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Modelling the non-linear elastic behaviour and fracture of metal powder compacts

Pär Jonsén *, Hans-Åke Häggblad, Gustaf Gustafsson

Division of Mechanics of Solid Materials, Department of Engineering Sciences and Mathematics, Luleå University of Technology, Luleå, Sweden

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ABSTRACT

In the powder metallurgy (PM) pressing process the mechanical properties of the green body are highly dependent on the material density. During the ejection stage of the pressing process the elastic behaviour is important especially for the crack formation in the powder compact. Experiments show a non-linear and also stress dependent elastic behaviour of green bodies. In this study diametral compression tests have been used to study elastic deformation during crack formation in a tensile fracture process of metal powder disc compacts. The powder material used for the experiments was a press-ready premix containing Distaloy AE, 0.5% graphite (uf-4) and 0.6% Kenolube. Tensile strength is used as a failure condition and limits the stress in the fracture interface. To control the tensile fracture, a cohesive zone model is used. The softening rate of the fracture model is obtained from the corresponding rate of the dissipated energy. The deformation of the powder material is modelled with an elastic–plastic cap model where an easy-to-use model for non-linearity in the elastic state due to stress is presented. The model is implemented in a finite element code and tested in simulation of a diametral compression testing. Results from simulations correlate well with experimental results and demonstrate the importance of including the non-linear elastic effect of the powder compacts. Results also show the necessity to accurate model the elasticity in the tooling to correct capture force–displacement response and fracturing processes.

1. Introduction

One common process in powder metallurgy (PM) is cold uniaxial compaction with rigid tools and a die. The main stages in the pressing process are powder filling, transfer, consolidation, axial load release, ejection, and post-ejection. High velocity compaction (HVC) is based on the principles of ordinary powder pressing. The main difference is the speed of the punches during compaction; see e.g. [1–5]. Green body cracks are primarily formed during compaction and ejection. Fracture in powder compacts can be defined as separation or fragmentation of a solid body into two or more parts under the action of stress. It is the result of crack initiation and propagation. According to Zenger and Cai [6], cracks in a green PM compact during powder pressing are characterised by broken inter-particle bonds and/or never formed inter-particle bonds during compaction. The main cause of broken inter-particle bonds is the pulling apart of powder particles which have been mechanically locked during compaction. The pulling apart of powder particles is caused by tensile forces, lateral shear forces, or a combination of these two.

The diametral compression test also called the Brazilian disc test or the diametrical tensile test is considered to be a reliable and accurate method to determine strength of brittle and low strength material [7,8]. These compressive stresses induce tensile stresses, perpendicular to the compressed diameter, which are constant over a region around the centre of the disc. Jonsén et al. [9] presented methods to characterise the fracturing process and estimate tensile strength σ_f and fracture energy G_f during diametral compression test for water atomised metal powder. A general fracture model based on energy assumptions was proposed by the authors in [10]. The model is based on experimental observations showing that tensile cracking in pressed metal powder is discrete and localised phenomenon exhibiting a softening effect caused by decreasing cohesive stresses. The elastic deformation of metal powders during die compaction has been largely ignored in computer simulations. The knowledge of the elastic response of metal powder compacts are essential to simulate possible dimensional changes (e.g. during unloading), correctly. Experiments on compacts have shown that linear elasticity is not appropriate to model the behaviour of metal powder when the stress state is in the elastic region [11,12]. This is observed e.g. during ejection of powder compacts from the tool. To overcome this problem the authors presented a preliminary work for a non-linear elastic model earlier [13], however some errors in that work were later found. In the present paper the authors describe a corrected model.

The aim of this work is to increase the quality in simulating the behaviour of powder compact in the green state, especially the non-linear elastic effects. This is done by introducing a non-linear elastic model and study diametral compression testing. The non-linear elastic

* Corresponding author. Tel.: +46 920 493460; fax: +46 920 491047.
E-mail address: par.jonsen@ltu.se (P. Jonsén).

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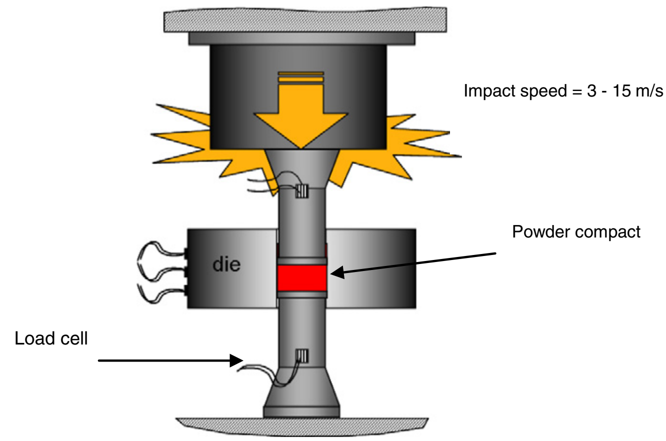

Fig. 1. Schematic view of high velocity compaction (HVC).

