Effects of Fuel Oil on the Geotechnical Properties of Clay Soil

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ABSTRACT

The present study highlights the effects of medium fuel oil (MFO) on the chemical, physical and mechanical properties of clay soil samples (disturbed and undisturbed) obtained from the site of the electrical power plant in the campus of the University of Baghdad at Al-Jadriah distract in Baghdad/Iraq. The soil sample has classified according to the unified soil classification system (USCS) as CL and described as lean clay of low plasticity. The medium fuel oil is an industrial wastewater disposed as a byproduct from the fuel used in the electricity power plant. The soil samples are artificially contaminated with two percentages of medium fuel oil, 10 and 20 % in related to the dry weight of soil. The soil samples had mixed with the contaminant (MFO) by the hands and then left for 4 days for homogeneity. A series of laboratory tests are conducted on both natural and artificially contaminated soil samples to measure the effects of medium fuel oil on the chemical, physical and mechanical properties of soil samples. The results of tests showed that the medium fuel oil has significant impacts on some properties of soil and slight effects on the others. Increasing the percentage of contaminant causes a slight decrease in the liquid limit and particle size distribution; on the other hand, it causes a considerable increase in the consolidation parameters and decrease in shear strength parameters. Also, there is a slight change in the chemical composition of soil samples.

Keywords: Industrial wastewater, fuel oil, soil contamination, geotechnical properties, clay soil.

تحري تأثيرات وقود النفط على الخواص الجيوتقنية للتربة الطينية

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الخلاصــــــــة

الدراسه الحاليه تسلط الضوء على دراسه تاثير وقود النفط متوسط الكثافة (MFO) على الخواص الكيميائية والفريائية والمكانيكية لنماذج التربه الطينيه المشوشه والغير مشوشه والتي تم الحصول عليها من محطة الجادرية لتوليد الطاقة الكهربائية في مجمع جامعة بغداد/الجادرية في مدينة بغداد/العراق. تم تصنيف التربة على اساس نظام تصنيف التربة الموحد (USCS) الى تربة طينية ضعيفة منخفضة اللدونة (CL). الملوث هو وقود النفط متوسط الكثافة والذي يطرح كناتج عرضي من الوقود المستخدم في محطة توليد اطاقة الكهربائية. تم تلويث التربة مختبريا وذلك عن طريق خلط التربة يدويا مع الملوث (MFO) بنسبتين (10 و 20) % من وزن التربة الجافة. بعد ان خلطت التربة جيدا مع الملوث وبعد التأكد من تجانس توزيع الملوث في التربة تركت لمدة اربعة ايام في حافظات مغلقة لدراسة تأثير الملوث على الخواص الكيميائية والفيزيائية والميكانيكية للتربة من خلال اجراء الفحوصات التقليدية لقياس تلك الخواص. ومن خلال نتائج الفحوصات المختربة اظهرت ان الملوث الصناعي (MFO) له تاثير كبير على بعض الخصائص وتاثير قليل على خصائص اخرى. أن زياده نسبه الملوث في التربة ادى الى ثاثير طفيف على قيم حد السيولة واللدونة وحجم الحبيبات. ان زياده نسبة الملوث تسببت في زيادة في معاملات الانضمام ونقصان في معاملات القص للتربة. وقد لوحظ ايضا ان هناك تغير في الخواص الكيميائيه لعينات التربة.

الكلمات الرئيسية: الملوثات الصناعية السائلة، وقود النفط، تلوث التربة، الخواص الجيوتقنية، التربة الطينية.

1. INTRODUCTION

The rapid development of industrialization and urbanization generate much higher quantities of wastewater, solid wastes and gaseous wastes that resulted in polluted environment intentionally or unintentionally. These wastes do not pollute the air or water only also the soil is being polluted. Soil contamination is not harmful for the groundwater only also the occurrences of contaminants in soil above a certain level cause loss some of the geotechnical soil properties. Consequently, this led to the detriment of structures constructed on/in it due to that alteration in the geotechnical properties of soil. This alteration resulted in loss some of the bearing capacity of the soil and increase in the settlement of the foundation under the structure which causing loses the function or failure of the structure **Rahman et al. 2010**. Therefore, it is important to determine the effects of the soil contamination on the foundation of the existing structure.

