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CHARACTERISTIC PROPERTIES OF PLASTIC WASTES: POSSIBILITY OF REINFORCING MATERIAL FOR SOIL

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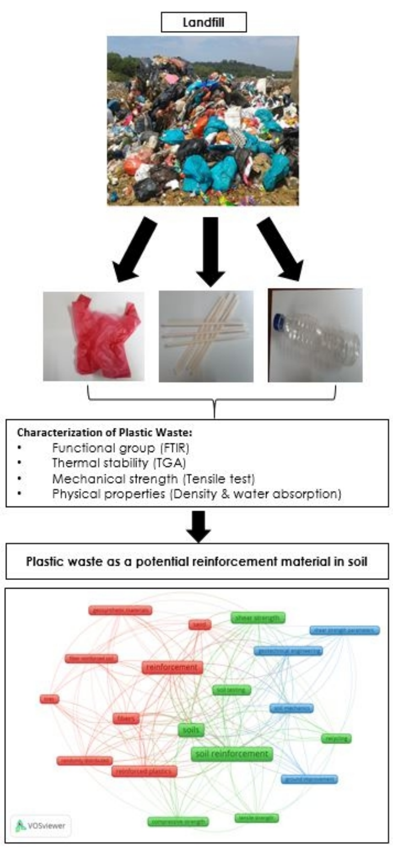
Graphical abstract



Abstract

The current statistic shows that the percentage of plastic has significantly increased in the landfill and leads to environmental issues due to its non-biodegradable characteristic. However, these challenges can be turned into opportunities by reusing and recycling such waste for civil engineering applications. Hence, the focuses of this paper are to analyze the possibility of utilizing plastic waste in the soil reinforcement field using VOSviewer software and to evaluate the chemical, thermal, physical and mechanical properties of the plastics (plastic straw, plastic bottle and plastic bag). The data for this study was collected from the articles published in Scopus. Nevertheless, there are very limited articles that relate soil reinforcement with thermal, chemical, physical and mechanical properties of plastic waste. Therefore, this paper aims to evaluate the properties of plastic waste, which were plastic bottle, plastic bag and plastic straw. The properties of plastic waste have been investigated to ensure it meets the requirement for soil reinforcement technology. The Fourier transform infrared (FTIR) spectra indicated the presence of carbon and hydrogen chains in those plastics waste. The plastic straw, plastic bag, and plastic bottle were degraded at 382°C, 456°C and 449°C, respectively. This finding indicated that all of these plastics waste were thermally stable in the tropical temperature. Moreover, the densities of the plastics waste were less than 1 g/cm^3, which contributes to the lightweight material and it's very crucial to eliminating the self-loading from the reinforcement material. The tensile strengths of the plastic straw and plastic bottle were 0.02 GPa and 2.22 GPa, respectively. The outstanding properties of these plastic wastes can provide manifold benefits in the geotechnical engineering application.

Keywords: Plastic waste, physical properties, mechanical properties, soil reinforcement, science mapping

Abstrak

Kebelakangan ini, jumlah statistik menunjukkan peningkatan kuantiti plastik di tapak pelupusan dan menyebabkan pencemaran alam sekitar kerana ciri-cirinya yang bukan biodegradasi. Walaubagaimanapun, cabaran-cabaran ini boleh dijadikan peluang dengan menggunakan dan mengitar semula sisa-sisa itu untuk aplikasi kejuruteraan awam. Oleh itu, fokus artikel ini adalah untuk menganalisis kebarangkalian penggunaan plastik dalam bidang pengukuhan tanah dengan menggunakan VOSviewer dan menilai sifat kimia, terma, fizikal dan mekanikal plastik (plastik straw, botol plastik dan beg plastik). Data untuk kajian ini dikumpulkan dari artikel yang diterbitkan dalam Scopus. Walaubagaimanapun artikel yang menghubungkan tentang kekuatan tanah dengan sifat termal, kimia, fizikal dan mekanikal sisa plastik adalah sangat terhad. Oleh itu, artikel ini bertujuan menilai sifat-sifat sisa plastik seperti botol plastik, beg plastik dan penyedut minuman plastik. Sifat-sifat sisa plastik telah disiasat untuk memastikan ia memenuhi keperluan untuk teknologi pengukuhan tanah. Spektroskopi inframerah transformasi Fourier (FTIR) menunjukkan kehadiran rantai karbon dan hidrogen dalam sisa plastik tersebut. Penyedut minuman plastik, beg plastik, dan botol plastik telah mula degradasi pada 382 ° C, 456 ° C dan 449 ° C. Keputusan ini menunjukkan bahawa semua sisa plastik ini stabil pada suhu tropika. Selain itu, ketumpatan sisa plastik kurang daripada 1 g/cm^3 telah menyumbang kepada bahan ringan dan sangat penting untuk menghapuskan beban diri dari bahan pengukuhan. Kekuatan tegangan penyedut minuman plastik dan botol plastik masing-masing adalah 0.02 GPa dan 2.22 GPa. Ciri-ciri sisa plastik ini dapat memberikan manfaat yang banyak dalam aplikasi kejuruteraan geoteknik.

1.0 INTRODUCTION

Plastics are mainly derived from petrochemical with a long chain of carbon and hydrogen [1, 2]. These plastics are categorized into two groups, namely thermoplastics and thermosets. Thermoplastics such as polyamide (PA), polyethylene (PE), polyethylene terephthalates (PETE), polypropylene (PP) and polyvinyl chloride (PVC) can be processed, melted and molded above a specific temperature and solidifies upon cooling [3]. In contrast with thermosets (epoxy, polyesters (PS), and polyurethane (PU)), the thermal and mechanical properties are more stable and unable to be remolded due to their permanent network structure [4]. Unfortunately, most of these fossil-based plastics are non-biodegradable and have been accumulated at the landfill [5].

