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Wall friction measurement and compaction characteristics of bentonite powders

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Abstract

This paper presents a new method (referred to as direct method) for measuring wall friction during powder compaction and ejection. The accuracy for wall friction force measurement by both new and conventional methods (referred to as indirect method) were first studied according to the theory of error propagation. The error sources for compact density measurement in both methods were also examined. Based on the accuracy in the measurement of wall friction force and compact density, the direct method is compared favorably to the indirect method. Two bentonites, Black Hills bentonite and Zhi-Hsing bentonite which were considered as the candidate buffer materials for the geological disposal of high-level radioactive wastes were adopted to conduct a series of compaction and ejection tests. The compaction characteristics of bentonite blocks were expressed in terms of compressibility curve, wall friction ratio and friction index. The Gurnham's equation was used to describe the compressibility curve. The effects of the aspect ratio of block on the friction ratio and friction index are discussed from both experimental and theoretical point of views. Ejection profiles of the compacted bentonite blocks during ejection phase were presented. The proposed measuring method is validated by comparing the readings of ejection force recorded by both upper load cell and ring-type load cell.

Keywords: Compaction; Ejection; Wall friction; Bentonite; Buffer material; Nuclear waste disposal

1. Introduction

Compaction is the process of densification that decreases the pore size and porosity and causes particle rearrangement by means of impact energy. Powder compaction technique is widely used in a net shape forming route, such as powder metallurgy [1,2], ceramic industries [3–5], and the buffer material forming for the nuclear waste disposal management in geotechnical field [6–12].

The excellent sealing and swelling properties of the highly compacted bentonite or bentonite–sand mixture blocks have made them primary candidate for the geological disposal of high-level radioactive wastes [13]. The emplacement of bentonite buffer material surrounding canisters and overpack has long been a feature of disposal concepts adopted for high-level waste and spent fuel disposal programs with a number of countries [14]. For performance assessment of the compacted bentonite-based buffer material, many researchers have devoted their efforts to the permeability and swelling behaviors of the compacted bentonite blocks [15–20]. Recently, Johoannesson and his coworkers conducted a series of studies on the compaction characteristics and industrial techniques for producing large scale and different shapes of bentonite blocks [8–10]. Available techniques for compacting bentonite blocks are isostatic compaction and uniaxial compaction. The advantage of isostatic compaction is that there is no friction problem, and thus resulting in homogeneous blocks. However, the isostatic compaction has two major drawbacks. One is that it requires much preparative work and thus is time-consuming. The other drawback is that the shape of block needs to be trimmed by a saw or a turner after compaction. The uniaxial compaction saves time and produces blocks with high precession in geometry. It is not necessary to reshape the geometry of the block after compaction. The uniaxial compaction technique is widely used in powder and ceramic industries and buffer material studies. The major disadvantage of uniaxial compaction is that the blocks may

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become inhomogeneous due to the friction between the block and the die.

The block–die wall friction plays a crucial role in the compaction and causes non-uniform packing densities within the blocks. High wall friction creates high stress gradients within the block, and hence causing significant density fluctuation [4]. To reduce the wall friction effect the following precautions may be taken: (1) use samples of low aspect ratio (i.e., ratio between the height and diameter of block, H/D), (2) use both an upper and a lower piston during compaction, (3) compact the powder at high water content, (4) use lubricant on the die. Several kinds of lubricants, such as calcium stearate, zinc stearate, molybdenum disulfide dry film or silicon oil, have been applied to reduce the effect of wall friction [4,9,21,22]. However, it is impossible to eliminate the wall friction completely, even with all the friction-reducing conditions applied including lubrication on mold, short pistons, low aspect ratio of specimen and higher water content sample. Because the mechanism of powder compaction and wall friction is very complicated and has not been fully understood, the wall friction of any specific material during compaction is usually investigated through experiments. To better understand the behavior of wall friction, assess its effect on the properties of the compacted block, and evaluate the friction-reducing methods, high quality measurement of wall friction during compaction and ejection is an important task. The wall friction measurement technique is very important in the fields of powder metallurgy, and ceramic industries. However, there is no report on the wall friction measurement in the bentonite-based buffer material compaction or ejection in the field of geological disposal of the high-level radioactive wastes. Thus, the effect of wall friction on stress gradient and density fluctuation within bentonite block and the wall friction prevention method is hard to evaluate quantitatively.