The most common soil contamination are fertilizers, pesticides, petroleum hydrocarbon, heavy metals, volatile organic compounds and organic compounds. These contaminants produced from the oil fields, thermal power stations, or in most cases results accidently from the spill oil during the transportation as leakage from the pipelines and storage tanks or during oil drilling processes. Hydrocarbons have significant effects on the geotechnical properties of soil and due to the volume and the quantities resulted from the industrial wastewater is larger than other wastes. The attention of researchers was focused on investigated the effects of contamination of industrial wastewater on the engineering properties of soil. **Abdul Rasol, 1999** investigated the influence of kerosene contamination on the geotechnical properties of clayey silt soil. The results showed significant effects for kerosene on the physical properties, parameters of consolidation and shear strength of soil.

Khamehchiyan et al., 2007 investigated the geotechnical properties of clayey and sandy soil samples contaminated by crude oil. The results indicated a noticeable reduction in the shear strength, the dry density, optimum moisture content and Atterberg’s limits by increasing the content of crude oil in the soil. **Karkush et al., 2013** investigated the effects of four types of contaminants on the geotechnical properties of clayey soil. The contaminants are kerosene, ammonium nitrate, copper and lead, each of them was mixed with soil in two percentages (10 and 25) %. The results showed diverse effects of these contaminants on the geotechnical properties of clayey soil. **Karkush and Resol, 2015** investigated the geotechnical properties of sandy soil synthetically contaminated with four ratios of industrial wastewater. The soil samples were contaminated synthetically with industrial wastewater by (10, 20, 40 and 100) % of solution used in the contamination process. The results showed diverse effects of industrial wastewater on the geotechnical properties of a sandy soil sample. **George et al., 2015** conducted experimental work to study the effect of diesel engine oil on the geotechnical properties of soil. The results showed that the addition of diesel engine oil has diverse effects on the geotechnical properties of the studied soil samples.

Bala et al., 2015 investigated the chemical characteristics of eight soil samples from Bangladesh. They studied effect of the contaminated on the salinity, organic content, chloride, pH, alkalinity, conductivity and moisture content. **Karkush and Abdul Kareem, 2016** investigated the geotechnical properties of clayey soil samples contaminated by industrial wastewater. The soil samples had artificially contaminated with four ratios of industrial wastewater disposed as a byproduct from thermal electricity power plant, also **Karkush and Altaher, 2017** investigated the effects of total petroleum hydrocarbons on the geotechnical properties of clayey soil samples contaminated in the field. The results showed diverse effects of industrial wastewater on the geotechnical properties of a clayey soil sample. The present study is a trial to determine the effects of the medium fuel oil (MFO), a byproduct effluent from fuel station of supply the electricity power plant in Al-Jadriah district on the geotechnical properties of lean clay soil by conducting an efficient laboratory-testing program on intact and contaminated soil samples.

2. INDUSTRIAL WASTEWATER AND SOIL CONTAMINATION

Industrial waste, refer to the wastes generated from the production of industrial activates and resources treatment and development. The industrial wastes can be solid wastes, semi-solid wastes, wastewater and gaseous wastes that are not permitted to discharge into the environment. The solid wastes are classified into organic and inorganic wastes based on their mineral composition and into hazardous and nonhazardous wastes base on pollution characteristics. Because many industrial wastes hold hazardous characteristics, they usually receive special attention. Large quantities of industrial wastes are generated every year due to growing of industrial activities. All these are harm to the human being health and the environment components. In general, industrial wastes are classified into the following major types **Li, 2004** and **Shi, 2004:**

a) Metallurgical industry;
b) Electrical power industry;
c) Chemical industry;
d) Light industries;
e) Industrial solid wastes such as metal dross, plating sludge, construction wastes and slag from processing in other industries.