The consumption of plastic around the world has been dramatically increased from approximately 1.5 million in 1950 to 322 million in 2015. Such waste will end at the landfill or illegally dumped at open dumpsites such as river and roadside. Solid Waste and Public Cleansing Management Corporation (SWCorp) reported that the plastic waste was the second largest household waste generated in Malaysia constitutes 14%, which generating 3,087765 tons of plastic waste per year [6]. Table 1 represents the plastic waste generation in Malaysia for 2015. Malaysia will be facing an enormous challenge of space limitation, environmental problem and health issue if the generation of plastic wastes were not at a manageable level.

Table 1 Generation of plastic waste per year in Malaysia for 2015 [6]

Type of plastic waste	Waste generation (ton/year)
Polyethylene (PE)	985,000
Polypropylene (PP)	450,000
Polyvinyl Chloride (PVC)	350,000
Polystyrene (PS)	215,000
Polyethylene terephthalates (PETE)	178,000

Based on Table 1, PE has the highest generation of waste per year, followed by PP, PVC, PS and PETE. In recent years, these types of plastics are widely used in packaging materials, agriculture, safety equipment, construction and automotive industry [7]. Nevertheless, the explosive growth of plastic waste generation leads to serious environmental issues, such as soil contamination at the landfill [8] and marine pollution [9]. Moreover, scholars have found that the microplastic debris has caused an increase of environmental issues [10]. Microplastic debris with particle size less than 5 mm was formed from the ultraviolet radiation of macroplastics at the landfill [11].

Small particles of microplastic debris made it easy to absorb into the soil by chemical or physical processes [9]. When it achieved the saturated level, the microplastic will be transported easily to the marine ecosystems, and it will pose a threat to ecosystems [13, 14]. These findings have shown that the dumping of plastic waste into the landfill has caused multiple problems.

Consequently, the awareness regarding the 3Rs (Reduce, Reuse, Recycle) initiative should be promoted and advocated to the consumers and manufactures to ensure the generation of plastic waste at a manageable level [15]. Through this practice, the amount of waste material dumped into the landfill can be diminished and the amount of carbon emission generated from the production of virgin plastic can be reduced. The term 'Reduce' seems impossible to be enforced due to the extensive use of plastics as our daily necessities. Meanwhile, the term 'reuse' was only reliable for certain type of plastic, since the reuse of plastic can release the hazardous chemical [16]. The recycle of plastic waste is emerging as a new alternative which has gained interest in sustainable construction material in the construction industry in the past few years.

Recently, plastic waste also widely used in the soil reinforcement technology due to their excellent performance, which are durable, lightweight and chemical resistant [17]. Soil reinforcement material should have a stable chemical, thermal and physical properties in order to increase the life span and serviceability of reinforced soil. On the hand, the reinforcement material needs to have an adequate strength in order to withstand the stress from the loading [18]. Thus, this paper aims to analyze the potential of utilizing plastic waste in soil reinforcement technology and to evaluate the chemical, thermal, physical and mechanical properties of the plastics (plastic straw, plastic bottle and plastic bag) that are commonly used in our daily life.

2.0 METHODOLOGY

2.1 Analyze the Possibilities of Plastic Waste as Soil Reinforcement Material through Science Mapping

The general workflow in a science mapping analysis has various steps: data retrieval, processing, mapping, visualization and analysis. The data was retrieved from Elsevier Scopus database from 2009 to 2020. For searching the articles published related to the plastic waste as soil reinforcement material, the keywords of "plastic waste" or "soil reinforcement" or "waste management" are used in the "title' tab of the Scopus website. Finally, the VOSviewer software processed the Scopus selection of publication data. The purpose of this analysis is to evaluate the possibilities of plastic waste as soil reinforcement and to analyze the current trend of soil reinforcement technology.

2.2 Material

Three different plastic wastes which were plastic bag, plastic bottle and plastic straw were characterized as shown in Figure 1(a) to 1(c). The chemical properties of samples were evaluated using Fourier transform infrared (FTIR) spectroscopy. The thermal stability of these plastics was investigated using thermogravimetry analysis (TGA). Meanwhile, the physical properties were determined using Archimedes method and percentage of water absorption. Finally, the strength performance of plastic waste was evaluated via tensile strength test.

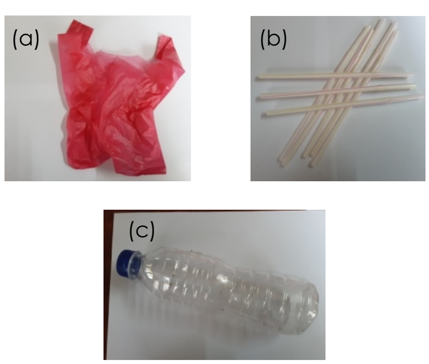


Figure 1 Plastic waste; (a) plastic bag, (b) plastic straw, (c) plastic bottle

2.3 Fourier Transform Infrared (FTIR) Spectroscopy

The FTIR test was carried out as accordance to ASTM E1252-98 (Reapproved 2013): Standard Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis. This method is widely used to determine the functional group of organic and inorganic material. The finely chopped waste synthetic polymers were scanned 16 times at the wavenumbers ranging from 4000 to 600 cm^{-1}.

