

A Review Applying Industrial Waste Materials in Stabilisation of Soft Soil

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ABSTRACT: Waste materials one of the most risky issues that the environment could be faced. So, many procedures have been taken by both the governments and individuals separately or together in order to reduce the effect of this global issue. One of these procedures were done by reduce the creating of the industrial waste, the reducing of waste does not mean there no waste will produce. However, the best way reduce the impact of industrial wastes by reusing them or employed in another application such as soft soil stabilisations. Thus, in this research paper will discuss the differences between the using of traditional stabilisers materials and the cement replacement materials on both the strength of soil and physical features.

KEYWORDS: Geo-polymer cement, Soft soil, Traditional materials and Waste materials.

1 INTRODUCTION

In this millennium, and due to industrial revolution waste materials considered one of the biggest problems in the world. UK in 2004 produce 335 million tonnes of waste from different sources (construction and demolition, industrial, commercial and etc.) [1]. While the European Union reported that the Member States produce 2 billion tonnes of waste every year and this amount will increase yearly. The construction & demolition, mining and industrial wastes present 74% of whole waste which considered huge amount of waste. The industrial waste causes environmental pollution to the soil and groundwater in condition of non-biodegradable waste, which could effect on human health and bio-diversity because of chemical components. Landfills are the most risky part in waste management process due to emission CH₄ and CO₂ from landfilling biodegradable waste which it would degrade in the absence of oxygen (anaerobic decomposition), releasing methane (CH₄) as a by-product of the decomposition process. Methane is one of the GHGs which around 20 times more effective at trapping heat in the atmosphere than carbon dioxide (CO₂). On the other hands, the landfills effect badly on the money abundance in any industries because many countries decided high landfill taxes levied. For these reasons the European Union found that the best solution to remove the mountains of wastes by prevent the initial production, recycling and use the waste materials in other

industrials which are ecologically and economically viable methods [2].

According to Moriconi and Bolden they found that the solid waste of construction and demolition could be used as recycling aggregates to reduce the huge amount of construction waste which about 32% of waste in UK [3,4]. Moreover, using the industrial waste materials in soil stabilisation, which present economical, alternative and an eco-friendly resource. which reduces the pollution and disposal problems [5]. Previous researches proved that, many waste materials could be used as partial cement replacement materials in concrete and soft soil stabilisation.

Soils is most important part in the constructions because of the soil has a great function in supporting loads that transported from the structure, so any problem in soft soil should be removed before constructing the foundation. Many issues could occur in soft soil such as: Liquefaction, fluidization, Expansive problem and holding the moisture because of the previous issues the soft soil should be stabilized. And there are many ways for soil stabilization, but common ways are mechanically or chemically, and in this paper will focus on the chemical stabilization methods by using cementitious materials [6].

The first using of ordinary Portland cement (OPC) as soil additives was used in the early 1940s to improve quality, durability and increase the strength of soft soils based on the interaction of cement with water, regardless of soil minerals (EuroSoilStab,

2002). At the same time, they showed a relationship between the non-confined pressure strength of the soil sample and corrosion control. The use of cement increased the strength of the unbounded pressure with low resistance to corrosion.

The using of cement and lime in soft soil stabilisation considered the most common stabilisation methods. The cement stabilisation results show improving in the compressive strength and cement is preferred for cohesion-less to moderately cohesive soil, while the cement losing its effectiveness in condition of using it in stabilising highly plastic soil. One the other hand, lime is used to stabilise the plastic clays, while it is considered non-effective in clay soil with high sulphate ratio. However, the researchers found the using of the solid waste in stabilisation along with cement/lime will address the issues faced with each soil types. As well as, the using of solid waste will provide a sustainable management for these wastes and remove the drawbacks of each soil. The using of waste materials in soil stabilisation comes in three different ways complementary, binary and ternary [7].

Cement and lime are used to stabilise the soil by mixing with soft soil and this technique is very effective and proofing it's successful for many years. However; scientists found many problems related to this way. The cement industry is the biggest energy and resource (raw materials) consumer. Also it has big role in climate change and global warming due to emission CO₂ and other greenhouse gases (GHGs) which about (5-6%) of all human activities. As well as each one tonne of clinker of cement produce between (0.72-1.41) tonne of CO₂ and other GHGs depending on the process of cement manufacturing which led to increase CO₂ concentration during the time as shown in figure1. In addition to that, cement manufacturing has bad effect on human health due to emission CO₂, CO, nitrogen oxides (NO₂), fluorides, chlorides, sulphur dioxide (SO₂), Toxic metals and dust resulting from burning, crushers and grinders the clinker. These emissions from cement factories effective badly on environment, ecological system and human health which could lead to serious problems in air, killing many kinds of life and effect badly on the breathing system. Many researches refer to a positive health relation between nitrogen dioxide concentrations at the atmosphere and heart disease and cancer cases [8].

