

# Plasticity and compaction characteristics on soft clay stabilised with coal ash and cement

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**Abstract.** This paper aims to determine the compaction and plasticity properties of marine clay stabilized with increasing percentages and different ratios of coal ash with cement. Coal ash with different ratio of bottom ash and fly ash (70:30, 50:50, and 30:70) were prepared at increasing percentages. Limited amount of ordinary Portland cement of 2% was added. The percentage of additives added to the marine clay were 5%, 8%, 10%, 15%, 20% and 25%, respectively. Standard Proctor test was done to determine the compaction characteristics while Atterberg limits was executed to acquire the plasticity characteristics of treated marine clay soil. In terms of plasticity, by increasing the additives percentages, the marine clay approaches CL group of plasticity which shows improvement in soil's plasticity. For compaction, the values of MDD of treated marine clay is higher while the OMC is lower when compare to untreated. Hence, with the addition of coal ash waste there is improvement in terms of soil's plasticity for all three ratios whilst for compaction values of treated marine clay does not change significantly between ratios.

## 1. Introduction

The increment in global population will in return increase the consumption of electricity which is vital in daily lives. As coal is considered cheaper when compared with oil and gas, the demand for coal has risen from time to time (1). From International Energy Outlook 2009, coal combustion for countries namely China, United States and India will forecast and increment of 88% between 2006 and 2030(2). In the United States, coal ash waste increases at a rate of 131 million tons yearly. Whilst in India, about 70% of electricity is generated by coal ash power plants. In return, about 120-150 million tons of fly ash and 100 million tons of bottom ash are produced yearly (3–5). In China, an approximate of 60 million tons of bottom ash is produced yearly(6). Based on the statistics given, it shows that there is an alarming need in utilizing coal ash waste. Moreover, due to the insufficient land available for the usage of landfill and high cost of landfill construction, concerns in terms of environmental and economic have arisen(7).



Marine clay is a type of soft soil which is considered problematic due to its high organic and water content. Moreover, its characteristics such as high compressibility, the ability change in volume due to water absorption and low in strength makes it unsuitable for construction purposes. With the present of clay minerals such as smectite and vermiculite, marine clay soil could easily expand(8). Marine clay could be found in abundance around the coastal and offshore areas(9). Due to the increase in development projects, there is a lack in available land, thus there is a need to construct on these deposits.

Coal ash waste consists of both fly ash and bottom ash. Fly ash is obtained from flue gases after the coal is burned(10), while bottom ash is accumulated from the bottom of the furnace(11). For this research, we are using coal ash from Tanjung Bin power station. The Tanjung Bin power station notably produces 180 tonnes of bottom ash and 1,620 tonnes of fly ash daily while burning 18,000 tons of coal each day. Regarding these statistics, it raises the importance of reutilizing fly ash and bottom ash as a means of sustainable construction materials and simultaneously helping to reduce the abundance of these waste materials. Based on previous studies, fly ash is usually reused back in order to provide pozzolanic and cementitious reactions with the soil(12). While bottom ash could contribute fine grained replacement for the soil, for example reusing it back as a road base material and aggregate replacement in concrete(11).

Hence, this research aims to acknowledge the compaction and plasticity properties of marine clay stabilized with increasing percentages of coal ash and with minimum amount Ordinary Portland cement(OPC). Moreover, the outcome of this paper would determine whether the different ratios of coal ash waste would provide any significant difference towards marine clay.

## 2. Materials and Method

For this particular research, the materials used were marine clay, while the additives were coal ash which consist of bottom ash and fly ash and also ordinary Portland cement.

### 2.1 Materials

Marine clay for this particular research was acquired from a development site in Iskandar Puteri, Johor at a depth of 1 m from original ground surface. Before any testing was done, the soil was initially prepared by air drying and sieving it passing 2 mm sieve. Next, it was kept in air-tight containers before proceeding to any testing. The physical and engineering properties for this marine clay soil were illustrated in Table 1. Coal ash, which is a combination of fly ash and bottom ash was obtained from Tanjung Bin Energy Power Plant in Johor. Properties of bottom ash and fly ash from Tanjung Bin Power Plant were summarized in Table 2 and 3. Bottom ash was prepared by oven drying it at 105 degrees Celsius for 24 hours. Later, it was sieved passing 2 mm in order to ensure that the bottom ash is within sand size. Additionally, fly ash exist in a fine grained form and there is no specific preparation done on fly ash and it is use as it is. Ordinary Portland cement (OPC) was obtained from the Structural Lab (D04), Universiti Teknologi Malaysia (UTM). Material characterization was later done for Marine clay, coal ash and OPC.

