MECHANICAL ACTIVATION OF A WASTE MATERIAL USED AS CEMENT REPLACEMENT IN SOFT SOIL STABILISATION

Hassnen M Jafer[1, 3], **W Atherton**[2], **F Ruddock**[2], **and E Loffil**[2]
[1] *Postgraduate Research Student, Liverpool John Moores University, School of the Built Environment, Henry Cotton Building,15-21 Webster Street, Liverpool, L3 2ET, UK*
[2] *Liverpool John Moores University, School of the Built Environment, Peter Jost Enterprise Centre, Byrom Street, Liverpool, L3 3AF, UK.*
[3] *University of Babylon, College of Engineering, Civil Engineering Department, Babylon, Iraq. E-mail address: H.M.Jafer@2014.ljmu.ac.uk*

ABSTRACT

Waste materials, sometimes called by-product materials have been increasingly used as replacement materials to reduce the usage of cement in different construction projects. In the field of soil stabilisation, waste materials such as pulverised fuel ash (PFA), biomass fly ash (BFA), sewage sludge ash (SSA), etc.; have been used since the 1960s. In this study, a particular type of a waste material (WM) was used in soft soil stabilisation as a cement replacement combined with the effect of mechanical activation, using grinding, to enhance the performance. The stabilised soil in this study was an intermediate plasticity silty clayey soil with medium organic matter content. The experimental investigations were conducted to find the optimum content of WM by determining the Atterberg limits and the unconfined compressive strength (UCS) of soil samples containing (0, 3, 6, 9, 12, and 15%) of WM by the dry weight of soil. The UCS test was carried out on specimens exposed to different curing periods (zero, 7, 14, and 28 days). Moreover, the optimum percentage of the WM was subject to different periods of grinding (10, 20, 30, 40mins) using a mortar and pestle grinder to determine the effect of grinding and its optimum time by conducting UCS tests. The results indicated that the WM used in this study improved the physical properties of the soft soil where the index of plasticity (IP) was decreased significantly from 21 to 13.10 with 15% of WM. Meanwhile, the results of UCS test indicated that 12% of WM was the optimum and this percentage developed the UCS value from 202kPa to 700kPa for 28 days of curing. In terms of the time of grinding, the results revealed that 10 minutes of grinding was the best for mechanical activation for the WM used in this study.

Keywords: Soft soil stabilisation, waste materials, grinding, and unconfined compressive strength.

INTRODUCTION

Soft soil stabilisation is a technique produced several decades ago. It intends to alter the undesirable soil properties on site, such as low strength, high compressibility, and the tendency to swell when its water content increases, to become suitable to reuse as a construction material (Kolias et. al, 2005). More precisely, soil stabilisation is suggested to help the engineer in being able to reuse the in-situ soil that exists on a project site as an engineering material with specific properties, especially strength, volume stability, permeability and durability (Tyrer, 1987). Ordinary Portland Cement (OPC) and lime are the most traditional materials which have been used in the field of soft soil stabilisation. They are sometimes mixed with special additives such as pozzolanic material which are rich in silica (SiO2). However, there are a plentiful number of research projects involving lime and OPC as binder material in soft soil stabilisation due to their ability to bond the particles of soft soil with each other forming a stronger material as indicated in (Abd El-Aziz et al, 2006; Farouk and Shahien, 2013; and Modarres and Nosoudy, 2015).

Due to the negative environmental influence and relatively high cost of cement production, researchers have been motivated to discover more environmentally friendly and cost effective materials to replace, or reduce the use of OPC in the concrete industry. These materials are in general by-product or waste materials and are sometimes called fly ashes (FA). These materials are most likely to have pozzolanic properties, which by themselves do not have any cementitious properties, but when added to cement, react to boost the hydration processes and these materials are categorised as FA class F. Moreover, some of fly ashes have an adequate calcium content which makes them highly reactivity when mixed with water, and this type of FA is called FA class C (Ghosh and Subbarao,2007). The waste material used in this study can be considered as class C fly ash since it has high calcium content.

There are numerous research papers on the use of different types of fly ashes such as palm oil fly ash (POFA), rice husk ash (RHA), pulverised fuel ash (PFA), ground blast furnace slag (GBS), silica fume (SF), etc., in soil stabilisation. These types have been used either as main additives to improve the physical and geotechnical properties of the week soils such as the UCS and soil resistance against swelling and shrinkage stresses as indicated by (Abd El-Aziz et al, 2006; Yadu and Tripathi, 2013; Jafer et al, 2015(1); and Mujah et al, 2015).

