CONSTRUCTION
E-ISSN: 2785-8731
VOLUME 3, ISSUE 2, 2023, 223 – 229
DOI: https://doi.org/10.15282/construction.v3i2.9744

RESEARCH ARTICLE

Enhancing the Compaction Characteristics of Peat Soil through Ground Granulated Blast Furnace Slag (GGBS) Stabilisation

N. Z. M. Yunus[1]*, M. H. Hasni[1], H. H. Mazlan[1], B. A. Othman[1], D. Z. A. Hasbollah[2]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Malaysia
[2]Centre of Tropical Geoengineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Malaysia

ABSTRACT - Peat soil is renowned for its compressibility problem that can give rise to issues such as ground settlement, particularly within the spectrum of construction endeavours. Conversely, the implementation of chemical stabilisation, involving the incorporation of suitable additives, is contemplated prior to commencing construction activities. Ground Granulated Blast Furnace Slag (GGBS), which is a byproduct of the iron and steel industry, stands out as a prominent additive that can augment the engineering attributes of peat soil. This investigation focuses on the compaction characteristics of peat soil treated with varying proportions of GGBS, as evaluated through the Modified Proctor test. It involved examining the impact of diverse GGBS additions on the liquid limit of peat soil. The findings showed that the introduction of GGBS yielded a substantial reduction in the liquid limit of peat soil, signifying an elevated susceptibility to moisture and an increase in plasticity. Moreover, the incorporation of GGBS into peat soil prompted an increase in its Maximum Dry Density (MDD) and a reduction in its Optimum Moisture Content (OMC). Notably, the peak MDD, registering at 1000 kg/m³, was achieved at a GGBS content of 50%, marking the highest value observed in this study. The OMC values further indicated the lowest moisture content, standing at 29%, with the addition of 25% GGBS to the peat soil. These outcomes convincingly advocate that the utilisation of GGBS in treating peat soil engenders positive enhancement in its compaction characteristics, specifically pertaining to MDD and OMC. Such enhancement in engineering properties holds promising implications for potential stability.

ARTICLE HISTORY

Received	:	12th Sept. 2023
Revised	:	24th Oct. 2023
Accepted	:	14th Nov. 2023
Published	:	21st Dec. 2023

KEYWORDS
Peat,
GGBS,
Compaction,

1.0 INTRODUCTION

Unlike other soil types, peat soil has poor strength and uneven distribution of soil particles, making it an avoided option for the construction industry. The issue of problematic soil necessitates a fresh countermeasure approach that considers the current economic and environmental conditions. Prominent improvements are imperative when dealing with such construction-related soil issues, including the addition of modifiers or stabilisers. Nevertheless, geotechnical engineers face difficulties due to the lack of fundamental data on tropical peat soil for construction projects. The challenges associated with construction failures on peat, stemming from issues related to structural integrity and the lifespan of the buildings, have been extensively documented in numerous studies and technical reports. Even though proper consideration is given during the design stage, difficulties inevitably arise during pre-construction and post-failure construction, leading to high costs [1].

This is further amplified by the high-water content and wide characteristics of peat soil that impose significant challenges to assess their physical and index values accurately. The process of altering soil properties to enhance its engineering characteristics is referred to as soil stabilisation. All forms of soil stabilisation can be broadly categorised into two groups: those that employ mechanical methods and those that utilise chemicals. Previous research has highlighted the low mechanical strength of peat soil and the challenges it poses in construction due to its inadequate structural stability [2]. Peat soil is rarely utilised for construction works in Malaysia following its inability to provide stability for built structures, as characterised by low shear strength and high-water content. This necessitates the application of stabilisation methods to enhance peat soil's suitability in construction projects. Additionally, the growing demand for real estate further amplifies the need to address problematic soil issues.

