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STRENGTH OF PALM KERNEL OIL-BASED POLYURETHANE FOAM/RESIN AS ALTERNATIVE METHOD FOR GROUND IMPROVEMENT

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ABSTRACT

Polyurethane has widely been used as a ground improvement for several years. The advantages of using polyurethane in ground improvement cannot be denied. Polyurethane foam is a very flexible and lightweight material which is so useful to increase the strength of soil. Polyurethane are used as grouting material in order to remediate settlement and uplifting the effected structure especially foundation to initial position. However polyol that used for polyurethane production are derived from petrochemical based. Concerns over petrochemical raw material volatility and non-sustainable material have caused the interest in substitutes the use of chemical based polyurethane to palm kernel oil-based polyurethane. This study perhaps can contribute to overcome those issues. Particularly, this study involves experimental work to evaluate the strength characteristic for different ratios of palm kernel oil based polyol to isocynate to form palm kernel oil based polyurethane (PKO-PU). The strength was tested using Unconfined Compression Test (UCT) for sample size of 50mm diameter and 100mm height. During mixing, expansions for every ratio were monitored. Stiffness and behaviour for every ratio was then being analysed using stress-strain curve. It is shown that, increasing in amount of polyol result in increasing the expansion but reduction in strength. PKO-PU shows rigid characteristics at the maximum strength which produce strong material, able to resist deformation but brittle beyond the maximum stress. Further increasing amount of polyol, PKO-PU shows flexible characteristic whereby it undergoes deformation but tend to elongate beyond the maximum stress. Higher stiffness and density recorded for rigid PKO-PU compared to flexible type PKO-PU.

Keywords: settlement, compressive strength, polyurethane, palm kernel Oil-based polyurethane.

INTRODUCTION

Malaysia consists of many problematic soils such as peat and clay. More than 70% of Malaysia coastal line consists of soft soil. These problematic soils can cause failure to subsurface condition thus affecting the structure above the ground. The characteristic of these soils are normally high in compressibility, low shear strength and low permeability (Budhu, 2011; Withlow, 2004). Normally the strength development of soft soil is reliant on time compare to other type of soil.

Due to scarcity of land in major cities such as Kuala Lumpur, Ipoh and Penang, urban developments have shifted to karst and ex-mining area. Without proper ground modification, development on karst and ex-mining area will expose to an engineering geologic problem such as settlement, landslide, subsidence and sinkholes (Tan, 2006).

The presence of negative pore water pressure also known as suction in partially saturated soil complicates the settlement issues. The presence of suction will influence the soil shear strength. When the water table rises, the soil becomes fully saturated. As a result the suction will drop to zero and the strength of the soil starts to decrease. Less suction within the soil particle will increase the voids hence trigger the settlement (Fredlund *et al*. 2012; Md. Noor, 2011, 2016; Mohamed Jais *et al*. 2015)

The ground with problematic soil should be modified before any construction of development take place. This is to ensure that the structures are sitting on a stable foundation hence prevent the settlement to occur. Nowadays, ground improvement technique that normally being used are stone column, preloading, electro-osmosis, underpinning and grouting. However, some of these techniques such as underpinning need excavation. This will lead to increase in construction cost due to mobilising, handling and labour cost. Although grouting does not involve any major excavation work, however it also contributes to other problem that related to time. Grouting by using cement as chemical admixture required several days for curing and properly setting.

Because of the demand for rapid solution of ground treatment and modification, polyurethane foam injection was introduced. Polyurethane foam (PU) derived from two polymer which is polyol and isosynate. The mixture of polyol and isosynate was injected into the ground through a small hole that had been drilled. The mixture then travel by itself searching and filling the void between the soil particles. The PU starts to expand from liquid based to foam based within several minutes. The expansion also can lift up road, highway, and concrete slab. Besides rapid curing and high in expansion, use of PU in ground improvement also can eliminate major excavation work.

PU is a lightweight material, so there is no excessive overburden pressure to initial soil. In Malaysia, there are several successful work that used Polyurethane for ground remediation such as Petronas (Chemical) MTBE, Gebeng Kuantan, KM 48.7 Karak Expressway,

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Route FT31 Jalan Banting Semenyih and KM 88.78 Ayer Hitam (Mohamed Jais *et al.*, 2015; Mohamed Jais *et al,* 2016). However, current polyurethane that being used now are derived from chemical based polyurethane. Concerns over petrochemical raw material volatility and non-sustainable material have caused the interest in substitutes the use of chemical based polyurethane to palm kernel oil-based polyurethane. Towards the development in innovation, therefore, this study is expected to provide a material that is at least equal to chemical based polyurethane so that the continuity of polyurethane foam can be best utilized.

