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PRELIMINARY STUDY ON PLASTICINE AS A SUBSTITUTE COHESIVE MATERIAL FOR GEOTECHNICAL PHYSICAL SOIL MODELING

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ABSTRACT

Plasticine is an artificial material made from solids such as gypsum, lime, mixed with petroleum jelly or micro wax and acid fat. The properties of plasticine are likely similar to natural clay and is influenced by oil content. The information about mechanical properties of plasticine is still very rare, and as such the study on it is riquired and must be conducted intensively. The preliminary laboratory study has been conducted to understand the behaviour of plasticines. Microwax and petroleum jelly based plasticines were utilised with the variation of oil content, whereas kaolin clay with the variation of water content is utilised as a reference material. The study is focusing on the stress-strain behaviour for both microwax and petroleum jelly based plasticines compared to the stress-strain behaviour of kaolin clay. This paper reports the result of preliminary investigation regarding the use of plasticine as an alternative artificial material for substitution of clay in soil modeling. Some engineering properties from unconfined compression strength (UCS) test and hand penetrometer are shown. The result indicates that the stress-strain behaviour of plasticine resembles the stress-strain behaviour of kaolin clay. The plasticine is suitable as a substitute cohesive material and it has a potential to be utilised for geotechnical material modelling in the future.

Keywords: artificial clay, plasticine, substitute cohesive material

1. INTRODUCTION

Physical modeling is a method in geotechnical studies for investigating the behavior of a prototype (Wood, 2006), such as deformation of the soil layer, the collapse of the foundation when subjected to external loads, the process of sliding slopes, shearing of retaining walls, etc. The International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) defines that physical modeling as a simplified physical representation of a finite boundary problem for which similarity is sought in the context of scaling laws (Marwan et al., 2020).

Generally, the soil media for modeling study is divided into non-cohesive and cohesive soils. To represent non-cohesive soil, granular material such as quartz sand is commonly used (Cheng et al, 2017; Cheira et al, 2019). Whereas to represent cohesive soil, fine-grained materials such as kaolin is commonly used as reported by Hu et al (2007), Cherie Angle et al (2017), Chandra et al (2017), Raharjo et al (2018), and Indraratna et al (2020). Sometimes, a mixture of non-cohesive and cohesive soils is also required to attain particular soil condition as reported by Purwana et al., (2012), Purwana and Nikraz (2015), Simpson and Evans (2016), Zhang et al., (2017) using a mixture of sand and kaolinite clay. In some cases, the soil is modeled using a particular shape such as rods (Nguyen et al., 2013), spherical shape (Radvilaite et al., 2017), using artificial material such as steel, wood, aluminum, and other suitable material.

This paper reports the result of preliminary investigation regarding the use of plasticine as an alternative artificial material for substitution of clay in soil modeling. Some physical properties from the unconfined compression strength (UCS) test and hand penetrometer are shown.

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2. NATURAL CLAY AND ARTIFICIAL CLAY

Natural Clay

According to the Unified Soil Classification System (USCS), clay is a type of geologic material in which the size of its particles is less than 0.075 mm. The physical properties of clay are strongly affected by its water content, the amount of water (by weight) compared to the amount of solid part. Clay experiences shrinking and very stiff when dry, and it will begin to change to be plastic when its water content is increasing, and finally, it will be liquid-like when its moisture content is relatively very high. Problematic soil in civil engineering is often linked to the amount of clay size in the soil layer and its water content. In other words, the properties of natural clay are based on the amount of water in it (water-based clay).

Articial Clay

For particular purposes, the attempts have been made to make a clay-like material. Most of them are focussing on the use of oil-based material. There are some kinds of oil-based clay-like materials, such as polymer clay, epoxy clay, and plasticine. The first is hardenable clay-like made from polymer polyvinyl chloride (PVC) resin mixed with a liquid plasticizer. This artificial material is able to harden when it is put into the oven for relatively low temperature. This material is generally used for kid's toy product industries. The second type of artificial clay in epoxy clay. The properties of this clay are quite different from the previous one. As the first type of artificial clay is affected by temperature, the second one will begin to harden when its parts are mixed without temperature requirement. The third type is plasticine, a non-drying material as its physical properties remain unchanged when it contacts directly with the air.