Furthermore, many researchers have used waste materials mixed with cement or lime in diverse types of research areas such as concrete mix; design of concrete pavements and soil stabilisation. They mixed these materials with cement or lime in order to reduce the usage of cement in order to decrease the negative environment effects of cement production.

In this case, these materials are called supplementary cementitious materials (SCM); they have a high content of amorphous silica (suitable pozzolanic reactivity) in addition to self-cementing property. Moreover, they can accelerate the hydration processes when mixed with lime or OPC as SCM by building more calcium silicate hydrate compound (C-S-H) which has the ability to strengthen the structure of the stabilised soil (Yilmaz and Degirmenci, 2009; and Modarres and Nosoudy, 2015).

There is a fact that, in addition to the pozzolanic reaction or/and the self-cementing property of the fly ashes, the specific surface area and the fineness have an important effect on the compressive strength of stabilised soil or concrete. It was proven that the fly ashes with more surface area or more fineness produced higher compressive strength of stabilised soil and concrete (Yazici and Arel, 2012; and Jafer et al, 2015(2)).

Many researchers that intended to study the effect of the fineness of fly ashes, have applied grinding effort either using ball mill or mortar and pestle techniques as a method of mechanical activation for the waste materials using different surface areas. The mechanical activation process is always used in advance to the any further activation such as chemical activation (Sadique et al, 2012; and Dewi et al, 2014).

This paper presents the results of experimental works for mechanical activation using grinding of a particular waste material (WM) which contains adequate calcium content to produce suitable soil stabilisation. The WM was added first to the soil with different percentages (0, 3, 6, 9, 12, and 15%) by the dry weight of stabilised soil to find the optimum percentage of the WM by conducting Atterberg limits and UCS tests. The specimens of UCS tests were subjected to four different periods of curing (zero, 7, 14, 28 days). Thereafter, the optimum percentage of WM was activated mechanically by being subjected to grinding using a mortar grinder. Four different periods of grinding (10, 20, 30, and 40 minutes) were adopted to study the effect of the time of grinding on the performance of the mechanically activated WM.

MATERIALS AND METHODOLOGY

Soil sample:

The soft soil used in this study was collected from the riverbank of the estuary of the River Alt located in High Town to the north of Liverpool City Centre in the UK. It was extracted from a depth about 30-50cm below ground level, then placed in sealed plastic bags of 20-25kg each before the transferring to the laboratory. When the soil arrived at the laboratory, a small specimen of soil was taken to determine the natural moisture content (NMC), and then the remaining soil was oven dried at 100^{o}C to be equipped for other experiments. All classification tests were conducted to find the soil characteristics such as grain size distribution, consistency limits, maximum dry density, optimum moisture content, etc. Figure 1 shows the particle size distribution of the stabilised soil in this study, while all main physical and geotechnical characteristics are listed in Table 1. BS EN ISO 17892-4:2014 for particle size distribution (European Committee for Standardization, 2014), and BS 1377-2 and 4:1990 (British Standard, 1998) were adopted to determine the geotechnical characteristics, Atterberg limits and compaction parameters respectively.

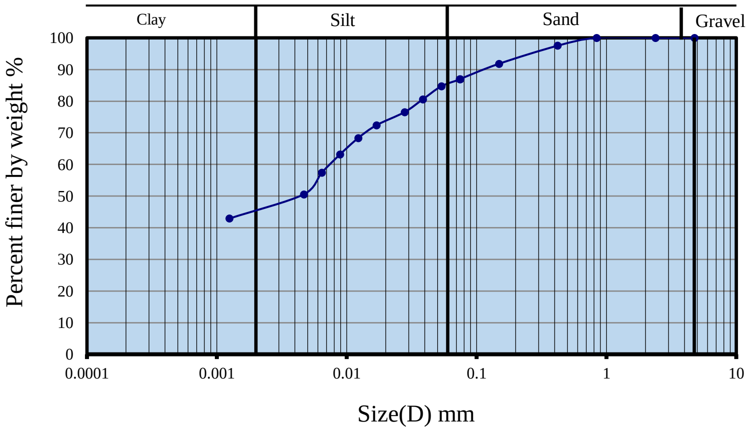

Figure 1: Particle Size Distribution

According to the Unified Soil Classification System (USCS), and depending on the particle size distribution, LL, and IP, the soil in this research project is an intermediate plasticity silty clay with sand (CI).