MATERIALS AND METHOD

Aluminium sheet of 25mm thickness was choosing for the mixing mould. The aluminium is cut into 150 mm by 220 mm square shape. The aluminium sheet was covered at the bottom, rolled and screwed tight to form a cylindrical mould with 50mm diameter and 150 mm in height as shown in Figure-1. The aluminium sheet is being used since it can facilitate the process of removing the sample from the mould.

Figure-1. Aluminium mould that use for mixing process.

The PKO-PU foam sample is then prepared by adding and mixing isosynate and polyol as shown in Figure-2. The two polymers were poured into the aluminium mould of 50mm diameter and 150mm height and followed by mixing these two admixtures. Volume of resin in liquid state and volume of resin in solid state was measured during the mixing. The reaction time is measured after the two admixtures were poured into the mould until their reaction stopped. The mixture is set aside to rest until it's solidifies become polyurethane foam. The PKO-PU foam was demolded after 15 minutes of its hardening state. After about 24 hours from demolded, the PKO-PU foam is cut into 100mm height. The sample was then weighed using analytical balance. All samples were prepared based on different ratio.

Figure-2. Polyol and isosynate.

Sample of PKO-PU was categorised based on three types namely Type I, Type II and Type III. Each type was described clearly in Table 1. Type I and Type III samples were tested for 5 ratio; 0.5, 0.75, 1.25, 1.5, and 1.75 while Type II sample was tested for ratio 1:1 only. The entire samples then are tested for strength using Unconfined Compression Test (UCT) as shown in Figure-3. In order to perform the test, the PKO-PU foam was demoulded form the sampling aluminium tube. PKO-PU foam was cut into diameter-to- length ratio of one to two; 50 mm diameter and 100 mm height

Table-1. Different Type of PKO-PU Sample.

Type	Description
I	Sample of Palm Kernel Oil-based Polyurethane that produce with constant polyol
II	Sample of polyurethane that produce with equal ratio of isosynate and polyol
III	Sample of Palm Kernel Oil-based Polyurethane that produce with constant isosynate

Figure-3. Specimen tested for Unconfined Compression Test (UCT).

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RESULTS AND DISCUSSIONS

Relationship between expansion and strength

Figure-4 shows the relationship of PKO-PU between compressive strength and expansion for different ratio of polyol to isosynate. Blue column and green column represent strength for type I and type III of PKO-PU, while blue line and green line represent expansion for type I and type III respectively. The graph clearly shows that, increase in polyol result in increase in expansion but reduction in strength. Meanwhile increase in isosynate result in reduction in expansion but increase in strength. Theoretically, the result are in line with the study of chemical based polyurethane (Mazlee, 2013; Sidek *et al.*, 2015). However, from findings, the strength and expansion of PKO-PU is more optimum when the rate of polyol and isosynate are close to equal amount. This finding reinforces the opinion by Sidek *et al.* (2016). Sidek *et al.* (2016) also stressed the need to take into account the rate of expansion for every mixing since polyol act as expansion agent that contributes to soft segment for the PKO-PU foam while isosynate act as the strengthen agent to the PKO-PU foam mixing. Thus, at ratio polyol to isosynate of 1:1 is the best mixing ratio for this study.

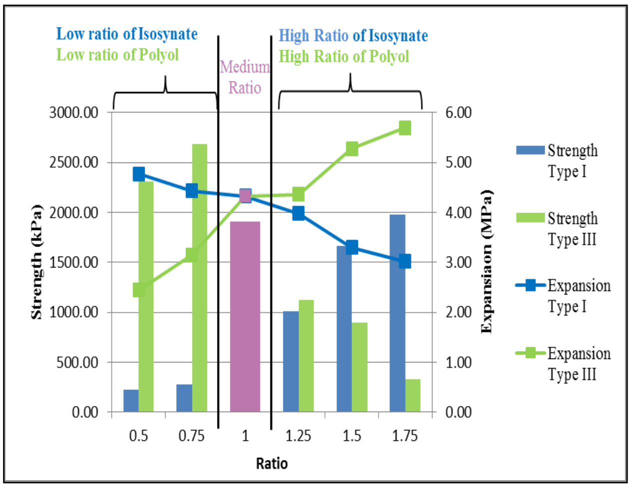

Figure-4. Relationship of PKO-PU with strength and Expansion.