Contaminated soil with percentages above a certain level will affect the geotechnical properties of soil. Soil contamination usually results from the percolation of wastes from the sanitary landfills or percolation of contaminated surface water to subsurface strata, leakage from underground storage tanks and pipes, leaching of waste direct from of industrial wastes and application of fertilizer and pesticides to soil. The contamination of soil is not challenge for the environmental specialists only, but also cause a deterioration of geotechnical properties of soil. Cohesive soils are electro-chemically active and affected largely by wastes **Rehman et al. 2007** and **Elisha, 2012**. The flow of contaminant in the soil or in water depends on many factors such as the permeability of the soil and adsorption properties of the soil solids **Nudelman et al. 2002**. The extent of contamination in the soil depends on the properties of soil and chemical composition of the contaminant **Fine et al. 1997**. However, contaminated the soil occurrence as mentioned earlier by different ways also have different concentrations consequently will affect the geotechnical properties of soil.

3. STUDY AREA

The industrial wastewater and soil samples have obtained from the study area. The study area is the site of electrical power plant of Al-Jardiah in the campus of the University of Baghdad in Baghdad city/Iraq of georeferencing coordinates, GPS (E: 44º 22' 49.833", N: 33º 15'56.424") as shown in **Fig. 1**. A trial pit was excavated by using a mechanical shovel to reach the required depth of 2 m below the existing ground level. Two types of soil samples have obtained from this trial pit disturbed and undisturbed soil samples, the disturbed soil samples were used to measure the effects of the contaminant on the chemical and physical properties of soil samples, while the undisturbed soil samples were used to measure the effects of MFO on the mechanical properties of soil. The soil samples put in airtight containers and labeled with necessary information then transported to the laboratory of soil mechanics. The field unit weight of soil measured according to ASTM-D2937-00 is 17.08 kN/m^3 and the natural moisture content measured according to ASTM-D2216 is 20.77 % **ASTM, 2003**. The soil is contaminated with two percentages of MFO (10 and 20) % in related to the dry weight of soil sample in the laboratory. The MFO has mixed with the soil by hands and the soil left for 4 days to allow chemical reactions between MFO and mineral composition of the oil. The medium fuel oil (MFO) is a mixture of water 30.2 % and oil 69.8 %. The density and chemical analysis of MFO used in this work have tested according to **ASTM, 2003**. The results of these tests are given in **Table 1**.

4. DRILLING AND SAMPLING

Disturbed and undisturbed soil samples were obtained from the study area. The soil samples used in this study are taken from a depth of 2 m below the existing ground level by using a shovel. The excavation process carried out by drilling a hole and then undisturbed soil samples were taken by using three Shelby tubes. The used Shelby tubes have a sharp end to reduce the disturbance of soil during the pushing of the Shelby tube into the soil. Shelby tubes were pushed vertically into the soil by using shovel and then the soil around the Shelby tubes was removed by using hand drilling to extract the tube easily, Shelby tubes were cleaned and the ends of the tubes were covered with wax to avoid the disturbance of soil samples and to keep the natural moisture content. Also, disturbed soil samples were obtained from the same depth by using hand drilling and put in plastic bags. Then, the soil samples were labeled with the necessary information and transported to the laboratory for conducting the experimental tests as shown in **Fig.2**

5. EXPERIMENTAL WORK

A series of laboratory tests are conducted on the undisturbed and disturbed soil samples. The soil samples are mixed with two percentages of fuel oil 10 and 20 % in relative to the dry weight of the soil samples used in the contamination process. The soil samples were contaminated artificially through mixing the contaminant with the soil samples by hands in the laboratory. The soil samples kept mixed with contaminant for 4 days to allow chemical reactions between the fuel oil and mineral composition of soil. Then, the soil samples are prepared to measure the effects of the contaminant on the geotechnical properties of soil. The process of mixing the contaminant with soil is shown in **Fig. 3**. The contaminated soil sample then remolded according to the field unit weight and moisture content for testing the mechanical properties of contaminated soils **Karkush et al., 2013; Karkush and Abdul Kareem, 2016.**

