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Effect of voids in kaolin stabilised by ground granulated blast furnaces slag mixtures

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Abstract. Kaolin is known as problematic soil which has a low strength that needs to improve before construction. Chemical stabilization with cement is used widely to stabilize different clay types; however, using it comes with disadvantages associated with carbon dioxide emission and sustainability issues. As an alternative to cement, Ground Granulated Furnaces Blast Slag (GGBS) has been applied to stabilise kaolin. The increment in the strength is due to the formation of new products that fill the soil voids. The formation of those new products is verified using Field Emission Scanning Electron Microscopy (FESEM). However, the changes in pore space cannot be quantified using FESEM. Thus, this study uses Image J to calculate voids area detected by (FESEM) for different kaolin-GGBS mixtures with different content of GGBS cured for different curing period. The book-like structure for the raw kaolin have changed slightly when mixed with GGBS. This is due to the formation of hydrate gels as a result of the pozzolanic reaction. The results from image J indicates that the void decreases as the content of GGBS increases as well as the curing period.

1. Introduction

Kaolin is widely distributed around the world, and it is considered the most common clay minerals. It is a problematic soil with low strength and relatively high compressibility. Such a soil needed to be stabilized before construction [1, 2, 3]. Cement is known to be the common binder used for soil stabilisation. However, using cement comes with disadvantages associated with large amount of carbon dioxide (CO_2) emission during the manufacturing, producing 1 ton of cement leads to the emission of 0.95 ton of CO_2 [4,5]. Generally, global cement production is responsible for 7% of the total amount of artificial CO_2 emission [2]. Globally annual emission of carbon dioxide increased from 17.78 billion tons in 1980 to reach 32.1 billion tons in 2015, this increment is about 100% in 35 years and it is expected to reach double this value in 2035. In Malaysia, CO_2 emission increased by 69% from 2000 to 2020 reached 285.7 million tons [6].

Finding alternative to traditional stabilisers (cement and lime) have been challenging to researchers. Nowadays a lot of by products materials have been used to replace cement and lime either fully or partially. By product materials such as silica fume [7], rice husk ash [1], calcium carbide residue [8, 9] and demolish concrete [3], fly ash and bottom ash [10] have been used to stabilise different soil type. Silica fume is used to replaced lime partially, it has improved soil characteristics by decreasing permeability and increasing strength. Replacing cement by up to 10% rice husk ash (RHA) have shown an increment of CBR value. However, the addition of more than 10% RHA decreases the CBR value [1]. Other additives such as calcium carbide residue and demolish concrete are used alone to replace cement and lime in soil stabilisation.

Nowadays, recycling waste materials becomes essential for reducing the landfilling areas. It helps to reduce the landfilling areas, to achieve a more sustainable environment and to reduce the use of other non-sustainable material such as cement and lime. Current study demonstrates the use of ground granulated blast furnaces slag (GGBS) as a sustainable material to stabilise kaolin. GGBS is a by product material from iron manufacturing [11, 12], and it is widely available in Malaysia. GGBS can be used with OPC or other pozzolanic materials to produce durable concrete [13]. GGBS has an advantage over ordinary Portland cement, the production of 1 ton of GGBS leads to the emission of 0.07 ton CO_2 [14, 15]. It is also known that GGBS can capture CO_2 while enhancing soil strength [16].

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This paper concerns on the effect of the GGBS content and the curing period in enhancing the soil strength by filling the voids within kaolin-GGBS mixture. The voids were determined by applying IMAGE J software on the images that have been produced from Field Emission Scanning Electron Microscopy (FESEM).

2. Methodology:
Slightly acidic brown kaolin was used in current study, it is a very fine powder with very little coarse particles; it has a brown color. Kaolin was bought from KAOLIN (MALAYSIA) SDN BHD factory, located in jalan Tapah – Bidor, 35000 Tapab, Parak, Malaysia. GGBS is a very fine off-white material with no course particle larger than 2mm. GGBS used in this study is a fine off-white material with no large particles (more than 2mm), it was collected from a local factory located in Johor Bahru, Johor, Malaysia. The physical properties for kaolin and GGBS are presented in Table 1 below.

Table 1. Properties of kaolin and GGBS.

Material	Kaolin	GGBS
Liquid Limit (%)	40.5	36.6
Plastic Limit (%)	22.5	-
Plasticity Limit (%)	18	-
Clay (%)	0.65	1.876
Silt (%)	92.6	98.124
Sand (%)	6.75	0
Specific Gravity	2.52	2.83
Optimum Moisture Content (%)	18	-
Maximum Dry Density (kg/m^3)	1640	-
UCS (kPa)	115	-
pH	4.33	10.6

Kaolin was mixed with 20% and 25% GGBS from its dry weight, then 18% distilled water was added to the mixture and mixed properly to ensure homogeneous sample. The GGBS contents chose were based on the suitable amount for kaolin stabilisation at earlier curing (7 days) which were 20% and 25% [17]. The mixture was placed in a cylindrical mould with 76mm and 38 mm diameter. Then, it was extracted and sealed properly to ensure no lost in moisture occurs. The samples were left to be cured for 0 and 7 days in a humidity chamber.

