Consideration of the compression property of soil mixed with deformable particles – One-dimensional compression behavior of rubber and aluminum chip mixtures

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ABSTRACT: In order to examine the modeling of compression behavior of soils mixed with deformable particles, one-dimensional compression tests of rubber and aluminum chips mixture packed into a cylinder were executed. Then, the compression behavior of the soil mixed with deformable particles such as rubber chips was observed quantitatively, and consider the effect of deformable particles on the compression property of the entire mixture. As a result, it was shown to be important to clarify the compression mechanism of the mixture including deformable particle. Further, it was found that the compression of the mixture were greatly affected by the nature of dominant skeleton constituted by the particles, and the volume change caused by the movement of constituent particles were developed rapidly when the skeleton of the mixture was loosened even a little.

Keywords: Mixed soil, Deformable particle, One-dimensional compression property

1 INTRODUCTION

As a contribution to solving environmental problems, the recycling of resources is one of the most important concepts. In the field of geotechnical engineering, it has been made the subject of a number of studies that attempted to effectively use a variety of used materials and waste, such as scrap tire chips, expanded poly-styrene waste, formed scrap glass and so on, as geomaterials (e.g. Hazarika et al. 2010, Yasufuku et al. 2000, Kubo et al. 2004). The authors have also been investigating some possibilities to effectively use of crushed expanded plastic waste, which was circulated for recycling, as a lightweight mixed soil. As a result, this plastic waste was shown to be useable as a geomaterial, because it was found that the strength parameters such as internal friction angle remained almost unchanged, while its compressibility increased (Kimata et al. 2001).

Thus, various recycled materials have shown the potential to be effectively utilized as geomaterials, some of which have a larger deformability, such as rubber or expanded plastic. Since a soil mixed with such materials has a large amount of deformation, it is necessary to clarify the deformation characteristics of such a soil in considering the actual use. Moreover, in a similar situation, the case of layering a flexible geosynthetic in the ground, deformation may also be a problem, making it also necessary to know the deformation characteristics of soil integrated with geosynthetics. For this reason, the authors have promoted research to elucidate the deformation characteristics of soil mixed with deformable particles, considering the mechanism of compressive deformation from a microscopic point of view. Specifically, the amount of mixed soil compression was thought to consist of ordinary soil compression (that is, the amount of compression when it is assumed to not include deformable particles in the soil skeleton) and a compression amount to be added due to the deformation of the deformable particles. Furthermore, with regard to the latter, it was thought that this is divided into [1] a component caused by the compression of the deformable particles themselves, [2] a component caused by the reduction of the pore space volume owing to the deformation of deformable particles and [3] a component caused by the volume change of pore space due to the further movement (rearrangement of the skeleton) of the deformed particles. Then, a one-dimensional rod-stack model compression test, using aluminum rod and rubber or expanded polystyrene rods, was conducted to evaluate each component added due to the deformable particles, and predict these components. As a result, it was found that the components [1] and [2] could almost always successfully be predicted by a relatively simple model, using a stress-strain relationship, the Poisson's ratio of deformable particles and taking into account the geometric deformation relationship during compression in the two-dimensional cross-section of a rod-stack model (Kimata et al. 2010).

However, the actual soil is in a three-dimensional state, and the movement of particles is significantly different from that in a two-dimensional state. Therefore, in this study, it was decided to proceed with a consideration by executing a one-dimensional compression test of a rubber and aluminum chip mixture packed into a cylinder, in order to extend the results obtained so far to the discussion of a three-dimensional state. In addition, the compression amount of the mixture divided into each component, from a macro point of view, was to be measured and considered because it is difficult to trace and analyze the movement of each component's particles individually. Specifically, in addition to the volume compression amount of the entire mixture, each compression component corresponding to the above mentioned [1], [2] and [3] was calculated separately. Then, the basic compression behavior of the mixture in a three-dimensional state was understood, and the effect of using rubber chips as deformable particles on the compression characteristics of the entire mixture was considered. In addition, it was also examined as to whether it is possible to build a three-dimensional model using a similar way of thinking as building the two-dimensional model.