Peat soil exhibits a substantial water content exceeding 200% [3]. This high-water content poses a significant challenge for engineering undertakings. The saturated nature of peat soil complicates handling and gives rise to concerns related to compaction and stability. With its low shear strength, peat soil is incapable of supporting the weight of structures or other loads. The shear strength of peat soil typically ranges between 5 to 20 kPa [4]. This characteristic is dictated by the internal structure of the soil and carries significant implications for the stability of structures and other engineering projects involving peat soil. Despite its frequent use in constructing slopes and embankments, peat soil's low shear strength renders it susceptible to landslides and slope instability. Feasibility studies on image processing techniques are being conducted in the realm of civil engineering, spanning structural, material, geotechnical, and highway applications.

***CORRESPONDING AUTHOR | N.Z.M.Yunus|** ✉ nzurairahetty@utm.my

It is imperative to implement an appropriate soil stabilisation method to enhance peat soil properties before undertaking any construction activities [5]. In this regard, the adoption of stabilisers like Ground Granulated Blast Furnace Slag (GGBS) and stone dust is becoming increasingly vital for addressing problematic soil conditions [6]. GGBS mitigates the heat of hydration, thus reducing the likelihood of thermal cracks. Substituting Ordinary Portland Cement (OPC) with GGBS leads to substantial reductions in carbon monoxide emissions, contributing to the conservation of non-renewable resources such as limestone [7].

Other researchers have also treated peat soil with various additives to achieve soil stabilisation. The introduction of cement and Petrasoil into peat soil leads to a reduction in water content, as evidenced by the decreasing percentage observed [8]. This phenomenon arises as cement and Petrasoil particles occupy the voids between peat particles, resulting in increased soil density and reduced compressibility. Furthermore, the application of fly ash and gypsum to peat soil enhances its characteristics [8]. The use of effective microorganisms (EM) for peat soil stabilisation resulted in an improved California Bearing Ratio (CBR) [10]. Employing the Standard Proctor test on peat soil also increases the dry unit weight (γd) from 0.169 g/cm³ to 0.519 g/cm³ [11]. However, this improvement is not significant without additives. Carbide lime, used as an additive for peat soil, has been proven to increase its strength [12]. Furthermore, reusable materials like palm oil fuel ash (POFA) have been proven effective for stabilising peat soil and enhancing its Unconfined Compressive Strength (UCS) in conjunction with OPC [13]. The utilisation of Eco-Processed Pozzolan has shown potential for increasing the dry density of peat soil [13]. Past research also used dry mixing peat soil with OPC at various percentages, ranging from 0% to 40% of the dried weight of peat soil, to prepare treated soil samples. In a previous study, OPC was used as a binding agent to alter the mechanical behaviour of peat soil. Due to its high organic content, untreated peat soils often exhibit elevated liquid limit values. The presence of significant organic matter enhances the soil's water absorption capacity [15, 16]. Therefore, treating peat soil with different concentrations of OPC can decrease its liquid limit values as OPC content increases. While the lime content in OPC has shown effectiveness in improving weak soil properties, it falls short in terms of generating significant heat during the hydration process.

Numerous studies have aimed to enhance peat soil stability [17, 18, 19], yet none have explored the sole application of Ground Granulated Blast Furnace Slag (GGBS), leaving several research questions unanswered. The effectiveness of additives in peat soil remains an intriguing subject especially on the selected location of the case study. Therefore, it is crucial to investigate the incorporation of GGBS in peat soil to assess its potential as a construction material.

2.0 TESTING PROGRAMME

This section outlines the systematic and sequential steps undertaken to fulfil the research objectives concerning the compaction characteristics of GGBS-treated peat soil. The study was conducted in a laboratory setting, involving experimental investigations into GGBS as a soil stabiliser for peat soil. All experimental procedures took place at the Geotechnical Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia, specifically focusing on conducting compaction tests using the Modified Proctor Method. The tests encompassed untreated and treated peat soil samples with varying GGBS contents of 5%, 15%, 25%, and 50% based on respective dry weight. Nevertheless, the study acknowledges limitations in repeatability analysis due to resource constraints and necessary apparatus modifications to address challenges posed by problematic weak soil.