Table 1: Main physical and engineering properties of the soft soil

Property	Value
Natural Moisture Content NMC %	52.14
Liquid Limit LL %	44
Index of Plasticity IP	20.22
Sand %	13.08
Silt %	43.92
Clay %	43.00
Specific Gravity (Gs)	2.57
γ dmax g/cm^3	1.57
Optimum moisture content OMC %	23
pH	7.78
Organic Matter Content %	7.95
Unconfined Compressive Strength qu (kPa)	202

g/cm^3= gram/cubic centimetre, kPa = kilopascal.

Waste Material (WM):

The waste material WM used in this study is a powder produced from the incineration of a particular type of waste material in a local power station. It has a sufficient content of calcium which makes it eligible to be used as SCM. Furthermore, this material is slightly coarse in comparison to the Ordinary Portland Cement as shown in Figure 2. However, this material would produce better results if it were to be exposed to grinding energy as suggested by Jafer (Jafer et. al, 2015(1)).

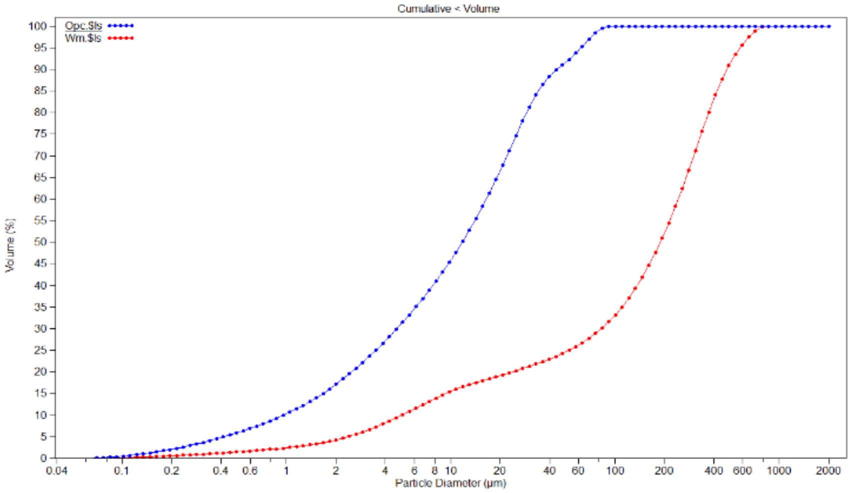

Figure 2: Comparison of cumulative particle size distribution of OPC and FA

Figure 3 shows a photo from a scanning electronic microscopy test (SEM) for WM; it shows that the particles of this material have a coagulated and flocculated shape.

EXPERIMENTAL WORKS

Sample Preparation and Conditioning:

After the drying process, the soil samples were pulverised to break lumps and then prepared for the Atterberg limits test along with compaction parameters test. The WM was added with five different percentages 0, 3, 6, 9, 12, and 15% by the dry weight of soil. The water was added directly to the mixture to make the stabiliser-soil paste then the paste was tested straight away according to BS 1377-2:1990 (British Standard, 1998).

Same percentages of WM as indicated above were used first to prepare the stabilised soil specimens for the UCS test in order to find the optimum WM content. The UCS test was conducted by using a computerised triaxial machine and the values of UCS were determined by applying vertical load only and removing the horizontal stress in the triaxial cell (σ3 = 0) as shown in Figure 4.

