EFFECTS OF PARTICLE SHAPE AND ROUGHNESS ON MECHANICAL RESPONSES OF GRANULAR MATERIALS IN TRIAXIAL TESTS

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1. INTRODUCTION

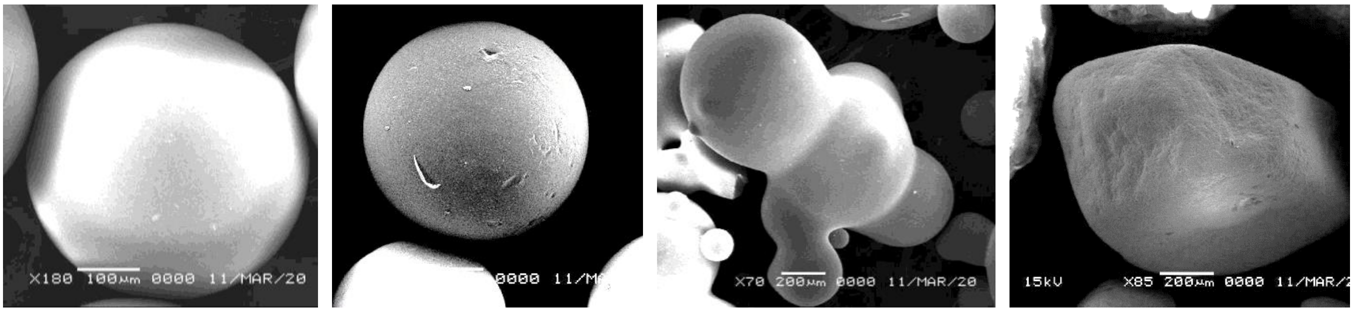
Particle shape and surface roughness have significant effects on the overall mechanical response of granular material (Santamarina and Cascante 1998, Otsubo *et al.* 2017). They are believed to be responsible for interlock and friction phenomena between particles (Cavarretta *et al.* 2010). However, the role of particle shape and surface roughness, as a combined or individually, on the overall mechanical response has not been well understood. In the present study, a series of triaxial tests were carried out on four materials with different particle shape and roughness. Stress-strain responses were examined in triaxial tests and elastic wave signals were detected by planar piezoelectric transducers installed in the bottom pedestal and top cap of the triaxial apparatus (Dutta *et al*. 2019). All tested materials were prepared following the criterion to maintain a void ratio at around 0.65 to eliminate the influence of packing density.

2. MATERIAL DESCRIPTION

Four types of materials were used: smooth spherical glass beads (SSGB), rough spherical glass beads (RSGB), smooth clumped glass beads (SCGB) and rough Kashima river sand (RKRS). In order to make the surface rough for RSGB and RKRS materials, one portion of tested material and two portions of silica sand No.8 (D_{50}=0.1mm) were mixed in a milling machine and rolled for 48 hours. The rough materials mixed with silica sand No.8 were sieved, washed and dried before tested. The material properties are listed in Table 1 and their SEM images are presented in Fig. 1.

Table 1 Properties of materials

	SSGB	RSGB	SCGB	RKRS
G_S	2.5	2.5	2.5	2.66
D_{50}(mm)	0.5	0.5	0.6	0.77



(a) (b) (c) (d)

Fig. 1 SEM images of tested materials (a) SSGB (b) RSGB (C) SCGB (d) RKRS

3. TESTING PROCEDURE

The specimens were prepared in a standard triaxial apparatus with a height of 150 mm and a diameter of 75 mm. The materials were consistently poured into the mould in five equal layers by using a funnel, and side tapping was applied by using a wooden hammer to densify the specimens in order to achieve the target void ratio. The relative density of SCGB was calculated to be above 100%. Because it was difficult to determine the e_{max} and e_{min} using the conventional measuring method due to its irregular and random shape. After sample preparation, the specimens were firstly consolidated under an isotropic confining pressure of 50 kPa, then sheared monotonically under drained and dry conditions with a constant strain rate of 0.00057%/sec. Before starting triaxial compression, P-wave and S-wave velocities were measured under the isotropic stress state. A single cycled sinusoidal waveform with an input frequency of 7 kHz and a double amplitude voltage of 140 V was inserted to the specimen to generate elastic waves. As for the calculation of wave velocity, the start-to-start method and the peak-to-peak method were applied to determine the arrival time of P-wave and S-wave, respectively, following Dutta *et al*. (2019).

4. RESULTS AND DISCUSSIONS

Figure 2 shows the variation of deviator stress (q) with axial strain (ε_a) of four tested materials during triaxial compression. The influence of particle shape can be seen when respectively comparing SSGB and SCGB, RSGB and RKRB. The peak

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q value of SCGB (406 kPa) is much greater than that of SSGB (74 kPa), the maximum *q* value of RKRS is 250 kPa, relatively greater than 89 kPa for RSGB. So more irregular shape results in higher peak deviator stress and the change in a stress response follows the discipline that the change from the spherical shape to artificial clumped shape is more sensitive than the change from spherical to natural shape. On the other hand, comparing two curves with SSGB and RSGB, the roughness of particle surface can surely increase the stress level, with a peak value of 89 kPa for the rough particles versus 74 kPa for the smooth case. While the effect of the surface roughness on overall mechanical response is less noticeable than the influence of the particle shape, also observed by Cavarretta *et al.* (2010). The specimen made of clumped shape particles shows a considerably higher shearing resistance and exhibits almost 450% increase in the maximum *q* value when compared with that made of spherical ones, while the roughness only contributes to a 20% rise (from 74 kPa to 89 kPa). But rough surface can effectively prevent fluctuation of stress responses, associated with inter-particle stick-slips.

