2P2-7

High power ultrasonic effect on soil compaction for different static pressure

Minseop Sim[1‡], Moojoon Kim[1], Kanglyeol Ha[1], and Jungsoon Kim[2] ([1]Pukyong Natl' Univ., Korea; [2]Tongmyong Univ., Korea)

1. Introduction

Many studies have been reported that the powder compaction is improved by decreasing the friction of powder caused by ultrasonic vibration[1-3]. Generally, the powder compaction is performed with ultrasonic vibration as well as high static pressure. Recently, we suggested a theoretical analysis of the ultrasonic effect on the powder compaction[4]. In this study, to analyze the improvement of compaction caused by ultrasonic vibration under various static pressure appling to the powder, the effective friction coefficient and sound speed of the powder are examined theoretically and experimentally.

2. Reduction of effective friction coefficient

The rate of density change to pressure is proportional to the amount of pore in the powder, and the relationship is given by[5]

$$\frac{\partial \rho}{\partial P} = K(1-\rho). \quad (1)$$

Here, the relative density, the pore fraction, the applied static pressure and the proportional constant are ρ, 1-ρ, P, and K, respectively. From eq. (1), the density can be expressed as a function of static pressure, as shown in eq. (2).

$$\rho = 1-(1-\rho_0)e^{-KP}, \quad (2)$$

where ρ_0 is the relative density without the applied static pressure. The density of the compacted powder depends on the effective friction coefficient, the Janssen coefficient of the powder, and the diameter of the container. When the diameter of the container and the Janssen coefficient are assumed constant, the density would be inversely proportional to the effective friction coefficient as follows.

$$\rho \propto \frac{1}{\mu}. \quad (3)$$

Therefore, the reduction of the effective friction coefficient μ_e by the ultrasound in compacting powder can be expressed as like

$$\mu_e = \frac{\mu_p}{\mu_u} = \frac{1-(1-\rho_{0u})e^{-K_u P}}{1-(1-\rho_{0p})e^{-K_p P}}. \quad (4)$$

Here μ_u, ρ_{0u}, and K_u are the effective friction coefficient, the initial relative density and the constant when both the static pressure and the ultrasound applied to the powder, whereas μ_p, ρ_{0p}, and K_p are the values for applying the static pressure only.

3. Measurement process

Figure 1 shows the experimental setup to examine the change of compacting rate of the powder with and without the ultrasonic vibration under different static pressure.

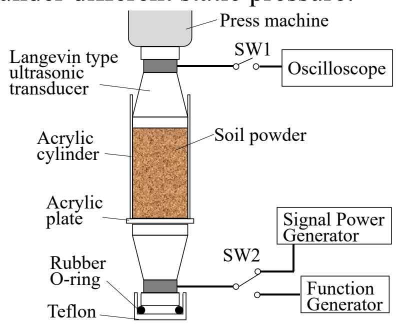

Fig. 1 Compaction system with ultrasound.

The soil powder filled the cylindrical acrylic container, which has the inner diameter of 46 mm, the outer diameter of 56 mm and the height of 197 mm. The container was fixed on the radiation surface of Langevin type ultrasonic transducer, which has the diameter of 42.7 mm, and resonant frequency of 29 kHz. Another Langevin transducer with the equivalent performance was placed on the powder surface to be contact with the radiation surface of the transducer. As shown in **Fig. 2**, the static pressures are applied to the upper transducer with a press machine and the density change of the powder is observed. At this time, the lower ultrasonic transducer radiates ultrasound to the powder and the density change of the powder is measured to examine the reduction effect of the effective friction coefficient by the ultrasound. To prevent the change of resonant mode, a rubber O-ring support the lower transducer, and a silicone rubber plate is inserted between the upper transducer and the press machine. To obtain the sound speed of the powder, a burst pulse was radiated from the lower transducer and it was received by the upper transducer through the powder in both case of with and without ultrasound.

kimjs@tu.ac.kr

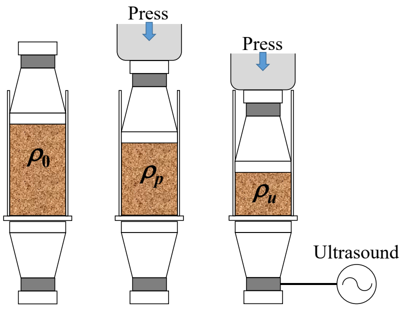

Fig. 2 Measurement process for the density change.