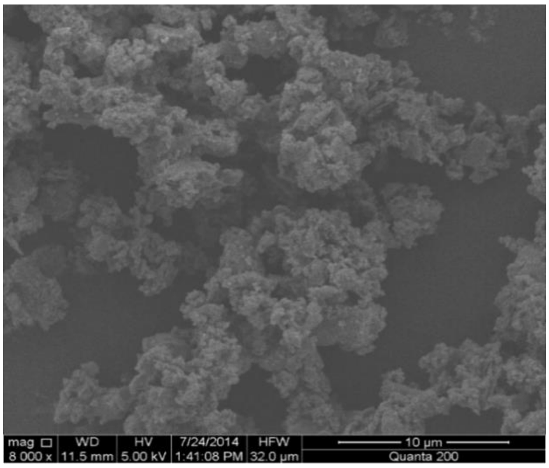

Figure 3: SEM Image of FWM

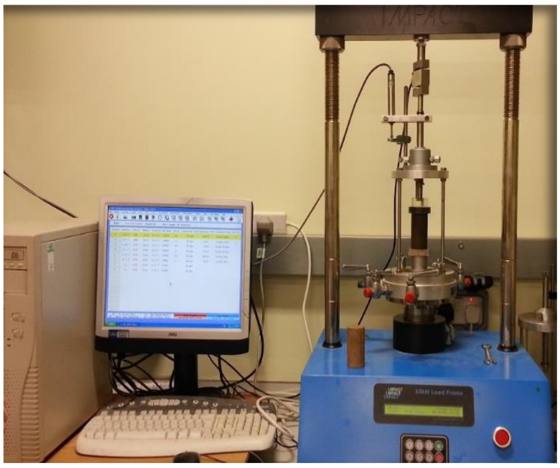

Figure 4: Computerised triaxial machine to measure UCS ($\sigma_3 = 0$)

A manufactured mould with constant volume shown in Figure 5 was used to make specimens for the UCS test with 38mm in diameter and 76mm in height with specific densities dependant on maximum dry density (MDD) and optimum moisture content (OMC) calculated from compaction testing for each corresponding percentage of the added WM.

The soil-WM mixture was compacted inside the mould, after adding the required water content, using hydraulic load. Then the specimens were extruded and weighed (Figure 6) then covered in cling film, enclosed in well-sealed plastic bags, and stored for curing at room temperature at approximately 20 ± 2^{o}C.

Laboratory Tests

The optimisation of the WM used in this study was dependant on the results obtained from the Atterberg limits and UCS tests, while the achieved improvement in UCS was mainly considered to study the effect of the mechanical activation of WM. The complete range of tests were:

- Atterberg limits tests - (Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI)). These limits were determined in accordance to BS 1377-2:1990 (British Standard, 1998). LL test was conducted using a Cone Penetrometer device.
- Standard Proctor compaction tests were conducted in accordance to BS 1377-4:1990 (British Standard, 2002) using approximately 2000g of dry soil or soil-binder passed through a sieve size of 3.35mm then moulded inside the standard mould in three layers after mixing with a required amount of water with each layer subjected to 25 blows using 2.5kg hammer. This test was performed for each different percentage of WM.
- Unconfined Compressive Strength testing was performed according to BS 1377-7:1990 (British Standard, 1998). At least two specimens were prepared for each corresponding percentage of WM and were tested for different periods of curing (7, 14, and 28 days) in addition to the uncured samples.

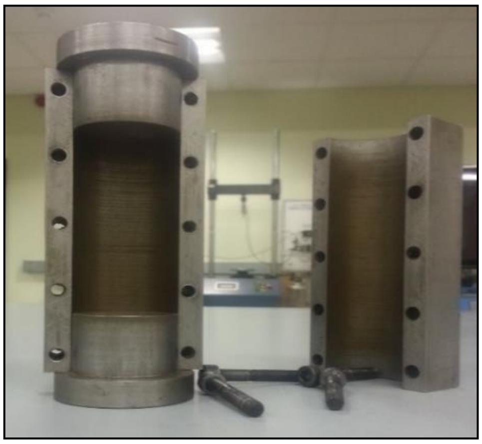

Figure 5: Constant volume mould used to prepare the soil

Figure 6: Hydraulic compaction and weighing of a specimen preparation

RESULTS AND DISCUSSION

Atterberg Limits:

Five different percentages of WM were added to the soft soil in order to find the effect of the waste material used in this study on the Liquid Limit and Plastic Limit of the treated soil, these percentages were 3, 6, 9, 12, and 15%. Figure 7 shows the relationship between WM content and the LL, PL, and PI of the stabilised soil.

From Figure 7, it can be seen that the WM used in this study has a significantly positive effect to improve the plasticity index for the treated soil where the PI decreased from 20 to less than 13.1 by adding 15% of WM while both the LL and PL increased with increase of WM. The reduction that occurred in the soil plasticity is due to the exchange of cations between the clayey minerals in the soft soil and the WM (Gharib et al, 2012).

