Waste plastic fiber as stabilizer in sub-base sand layer for road construction project

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Abstract. Pollution dilemma due to plastic bottle waste disposal and buildup is a growing and persistent problem in Malaysia. Clearly, innovate use of such wastes through recycling application in engineering must be found. This research was aimed to utilize waste plastic fiber in problematic road construction project that can be both economical and environmentally friendly. Additionally, it has the potency to increase the mechanical strength of commercial sand through the CBR parameter of the road pavement sub-grades. The sand usually possesses low CBR value which on its own may not be entirely suitable for the road construction works unless additive or stabilizer was added. In this study, the specimen used as additive to the sand involved 5 mm wide × 10 mm wide plastic fiber which was obtained from shredded waste plastic bottles. There were several percentage of waste plastic fibers that had considered in the research apart from the control specimen namely at 0 %, 0.1% and 0.5% in conjunction with 5 % cement and water at optimum moisture content level. Several laboratory tests had been prescribed namely characterization tests, compressibility test and CBR test. The result shows that as the percentage of waste plastic fiber increased, the CBR value also increased indicating positive relationship between the two variables.

1. Introduction

Malaysians have taken for granted that the unrelenting singular use of non-biodegradable plastic packaging and implements in their daily socio-economic activities has inevitably led to massive dumping of such wastes in the sanitary landfills. This situation has put pressure on the environment as more and more territorial spaces have to be sacrificed to this unsavory and unsustainable practice, as it creeps ever closer to the periphery of human habitations and sensitive ecosystems. Simply burning them is out of the question as it will introduce another level of pollution-related hazards in the form of charred remains and dioxin emissions with consequent health and environmental risks. While it is true that some disused landfills were developed for future occupation, the engineering and environmental uncertainties over such battered ground could create unfathomable analysis and design complexities. Clearly, a better management practice for the plastic waste is needed here to mitigate such potentials.

Malaysia is experiencing intense infrastructural development at present which among others involves the construction of new or upgrading existing road network system across the country, which is imperative to sustain economic growth and national development. At the same instance, it is faced with raw material shortage and unsuitability of borrowed conventional practices, and even technical failures when such concerns were not adequately addressed. One of the standing issues involves the inadequacy of the mechanical strength of the sand material that forms the primary constituent of the crucial sub-
base course of the road pavement construction, which in turn supports the traffic loads as well as the overlying surface and base courses, and concrete slab and base course for flexible and rigid pavements respectively. In many an occasion, it was found that the conventional way of constructing road do not provide enough load bearing capacity to sustain the ever increasing traffic loads, which resulted in various road deformation patterns such as corrugations, depressions, rutting and shoving. A workable alternative is needed here to enhance the strength of the sand material particularly in sandy coastal areas through additive reinforcement such as bio-polymer, waste paper sludge, starch, plastic fiber and other binding elements. Based on previous research [1], such admixture between sand and foreign additives could indeed increase the strength and stability of soil effectively.

However, most prior researches were conducted using intentionally manufactured additives, which although did serve the intended purpose of soil strength and stability enhancement, are nonetheless expensive, difficult to acquire and non-beneficial to the environment as they were not essentially by-products of discarded waste recycling process. In addition, most of the tests were conducted on clayey soil and rarely on sand which evidently has distinct mechanical and engineering properties when compared to the former. According to Perfect et al [2], clay has fine particles which are bound together while sand has predominantly discrete coarse particle constituent. Previous research has also indicated that pollution due to plastic bottle wastes are on the rise with up to 8 million of metric tons of plastic were dumped into the ocean daily [3]. These arguments further justifies the use of plastic waste by-products as one of the additive ingredients. As it happened, the various method to enhance compaction of sand at present also involves reinforcing soil with additive such as waste plastic fiber apart from the usual pre-compression process, vibration process, etc. The various techniques to increase sand compaction is shown in Figure 1 below.

There are a few problems that need to be clarified in this research regarding the use of additive in reinforcing sandy soils. This revolves around the premise of whether the additive chosen in this study namely waste plastic fiber really helps in increasing the compaction strength of sand. In order to analyze the effectiveness of the waste plastic fiber as additive in increasing the mechanical strength of soil, the California Bearing Ratio (CBR) test will be conducted in laboratory in accordance to specifications and procedures outlined in BS 1377-2:1990 and also adopted in a prior parallel research [4]. Naturally, the main point of contention to be resolved is on the optimal ratio of fiber and sand mix which has the effect of maximizing the degree of compaction experienced by the sand and as such potentially arrest aggravated compressibility tendency. In order to know the optimal percentage of sand versus waste plastic fiber to be added to achieve the maximum mechanical strength of sand, several percentage of waste plastic fiber, W had been designed namely 0.00 %, 0.10% and 0.50% of the total weight of sand. This is given in the following equation which is also prescribed in a prior research [4] and Figure 2 shows the type of waste plastic bottle used in this research:

\[ W = \frac{W_f}{W_s} \times 100 \]  

(1)

where:

- \( W_f \) = Weight of waste plastic fiber
- \( W_s \) = Weight of sand
Figure 1. Various Method to Improve Compaction of Sand

Figure 2. Domestic Waste Plastic Bottle (Source: http://www.star.com.my)
2. Material and Methods

2.1. Sample Preparation

There were two types of raw materials used in this study namely commercial sand and waste plastic bottles. For commercial sand, the type used was graded sand which is typically found in the construction industry and supplied domestically. The sand was oven-dried for 24 hours using laboratory oven at about 100°C and sieved through sieve aperture range of 0.4 mm to 0.0063 mm as prescribed in a prior research [5]. The waste plastic bottles were machine-cut in a recycling factory to shredded pieces of 10 mm long and 5.0 mm wide (see Figure 3). The waste plastic bottles were originally typical Malaysian drinking vessels produced from hetero-chain thermoplastic group. Table 1 show the chemical composition of the waste plastic bottles used in this study.