Plasticine

Plasticine is an artificial material made from solids such as gypsum, lime, mixed with petroleum jelly or micro wax, and acid fat. Plasticine was for the first time invented by Harbutt (1897) for teaching art in school in UK. Since then, it has been used in many areas such as animation in the film industry, children's toys product, temporary automotive design, and military purposes. It was utilized as a substitute non-hazardous, steril, soft, and not drying material when contact with air directly. The original color of plasticine was grey, and recently, it has been developed in various colors. Some experimental studies indicate that baking flour can be used as a bulking agent to replace gypsum.

Unlike water-based natural clay, the property of plasticine is influenced by oil content. Its plasticity is likely similar to natural clay. It might be considered plastic material as it experiences a permanent deformation when the external load is imposed. So far, there has not been reported how is the physical, mechanical properties of plasticine, and the properties of plasticine are similar to the properties of clay or not. For physical soil modeling, materials are sometimes colored to make it easy to be visually observed. Easy-colored materiel can be one of the advantages properties of plasticine

3. EXPERIMENTAL METHOD

In this experimental study, the main materials for making plasticines were baking powder, micro wax, petroleum jelly, and palm oil. Note that a ready to use plasticine from the market was also investigated. The micro wax, petroleum jelly and palm oil were utilised as plasticizer agents, whereas baking powder was employed as a filler. Additional colouring agent was utilised to differentiate samples for particular purpose. Table 1 shows the proportion of materials for two types of plasticines; micro wax-based and petroleum jelly-based plasticines. These proportions were chosen after conducting some tests previously. For each sample, 100 gr of baking powder was employed. To compare the engineering properties of plasticine and natural clay, the kaolin clay with the variation of water content was utilised as presented in Table 2

Table 1. Proportion of material for plasticine

No	Baking flour (gr)	Micro wax-based		Petroleum-based	
		Micro wax (gr)	Palm oil (gr)	Petroleum jelly (gr)	Palm oil (gr)
1	100	50	30	50	10
2	100	50	35	50	15
3	100	50	40	50	20
4	100	50	45	50	25
5	100	50	50	50	30

Table 2. Kaolin clay with variation amount of water

No	Kaolin Clay (gr)	Water (gr)	Water content (%)
1	100	55	55
2	100	60	60
3	100	65	65
4	100	70	70
5	100	75	75

Baking flour, micro wax /petroleum jelly and palm oil were mixed thoroughly using electric mixer for at least 10 minutes to obtain a homogenous plasticine (Figure 1). They were then put into a desiccator for curing for at least 24 hours. The same treatment was also conducted to the kaolin clay. The samples were pressed into cylindrical mould to formed a cylinder-like sample for shear strength test preparation as shown in Figure 2 Initially, complete index properties tests on kaolin clay such as specific gravity, gradation, Atterberg limits and bulk density tests were conducted. One of the main goals of these tests were soil classification, according to ASTM D 2487-06 (2007). However, other than bulk density, the similar index properties tests on plasticine were not conducted yet due to unavailability of standard test for oil-based material.

Figure 1. Micro wax-based plasticine (left), petroleum jelly based plasticine (right)

The effect of drying of kaolin clay and plasticine due to evaporation was investigated. The investigation was conducted by recording the change of water content (for kaolin clay) and oil content (for plasticine) when they were kept in open-aired room for the total period of 14 days. Two type of shear strength tests were conducted on plasticines as well as on kaolin clay using unconfined compression strength test/UCS referring to ASTM D 2166-00 and hand penetrometer/HPT referring to ASTM D1558 D 2573 as shown in the Figure 3. The method of both UCS and HPT for shear strength test in laboratory was similar to the test for clayey soil by Yasun (2018). During the test, those samples were observed to investigate their behaviour such as stress-strain and modulus of elasticity.

Figure 2. Formed plasticine (left) and formed kaolin clay (right)

Figure 3. Unconfined compression strength test (left) and hand penetrometer test (right)

4. RESULT AND DISCUSSION

Kaolin Clay

The index properties test on kaolin clay reveals that the value of liquid limit is higher than 50%. According to USCS this material is classified high plasticity material. This material has the ability to absorve relatively high amount of water, and in many cases it contributes to many problematic soil such as soft soil and mud flow when it experience relatively high water content. The result of its properties test is firstly presented here as shown in Table 3.

