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Measurement of grass root reinforcement for copper slag mixed soil using improved shear test apparatus and calculating formulas

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ABSTRACT

The root permeated copper slag mixed soil is a effective way to reinforce soft soil and dispose the copper slag. In order to better investigate the strength rule of it, firstly, a new shear test apparatus is developed for the purpose of measuring the root reinforcement for copper slag mixed soil. The utilized apparatus has a much larger measurement range compared to the traditional apparatus. Secondly, based on the developed measurement equipment, the formulas for calculating the shear strength of the mixed soil is derived by taking a full consideration on the dynamic changes of the effective shear area. Thirdly, 4 different kinds of soil samples are chosen and tested in a case study to demonstrate the use of the apparatus. The calculation of the shear strength between the traditional formula and the newly proposed method is compared in the measurement results. Finally, the reinforcement effect of Bermuda grass roots on copper slag-soil mixture is studied. The influence of weight percentage of copper slag, roots content, and moisture content on the shear strength of mixed soil are investigated. The authenticates results showed that the soft clay in combination with copper slag and root of grass has promising mechanical properties over the original soil in geotechnical engineering applications.

1. Introduction

The increasing global urbanization and economic growth have resulted in an increase of wastes generated over the past decades [1]. As a major kind of solid waste, cooper slag is a by-product obtained during the smelting and refining process of copper metal, approximately 68.7×10^6 tons of copper slag is generated per year from the world copper industry. In China, the annual production of copper slag is nearly 20.25×10^6 tons which is the uppermost production between all nations and shared about 29.47% of world's production [2,3]. This leads to a large required area for disposal of the waste and would cause potential risks of pollution [4,5]. It is a challenge task for the engineers to dispose the copper slag in a sustainable way. Possible ways of treating the copper slag waste is to recycle it and use it in the concrete mixture. For example, its use in the pavement improvement has been reported in [6–10]. In fact, the copper slag has a great potential for the use in reinforcing soil materials. However due to angularity of copper slag particles, the soil strength may be reduced and the soil structures may suffer certain installation damages [11]. When using copper slag-clay mixture to replace the soft soil at the slope surface, the strengthening effect is remarkable at beginning, but however the mixture are prone to softening later of the time which might finally lead to slope failures [12]. Reinforcement by the root of plant grass is potentially a cost-effective and environment-friendly method for improving the strength of mixed soils [13–20]. The reinforcement of grass root depends on the interaction between the grass roots and the soil geotechnical parameters which are relevant to soil strength. The best advantage of this method is the medium–long term effect. That is, the soil structures become self seeded over time. Then the reinforce effect of grass root starts to take place and the effect will not be weaken due to the natural regeneration of grass roots [21,22], so permeating plant root to the mixture is a effect way to sustain the stability of the mixture. The medium–long term reinforcing effect of grass root on copper slag mixed soil is expected to be remarkable and worth for a study for the future development of pavement improvement.

The study on the reinforcement of root-permeated mixed soil (copper slag mix with soil) has significant meanings. Not only because it helps to recycle the generated copper slag, but also the medium–long term effect of grass root could help to ensure the stability of geotechnical engineering structure. Unfortunately, researches on the use of root-permeated mixed soil is rarely seen, only limited studies on the measurement of mechanical properties of metal mixed soils are reported in [23–28]. The influence of weight percentage of copper slag, moisture content, and grass roots content to the mechanical properties

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of mixed soils needs to be investigated. This has to be done by a series of accurate experimental studies and theoretical analysis. The most important experiment is the shear tests which measured the strength of copper slag-soil mixture permeated with grass root [29,30]. However, the traditional equipment for measuring the shear strength has very limited measurement range and unchangeable specimen size which could not meet the experiment requirement in this study. Moreover, the traditional analytical method for estimating the shear strength from the measurement is no longer applicable for the mixed soil problem. During the shearing process, it is very likely to have some relative movement between the specimen box and the shear test equipment. The effective shear area is in fact gradually decreasing in the whole measurement process [31]. The traditional formula used to calculate the shear strength assumes the shear area to be constant. However, this is definitely not the case in reality. For example, when doing the shear test to the soil, the moisture content can be changed in certain extent. Therefore, if it is used to calculate the shear strength from the traditional measurement, it might give overestimated results [32–34]. The traditional shear test apparatus and traditional formulas need both improvement to investigate the mixed soil problem in the present study.

Above all, this study aims to improve the accuracy of traditional shear test experimental method for the purpose of measuring the strength of copper slag mixed soil with Bermuda grass roots. The previous studies are focused on the effect of grass roots on shear behavior of soil or the mechanical properties of slag mixed soil, based on those, this paper aim to study the effect of grass roots on shear behavior of copper slag-soil mixture and investigate the change rule of shear strength. The paper is organized as follows. Section 2 will provide an overview of the existing techniques in the literature for shear test measurement. Section 3 will then introduce the setup of an improved shear test apparatus for measuring the shear strength of mixed soil. Based on this measurement apparatus, the exact formula for calculating the shear strength of the soil will be derived and given. Section 4 then present a case study for calculating the strength of copper slag mixed soil with grass root reinforcement. The analysis will also investigate the optimum scenarios of weight percentage of copper slag, roots content, and moisture content in obtaining the desired soil mixture. The final conclusions and findings are summarized in Section 5.