2.4 Thermogravimetric Analysis (TGA)

The TGA was conducted as accordance to the ASTM E2550-17: Standard Test Method for Thermal Stability by Thermogravimetry. In addition, the difference thermogravimetric (DTG) curve can determine the thermal degradation stages. Samples of 5 g from each waste were analyzed in nitrogen atmosphere at temperature range between 30°C to 500°C. The heating rate was 10°C/min.

2.5 Specific Gravity and Density

The specific gravity and density of plastic waste were measured by following the ASTM D792-13: Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement. This method is widely used to determine the specific gravity of sheets, rods, tubes or molded samples. Firstly, the samples were cut into 10 mm (length) and 10 mm (width) with at least 1 g of weight. The specific gravity of samples was calculated by using the formula in Equation 1.

$$\text{Specific gravity} = a/b \tag{1}$$

Where:
a = Mass of sample in air, g
b = Mass of sample during immersion in water, g

2.6 Water Absorption

The water absorption of waste synthetic polymers was carried out by following the ASTM D50-98: Standard Test Method for Water Absorption of Plastics. This test was suitable with all types of plastics with at least 0.13 mm in thickness. The percentage of water absorption was calculated using Equation 2.

$$\text{Water absorption (\%)} = (M_w - M_d)/M_d \tag{2}$$

Where:
M_d = Mass of dried sample, g
M_w = Mass of sample after immersion in water, g

2.7 Tensile Properties

The tensile properties of the materials, such as ultimate tensile stress and modulus of elasticity, were evaluated using Lloyd Model LR30K Tensile tester. The tensile test was conducted as accordance to the ASTM D882. The plastic straw with the dimension of 10 mm (width) x 100 mm (length) x 0.2 mm (thickness) was prepared for this test. The test length and strain rate were maintained at 50 mm and 20 mm/min.

3.0 RESULTS AND DISCUSSION

3.1 The Potential of Utilizing Plastic Waste as Soil Reinforcement Material by Science Mapping

Interactive version of the map visualization is illustrated in Figure 2. To create this visualization, tittles and abstracts of 130 publications regarding soil reinforcement using waste synthetic polymers or also known as plastic waste were analyzed. For each publication, the terms existed in the tittle, abstract, index keywords and year of publications were identified. Each term was represented by a circle. The size of the circle reflects the number of publications. Meanwhile, the distance between the two terms offers an approximate indication of the relatedness of the terms. On the other hand, colors represent groups of terms that are strongly related to each other. In the visualization, the strongest relations between terms are also indicated using curve lines [19].

There are five clusters revealed through the co-occurrence analysis of the plastic waste in soil improvement, namely soil reinforcement (cluster 1), recycling (cluster 2), geosynthetic materials (cluster 3), geotechnical engineering (cluster 4) and shear strength (cluster 5). The most dominant cluster in the field of soil improvement using plastic waste was soil reinforcement. Soil reinforcement (cluster 1) method mainly utilizes a synthetic and non-synthetic material, such as natural fiber and plastics, respectively.

As a result, scholars have developed the geosynthetic materials (cluster 3) from the plastic waste in order to increase the recycling (cluster 2) rate. Nevertheless, the circle regarding the plastic waste as soil reinforcement material was small which indicated that the number of publications was lower. Table 2 shows the list of literature for reinforced soil with plastic waste from 2015 to 2020. Most of the papers were retrieved from Taylor and Francis, Elsevier and Springer publisher. It can be seen that the geotextiles and geomembranes, geotechnical and geological engineering and sustainable civil infrastructures were the most journals that issued the articles regarding the reinforcement of soil by using plastic waste.

Based on the articles in Table 2, there were quantum factors that need to be justified in the development of reinforcement material for the geotechnical engineering applications (cluster 4). Scholars have been extensively investigated the dependent variables (length, ratio and surface roughness) of plastics waste as a reinforcement material in the soil. Then, the feasibility of plastic waste as reinforcement materials have been widely evaluated using unconfined compressive strength (UCS), California bearing ratio (CBR) and shear strength (cluster 5). They have found that the utilization of plastic waste has significantly increased the strength and stiffness of soil.

Therefore, there are ample chances of using plastic waste for soil reinforcement material. However, the publications regarding the characterization of plastic waste in soil reinforcement field were very limited. Some scholar mainly focused on the mechanical properties of the plastic waste instead of other properties, such as chemical, thermal and physical properties. In addition, to ensure that the plastic is appropriate to be used for soil condition, the thermal properties of the plastic waste must be investigated.

Moreover, the specific gravity and density of the plastic waste need to be evaluated in order to ensure the material are lightweight. Vaslestad *et al.* [20] found that the insertion of lightweight fill material will not give stress to the soil. It can be deduced that the plastic waste has viability as a reinforcement material in soil reinforcement technology.