Tabel 3. Index properties of kaolin clay

Soil Properties	Notation	Value
Specific gravity	Gs	2.44
Liquid limit (%)	LL	57.57
Plastic limit (%)	PL	42.26
Plasticity index (%)	PI	15.31
Finer no.200 (%)		100
Classification (USCS)	ML/OH	

Figure 4 shows the result of air drying of both kaolin clay and plasticine for 14 days period. It indicates that there was water loss due to the evaporation of whole kaolin clay samples. It was recorded from the first day that water in kaolin clay was very easy to evaporate until the 9th day. Beyond that day, the water loss was insignificant. However, different from kaolin clay, there was no indication of oil loss of plasticine even from the first day until the 14th day. The kaolin clay samples tend to harden when their water content was decreasing. Whereas the oil content and plasticity of plasticine remain unchanged throughout the time. This can be a good indication of the favourable properties of the plasticine compared to the kaolin clay.

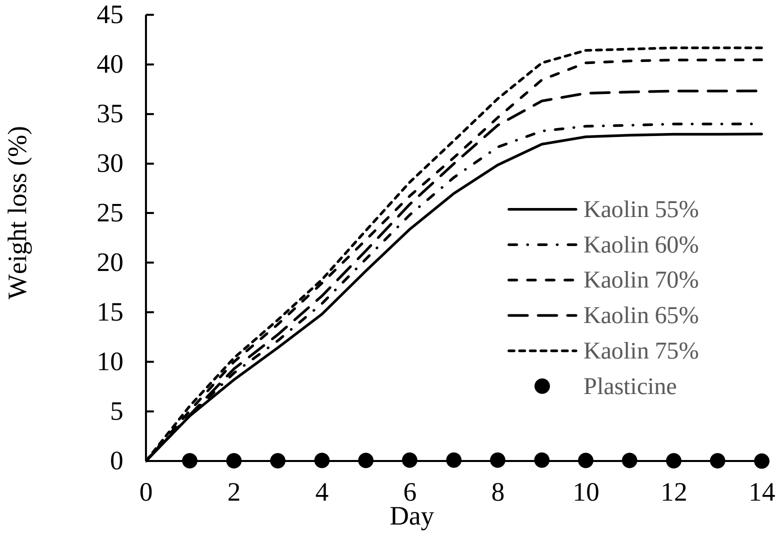

Figure 4. Water loss of kaolin clay and oil loss of plasticine due to evaporation in room temperature

Figure 5 shows the bahaviour of stress-strain of kaolin clay for 55% and 60% water content respectively. Note that the kaolin clay with water content > 65% were very soft, causing it was deformed by its own weight before testing. Therefore, the UCS test on very soft soil was not able to be carried out. It is clear from the figure that the elasticity of sample is influenced by water content. The higher water content the softer the kaolin clay. It also indicates that the compression stress versus strain is not linear, as commonly happen to natural clay.

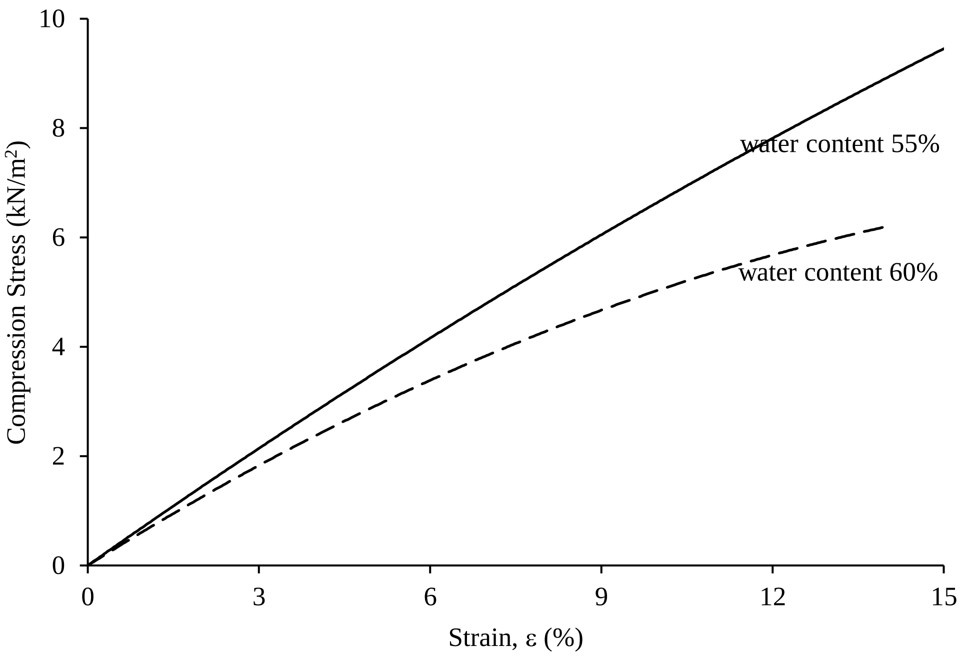

Figure 5. The stress-strain behavior of kaolin clay obtained from UCS for 55% and 60% of water content

