The 6th International Symposium on East Asian Resources Recycling Technology
October 23 - 25, 2001, Gyeongju (慶州), Korea
ISBN: 89-952527-0-7 93530

Study on the Mixing Behavior of Excavated Soils and Additives in the Mixing Chamber of Excavated Soil-Recycling Machine

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Recently, an excavated soil-recycling machine has been receiving considerable attentions. The mobile type excavated soil-recycling machine is able to improve the soils by adding the additives such as slaked lime and cement at the construction site. However, not only the mechanical factors such as paddle inclination angle and pitch of the paddle but also the physical properties of the excavated soils affect the mixing performance of the excavated soils and additives. In this sense, experimental investigations are uneconomical and ineffective. This paper concerns with the numerical simulator to analyze the mixing behavior of excavated soils and additives in the soil-recycling machine with dual shafts in order to assist the economical and effective design of the optimum soil-recycling machine. By using the simulator, several simulations were carried out, and the effects of some mechanical parameters such as the paddle inclination angle and pitch of the paddle on the mixing performance were made clear.
Keywords: Soil-Recycling Machine, Excavated Soils, Additives, Mixing, DEM Simulation

1. Introduction

In order to construct the lifeline such as water and gas pipeline in the subsurface, the ground has to be excavated to make a long ditch. After the pipeline is set in the ditch, this ditch has to be filled by the soil. However, the moisture and the viscosity of excavated soils produced in the construction site are usually rather high. Therefore, it is almost impossible to recycle the excavated soils at the construction site. In order to recycle the excavated soils, it is necessary to improve them at the soil-processing plant. Now, the excavated soils are transported by the dump truck to the soil-processing plant and they are improved by adding the additives. However, as the cost of transporting soils is expensive, the excavated soils are illegally discarded on the way to the plant. And recently, discarding the excavated soils is a serious social problem. Furthermore, transporting the excavated soils by the dump truck cause the disperse of the dust and heavy traffic jam.

Therefore, an excavated soil-recycling machine has been receiving considerable attentions recently. The mobile type excavated soil-recycling machine is able to improve the soils by adding the additives such as slaked lime and cement at the construction site. However, not only the mechanical factors such as paddle inclination angle and pitch of the paddle but also the physical properties of the excavated soils affect the mixing performance of the excavated soils and additives. In this sense, experimental investigations are uneconomical and ineffective [1].

Therefore, the purpose of this study is to develop the numerical simulator to analyze the mixing behavior of excavated soils and additives in the soil-recycling machine with dual shafts in order to assist the economical and effective design of the optimum soil-recycling machine.

2. Outline of the Simulator

In this study, Distinct Element Method (DEM) is used to develop the simulator. DEM is often used to analyze the behavior of granular materials [2]. In the calculation of DEM, an equation of motion is given in each element to analyze the behavior of elements. In order to derive the equation of motion, it is necessary to estimate the forces acting among elements. Usually, the model as shown in Figure 1 is used. When the two elements contact each other, a spring and a dashpot are introduced between two elements in the normal and tangential direction. The spring and dashpot indicate the effect of elasticity and viscous resistance, respectively. Furthermore, a slider is set in the tangential direction to consider the frictional effect.

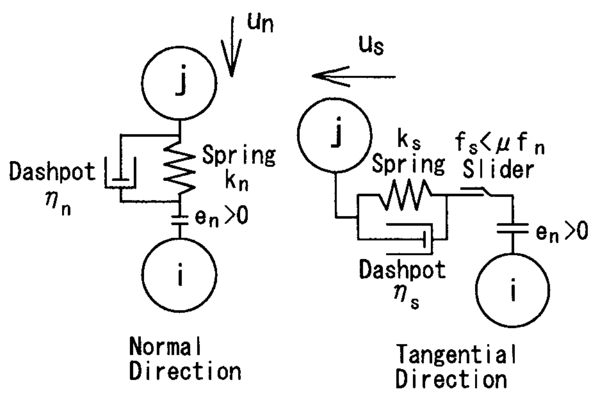


Figure 1 Contact model in DEM simulation.

In Figure 1, k_n and k_s are spring constant in normal and tangential direction, respectively. η_n and η_s are coefficient of viscosity of the dashpot in normal and tangential direction, respectively. $\mu$is the friction coefficient.

Figure 2 shows the mixing chamber of the soil-recycling machine with dual shafts used in this simulation. The shape and scale of the chamber and paddles are the same as the experimental apparatus which will be mentioned later. The calculation section is one pitch (120mm). 3000 spherical elements were packed in this section and numerical simulation was carried out. In this simulation, a super computer of Tohoku University, SX-4 was used. The time interval of calculation was 0.00025 sec. and the mixing time was 30 sec. in this simulation.