**Table 1.** Properties of Marine Clay Soil from Iskandar Puteri.

Properties	Standard used	Values
Grain size distribution	BS 1377-2	
Sand(%)		10
Silt(%)		27
Clay(%)		63
pH	BS 1377-3	7.5

Natural Moisture Content(%)	BS 1377-1	51
Specific gravity	BS 1377-2	2.57
Organic contents(%)	BS 1377-3	5.98
Atterberg Limits	BS 1377-2	
Liquid Limit, LL(%)		47
Plastic Limit, PL(%)		23
Plasticity Index, PI (%)		24
Mechanical properties		
Optimum Moisture Content, OMC (%)	BS 1377-4	24
Maximum Dry Density, MDD (kg/m <sup>3</sup> )	BS 1377-4	1530
Unconfined Compressive Strength, UCS(kPa)	BS 1377-7	88
BS Classification	BS 5930	CL
Chemical elements of marine clay		
O (%)		47.33
Al (%)		13.66
Si (%)		23.34
K (%)		2.57
Fe (%)		3.59
C (%)		7.28

**Table 2.** Properties of Bottom Ash from Tanjung Bin Powerplant, Johor.

Properties	Values
Colour	Black
Specific gravity	2.36
Chemical Elements of Bottom Ash	
O (%)	40.0
Al (%)	16.1
Si (%)	22.9
Ca (%)	2.2
Fe (%)	4.8
C (%)	10.1
K (%)	2.1

**Table 3.** Properties of Fly Ash from Tanjung Bin Power Plant, Johor.

Properties	Values
Colour	White
Texture	Powder
Specific gravity	2.16
Chemical Elements of Fly Ash	
O (%)	49.3
Al (%)	16.9
Si (%)	18.1
Ca (%)	1.1
Fe (%)	1.6
C (%)	10.6
K (%)	0.9

## 2.2 Testing Materials

Coal ash and Ordinary Portland Cement (OPC) were mix together at increasing percentages varying from 5%, 8%, 10%, 15%, 20% and 25%. Minimum amount of Ordinary Portland Cement (OPC) were use in this research at a fixed percentage of 2%. Furthermore, both bottom ash and fly ash (BA:FA) were combine together in different ratios starting from 70:30, 50:50 and 30:70.

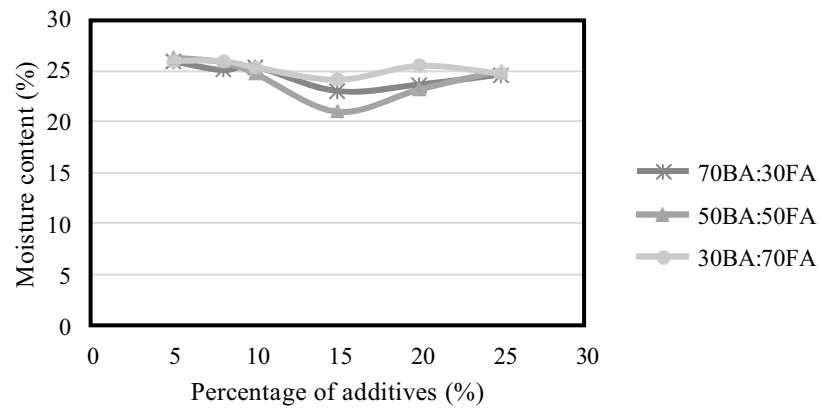
Atterberg limits which consist of plastic limit and liquid limit were performed on both treated and untreated marine clay. This test was done by following the British Standard 1377: Part 2. Marine clay was first air-dried and later sieved passing 425 $\mu$ m. About 300g of marine clay and additives would be mixed together homogeneously. Before both liquid limit and plastic limit were conducted, soil samples were first prepared by mixing marine clay with water and keeping it in a plastic seal bag for 24 hours before testing.

