Effect of different fibre reinforcement type to the shear strength of soft soil at varying moisture condition

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Abstract. The utilisation of discrete fibre in the soil reinforcement technique to overcome the problems of soft compressible soil are investigated in this paper. Two different type of fibre is used herein, i.e. polypropylene and plastic fibre. Shear strength of soils is highly affected by moisture conditions. In practice, a laboratory investigation conducted to determine the shear strength of soil is prepared at optimum moisture content. However, at field conditions, the actual water content may vary. The effect of moisture variation with respect to optimum moisture content is investigated in this study. Unconfined Compressive Strength Test was carried out to study the effect of fibre type, fibre content and soil moisture condition. The test results indicated that the reinforced soil using polypropylene fibre provides higher strength increment compared to plastic fibre. The highest strength was achieved at 0.15% additional of polypropylene fibre in the dry moisture condition.

1. Introduction
Distribution of alluvium soft soil in Malaysia in the coastal area of the west coast and east coast of Peninsular and East Malaysia covers about 30% from the whole land country [1]. Most of the development and construction works focus on those places due to their strategic location and viability. However, many construction problems on soft ground such as excessive settlement, bearing capacity failure and slope failure occur because of low shear strength and highly compressible. According to statistical data of geotechnical forensic carried out by PWD (Public Work Department of Malaysia) approximately 72% of the reported cases are related to soil settlement problems [2].

In current practices, three soil improvement techniques methods available to stabilise the soft soils, which are physical, mechanical and chemical methods. Physical method is widely used and very practical with high-level technology. Densification, vibroflotation, dynamic tamping and vibro replacement are some examples of physical soil improvement techniques. These techniques incurred at a very high construction cost. The mechanical method changes the physical characteristics of the soil using discrete fibrous material, for instance, plastic fibre, polypropylene (PP), polyethylene (PE) and some natural fibre including coir, sisal, jute, and bamboo [3]. The chemical method utilizes chemical
additive to improve the strength by altering the bonding properties between the particles such as polymeric resins, cement and lime.

Discrete fibre reinforcement offers several advantages over other conventional geosynthetics (strips, geotextile, geogrid, etc.) because it is simple, versatile and safe. The discrete fibres are simply added and mixed with soil in random distribution planes. Randomly distributed fibres will constrain the potential failure planes that can develop in the parallel direction like in the conventional technique. [4]. This technique is based on the principle of friction, in which the soil-fibre composite will be compacted thus the strength will increase as the contact surface between soil-fibre increases [5]. According to Tang et al., [6], fibre reinforcement effects on the mechanical properties by governing the interfacial friction and cohesion.

Synthetic fibres have been proven to increase the strength of soil [7], [8], [9]. Even though synthetic fibres are unable to absorb moisture in the soil, this material can improve the strength due to robustness and high resistance to fatigue, physical damage, chemical solvents, bases and acids. This paper aims to investigate the effect of polypropylene and plastic fibre to the shear strength of the soil. Polypropylene fibre is produced from crystalline thermoplastic and mostly used daily works. It was known to have high tensile strength as well as durable. Plastic fiber is made from polymer and is known to be robust under bending and stretching. Several untreated and treated soil specimens were prepared at different moisture conditions subjected under unconfined compressive strength.

2. Methodology
The soil sample was collected atNibong Tebal, Penang, Malaysia. The GPS coordinate is given by 5.180451, 100.473583. The soil was retrieved from 1.5 to 2-meter depth below the ground surface by using hand auger boring equipment. The collected soil was air-dried, crushed and passed through 2 mm sieve. Physical index tests were conducted to classify the type of soil samples. The reinforced soil specimens were prepared by mixing dry soil, distilled water and fibres. Fibres were mixed manually with the wet soil at small increments. To ensure uniform mixtures, the mixed samples were rested for 24 hours in a closely packed container.

In this experiment, three water contents i.e. optimum moisture content (20.75%), dry of optimum (18.75%) and wet of optimum (22.75%) were chosen. The optimum moisture content can be obtained from the standard Proctor Test, which was carried out earlier. This test followed the standard procedures outlined in the British Standard (BS1377-4). Two types of fibre were used in this study i.e. polypropylene fibre (fraction 0.05%, 0.15%, 0.25% and 0.35%) and plastic fibre (fraction 0.5%, 1.0%, 1.5% and 2.0%). Both polypropylene and plastic fibre fraction adopted in this study were based on previous findings [10] and [11]. A total of 30 groups of specimens were prepared for investigating the effect of different type of fibres, amount of fibre inclusion and water content to the shear strength of the soil.