2.1 Basic Characteristics of Peat Soil

To determine the fundamental characteristics of peat soil, several laboratory tests were conducted as an initial identification of the problematic soil. The effect of GGBS on Liquid Limit (LL) was also investigated to acknowledge its effect on the changes in moisture content. It also served as an indication of changes in the optimum moisture content (OMC) as a result of the compaction test. The peat soil was mixed with varying proportions of GGBS, ranging from 0% to 25%.

2.2 Compaction Characteristics of Peat Soil

Following the British Standard guidelines, a cylindrical mould was prepared whilst ensuring that its surfaces were free from dirt or debris. A 2.5 kg metal rammer was dropped from a height of 300 mm, delivering 27 blows to the soil. The peat soil-GGBS mixture was placed in a compaction mould with a diameter of 0.1 m and a detachable base plate for the modified proctor compaction test. A removable steel extension collar was attached to the top of the mould before adding the mixture. The material was placed inside the mould and compacted using a 4.5 kg steel rammer, delivering 27 blows per layer. This test employed two equations to determine the values of maximum dry density (MDD) and optimum moisture content (OMC).

2.3 California Bearing Ratio (CBR)

In this specific test, the peat soil was placed through a 20 mm sieve and 4.5 kg of the soil sample was combined with the appropriate quantity of additive. The resulting mixture was proportioned with water and divided into five equal portions. Using the same 5 kg metal rammer dropped from a height of 450 mm, each layer underwent compaction with 62 blows. The compacted sample was then positioned on the lower platen of the California Bearing Ratio (CBR) machine, with a surcharge load of 4.5 kg applied to the surface. This load was transferred to the penetration piston, causing the plunger to penetrate the soil sample. Readings of the load dial were recorded at the intervals of 0.25 mm penetration. Two equations were employed to calculate CBR values at the penetration depths of 2.5 mm and 5.0 mm.

2.4 Correlation to Strength Characteristics of Peat Soil

This objective was achieved by comparing the compaction test parameters (MDD and OMC) to the Unconfined Compressive Strength (UCS) value. The UCS value at 0 days served as an indicator, reflecting the immediate strength of the peat soil post-compaction. The optimal ratio for both tests would be comprehensively discussed to gain valuable insights into the necessary compaction standards for achieving optimal peat soil strength.

3.0 EXPERIMENTAL RESULTS

This study explored the compaction characteristics of GGBS-treated peat soil by administering CBR testing to determine the optimal ratios of selected samples. Table 1 presents a summary of the mechanical properties of peat soil that was extensively investigated in this research. The data indicates that untreated peat soil recorded a UCS value of 50 kPa, indicating inadequate strength for construction purposes. The compaction test results for untreated peat soil revealed an MDD of 750 kg/m^3 and an OMC of 45%, both of which pose concerns for construction due to the associated high moisture content leading to weak soil and potential settlement. Furthermore, a high liquid limit of 136%, which is consistent with previous studies reporting that most peat soils have a liquid limit of 100% or higher. The high value is attributed to the substantial organic content of peat soil, which stands at 77% and enhances its water retention capacity.

Table 1. Properties of peat soil used in this research

Properties	Peat Soil
Unconfined Compressive Strength (kPa)	50
Maximum Dry Density (kg/m^3)	750
Optimum Moisture Content (%)	45

Figure 1 illustrates the Liquid Limit (LL) values for various GGBS content percentages, including 0% (untreated peat), 5%, 15%, 25%, and 50%. It is evident that the addition of GGBS caused a reduction in the LL of peat soil, ranging from 136% to 99%. This showcases significant variations across different content levels.