Compaction Test:

One of the necessary tests that should be carried out on stabilised soil is the compaction parameters test which identifies MDD and OMC. This test should be repeated for each type of soil as well as for each different type and percentage of binder. Furthermore,

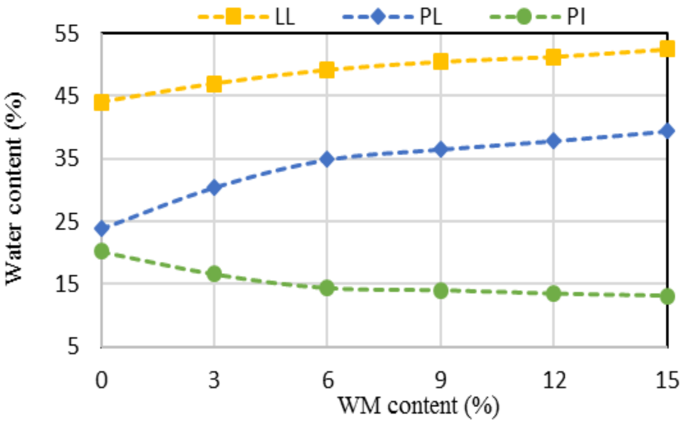

Figure 7: Atterberg Limits for soil treated with WM

the preparation of soil-binder specimens required to find the other geotechnical properties such as the UCS, consolidation, Triaxial, California Bearing Ratio tests, etc., is dependant essentially on the values of MDD and OMC obtained from compaction test for each corresponding percentage of the added binder.

In this study, untreated and soil treated with 3, 6, 9, 12, and 15% by the dry weight were subjected to standard Proctor compaction tests to find the MDD and OMC for each of the corresponding percentages of WM. The results of this test are shown in Figure 8. It can be easily recognised that the WM has a significant effect to decrease the MDD of the stabilised soil. Additionally, the OMC increased significantly with the continuous increase of WM content. However, the results of the compaction test showed that MDD decreased from 1.56g/cm^3 for untreated soil to 1.40g/cm^3 by adding 15% of WM, while OMC increased significantly from 23% to 30.5% by using 15% of WM. This behaviour is due to the increase in water demand for hydration which occurs with the existence of calcium oxide in the WM.

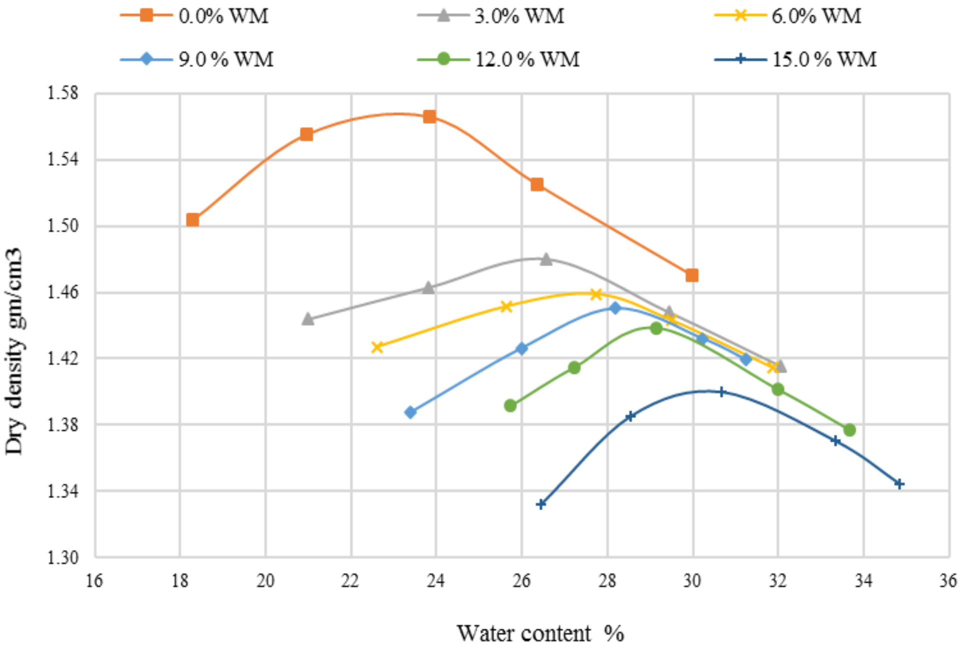

Figure 8: Compaction parameters for the soft soil treated with WM.