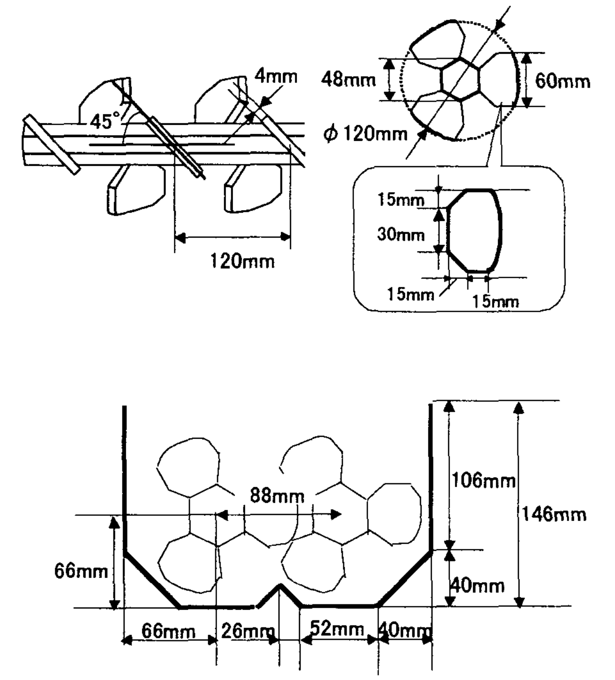


Figure 2 Outline of the mixing container used in this study.

3. Experimental Considerations on Mixing

3.1 Experimental apparatus and procedures

Figure 3 shows the schematic diagram of the experimental apparatus. The apparatus consists of feeder area of the soils and additives, mixing area and discharge area. The video camera was set above the mixing area to record the mixing behavior. The length of the mixing chamber is 1350mm. The section of 0-200mm, 200-1200mm and 1200-1350mm is the feeder area, mixing area and discharge area, respectively. Processed soils are discharged in order to keep the constant volume of soils in the mixing chamber. The shape and size of the mixing chamber and paddle are the same as shown in Figure 2.

First, the soils are packed in the mixing chamber to achieve the desired packing rate. Then, two shafts rotate and excavated soils and additives are fed into the chamber to keep the constant packing rate. Furthermore, the mixing behavior was recorded by the video camera. After 30 seconds, the rotation of the shafts is stopped and processed volume of the excavated soils and distribution of the additives are measured. The processed volume was obtained by measuring of the weight of discharged soils. The distribution of the additives was measured by the sampling probe of 15mm diameter. In this experiment, the black soil is used. The density of the black soil is 712kg/m^3. The quartz sand of 0.7mm diameter was used as additives for the black soil.

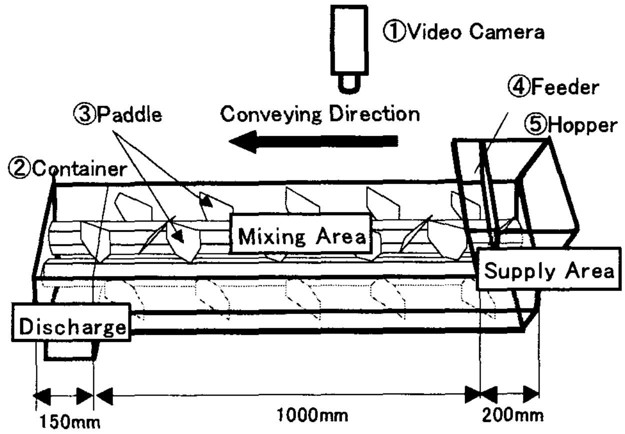


Figure 3 Schematic Diagram of experimental apparatus.

3.2 Experimental Results

The representative factors to indicate the mixing performance are "processed volume of the excavated soils per unit time" and "degree of mixing ". Furthermore, the mixing length is also an important factor because this length determines the size of the machine. The length which the mixing is completed is directly related to the "degree of mixing". Therefore, in this study, "the length of mixing completion" is investigated instead of "degree of mixing". The experiments were carried out under the condition of 30 rpm of the shaft and 100% packing rate. In this simulation, the calculation time was 10 minutes for 1second simulation of mixing by using SX-4.

1)Processed volume

The definition of the processed volume of the soils is the one which is discharged from the discharged section per unit time. Figure 4 shows the relationship between the processed volume of the soils and spring constant of the normal direction. The symbols in Fig.4 show the simulated results which were obtained for several spring constants, and the dashed line indicates the experimental result. As shown in this figure, the processed volumes are almost constant in the range of 50-100kN/m of the spring constant. However, they increase linearly with increase of the spring constant in the range of 100-150kN/m. The experimental result coincides with the simulated result at 112.5kN/m. Therefore, it can be considered that the most optimum spring constant for processed volume is 112.5kN/m.