Once the curing period is finished, the sample was placed on the oven for 24 hours, then crushed to small pieces and sieved. The particles with diameter less than 2 mm was collected and used for the FESEM analysis, to take microstructure image. Those images were used for image J analysis.

Image J is an image processing program that uses Java, and it was developed at the National Institutes of Health (NIH). The current study used this software to process the FESEM images and measure the voids in raw kaolin and other selected treated kaolin samples under ambient conditions. Image J involves two methods to measure the voids, the one used in this study is threshold method. Figure 1 shows the example of voids detected by image J using the threshold method. The voids are shown in this figure in black color. Afterward, the software calculates the voids area and presents it in Excel sheet.

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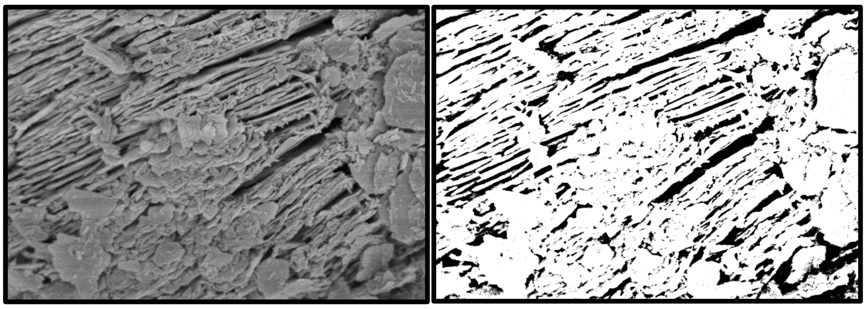

(a) (b)

Figure 1. Voids in kaolin clay detected by image J.

3. Result and discussion:

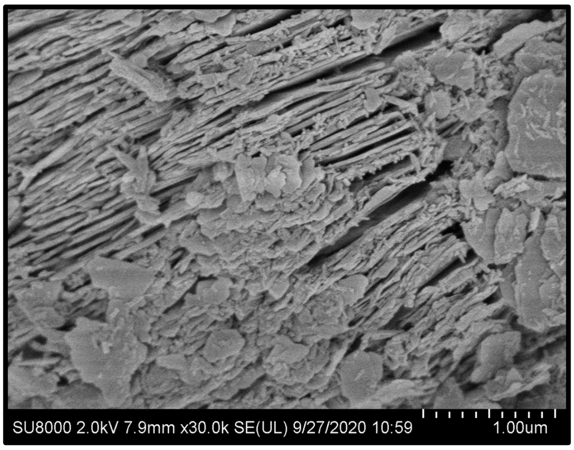

Figure 2. FESEM image for untreated kaolin.

Figure 2 shows the microstructure image for untreated kaolin taken at 30000 magnification. The shape of kaolin particles can be described as flaky and platy formation with smooth surface. The book like structure of kaolinite minerals is observed and it is considered the dominant feature of brown kaolin. Kaolin is known to have edge to face and edge to edge aggregate flocculated structure [18, 19, 20]. Based on the image, it can be seen that the structure of untreated kaolin contains large voids. The occurrence of voids leads to low strength.

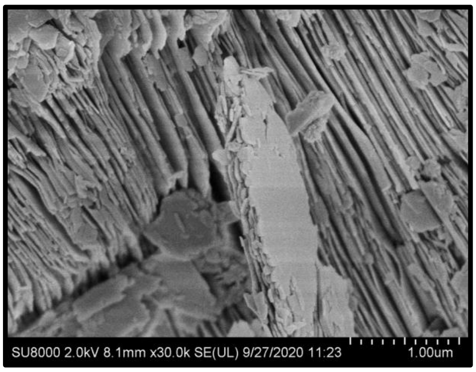

Figure 3. FESEM image of treated kaolin with 20% GGBS cured for 0 days.

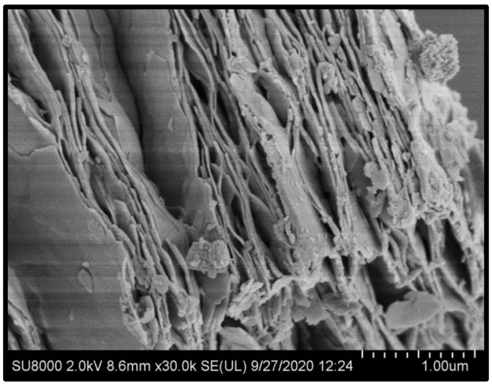

Figure 4. FESEM image of treated kaolin with 25% GGBS cured for 0 days.

