Effect of Marble Dust and Glass Fiber on Expansive Soil

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Abstract

India shares a significant production of glass fiber and marble wastes in the world, which poses a big disposal problem. This study assesses the suitability of glass fiber and marble dust to enhance the behaviour of expansive soil. The Atterberg's limits and plasticity index improves by mixing marble dust into the soil. Whereas, the effect of glass fiber on the Atterberg's limit is not very encouraging. The shear strength increases with the addition of marble dust as well as glass fibers. The effect of glass fiber on strains corresponding to peak stress is significantly higher than the marble dust. The strength of fiber-reinforced soil initially increases with the addition of marble dust, to a certain extent, beyond which it decreases. The effect of marble dust on variation in peak stress and corresponding strains is that fiber-reinforced soil is almost the opposite. The optimum quantity of marble dust and glass fiber is found to be 10%-15% and 3%, respectively.

Keywords: *compressive strength, reinforcement, fibers, marble dust, stabilization*

Introduction

Expansive soils, which is popularly known as black cotton soil is spread over more than 22% (Shukla and Parihar, 2016). The colour black is contributed to the presence of high iron, magnesium minerals and humus. Soils cover, Gujrat, Madhya Pradesh, Maharashtra, Karnataka Andhra Pradesh, and Tamilnadu states of India. These soils contain a large quantity of montmorillonite and illite minerals, and soil swell and shrink with absorption and discharge of water. The bond between soil elements brokes with the absorption of water (Wang, 1998). A number of studies presented photographs showing the cracks developed in the road, buildings and other civil engineering structures (Shukla et al., 2014).

India is a developing country and growing industrialisation results in the production of waste products as a byproduct of various construction activities. Agarwal et al. (2015) presented a study discussing the scenario of waste produced in India. A similar scenario exists in almost all developing countries. Though, the waste management policy available at the municipal level or state level, there is no national policy or guideline to store and utilize these waste materials for sustainable development. Some of the waste materials are hazardous but some waste materials are non-hazardous, which can be used as a construction material for sustainable development (Letcher & Vallero, 2019). These materials include, fly ash, sawdust, metal slags, alccofine, ground granulated blast furnace slag, natural and synthetic fibers, marble dust and other stone dust (Parihar et al., 2017; Ikeagwuani, & Nwonu, 2019).

India shares a significant production of marble waste in the world. Almost 3,172 thousand tons of dust was created by marble industry in 2009-10. It is nowadays available very easily in the market at 15 US dollar/ tonne, which is very cheap comparing other alternative materials. A number of studies have explored the use of marble dust (MD) as a construction material for different purposes. Waste marble dust has been used as brick material and building material (Karasahin & Terzi, 2007; Sarkar, et al., 2006). Some studies used marble dust in the production of cement, infiltration material and mortar (Davini, 2000; Acchar et al., 2006; Saboya et al., 2007; Hwang, 2008). A few studies used marble dust to stabilize the expansive soils (Palaniappan & Stalin, 2009, Agrawal et al., 2011; Sabat & Nanda, 2011). However, these studies were mostly considered some properties in the analysis.

Production of glass fiber waste in India is increasing every year. In the last decade, few studies explored the application of glass fiber (GF) on different soils. Yin and Yu (2009) found that glass fiber along with cement could be an alternative to reinforce the soft subgrade. Fang et al. (2011) observed that glass fiber are more efficient at large strains in sandy soil. Asadollahi and Dabiri (2017) varied glass fiber content from 0.25 % to 1.5 %, and maximum shear strength is found at 1% fiber content. Saha and Bhowmik (2018) determined the effect of glass fibers on shear strenth for different water contents on the sand-clay mixture. Syed and GuhaRay (2020) varied polypropylene (PPF) and glass fiber (GF) from 0 to 0.4%, and observed an increase in unconfined compressive strength and CBR of expansive soil.

