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EFFECTS OF CONSTRUCTION WASTE CLAY BRICKS ON GROWTH OF PEPPER AND IMPROVEMENT OF CLAY PROPERTIES

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Keywords: Construction waste, Resource utilization, Clay, Soil nutrients, Triaxial test

Abstract

Pot experiment, indoor detection and triaxial experiment were carried out to study the effects of construction waste clay bricks on the growth of pepper and improvement of clay nutrient and strength properties. The clay from southern Shaanxi was rolled and screened by 2mm, and the construction waste clay bricks were ground to 0-2, 2-5 and 5-7 mm. Construction waste with different particle sizes was mixed with clay in a mass ratio of 0:1 (CK), 1:1, 1:2, and 1:3. Construction waste accounted for 0, 50, 33 and 25% in the four mixed matrices, respectively. About 33~50% construction waste clay bricks with particle size of 5~7mm mixed with pure clay showed higher nutrient levels than that of pure clay. The plant height and yield of cultured pepper were the highest in construction waste clay bricks of 33~50%, with particle size of 5~7mm mixed with pure clay and the soil strength 33.2% higher than that of pure clay. This treatment provides sufficient nutrient conditions for plant growth. This not only provides sufficient nutrient conditions for pepper growth, but also meets the corresponding shear strength and suitability for clay area soil improvement, especially for clay slope stability improvement. The application value and prospect of using construction waste in land engineering construction and soil organic reconstruction and identified a new way of utilizing construction waste as a resource were explored.

Introduction

With the rapid development of China's industrialization, urbanization and urban civilization, a large amount of construction waste has emerged. Construction waste is all kinds of solid waste generated in the process of construction, renovation, decoration and demolition of various buildings, structures and their auxiliary facilities, mainly including waste soil, waste concrete, broken bricks, tiles, waste asphalt, wood, etc. According to its different sources, it can be divided into five categories: soil excavation waste, road excavation waste, building demolition waste, construction waste, and building material production waste (Zhu 2018). The discharge of urban construction waste in the country reached 2.10×10^{12}~2.80×10^{12}kg per year, accounting for 30-40% of the weight of urban solid waste (Zhu 2018). Due to the low utilization rate, most of the construction waste is directly transported to the suburbs for storage or landfill without treatment, resulting in a waste of land resources of hundreds of millions of square meters every year (Nie and Gao 2017, Zhou *et a*l. 2009 and Zhao *et al*.2021). Recycling of construction waste has become the development goal of the industry. The recycling rate of construction waste in China is less than 5% (Birgisdóttir *et al.* 2006, Wang 2014, Wang *et al.* 2014), and most of them are reused in the construction industry as building materials, coarse and fine aggregates, road basic materials, etc., and the consumption is extremely limited. Few studies and applications are carried out based on its physical and chemical properties, biological activities, etc., and it is even rarer to use it as a soil improvement material in planting and ecological environment restoration.

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In the existing cultivated land in China, the area that needs to be improved due to the sand or stickiness of the plough layer is 0.067×10^8~0.133×10^8 hm^2. Such a soil configuration cannot meet the needs of crops for coordinated supply of water, fertilizer, air and heat, which makes the root system of the plant grow slowly, and it is difficult to grow vertically. Therefore, appropriate improvement measures should be taken. At the same time, with the rapid development of China's economic construction, the instability of the slope has brought huge losses to people's lives, engineering construction and social economy. The occurrence of landslides is closely related to the strength characteristics of the sliding zone soil and the stress state on the sliding surface (Li *et al.* 2010, Cao and Li 2018, Gao *et al.* 2016, Wang *et al.* 2019). It is usually caused by the increase of the shear stress of the soil or the decrease of the shear strength of the soil.