2.1. Materials
The soil sample used in this study was tropical soft soil; a typical clay-based soil extensively distributed in the northern region of Peninsular Malaysia. The basic properties of the soil such as grain size analysis, the specific gravity of the soil and Atterberg limits (liquid limit and plastic limit) were determined according to classification tests of British Standard (BS1377-2). This soil can be classified as sandy silt of low plasticity (ML). Basic properties of the used soil are presented in Table 1. Polypropylene fibre and plastic fibre used in this investigation were obtained from local industry. The mechanical properties of these fibres are shown in Table 2. The samples of fibres used in this study are shown in Figure 1. During the sample preparation process, the plastic fibre was cut into 25 mm to ease mixing and standardisation process. The fibres must be uniformly distributed in the soil-fibre interface, so that surface contact friction could be developed uniformly across the samples.
### Table 1. Physical Properties of soil samples

| Characteristics                                      | Index Properties |
|------------------------------------------------------|------------------|
| Natural Water Content (%)                            | 71.46            |
| Specific Gravity                                     | 2.68             |
| Particle Size Distribution; Sand (%), Silt (%) Clay (%) | 38, 35, 27       |
| Liquid Limit (%), Plastic Limit (%), Plasticity Index (%) | 45, 32, 13      |
| Optimum Moisture Content, OMC (%)                    | 20.75            |
| Maximum Dry Density, g/cm³                           | 2.10             |

### Table 2. Mechanical Properties of polypropylene and plastic fibers

|                        | Polypropylene [10] | Plastic Fiber [12] |
|------------------------|--------------------|--------------------|
| Tensile strength at break (MPa) | 350                | 70                 |
| Elongation at break (%)  | 7.4                | 70                 |
| Modulus Elasticity (MPa) | 3500               | 2400               |
| Melting point (℃)       | 590                | 260                |

**Figure 1.** Polypropylene fiber (left) and Plastic fiber (right)

2.2 *Unconfined Compressive Test (UCT)*

The Unconfined compressive test (UCT) is a type of triaxial test in which a cylindrical specimen is failed due to the axial compressive stress only, without any lateral stress. The test is typically used as a quick and economical technique to determine the estimated strength of the remoulded sample. For many small projects on which expenditure on the extensive testing programme is not provided, the soil strength can be assessed swiftly and easily from UCT. After the prepared sample reached the homogenisation in moisture at about 24 hours, all the 30 samples were tested with the UCT machine. The samples are placed in load frame machine driven strain rate controlled at 1.2 mm/min until failure take part. The specimen was tested until fail or 20% of axial strain reached. The failure occurs along the weakest portion of the sample and hence the test gives conservative shear strength value. The test was conducted in accordance with BS 1377-7.
3. Results and Discussions
3.1 Unconfined Compressive Strength (UCS)

The effect of fibre inclusion to the unconfined compressive strength of the soil samples was determined based on three parameters i.e. type of fibre used, amount of fibre and moisture content as shown in Figure 2(a–c) and Figure 3(a–c) for polypropylene and plastic fibre respectively. Here, the observed Unconfined Compressive Stress (UCS) is thought to be the maximum shear stress necessary to break the bonds between soil particles along the failure plane.

As can be seen from Figure 2, the overall behaviour of the fibre-reinforced soil was influenced by the three factors. Brittle behaviour can be seen for the samples with low moisture content. Gradually, the behaviour changes to ductile as the moisture content increases. Initially, the addition of polypropylene fibres causes an increment of the peak strength. However, as the inclusion of fibre keeps increasing, the peak strength starts to reduce, in which the optimum amount of polypropylene fibre required to reach the maximum strength can be identified. For dry of optimum condition, the required amount of polypropylene fibre to achieve the highest strength is 0.15%. Meanwhile, for both optimum and wet moisture content, the suitable percentage to attain the maximum strength is 0.25% respectively.

![Figure 2](image-url)  
**Figure 2.** Effect on the inclusion of polypropylene fibre into soil matrix at different moisture conditions

Similar behaviour was observed for the soil samples reinforced with plastic fibres. When the amount of fibre added, the peak strength increased. At dry of optimum moisture content, the maximum strength is reached when the amount of plastic fibre is 1.0%. At optimum of moisture content, the required amount to mobilise the shear strength is 1.5%. At wet of optimum moisture condition, 1.5% of the plastic fibre is needed to attain the highest shear strength. The development of interfacial force and interlock between soil and fibres in the compacted soil specimens give an improvement in the friction resistance.
to force application and consequently, the strength of the fibre reinforced soil increased. This is in line with the previous study conducted which reported that fibre content found as the main factor that affects the strength of the soil specimens [8], [9], [10], [11].