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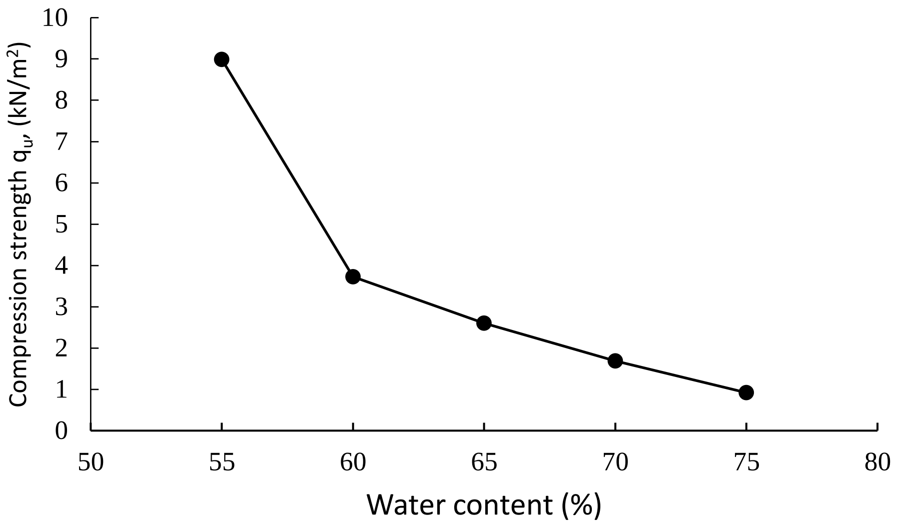

Figure 6. The compression strength of kaolin for various water content adapted from hand penetrometer

Figure 6 shows the value of compression strength q_u adapted from hand penterometer test for various water content of kaolin clay. It indicates that the increasing in water content causing the decreasing in compression strength. It also shows that the increasing of 20 % water content (from 55 % to 75 %) could cause 900 % to the decreasing in compression strength (from 9 kPa to 1 kPa). The relation of strength and water content is not linear.

Micro wax-based plasticine

This type of plasticine was made using microwax as a base material. The bahaviour of stress-strain for 20 %, 23.3 %, and 26.7 % of oil content respectively is shown in the Figure 7. It is clear from the figure that the elasticity of sample is influenced by oil content. Note that the plasticine with oil content > 26.7 % were very soft, causing it was deformed by its own weight before testing. The UCS test on very soft plasticine was not able to be carried out. It is clear from the figure that the elasticity of sample is influenced by oil content. Note that the plasticine with oil content > 26.7 % were very soft, causing it was deformed by its own weight before testing. It is also observed from the figure that the relation of compression stress and strain is not linear. The similar condition occurs to the kaolin clay.

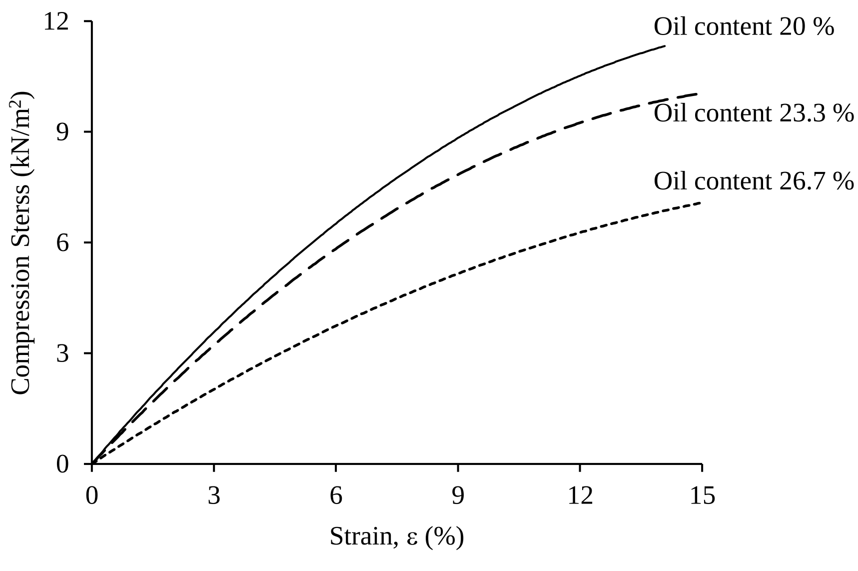

Figure 7. The stress-strain behavior of micro wax plasticine obtained from UCS
for 20 %, 23.3 %, and 26.7 % of oil content