In the present study, the porosity of clay bricks taken from construction waste was analyzed and different clay brick sizes and their clay proportions, retention characteristics, and shear capacity using a pot experiment and indoor test were analyzed. It was found that clay bricks from construction waste can be used as an improved clay material preparation of optimization scheme. The application value and prospect of using clay bricks in land engineering construction and soil organic reconstruction can be explored to enhance the cultivability of land and slope stability, and seek a new way of resource utilization of construction solid waste (Lu 1999, Bao and Dong 2005, Zhou *et al.* 2009, Li *et al.* 2013, Liang 2015, Li *et al.* 2015)

Materials and Methods

In the pot experiment pepper with short growth period was planted and easy fruit bearing, the variety was a hybrid generation of Yangling High Section Changshun Prince. In the experiment, the clay from southern Shaanxi was rolled and screened by 2 mm, and the construction waste clay bricks were ground to 0-2, 2-5 and 5-7 mm (Fig. 1). Construction waste with different particle sizes was mixed with clay in a mass ratio of 0:1 (CK), 1:1, 1:2, and 1:3. Construction waste accounted for 0, 50, 33 and 25% in the four mixed matrices, respectively. A round plastic flowerpot (30 cm high and 25 cm in diameter) with a construction waste of different particle sizes having bulk density of $1.3 g/cm^3$ was filled in order to ensure good water permeability of soil, a 5cm thick sand layer was laid on the bottom of the basin. Three replicates were set for each substrate treatment, and the experimental treatment is presented in Table 1. A1 in the table was the general name of the three replicates A11, A12 and A13, and the value of A1 was the mean value of the three replicates, and so on. During crop growth, the amount of water and fertilizer used in each treatment remained the same.

Fig. 1. Construction waste of different particle sizes.

Pepper seedlings were grown in seedling tray and transplanted into a pot. After seedling growth is stable, 1 plant in each pot was allowed to grow. The plant height of pepper in different treatments was measured every 7 days after seedling setting. After maturity, pepper was collected to measure production, and potted soil samples were collected to measure nutritional indexes.

Table 1. Test proportioning table.

Particle size of construction waste	0~2mm	2~5mm	5~7mm	CK
	A11	A21	A31	
A Construction waste content of 50%	A12	A22	A32	CK01
	A13	A23	A33	
	B11	B21	B31	
B Construction waste content of 33%	B12	B22	B32	CK02
	B13	B23	B33	
	C11	C21	C31	
C Construction waste content of 25%	C12	C22	C32	CK03
	C13	C23	C33	

According to the "geotechnical test regulations" (Ministry 2007), the triaxial specimens meeting the test requirements were prepared. Triaxial samples (diameter: 3.91 cm and height: 8 cm) were prepared by mixing construction waste clay bricks (0~2, 2~5, 5~7 mm) with southern Shaanxi clay at different mass ratios (50, 33, 25%). The moisture content of the sample was 13%, and the dry density was 1.3 g/cm3. The prepared sample was sealed with plastic wrap and marked. Three samples with each dosage were prepared, and unconsolidated and undrained (UU) shear tests were carried out at confining pressures of 100, 200 and 400 kPa, respectively, to obtain the relationship between the deviant stress and strain at the time of failure, and to obtain the regularities of the variation with the addition size and proportion of construction waste clay bricks.

The 5-point sampling method was used to collect 0~10 cm soil samples with potted sampling drill. Kjeldahl method was used to determine soil total nitrogen. Available phosphorus and available potassium were determined by flow analyzer. Organic matter was determined by exogenous heating method of potassium dichromate. Fresh soil samples are baked at 60℃ in the oven until constant weight.

After ripening, the plant height was measured and the yield was weighed. Microsoft Excel 2013 and SPSS 18.0 software were used for statistical processing and mapping of data (Zhao *et al.* 2021).

Results and Discussion

Effects of different particle sizes and proportions on pepper height are shown in Fig.2, and the growth of pepper is shown in Figs 3-4. The average pepper height varied significantly with the increase of time during the whole growth period.

When the particle size of construction waste clay bricks was 0-2 mm, the average plant height of pepper in pot containing 25% waste (C1) was the highest (17.82 cm), the plant height of pepper containing 33% waste (B1) was 7.95cm, and the plant height of pepper containing 50% waste (A1) was the lowest (4.54 cm). When the particle size of construction waste clay bricks was 2-5 mm, the plant height of pepper in pot with 25% waste content (C2) was the highest (27.36 cm), followed by the plant height with 33% waste content (B2), and the plant height with 50% waste content (A2) was the smallest. When the particle size of construction waste clay bricks was 5-7 mm, the plant height of pepper in pot containing 50% (A3) of waste was the highest, which was