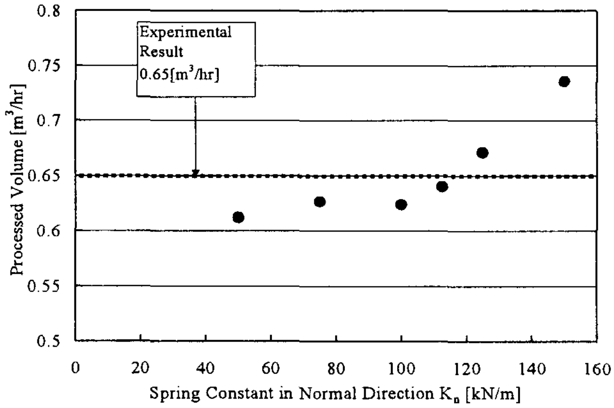


Figure 4 Comparison between the experimental results and simulated ones for processed volume of black soils.

2) The length of mixing completion

One of the features of the paddle type mixer is that the mixing and carrying the excavated soils and additives are conducted at the same time. That is, if the length of the mixing chamber is long, this means that long period of mixing is possible. However, the mobile type soil-recycling machine should be designed as compact as possible. Therefore, as mentioned above, it is very important to know the minimum mixing length. In this study, the first, the relationship between the mixing deviation and mixing length was obtained. The mixing deviation decreased with increasing the mixing length. At the beginning of mixing, the mixing deviation is large. However, the mixing deviation will decrease according to the mixing and if the excavated soils and additives is fully mixed, the mixing deviation will approach to zero. Therefore, the decrease of the mixing deviation means that mixing of excavated soils and additives is carrying out according to the increase of the mixing length. However, as the scatter of the data was large, it was almost impossible to judge when the mixing was completed. Therefore, secondly, the approximated curve was obtained by using the experimental data. In this study, the length of mixing completion is defined as the length at which the tangent of the approximated curve is less than the threshold value.

Figure 5 shows the relationship between the length of mixing competition and spring constant of the normal direction. The simulated results of 75kN/m and 150kN/m of the spring constant are nearly equal to the experimental results. However, as the scatter of the data is large, is it very difficult to determine the optimum spring constant for the length of mixing completion. By considering the fact that the error between the simulated results of 50kN/m and 100kN/m and experimental results are very large, 150kN/m was adopted as an optimum spring constant for the length of mixing completion.

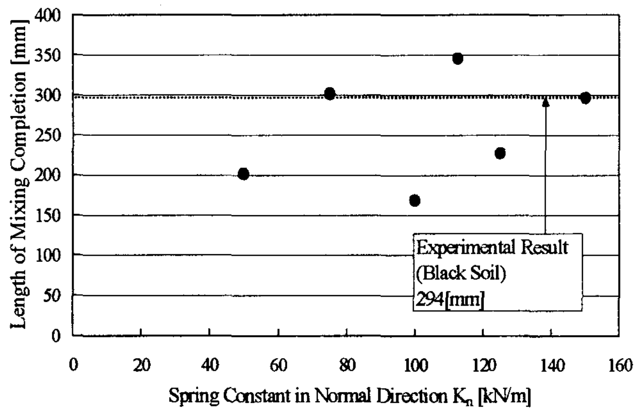


Figure 5 Relationship between the length of mixing completion and spring constant.

In this study, the spring constant for the black soil was obtained by the following equation.

$$k_n = \frac{W_1 C_1 + W_2 C_2}{W_1 + W_2} \quad (1)$$

Here, C_1 and C_2 are optimum spring constant for the processed volume and the length of mixing completion, respectively. W_1 and W_2 are weighted values for C_1 and C_2, respectively. In this study, W_1=4 and W_2=1. Then, the spring constant for the black soil is calculated as 120kN/m.

4. Effect of Several Parameters on the Mixing Performance

Several simulations were carried out by using the developed simulator and obtained optimum spring coefficient for the black soil, and effects of 1)rpm of the shafts, 2)paddle inclination angle, 3)pitch of the paddle and 4)packing rate on the mixing performance were numerically investigated.

4.1 RPM of the Shafts

Figure 6(a) shows the relationship between the rpm of the shafts and processed volume of the soil. Figure 6(b) shows the relationship between the rpm of the shafts and the length of mixing completion. Processed volumes of the soils increase with increasing the rpm of the shafts. On the other hand, the effect of the rpm of the shafts on the length of mixing completion is not significant, and the length of mixing completion is approximately 350mm.