The literature review shows that some recent studies determined the effect of fiber and marble dust on soils, separately. Only a very few studies considered the effect of marble dust on expansive soils. However, studies have not explored the effect of glass fibers on shear strength of expansive soil. Earlier studies mostly limited fiber content to 1%. It needs to explore the possibility of using fibers more than 1%. The main objective of the study is to find out the effect of glass fiber on expansive in the presence and absence of marble. The fiber content has been varied from 0 to 4% with an increment of 1%, and marble dust has been varied from 0 to 25%.

Fig. 1. Sampling location (modified after Chadha, et al.,2005)
Rys. 1. Miejsce pobierania próbek (zmodyfikowane za Chadha i in., 2005)

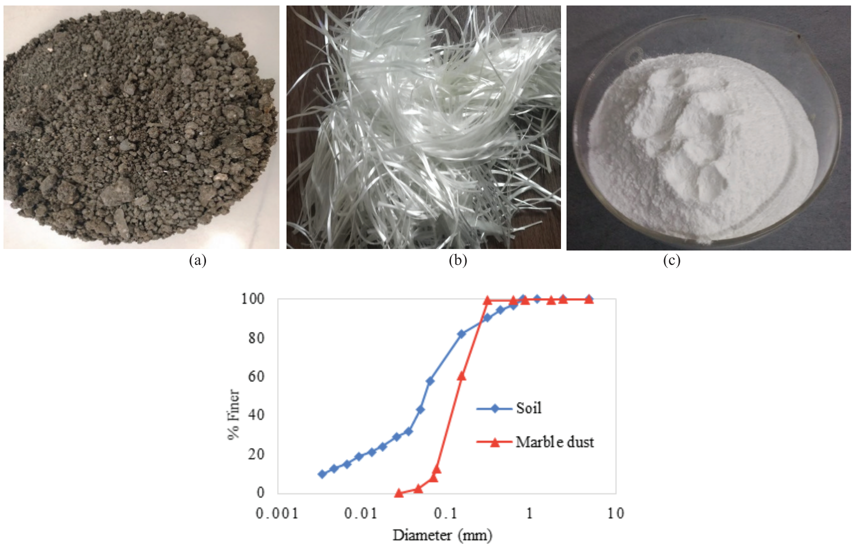


Fig. 2. Material used in testing: (a); Soil (b) glass fiber; (c) marble dust (d) grain size distribution of soil and marble dust
Rys. 2. Materiał użyty do badań: (a); gleba b) włókno szklane; c) pył marmurowy, d) rozkład wielkości ziaren gleby i pyłu marmurowego

The material used in the study

The expansive soil used in the present study is collected near to Ashok Nagar society, Navsari district of Gujrat.

The sampling location is shown in Fig. 1 and highlighted in red colour. The expansive soils cover almost 30% of the land cover of the Gujrat state. Based on Indian standard, the soil is classified as soil clay of high plasticity (CH). Considering its free swelling index (FSI), the soil is grouped into highly expansive soil (FSI>50%). This soil is also classified as a deep black cotton soil by government. The marble dust and glass fiber used in the study is collected from the market of Ahmedabad.

The marble dust consists of calcium oxide, silicon dioxide, magnesium oxide, and ferric oxide. The specific gravity of marble dust is found to be 2.78-2.80, which is greater than the specific gravity of used soil. The glass fibers and marble dust used in the study is shown in Figure 1. Fig. 1 (d) shows the grain size distribution of expansive soil and marble dust. The particle size of marble dust is relatively larger than the soil particles. The majority of marble dust falling in the range of 0.3 mm to 0.75 mm, which is size of fine sand.

Methodology

The liquid limit of untreated and modified soils was determined using the Casagrande apparatus. The plastic limit of soil was evaluated by the thread rolling method. The detailed procedure to determine the LL and PL is given in IS: 2720: Part-V. Shrinkage limit of soil samples was estimated by mercury displacement method by following a procedure specified in IS: 2720: Part-VI. To determine the Atterberg limits of modified soil, sufficient time was provided to allow the uniform mixing of water within the soil samples. Following the plasticity chart is given in the Indian standard, IS 1498 (2007), this soil is classified as clay of high plasticity (CH).