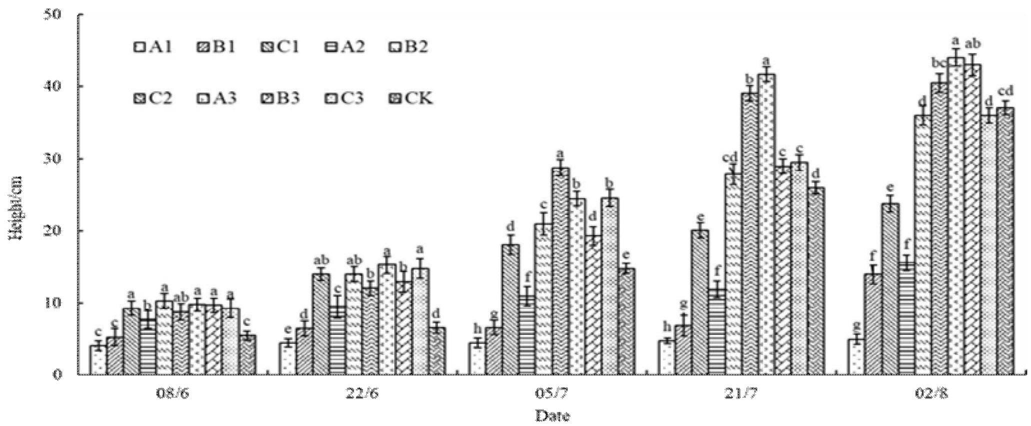


Fig. 2. Comprehensive pollution index of heavy metals in surface soils.
Different lower-case letters indicate significant difference（$p < 0.05$）between treatments. The same below.

Fig. 3. Growth of potted peppers with the same proportion and different particle sizes.

Fig. 4. Growth of potted peppers with the same particle sizes and different proportion.

28.88 cm, followed by pot containing 33% (B3) of waste and pot containing 25% (A3) of waste, which were 24.2 and 23.77 cm, respectively. Comprehensive analysis showed that the average plant height of potted plants with 5-7mm particle size was 23% higher than that of potted plants with 2-5 mm particle size and 53% higher than that of potted plants with 0-2 mm particle size. The height of all potted plants was as follows: A3 > C2 > B3 > C3 > B2 > CK > C1 > A2 > B1 > A1.

When the particle size was 5-7mm and the content of construction waste clay brick was 50%, the pepper plant height was the highest and the most suitable for pepper growth.

Results of the influence of construction waste clay bricks with different sizes in different proportions on the contents of organic matter, total nitrogen, available phosphorus and available potassium in potted soil is presented in Fig. 5. The soil nutrient index standard in the New Cultivated land Quality Standard of Shaanxi Land Consolidation Project (Trial) was used to evaluate and analyze the data. The soil nutrient index standard were ≥ 2.0 g/kg for organic matter, ≥ 0.3 g/kg for total Nitrogen, ≥ 2.0 mg/kg for available phosphorus and ≥ 20.0 mg/kg for available potassium. Soil nutrients are essential to crop growth and is also one of the important indicators for evaluating soil fertility. Its utilization rate is a key factor for evaluating high and stable crops yields (Li 2017, Huang *et al.* 2019, Friedel and Ardakani 2021).