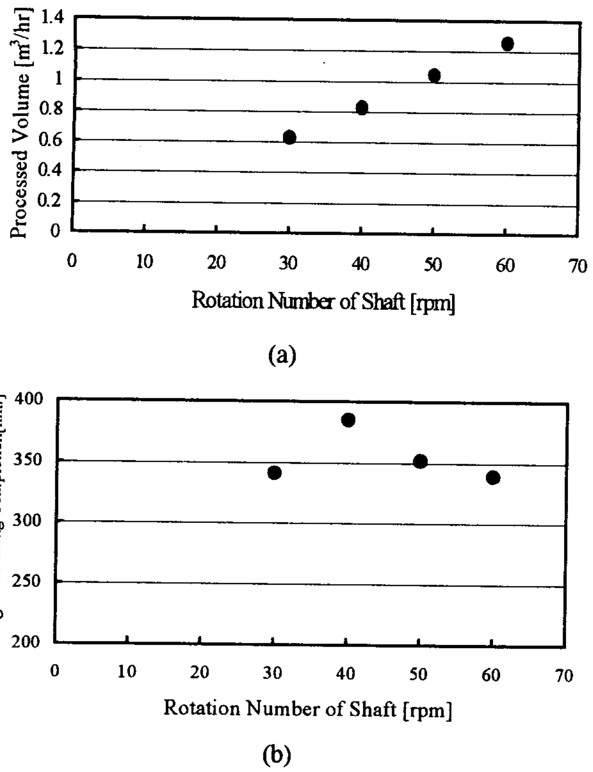


Figure 6 Effect of rpm of the shafts on the mixing performance: (a) Processed volume, (b) Length of the mixing completion.

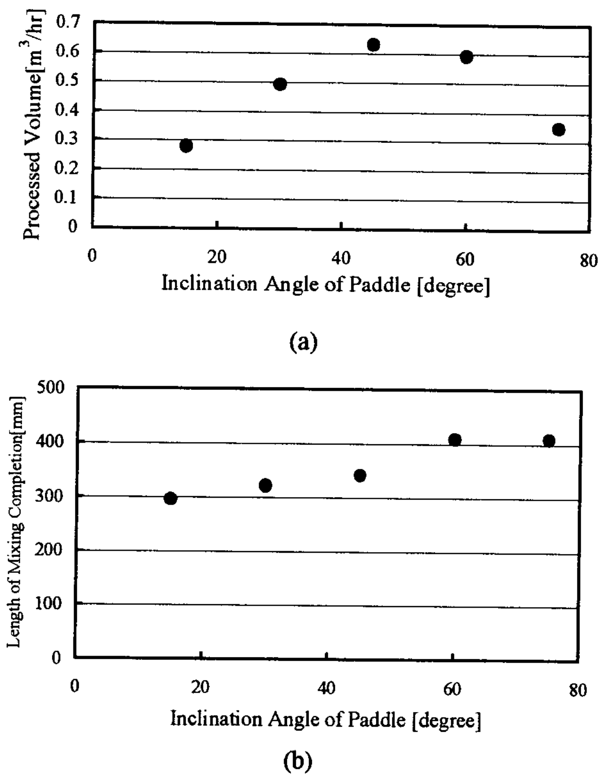


Figure 7 Effect of the paddle inclination angle on the mixing performance: (a) Processed volume, (b) Length of the mixing completion.

4.2 Paddle Inclination Angle

Figure 7(a) shows the relationship between the paddle inclination angle and processed volume of the soil. Figure 7(b) shows the relationship between the paddle inclination angle and the length of mixing completion.

Processed volume shows a maximum in the vicinity of 45 degrees. Therefore, it is found that the paddle inclination angle should be set at 45 degrees to achieve the high mixing performance. On the other hand, it is found that the length of mixing completion decreases with decreasing the paddle inclination angle. However, the difference between the value at 15degrees and 75 degrees is not so large. Therefore, it can be concluded that the paddle inclination angle should be set at 45 degrees.

4.3 Pitch of the Paddle

Figure 8(a) shows the relationship between the paddle pitch and processed volume of the soil. Figure 8(b) shows the relationship between the paddle pitch and the length of mixing completion.

