – axial true stress relationships of samples treated at different temperatures.

Fig. 5.- Detail corresponding to the initial stage of Fig. 4.

Figs. 6 and 7 present the results, in terms of axial and volumetric true strain, obtained with samples compacted to different densities and treated at 550°C.



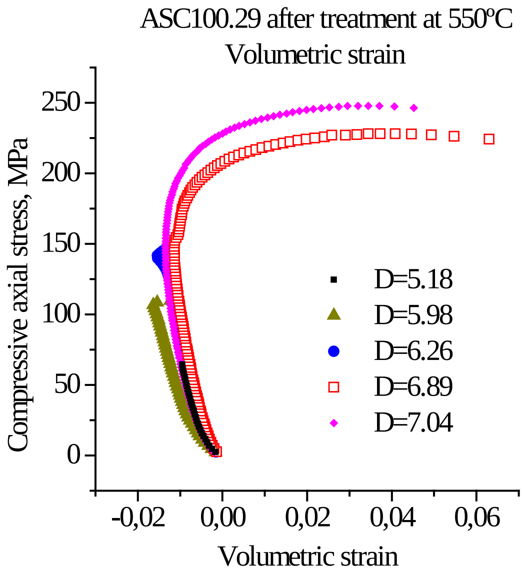


Fig. 6.- Axial true strain vs. axial true stress of samples with different density, thermally treated at 550°C.

Fig. 7.- Volumetric true strain vs. axial true stress of samples with different density, thermally treated at 550°C.

The evolution of the axial and volumetric components of the strain during the compression is similar to that observed in non-treated samples. To facilitate the comparison, in Figs. 8 and 9 the results corresponding to an average density of 6.90 Mg/m^3 are shown including those obtained in as compacted samples.

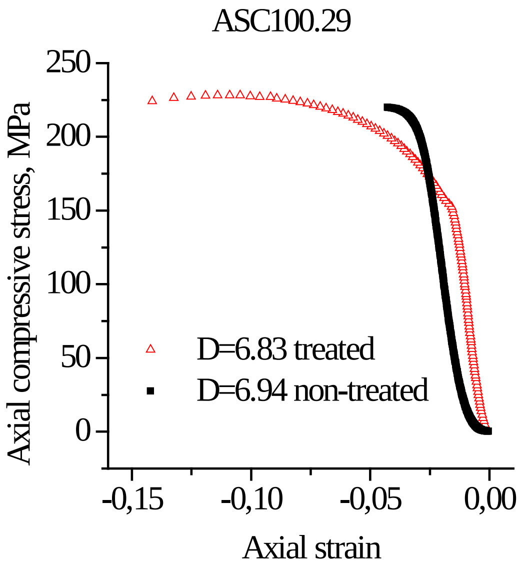


Fig. 8.- Axial true strain before and after heat treatment.

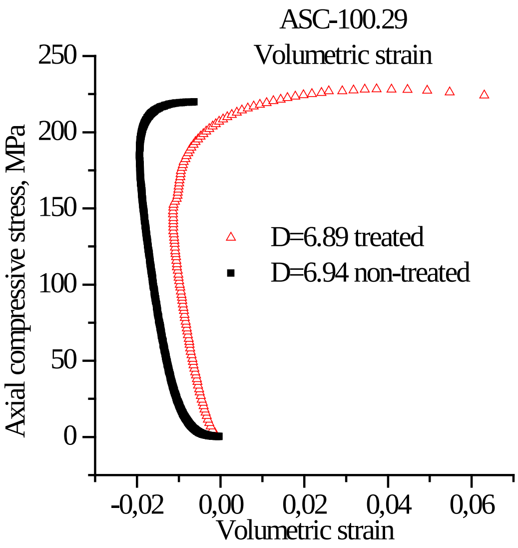


Fig. 9.- Volumetric true strain before and after heat treatment.

Now, the initial plastic *foot* is less marked, what contradicts the theory stating that this stage is due to the closure of microcracks developed during the ejection of the sample from the die because they will not disappear only by thermal treatment.

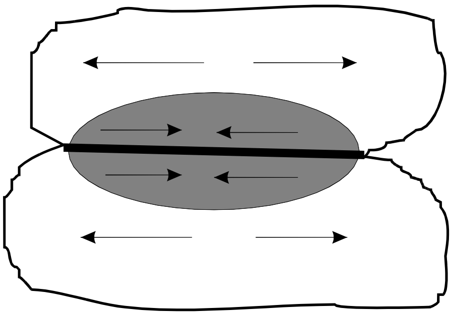


Fig. 10.- State of stresses in the contact area between particles.

This behaviour can be better understood as the effect of local residual stresses in the plastified region below the contact areas between grains. Compression stresses of the type shown in Fig. 10 are developed in these regions because the non-deformed internal part of the grains constrains the plastic deformation of the contact areas. The release of the residual stresses by thermal treatment will have the effect of increasing the contact area between grains.

4. CONCLUSIONS

The initial deformation stage during a compression test applied on metallic aggregates, is highly dependent on non-sintering thermal annealings. Therefore, the plastic *foot* observed in non-thermally treated compacts can be attributed to residual stresses developed in the contact areas between particles during the compaction process.

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