4. Results

The change of average density of the powder under the static pressure in range of 0 ~ 1 MPa by the press machine is shown by square symbol in **Fig. 3**. In this result, the average density increases with the static pressure until it converges into a constant value. The black solid line shows the result of fitting using eq. (2) with K=3.5. Meanwhile, the average density with the ultrasound as well as the static pressure is shown by the red circles in Fig. 3. The red solid line is the fitting result using the theoretical formula when K=3.0.

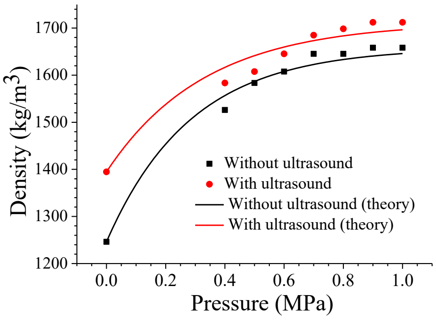

Fig. 3 Density of the powder under different conditions.

Figure 4 shows the reduction effect of the effective friction coefficient by ultrasound, which is obtained by using eq. (4). The reduction effect decreases gradually as the external static pressure increases, and it becomes a constant value for pressures over than 0.5 MPa. In order to investigate the change of the physical property of the powder by the ultrasound, the sound speed of the powder was measured under the different static pressure. The sound speed is determined by the bulk modulus B and the density ρ from eq. (5).

$$v_p = \sqrt{\frac{B}{\rho}}\,. \tag{5}$$

The sound speed of the powder was measured under the given range of static pressure, as shown in **Fig. 5**. In the case without ultrasound, the change of sound speed is insignificant even though the static pressure increases. It means that the bulk modulus also increased with the same rate when the density increased as the static pressure increased, shown in eq. (5). Meanwhile, in the case with ultrasound, the sound speed increases exponentially with the static pressure. It shows that the increment of the bulk modulus is larger than that of the density as the static pressure increases. It can be seen that the powder compaction with the ultrasound causes not only the density increase but also the increase of elastic coefficient.

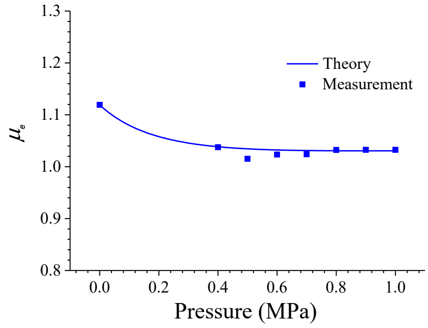

Fig. 4 Effective friction reduction by ultrasound.

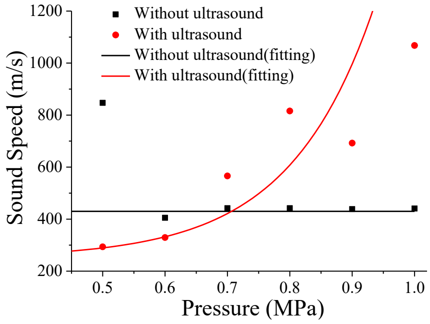

Fig. 5 Sound speed with and without ultrasound.

5. Summary

A soil powder was compacted with static pressure in the range of 0 ~ 1.0 MPa. As the results, the density compacted with ultrasound of 29 kHz increased 3 ~ 12% than that without ultrasound, while the effective friction coefficient decreased 3 ~ 10.6%. The sound speed of compacted powder without ultrasound showed around 420 m/s for different static pressure, in the case with ultrasound, the sound speed increased exponentially from 300 to 1100 m/s.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2015R1C1A2A01054839).

References

1. A. Feeney, S. Sikaneta, P. Harkness, and M. Lucas: Ultrasonics **76** (2017) 136.
2. V. Fartashvand, A. Abdullah, and S. Vanini: Ultrasonics Sonochemistry **36** (2011) 155.
3. J. Tsujino and H. Suzuki: Jpn. J. Appl. Phys. **31** (1992) 260.
4. J. Kim, M. Sim, J. Kim, and M. Kim: Jpn. J. Appl. Phys. **57** (2018) 07LE04.
5. R. Heckel: T. Metall. Soc. AIME. **221** (1961) 671.