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J-SUE

http://publisher.uthm.edu.my/ojs/index.php/j-sue

e-ISSN : 2821-2851

Journal of Sustainable Underground Exploration

Compressibility Behaviour On Carbonation of Ground Granulated Blast Furnace Slag (GGBS) Treated Kaolin

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DOI: https://doi.org/10.30880/jsue.2023.03.01.001
Received 19 December 2022; Accepted 24 December 2022; Available online 31 July 2023

Abstract: With the growing worry over pollution in the environment, the necessity to comprehend this phenomenon has multiplied. Not only that, the economic gain made in the last decade, along with the fast growth of the world population, has come at a huge environmental cost. One of the never-ending issues is carbon dioxide emission and notably, the construction sector is no exception to mean to contribute through many development activities. Therefore, this study focuses on the compressibility behaviour of Ground Granulated Blast Furnace Slag (GGBS) treated kaolin clay due to carbonation. This study discusses the effect of carbonation on GGBS-treated kaolin as an effort to use sustainable materials which able to improve the geotechnical properties of soil and safe to say, help to reduce the emission of CO2. Testing program via one-dimensional consolidation test found that the compressibility characteristics improved as increased the GGBS content. Overall, the results illustrate that higher GGBS content and longer curing period gives lower compressibility characteristic. It was also found that the carbonated kaolin sample further improve the compressibility characteristics as compared to ambient condition of treated kaolin sample. In conclusion, GGBS can improve the compressibility characteristic of kaolin with carbonation consideration.

Keywords: Kaolin, strength, Granulated Grounded Blast Furnace Slag (GGBS), carbonation, consolidation

1. Introduction

Nowadays many developments were constructed for the sake of urban infrastructure, roads, bridges and highways, particularly in Malaysia. The growth of this vast development caused many areas to be discovered to accommodate the total population in Malaysia which required more buildings and residency. More than 100 million tons of kaolin resources have been discovered in the Malaysian states of Perak, Johor, Kelantan, Selangor, Pahang, and Sarawak [1]. In general kaolin clay can shrink when dried and expand when it is wet. The failure of buildings can be caused by the shrinkage and swelling of subgrade soil. Kaolin clay soil tends to invite many failures for the foundation footing, subgrade for roadways, foundation wall and collisions of the structure as it is commonly related to compressibility issues, as well as moisture content variations owing to rainfall and groundwater fluctuation [1]. Furthermore, kaolin is a geochemically and industrially versatile mineral [2] that is employed in a variety of industrial goods, such as construction materials and healthcare items. With the growth of development, chemical stabilization is being discovered to improve soil properties and overcome from structural failure. The most worldwide method for the

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chemical stabilization was using cement because cement is rich with the calcium (Ca) compound that will be reacted with hydroxide (OH-) to form C-S-H gel and pozzolanic reaction due to high hydration rate [2]. However, the immense use of cement contributes to high carbon dioxide (CO2) emission which is about 15% of carbon dioxide (CO2) emission [3]. Alternatively, several researchers exploring the usage of other sustainable materials to fits the environmental concern and attention. Ground granulated blast-furnace slag (GGBS) is one of the chosen materials as it has a favorable impact on the geotechnical properties of weak soil, especially on clays. GGBS is the waste product from the industry that have utmost oxide components of slag such as calcium, magnesium (basic oxides), silica and alumina [4]. In this study GGBS is the main stabilizer soil used as its ability reacts with carbonation mineral will then significantly produce an expansive reaction which finally fills available pores. Consequently, the hydrated carbonated formed massively and effectively compress the treated clay and improved its geotechnical properties.

2. Materials & Sample Preparation

2.1 Materials

2.1.1 Physical Properties of Kaolin Clay

Fig. 1 illustrated materials used in this study which are brown kaolin and fined-size GGBS. Table 1 summarizes the physical properties of kaolin clay from other findings. It can be seen that maximum dry density (MDD) value of kaolin range 1.3mg/m^3 to 1.8mg/m^3. OMC range from 18% to 29% while PL, LL and PI range from 20% to 38%, 38.2% to 61% and 18% to 29% respectively. Kaolin clay sample not appeared any gravels content but little percentage of sand particles which range from 6% to 7%. Most of the kaolin clay composition consist of clay and silt apparently range from 92% to 100%. The specific gravity ranges from 2.43 to 2.69 among the previous studies which is not very different from each other. The pH value for kaolin clay as stated in [5] is the highest which is 8 because the sample is taken from real site north of Iran (Jirandeh, Guilan) while the other sample is manufactured clay.