Moreover, due to the issues of cement/Lime manufacturing and the high cost of both manufacturing and resources along with increasing the problems of waste materials specially the industrial waste. The industrial waste materials could use as pozzolanas materials, due to them high minerals amounts of either siliceous and aluminous or high Calcium. Poz-

zolanic materials could be found in natural and artificial form, which produce from burnt clays, shales, certain siliceous rocks, rice husk and the residue of the industrial process. According to Sherwood [9], the pozzolanic materials in water presence and high temperature have a chemical reaction to produce insoluble compounds possessing cementitious properties. The using of waste materials in soil stabilisation comes in three different ways complementary, binary and ternary.

"Researchers around the world have been continuously trying to develop new cementitious materials which can be used as a supplementary cementitious material (SCM). Cement manufacturers are using SCM to improve the properties of their products like workability, durability, and strength [10]. SCM materials are either waste or by-product materials, they have been increasingly used due to their performance as cementitious or pozzolanic materials. Various materials like, ground granulated blast furnace slag (GGBS), silica fume (SF), cement kiln dust (CKD), and pulverised fuel ash (PFA), are used alone or mixed with cement and/or lime in all types of construction projects [11]."

Jafer, et. al., they used different proportion of waste materials consists of High Calcium fly ash (CFA) to stabilised the soft soil to provide sustainable waste management and soil stabilisation. They use the waste materials produced from the incineration processes in domestic power stations, which content high (CaO) percentage with suitable amount of SiO₂ to provide cementitious and pozzolanic reactions for silty-clay stabilisation. The results of this study showed that the optimum proportion of fly ash for improving the soft soil properties is (12%). In the optimum proportion the plasticity index was decreased to a third and decrease maximum dry density (MDD), while the optimum moisture content (OMC) and UCS were increased. "These results lead to improve soil resistance against swelling and shrinkage effects and improve the physical and engineering properties within short periods of curing [12]." Later on Jafer, et.al, make other tests to compare the results of using OPC with the same high Calcium fly ash (CFA) ratios for soil stabilisation purposes. They found that the using of either (CFA) or OPC improve the physical properties of the soft soil, but OPC gives higher compressive strength rather than (CFA) [13].

To overcome this problem, where many researchers introduced that geo-polymers that could be an alternative replacement of OPC due to low-cost production and environmental friendliness. The production of the geo-polymer requires 60% less energy with almost 80% reduction of CO₂ compared to OPC [14]. This by-product undergoes a geopolymeriza-

tion process that consists of silicates and aluminates sources that may be used to manufacture pre-cast structures and non-structural elements, concrete products, and concrete pavements. Meanwhile, it may restrain the production of toxic waste that are resistant to heat and aggressive environment, and stabilize weak soils.

Recent advances in employing geopolymer materials for civil engineering purposes make it possible to use it for soil stabilization especially when mitigating subgrade layer for road pavement. By replacing unproductivity cementitious additives with new green additives is likely to give new hope to reduce pollutants in the environment [15]. This review draws on an executive review of geopolymerization and the benefits of geopolymer. Soil stabilization using geopolymer material additive for subgrade is proposed to replace the traditional method.

1. The effect of stabilizers materials

2.1. Cement and lime

AYTEKIN and NAS studied the effect of cement and lime on three different soils [(CL (yellow)), (CH (brown)) and (ML (red)) which widespread in Yolüstü village of Arsin/ Trabzon/ Turkey. During the study, the researchers added three ratios (7, 15 & 30)% of both cement and lime on each soil type to produce (18 samples) in addition to three plain samples without any additives to notice the changing in the strength and physical behavior for these soils. And the physical properties with unconfined strength and parameters of shear resistance for these soil as shown below in table (1) [16].

Table 1 – Soil properties by consistency and compacting test as well as Un-confined strength with the parameters of shear resistance for tested soil.