The soil samples studied in this work have designated as follows: intact soil is MFO0, soil contaminated with 10 % of medium fuel oil is MFO1 and soil contaminated with 20 % of medium fuel oil is MFO2. The chemical properties of soil samples play an important role in the engineering behavior of cohesive soils. The chemical and x-ray diffraction tests were carried out on the disturbed intact and contaminated soil samples. The physical properties of soil samples measured in this work are specific gravity ASTM-D854, particle size distribution ASTM-D422 and liquid and plastic limits ASTM-D4318**.** The mechanical tests conducted on the undisturbed intact soil samples and remolded contaminated, soil samples. The tests conducted to measure the mechanical properties of soil samples are 1-D consolidation test (ASTM-D2435), unconfined compressive test, UCT (ASTM-D2166) and direct shear test, DST (ASTM-D3080) **ASTM, 2003; Head, 2006; Head, 1994** and **Head, 1992**.

6. RESULTS AND DISCUSSIONS

6.1 Chemical Properties of Soil

The results of chemical and x-ray diffraction tests conducted on soil samples are given in **Tables 2** and **3**. Sulfur trioxide increases with increasing the content of medium fuel oil, while the calcium oxide decreases with increasing the content of medium fuel oil, this reduction may be resulted from the participation of sulfate ions in a new reaction with the minerals of soil solids. Also, the value of pH increases with increasing the percentage of contaminants could be resulted from the accumulation of exchangeable bases such as Na or Ca in the soil, which causes a reduction in the exchangeable acidity and affect the cation exchange capacity.

6.2 Physical Properties of Soil

The summary of physical properties of soil samples tested in this work is given in **Table 4**. Based on these results, increasing the percentage of contaminant causes a significant decrease in the values of specific gravity due to the low density of contaminant, while this increasing in the percentage of contaminant lead to a slight decrease in the percentage of fine particles because of formation of soil clods. Also, in hydrometer test, the salts cover the soil particles will dissolve in the water and this action depends on the solubility of existing salts in the water as shown in **Fig. 4**. The liquid limit decreases with increasing the percentage of contaminants due to the participation of medium fuel oil in coating the surfaces of solid particles, but the medium fuel oil causes increased the plasticity of soil due to the viscosity of such contaminant. The first contact of the medium fuel oil was with the soil particles and not with the water due to the immiscibility of petroleum products with water. The liquid and plastic limits are the moisture contents where the soil will deform as liquid or plastic respectively. This was less when the percentage of medium fuel oil content increased, therefore, liquid limit decreases and plastic limit increases.

6.3 Mechanical Properties of Soil

The results of mechanical properties of soil proved that for the contaminant has a considerable effect on the consolidation parameters and shear strength parameters. In the consolidation test, it was noticed a significant increasing in the coefficient of volumetric change (m_v) and the coefficient of permeability (k) of soil sample MFO1 compared with that of the intact soil sample due to the rearrangement of the newly bonded soil particles into macro voids in the soil. However, for MFO2 the reduction in m_v and k is less than that of MFO1 due to the presence of fewer voids as more bonded soil matrix was formed by higher fuel oil content in the contaminated soil. The results of 1-D consolidation tests are shown in **Fig. 5** and **Table 5**.

