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Characterization and modelling of a carbon ramming mix used in high-temperature industry

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ABSTRACT

This paper is devoted to the modelling of a specific ramming mix mainly used in the high-temperature industry due to its high-compacting behaviour. This material has the ability to absorb the deformation of parts submitted to high thermal loads. Triaxial and instrumented die compaction tests were carried out in order to identify the shear and hardening behaviours, respectively. Tests on the ramming mix were led for a temperature range between 20 °C and 80 °C. The temperature effect is particularly observed on the material response when it is compacted. The main features of the behaviour of the ramming mix can be represented by the theoretical framework of the Modified Cam-Clay model. A single variable allows to accurately reproduce the hardening behaviour depending on the temperature. Moreover, an extension of the model for the hardening behaviour at high pressures is proposed. A good agreement between the experimental data and numerical tests is reached with this model.

1. Introduction

The steel industry requires huge structures mainly composed of refractory materials. The thermomechanical properties of these materials suit perfectly high temperature applications. However, the expansion of these constituents can damage some parts of the structure. To avoid this damage, ramming mixes are often used to absorb the deformations. Indeed, these loose materials are well-known for their high-compacting behaviour. An appropriate modelling of this material must at least be able to reproduce the compaction behaviour sensitive to the temperature effect.

This paper investigates the case of a ramming mix composed of graphite (80%) and coal tar (20%). Its aspect can be compared with a bituminous sand. In the literature, many studies were carried out in order to predict the behaviour of loose geological materials (Bousshine et al., 2001; Liu and Carter, 2002), pharmaceutical powders (Wu et al., 2005; Han et al., 2008) or metallic powders (Park et al., 1999; Chtourou et al., 2002; Khoei et al., 2006). The modelling of loose materials whose behaviour is highly dependent on the porosity rate is classically based on micro-mechanical and macro-mechanical approaches. The first one assumes that each particle is a sphere. It takes also into account the contact interactions between the particles (Helle et al., 1985; Fleck et al., 1992; Biba et al., 1993; Fleck, 1995). From a discrete approach, the macroscopic behaviour of a material can be evaluated by means of homogenization methods (Piat et al., 2004; Le et al., 2008). Although micro-mechanical models are devoted to understand the physical behaviour of the constituents, macro-mechanical models (Shima and Oyane, 1976; Gurson, 1977; Haggblad, 1991) are well-adapted for engineering applications which often occur at a large scale. The phenomenological models were mainly developed for applications in soil mechanics, such as the Drucker–Prager Cap model (Drucker and Prager, 1952), the Modified Cam-Clay model (Roscoe and Burland, 1968) and the Di Maggio–Sandler model (Di Maggio and Sandler, 1971). These Cap models allow to reproduce the hardening behaviour in compaction of initially loose powders. In the same approach, many extensions of these models for porous materials were developed (Chtourou et al., 2002; Aubertin and Li, 2004; Khoei and Azami, 2005; Park, 2007). The Drucker–Prager Cap model remains one of the most used due to its ability to reproduce shearing and compaction behaviours. The parameters of this model are simply identified by carrying classical tests. The hardening behaviour is described by a Cap parameter dependent on the volumetric inelastic strain (Doremus et al., 2001; Wu et al., 2005). In these studies, Young's modulus and Poisson's ratio defining the elastic part are assumed to be constant. In order to reproduce a possible nonlinear elastic behaviour, some authors have chosen to identify elastic and yield surface parameters evolving with the relative density (Kim et al., 2000; Sinka et al., 2003; Michrafy et al., 2004; Han et al., 2008). The influence

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