The relationship between moisture content and dry density of soil was determined by the method described in, Indian standard IS: 2720: Part-VII was used. Unconfined compressive strength tests, performed with and without the inclusion of glass fiber and marble dust as per IS: 1943, Part X: 1981 The specimens for determination of UCS were prepared with the help of a metallic split mould having a detachable collar. This mould is having a diameter of 38mm and height 76 mm. The detachable collar is attached to the end of the mould and it remains orthogonal with the vertical axis of mould. Water equal to OMC of soil was added to the soil to get the maximum advantages of soil reinforcement and modification. After mixing the fibers in the soil, the soil samples of different fibre content and different aspect ratio were prepared for testing. The samples were prepared and then tested for the unconfined compressive strength to evaluate the effect of different amount of fibre content and aspect ratio of fibers on the unconfined compressive strength of the soil. The fiber content was varied from 0 to 4% with an increment of 1%, while marble dust was varied from 0 to 30% with an increment of 5%.

Tab. 1. Properties of expansive soil used in the study
Tab. 1. Właściwości gruntów ekspansywnych zastosowanych w badaniach

Properties	Description	Properties	Description
Specific gravity (G)	2.62-2.65	Shrinkage limit (SL)	10-12 %
Liquid limit (LL)	70-72 %	Maximum dry density	1.45 gm/cc
Plastic limit (PL)	20-22 %	UCS	84 kPa
Plasticity index (PI)	49-52 %	Free swelling index	88-92%

Result and Discussion

Fig. 3 shows that the addition of marble dust (MD) improves the stress-strain behavior of expansive soils. The improvement in peak stress is more pronounce in soil treated with 10% marble dust. The peak stress corresponding to 10% of marble dust is significantly higher than other MD content. However, interestingly, the post-peak behavior does not shows any significant improvement. In all cases, the peak is always more than untreated soil. The effect of marble dust on sample failure is shown in Fig. 4. The soil sample always fails in shearing, irrespective of marble dust content.

The stress-strain behaviour of glass fiber reinforced soil is shown in Fig. 5 for different glass fiber content. It shows improvement in the stress-strain behaviour of soil with an increase in fiber content. Expansive soil with a glass fiber content of 3% fibers exhibits relatively higher peak stress than other fiber contents (1%, 3%, and 4%). However, the strains corresponding to peak stress increases with an increase in the fiber content. In general, the ductile behaviour of reinforced soil enhances with increase the fiber content, irrespective of peak stress. Soil shows an abrupt reduction in stress after peak stress; however, this post-failure behaviour of expansive soils improves significantly with fiber content.

Variation in unconfined compressive strength (UCS) and corresponding strain in glass fiber reinforced expansive soil is shown in Fig. 6. It shows that the UCS increases significantly up to 3% of glass fiber (Figure 6a) and then reduces. Earlier studies also observed a linear increase in the shear strength of soil polypropylene fiber content (Hussein and Ali (2019; Shukla et al., 2016). Contrary to variation in stress, the strains corresponding to peak stress (UCS) increases continuously with glass fiber content (Fig. 6c, d).

The strain increases by 700% for 4% of glass fiber, which is a substantial change as compared to change in UCS, which is almost 56% (Fig. 6 b, d). It indicates a huge increase in deformation resistance with the incorporation of glass fiber.A similar observation was made in earlier studies for other types of fibers (Sharma et al., 2015; Parihar et al., 2018). Also, the rate of increase in peak strain enhances with fiber content, which is again in contrast to variation in peak stress (Fig. 6 a-d). The increase in the peak stress and corresponding stains are due to the bridging effect induced by fibers in the soil-fiber matrix. It prevents extensive dissertation and the formation of cracks in the soil..