2 SPECIMENS AND TESTING METHOD

2.1 *Specimens*

In this study, aluminum chips (density: 2.69 g/cm^3) and nitrile rubber chips (density: 1.38 g/cm^3) were used as soil particles and deformable particles respectively. The diameter and length of the chips were both 3mm. The specimens were prepared by mixing these chips in a real volume ratio and packing them into an acrylic cylinder of 50mm inner diameter, and adjusting the height to 100mm. As for the mixing ratio, the volume ratio of rubber chips to all chips, was set to 0.0, 0.33, 0.5, 0.67 and 1.0. The void ratio of specimens was adjusted to 0.70 and 0.60 in spite of the mixing ratio. This was because the fundamental skeletal structure of the specimens was thought to be almost the same regardless of the mixing ratio, since the rubber chips and the aluminum chips used in this study were of the same shape and size. Further, as a result of determining the minimum void ratio of a mixture of these chips according to the 'Test method for minimum and maximum densities of sands' (The Japanese Geotechnical Society, 2015), it was found to be about 0.54. Accordingly, even when a specimen of an initial void ratio of 0.54 was prepared, this was regarded as the specimen of the densest skeleton state at which the movement of particles does not occur at all. The initial condition of the specimens is listed in Table 1.

Table 1. Initial specimen conditions.

Target void ratio	Mixture ratio	0.0	0.33	0.5	0.67	1.0
0.54 (densest)	Density (g/cm^3) Void ratio	1.76 0.53	1.48 0.54	1.33 0.55	1.18 0.55	0.91 0.54
0.6	Density (g/cm^3) Void ratio	1.66 0.60	1.41 0.60	1.27 0.60	1.14 0.60	0.87 0.58
0.7	Density (g/cm^3) Void ratio	1.58 0.72	1.33 0.71	1.20 0.68	1.06 0.69	0.81 0.70

2.2 *Testing method*

A specimen was prepared and using the apparatus shown in Figure 1, incorporating an acrylic cylinder, a one-dimensional compression test was performed. A feature of this equipment is that the pore space of the specimen is saturated with water and drainage from the pore space is also measured. Thus, in addition to the volume change of the whole specimen by compression, the pore space volume change can also be measured separately. Incidentally, specimens were saturated with deaerated water by using the double negative pressure method. Compression tests were conducted at slow axial strain rates of 0.1 – 0.4 %/min depending on the stiffness of a specimen, and continued until the axial stress became about 600 kPa.

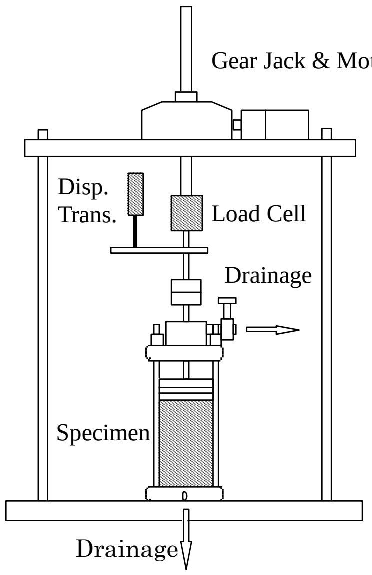

Figure 1. One-dimensional compression test apparatus.

3 TEST RESULTS AND DISCUSSIONS

3.1 *Concept of compression components*

After considering the results of previous studies, the deformable particle compression components to be added are three, as mentioned above, and the volumetric compression strain of a mixed soil is considered to be classified as Figure 2 (component [0] is a usual volumetric strain of pure soil). Therefore, in the experiments conducted in this study, the difference between the volumetric strain of the whole specimen and the pore space (corresponding to the amount of drainage) becomes a component [1] which is the volumetric strain caused by the compression of rubber chip. The component caused by the rearrangement of the soil particle skeleton [0] (corresponding to the volume compression of normal pure soil) is obtained from the test results of the mixing ratio of 0.0 (aluminum chip only). Further, it is possible to evaluate component [3] according to the further movement of the deformable particles by considering the test results of the densest skeleton state specimen. Based on this concept, the discussion to analyze the results was advanced.