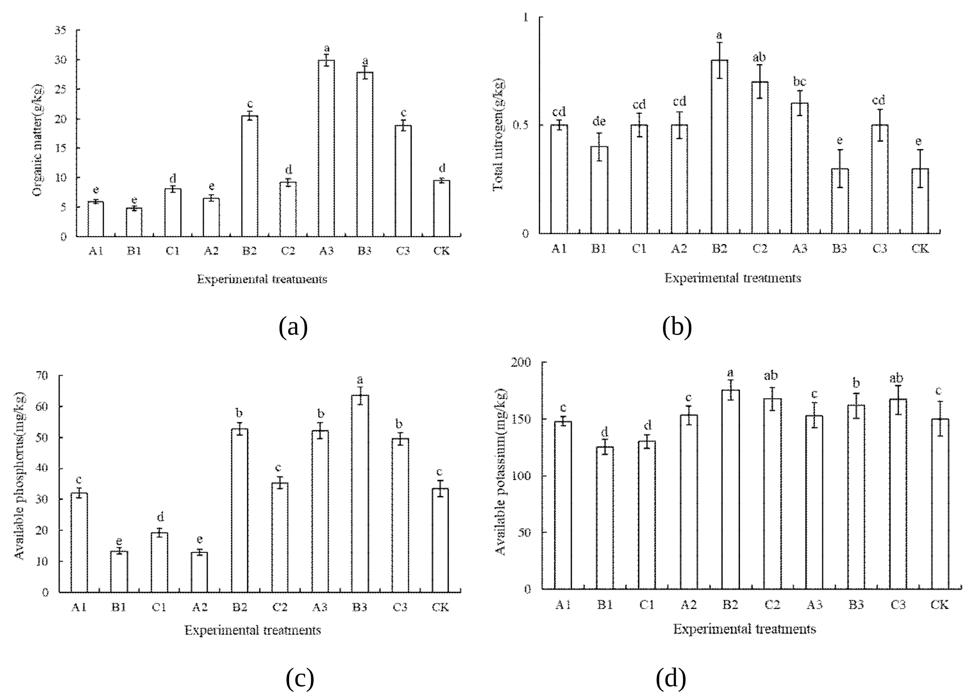


Fig. 5. Nutrient content of potted soil samples with different particle sizes and proportions.

The contents of organic matter in potted soil samples with different particle sizes and different proportions were higher than the standard value (Fig. 5a). There was no significant difference in soil organic matter content of pot with the same particle size (except 2~5 mm). And there was a significant difference in soil organic matter content of pot with the same particle size ($p < 0.05$). The contents of organic matter in A3, B3 and C3 were higher than the standard value of 2 g/kg and CK value of 9.5 g/kg. The content of A3 was the highest at 29.9 g/kg, followed by that of B3 at 27.8 g/kg. This indicated that the addition of 5-7 mm particle size can regulate the release of nutrients in the original soil and change the growing conditions of the peppers, thus promoting the accumulation of organic matter, which is suitable for clay improvement. The organic matter of A1, B1 and C1 is lower than that of CK, indicating that the addition of 0~2 mm particle size affects the release of organic matter content and is not suitable for clay improvement materials.

The total nitrogen content of potting soil samples with different particle sizes and different proportions showed no significant difference, which was higher than the standard value of 0.3 g/kg and CK value of 0.3 g/kg (Fig. 5b). The total nitrogen content of potted soil samples with diameters of 2-5 and 5-7 mm was higher than that of 0-2 mm. These means that the total nitrogen content of potted soil samples with diameters of large was higher than that of small. The newly purchased soil mixed with abandoned building clay bricks has a high total nitrogen content due to its strong absorbability and fertilizer retention, as well as certain nutrients in the soil parent material. The total nitrogen content of B2 was the highest at 0.8 g/kg, which was 2.7 times that of the CK soil, followed by C2 at 0.7 g/kg, and B3 at the lowest at 0.3 g/kg, which was the same as that of the CK soil.

The content of available phosphorus and available potassium is very important for crop growth and is an important nutrient element of soil nutrients (Zhou and Shen 2013, Wang 2014, Zeng *et al*. 2014). Available phosphorus and available potassium contents of different treatments are presented in Fig. 5cd showed that there was no significant difference in available potassium content among different treatments. The available phosphorus content of potting soil samples with particle size of 5-7 mm was significantly different from that of the other two treatments. The available phosphorus content of potting soil samples with particle size of 5-7 mm was higher than that of the other two groups, and was higher than CK value of 33.4 mg/kg. The construction waste content of 33% (B3) was the highest, which was 63.5 mg/kg and 4 times higher than the minimum content. These showed that the particle size and proportion are suitable for clay amelioration The available phosphorus content of potting soil samples with diameters of 0~2 mm was the lowest, which was lower than CK value, indicating that the diameters were not suitable for clay improvement. At the same time, by comparing the data of organic matter content, it was found that soil samples with high organic matter content had high content of available phosphorus, because soil with high organic matter content had weak phosphorus fixation effect. The available potassium content of all pot culture soil samples was higher than the standard value of 50.0 mg/kg. The available potassium con-tent of potted soil samples with the particle size of 0-2 mm was lower than that of the other two groups, and 150 mg/kg lower than CK value, indicating that the particle size was not suitable for clay improvement. The available potassium content of potted soil samples with diameters of 2-5 mm and 5-7 mm was between 153 and 175 mg/kg, which were higher than CK value. The highest content of B2 was 175 mg/kg, and the lowest content of A2 and A3 was 153 mg/kg, which were suitable for clay improvement. Waste clay bricks improved permeability of clay and accelerated plant root metabolism. Metabolites from plant roots activate soil K and convert it into available K to meet crop physiological needs. With the different diameters of the construction waste clay bricks, the improvement effect of clay is different, so the metabolic activity of plant roots is obviously different, so the improvement of soil available potassium is obviously different.