The effect of fiber content on expansive soil sample failure is shown in Fig. 7 The unreinforced soil fails within a small strain level (2.6 %) with large cracks. The size of cracks developed on the failed sample reduces significantly with glass fibers (Fig. 7 b-e). With further increase in the fiber content (>3 %), the cracks on soil samples decrease significantly, but bulging increases continuously. This is contrary to MD-treated soil, where soil samples fail in shearing with a number of cracks on soil samples (Fig. 4). At 4 % fiber content, the fibers start coming out from the soil sample, indicating excess fiber content. The interfacial friction between soil and fiber also contributes to enhancing ductile behaviour and stretching resistance (Tang et al., 2007). Similar to the present study, earlier studies also found that the inclusion of fibers in the clay matrix reduces the brittleness behaviour and soil deformation (Tang et al., 2016).

Fig. 8 shows the effect of marble dust on the stress-strain behaviour of glass fiber reinforced expansive soil. The modulus of elasticity (Ei = stress/strain) is maximum for 5-10% of marble in glass fiber reinforced soil. However, with the further addition of marble dust, the modulus of elasticity reduces significantly, and the minimum is observed for the marble dust of 20%. The detailed variation in peak stress (UCS) and corresponding strain with the addition of marble dust in fiber-reinforced soil are shown in Fig. 9. The peak stress of soil increases up to 10% of fiber content, and further addition of marble causes a reduction in peak stress (Fig. 9 a). The addition of marble dust of 20% reduces the shear stress even less than those observed when marble is absent. Fig. 9 b shows a 16 % increase in UCS of fiber-reinforced soil with the addition of marble dust. However, when comparing with unreinforced soil, the increase is found to be 80% due to the combined effect of glass fiber and marble dust, which is more than the distinct effect of glass fiber, where UCS was increased by 57% (Fig. 9 c and Fig. 8 b).

The marble dust in the glass fiber-soil matrix may enhance the geo-polymerization reaction and modifies the montmorillonite morphology (Syed et al., 2020). Marble dust causes the agglomeration of the soil particles and the better formation of clay-fiber-marble dust matrix. Glass fiber also induces the bonding effect. These effects contribute to increased soil shear strength. The decrease in soil strength with higher marble dust (MD>10%) may be attributed to expansive soil's enhanced moisture capacity at excess marble contents. Though the stresses increase significantly up to marble dust of 5%, the corresponding strains are less than those recorded for GF reinforced soil without any marble dust (Fig. 9 d). However, a further increase in the marble dust increases the strain corresponding to peak stress, and for 20% marble dust, it almost reaches the level of fiber-reinforced soil. The strain corresponding to peak stress reduces to 40% of fiber-reinforced soil with the addition of 5% MD (Fig. 9 e). Compared with unreinforced soil, the increase in strain is 380% due to 3% glass fiber. However, the addition of marble dust reduces the strain level from 380% to 110% with 5% marble dust (Fig. 9 f). However, further addition of marble dust enhances the strain corresponding to peak stress.

Effect of marble dust and glass fibers on soil expansion is

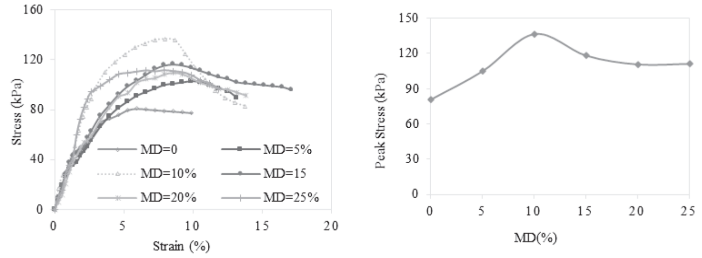


Fig. 3. Variation in liquid limit with marble dust and glass fiber
Rys. 3. Zmiana granicy płynności w przypadku pyłu marmurowego i włókna szklanego

