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VIETNAM NATIONAL UNIVERSITY, HANOI

Advances in the Earth, Mining and Environmental Sciences for Safe and Sustainable Development

Volume 1

Advanced Technologies and Artificial Intelligence in the Earth and Environmental Sciences

PUBLISHING HOUSE FOR SCIENCE AND TECHNOLOGY

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Part 1: Earth Technology and Geotechnical Engineering

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Doi: 10.15625/vap.2024.0317

Possibility of using Ground Granulated Blast Furnace Slag (GGBF in combination with sea sand and cement for soft grour improvement

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Abstract: Every year, iron and steel plants in Vietnam release a large amount of slag, causing negative impacts on the environment and taking up a large area of waste dumps. Therefore, research is necessary to utilise this waste source is necessary. Vietnam has a long coastline with an abundant source of sea sand, but it has not yet been sufficiently researched for use in the construction field due to the salt-contaminated problem. With a much cheaper price than river sand and recent shortage of river sand, sea sand will be studied more to gradually replace river sand sources. To take advantage of the abundant sources of slag and sea sand, this article will evaluate the possibility of using ground granulated blast furnace slag (GGBFS) combined with sea sand and cement for the improvement of soft soil. Research results showed that the optimum amount of GGBFS that can be added to the sea sand cement mixture to achieve the maximum compressive strength was 50% of the the weight of sand. Additionally, research also revealed that GGBFS can be used to partially replace cement with a content of 10 to 70%. In particular, 30% of the replacement cement from GGBFS is the optimum replacement proportion. The research results have contributed to the theoretical basis for improving soft soil ground using sea sand - cement - GGBFS column. Research is of practical significance to utilise GGBFS from iron and steel factories, reduce the amount of waste disposed of to the environment, utilize the abundant sea sand materials, and reduce the construction cost as well.

Keywords: GGBFS, sea sand-cement column, soft ground improvement, unconfined compressive strength.

Introduction

Vietnam is one of the largest crude steel producers in the world with a total volume of about 20 million tons of crude steel in 2022 (World Steel Association, 2023). Every year, iron-pig plants in Vietnam generate a huge amount of granulated blast furnace slag (GBFS). This is a solid waste product that can cause negative impact on the soil, water, and air environment (Bui Truong et al., 2020). Ground granulated blast furnace slag (GGBFS) is a by-product of blast furnace slag. GBFS and GGBFS can be used for different purposes, such as concrete aggregate, fill material, embankment material, additive for cement production, partially replace clinke in cement production (GGBFS cement) and soft soil improvement (Behnood, 2018). In the world, GGBFS has been widely investigated for the improvement of soft soils. Yadu and Tripathi (2013) reported that GGBFS alone can be used to stabilise soft soil for rural roads with the optimum GGBFS content of 9%. Nguyen et al. (2020) indicated that the strength of soft soil cement-GGBFS reached the highest value with 30% of GGBFS. Sharma and Sivapullaiah (2016) used GGBFS and fly ash to stabilise expansive soil and showed that 20% of GGBFS is an optimum content. Accordingly, Sekhar et al. (2017), the UCS of the ithomargic clay-cement-GGBFS mixtures obtained the highest value with 25% GGBFS. Recently, Jwaida et al. (2024) revealed that the combination of GGBFS and cement kiln dust (CKD) significantly increased the strength of clay soil. Consequently, 25% of GGBFS and 75% of CKD were the optimum mixture, which increased the strengths of stabilised soil by about 6 times than untreated soil. In Vietnam, GGBFS S95 from

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Hoa Phat company has been used for cement production in Vietnam and exporting to Australia (Hoa Phat, 2022). For soft soil improvement, the combination of Portland cement and GGBFS has significantly increased the strength of stabilised soil (Nu et al., 2020a). Nguyen et al. (2020) also showed that GGBFS can partially replace cement in the soil-cement deep mixing improvement method. The research reported that cement can be replaced by 10-60% GGBFS, in which the opitmum replacement ratio is 30%. However, the amount of GBFS discharged annually is very large and current research applications are still limited, so the amount of unused waste material is still high. Therefore, research on the utilisation of GGBFS for other purposes needs to be promoted such as use for soft ground treatment.