**Figure 3.** Effect on the inclusion of plastic fibre into soil matrix at different moisture conditions

### 3.1.1 Effect of Fibre Content

The increment of stress strength required to mobilise the internal shear resistance in fibre-reinforced soil is mainly due to interfacial mechanical interactions between fibre surface and soil particles. Consequently, fibres could share some tensile load in the soil matrix and therefore increase the shear strength. However, as too many amounts of fibre added cause reduction on the effectiveness of the improvement in the strength. This was probably due to the fibres adhering to each other to form lumps and therefore could not fully contact with the soil particles.

### 3.1.2 Effect of Fiber type

Reinforcement with both fibre types i.e. polypropylene and plastic fibre could enhance the mechanical strength of the soft soil. Generally, soil reinforced with polypropylene fibre provides a higher increment in the shear strength as compared to the plastic fibre (Figure 4). Without a doubt, the unique mechanical properties of those fibres contribute to the variation in the strength enhancement provided by each of the fibres as can be seen from Table 2.

Polypropylene generally has higher tensile strength, elastic modulus and strain elongation. In the dry condition, the strength increment achieved by polypropylene reinforced soil was 35% higher than plastic reinforced soil. The possible reason for large differences in the strength enhancement was due to the larger area contacts between the soil matrix and the polypropylene surface fibre. The stress transfer from
the weak soil matrix to the fibre that have high tensile strength. The stronger the adhesion between the fibre and the matrix, the greater the strengthening effect. Meanwhile, in the condition of optimum moisture and wet of optimum water content, the differences are only 6% and 5% respectively. The presence of higher water content in the soil matrix was the reason for the reduction of strength increment.

**Figure 4.** Effect of different fibre type to the unconfined compressive strength of soil

3.1.3 Effect of Soil Moisture Content

Moisture contents of soils are rarely uniform in the field. Variations in moisture contents will cause changes in the interfacial force and friction resistance of the soil-fiber matrix. The interfacial and friction resistance generally reduced as the moisture content increased. This reduction can be attributed to the decrease in soil suction that concurrently occurred with the increase in the moisture contents and the possible development of excess pore water pressure [13]. As depicted in Figure 5, the shear strength increased as the moisture content is low. This was true for polypropylene fiber reinforced soil though, however different behaviour exhibited by plastic fiber reinforced soil.

At optimum moisture condition, the highest shear strength was achieved. It is believed that this could be related to the dry density of the soil. At optimum moisture content, the maximum dry density was reached. Dry density affects the contact conditions of soil particles. A higher dry density leads to more contacts between soil particles. The greater bonding force between particles was created and therefore greater shear strength. Moreover, the increase of dry density causes rise to the soil-fiber interfacial contact area, which could enhance the interfacial mechanical interactions and increase the interfacial shear strength [14]. Findings in this study prove that the wetter moisture condition provides lower strength compared to the optimum and drier side. These findings also in line with the previous researchers that utilisation of discrete synthetic fibres as soil reinforcement are capable to increase the strength of weak soil [15], [16], [17].
Figure 5. Effect of fibre amount to the strength of fibre-reinforced soil polypropelene (left) and plastic fibre (right)

4. Conclusion

The following conclusions were drawn from the tests conducted in this study:

(i) The contribution of the synthetic fibre i.e. polypropylene and plastic fibre to the strength increment of the weak soil has been successfully proven by using Unconfined Compressive Strength Test. As the quantity of the fiber increased, the strength was also greater. Stress transfer from the weak soil matrix and shared by the interaction of soil matrix interface. The enhanced strength was attributed by interfacial force and friction resistance in between the soil-fibre. However, adding too much fibre could significantly reduce the strength as the fibre accumulate closer to each other and thus denying the development of interfacial strength.

(ii) Polypropylene fiber reinforced soil exhibits greater increment of the shear strength due to the higher tensile strength of the fibre itself. Interfacial force and friction resistance in between the soil-fiber matrix greater due to the larger surface contact area of the soil fibre matrix.

(iii) Soil moisture content directly influenced the fibre reinforced soil. The more water content could significantly reduce the soil strength. At dry condition, the suction and cohesion force governed the interfacial force of the soil-fiber matrix. As the soil getting wetter, the development of pore water pressure cause reduction of the interfacial force, hence reducing the shear strength.

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