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Modification of silty clay strength in cold region's pavement using glass residue

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ABSTRACT

In cold regions, freezing and thawing of soil can make some intense changes in mechanical and geotechnical properties of it. This paper, for the first time, focuses on the effect of adding a newly identified fine grained material so called glass residue attained from glass production plant, in modifying the mechanical behavior of fine grained soil after experiencing numerous freeze-thaw cycles. For the purpose, cylindrical samples of silty clay-glass residue mixture were evaluated through uniaxial compression and splitting tensile strength test after 0 cycle and 3, 6, 9 and 11 cycles of freezing-thawing. The results show using glass residue can help the soil treatment in terms of tension and compression strength. In addition, the highest modification obtained at 14 days of curing. Furthermore, glass residue lowers the strength reduction during freeze-thaw cycles. The amount of strength loss (compression, tension) of samples without stabilizer and others with 10%, 15%, 20% of glass residue are (65%, 70%), (48%, 66%), (35%, 57%) and (41%, 54%), respectively.

1. Introduction

Freezing annually generates significant damage to various fields such as road, building, and dam construction in cold regions. The assessment of the changes caused by freeze-thaw cycle and the efforts to be made to finite the undesirable effects of freezing are two main challenges for geotechnical researchers in permafrost regions. Therefore, soil retrofitting is needed to increase strength against freezing along with improving soil mechanical properties. Qi et al. (2006) drew conclusion that pure loose soils became denser against dense ones; and both loose and dense samples have been had the same void ratio after Freeze-Thaw Cycles (FTCs). Wang et al. (2015) found that the denser specimens of silty soil showed inflation deformation against those with lower degree of compaction after FTCs. Wang et al. (2017) revealed detailed structural changes such as moisture redistribution, void ratio, and dry density variation through scanning pure specimens of clay before and after FTCs by three-dimensional (3D) X-ray computed tomography. It was found short-term volumetric shrinkage ratio related to the freezing temperature and had a linear relationship with the freeze equilibrium time.

Nowadays, utilizing waste materials such as rubber, plastic, glass jars, geosyntheitics, cement, bitumen, and some others from various industries has been significantly developed to improve the mechanical behavior of soils. In the last decade, crushed glass, glass waste, micro and nano silica have been introduced as the most popular glass derivatives used for soil improvement.

Grubb et al. (2006a,b) declared that the addition of crushed glass to dredged material causes significant improvements in the physical properties of dredged material, including reduction in moisture content, organic content, and plasticity index as well as coarsening the grain size distribution and improvement in Cone Penetration Test (CPT) results. Grubb et al. (2008) also concluded that using crushed glass is more economical than other methods of dredged material stabilization such as using Portland Cement (PC). From Ooi et al. (2008), Fauzi et al. (2016), Marcus et al. (2017), Mishra (2017) and Nirmala and Shanmugapriya (2017), it can be concluded that using glass powder/ fiber and fine grain crushed or recycled glass have beneficial effect on improvement of shear strength, California Bearing Ratio (CBR) value and internal friction angle of pure soil as well as decrease in Plasticity Index (PI) and optimum water content; and also is more functional than asphalt pieces/ plastic strips as a soil modifier.

Disfani et al. (2011) proved the applicability of Recycle Crushed Glass (RCG) as a replacement material in road construction regarding higher shear resistance, lower water absorption and optimum water content, higher maximum dry unit and internal friction angle of medium RCG rather than fine RCG sample. The results of Confined-Drained (CD) triaxial shear test confirmed the findings of direct shear tests. So, coarse recycled glass was found to be unsuitable for

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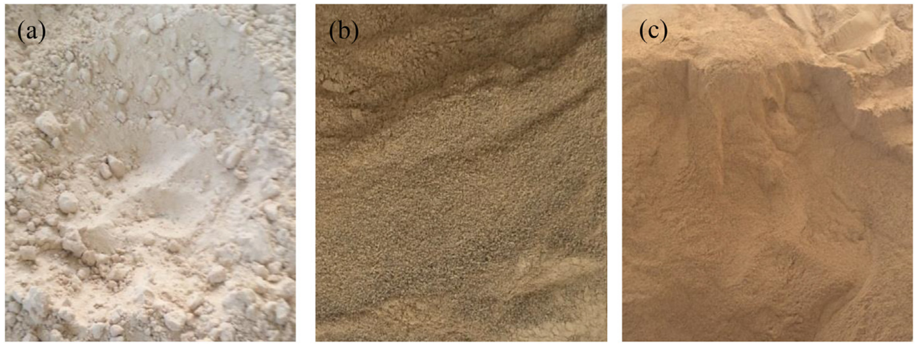

Fig. 1. GR (a), silt (b) and clay (c).

geotechnical applications. Arabani et al. (2012) expressed that the use of cement-crushed glass-sand combination could be useful to increase the strength and decrease the settlement of embankments. Güllü et al. (2017) added different glass content to the clayey cement-based grout samples with different water content. The results showed that Unconfined Compressive Strength (UCS) of samples increased alongside decreasing water content and increasing the curing time. The replacement of glass powder by 3% produces better UCS response.