Results of the yield of pepper in pot with different particle sizes and proportions showed that there was no significant difference in pepper yield between different treatments (Fig. 6). There was significant difference between the yield of pepper with different treatments and CK. These means that adding construction waste with different particle sizes in different proportions did not affect the yield of pepper, but contributed to the increase of pepper yield. According to the analysis in Fig. 6, the total output of potted plants with diameters of 5-7 mm was the highest (74.32 g), followed by those with diameters of 0-2 mm (62.20 g), and those with diameters of 2-5 mm (53.88 g). When the particle size was 5-7mm, the yield of pepper in pot containing 25% construction waste (C3) was 31.74 g, which was 5 times higher than CK. This might be because the potting soil with large construction waste particle size has relatively large pores and good air permeability, which is conducive to the growth of crop roots. At the same time, the nutrient content is relatively high, and the root system is easier to absorb nutrients, which is conducive to crop growth and yield improvement.

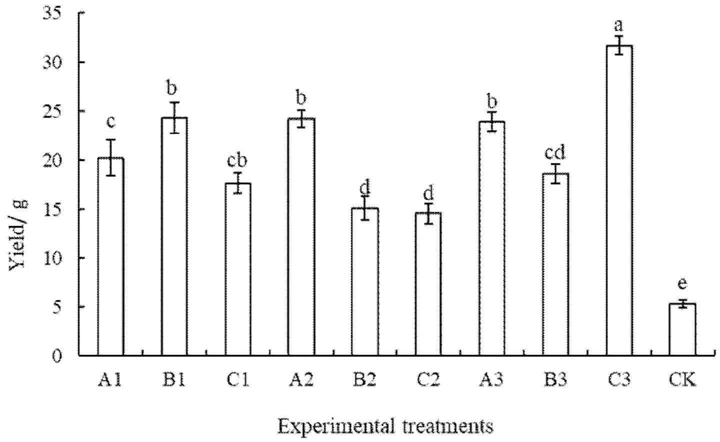


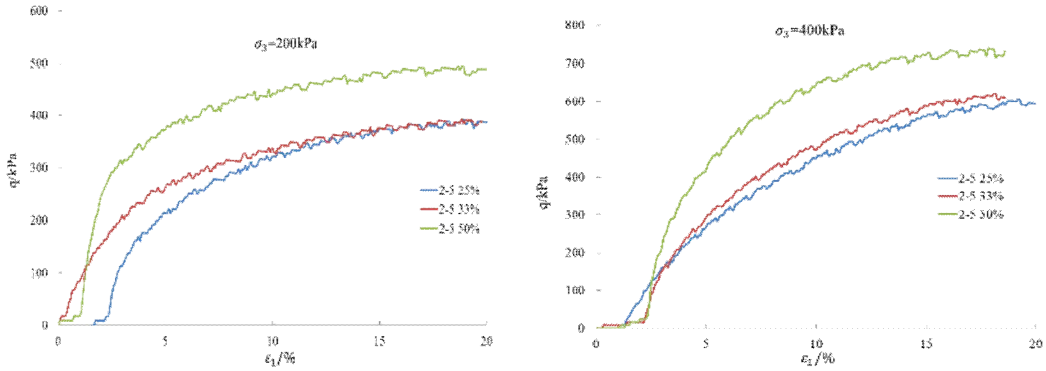
Fig. 6. Yield of chilies with different particle sizes and proportions.

The difference in confining pressure, construction waste content and particle gradation has an important influence on the meso-structural characteristics of composite soil, which can be divided into "suspension dense structure", "compact-skeleton structure" and "skeleton-void structure". The difference structural characteristics affects the strength characteristics to a large extent (Fei *et al.* 2015, Zhang 2015, Tang *et al.* 2018, Kyambadde *et al.* 2014, Wen 2015), as shown in Fig. 7.

Fig. 7. Influence of different particle size and confining pressure on soil failure mode.