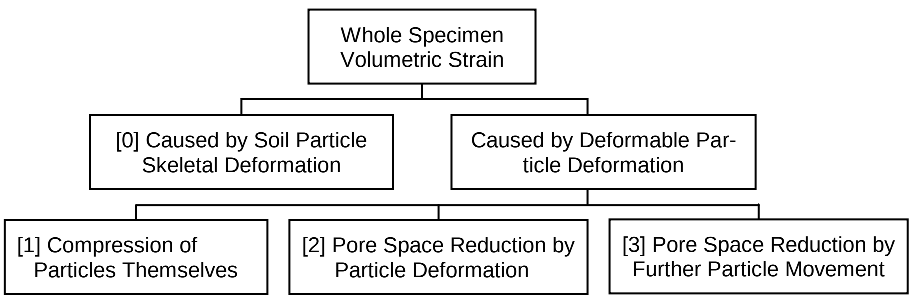

Figure 2. Volumetric strain component classification.

3.2 *Compression components due to particle deformation*

Figure 3 shows a plotting of the volumetric strain of the whole specimen (solid lines) and the pore space (dotted lines), which were obtained from the results of one-dimensional compression tests of the void ratio 0.7 specimen. The numerical value of the legend represents the mixing ratio (hereinafter the same). From this figure, the importance of building a compression model can be recognized, because it is confirmed that much larger volume compression occurs in the specimen mixed with rubber chips than the specimen of aluminum chips only (mixing ratio 0.0). In addition, it is also confirmed that the most volumetric strain caused by compression is in the volume change of the pore space (component [0] and [2] + [3]) and the volume compression amount of the rubber chip (component [1]: the difference between the whole and pore part [0] + [2] + [3]) is very small. Judging from the general fact that rubber is regarded as hard to compress because of a Poisson ratio of close to 0.5, such results are considered to be reasonable.

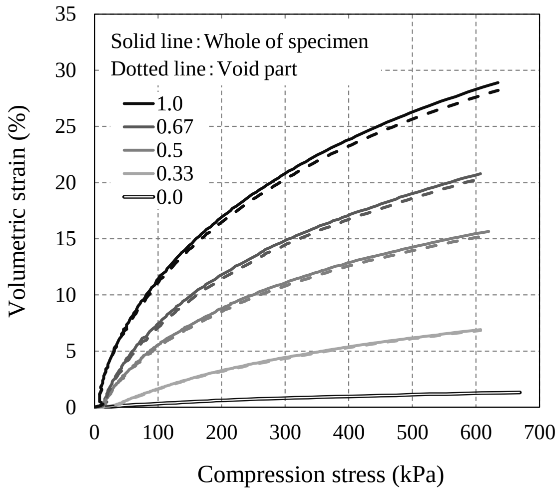

Figure 3. Volumetric strain of whole and void part of specimens.

Figure 4 shows the volumetric strain component of the rubber chips [1]. From this figure, it can be seen that the components of [1] are less than 1% at the maximum and that most of them occur in the initial stage of loading. It is considered that, among the compressive components added by the deformable particles, the volume change of the deformable particles themselves is almost all completed in the initial stage of compression, thereafter the volume change of pore space due to the deformation of particles becomes dominant. This fact is thought to be an important point to which we should pay attention at the time of considering the modeling of soil mixed with deformable particles.

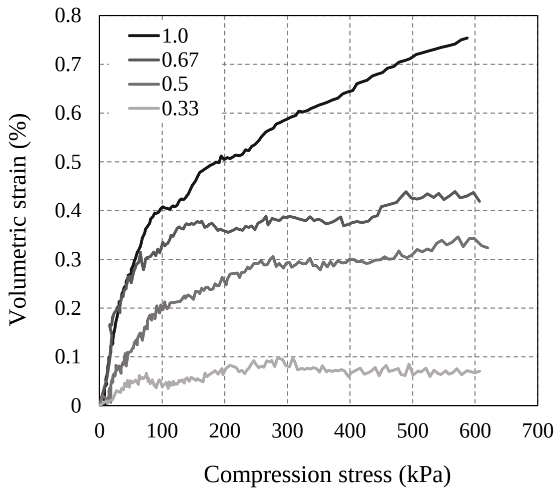

Figure 4. Volumetric strain component of rubber chips [1].