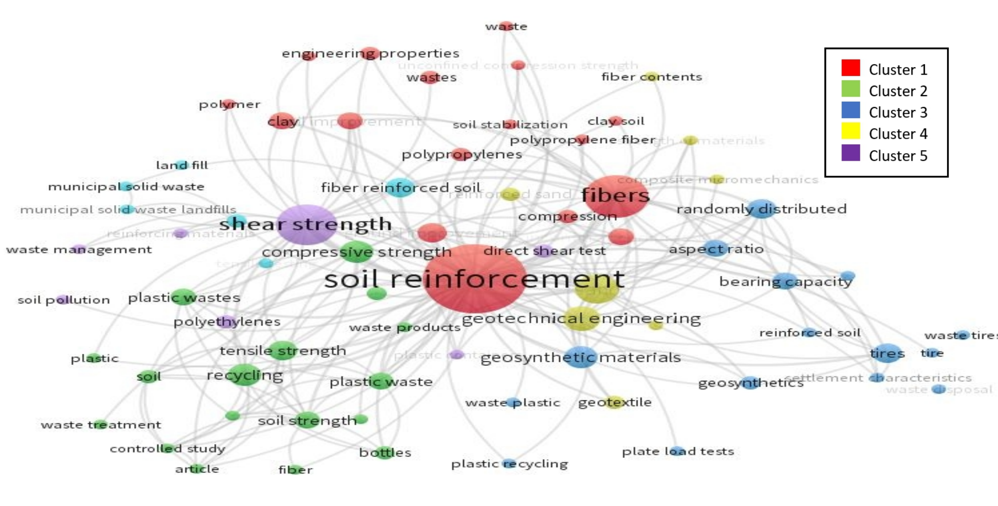


Figure 2 Knowledge map based on index keywords from Elsevier Scopus from 2009 to 2020

Table 2 List of literature for soil reinforced with plastic waste

No.	Publisher	Journal Name	Title	Plastic code	Reinforcement material form	Size (mm)	Ratio (%)	Comment	References
1.	Springer	Advances in Sustainable Construction Materials and Geotechnical Engineering	Improving the Soil Subgrade with Plastic Waste Reinforcement—An Experimental Study	PET	Geogrid	-	-	The reused of geogrid from waste plastic bottle has increased the CBR strength of subgrade soil up to 10 %. The structure of the geogrid provides a confinement to the soil.	[21]
2.	Taylor & Francis	Geomechanics and Geoengineering	Soil reinforcement and slope stabilization using recycled waste plastic sheets	PET	Geosynthetic	-	-		[22]
3.	Springer International Publishing	Geotechnical and Geological Engineering	Experimental Study on Effect of Waste Plastic Bottle Strips in Soil Improvement	PET	Strip	15	0.2, 0.4, 0.6, 0.8	The mixing of waste plastic strips in the soil has improved both shear strength and CBR strength of soil. The rough surface of plastic strip has increased the cohesion and internal friction of soil. Meanwhile, the index properties of soil would be different if the type of plastic is different.	[23]
4.	Springer Nature Switzerland	Sustainable Civil Infrastructures	Soil Reinforcement Using Recycled Plastic Waste for Sustainable Pavements	PET	Strip	25	0.20, 0.40, 0.60, 0.80, 1.00, 1.20		[24]
5.	American Society for Civil Engineer	Paving Materials and Pavement Analysis	Utilization of Plastic Wastes for Improving the Sub-grades in Flexible Pavements	HDPE	Strip	12	0.25, 0.5, 1.0, 2.0 and 4.0		[25]
6.	Elsevier	Geotextiles and Geomembranes	Swell–compression characteristics of a fiber–reinforced expansive soil	PP	Fiber	15	0.0, o.5, 1.0 and 1.5	Soil reinforced with fiber presented the ductile behavior to the soil due to the interlocking of fibre between the soil.	[26]
7.	Taylor & Francis	Road Materials and Pavement Design	The strength behavior of lime-stabilized plastic fiber-reinforced clayey soil	PE	Fiber	15	0.0, 0.5, 1.0, 1.5 and 2.0		[27]
8.	Elsevier	Geotextiles and Geomembranes	Stress–strain behavior of a silty soil reinforced with polyethylene terephthalate (PET)	PET	Fiber	50	0.0, 0.1, 0.3, 0.6 and 1.0		[28]

3.2 Fourier Transform Infrared (FTIR) Spectroscopy

FTIR was performed to analyze the functional groups of plastic straw, plastic bag and plastic bottle. Figure 3 displays the FTIR spectra for plastic straw, plastic bags and plastic bottles. The FTIR spectra of these plastics waste showed various peaks between 500 to 4000 cm^{-1} wavenumbers. The FTIR spectrum for each plastic waste differed from one to another. This finding revealed that all the plastic wastes were not from the similar plastic code.