Relationship between stiffness and density

Figure-5 shows the relationship of PKO-PU between stiffness and density for different ratio of polyol to isocynate. Red column and blue column represent stiffness for type I and type III of PKO-PU, while red line and blue line represent density for type I and type III respectively. From the graph, the stiffness will increase when the amount of isocynate is more than the amount of polyol. As well as the results obtained from the stiffness, the density of PKO-PU will increase if the amount of isocynate is higher than the amount of polyol. This finding supports by the data obtained from Valentino *et al.* (2014) and Badri (2012).

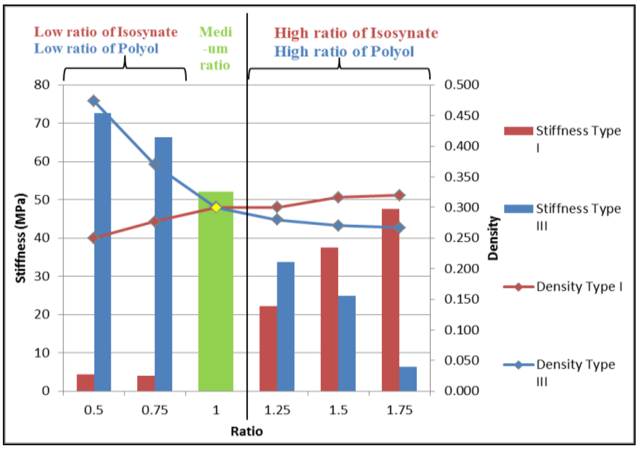

Figure-5. Relationship between stiffness and density.

Behaviour of PKO-PU

Figure-6 shows the graph of stress against strain for PKO-PU Type I, Type II and Type III. There are three (3) zone that can obtains form the curve. The zones are categories based on the gradient of the curve. The first zone is Zone I, which is the zone where the specimens are, behave as rigid material. Specimens that fall in this region are specimen ID2, ID3, IE2, IE3, IIIA1, IIIA2, IIIA3, IIIB1, IIIB2, which is polyol to isosynate ratio ranging from 1:1.5, 1:1.75, 0.5:1, and 0.75: 1 respectively. From the ratio, all the specimens in Zone 1 are containing higher amount of isosynate rather than polyol. Zone I specimens are very high in compressive strength and required more force in order to reach breaking point. Consequently, the specimens behave as brittle elastic since the occurrence of a sharp increase in strain and final failure occurs after the yield point. Even though the PKO-PU foam that fall in this zone can sustain more stress, but it is not suitable to use as an alternative for ground improvement. It is predicted to have massive settlement as it can't withstand more elongation before breaking. Thus, higher amount of isosynate contribute to produce rigid PKO-PU with strong, elastic but tend to break at the maximum load.

Specimens that fall in Zone II region are IC1, IC2, IC3, ID1, IE1, IIA1, IIA2, IIA3, IIIC1, IIIC2, IIIC3, IIID1, IIID2, and IIID3 which represent polyol to isosynate ratio of ranging from 1:1.25, 1:1, 1.25:1, and 1.5:1. At this region, the amount of polyol and isosynate are almost balance thus the PKO-PU. The specimen behave as rigid material however it doesn't experience massive failure as in Zone I specimen. The steep gradient occurs before the yield point. The specimens experience deformation while the force keep increasing thus it behave as an elastic deformation. Further increase in forces cause the PKO-PU undergoes plastic state. The plastic states occur after the specimens fail at the maximum load and it start to elongate. The flexible material continues to elongate without any increase in stress. Since Zone II specimens can sustain on high pressure and keep to elongate after reach the maximum loading, it is seem to be more preferable to fit as an alternative method in ground improvement. This finding seem to follow same results as

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in Buzzi *et al.* (2008) where the unconfined uniaxial compression behaviour of polyurethane foams displays an elastic-perfectly plastic behaviour followed by a densification phase when compressed along the rising direction