Unconfined Compressive Strength Test (UCS):

The soft soil was treated first with different amounts of WM in order to find the optimum percentage of WM and these percentages were 0, 3, 6, 9, 12, and 15% of the dry weight of the soft soil. Moreover, the specimens were subject to the UCS test after different times of curing (0, 7, 14, and 28 days). Figure 9 shows the relationship between the higher values of compressive strength obtained from the stress strain diagram of the UCS tests versus the percentages added of WM for different periods of curing. It can be seen that the UCS increased with the increase in WM percentage, as well as, the increase in the time of curing but there was a slight decrease in UCS value for the soil treated with 15% WM in comparison with soil treated with 12% WM. However, the results of this test indicated that 12% of WM is the optimum percentage and this percentage was adopted in the mechanical activation testing.

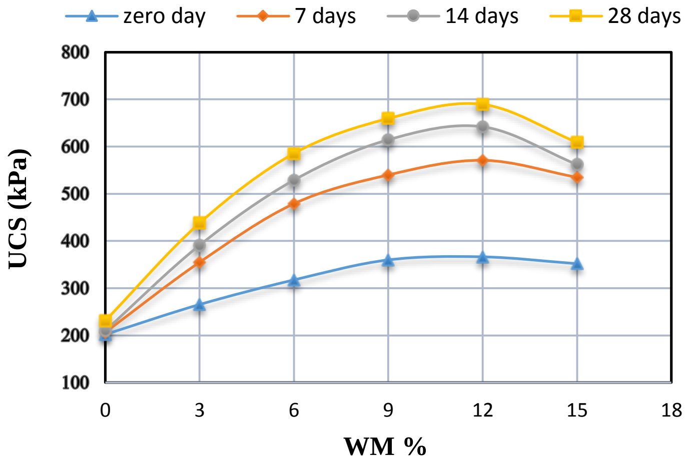

Figure 9: Relationship between UCS and WM percentage in different periods of curing

Mechanical Activation results:

The optimum percentage of WM obtained from the UCS testing was subjected to four different periods of grinding using a mortar and pestle grinder; these periods were 10, 20, 30, and 40 minutes. UCS testing was conducted on specimens of 12% WM treated soil to find the optimum grinding time. The results shown in Figure 10 indicated that 10 minutes grinding was the optimum time to produce the higher value of UCS.

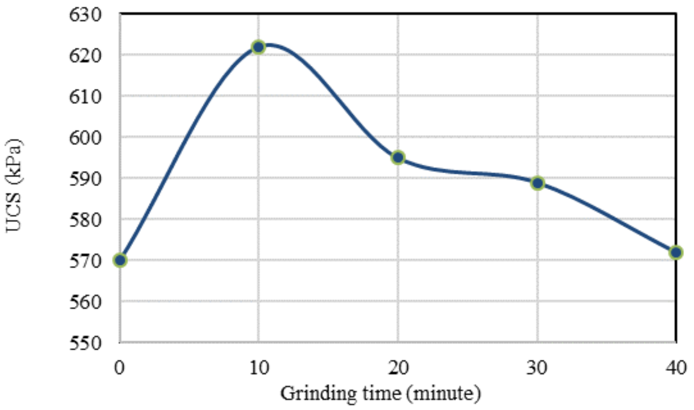

Figure 10: Effect of grinding time on UCS for specimens with 12% WM and 7 days age.

The use of grinding effort applies an external dynamic load on the solid particles due to crashing, and this process promotes the particles to be electronically exited and disturbs the electronic assembly of bonding (Sadique et al, 2012). Furthermore, the results of mechanical activation indicated that the grinding technique is helpful to get finer material and generate more surface area which boosts the pozzolanic reactivity of the WM, but in turn, grinding for long periods leads to agglomeration phenomenon which acts as a retarder against the pozzolanic reaction.

Figure 11 shows the particle size analysis for the WM ground with different periods in comparison with its unground grade. This figure provides evidence to explain the reason for the reduction in the UCS with WM ground for longer than 10 minutes. It can be concluded that the dynamic force of grinding for long periods caused an electronic activation for WM particles in addition to the mechanical activation. This electronic activation made the particles agglomerate directly when combined with water and this phenomenon in turn decreased the pozzolanic reaction for the WM.