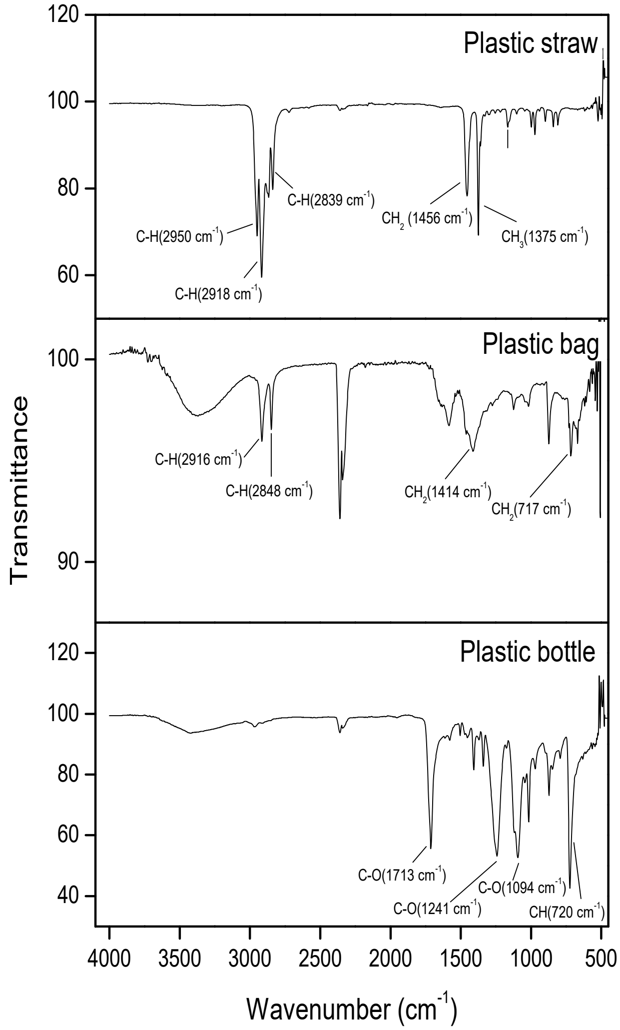


Figure 3 FTIR spectra of plastic straw, plastic bag and plastic bottle

The absorption peaks of plastic straw were apparently observed at 2950 to 2839 cm^{-1}. At this range, the absorption peak was attributed to the carbon-hydrogen (C-H) stretch vibration of alkene group. The intensity for the absorption bands at 2950 cm^{-1}, 2918 cm^{-1} and 2839 cm^{-1} were medium sharp, strong sharp and small sharp, respectively. The absorption peaks found at 1454 cm^{-1} and 1375 cm^{-1} were assigned to the -CH_2 and -CH_3 bending vibration. The intensity for peak observed at 1454 cm^{-1} and 1375 cm^{-1} were medium sharp and strong sharp, respectively. The FTIR spectrum for plastic straw is similar to that of virgin polypropylene [2].

Small intensity of C-H stretch vibration at 2916 cm^{-1} and 2848 cm^{-1} peaks was clearly observed for plastic bag sample. The small sharp peak intensity of C-H stretch was corresponded to alkene group. Then, CH_2 stretch vibrations were observed at 1414 cm^{-1} and 717 cm^{-1}. Moez *et al.* [29] claimed that the FTIR spectrum for LDPE was similar to that of plastic bag.

The absorption peaks of plastic bottle were observed in the range of 1713 cm^{-1} to 720 cm^{-1}. Four main peaks were determined at 1713, 1241, 1094 and 720 cm^{-1}. The carbon-oxygen (C = O) stretch vibration with strong sharp intensity was observed at 1713 cm^{-1} and corresponded to the ketone group. The strong sharp intensity of C-O stretch vibration was found at the wavenumber of 1241 and 1094 cm^{-1}. Then, the strong sharp peak of C-H rocking vibration was observed at 720 cm^{-1} wavenumber. The FTIR spectrum of plastic bottle was similar to FTIR spectrum of PET. Loakemidis *et al.* [30] also claimed that the peak observed in PET plastic was in the range of 1715 to 730 cm^{-1}.

Table 3 presents the comparison of IR spectra of plastic straw, plastic bag and plastic bottle. The presence of these chemical compounds proved that the plastic straw, plastic bag and plastic bottle contained hydrocarbon compound. Researchers have suggested that incineration or thermal recycling of hydrocarbon compound can be used as energy generation [31]. Furthermore, the presence of carbon in plastic can be used to synthesize carbon nanotube. However, the incineration of hydrocarbon compound could lead to environmental issues due to the formation of dioxins and furans [32]. Therefore, this study is carried out to reuse plastic waste in engineering application.

Table 3 Comparison of IR spectra of plastic straw, plastic bag and plastic bottle

Plastic waste	Absorption bands (cm^{-1})	Assignment	Intensity
Plastic straw	2950	C-H stretch	Medium
	2918	C-H stretch	Strong
	2839	C-H stretch	Small
	1456	CH_2 bend	Medium
	1375	CH_3 bend	Strong
Plastic bag	2916	C-H stretch	Small
	2848	C-H stretch	Small
	1414	CH_2 bend	Small
	717	CH_2 rock	Small
Plastic bottle	1713	C = O stretch	Strong
	1241	C-O stretch	Strong
	1094	C-O stretch	Strong
	720	C-H rock	Strong

Note: C(Carbon), H(Hydrogen), O(Oxygen)

3.3 Thermogravimetric Analysis

The TGA study was conducted to evaluate the thermal properties of plastic waste such as thermal degradation temperature, maximum decomposition temperature and thermal stability. Plastic straw, plastic bag and plastic bottle have single step of mass loss. Based on the thermogram, no weight loss was observed at temperature below 250°C. The derivative weight loss (DTG) curve to indicates the most apparent point of weight loss. Figure 1, Figure 2 and Figure 3 present the TGA/DTG curve for plastic straw, plastic bag and plastic bottle, respectively.

Figure 4 displays the TGA/DTG curve for plastic straw. The degradation temperature of plastic straw started at 298°C. The maximum decomposition temperature occurred at 365°C. The maximum mass loss can be seen at the DTG curve, where the temperature was 382°C. The percentage of weight loss for plastic straw was 100 %, no residue or char left after the decomposition process. This could be due to the conversion of hydrocarbon into gaseous products after the temperature surpassed 382°C. This finding showed similar trend with the TGA/DTG curve of virgin PP [33].