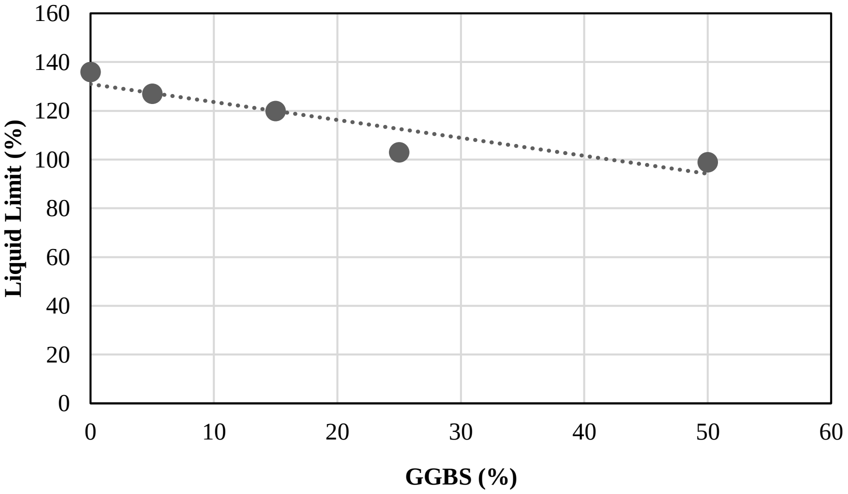

Figure 1. Effect of GGBS content on the Liquid Limit of peat soil

3.1 Compaction Characteristics of Peat Soil

The compaction test was conducted in accordance with the specifications outlined in BS 1377 1990: Part 4. The experimental setup consisted of five distinct segments, with each segment containing different proportions of GGBS: 0%, 5%, 15%, 25%, and 50%. However, an issue was encountered during the 0% GGBS test where water overflowed from the base of the mould during the compaction process, leading to inconsistent moisture content measurements. To address this problem, the soil underwent a dual treatment involving air drying for approximately three days, followed by oven drying for an additional day. Figure 2 illustrates the comprehensive compaction characteristics of peat soil with varying GGBS additions (5%, 15%, 25%, and 50%) in comparison to untreated peat (0%). Furthermore, Figures 3 and 4 depict the impact of each GGBS addition on MDD and OMC, respectively.

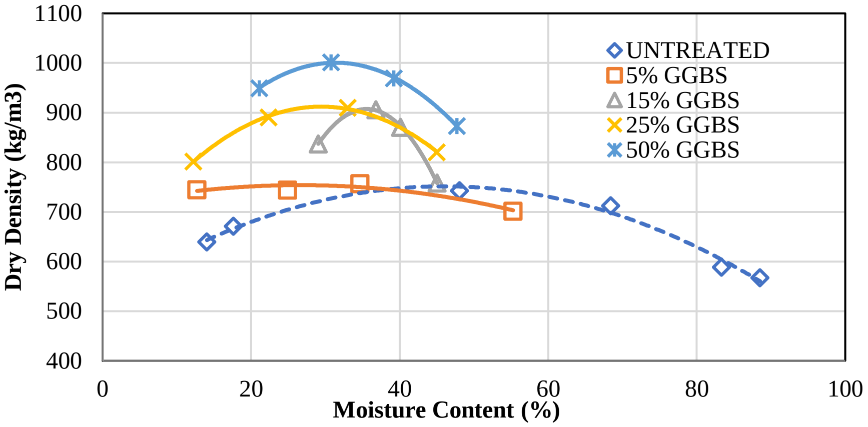

Figure 2. Compaction characteristics of peat soil treated with varied amounts of GGBS at 0%, 5%, 15%, 25%, and 50%