Table 1 - Physical properties of kaolin clay

Authors & Properties	[6]	[7]	[8]	[9]	[10]
MDD (Mg/m^3)	1.64	1.33	1.56	1.78	1.56
OMC (%)	18	29	28.5	18.37	24
PL (%)	22.5	38.13	38.2	20	32
LL (%)	40.5	57.78	57.2	48	61
PI (%)	18	19.65	19	28	29
Gravel (%)	-	-	-	0	-
Sand (%)	6.75	-	-	7.82	-
Clay + Silt (%)	93.2	100.00	-	92.18	-
5					
Specific gravity	2.52	2.46	2.69	2.43	2.57
pH	4.33	5	8.82	-	4.6

2.1.2 Chemical Properties of Kaolin Clay

From Table 2, it can be concluded from the previous finding that silica oxide dominates the kaolin soil at the range of 46% to 58% followed by aluminium oxides at the range of 29% to 35%. Then there is a small chemical constituent existing in the kaolin clay which are ferric oxide, potassium oxide and phosphorus pentoxide in the ranges of 0.7% to 1.0%, 0.5% to 8.8% and 0.1% to 9.4% respectively. Other chemical constituents such as calcium oxide, magnesium oxide and sodium oxide are less than 1.0%. In this study, the soil taken in use was acidic and in brownish colour kaolin obtained from Kaolin (Malaysia) Sdn Bhd located in Perak, Malaysia. Both physical and chemical properties of kaolin used as similar as [6]

Table 2 - Chemical composition of kaolin clay from other findings

Chemical properties of kaolin clay	[6]	[11]	[12]	[13]	[14]
SiO_2 %	49.5	48.18	49.5	58.26	46.31
Al_2O_3 %	30.31	31.10	30.31	29.43	35.12
Fe_2O_3 %	1.02	1.03	1.02	1.14	0.68
CaO %	0	-	-	0.89	0.06
MgO %	0	0.86	-	0.16	0.12
K_2O %	8.78	4.01	8.78	0.51	1.52
CO_2	-	1.34	1.4	-	-
SO_3	-	2.07	2.05	-	-
P_2O_5	-	9.37	4.03	-	0.10
Na_2O	-	-	0.79	0.1	0.30

2.1.3 Physical and Chemical Properties of GGBS

Meanwhile, the GGBS was obtained from a local plant situated in Johor Bharu, Johor, Malaysia. Table 3 consists of both the physical and chemical properties of GGBS as after [6]

Table 3 - Physical and chemical properties of GGBS used in this study

Physical properties		Chemical Properties	
Liquid limit (%)	36.6	SiO_2 %	30.5
Plastic limit (%)	-	Al_2O_3 %	10.4
Plasticity Index (%)	-	Fe_2O_3 %	0.30
Clay (%)	1.876	CaO %	47.6
Silt (%)	98.124	MgO %	4.88
Sand (%)	0	K_2O%	0.317
Specific gravity	2.83		
Optimum moisture content (OMC)	-		
Maximum dry density (MDD) kg/m^3	-		
pH	10.6		

(a)

(b)

Fig. 1 - (a) Brown kaolin and; (b) GGBS

2.2 Methodology

The odometer test was conducted on carbonated of GGBS treated kaolin clay. Each duplicate sample was prepared with different GGBS content from 5%,15% and 25% at 7 and 28 days of the curing period. As for the carbonation process, the samples were then quarantined at 24hours with 200kPa of carbonation pressure. The weight of samples before and after carbonation injection was recorded. Once the carbonation cell was removed, the samples were then tested for odometer test. Each load's vertical compression is monitored at appropriate intervals, often for up to 24 hours. Table 4 summarised the experimental work details. The laboratory tests were performed in the laboratories of the School of Civil Engineering at Universiti Teknologi Malaysia (UTM) in Skudai, Johor Bahru, Malaysia.

Table 4 - Summary of odometer carbonation experimental work

Content of GGBS (%)	**5%**		**15%**		**25%**	
Carbonation period (hours)	24		24		24	
CO_2 Pressure (kPa)	200		200		200	
Curing period (days)	7	28	7	28	7	28
Number of samples	2	2	2	2	2	2

3. Results & Discussion

3.1 Compressibility Characteristics

Consolidation testing is often used to examine the compressibility behaviour of soil. Consolidation tests may be performed in laboratories using the Rowe cell test, constant rate of strain (CRS) test, and 1D oedometer [15]. This study emphasizes on 1D oedometer usage for GGBS treated kaolin under carbonation conditions by using a conventional oedometer. Typically, a 1D oedometer detects the soil's vertical displacement when a force is applied that is rising, which correlates to volume change. Assorted parameters such as compression index (C_c), yield stress (P_c), coefficient of volume compressibility (m_v), coefficient of consolidation (C_v) and swelling index (C_s) are used to measure soil compressibility. The load increment ratio (LIR=2) applied was 6 kPa, 12 kPa, 25kPa, 50kPa, 100kPa, 200kPa, 400kPa,800 kPa, 1600kPa, and lastly 3200kPa while two decrement ratios applied during reloading phase which were 800kPa and 200 kPa.