Figure 3 and figure 4 show the image of treated kaolin cured for 0 days with 20% and 25% of GGBS. Similarly, images were taken at 30000 magnifications. The shape of micrographs does not differ compare to the untreated kaolin in which the dominant book like structure remains the same. Voids in the structure are still observed. In figure 4, for the treated kaolin with 25% GGBS calcium hydroxide ($Ca(OH)_2$) are observed, as a result the particles are slightly ponded and the voids became less .

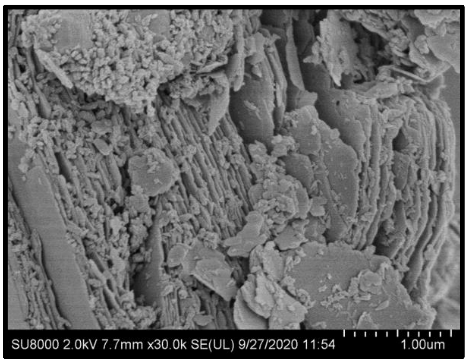

Figure 5. FESEM image of treated kaolin with 20% GGBS cured for 7 days.

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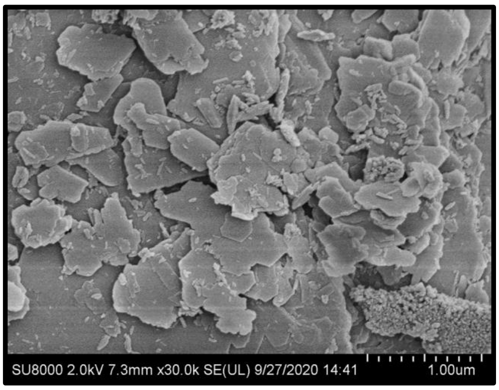

Figure 6. FESEM image of treated kaolin with 25% GGBS cured for 7 days..

Figure 5 and figure 6 shows the microstructure image at 30000 magnification for the treated kaolin with 20% and 25% GGBS cured for seven days. Changes start to occurs on the kaolin structure, the cementitious gels from pozzolanic reaction pond and coated the particles together, this makes the voids less. The kaolin structure changes from flaky structure to flocculated structure. Moreover, the voids in figure 6 are hardly detected.

In addition, Image J was used to determine the area of the available voids using the images detected from FESEM analysis.

Table 2. Voids measured in different kaolin-GGBS mixtures using Image J

Mixture	Total Area (um)	Voids Area (um)	Percentages of Voids (%)
Kaolin	11.84	2.11	17.8
20%GGBS-kaolin cured for 0 days	11.84	1.86	15.68
20%GGBS-kaolin cured for 7 days	11.84	1.69	14.27
25%GGBS-kaolin cured for 0 days	11.84	1.8	15.2
25%GGBS-kaolin cured for 7 days	11.84	1.37	11.57

Table 2 shows the calculate voids in different kaolin-GGBS mixtures using image J. The results illustrate that the voids in the raw kaolin represent about 17.8% from the total area. The percentage of voids decreases with the addition of GGBS. Adding 20% GGBS to kaolin reduces the voids by 2% while the addition of 25% GGBS to kaolin reduces its void by 2.5% at 0 days curing. Likewise, the voids have shown further reduction after 7 days of stabilization process. Significant drop on the percentage of voids from 0 to 7 days can be seen on 25% GGBS-kaolin mixture with 11.5% voids from the total area of the mixture. 25% GGBS-kaolin mixture shows less voids compare to 20% GGBS-kaolin and the raw kaolin may due to the availability of more calcium in 25% GGBS-kaolin mixture compare to other mixtures. Calcium reacts with silica and aluminum in kaolin to produce calcium silicate hydrate gels which bond soil particles hence reduce the voids. Higher curing period (7 days) results in a lower void compare to a lower curing (0 days) hence increase the strength more. 7 days curing allow GGBS to hydrate and form more gels that bond the particles together.

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4. Conclusion:

Image J was used to determine the changes in voids within kaolin-GGBS. It was found that the addition of GGBS content decreases the voids available, is due to the pozzolanic reaction and the formation of the gels such as calcium silicate hydrate gels that bond the soil particles hence increases the soil strength. It is assumed that lesser voids can be observed with longer curing period, as it allows the calcium within the GGBS to hydrate and produce more gels to bond the particles.

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