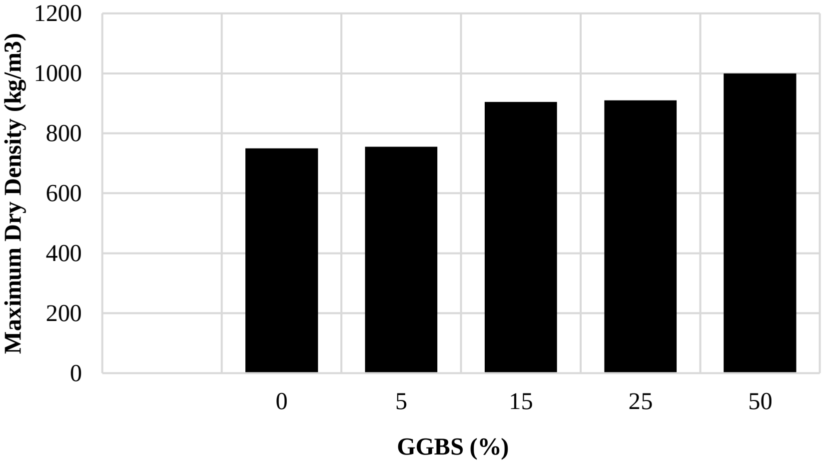

Figure 3. Effect of GGBS content on MDD

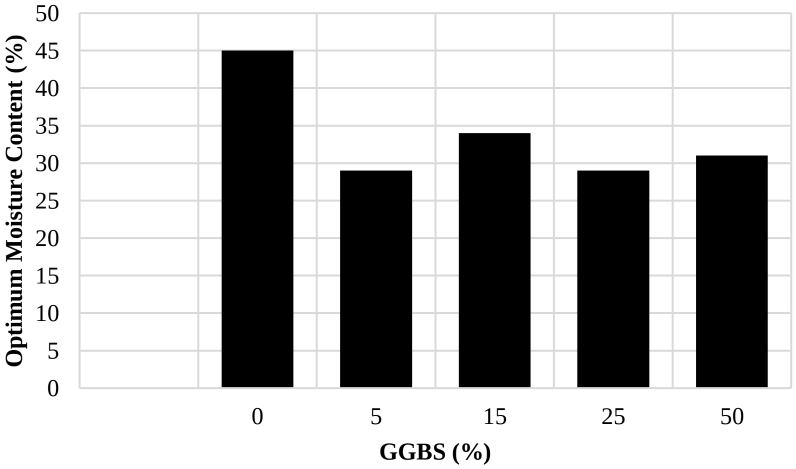

Figure 4. Effect of GGBS content on OMC

As shown in Figure 3, the data demonstrated that the MDD values for treated soil samples exceeded those of untreated soil sample. Specifically, the treated samples obtained an MDD value of 755 kg/m^3, which was nearly identical to the MDD value of 750 kg/m^3 recorded by the untreated sample. The peak MDD of 1000 kg/m^3 was recorded by the sample with a 50% GGBS addition. In terms of the Optimum Moisture Content, all treated peat soil samples had lower OMC values compared to the untreated soil sample. Notably, the OMC data does not exhibit a consistent linear trend. This deviation might be attributed to errors during the laboratory testing process, such as water spillage from the mould's base. Modifications to the apparatus were necessary to ensure consistent handling of peat soil. Among the GGBS additions, 5% and 25% exhibited the lowest OMC value of 29% while the addition of 15% GGBS yielded the highest OMC value.

However, the incremental addition of additives did not significantly affect OMC, with treated sample values ranging from 29% to 34%. A comparison between MDD and OMC values for untreated and treated peat soil indicated a positive correlation. The findings suggest that the optimal ratio for GGBS addition is 25%, resulting in the lowest OMC value while maintaining the second-highest MDD value, which is only marginally different from the 50% GGBS addition that yielded the highest MDD.

3.2 California Bearing Ratio (CBR)

The CBR parameter plays a pivotal role in the pavement design process, serving as a key factor in assessing the bearing capacity of a subbase. This parameter is instrumental in determining the load-bearing capability of a pavement structure. *Jabatan Kerja Raya* (Public Works Department) has established the Standard Specification for Road Works: Section 4 (Flexible Pavement), last revised in 2008 [20]. These specifications stipulate that the sub-base must exhibit a minimum CBR of 30% when compacted to 95% of its maximum dry density while undergoing soaked conditions.

However, a significant challenge arose in this test concerning the availability of GGBS resources. Due to limitations in GGBS material, there was insufficient supply for conducting tests under soaked conditions. As a result, the testing was conducted solely under unsoaked conditions. Figure 5 illustrates the CBR values at 2.5 mm and 5.0 mm penetration depths, which were determined as 26% and 30%, respectively. It should be noted that when considering soaked conditions, all relevant parameters were accounted for, leading to CBR values lower than those observed under unsoaked conditions.