Table 5 illustrates the findings and analysis for oedometer test after 7 days curing period at varying GGBS content. Basically, each sample was prepared according to an initial water content respectively OMC from each GGBS content resulted from compaction test performed earlier. The compression index, C_c for carbonated but untreated sample was 0.26 and decreased to 0.061 with 25% of GGBS content. Also, the settlement decreases from 6.68mm to 4.50mm as obviously shows untreated sample has higher compressibility criteria compared to other treated sample even though under carbonation condition. This can be anticipated that the presence of magnesium in GGBS contributes major difference, especially in the carbonation process.

Table 5 - Summary of oedometer test for carbonated GGBS treated kaolin at 7 days curing period

Samples	**Carbonation condition at 200kPa for 24 hours**			
	Untreated	**5% GGBS**	**15% GGBS**	**25% GGBS**
Initial diameter (mm)	50	50	50	50
Initial height (mm)	20	20	20	20
Final Settlement (mm)	6.68	5.99	4.70	4.50
Initial void ratio, e_i	0.45	0.99	1.03	1.06
Compression index, C_C	0.26	0.143	0.082	0.061
Preconsolidation pressure, P_c (kPa)	350	370	380	400

From Fig. 2, the initial void ratio increased as increasing the GGBS content, which in agreement with [8], [16], [17] stated that more additives are added to the weak soil, more binders tend to fill the void among the soil particles. Additionally, when the amount of GGBS in soil increases, more aggregates form larger voids between inter-aggregates of soil, raising the soil's void ratio. When surcharge loads are applied to the soil, the increased porosity aids in the release of pore-water pressures that have built up as mentioned by [18]. However, it can be seen from the graph that insignificant changes among the carbonated samples, even more, stress applied because GGBS is considered as waste materials that required longer time to bind foster closer with soil particles as well as to form a considerable amount of cementing agents such as calcium silicate hydrate [19].

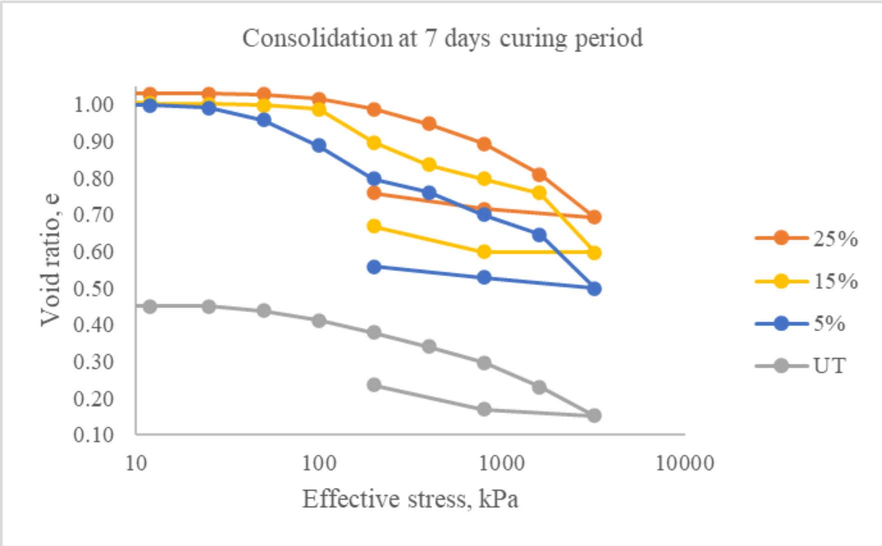

Fig. 2 - Compression curve of carbonated GGBS treated kaolin with 5% , 15% and 25% of GGBS content at 7 days curing period

Table 6 illustrates the findings of GGBS treated kaolin after 28 days curing period. Basically, each sample was prepared according to an initial water content respectively OMC from each GGBS content resulting from the compaction test performed earlier. The compression index, C_c for the carbonated but untreated sample was 0.08 and decreased to 0.031 with 25% of GGBS content. The more GGBS content the value of C_c decreased.