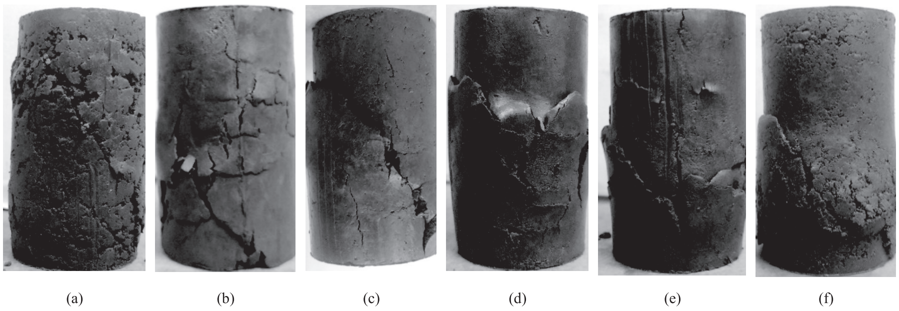


Figure 4. Effect of MD on failure of soil sample: (a) MD= 0%; (b) MD= 5%; (c) MD=10%; (d) MD=15; (d) D=20%; (e) MD=25%
Rys. 4. Wpływ MD na zniszczenie próbki gruntu: (a) MD= 0%; (b) MD= 5%; (c) MD=10%; (d) MD=15; (d) D=20%; (e) MD=25%

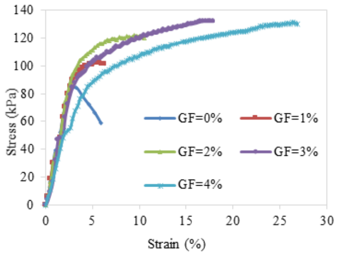


Fig. 5. Stress-stain characteristic of GF reinforced soil
Rys. 5. Naprężenie-plama charakterystyczna dla gruntu zbrojonego GF

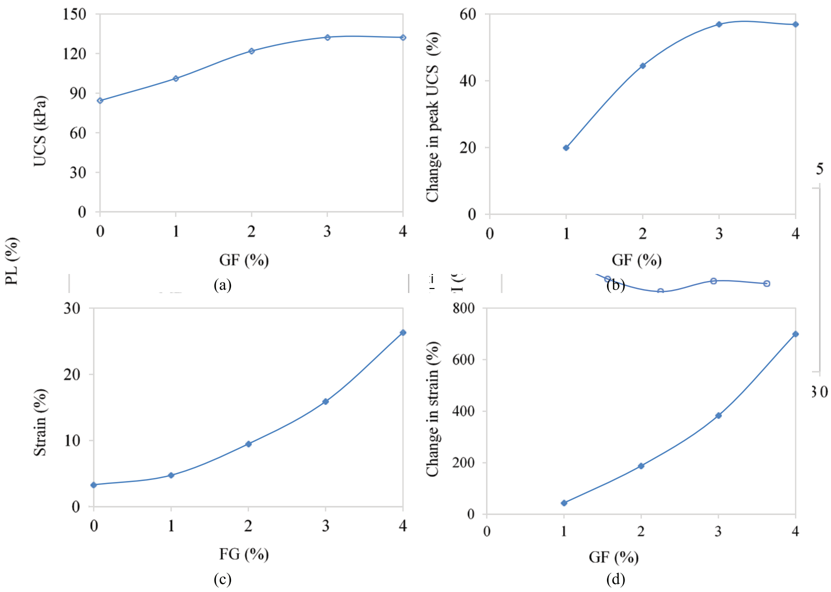
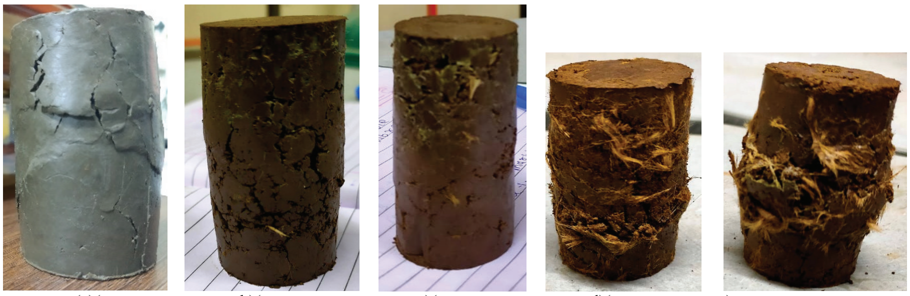