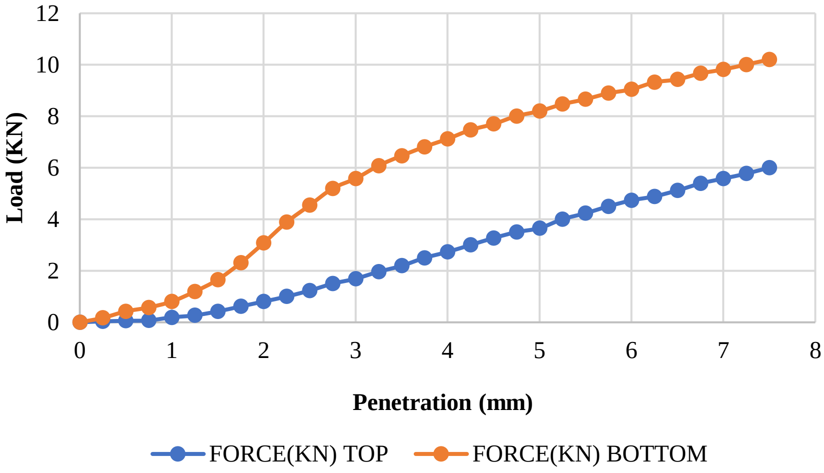

Figure 5. CBR results for 25% GGBS under unsoaked condition

3.3 Correlation to the Strength Characteristics of Peat Soil

Figure 6 illustrates the comparison results between the UCS and MDD values. While Figure 2 showcases slight disparities, the compaction test results accomplished the optimal combination for desired geotechnical characteristics (MDD = 910 kg/m³; OMC = 29%) with a 25% incorporation of GGBS. In contrast, the UCS test revealed the highest value of 174 kPa when the MDD reached 904 kg/m³, which was associated with a 15% addition of GGBS. This indicates a noteworthy marginal difference in UCS values between peat soil samples containing 15% and 25% of GGBS.

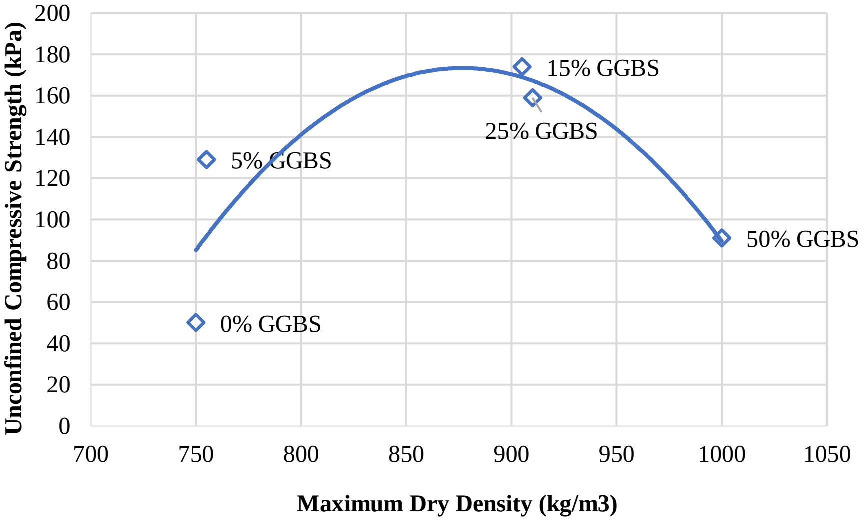

Figure 6. Comparison between UCS and MDD values

Such inconsistency could be attributed to various possible factors. It includes the presence of organic particles within the peat soil, which could hinder compaction by diminishing its density. This may elucidate the higher GGBS content needed to achieve the targeted dry density and optimal moisture content as indicated by the compaction test results. Another potential factor might involve water spillage or seepage from the mould's base during the compaction process, leading to reduced soil density and strength. Additionally, the inherent high porosity of peat soils implies the presence of substantial air voids, contributing to swelling and sponginess that hinder achieving high compaction levels.