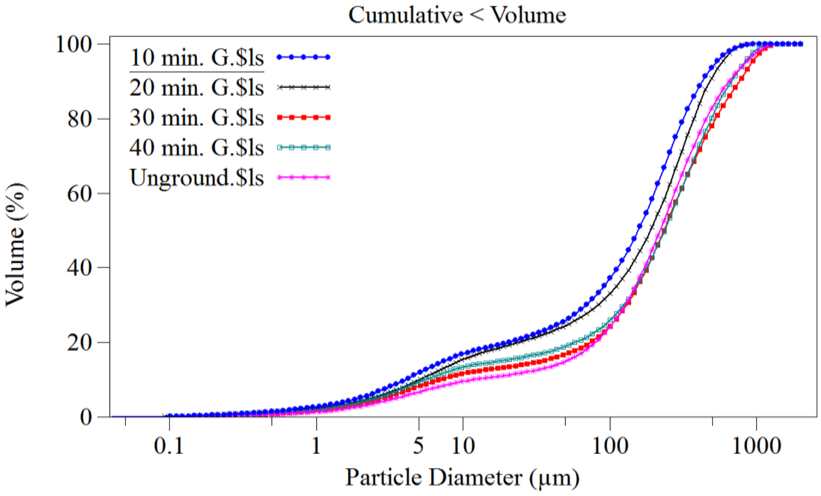

Figure 11: Effect of grinding time on particle size distribution of WM

Furthermore, the development in the UCS of the soil stabilised with 12% mechanically activated WM was investigated to find the growth in UCS with time of curing in comparison with those for untreated and soil treated with non-activated 12% WM as shown in Figure 12. From this figure, it can be seen that for 28 days of age, the UCS was increased from 689.5kPa to 776kPa by using 10 minutes grinding due to the increase in surface area which was achieved by the grinding process.

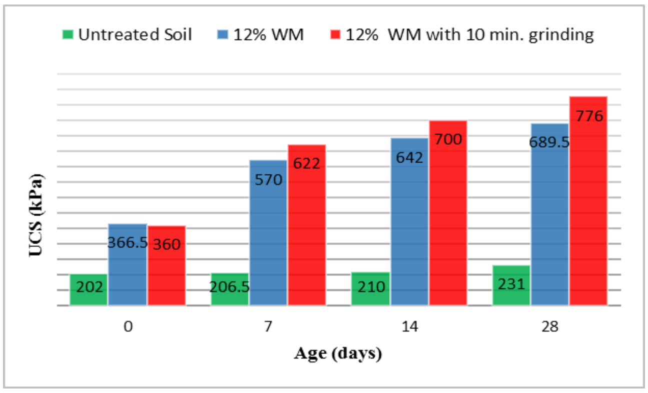

Figure 12: Effect of grinding activation on the development of UCS with the time of curing

CONCLUSION

The physical and geotechnical properties of a soft soil stabilised with a particular kind of a waste material were investigated by conducting Atterberg limits, compaction parameters, and UCS tests. Later, the UCS test was conducted to study the effect of mechanical activation using a grinding technique. According to the findings of this study, the following conclusions can be drawn:

- The waste material used in this study improved the physical properties of the selected soil significantly, especially in terms of the plasticity index. The results indicated that the PI decreased from 20 to 13 by using 15% of WM by the dry weight of the soft soil. This would increase the soil resistance against the swelling, and shrinkage phenomenon that occurs due to higher changes in water content.
- In terms of the UCS test, 12% was the optimum percentage and this percentage increased the UCS of the stabilised soil significantly. The UCS increased from 200kPa for untreated soil up to 690kPa after 28 days curing which is approximately 3.5 times the UCS for untreated soil. Moreover, WM also improved the early strength of the stabilised soil by 1.81 times without curing as shown in Figure 12.
- The results indicated that the WM used in this study could be activated mechanically by using low grinding energy. The results of mechanical activation indicated that long periods of grinding leads to agglomeration which caused a reduction in the compressive strength due to the decrease in pozzolanic reactivity. Thus, the use of a de-agglomeration material to mix with WM during the grinding process would mitigate the effect of extended periods of grinding.