Fig. 6. Effect of glass fiber: (a) UCS; (b) change in UCS; (c) Strain corresponding to peak stress; (d) change in strain corresponding to peak stress
Rys. 6. Wpływ włókna szklanego: (a) UCS; b) zmiana UCS; (c) odkształcenie odpowiadające szczytowemu naprężeniu; (d) zmiana odkształcenia odpowiadająca szczytowemu naprężeniu



(a)(b)(c)(d)(e)

Fig. 7. Failure of soil samples with glass fiber content: (a) Unreinforced, (b) 1%, (c) 2%, (d) 3%, (e) 4%

Rys. 7. Uszkodzenie próbek gruntu z zawartością włókna szklanego: (a) niewzmocniony, (b) 1%, (c) 2%, (d) 3%, (e) 4%

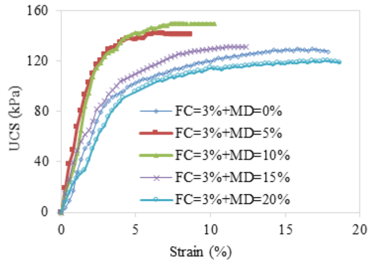


Fig. 8. Effect of marble dust on fiber reinforced soil

Rys. 8. Wpływ pyłu marmurowego na grunt zbrojony włóknem

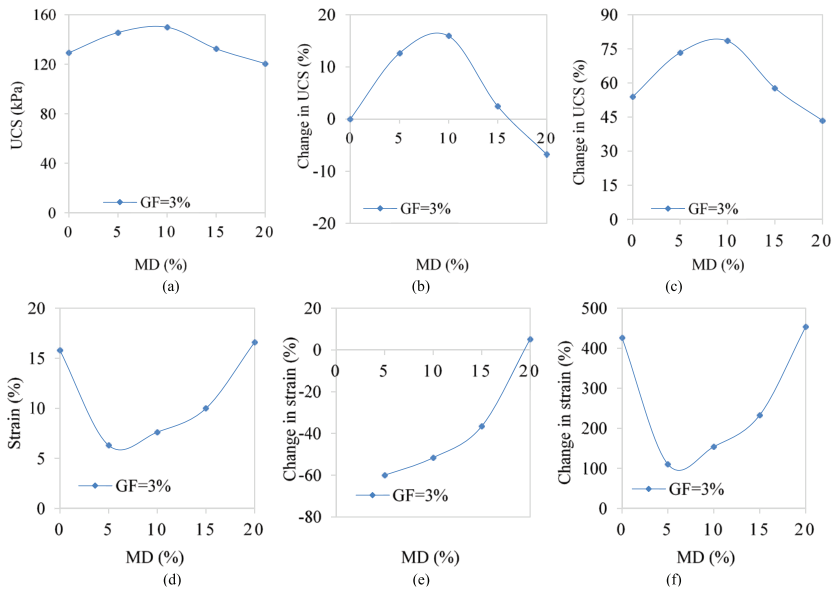


Fig. 9. Effect of marble dust on expansive soil: (a) variation in UCS; (b) % change in UCS in comparison to fiber reinforced soil; (c) % change in UCS in comparison to untreated soil; (d) variation in strain; (e) % change in strains in comparison to fiber reinforced soil; (f) % change in stain in comparison to untreated soil

Rys. 9. Wpływ pyłu marmurowego na ekspansywny grunt: (a) zmienność UCS; b) procentowa zmiana UCS w porównaniu z gruntem zbrojonym włóknem; (c)% zmiany w UCS w porównaniu z nieoczyszczoną glebą; d) zmienność naprężenia; e) procentowa zmiana odkształceń w porównaniu z glebą zbrojoną włóknem; (f)% zmiany zabarwienia w porównanie z nietraktowaną glebą

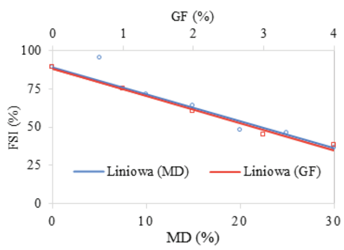


Fig. 10 Effect of marble dust on free swelling index

Rys. 10. Wpływ pyłu marmurowego na wskaźnik swobodnego pęcznienia shown in Fig 10. The free swelling index (FSI) of soil initially increases with an increase in marble dust, and after a certain amount of marble dust, FSI is found to decrease. The tests have been repeated many times as the observation is contrary to earlier study results. However, every time the same results have been observed.