The results of 1-D consolidation test experienced a significant increase in the compression indices and the void ratio by increasing the percentage of contaminants due to decreasing the percentage of fines as they were bonded to form pseudo-sand and sand sized particles that created large void space in the soil matrix. The medium fuel oil contamination causes reduction in the cohesion and angle of internal friction of intact soil. The lubrication property of fuel oil lead to sliding the soil particles over others and consequently the weak bonding between the soil particles causes a significant reduction in the shear strength parameters of soil. A summary of shear strength tests is given in **Table 5**. The results of unconfined compressive tests showed decreasing the undrained shear strength, c_u by 15.7 and 31 % in soil samples MFO1 and MFO2 respectively. This reduction was corresponding to a large reduction in strain by 73 and 76 % for soil sample MFO1 and MFO2 respectively as shown in **Fig. 6**.

The results of direct shear tests showed a decrease in the value of cohesion of soil by 44 and 66 %, but the angle of internal friction decreased by 18 and 33 % for soil sample MFO1 and MFO2 respectively as shown in **Fig. 7**. It’s noticed that medium fuel oil has more effects on cohesion rather than friction between soil particles. This behavior may be attributed to the coating of the surface of soil solids with MFO that causes a reduction in bonding between particles.

7. CONCLUSIONS

The medium fuel oil has negative effects on the geotechnical of lean clay soil and these effects increase with increasing the percentage of MFO in the soil. Based on the results of this work by increasing the percentage of MFO in the soil, the following actions are noticed:

1) Decreasing the specific gravity and liquid limit of soil, but there is slightly increase in plastic limit and also was noticed that the percentage of finer for the soil particles was slightly reduced which made the soil particles are coarser than in case of intact soil.
2) The medium fuel oil causes increased the initial void ratio, coefficient of volume compressibility and coefficient of permeability with increasing medium fuel oil content in the soil.
3) The effects of medium fuel oil on the shear strength parameters depend on the type of test and concentration of medium fuel oil in the soil.
4) The direct shear test significantly affected by medium fuel oil and less effect was noticed in the soil samples tested by unconfined compressive test and unconsolidated undrained triaxial test.
5) The results of unconfined compressive tests showed decreasing the undrained shear strength by 15.7 and 31 % and the corresponding strains by 73 and 76 % for soil samples MFO1 and MFO2 respectively.
6) The results of direct shear tests showed decreasing the cohesion of soil by 44 and 66 % for soil sample MFO1 and MFO2 respectively.

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Table 1. Density and chemical analysis of MFO.

Industrial Wastewater	Density kg/m^3	Concentration of Minerals					
		Mineral	ppm	Mineral	ppm	Mineral	ppm
MFO	991.1	Na	12.23	Pb	1.13	Cu	2.26
		K	10.11	Zn	77.66	Al	13.27
		Li	0	Si	21.09	Fe	88.26
		Mg	23.13	Cr	0.85	Mn	6.45
		Ca	1237.14	Ni	28.5	C	70.03

Table 2. Results of chemical tests.

Soil Sample	SO_3 %	Na %	Cl^{-1} %	TSS %		TDS %	CaO %	pH value
MFO0	0.26	0.79	0.15	3.1		0.72	18.75	5.0
MFO1	0.73	0.72	0.16	2.4		0.65	17.89	5.35
MFO2	1.83	0.97	0.36	2.5		0.51	16.02	7.0

Table 3. Results of x-ray diffraction tests.

Soil Sample	Minerals, %					
	Quartz	Calcite	Orthoclase	Montmorillonite	Feldspar	Dolomite
MFO0	27	14	7	25	21	7
MFO1	32	20	9	9	11	4
MFO2	20	22	1	6	47	3

Table 4. Physical properties of soil samples.

Soil Sample	Gs	Sand, %	Silt and Clay, %	LL, %	PL, %	PI, %
MFO0	2.68	7.25	92.75	33	11	22
MFO1	2.53	9.79	90.21	32	15	17
MFO2	2.45	10.34	89.66	30	17	13

Table 5. Results of mechanical properties of soil samples.