Soft soil is very common in Vietnam with different types and large thicknesses, especially in coastal areas. Treatment and improvement of soft soil ground before construction is mandatory. In coastal areas, in addition to the wide distribution of soft ground, sea sand also exists in many places with large reserves. As estimated, the total area of sea sand and coastal dunes in Vietnam is more than 500,000 hectares (Nguyen et al., 2021). Currently, sea sand has been studied to partially replace river sand in the manufacture of reinforced concrete, sand concrete for rural roads. Recently, in the Mekong Delta, sea sand has been used for road embankment in some pilot projects (Ministry of Transport of Vietnam, 2022). River sand is increasingly depleted, so in a few months sea sand will be widely used to gradually replace river sand for road embankments in the Mekong delta region. Furthermore, sea sand has also been studied for use in soft ground improvement. Nguyen et al. (2020) showed that cemented sea sand columns can be used to improve soft ground to take advantage of abundant sea sand resources. The sand-cement column is a soft ground improvement method in which its function is a combination of sand column and soil-cement column (Ta and Nguyen, 2019; Ta et al., 2020). In this study, to take advantage of the abundant GGBFS and sea sand resources in Vietnam, the effect of GGBFS on the compressive strength of the sea sand cement column for soft ground improvement will be investigated.

Materials and Methods

Sea sand sample

The sea sand sample was collected from Xuan Hoi coastal area of Nghe An province (Figure 1). The particle distribution of the sand sample is shown in Figure 2. As shown, the sea sand sample is fine and poorly graded (uniformity coefficient, Cu = 1.78). The salt content in the sea sand sample is 0.3%.

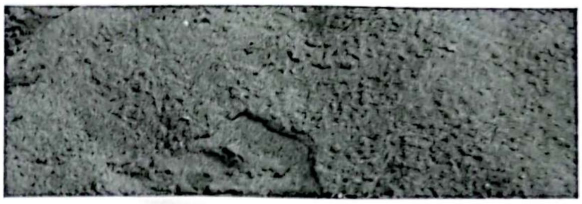

Figure 1. Sea sand sample

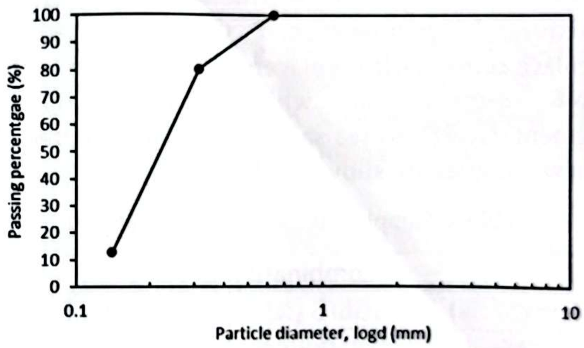

Figure 2. Particle distribution of the sea sand sample

Cement and GGBFS

The cement used in this study was PC 40 But Son. GGBFS S95 was purchased from Hoa Phat. The chemical compositions of PC 40 cement and GGBFS S95 are listed in Table 1.

Table 1. Chemical composition of GGBFS and cement

Chemical compositions	Content (%)	
	GGBFS	Cement PC 40 But Son
SiO_2	36.88	19.74
Al_2O_3	12.29	5.18
Fe_2O_3	0.15	3.11
CaO	38.45	63.14
MgO	7.52	1.61
Na_2O	0.21	0.15
K_2O	0.76	0.70
SO_3	0.04	1.85
TiO_2	0.75	0.12
FeO	0.31	N/A
MnO	1.23	N/A
LOI (Loss of Ignition)	N/A	2.58

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Sample Preparation and Test Procedures

Sample Preparation

According to Farouk and Shahien (2013), the cement content used in soil improvement using a deep-mixing method often ranges from 5 to 16% of the soil weight. Therefore, in this study, 15% cement content will be used to mix with sea sand. To investigate the possibility of using GGBFS, it is mixed into the sea sand-cement mixture with two combinations: Combination 1) GGBFS is added to increase the strength of the sea sand-cement mixture (enhancement purpose); Combination 2) GGBFS is used to partially replace cement (replacement purpose). In combination 1, GGBFS with different contents from 5 to 60% of the dry sand mass is added to the sea sand-cement mixture. In combination 2, GGBFS is used to replace cement with replacement ratios from 10 to 70% cement. In which, the ratio of cement+GGBFS to sea sand = 15%. The denotes of these samples are shown in Tables 2, 3.

Table 2. Sample mixtures in combination 1

Combination 1		
Cement (%)	GGBFS (%)	Sample symbol
15	0	0%GGBFS
15	5	5%GGBFS
15	10	10%GGBFS
15	15	15%GGBFS
15	20	20%GGBFS
15	40	40%GGBFS
15	50	50%GGBFS
15	60	60%GGBFS

Table 3. Sample mixtures in combination 2

Combination 2 (Cement+GGBFS = 15%)	
Ratio of Cement:GGBFS (%)	Sample symbol
100:0	100%C
90:10	90%C+10%GGBFS
80:20	80%C+20%GGBFS
70:30	70%C+30%GGBFS
50:50	50%C+50%GGBFS
30:70	30%C+50%GGBFS