The free swelling decreases with any marble content greater than 5%. It is similar to earlier study results. For a marble content of 25%, the FSI reduces to less than 50 % of untreated soil. The characteristics of marble dust change with change in the characteristics of parent marbles. This can be a reason for different swell behaviour of soil with marble dust.

The addition of glass fiber linearly reduces the free selling index of soil. More is the fiber content; more is the reduction in soil swelling, which does not match with variation in shear strength, where strength enhancement ceases after 3% fiber content. Al-Akhras (2008) also observed a reduction in soil swelling with fiber content.

The maximum reduction was observed at 5% fiber content, which is significantly higher than earlier other studies, where optimum fiber was 0.75 to 1%.

Conclusion

The glass fiber and marble duct were mixed with highly plastic expansive clay. The denhacement in soil properties with the addition of marble dust is mainly contributed to the change in soil gradation. Glass fiber enhances not only pre-peak behaviour but post-peak behaviour also. The enhancement in strain corresponding to peak stress is relatively significant as compared to change in soil strength. In general, the ductility of reinforcement soil enhances continuously with an increase in the glass fiber. The unconfined compressive strength of fiber-reinforced soil increases initially with an increase in the marble dust in fiber-reinforced soil, to a certain extent, but beyond 10% of marble dust, it starts decreasing. However, the change in strain corresponding to peak stress of fiber-reinforced soil is almost opposite to the change in peak stress with the addition of marble dust. The addition of marble dust and glass fiber linearly reduces the free swelling index. The reduction is almost identical. The long-term performance of glass fibers and the effect of marble dust on glass fiber reinforced soil needs further research. The release of calcium ions under different temperatures and time intervals needs to be explored in future studies.

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Wpływ pyłu marmurowego i włókna szklanego na ekspansywną glebę

Gleby ekspansywne to gleby, które mają zdolność kurczenia się i / lub pęcznienia, a tym samym zmiany objętości, w zależności od zmian wilgotności. Utylizacja odpadów przemysłowych to duży problem w Indiach. Obecnie wiele produktów odpadowych stało się popularnymi materiałami konstrukcyjnymi. W niniejszej pracy oceniano przydatność zbrojenia włóknem szklanym do poprawy wytrzymałości gruntu ekspansywnego. Ponadto określa się również wpływ pyłu marmurowego na grunt wzmocniony włóknami. Limity Atterberga i wskaźnik plastyczności poprawiają się poprzez mieszanie pyłu marmurowego z glebą. Natomiast wpływ włókna szklanego na granicę Atterberga nie jest zachęcający. Wytrzymałość na ścinanie wzrasta wraz z dodatkiem pyłu marmurowego oraz włókien szklanych. Jednak wpływ włókna szklanego jest relatywnie bardziej zauważalny w porównaniu z pyłem marmurowym. Stwierdzono, że optymalna ilość pyłu marmurowego i włókna szklanego wynosi odpowiednio 15% i 3%. W przypadku włókna szklanego wytrzymałość na ściskanie i odpowiednie odkształcenie wzrastają odpowiednio o 55–58% i 700%. W gruncie zbrojonym włóknem wytrzymałość początkowo wzrasta wraz z dodatkiem pyłu marmurowego, do pewnego stopnia, po przekroczeniu której maleje. Stwierdzono, że wpływ pyłu marmurowego na zmienność szczytowych naprężeń i odpowiadających im odkształceń gleby wzmocnionej włóknami jest prawie przeciwny.

Słowa kluczowe: *depozycja na czynniki atmosferyczne, huta miedzi, emisje, metale*