Standard Proctor test was conducted in accordance to British Standard 1377: Part 4 for untreated and treated soil samples. Marine clay was sieved passing 2 mm and later mixed with water and kept for 24 hours before testing in order to ensure moisture had distribute evenly in the soil. Before executing the test, the mixture of soil and water was mixed with additives. The outcome obtained from this test is the determination of maximum dry density (MDD) and optimum moisture content(OMC) for both untreated and treated soil samples.

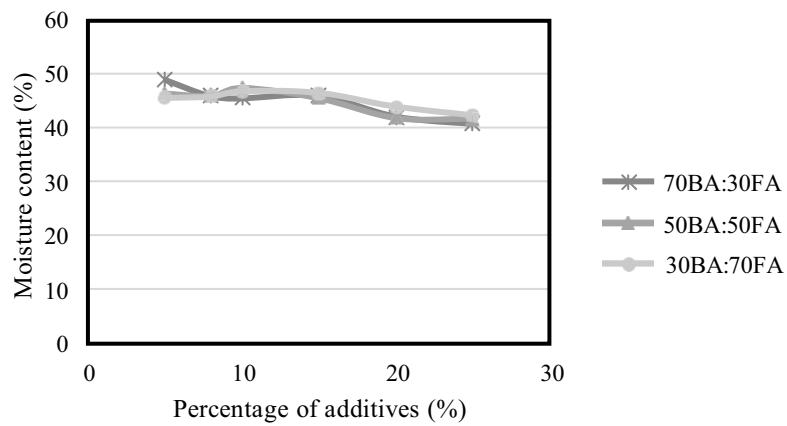
## 3. Results and Discussions

### 3.1 Atterberg limits

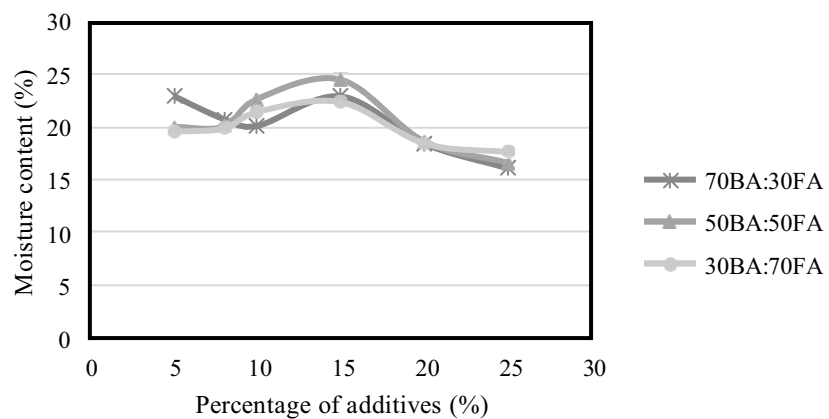
Atterberg limits for different ratios of bottom ash to fly ash with increasing percentages were investigated on marine clay and are shown in Figure 1-3. Figure 1 shows a graph of plastic limit of marine clay treated with different ratios of bottom ash and fly ash at increasing percentages. From the graph, it could be perceived that the plastic limit is the lowest at 15% for all three ratios with 50BA:50FA being the lowest which is 20.95%. The highest percentage of plastic limit is obtained at 5% with a ratio of 50BA:50FA being the highest which is 26.31%. The range of treated plastic limit is within 20% to 26%. Graph in Figure 2 shows the liquid limit of marine clay treated with increment percentage of different ratios of bottom ash and fly ash. From the graph, it could be perceived that with increasing percentages of additives there would be a decrement of liquid limit values. This is the same trend for all ratios of bottom ash and fly ash. The range values of liquid limit for treated marine clay varies from 40% to 48.89%. In terms of plasticity index, it could be identified from the graph in Figure 3 that the highest value of plasticity index is obtain at 15%. This is similar for all of the ratios of bottom ash and fly ash. The plasticity index of treated marine clay values ranges from 16% to 25%. When referring to the plasticity chart, untreated marine clay is categorized as clay of intermediate plasticity. With increasing percentage of additives, the marine clay approaches CL group of plasticity. This shows that there is an improvement in the engineering characteristics when there is a reduction in the soil's plasticity.