Table 6 - Summary of oedometer test for carbonated GGBS tretaed kaolin at 28 days curing period

Samples	Carbonation condition at 200kPa for 24 hours			
	Untreated	**5% GGBS**	**15% GGBS**	**25% GGBS**
Diameter (mm)	50	50	50	50
Height (mm)	20	20	20	20
Final settlement (mm)	6.68	5.20	3.95	3.28
Initial void ratio, e_i	0.45	0.99	1.01	1.03
Compression index, C_C	0.26	0.084	0.048	0.031
Preconsolidation pressure, P_c (kPa)	350	400	480	500

Fig. 3 shows the compression curve of carbonated GGBS treated kaolin at 28 curing periods. It can be seen clearly after 28 days; major difference occurs among the carbonated samples. The difference of void ratio of 5% carbonated GGBS treated kaolin is 0.397 while for 15% GGBS content is 0.183. The settlemet reduced at the GGBS increased as implies that the treated kaolin possesses less compressibility criteria after longer curing period. Also,the highest GGBS content which is at 25% the difference of void ratio appeared 0.1197. It shows that the void of carbonated samples for GGBS treated kaolin decreases with increasing GGBS content as prolong the curing period. This also proved that sufficient content of MgO and CaO from GGBS causes the enjoyment of mineral carbonation hence entitled for improving in soil's strength and less compressibility characteristics.

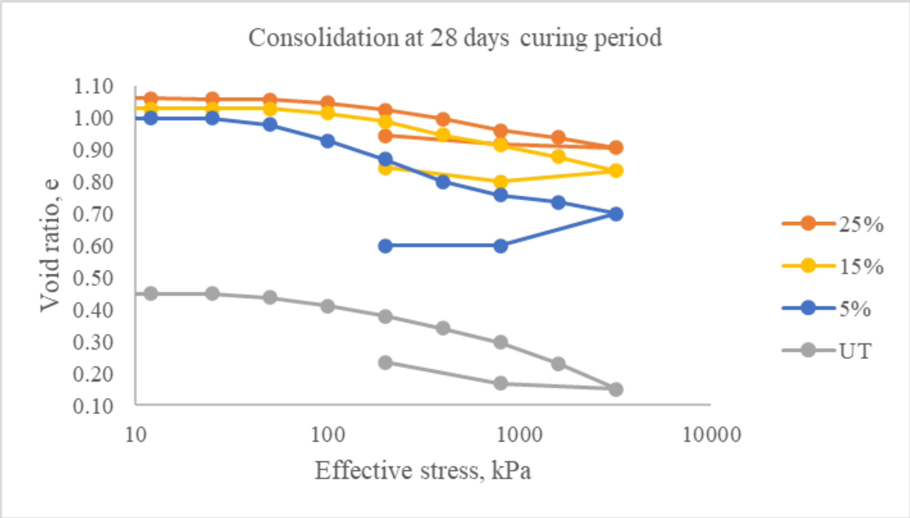

Fig. 3 - Compression curve of carbonated GGBS treated kaolin with 5% , 15% and 25% of GGBS content at 28 days curing period

Fig. 4 and Fig. 5 show the effect of carbonated GGBS treated kaolin clay in terms of coefficient of consolidation (c_v) at 7 and 28 days respectively. The rate of consolidation could be determined by measuring the coefficient of consolidation (c_v) obtained for each specimen at corresponding applied pressure. Based on that Fig., it can be seen the value of c_v decrease as increasing GGBS content which indicates that the samples experienced less compressible behaviour. Moreover due to the carboantion reaction that taking place between carbon dioxide and hydration products of cementitious materials, carbonates are well formed which causes the reduction in alkalinity of kaolin [20] and resulting in lesser compressibility of soil. Consequently, a decrease in c_v values were observed on lime-treated marine clay with higher GGBS content. From Fig. 4 we can see that, the coefficient of consolidation (c_v) for 28 days curing period for carbonated untreated kaolin is 17.9 m^2 /years at 100 kPa than it increases to 58 m^2 /years at 6400 kPa. Meanwhile at highest GGBS content perceive 100kPa, GGBS treated kaolin treated embark the coefficient of consolidation is decrease to 10.39 m^2 /years compare to at highest load appiled which is 37 m^2/year.