Soil Sample	1-D Consolidation			UCT	DST	
	e_o	$m_v \times 10^{-4}$ (m²/kN)	$k \times 10^{-8}$ cm/sec	c_u kPa	c kPa	φ degree
MFO0	0.54	0.6526	1.348	35	66	36
MFO1	0.64	4.1211	7.579	29.5	37	29.5
MFO2	0.74	3.6561	6.075	24	22	24

Figure 1. Satellite image of electrical power plant of Aljadriah at the campus of University of Baghdad.

Figure 2. Drilling and soil sampling in the study area.

Figure 3. Mixing the fuel oil with soil in the laboratory of the University of Baghdad.

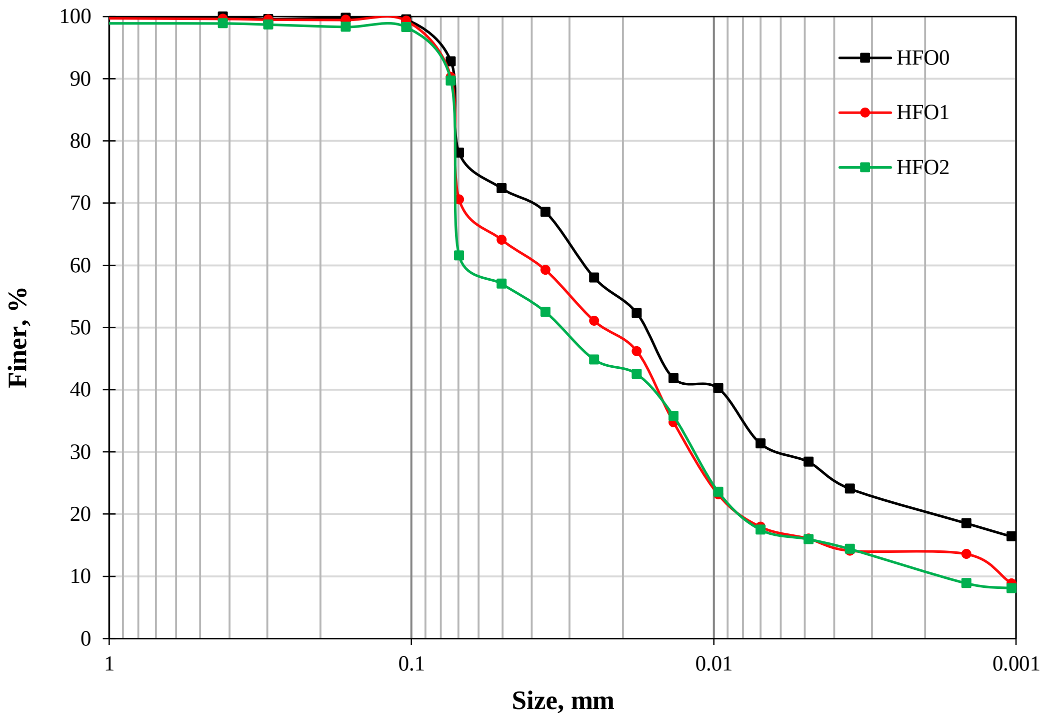

Figure 4. Particle-size distribution curves of intact and contaminated soil samples.