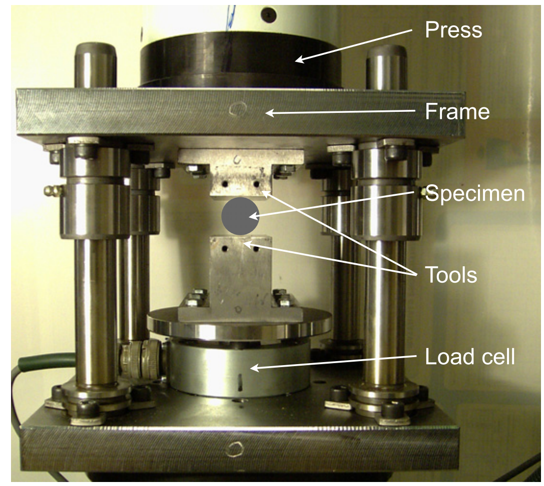

Fig. 3. Experimental setup for diametral compression test.

model relates elastic properties due to the stress level with physical based easy-to-find parameters. The powder material is modelled with this non-linear elastic model coupled to a plastic cap model for the plastic deformation and with a cohesive zone model for the fracture process. For validation of the model a finite element simulation of the diametral compression test is carried out and compared with experimental tests. Included in the present paper are also findings regarding modelling of the tooling and its consequences for the fracturing behaviour of powder compacts.

2. Manufacturing of test samples

The samples were manufactured by single sided compaction in a 25 mm diameter die. The sample thicknesses were 5 mm. The compaction was performed using a laboratory HVC-machine with a hydraulic driven hammer which has maximum compaction energy capacity of 4 kJ. The hydraulic hammer consists of two parts: The hydraulic piston and a weight, which is connected to the piston rod. During compaction a constant acceleration is applied the hydraulic hammer. The total mass accelerated was 31 kg. See Fig. 1 for a schematic view.

The powder used in the experimental study was Distaloy AE added with C-UF4 0.5% Kenolube 0.6% from Höganäs AB, Sweden. It is an iron based water atomised powder mix with particle size range of 20–180 μm, apparent density of 3.10 g/cm^3 and full green density of 7.48 g/cm^3.

Due to the constant acting load, the energy level is easily adjustable by varying the acceleration distance of the hammer, i.e. the distance between the start position and the impact position. The level of energy can be calculated by multiplying the accelerating load and the distance. Further, the machine was equipped with a load-cell, located below the bottom punch. Load data were acquired by a high speed data acquisition system (DAQ), capable to measure very sharp and short peak loads due to the impact, see e.g. [3]. The sampling rate in this case was 200 kHz. The HVC process starts typically with a pre-compaction, during which the powder is compacted from the apparent density to a density of 5 g/cm^3 approximately, and thereby the main amount of air is evacuated from the cavities. During the high velocity compaction the die was mechanically fixed. A single HVC stroke results in several load peaks, see Fig. 2. This is because the hydraulic hammer bounces on the top punch until the impact energy is fully dissipated. The maximum compaction pressure occurs in the first and highest load peak. The compaction shown in Fig. 2 has an impact velocity of 13.2 m/s corresponding to impact energy of 2.7 kJ and a peak load of 780 kN with a maximum compaction pressure of 1580 MPa. The resultant relative density for the powder compact is 0.99. The maximum overall strain-rate is of the order 10^2 s^{-1} during the compaction.

3. Diametral compression test

The experimental setup for diametral testing consists of a frame in which two fixtures and a load cell are integrated, see Fig. 3. The load cell can measure loads up to 5.0 kN with an accuracy of ±0.5 N. To be able to measure the load on the tested disc without influence of friction between pistons and frame, the load cell was mounted between the two plates of the frame. The load under the compressive loaded surface must

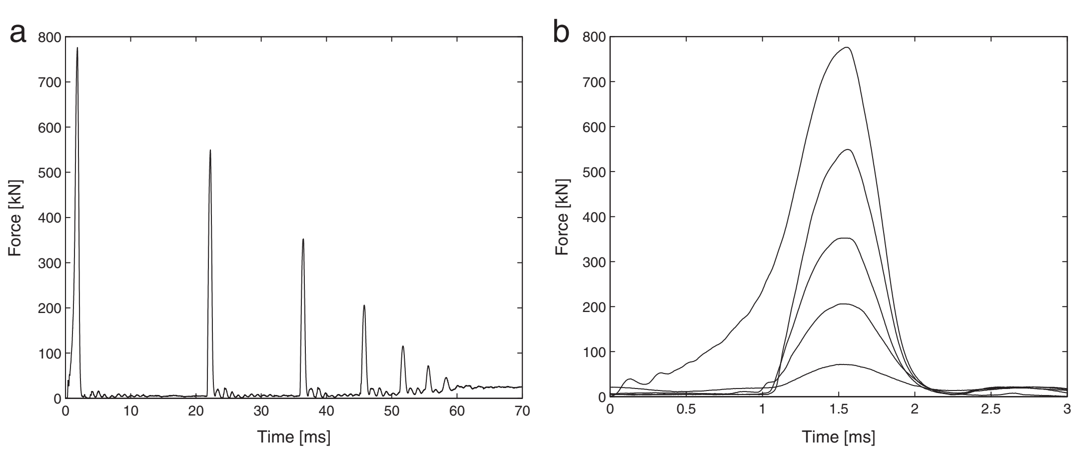

Fig. 2. HVC load curve measured during a high velocity compaction with impact energy of 2.7 kJ, a) complete curve, b) peaks only.