Processed volume of the soil increased with decreasing the paddle pitch. Furthermore, the length of the mixing completion decreased with decreasing the paddle pitch. This means that the mixing performance of excavated soils and additives increases with decreasing the paddle pitch. However, small pitch will cause the

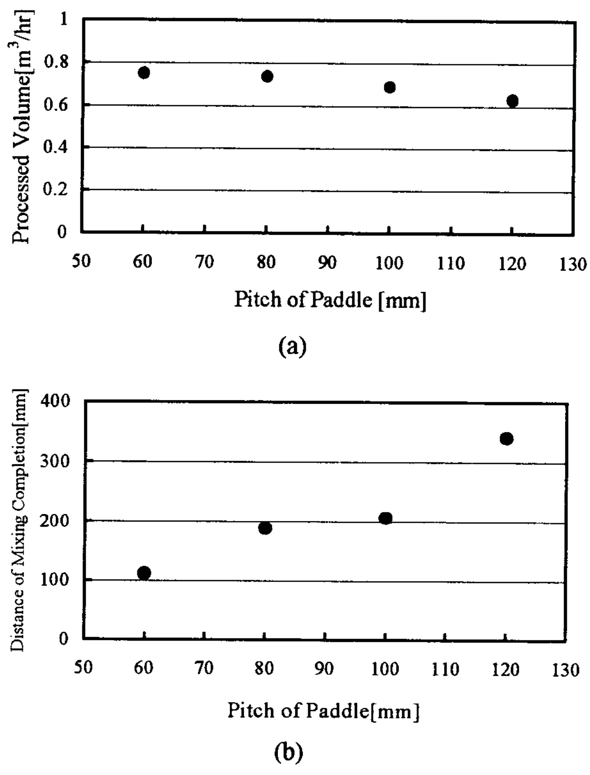
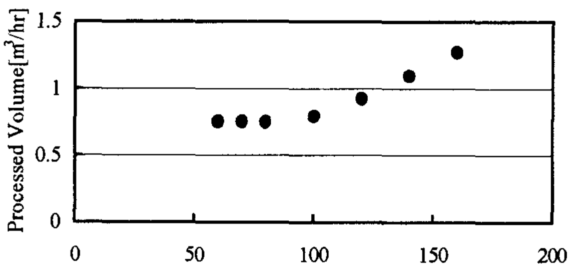


Figure 8 Effect of the paddle pitch on the mixing performance: (a) Processed volume, (b) Length of the mixing completion.

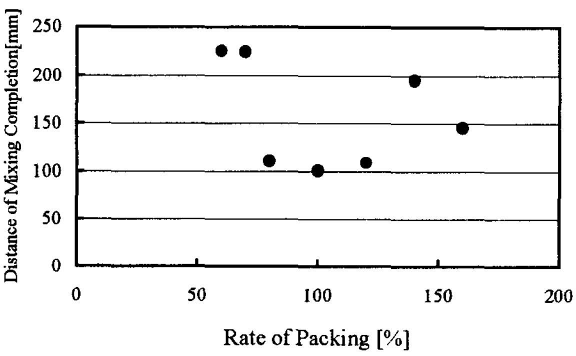
bridging of the excavated soils. Furthermore, if the paddle pitch is set to be small, many paddles are necessary. When many paddles interact with the excavated soils, large power is necessary to rotate the shaft because the friction between these paddles and soils is very large. The amount of the power which is able to be equipped is limited for the mobile type machine. Therefore, too small pitch of the paddle is not desirable from the viewpoint of the power consumption. Therefore, the paddle pitch should be determined by considering both the mixing performance and machine power.

4.4 Packing Rate

Figure 9(a) shows the relationship between the packing rate and processed volume of the soil. Figure 9(b) shows the relationship between the packing rate and the length of mixing completion. Processed volumes of the soil were almost the same in the range of 60-100% packing rate. However, they increased with increasing the packing rate over 100% packing rate. On the other hand, the length of completion was about 100-110mm in the range of 80-120% packing rate, but it showed a large value at both lower and higher packing rate. Therefore, it can be said that packing rate of the excavated soils in the mixing chamber should be restrained up to 100% packing rate.



(a)



(b)

Figure 9 Effect of the packing rate on the mixing performance: (a) Processed volume, (b) Length of the mixing completion.

5. Conclusions

In this study, the numerical simulator to analyze the mixing behavior of excavated soils and additives in the soil-recycling machine with dual shafts was developed. Furthermore, the mixing experiment was carried out, and the spring constant for the excavated soils, which is necessary for the mixing simulation was determined through the experiments. Numerical simulations were carried out by using the developed simulator and effect of the machine factors on the mixing performance was made clear. It was confirmed that the paddle inclination angle should be set at 45 degrees to achieve the high mixing performance.

Acknowledgment

A part of this study is financially supported by "Charitable Trust TATSUJIRO KATO Memorial Construction Machine Research Promotion Fund". We would like to express our appreciation for their financial support.

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