For sea sand-cement mixtures, the water-to-cement ratio (W/C) is often very high. According to Nguyen Thi Diu et al. (2020), for sea sand cement mixtures with cement content from 5 to 15%, the W/C ratio ranges from 1.75 to 4.87. In t study, with a cement content of 15%, combination 1, the W/C ratio = 2 is used. I combination 2, the water-to-binc (cement+GGBFS = 15%), W/B ratio = 2 is also use

The mixture of sea sand, cement and GGBFS well mixed by hand in a bucket for 5 minute then water is added and mixed well again fo another 5 minutes. The mixing ratio of th samples is shown in Tables 2, 3. The sample is then placed in a cylindrical mould with a height of 10 cm and a diameter of 5 cm. The sample is processed by vibrating method, ensuring that there are no voids and no air within the sample. After casting, the top of the sample is sealed by plastic bags and the sample is left in the mould for 1 day. After 1 day, the sample was removed from the mold, put into plastic bags, and cured in a moisture condition at room temperature of 27 °C, humidity of 95% until the experimental age.

Test procedures

In this study, the unconfined compressive strength (UCS) of the mixture samples was determined from the unconfined compressive test with a loading rate of 1 mm/min according to ASTM D2166 (2000). To determine the optimal content of GGBFS, the UCS values were determined after 28 days of curing. To investigate the effect of GGBFS on the strength development of the sample mixture, the UCS values were determined at different curing times of 3, 7, 14, and 28 days.

Test results and discussions

Addition of GGBFS to the mixture of sea sand-cement

The average UCS of sea sand cement mixtures with different contents of GGBFS at 28 days of curing is plotted in Figure 3. As shown, the UCS of sea sand-cement mixtures increases with increasing GGBFS content up to 50%. When the GGBFS content is higher than 50%, the UCS value tends to decrease. When 50% GGBFS is added to the sea sand cement mixture, the UCS value of the mixture samples reaches the highest value and is about 22.5 times higher than the sample of the mixture without GGBFS. Therefore, 50% of GGBFS is the optimum content to obtain the highest UCS value of the sea sand-cement

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mixture. In this case, the addition of GGBFS will help increase the strength of cemented sea sand column (for strength enhancement purpose).

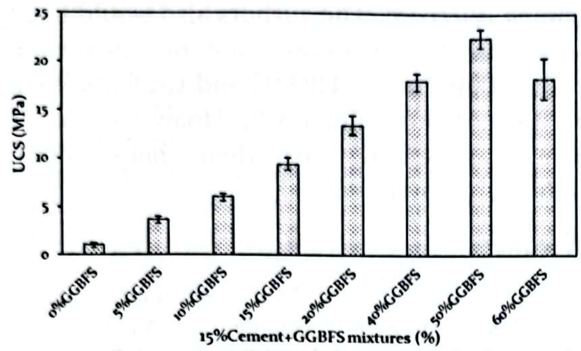

Figure 3. Effect of additional GGBFS on the UCS value

GGBFS replacement cement

In this study, GGBFS is used to partially replace cement in the sea sand-cement mixture. Figure 4 shows the UCS value of mixture samples with the GGBFS replacement cement from 10% to 70%. It can be seen that when the replacement of GGBFS gradually increases, the UCS value of the mixture sample tends to increase. However, when the GGBFS replacement is greater than 30%, the strength shows a decrease trend. The optimum content of GGBFS replacement is 30%. With 30% GGBFS replacement, the UCS strength of the mixture sample is approximately 3 times higher than that of the mixture sample without GGBFS replacement. As shown in Figure 4, with 70% GGBFS replacement, the strength of the mixture sample is still high and higher than that of the 100% C sample (without GGBFS replacement). Therefore, in this study, GGBFS can be used to replace cement from 10% to 70%.