Figure 8 shows the value of compression strength q_u obtained from hand penterometer test for various oil content of plasticine, carried out for whole variation of oil content. It indicates that the increasing in oil content causing the decreasing in compression strength. It also shows that the increasing in 13 % oil content (from 20 % to 33 %) is causing the decreasing around 4 times in compression strength (from 6.5 kPa to 1.5 kPa). The relation of strength and oil content is not linear

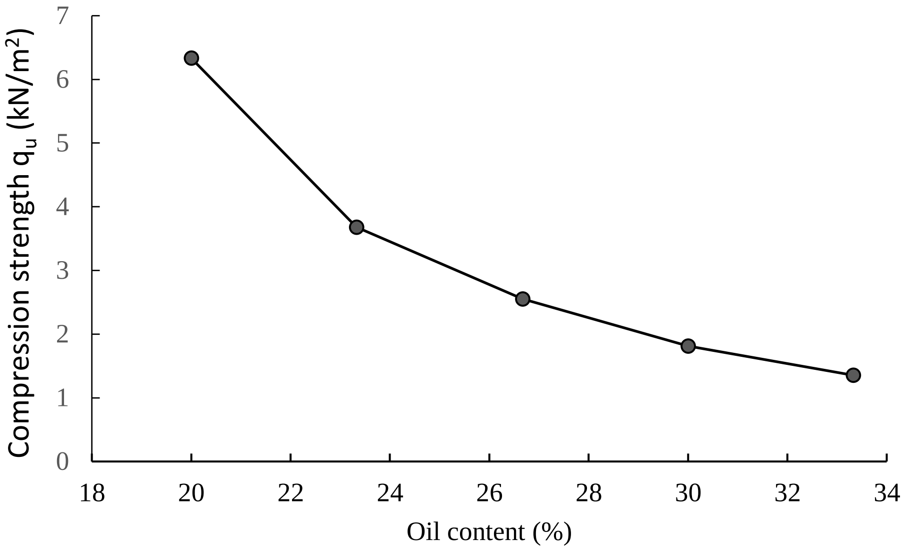

Figure 8. The compression strength of micro wax-based plasticine for various oil content adapted from hand penetrometer

Petroleum Jelly-based Plasticine

This type of plasticine was made using petroleum jelly as a base material. The bahaviour of stress-strain for 3.3 %, 6.7 %, and 10 % of oil content respectively is shown in Figure 10. It is clear from the figure that the elasticity of sample is influenced by oil content. Note that the petroleum jelly-based plasticine with oil content > 10 % were very soft, causing it was deformed by its own weight before testing. The UCS test on very soft plasticine was also not able to be carried out due to very soft.

Figure 10 shows the value of compression strength q_u obtained from hand penterometer test for various oil content of the petroleum jelly-based plasticine, carried out for whole variation of oil content. It shows that the increasing in 10 % of oil content (from 3 % to 13 %) is causing the decreasing 5 times in compression strength (from7.5 % to 1.5 %). The relation of compression strength and oil content is also nonlinear.