The deviation stress-axial strain relationship (stress-strain relationship) of construction waste clay bricks with the same particle size and confining pressure and different contents is shown in Fig. 8. All samples showed strain hardening characteristics.

After reaching 3%, it grew slowly, showing strain hardening characteristics. When the content of waste clay bricks was 50%, the deviational stress is much higher than that of the other two groups, and there was little difference in the deviation stress of the other two groups. Therefore, there was an obvious relationship between deviation stress and construction waste content, but the construction waste content was different under different confining pressures.



（a） （b）

Fig. 8. Stress-strain curves of different contents under the same confining pressure.

Figure 9 showed the relationship between peak strength and addition amount of the same particle size under different confining pressures. When the confining pressure was 100 kPa and the content of waste clay brick was 33%, the curve showed an upward trend and the failure strength increased gradually. This might be due to the fact that when the content of construction wastes was small, they are dispersed in the soil in a suspended state, which is equivalent to replacing part of pure soil with higher strength construction wastes, so that the strength of the sample was relatively improved. At the same time, the skeleton of soil-rock mixture is formed, and the interlocking and interlocking effect between particles was constantly enhanced, which was reflected in the strength enhancement. But increased to 50% when the content of construction waste, the curve was falling, strength reduced instead, this is because along with the increase in content of construction waste, fine particle content was less, fine particles between the cohesive force of sharply reduced, at the same time building waste produced more space between failed to fill completely compacted by clay, leading to mild decline (Zhao *et al.* 2017, Hu *et al.* 2018, Wang and Zhan 2011).

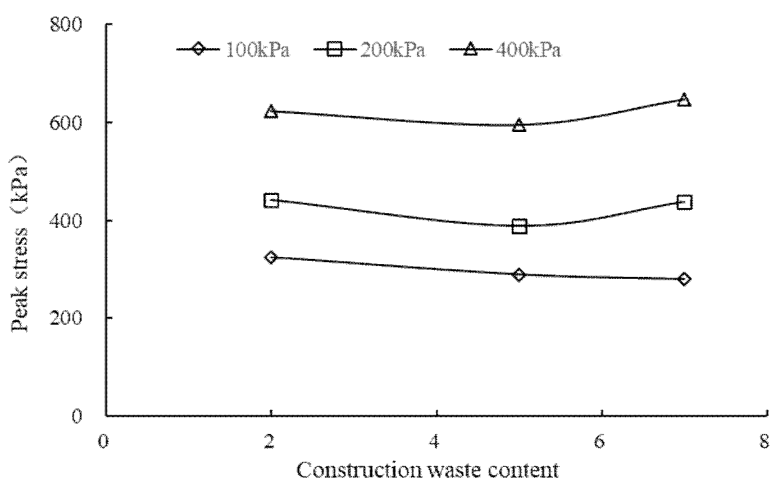


Fig. 9. Relation curve between peak deviatoric stress and construction waste content.

When the confining pressure increased to 200 and 400 kPa, the curve showed a rising trend, and the strength increased with the increase of construction waste content. This is because under high confining pressure, the gap between construction wastes can be reduced, so that the sample can reach a dense state. The increase of construction waste content also increased the skeleton function gradually formed by it in the sample, and the soil was more dense than other clays, which can share the load borne by clay particles and contribute to the transfer of force, and then the partial stress of the sample increases.

When the content of construction waste clay bricks was 25%, the deviation stress-axial strain relationship (stress-strain relationship) of different particle sizes under three kinds of confining pressures (Fig. 10).