Sample	Additive Ratio and type		Liquid Limits (LL)%	Plastic Limits (PL)%	Plasticity Index (PI)%	Optimum water content (%)	Max. Dry Density	Unconfined Test	
								qu (aver.) (kg/cm ²)	c (aver.) (kg/cm ²)
Yellow Soil	0	Plain	49	24	25	20	1.67	0.564	0.282
	7%	Lime	37	33.5	3.5	18.3	1.72	3.586	1.793
	15%		38	34.3	3.7	21.3	1.64	3.767	1.884
	30%		38.4	32	6.4	22.8	1.59	4.71	2.355
	7%	Cement	40	34.1	5.9	17	1.72	18.39	9.196
	15%		41	35.9	5.1	17.5	1.74	23.3	11.66
	30%		39	32.2	6.8	18	1.77	33.62	16.82
Red Soil	0	Plain	44.5	35	9.5	29	1.42	0.708	0.354
	7%	Lime	46.5	42.3	4.2	22.8	1.48	13.31	6.65
	15%		47	39	8	26.3	1.47	11.7	5.86
	30%		48	42	6	28.8	1.39	11.12	5.56
	7%	Cement	48	40.3	7.7	22.5	1.56	6.22	3.11
	15%		9	40.7	8.3	26.3	1.53	25.96	12.98
	30%		46	41	5	30	1.5	40.14	20.07
Brown Soil	0	Plain	84	40	44	36	1.29	0.888	0.444
	7%	Lime	-	-	-	37.5	1.32	1.677	0.838
	15%		-	-	-	38.5	1.46	5.98	2.99
	30%		-	-	-	41.2	1.3	4.84	3.42
	7%	Cement	-	-	-	29.6	1.35	4.32	2.16
	15%		-	-	-	34.6	1.37	5.448	2.724
	30%		57	41.5	15.5	36.8	1.39	21.179	10.589

The changes that had been after added thee additives were recorded in the table (1). Where the changes in soil properties were in accordance with the type and amount of additives and the soil features were optimum water content, maximum dry, plasticity index and unconfined compressive strength. So the opti-

imum water content was increased proportionally with increase the amount of additives for all soil types. However, plasticity index for yellow and red soils were decreased due to the additives work, but the decrement ratio is differ depending on the soil type, additive type and additive ratio. On the other hand, the unconfined compressive strength for the

prepared samples. During the sample testing, it had been observed the breaking of some samples into many pieces, and some of them divided into two pieces by forming a failure surface of approximately $(45+\theta/2)$ with horizontal. Changes in the compressive strength due to the amount of lime and cement additives can be seen in table (1). The using of cement and lime as additives, the plasticity index is not dependent merely on the 7%, 15 % and 30% rates of additives. From the unconfined test samples, it has been observed that when lime has been used as additive, additional ratios aver 15% are ineffective on the increase of compressive strength. When the amount of lime additive is increased in large amounts (up to 30%), there are decreases in compressive strength. Contrary to this with additional increases in the rate of cement, continuous increases are being observed in the unconfined compressive strength. Therefore choice of the type and amount of additives must be made in accordance with the purpose sought.

2.1.1. *Problem associates with using traditional stabilisation materials*

There are many issues related to using of cement and lime in stabilizing soft soil and the other construction project such as the maintenance cost, environmental problems, and long-term durability of the material during hot and cold seasons [17].

A. *Cost estimated for road pavement*

The gradual increase in population as well as rapid development and increase in traffic volume in the world, have made more urgent than ever to find a high performance and durable construction materials for pavement structure. However, the cost of construction and rehabilitation on the road surface can

be minimized by increasing the life circle on the subgrade structure.

High-quality soils as materials for road construction are rare in many parts of the world, and most often than not, engineers are forced to seek alternatives to reach the stipulated requirements. For example, according to World Bank reports (2000), average works costs on rehabilitation of paved roads was 214,000 \$/km, rehabilitation of unpaved roads was 31,000 \$/km and improvement of unpaved roads was 72,000 \$/km. Meanwhile, in British Columbia (BC) itself will invest \$380 million to resurface provincial highways and increase the investment to \$270 million for improving the condition of provincial side roads which includes hard surfacing, gravelling base construction, dust control, shoulder widening, and other safety improvements over the next three years. According to Federal Infrastructure Programs in 2014/15, approximately \$73.4 million in federal funding was secured for highway improvement projects in the province. The total sum of the investment cost for the road rehabilitation only in BC province is extremely higher [18].

B. *Variant temperature effects*

One of the factors that contributed to the inefficiency of soil stabilization is the long-term durability of the material due to varying temperatures, especially in Canada. Table 2 below presents the climate trends for five cities within the BC province that experience minimum and maximum temperature between the year 1981 and 2010. The presence of temperatures effects for a pavement structure needs to be considered in improving the road pavement in BC.