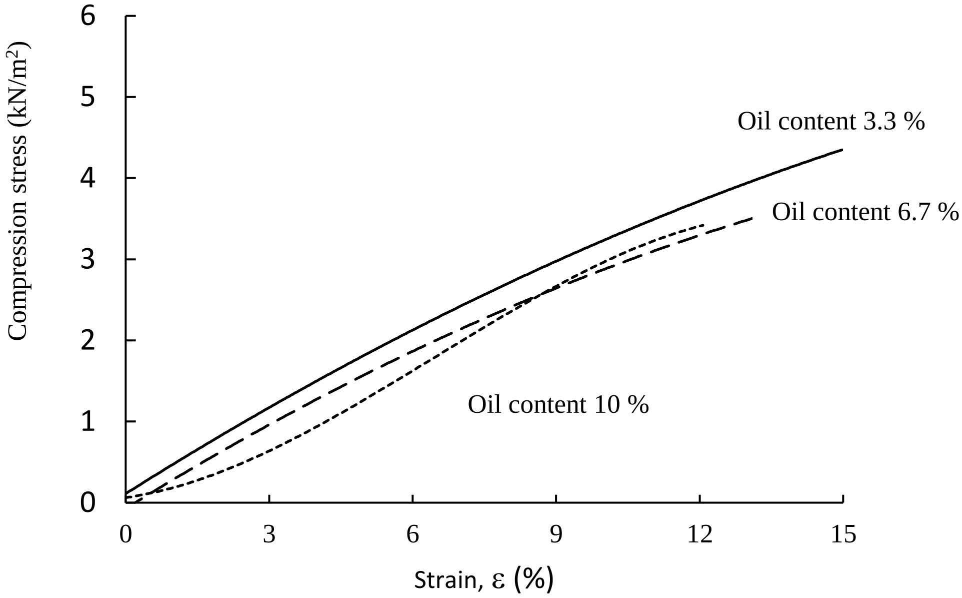

Figure 9. The stress-strain bahaviour of petroleum jelly-based plasticine obtained from UCS

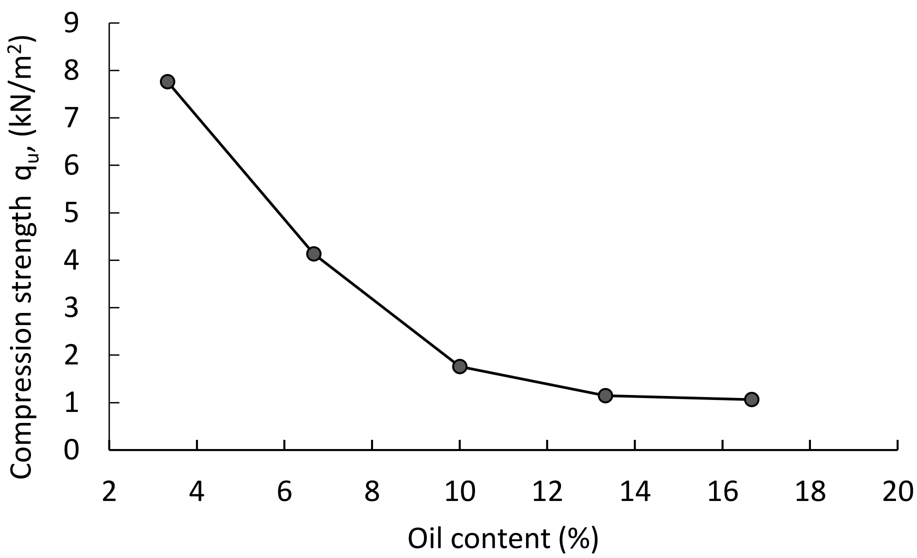

Figure 10. The compression strength of petroleum jelly based plasticine for various oil content adapted from hand penetrometer

Kaolin Clay and Plasticine Comparison

The objective of this study is to investigate the potential employment of plasticine as a substitute material for natural clay in geotechnical soil modelling. The study is focusing on the compressive stress versus strain behaviour and compression strength for various water content (or oil content). Stress versus strain curves of entire kaolin clay and plasticines with various water content and oil content have been investigated. It is indicated that the behaviour plasticine with particular oil content resembles the behaviour of kaolin clay with particular water content. **Figure 11** shows the example that the behaviour of micro wax-based plasticine with 26.7 % oil content is very close to the behaviour of kaolin clay with 60 % water content. The nonlinearity relation of kaolin clay is resembled by the nonlinearity of plasticine.