Only PKO-PU foam from ratio 1:0.5 (IA1, IA2, IA3), 1:0.75 (IB1, IB2, IB3) and 1.75:1 (IIIE1, IIIE2, IIIE3) are categorise in Zone III. Form the graph, Zone III PKO-PU experiences same behaviour as Zone II PKO-PU. However, the specimen in this region only can hold lower compressive strength before it tends to fail. This is because, the amount of polyol higher than the amount of isosynate, thus the materials become soft since the polyol only react as an expansion agent.. The specimens then start to elongate after it reach the maximum loading. During the UCT test that done in laboratory, the specimens seen to be easy to compress even under a small loading. The length of the specimen decreases while under compression loading and the specimen start again to increase its length again after 24 hours of unloading. However, during the time, the specimen did not recover its original length. All in all, the Zone III PKO-PU foam very flexible and soft material. Hence, it is not suitable for use as grouting material in ground improvement. Figure 7 shows samples with high ratio of isosynate compare to polyol whereas Figure-8 shows samples with low ratio of isosynate compare to polyol. The behaviour for every ratio are tabulated in Table-2.

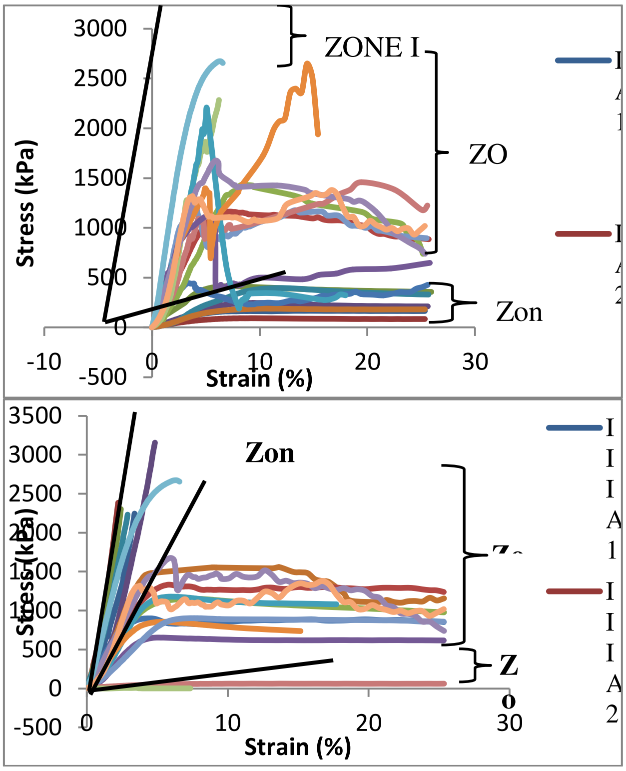

Figure-6. Stress-strain curve for PKO-PU Type I, II and III.

Figure-7. Sample with high ratio of isosynate compare to polyol.

Figure-8. Sample with low ratio of isosynate compare to polyol.

Table-2. Behaviour of PKO-PU.

Ratio Polyol: Isosynate	Zone	Behaviour
1:0.5	3	Flexible, soft material
1:0.75	3	
1:1.25	2	Rigid, strong material
1:1.5	1	Rigid, brittle material
1:1.75	1	
1:1	2	Rigid, strong material
0.5:1	1	Rigid, brittle material
0.75:1	1	
1.25:1	2	Rigid, strong material
1.5:1	2	
1.75:1	3	Flexible, soft material

CONCLUSIONS

At polyol to isocynate ratio of 1:1 is the optimum ratio for the PKO-PU foam. The maximum strength PKO-PU for ratio 1:1 can achieve up to 2 MPa with stiffness of 52 MPa. The strength of PKO-PU is four (4) time higher than chemical based polyurethane.

As the amount of polyol increase, the expansion also increases. The expansion of PKO-PU foams varies from two (2) to six (6) times from its liquids state but lower than to the rate of expansion for chemical based polyurethane. As the amount of isocynate increase, the density of PKO-PU foam also increases. Resin density is strongly influence by the isocynate portion in a mixture but it also depends on the type of polyurethane resin that are being used

PKO-PU shows rigid characteristics at the maximum strength which produce strong material, able to resist deformation but brittle beyond the maximum stress. Further increasing amount of polyol, PKO-PU shows flexible characteristic whereby it undergoes deformation but tend to elongate beyond the maximum stress.

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