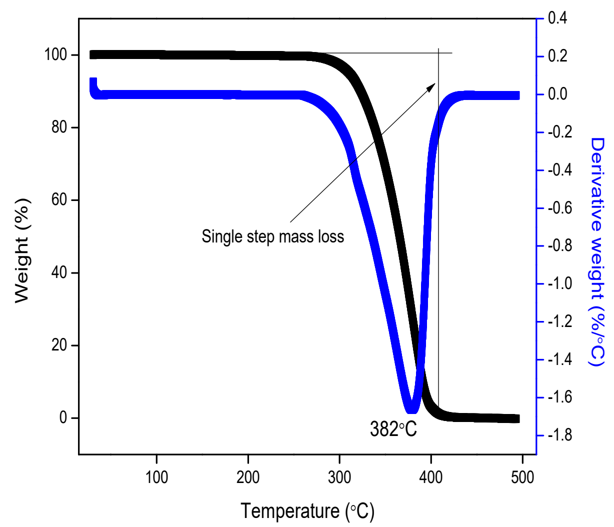


Figure 4 TGA/DTG curve for plastic straw

The TGA/DTG curve for plastic bag is shown in Figure 5. The degradation temperature for plastic bag started at 415°C. At 460°C, the weight loss temperature ($T_{50\%}$) was 50 % observed. The maximum temperature of weight loss was 456°C as shown in the DTG curve and the percentage of weight loss was 68.06%. Mubarak and Abdulsamad [34] reported that the LDPE weight loss was due to the thermal degradation of PE backbone. Based on Figure 5, the LDPE can be categorized as a material that degrades faster at the temperature range between 415°C to 456°C.

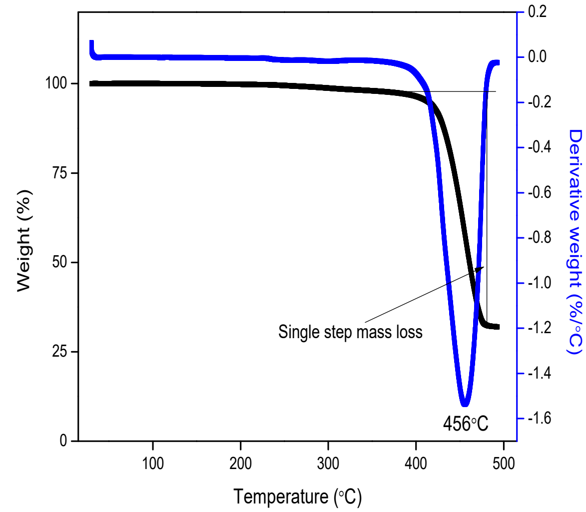


Figure 5 TGA/DTG curve for plastic bag

The TGA/DTG curve for plastic bottle is shown in Figure 6. The degradation temperature began at 372°C and ended at 449°C. The maximum temperature of weight loss was 456°C as shown in the DTG curve and the percentage of weight loss was 86.71% due to the thermal degradation of PET backbone. This finding is in agreement with that of reported by [35].

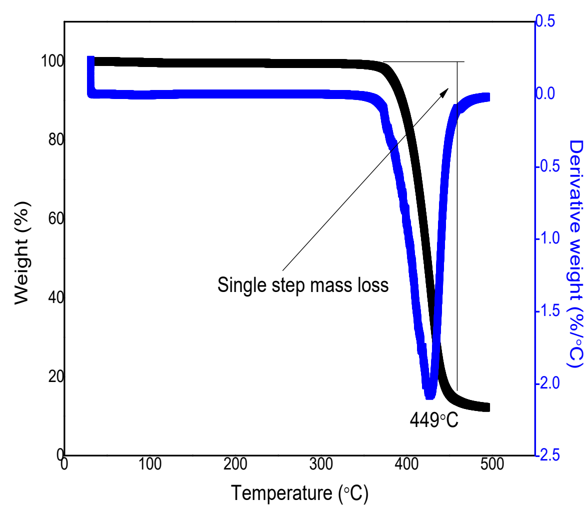


Figure 6 TGA/DTG for plastic bottle

Table 4 presents the comparison of thermal stability for plastic straw, plastic bag and plastic bottle. The plastic bag has higher thermal stability compared to the plastic straw and plastic bottle as the temperature started at 415°C. On the other hand, the weight loss for plastic bag was lower compared to the plastic straw and plastic bottle. In contrast with plastic straw, there was no residue left after the decomposition process.

This finding indicated that the plastic bag and plastic bottle were not suitable to undergo an incineration process. Plastic straw has shown its suitability for remolding since the maximum decomposition temperature was lower compared to other plastic waste. In geotechnical perspective, plastic straw is very suitable to be used as reinforcement material due to the tropical temperature in Malaysia was around 30 to 50°C.

Table 4 Comparison of thermal stability for plastic waste

Type of plastic	Code	Degradation Temperature range (°C)	T_d (°C)	$T_{50\%}$ (°C)	Weight loss (%)
Plastic straw	PP	298 – 382	298	365	100.00
Plastic bag	LDPE	415 – 45 6	415	460	68.06
Plastic bottle	PETE	372 – 449	372	423	86.71

Note: T_d (Onset temperature), $T_{50\%}$ (Maximum decomposition temperature)

3.4 Physical Properties

The densities of plastic straw, plastic bag and plastic bottle were lower than the density of water. The density was 0.72, 0.40 and 0.80 g/cm^3 for plastic straw, plastic bag and plastic bottle, respectively. Meanwhile, the percentage of water absorption of these plastic wastes was 0% because of their hydrophobic properties. The hydrophobic behavior of plastic makes it very compatible for application in geotechnical engineering because it can prevent moisture from soil to seeping through the soil structures [36].

Plastic wastes with lower density can be used to develop a lightweight reinforcement material for geotechnical application. The reinforcement of weak soil using lightweight materials will increase the strength of soil and reduce the differential settlement because lightweight materials will not generate stress to the soil [37, 38]. Moreover, the reinforcement material developed using these plastic wastes will not easily degrade in the soil because of its hydrophobic properties. Table 5 shows the physical properties of plastic waste.