Table 2 – Climate trend from the year 1981 to 2010 for five locations in British Columbia

City	Mean Annual Temperature (°C)	Extreme Min Temperature > 30 years	Extreme Max Temperature > 30 years
Rossland	6.5	-29.0	36.6
Vancouver	10.4	-14.0	35.1
Kelowna	9.2	-24.2	38.4
Prince George	4.3	-37.8	33.9
Kamloops	8.9	-28.6	39.2

2.1.2. *Using of waste materials as a cement replacement*

There are many studies in soil stability by using different additive materials. Generally, the materials for soil stabilisation are divided into two kinds: traditional materials like (Portland cement, cement-fly ash, lime, fly ash with lime, etc.), and non-traditional materials (Jeb et. al., 2007), (Makusa, 2012) and

(Dhanao, 2013). Recently, researchers have tried to develop new cementitious materials for soil stabilisation purposes. These supplementary cementitious materials could be used alone or mixed with small amounts of cement and lime. The non-traditional materials could be pozzolanic materials or waste materials like silica fume (SF), ground granulated blast furnace slag (GGBS), pulverised fuel ash (PFA) and cement kiln dust (CKD). These materials character-

ised by their eco-friendly credentials, reduction of industrial waste, reduction of landfill, low cost, ease of application, short curing time etc. Such materials could be used with cement to improve the properties of cement based stabilisers such as workability, durability, and strength [10].

According to Al-Khafaji, et.al. [19] The using of the Fluid Catalytic Cracking Catalyst Residue (FC3R) as a cement replacing materials in soft soil stabilisation has an incredible effect on soft soil. Where in this study the binder ratio was (9% of soil dry weight) which replaced by (8.1, 7.2, 6.3, 5.4, 45) %

of (FC3R). And the results show a significant development in the plasticity index and the compressive strength, where mixing soft soil with 9% binder consists of (70% Ordinary Portland Cement+ 30% (FC3R)) present better results than using of (9)% binder consists of (100)% Cement due to the effect of high Silica-Alumina effect which present the main components. As well as the physical properties was developed with an increasing in the optimum moisture content along with decreasing the maximum dry density for the soil.

Table 3 – The results of the Atterberg limits and compaction tests.

Ratio and sample ID	LL	PL	PI	Optimum water content (%)	Max. Dry Density
VS (Plain Soil)	39.20	20.85	18.35	1.63	20
Ref. (Plain Soil+ 9% OPC)	44.00	30.80	13.20	1.58	21
B1 (Plain Soil+ 8.1% OPC + 0.9% FC3R)	44.40	30.96	13.44	1.575	21.5
B2 (Plain Soil+ 7.2% OPC + 1.8% FC3R)	44.60	32.12	12.48	1.565	22
B3 (Plain Soil+ 6.3% OPC + 2.7% FC3R)	44.80	32.05	12.75	1.56	22.5
B4 (Plain Soil+ 5.4% OPC + 3.6% FC3R)	44.60	31.74	12.86	1.55	22.5
B5 (Plain Soil+ 4.5% OPC + 4.5% FC3R)	44.70	31.68	13.02	1.535	23