Among new chemical additives, Latifi et al. (2017a, b) proved the enhancement of mechanical and chemical specifications of white clay and bentonite after adding low-carbon sodium silicate and a new calcium-based powder attained from biomass silica. Al-Bared et al. (2018) used Recycled Blended Tiles (RBT) as a derivative of ceramic factory to stabilize marine clay on the basis of high sodium and magnesium percentage. Using nanomaterial as soil stabilizer were utilized by Tabarsa et al. (2018) who test nanoclay-natural loess blend through laboratory and in the field tests at the Gonbad dam irrigation channel site.

Some experimental and theoretical studies have been carried out about soil freezing. These efforts concentrated to estimate the engineering parameters of soils at different manners (naturally or artificially frozen, moist, and thawed after freezing).

Hohmann-Porebska (2002) introduced kaolinite as a more effective mineral than smektite in changing the geotechnical properties of frozen clay based on the experimental tests. Yarbesi et al. (2007) showed the enhancement of UCS and CBR values against FTCs increase by adding lime, PC, waste materials from Ferro chromate factories, spherical glass from waste heat plants and waste aluminium plants. In addition, the strength loss of unmodified samples decreased significantly by adding modifiers.

Some researchers concentrated on other new/recycled materials to introduce in cold regions as an additive/modifier/stabilizer. Kalkan (2009) used micro silica for landfills; Christ and Park (2009) added rubber granule to frozen sand; Ghazavi and Roustaei (2010) conducted some Unconfined Compression Tests (UCTs) on reinforced clay by fiber under freezing-thawing; and Zaimoglu (2010) studied polymer fibers-soil strength modification. Gullu and Hazirbaba (2010) used geofiber to prevent the amount of CBR range under freezing-thawing cycles in both saturated and unsaturated samples. Ghazavi and Roustaie (2013) provided modification of clay by means of geotextile layers attained from waste tire. Chaduvula et al. (2014) studied on polypropylene-soil mixture.

The effect of moisture content and FTCs on clayey and silty pavement subgrade behavior has been studied by Liu (2016), using Drucker Prager Cap model. The results showed that the specimens with lower moisture content have exhibited higher yield stresses at the same volumetric strain. Also, the maximum deformation of subgrade with high elastic modulus of asphalt and base, and a situation with low moisture content and freezing condition became low. L- Tremblay (L-Tremblay et al., 2017) reported that samples containing glass under FTCs were damaged faster than the pure mixture however, both group of samples (pure and stabilized) reached identical damage after 10 cycles. Glass and basalt fiber fractions in various percentages were mixed with a kind of fine-grained soil by Orakoglu and Liu (2017) to conclude that the strength of unreinforced soil reduces with increasing number of the FTCs while fiber-reinforced soil has shown greater effect; and the amount of strength reduction has reduced from 40% to 18%.

Having these results in mind, it is obvious that there is no research data in the literature about using Glass Residue (GR) among other glass derivatives and its effect on tensile strength in order to soil modification in spite of being a popular waste material. Considering the knowledge gap on the geotechnical characteristics of waste glass in general and particularly on the one produced in Qazvin, Iran, laboratory tests such as uniaxial compression test and splitting tensile strength have been conducted to investigate the improvement of silty clay by various GR contents during different FTCs. The stress–strain behaviors have also been discussed for the contribution to the elasticity modulus. This study is believed to be beneficial for both soil improvement and environmental affairs.

2. Experimental method

2.1. Material

The soil which has been used in this research is a rebuilt silty clay, CL-ML (clay-silt ratio is 1:1) based on unified soil classification system (ASTM D2487, 2006b) provided by clay mine near Qazvin city. Noticeably, the effects of FTCs are more considerable in fine-grain soils in comparison with sand or gravel (Qi et al., 2006). The stabilizer is GR from Qazvin glass factory, Iran (Fig. 1). The nature of the stabilizer is so low-absorbent water and nonplastic that Atterberg limits results could not be obtained and shows a modest alkaline nature with the pH values equal to 9.3. The soil plasticity properties and the grading curve of GR have been presented in Table 1 and Fig. 2, respectively.

Standard proctor compaction tests have been performed on the pure soil and the blend with 10%, 15% and 20% GR following the modified proctor energy (ASTM D1557, 2007). Then, the amount of optimum moisture content and the peak dry mass density have been obtained (Fig. 3).

As it shown in Fig. 3, adding GR to the blend decreases the optimum moisture content from 11.7% to10.8%. This shows the low sensitivity of mixture containing GR to water content changes. Consequently, flatter compaction curves at peak points which enable samples to have stable compaction behavior and good workability over a wide range of water content have been achieved. Also, the maximum dry density decreases

Table 1
Soil plasticity specifications (ASTM D4318, 2006c; and ASTM D854, 2006d).

Pararmeter	LL	PL	PI	G_s
Value	22	15.8	6.8	2.66