Figure 5 shows the volumetric strain compared to the volume of the rubber chip itself, which is calculated from the above test results (calculate the volume compression of rubber divided by the volume of rubber). From this figure, it can be seen that they show almost the same behavior, except the specimen with a mixing ratio of 0.33. This shows the fact that all the particles contained in the mixture received the same stress, and that they were compressed according to the stress. This is an important clue to elucidate the compression mechanism of the mixture. In addition, the reason for only the 0.33 mixing ratio specimen being different from the others, is thought to be due to the skeleton formed by aluminum chips preventing the compression of rubber chips. These properties were not able to found from two-dimensional rod-stack model experiments, and were considered to be very important at the time of the modeling of soil mixed with deformable particles.

Although it was omitted in this paper, the behavior described above was observed also in the specimens with a void ratio of 0.6 and in the densest state.

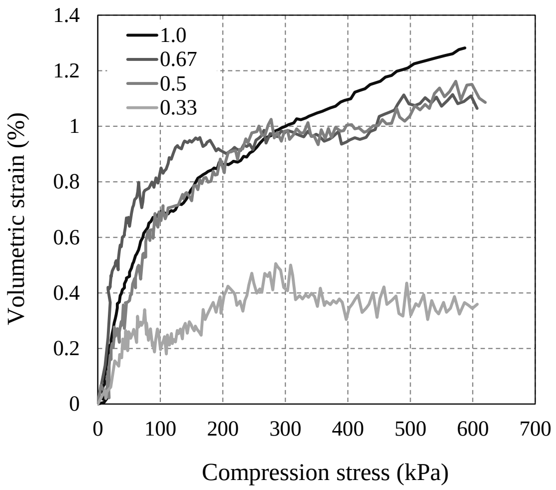

Figure 5. Volumetric strain to the volume of rubber chip itself.

3.3 *Compression components due to movement of particles*

Figure 6 shows a comparison of the pore volumetric strain at void ratios of 0.7 and 0.6 and the densest state (void ratio of about 0.54) for the specimens of only rubber chips (mixing ratio 1.0). In this figure, when comparing the volumetric strain at the compression stress of 500 kPa for example, it can be seen that there is a 7% difference between the void ratio 0.54 (densest, there is no particle movement) and the void ratio 0.6 (dense, but there is a movement of some particles), while there is only a difference of about 3% between the void ratio 0.7 and 0.6. Since this difference is due to the existence of component [3] due to the movement of rubber chip particles, it is considered to indicate the fact that component [3] develops suddenly when the skeleton of the mixture is loosening even a little from the densest state (in other words, it is not so affected by the void ratio in the less than densest state). Therefore, it is necessary to take into account these characteristics sufficiently, when considering the compression mechanism of soil mixed with such deformable particles.

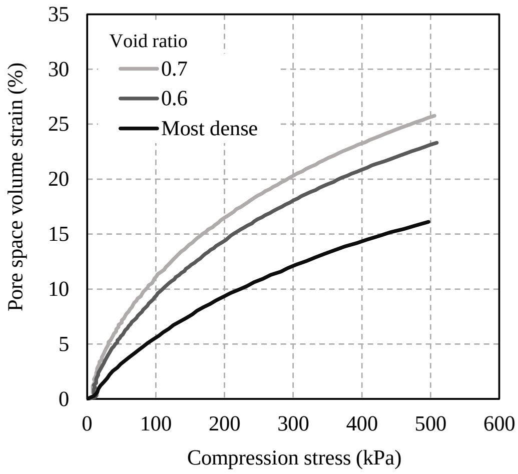

Figure 6. Comparison of volumetric strain in pore space.

4 CONCLUSIONS

In this study, one-dimensional compression testing using a mixture of rubber and aluminum chip was conducted to elucidate the compression properties of soil mixed with waste tire chips from a granular material point of view. By measuring and evaluating the amount of compression and classifying it into its components, the compression mechanism of mixed soil was considered. As a result, even in the case of a rubber chip itself, which is almost uncompressible, it was shown that a large change in the pore space volume due to deformation is caused, confirming the importance of elucidating the compression mechanism. In addition, it was found that the compression amount of the mixture was greatly affected by the properties of the dominant skeletal structure formed by constituent particles, and the volume change due to the movement of particles which were developed rapidly when the skeleton is loosened even a little, and so on. In the future, there is an intention to examine each compression component, from a geometric viewpoint, by also executing a modeling experiment using spherical rubber and aluminum.

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