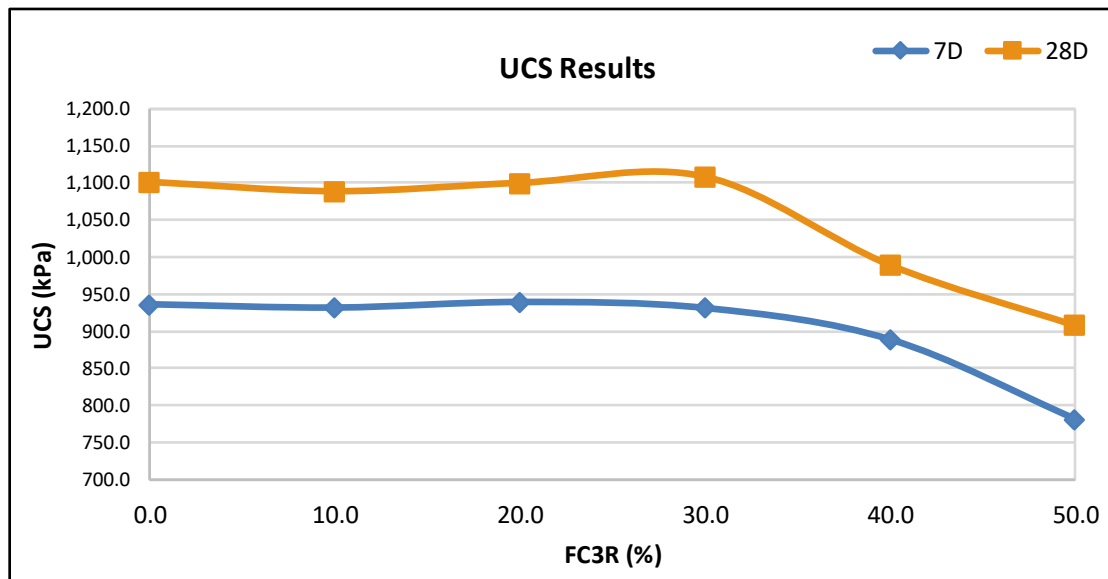


Figure 1 – Development of UCS result after replacement OPC by FC3R in soil stabilisation.

According to Al-khafaji, et.al. [20] The using of FC3R was led to a considerable decrease in the maximum dry density, but it increased the water content. Also, adding FC3R improves the unconfined compressive strength for soil; UCS results indicated a significant increase in soil strength from 134.2kPa for untreated sample to 1107kPa for sample treated with BM3 (70% OPC + 30% FC3R) after 28 days of curing. The improvement percentage for the sample B3 was eight times higher than VS sample results. UCS results showed that soil samples treated with 9% of B3 indicated compressive strengths higher than that RF samples. While the physical soil prop-

erties were improved such as reducing the plasticity index (PI) from 18.35 to 13.02 for 50% FC3R by the dry soil weight.

The using of industrial waste materials was improve the strength of soil and giving better results than the at the same time reducing the emission of CO₂ that produced from the manufacturing processes of both cement and Lime in addition to CO₂ emitted from landfills. However, the partial using for waste material mitigate the problems, but it does not solve the problems for this reason the researchers try to find better solution for these issues, so they try to use the geo-polymer cement in the recent studies.

2.1.3. Using of Geo-polymer cement

The production of conventional additives, particularly Portland cement and lime, consumes a large amount of resources and energy resulting in the release of substantial amounts of carbon dioxide. The demolitions of cement materials or earthquake effect can release a certain amounts of cement dust which may cause particulate dust emission through air consequently raising the environmental problem [21].

On the other hand, non-traditional additives consist of various combinations such as enzymes, polymers, resins, acids, silicates, ions, and lignin derivatives. The majority of these additives contain secondary additives such as catalysts, surfactants, and ultraviolet inhibitors. Additionally, non-traditional chemical additives are usually concentrated liquids that are diluted with water and then sprayed on the soil before compaction, and also are to being cheaper to transport than traditional bulk stabilizer materials. It is worth to mention that, with the aim of controlling the environmental impact of traditional additives, an alternative green additive that is geopolymer can achieve the interest from worldwide. By having strong materials as well as concerning the environmental impact is the ultimate goal in constructing a good road pavement. Laying the surface pavement on top of the strong subgrade layer may reduce the construction cost because of only a thin layer of surface pavement is needed and subsequently the maintenance may be reduced [22].

Geopolymers exhibit different properties and characteristics, depending on the raw materials selection and processing conditions. Much research has found the benefits of geopolymers such as excellent mechanical strength, long-term durability, fire resistance, low thermal conductivity, low shrinkage, fast setting and acid resistance [14, 23]. Moreover, this green material is low in energy consumption because of the low temperatures involved in processing the natural alumina-silicate with suitable geopolymeric raw materials. In addition, geopolymers can be synthesized from a different types of low-cost alumina-silicate materials or even industrial wastes, such as fly ash, red mud, metakaolin, furnace slag, and rice husk ash [24, 25].

Ayyappan, et.al. Project aims to verify the effectiveness of Geopolymer as an environmentally friendly bond material in improving the properties of the strength of soft clay and sand mixtures. Geopolymer, with its high efficiency, low cost, low energy consumption and CO₂ emissions during assembly, provides a promising alternative to the traditional materials discussed. In this study, methanol-based glycol with different concentration (2% and 4%) to study the feasibility of polymer geological stability in the soil. Geopolymer stable soil samples were characterized by the non-confined pressure resistance test (UCS), the standard Proctor pressure test. This study showed that methacolas-based geopolymers can be effective soil stabilizers in clay soils. And the result that had found as demonstrated in Figure [26]

