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Prediction of the Ram Extrusion Force of Cement-Based Materials

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Abstract:
The aim of this study is to propose a theoretical frame that is able to lead someone to an appropriate way of modeling cement-based material extrusion. It clearly appears that different extrusion scenarios may occur. Cement-based materials are viscoplastic materials that may undergo drainage during an extrusion process carried out at low velocity. Four material behaviors can be encountered: perfect plastic, viscoplastic, frictional plastic (with evolving properties) and frictional viscoplastic (that has never been reported in the literature as drainage occurs when ram velocity is low and thus when viscous effects can be neglected). In this work, criteria are proposed to choose the more relevant way to model extrusion. Then, models are proposed for the possible extrusion scenarios.

Key words:
extrusion, frictional behavior, cement-based materials, drainage

1 INTRODUCTION

Nowadays, extrusion is a common forming process used for a wide range of materials (food, fertilizers, pharmaceuticals, clay, polymers, cold and hot metal forming, ...). It is an interesting forming process which induces high productivity and reduced air content. This process is developed and used since a long time for perfect and homogeneous plastic and viscoplastic materials. In this case, the stress distribution and the material flow have been well described. It is not the case of more complex materials such as cement-based pastes. For these saturated and concentrated suspensions which present high solid volume content, extrusion should be an interesting way to decrease their porosity and improve their mechanical strengths, which are the main characteristics of building materials [1–4]. However, it has been reported that heterogeneities may appear within the material during the flow of such firm granular doughs. For example, an hardening of the paste in the non-flowing dead zone located around the die is reported in many studies [5–7]. Moreover it has been observed that very concentrated suspensions are likely to undergo liquid filtration during their extrusion [5, 6, 8–22].

According to Toutou et al. [21], a granular paste must have an internal yield stress around 20 kPa to be suitable for extrusion. This critical value corresponds to a paste firm enough to keep its shape at the extruder outlet and sufficiently "soft" to limit extrusion force due to plastic deformation and internal friction. Several recent studies suggest that cement-based materials are likely to undergo drainage during extrusion. Authors have proposed criteria based on filtration velocity linked to paste permeability. Stress distribution, internal friction and wall friction remain constant if extrusion process is largely faster than filtration. In this case, the material remains homogeneous, its behavior remains viscoplastic and the process corresponds to a proper extrusion. On the contrary, if filtration is allowed by a low speed of extrusion, solid volume fraction increases and particles may percolate.

If the percolation threshold is reached, the material behaviour becomes frictional. As a result, shear and friction stresses largely increase [23]. In this case, normal forces due to shearing appear and induce an inter-

a new non-dimensional drainage number Dc is defined. It takes into account both the amplitude of rheological behavior variation due to liquid migration and the velocity of this filtration. This criterion is then successfully applied on the studied pastes.

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