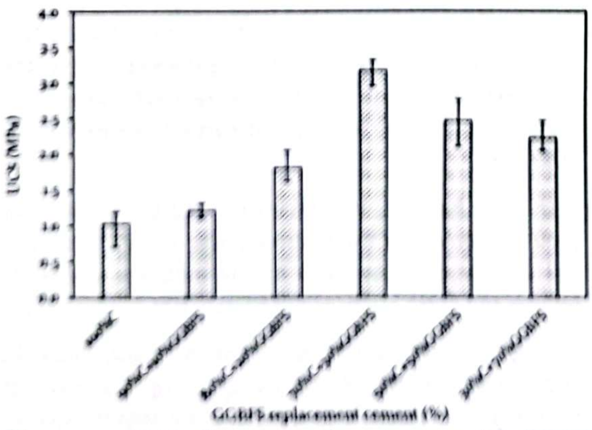

Figure 4. UCS of the sample mixture with GGBFS replacement cement

It can be seen that the UCS of the mixture sample increases with increasing GGBFS content to a threshold that is optimum content. When GGBFS is higher than the threshold, the UCS tends to decrease. As reported, the strength characteristics of stabilized soil with GGBFS can be explained based on the formation of cementitious products and the characteristics of GGBFS (eg, Yadu and Tripathi, 2013; Sharma and Sivapullaiah, 2016; Sekhar et al., 2017; Nguyen et al., 2020). GGBFS contains a high content of SiO_2 and CaO components that enhance the formation of cementitious products through pozzolanic reactions (Sekhar et al., 2017; Sharma and Sivapullaiah, 2016). The pozzolanic reactions will form the cementitious components such as calcium – silicate – hydrates (C – S – H), calcium – aluminate – hydrates (C – A – H) and calcium aluminate – silicate – hydrates (C – A – S – H). The pozzolanic reaction is time-dependent and can be expressed as follows (Sharma and Sivapullaiah, 2016):

$$Ca(OH)_2 \text{ (ionization of lime)} \rightarrow Ca^{2+} + 2(OH)^- \quad (1)$$

$$Ca^{2+} + OH^- + SiO_2 \rightarrow \text{calcium-silicate-hydrate} \quad (2)$$

$$Ca^{2+} + OH^- + Al_2O_3 \rightarrow \text{calcium-aluminate-hydrate} \quad (3)$$

The formation of cementitious products is responsible for the increase of UCS strength of sea sand-cement-GGBFS mixtures. When the GGBFS content increases, the amount of cementitious products will increase and resulting in an increase in UCS strength. However, when the GGBFS content increases over the threshold, the pozzolanic reactions will not completely occur. The GGBFS is a non-plastic material, so if the GGBFS content exceeds the threshold, the strength of the mixture sample will reduce accordingly (Sekhar et al., 2017; Sharma and Sivapullaiah, 2016).

Strength development of sea sand-cement-GGBFS mixture

The strength development of the mixture sample with and without GGBFS from 3 days to 28 days of curing is shown in Figure 5.

It can be seen that at early days of curing (3 days), the strength of sample without GGBFS (100%C) is slightly higher than that of sample with GGBFS (70%C+30%GGBFS). This is because pozzolanic is

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time -dependent reaction (Sharma and Sivapullaiah, 2016) and at the early days of curing, this reaction has not occurred yet. This phenomenon leads to a low strength of sample with GGBFS. In other words, the presence of GGBFS has delayed the strength development at early age. However, after 7 days of curing, the strength of sample with GGBFS significantly develop. At 7 days of curing, the strength of the sample with GGBFS is 1.4 times greater than that of the sample without GGBFS; this factor is increased to 1.6 times at 14 days and 3 times at 28 days of curing.

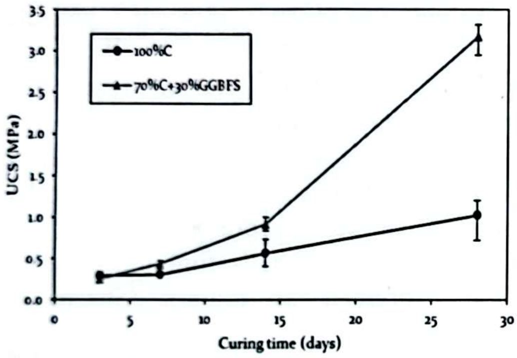

Figure 5. Strength development of mixture sample with and without GGBFS

Conclusion

Based on the analysis of laboratory test results, some conclusions can be drawn as follows:

The addition of GGBFS significantly increases the strength of the sea sand-cement mixtures. The optimum content of GGBFS used to enhance the strength of sea sand-cement mixture is 50%. With 50% of GGBFS, the UCS of the mixture sample is about 22.5 times higher than that of controlled sample (without GGBFS).

Besides strength enhancement, the GGBFS can be used to partially replace cement. In this study, for sea sand-cement mixture, GGBFS can replace cement from 10 to 70%. In which, 30% of replacement cement is optimum. With 30% replacement cement, the strength of stabilized mixture is about 3 times higher than that of mixture without GGBFS

At the early days of curing, the GGBFS can delay the strength development of mixture samples. However, after a long day of curing, the GGBFS has significantly increased the strength of stabilized mixtures through the pozzolanic reactions.

Acknowledgment

This research is funded by project code B2024-MDA-07 under the Ministry of Education and Training, Vietnam. The authors also would like to thank the Geotechnical Lab of Engineering Geology Department-HUMG and students Vuong Van Quy, Pham Thien Cu, Hoang Tuan Hai, Pham Van Quang for their helps during conducting experiments.

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