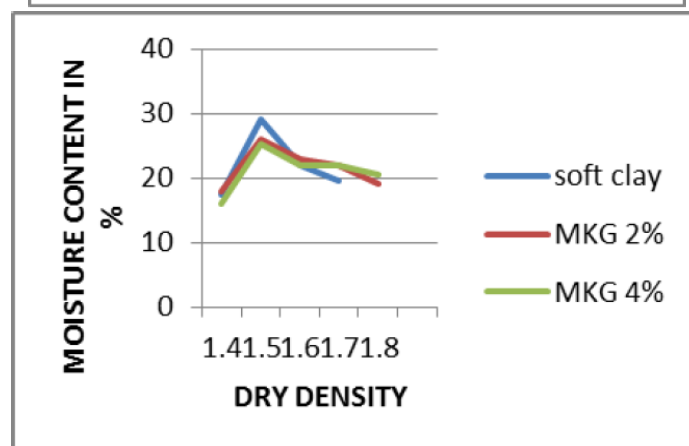
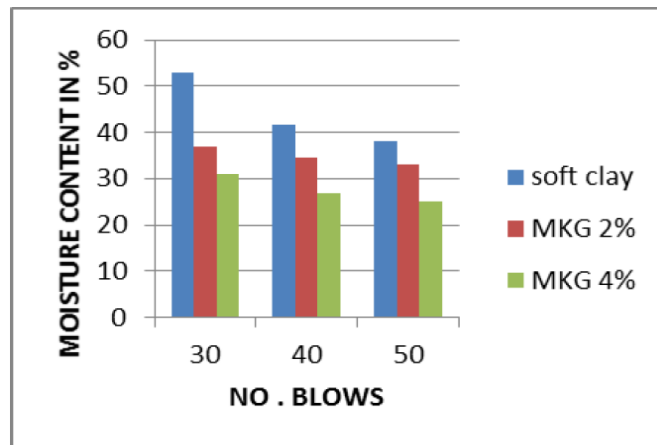


Figure 2 - Liquid Limit

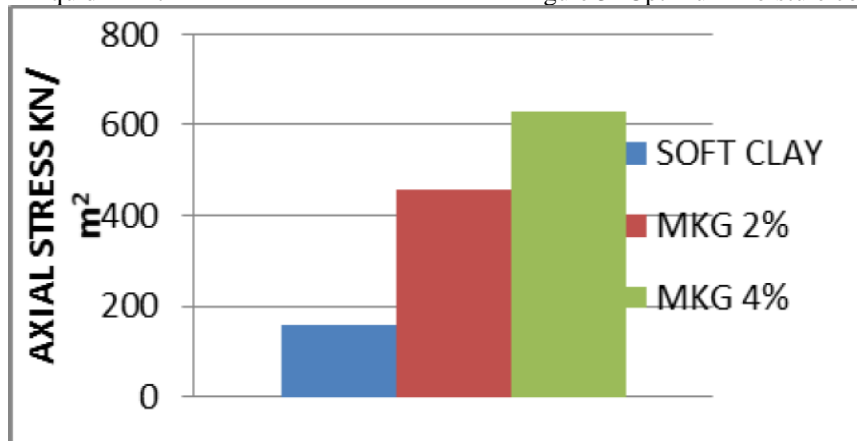


Figure 3- Optimum moisture content & Max. Dry density

Figure 4- UCS Comparison of Soft Clay & Mkg

From the results that had been recorded the increasing of metakaolin amount lead to increase the compressive strength. The Cohesion (C) of soft clay with metakaolin had been considerably improved with increasing the ratio of geopolymer amount. As well as different percentages of geopolymer to the blends of

3. CONCLUDING REMARKS

The soft soil suffering from many issues and in order to solve this issues traditionally by remove the soft soil and replace it by strong soil to mitigate the soft soil problems. Due to high cost for replacing the researchers found the best, easiest and cheapest way could be investigated by mixing the soil with active materials (cement and lime), after some time the researchers found creating another issues relating to active materials manufacturing and increasing the environmental pollutions. Thus the employing of the waste materials become very necessary, and according to the previous results the replacing of active materials by waste materials give higher strength and improve the physical behaviour better than the other techniques. On the other hand, using of geopolymer cement give many favourite features in addition to the very low cost comparison with other techniques as well as this technique is environmentally friendly so it could continue in using for long time period.

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soft clay with metakaolin proved to be effective in improving the strength parameters. The same trend was observed to be very much similar for all the percentages of geopolymer content i.e., 0%, 2% and 4% for both Cohesion and compression strength.

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