The study demonstrates a reasonable yet not fully established correlation between compaction characteristics and strength. However, the observed relationship could be influenced by limitations in repeatability analysis due to material shortage and apparatus-related concerns. Despite these limitations, the data presented in this study reflects the correct trend.

4.0 CONCLUSION

This paper proposed a novel additive for peat soil stabilisation by presenting the compaction characteristics of treated peat soil. The study successfully achieved its outlined objectives, with the following summarised key findings:

1) Untreated peat soil displayed distinctive features, including a high liquid limit, substantial organic content resulting in high water-holding capacity, and low shear strength, subsequently indicating its inherent weakness and the need for stabilisation prior to construction.
2) The compaction characteristics exhibited a positive correlation with two crucial parameters: maximum dry density (MDD) and optimum moisture content (OMC). Treated peat soil demonstrated an increased MDD compared to untreated soil, reaching a maximum value of 1000 kg/m³ as compared to 750 kg/m³ obtained by untreated soil. Furthermore, the OMC of treated peat soil consistently decreased and achieved a minimum of 29% in contrast to the 45% recorded by untreated soil. Notably, all treated samples exhibited lower OMC values than the untreated sample.
3) The CBR values obtained from 25% GGBS addition, at 26% for 2.5 mm penetration depth, and 30% for 5.0 mm penetration depth under unsoaked conditions did not meet the subgrade standards set by *Jabatan Kerja Raya* Malaysia.
4) The optimal GGBS ratios differed between the compaction test (25% GGBS) and the UCS test (15% GGBS), yielding the highest UCS value of 174 kPa at 15% GGBS. However, the 25% GGBS ratio recorded the UCS value of 159 kPa, which was optimal for compaction. Despite this discrepancy, a correlation was observed as both ratios exhibited a decrease in OMC from 34% to 29%, while MDD increased from 905 kg/m³ to 910 kg/m³.

These experimental findings indicate that the inclusion of ground granulated blast furnace slag (GGBS) in peat soil significantly reduces its moisture content. The outcome suggests that GGBS can enhance soil stability and quality. In conclusion, this study introduces a potential approach for peat soil stabilisation using GGBS, ultimately revealing improvements in compaction characteristics and overall soil quality.

5.0 AUTHORS’ CONTRIBUTIONS

Nor Zurairahetty Mohd Yunus: Conceptualisation, Methodology, Writing, Validation

Muhammad Hafiz Hasni: Data curation (compaction), Writing, Original draft preparation

Harith Haiqal Mazlan: Data curation (peat characterisation), Writing, Original draft preparation

Bakhtiar Affandy Othman: Reviewing and Editing

Dayang Zulaika Awang Hasbollah: Validation and Reviewing

6.0 FUNDING

This research received funding from Universiti Teknologi Malaysia under the UTM Fundamental Research with the research grant vote number Q.J130000.3822.22H32.

7.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included in the article.

8.0 ACKNOWLEDGEMENT

The authors would like to thank the Geotechnical Laboratory of the Faculty of Civil Engineering, Universiti Teknologi Malaysia for providing the experimental facilities. Heartfelt gratitude also goes to all technicians for their assistance and support.

9.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

10.0 REFERENCES

[1] A.A. Mahmod, S. Mohd, M.I.M. Masirin, S.A.A. Tajudin, I. Bakar, A. Zainorabidin, A.Z. Kifli, and L.J. Hua, “Construction of buildings on peat: case studies and lessons learned,” *MATEC Web of Conferences*, vol. 47, no. 03013, pp. 1-5, 2016.

[2] S. Karthigeyan, and A. Ramachandran, “Strength and compressibility characteristics of peat soil. International *Journal of Engineering Research & Technology*, vol. 8, no. 12, pp. 296–302, 2019.