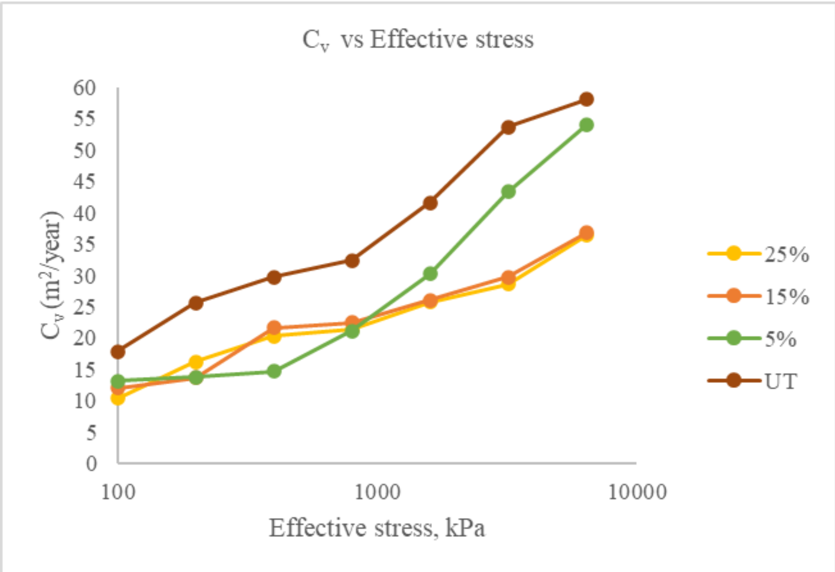

Fig. 4 - Effect of carbonation of GGBS treated kaolin on coeffiecient at 7 curing days

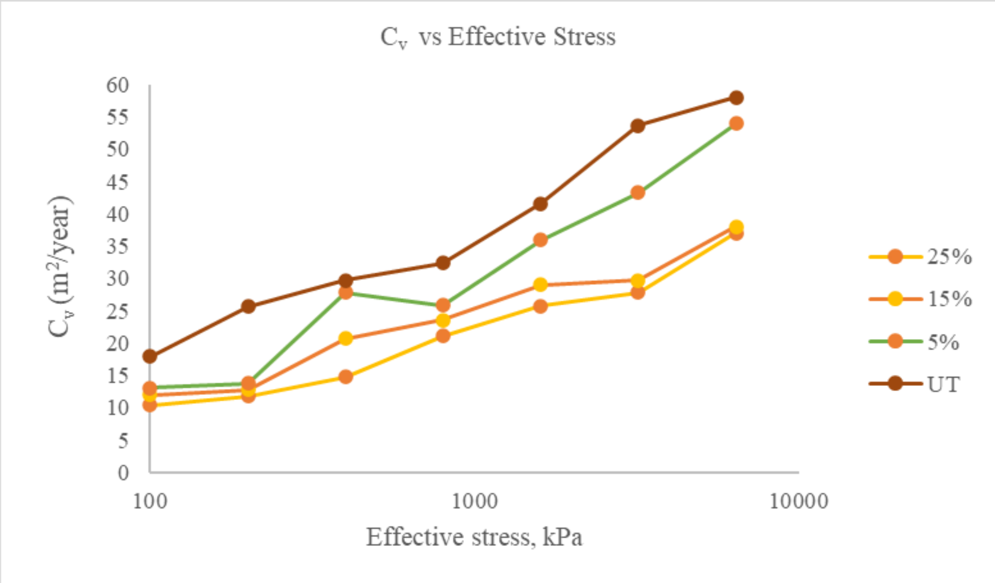

Fig. 5 - Effect of carbonation of GGBS treated kaolin on coefficient at 7 curing days

4. Conclusion

In this paper, GGBS was used as a stabilizer for kaolin soil. A series of tests were performed on samples of Kaolin clayey soil stabilised with varying percentages of GGBS, curing times, and conditions (carbonated or uncarbonated). Findings conforming to the objectives of this study can be summarised as below:

1. GGBS can reduce the compressibility of clayey soil depending on the content of the stabilizer. The higher the GGBS content, the lower the compressibility of the soil.
2. Curing period also give effect towards the compressibility of soil. The longer the curing period, the lower the compressibility characteristic.
3. The presence of carbon dioxide (CO2) causes the carbonation takes place eventually improved the compressibility behaviour og GGBS treated kaolin. Carbonation helps to reduce the compressibility of kaolin soil better as compared to treated samples under uncarbonated condition.

This study concludes that, GGBS is a sustainable material that able to stabilized the soil and lower the compressibility characteristics plus, the carbonation of GGBS treated kaolin improved the compressibility behaviour prominently.

Acknowledgement

The authors would like to acknowledge financial supports from UTM Fundamental Research Grant (UTMFR) Universiti Teknologi Malaysia with research grant no Q. J130000.3822.22H32 and UTM Fundamental Research Grant (UTM FR) under cost centre (Q. J130000.2551.21H42).

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