![Figure 3. Plastic Fiber of 5 mm wide x 10 mm long](image)

| Table 1. Chemical composition of plastic bottle [Source: Plastic Chemical Compound, Encyclopedia, Britannica (2017)] |
| --- |
| Polymer Family and Type | Density (g/cm³) | Degree Of Crystallinity | Glass Transition Temperature (°C) | Crystal melting Temperature (°C) |
| Low density polyethylene | 0.93-0.93 | Moderate | -120 | 110 |

2.2. Physical Properties Test

Soil physical properties tests namely specific gravity and sieve analysis tests were conducted at the early stage to determine the basic physical characteristics of the soil sample. The tests were conducted based on BS 1377:1990.

2.3. Compressibility Test (Standard Compaction Test)

Compressibility test was the primary test used to identify whether the waste plastic fiber can actually increase the mechanical strength of the sand or vice versa. The test was conducted following prescribed standard test [6]. This involved preparation of a control specimen without any additive added (0 % cement content and 0 % plastic fiber content) and three other specimens with different percentage of additive added to them (5 % cement content and 0 % plastic fiber content, 5 % cement content and 0.1% plastic fiber, and 5 % cement content and 0.5 % plastic fiber content). In preparation of the specimen,
the sand was first oven-dried and then divided into 4 to 6 distinct portions. Water was added in increment of 3 % to 5 % for each test cycle until the optimum moisture content which coincide with the point of maximum dry density has been clearly identified. Next, the sample was placed into the mold in 3 different lifts and each lift was compacted with 25 blows of standard hammer. The experiments were repeated until all of the intended specimens had undergone the testing process.

2.4. California Bearing Ratio (CBR) Test
Following the determination of the optimum moisture content from the compressibility test, specimens were further prepared with different waste plastic fiber-cement composition namely 0 % cement content and 0 % plastic fiber content (control specimen), 5 % cement content and 0 % plastic fiber content, 5 % cement content and 0.1 % plastic fiber, and 5 % cement content and 0.5 % plastic fiber content. The experiment was based on a prior research [6]. The CBR can be calculated based on load at 2.5 mm and 5 mm penetrations using the following standard formula:

\[
CBR = \frac{F_{\text{measured}}}{F_{\text{standard}}} \times 100\% \tag{2}
\]

The CBR value had been worked out from either standard penetration of 2.5 mm and 5.0 mm whichever greater.

3. Results and Discussion
3.1 Results from Physical Properties Test
The results for sieve analysis test are shown in Figure 4 below. From the analysis data, the sample of soil used is classified as well graded gravelly-SAND with coefficient of uniformity and curvature are 4.48 and 0.69 respectively. The specific Gravity test was conducted at least on three (3) times and the average of particle density of the soil is 2.61 m/m^3.

![Figure 4. Particle Size Distribution Result](image)

3.2 Effect of Waste Fiber on Compressibility Test (Standard Compaction Test)
The results of the compressibility tests performed on the prescribed four specimens is shown in Table 2. It shows that as the percentage of waste plastic fibres increased, the optimum moisture content, which is indicative of the maximum compaction level that the specimen can experienced under test condition, would also rise. This could be explained through further chemical reaction requiring moisture to produce inter-particle binding particularly involving increasing amount of plastic fiber particles. The exception
can found with the control specimen in which inter-particle binding must solely be achieved by the weaker sand material alone.

**Table 2. Variation of Maximum Dry Density and Optimum Moisture Content of Sample with Increasing Percentage of Plastic Fiber**

| % Of Plastic Fiber (pf) and % of Cement Content (cc) | Maximum Dry Density (g/cm³) | Optimum Moisture Content (%) |
|-----------------------------------------------------|-----------------------------|-----------------------------|
| 0.00% pf 0.00% cc                                  | 1.69                        | 14.50                       |
| 0.00% pf 5.00% cc                                 | 1.89                        | 11.98                       |
| 0.10% pf 5.00% cc                                 | 1.96                        | 12.39                       |
| 0.50% pf 5.00% cc                                 | 1.90                        | 13.50                       |

3.3 **Effect of Waste Plastic Fibre on CBR value**

Based on the result obtained from the laboratory tests, it can be deduced that the waste plastic fiber do provide positive impact to the mechanical strength of sand as indicated in Figure 5 for both soaked and un-soaked testing conditions. Furthermore, small percentage increment in waste plastic fiber would only increase the CBR value in the presence of a small amount of binding element namely cement at the optimum moisture content. However, further tests would need to be carried out to verify whether this trend would still hold true with further percentage increment in the waste plastic fiber. The control specimen indicates the weakest condition of all in which the strength must be achieved through the sand material alone.

![Figure 5. Graph of CBR Values vs Plastic Fiber Percentage](image)

(a) Unsoaked Condition  
(b) Soaked Condition

**4. Conclusion**

The research has proven that the waste plastic fiber and the sand mix in the presence of a small binding element namely cement at the optimum moisture content could help in further stabilizing and strengthening the sub-grade in the road construction works. Furthermore, the pitfall of having to deal with massive plastic bottle waste problems could be systematically addressed through innovative application in the engineering practices.
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