[3] A. Zainorabidin, and D.C. Wijeyesekera, “Geotechnical challenges with Malaysian peat,” *Proceeding Advances in Computing and Technology,* pp. 252–261, 2007.

[4] S.N.M. Razali, I. Bakar, and A. Zainorabidin, “Behaviour of peat soil in instrumented physical model studies,” *Procedia Engineering*, vol. 53, pp. 145-155, 2013.

[5] M.S. Islam, R. Hashim, “Bearing capacity of stabilised tropical peat by deep mixing method,” *Australian Journal of Basic and Applied Sciences*, vol. 3, no. 2, pp. 682-688, 2009.

[6] C.K. Behera, and S. Senapati, “Soil stabilization by industrial waste (GGBS and stone dust), *International Journal of Engineering Research & Technology*, vol. 10, no. 9, pp. 409-415, 2021.

[7] L. Manjunatha, GGBS: An Aberrant Alternative. Architecture Update, pp. 16-18, 2016.

[8] A.H. Ibrahim, J. Fikri, M.S. Ramadhinata, and Maryani, “Stabilization of peat soils using petrasoil with cement viewed from CBR value and free compressive strength value of soils,” *Journal of Physics*, vol. 15, pp. 1742-6596, 2019.

[9] P.K. Kolay, and M.P. Pui, “Peat stabilization using gypsum and fly ash,” *Journal of Civil Engineering, Science and Technology*, vol. 1, no. 2, pp. 1-5, 2010.

[10] M.R. Ramadhani, and Rusdiansyah, “The stabilization effect of peat soil using an effective microorganism reviewed from CBR Value,” *Journal of Engineering Sciences and Innovation*, vol. 7, no. 3, pp. 363-372, 2022.

[11] Roesyanto, and V.R.E. Putri, “Effect of compaction and direct shear test values on peat soil of Batubara Regency, Sumatera Utara Province,” *IOP Conference Series: Materials Science and Engineering*, vol. 801, pp. 1757-899, 2019.

[12] J.M. Said, and S.N.L. Taib, “Peat stabilization with carbide lime,” *Journal of Civil Engineering, Science and Technology,* vol. 1, no. 1, pp. 1-6, 2009.

[13] J. Ahmad, A.R.A. Samad, M.A.M. Ridzuan, and A.R.K. Farhan, “Peat Soil treatment using POFA,” *IEEE Colloquium on Humanities, Science and Engineering*, Penang, Malaysia, pp. 66-70, 2011.

[14] M.S. Sutarno, and H.M. Mohamad, “Peat soil compaction characteristic and physicochemical changes treated with eco-processed pozzolan,” *Civil Engineering Journal*, vol. 9, no. 1, pp. 86–103, 2023.

[15] P.K. Kolay, and S.N.L. Taib, “Physical and geotechnical properties of tropical peat and its stabilization,” Peat-InTech, p. 74173, 2018.

[16] B.C. O’Kelly, “Briefing: Atterberg limits and peat,” *Environmental Geotechnics*, vol. 3, no. 6, pp. 359–363, 2016.

[17] S. Hebib, and E.R. Farell, “Some experiences on stabilization of Irish peats,” *Canadian Geotechnical Journal*, vol. 40, pp. 107-120, 2003.

[18] G. Rajasekaran, K. Kurali, and R. Srinivasaraghavan, “Effect on chlorides and sulphates on lime treated marine clays,” *Soils and Foundations*, vol. no. 2, pp. 105-115, 1997.

[19] M.R. Aminur, P.K. Kolay, S.N.L. Taib, M.I.S. Mohd Zain, and A.A. Kamal, “Physical, geotechnical and morphological characteristic of tropical peat soils from Sarawak,” *Journal of the Institution of Engineers Malaysia*, vol. 72, no. 4, pp. 12-16, 2011.

[20] Jabatan Kerja Raya Malaysia, Standard Specification for Road Works Part4 Flexible Pavement, JKR/SPJ/2008-S4 Reapproved, JKR Specification for Road Works Part 4 Flexible Pavement, no. 7, 2008.