**Figure 1.** Plastic Limit of Marine Clay Treated with Different Ratios of Bottom Ash (BA) And Fly Ash(FA) at Increasing Percentages



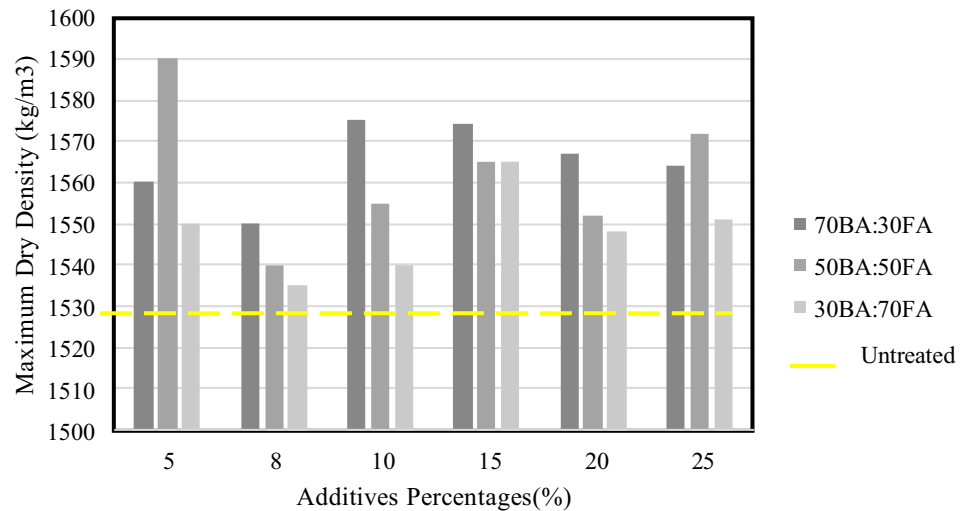
**Figure 2.** Liquid Limit of Marine Clay Treated with Different Ratios of Bottom Ash (BA) And Fly Ash(FA) at Increasing Percentages



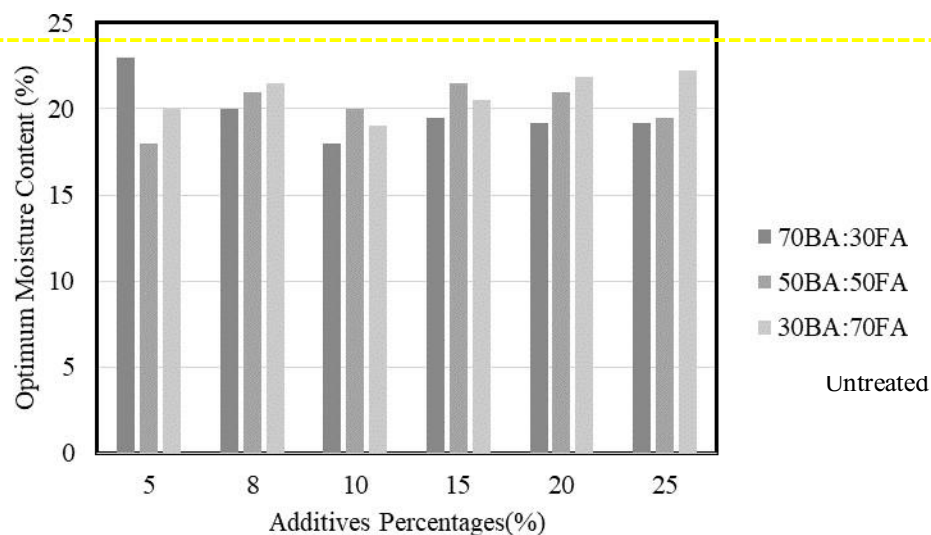
**Figure 3.** Plasticity Index of Marine Clay Treated with Different Ratios of Bottom Ash (BA) and Fly Ash(FA) at Increasing Percentages

### 3.2 Compaction

This section presents and summarises the results of the compaction data. The values of the MDD and OMC from the compaction test were compared according to the additive's percentages. The Standard Proctor Compaction test was conducted on treated marine clay soil samples with varying increments of moisture content as stated in BS 1377:1990. Figures 4 and 5 display a comparison between MDD and OMC based on the percentages of additives at 5%, 8%, 10%, 15%, 20% and 25% respectively with regards to the ratios of bottom ash to fly ash.