Table 5 Comparison of physical properties of plastic waste

Type of plastics	Code	Density	Water absorption (%)
Plastic straw	PP	0.72	0
Plastic bag	LDPE	0.40	0
Plastic bottle	PETE	0.80	0

3.5 Mechanical Properties

Table 6 shows the tensile strength for plastic straw and plastic bottle. However, the tensile strength for plastic bag was not evaluated because the value cannot be obtained due to its lower strength. Based on the table, the tensile strength and Young modulus of plastic straw was lower compared to the plastic bottle. The tensile strength of plastic straw and plastic bottle were 0.02 GPa and 2.22 GPa, respectively.

The Young modulus of materials would increase with the increase of tensile strength. However, the percentage of elongation at break of plastic straw (369.42 %) was higher compared to the plastic bottle (37.29 %). This result showed that plastic straw was more ductile compared to the plastic bottle. Thus, the plastic bottle is easier to rupture than plastic straw. Moreover, researchers have found that the reinforcement of high ductility or stiffness of reinforcement material can increase the bearing ratio of soil [39].

Table 6 Comparison of mechanical properties of plastic waste

Type of plastics	Code	Tensile strength (GPa)	Young modulus (GPa)	Elongation at break (%)
Plastic straw	PP	0.02	0.78	369.42
Plastic bag	LDPE		Negligible	
Plastic bottle	PETE	2.22	149.18	37.29

4.0 CONCLUSION

This paper intends to contribute to the understanding of chemical, thermal, physical and mechanical properties of plastics waste such as plastic straw, plastic bag and plastic bottle. Such kind of plastics have been used widely in everyday life. The possibility of utilizing plastics as soil reinforcement material was revealed using science mapping from 2000 to 2020. Scholars have shown their interest in utilizing plastic waste as reinforcement material and PP fiber and PET bottle widely used today. However, the article published regarding the fabrication of geosynthetic material using waste material was very limited. Virgin plastic is normally used to fabricate the geosynthetic material which can increase the generation of plastic and carbon emission. Thus, this study presents the characterization of three types of plastic wastes in order to determine whether it could be reused in soil reinforcement purpose.

The plastic straw, plastic bag and plastic bottle were categorized as PP, LDPE and PET based on their functional groups and thermal stability. The functional groups and thermal stability were found to be similar to that of virgin plastics. The tensile strength and Young modulus of PET was higher compared to PP. However, the percentage of elongation at break for PP was higher compared to the plastic bottle. Therefore, plastic with high elongation is suitable for geotechnical use, since it can withstand stress without rupture. It can be concluded that the plastic straw was more ductile compared to plastic bottle. Since the properties of plastic straw or PP provided promising results as reinforcement material, these plastic wastes can be considered as potential material for soil reinforcement.

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References

[1] Hopewell, J., Dvorak, R., & Kosior, E. 2009. Plastics Recycling: Challenges and Opportunities. *Journal of Philosophical Transactions of the Royal Society B: Biological Sciences.* 364(1526): 2115-2126.

[2] Jung, M. R., Horgen, F. D., Orski, S. V., Rodriguez, V., Beers, K. L., Balazs, G. H., Jones, T. T., Work, T. M., Brignac, K. C., Royer, S. J., Hyrenbach, K. D., Jensen, B. A., & Lynch, J. M. 2018. Validation of ATR FT-IR To Identify Polymers of Plastic Marine Debris, Including Those Ingested by Marine Organisms. *Journal of Marine Pollution Bulletin*. 127: 704-716.

[3] Kumar, R., Bhargav, C., & Bhowmik, S. 2018, August. Bamboo Fibre Reinforced Thermoset and Thermoplastic Polymer Composites: A Short Review. *AIP Conference Proceeding*. 020018: 1-3.

[4] Scheutz, G. M., Lessard, J. J., Sims, M. B., & Sumerlin, B. S. 2019. Adaptable Crosslinks in Polymeric Materials: Resolving the Intersection of Thermoplastics and Thermosets. *Journal of the American Chemical Society*. 141(41): 16181-16196.

[5] Ahmed, T., Shahid, M., Azeem, F., Rasul, I., Shah, A. A., Noman, M., Hameed, A., Manzoor, N., Manzoor, I & Muhammad, S. 2018. Biodegradation of Plastics: Current Scenario and Future Prospects for Environmental Safety. *Journal of Environmental Science and Pollution Research*. 25(8): 7287-7298.

[6] Solid Waste and Public Cleansing (SWCorp) Malaysia Final Solid Waste Management Report 2015.

[7] Subramanian, P. M. 2000. Plastics Recycling and Waste Management in the US. *Journal of Resources, Conservation and Recycling*. 28(3-4): 253-263.

[8] Ng, W., Minasny, B., & McBratney, A. 2020. Convolutional Neural Network for Soil Microplastic Contamination Screening Using Infrared Spectroscopy. *Journal of Science of The Total Environment*. 702: 134723.

[9] Gambardella, C., Piazza, V., Albentosa, M., Bebianno, M. J., Cardoso, C., Faimali, M., Garaventa, F., Gonzalez, S., Perez, S., Sendra, M., & Beiras, R. 2019. Microplastics Do Not Affect Standard Ecotoxicological Endpoints in Marine Unicellular Organisms. *Journal Marine* Pollution Bulletin. 143: 140-143.

[10] Lahtela, V., Hyvärinen, M., & Kärki, T. 2019. Composition of Plastic Fractions in Waste Streams: Toward More Efficient Recycling and Utilization. *Journal of Polymers*. 11(69): 1-7.