Figure 3 presents the P-wave and S-wave velocities (V_P and V_S) under the initial isotropic stress condition, where the previous conclusions about stress-strain responses are not applicable. SCGB has higher V_P (468 m/s) and V_S (277 m/s) than those for SSGB (462 m/s and 222 m/s, respectively), while RKRS shows lower V_P (389 m/s) than that of RSGB (423 m/s). The variation of wave velocities is not affected by the change of shape as obviously as this does to stress-strain response. The increases in wave velocities of SSGB and SCGB are 1.3% for V_P and 125% for V_S, respectively. Even a growth of V_S for RKRS (210 m/s) is observed when compared with that of RSSG (203 m/s). When comparing V_P and V_S between SSGB and RSGB, the rougher specimen has lower wave velocities, which is consistent with the results by experimental tests (Santamarina and Cascante 1998) and DEM simulations (Otsubo *et al.* 2017).

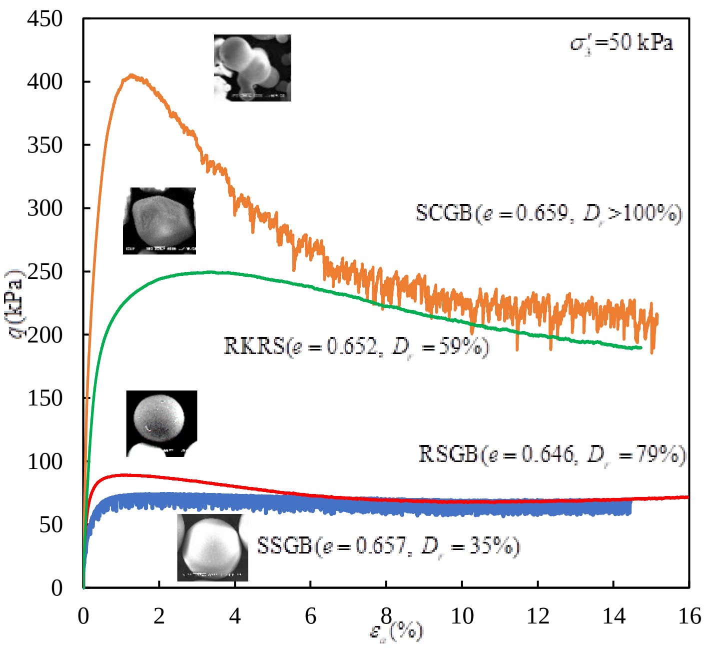

Fig. 2 Variation of deviator stress (q) with axial strain (ε_a) during triaxial compression with different particle shape and roughness.

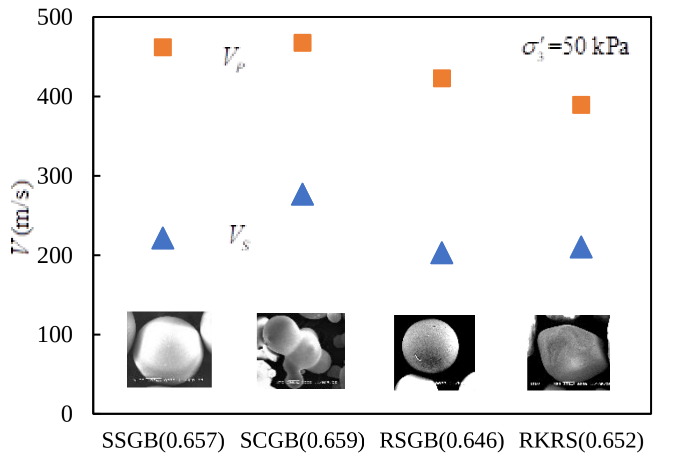

Fig. 3 Variation of P- and S-wave velocity under isotropic state (σ_3'= 50 kPa)

5. CONCLUSIONS

This study has conducted triaxial tests considering the effect of particle shape and roughness on the mechanics of granular materials; conclusions are listed as follows.

- The maximum deviator stress is significantly increased by changing the spherical particles to more irregular particles.
- The deviator stress changes more sensitively according to particle shape than roughness.
- Changing from spherical shape to clumped shape increases both velocities, while V_P and V_S have opposite changes when the spherical shape is compared with more natural shape.
- The peak stress value increases with the higher degree of surface roughness while the V_P and V_S show a reverse trend.

REFERENCES

Cavarretta, I., Coop, M., O'Sullivan, C.: The Influence of Particle Characteristics on the Behaviour of Coarse Grained Soils. Géotechnique, 2010, 60(6), pp. 413-423.
Dutta, T. T., Otsubo, M., Kuwano, R. and O'Sullivan, C.: Estimating Stress Wave Velocity in Granular Materials: Apparent Particle Size Dependency and Appropriate Excitation Frequency Range, Geotechnique Letters, 2019, 9(3), pp. 1-26.
Otsubo, M., O'Sullivan, C., Hanley, K., and Sim, W.: The Influence of Particle Surface Roughness on Elastic Stiffness and Dynamic Response, Géotechnique, 2017, 67(5), pp. 452-459.
Santamarina, C. and Cascante, G.: Effect of Surface Roughness on Wave Propagation Parameters, Géotechnique, 1998, 48(1), 129-136.