**Figure 4.** Maximum Dry Density of Marine Clay Treated with Increasing Percentage of Additives According to Different Ratio of Bottom Ash and Fly Ash (BA:FA).



**Figure 5.** Optimum Moisture Content of Marine Clay Treated with Increasing Percentage of Additives According to Different Ratio of Bottom Ash and Fly Ash (BA:FA).

Figure 4 shows the effect of different percentages of additives with different ratios of bottom ash to fly ash on the MDD. From the figure, it could be perceived that all of the MDD treated values

are higher than the untreated sample. The untreated marine clay has a maximum dry density of  $1530 \text{ kg/m}^3$ . The highest MDD was shown at 5% additives for the proportion of 50BA:50FA while the lowest MDD were shown at a mixture of 8% for the proportion of 30BA:70FA. As for the bottom ash and fly ash proportion of the same percentage of additive, increasing the proportion of bottom ash will increase the maximum dry density of the mixture. Sivakumar (2015), and Kumar et al. (2014) investigated that stated that the MDD of soil mixture would increase with increasing percentage of bottom ash. This is due to the bottom ash having a higher specific gravity when compared with fly ash, as shown in the research by Kumar et al. (2014). In addition, higher ratio of bottom ash and fly ash will fill in the pores available in the soil particles which is return will provide a much a higher MDD value. The range of MDD for treated marine clay is between 1535 to  $1590 \text{ kg/m}^3$ .

From Figure 5 it could be deduced that all of the optimum moisture content values are lower than the untreated sample. An addition of 5% additive at ratio of 50BA:50FA shows the lowest value for the optimum moisture content while 25 % at a ratio of 70BA:30FA shows the highest value of optimum moisture content. However, adding up additives does not affect the optimum moisture content significantly as its values only range between 18 % and 23 %. To summarize, when coal ash and OPC are mixed with marine clay soil the MDD gives a range between 1535 and  $1590 \text{ kg/m}^3$  while the OMC ranging from 18-23 %.

#### 4. Conclusions

As a conclusion, in terms of plasticity characteristics, the lowest value of plastic limit for all three ratios was obtained at 15% while the highest at 5%. Both of the lowest and highest values was obtained at a ratio of 50BA:50FA. The range of treated plastic limit is within 20% to 26%. Moreover, by increasing the percentage of additives, the value of liquid limit would also decreases. The range values of liquid limit for treated marine clay varies from 40% to 48.89%. For plasticity index, for all ratios of bottom ash and fly ash the highest value was obtained at 15%. The plasticity index of treated marine clay values ranges from 16% to 25%. Plus, with increasing additives percentages the marine clay approaches CL group of plasticity which shows improvement in soil's plasticity.

In terms of compaction properties all of the treated sample have higher MDD values and lower OMC values than the untreated sample. The highest MDD was obtained at a percentage of 5% additives for the proportion of 50BA:50FA while the lowest MDD were shown at a mixture of 8% for the proportion of 30BA:70FA. An addition of 5% additive at ratio of 50BA:50FA shows the lowest value for the optimum moisture content while 25 % at a ratio of 70BA:30FA shows the highest value of optimum moisture content. The range of MDD for treated marine clay is between 1535 to  $1590 \text{ kg/m}^3$  while for OMC the range is between 18-23%. By comparing both MDD and OMC of treated samples, these values does not change significantly with increment of additives and different ratio of bottom ash to fly ash.

To summarize, with the addition of coal ash waste there is improvement in terms of soil's plasticity for all three ratios whilst for compaction values of treated marine clay does not change significantly between ratios.

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