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References

Abd El-Aziz, M., Abo Hashem, and El. Shourbgy. (2006), The Effect of Lime-Silica fume Stabilizer on Engineering Properties of Clay Subgrade. In proceeding of Fourth Monsoura International Engineering Conference (4th IEC), Faculty if Engineering University, Egypt.

Abd El-Aziz, M., Abo Hashem, and El. Shourbgy. (2006), The Effect of Lime-Silica fume Stabilizer on Engineering Properties of Clay Subgrade. In proceeding of Fourth Monsoura International Engineering Conference (4th IEC), Faculty if Engineering University, Egypt.

British Standard, (1998) BS 1377-4-7:1990. Method of Test for Soils for Civil Engineering Purposes. London, UK: British Standard Institution.

British Standard, (2002). BS 1377-4:1990. Method of Test for Soils for Civil Engineering Purposes, part 4: Compaction-related Tests. London, UK: British Standard Institution.

DEWI, S. J., RAMADHANSYAH, P. J., NORHIDAYAH, A. H., MD. MANIRUZZAMAN, A. A., HAININ, M. R. & MOHD HAZIMAN, W. I. 2014. Effect of Rice Husk Ash Fineness on the Properties of Concrete. *Applied Mechanics and Materials,* 554**,** 203-207.

European Committee for Standardization, (2014). BS EN 17892-4. Geotechnical Investigation and Testing - Laboratory Testing of Soil, Part 4: Determination of Particle Size Distribution. London, UK: British Standard Institution

Farouk, A., and Shahien, M. (2013) Ground Improvement Using Soil-Cement Columns: Experimental Investigation. *Alexandria Engineering Journal*, 52, pp. 733-740.

Gharib, M., Saba, H., and Barazesh, A. (2012). Experimental Investigation of Impact of Adding Lime on Atterberg Limits in Golestan Province Soils. International Research *Journal of Applied and Basic Science*, 3(4), 796-800.

GHOSH, A. & SUBBARAO, C. 2007. Strength Characteristics of Class F Fly Ash Modified with Lime and Gypsum. *JOURNAL OF GEOTECHNICAL AND GEOENVIRONMENTAL ENGINEERING,* 7**,** 757 – 766.

JAFER, H. M., ATHERTON, W. & RUDDOCK, F. M. 2015. Soft Soil Stabilisation Using High Calcium Waste Material Fly Ash. *12th International Post-Graduate Research Conference 2015.* Manchister MediaCityUK

JAFER, H. M., ATHERTON, W., RUDDOCK, F. M. & LOFFIL, E. 2015. Assessing the Potential of a Waste Material for Cement Replacement and the Effect of Its Finennes in Soft Soil Stabilisation. *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering,* 9(8)**,** 794-800.

Kolias, S., Kasselouri, V., and Karahalios, A. (2005) 'Stabilisation of clayey soils with high calcium fly ash and cement'. *Cement & Concrete Composites*, 27 (2005), P. 301–313.

Modarres, A., and Nosoudy, Y. M. (2015), Clay Stabilisation Using Coal Waste and Lime – Technical and Environmental Impact. *Applied Clay Science*, pp. 1-8.

MUJAH, D., RAHMAN, M. E. & ZAIN, N. H. M. 2015. Performance evaluation of the soft soil reinforced ground palm oil fuel ash layer composite. *Journal of Cleaner Production,* 95**,** 89-100.

SADIQUE, M., AL NAGEIM, H., ATHERTON, W., SETON, L. & DEMPSTER, N. 2012. A new composite cementitious material for construction. *Construction and Building Materials,* 35**,** 846-855.

Tyrer, M. J. (1987) Stabilisation of Clay Type Soils With Cementitious Material, Ph. D. thesis, Department of Civil & Structural Engineering & Building, Middlesbrough Cleveland.

Yadu, L., and Tripathi, R. K. (2013) Stabilisation of soft soil with Granulated Blast Furnace Slag and Fly Ash. *International Journal of Research in Engineering and Technology*, 2 (2), P. 115-119.

YAZICI, S. & AREL, H. S. 2012. Effects of fly ash fineness on the mechanical properties of concrete. *Indian Academy of Sciences,* 37**,** 389–403.

YILMAZ, A. & DEGIRMENCI, N. 2009. Possibility of using waste tire rubber and fly ash with Portland cement as construction materials. *Waste Management,* 29**,** 1541- 1546.