2. Literature review

2.1. Recycle of copper slag

Many former experiments have been done on the copper slag, the investigations show that copper slag are non-toxic and possess no environmental hazard even under extreme environmental and weather conditions [35–38]. Several studies have demonstrated various ways of using the copper slag, for example, by means of raw material in cement production [39,40], substitute of sand in concrete [41,42], fine aggregates [43–46] and coarse aggregates in asphalt and concrete pavements [47], base course of flexible and rigid pavements [48], ballast and fill [49], abrasive [50], and bricks [51]. Bharati et al. [19] studied the use of copper slag in cement-treated Singapore marine clay and they concluded that the compressive strength of cement-treated clay can be increased by increasing the amount of copper slag mixed in the cement content. However, the compressive strength of the mixed concrete remained the same at low cement content. Nikolov et al. [32] have studied the cohesion effect between copper slag and bitumen and it was found the cohesion is very strong. Murari et al. [1] have found the properties of mixed concrete can be enhanced by using copper slag from experimental studies. They found that the addition of copper slag could help to increase the strength of the pure concrete by a percentage around 60–70%. If the optimum mixing scenario is adopted, the strength can be increased even higher. Behnood et al. [16] studied the utilisation of copper slag as aggregates in the cold in-place recycling mixtures and found the moisture resistance of the mixture can be largely enhanced. Hassan and Al-jabri [17] investigated the indirect tensile strength of hot-mix asphalt concrete containing copper slag aggregate. They also reported the material mechanical properties can be improved by the slag material. Oluwasola et al. [18] once concluded that the substitution of 20% copper mine tailing in asphalt mixture can be applied for the construction of roads. Prasad and Ramana [6] had conducted studies on the interaction between geogrid and copper slag from pullout tests and demonstrated that copper slag can be effectively used as a fill for reinforcing soil structures. Above all, the literatures about the recycle of copper slag are focused on the ways of application, substitution rate of copper slag in mixture, strength increased percentage, and so on.

2.2. Reinforcement of root

Recent years, using the grass root as ways of reinforcing the strength of soil has become popular as it is a bio-geotechnical and effective method [52–54]. The tensile strength of grass root are important which can significantly affect the soil mechanical properties [55–56]. However, the shear resistance of root-permeated soils enhancing by grass roots in soil is always estimated based on simple force equilibrium theory and limited experimental data [57]. Norris [7] investigated the grass root reinforcement of natural vegetation growing on a slope of M11 motorway in south-east England. It concluded that the failure of the grass roots can be categorized into three modes: Mode A: single root failure with rapid rise in pull-out resistance; Mode B: double peak failure of a forked or branched root and Mode C: stepped failure with multiple branches failing successively. Greenwood [33] produced a straightforward computer program (called SLIP4EX) to investigate the vegetation effects of enhanced cohesion, changed water pressures and root reinforcement forces on soil reinforcement. Pollen and Simon [36,40] estimated the shear resistance contributed by roots for root-permeated soils by applying a fiber bundle model to estimate, in which the external load is assumed to be carried by a bundle of parallel roots. Thomas and Pollen-Bankhead [37] adopted the fiber bundle model in association with Monte-Carlo simulations to investigate the effect of root orientation on root reinforcement. Fan C [9] presented a displacement-based model for predicting the relationship between the increase in shear resistance and shear displacement for soils permeated with grass root system. The study showed that the value of shear displacement increases significantly with the value of shear resistance. The short roots play an important role in the contribution of root systems to the shear resistance of the soil. Ye et al. [41] evaluated the effects of Bahiagrass root distribution characteristics on soil shear resistance and soil detachment rates. It concluded that the root area ratio is the most significant parameter that governs the soil reinforcement. Liang et al. [48] used a geotechnical centrifuge to achieve a comparable soil stress states and investigated the potential to use plant roots in small scale tests of slope failure, the results showed that 1:15 scale between rooting depth and root reinforcement was a suitable compromise for studying slope failure in a geotechnical centrifuge. AK Leung et al. [50] investigated the influences of transpiration-induced suction and mechanical reinforcement of different root geometries to the slope stability subjected to an intense rainfall with an intensity of 70 mm/h, the results revealed that heart-shaped roots induced higher suction, leading to 14% reduction of rainfall infiltration and 6% increase in shear strength, it can provide greater stabilization effects to sand slope than tap-shaped roots. Above all, the literatures about the reinforcement of root are focused on the shear resistance of soils enhancing by roots, the reinforcement mechanism, the root distribution ratio, and so on.

2.3. Limitation of past works

Base on the above literature review, it can be concluded that no research works has been done on the measurement and analysis of reinforcement of root-permeated soils mixing material (slag mix with