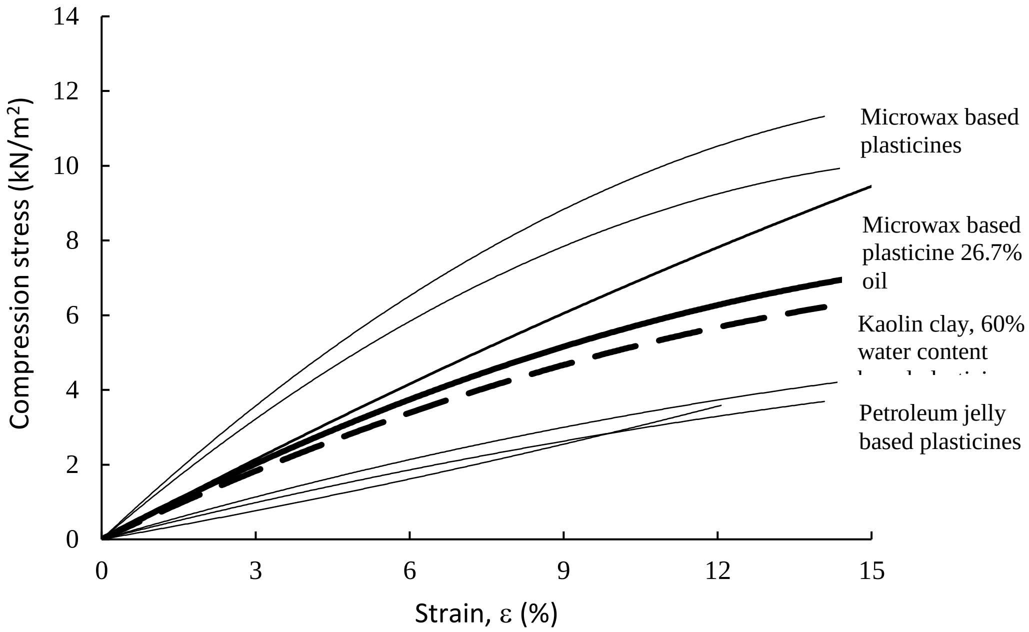

Figure 11. Comparison of compression stress vs. strain for kaolin clay, micro wax-based and petroleum jelly based plasticines

Compression strength of kaolin clay with the variation of water content and compression strength of plasticine with variation of oil content obtained from HPT are compared as presented in the **Figure 12**. It shows that compression strength of 4.8 kPa of kaolin clay with 6 % of water content can be resembled by micro wax- based plasticine with 22 % of oil content or petroleum jelly-based plasticine with 58 % of oil content. Observing to the similarity behaviour of kaolin clay and plasticines, the authors suggest that the behaviour of kaolin clay of particular water content can be attained by plasticine with particular oil content

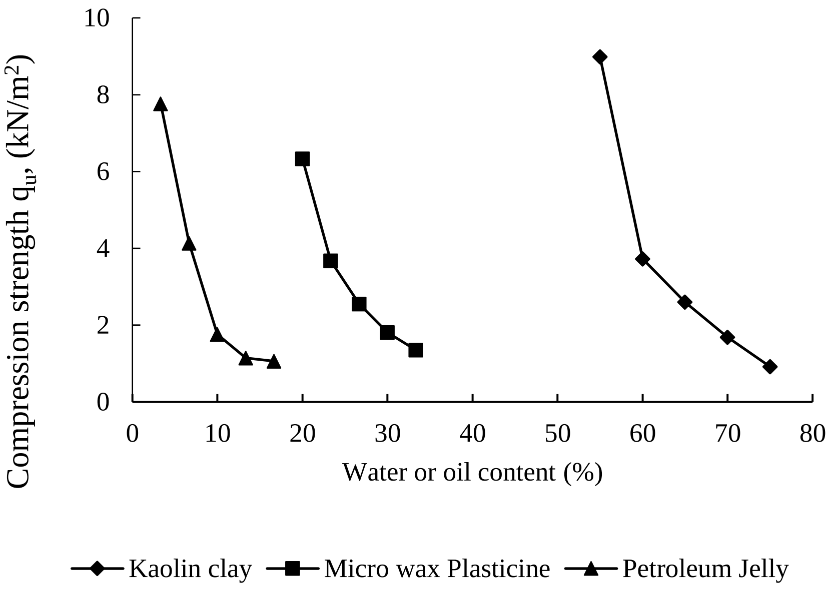

Figure 12. Compression strength versus water content (for kaolin) and oil content (for plasticine)

5. CONCLUSION

Based on preliminary experimental laboratory study it is concluded that:

1. Plasticine is a non-drying artificial material as its oil content remain unchanged when it contacts directly with the air in open-aired room.
2. The stress-strain behaviour of plasticine with particular oil content resembles the stress-strain behaviour of kaolin clay with particular water content.
3. The petroleum jelly-based and micro wax-based plasticine are suitable as the substitute cohesive material and they have a potential employment for geotechnical material modeling in the future.

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