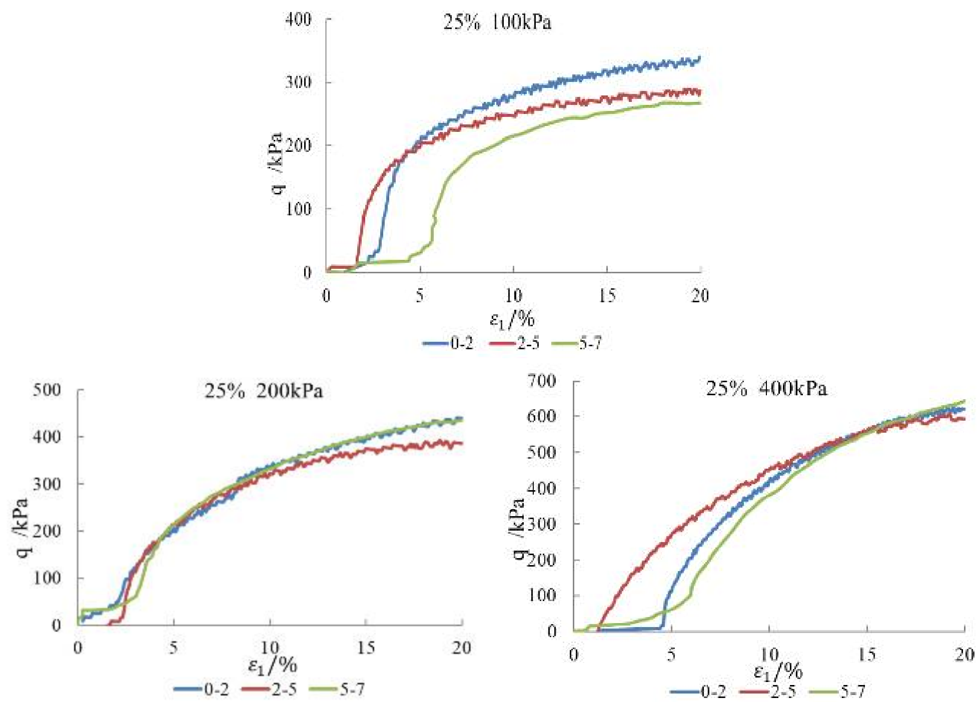


Fig. 10. Stress-strain curves of different particle sizes under the same confining pressure.

When the confining pressure was 100 kPa and the axial strain was before 7%, the three curves rised rapidly. After the axial strain reaches 7%, the three curves developed horizontally. When the confining pressure increases from 100 to 200 and 400 kPa, the three curves also rise rapidly before the axial strain reached 7%, and grow slowly after the axial strain reached about 7%, showing strain hardening characteristics. The strength changes of the three curves are almost the same. In order to show it more clearly, the relationship between peak intensity and particle size of construction waste clay bricks under different confining pressures and the content of 25% clay bricks is shown in Fig.11. According to the three curves, there was little difference in strength between different particle sizes, ranging from 8% to 14%.

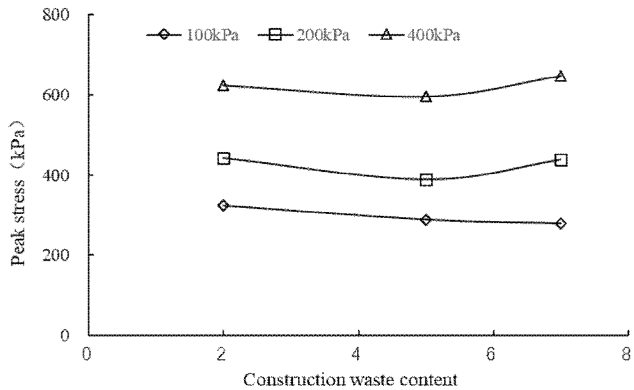


Fig. 11. Relationship curve between peak deviatoric stress and particle size of construction waste.

From the study it may be concluded that plant growth and slope stability should be considered comprehensively when clay bricks from construction waste are used as clay improvement materials. In the present study, pot, field, and mechanical experiments were carried out to improve the clay properties using construction waste clay bricks. When construction waste with a particle size of 5-7 mm and a content of 33-50% was mixed with clay, the soil content levels of available phosphorus, potassium, organic matter, and peppers yields were higher than those with other compound forms. At the same time, the strength of the composite soil was 33.2% higher than that of pure soil. Therefore, the improved soil can not only provide sufficient nutrient conditions and meet the performance conditions of water and fertilizer preservation, but also achieve the corresponding shear strength.

This study focused on construction waste and analyzed the feasibility and theoretical basis of mixing construction waste with clay of different sizes and shapes to be used as clay improvement materials and to seek a novel way utilizing construction waste as a resource. The soil analysis results indicate that construction waste is feasible as a resource for improving soil strength and fertility. The recycling of construction waste into a resource improves the efficiency of natural resource use, minimizes environmental pollution, and contributes to sustainable development. To further improve the utilization of construction solid waste as a resource in urban development and land engineering construction, future research should focus on the basic properties of water conductivity, bulk density, water transport law, and aggregate after the combination of construction solid waste and clay.

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