This paper presents two methods for wall friction measurement during the bentonite block compaction. One is the indirect method, which is widely used in the fields of powder metallurgy. The other is the direct method, proposed by the authors. In general, both wall friction and ejection forces can be regarded as a kind of friction force between the bentonite block and the die wall. Thus, the direct method is not only suitable for measuring the wall friction during compaction phase but also for measuring the ejection force during ejection phase.

In this paper, as in the literature, the friction force between the bentonite block and the die wall during compaction phase is referred to as "wall friction," and the friction force between the powder and the die wall during ejection phase is referred to as "ejection force".

The emphasis of this paper is on the direct measurement method for friction force during powder compaction and ejection. The advantages and disadvantages of both the indirect and the direct measurement methods are evaluated on the basis of the measurement accuracy and the ease and convenience of operation. To validate the applicability of the direct method, a series of compaction and ejection tests were performed. Two bentonite powders (Wyoming Black Hills bentonite and Zhi-Hsing bentonite) were adopted for the experimental program. Based on the results of compaction test, the relations between applied compaction force and wall friction force of bentonite block with different aspect ratio were established. The friction ratio of bentonite blocks with different aspect ratio were examined both from theoretical and experimental viewpoints. In addition, the ejection forces measured by the proposed direct method were compared with those by the conventional indirect method.

2. Direct and indirect methods

2.1. Measurement methods

The indirect measurement method for the wall friction employs two load cells as shown in Fig. 1(a). The upper and lower load cells measure the applied force F_a on the upper piston and the transmitted force F_t on the lower piston, respectively. The wall friction F_w during powder compaction can be determined from the applied force F_a and the transmitted force F_t as:

$$F_w = F_a - F_t. \quad (1)$$

The indirect method as shown in Fig. 1(a) has been used widely for wall friction measurement in the field of powder metallurgy [1,2,4,21,23–25].

The direct method proposed by the authors as shown in Fig. 1(b), on the other hand, adopts a ring-type load cell (some manufactures called it washer-type or donut-type load cell) that is installed under the die to measure the wall friction directly. The base of die transmits the friction between the powder and the wall of die during compaction. Thus, the force measured by the ring-type load cell is exactly equal to the wall friction. Most commercial load cell manufactures supply varied capacity and dimensions of ring-type load cells and often take special orders.

It should be noted that the inner diameter of the ring-type load cell must be slightly bigger than the diameter of the lower

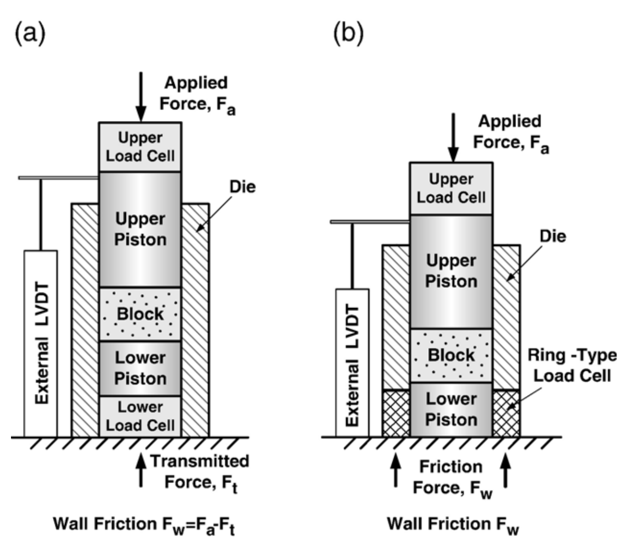

Fig. 1. Wall friction measurement methods during compaction (a) the indirect method (b) the direct method.