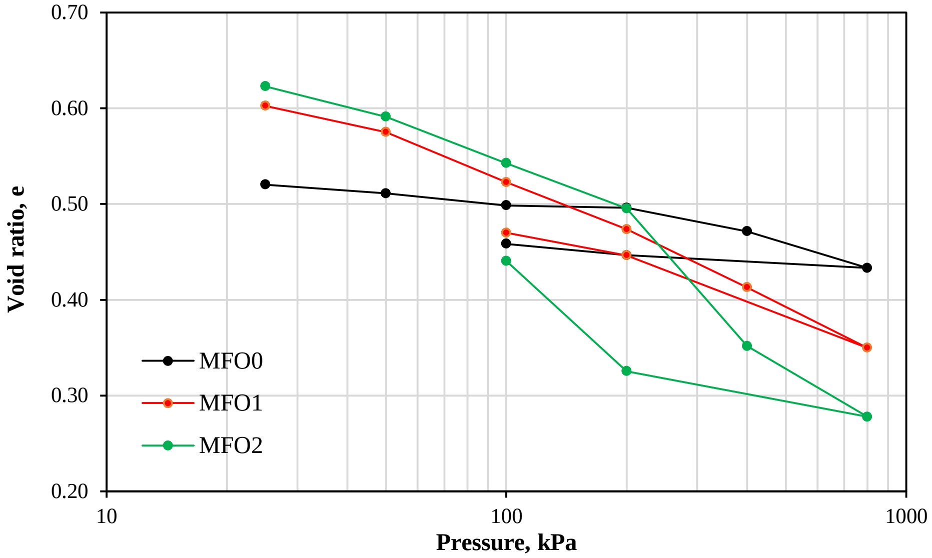

Figure 5. Void ratio versus log of pressure of intact and contaminated soil samples.

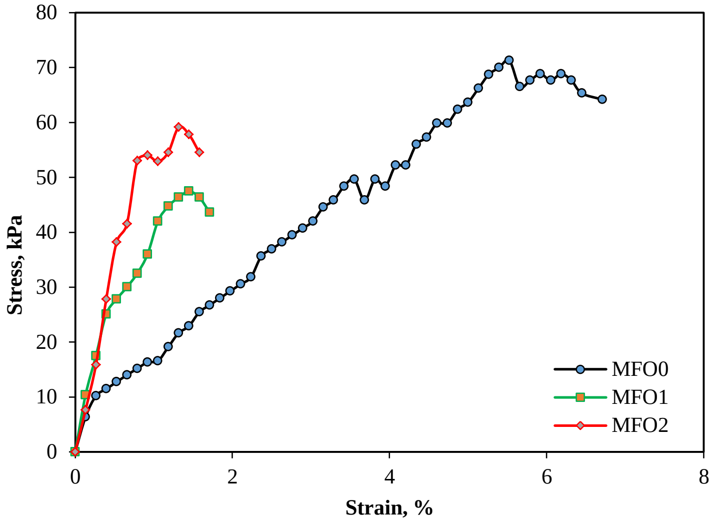

Figure 6. Stress-strain curve of unconfined compressive tests.

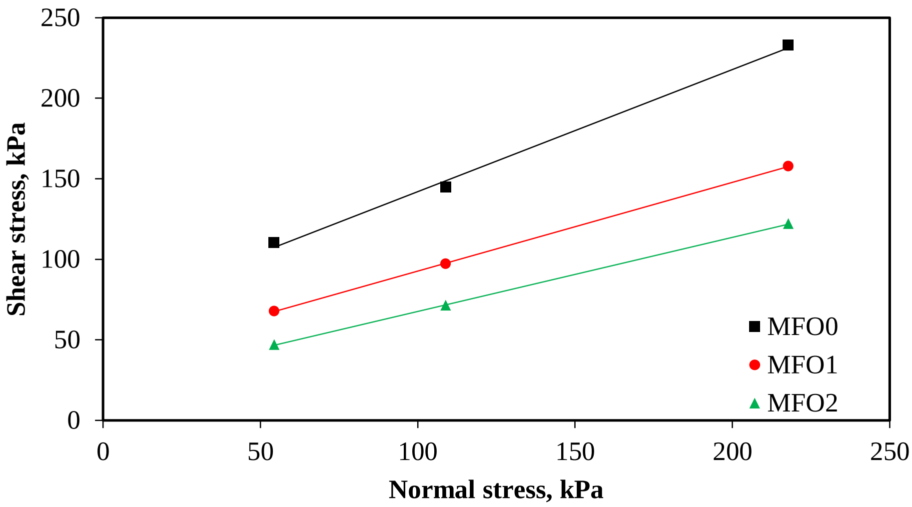

Figure 7. Normal stress versus shear stress of direct shear tests.