[11] Free, C. M., Jensen, O. P., Mason, S. A., Eriksen, M., Williamson, N. J., & Boldgiv, B. 2014. High-Levels of Microplastic Pollution in a Large, Remote, Mountain Lake. *Journal of Marine Pollution Bulletin*. 85(1): 156-163.

[12] Chae, Y., & An, Y. J. 2018. Current Research Trends on Plastic Pollution and Ecological Impacts on the Soil Ecosystem: A review. *Journal of Environmental Pollution*. 240: 387-395.

[13] Zhang, W., Zhang, S., Wang, J., Wang, Y., Mu, J., Wang, P., Lin, X., & Ma, D. 2017. Microplastic Pollution in the Surface Waters of the Bohai Sea, China. *Journal of Environmental Pollution*. 231: 541-548.

[14] Scheurer, M., & Bigalke, M. 2018. Microplastics in Swiss Floodplain Soils. *Journal of Environmental Science & Technology*. 52(6): 3591-3598.

[15] Moh, Y. 2017. Solid Waste Management Transformation and Future Challenges of Source Separation and Recycling Practice in Malaysia. *Journal of Resources, Conservation and Recycling*. 116: 1-14.

[16] Schmid, P., Kohler, M., Meierhofer, R., Luzi, S., & Wegelin, M. 2008. Does the Reuse of PET Bottles during Solar Water Disinfection Pose a Health Risk Due to the Migration of Plasticizers and Other Chemicals into the Water? *Journal of Water Research*. 42(20): 5054-5060.

[17] Hejazi, S. M., Sheikhzadeh, M., Abtahi, S. M., & Zadhoush, A. 2012. A Simple Review of Soil Reinforcement by Using Natural and Synthetic Fibers. *Journal of* Construction *and Building Materials*. 30: 100-116.

[18] Moghal, A. A. B., Chittoori, B. C., & Basha, B. M. 2018. Effect of Fibre Reinforcement on CBR Behavior of Lime-Blended Expansive Soils: Reliability Approach. *Journal of* Road *Materials and Pavement Design. 19*(3): 690-709.

[19] Van Eck, N. J., & Waltman, L. 2017. Citation-based Clustering of Publications using CitNetExplorer and VOSviewer. *Journal of Scientometrics*. 111(2): 1053-1070.

[20] Vaslestad, J., Bartlett, S. F., Aabøe, R., Burkart, H., Ahmed, T., & Arellano, D. 2019. Bridge Foundations Supported by EPS Geofoam Embankments on Soft Soil. *Geofoam Blocks in Construction Applications Conference 2018.* Kyrenia, Northern Cyprus. 9-11 May 2018. 281-294.

[21] Shah, A., & Modha, H. 2020. Improving the Soil Subgrade with Plastic Waste Reinforcement—An Experimental Study. *Journal Advances in Sustainable Construction Materials and Geotechnical Engineering*. 35: 153-161.

[22] Salimi, K., & Ghazavi, M. 2019. Soil Reinforcement and Slope Stabilization Using Recycled Waste Plastic Sheets. *Journal of Geomechanics and Geoengineering*. 1-12.

[23] Peddaiah, S., Burman, A., & Sreedeep, S. 2018. Experimental Study on Effect of Waste Plastic Bottle Strips in Soil Improvement. *Journal of Geotechnical and Geological Engineering*. 36(5): 2907-2920.

[24] Hafez, M., Mousa, R., Awed, A., & El-Badawy, S. 2018. Soil Reinforcement Using Recycled Plastic Waste for Sustainable Pavements. *Journal of Sustainable Civil Infrastructures*. 7-20.

[25] Choudhary, A. K., Jha, J. N., & Gill, K. S. 2010. Utilization of Plastic Wastes for Improving the Sub-Grades in Flexible Pavements. *Journal of Paving Materials and Pavement Analysis*. 320-326.

[26] Soltani, A., Deng, A., & Taheri, A. 2018. Swell–Compression Characteristics of a Fiber–Reinforced Expansive Soil. *Journal of Geotextiles and Geomembranes*. 46(2): 183-189.

[27] Dhar, S., & Hussain, M. 2019. The Strength Behavior of Lime-Stabilized Plastic Fiber-Reinforced Clayey Soil. *Journal of Road Materials and Pavement Design*. 20(8): 1757-1778.

[28] Botero, E., Ossa, A., Sherwell, G., & Ovando-Shelley, E. 2015. Stress–Strain Behaviour of a Silty Soil Reinforced with Polyethylene Terephthalate (PET). *Journal of Geotextiles and Geomembranes.* 43(4): 363-369.

[29] Moez, A. A., Aly, S. S., & Elshaer, Y. H. 2012. Effect of Gamma Radiation on Low Density Polyethylene (LDPE)

Films: Optical, Dielectric and FTIR Studies. *Journal of Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 93: 203-207.

[30] Ioakeimidis, C., Fotopoulou, K. N., Karapanagioti, H. K., Geraga, M., Zeri, C., Papathanassiou, E., Galgani, F., & Papatheodorou, G. 2016. The Degradation Potential of PET Bottles in the Marine Environment: An ATR-FTIR based Approach. *Journal of Scientific Reports*. 6(1): 1-8.

[31] Kumar, S., Panda, A. K., & Singh, R. K. 2011. A Review on Tertary Recycling of High-Density Polyethylene to Fuel. *Journal of Resources, Conservation and Recycling*. 55(11): 893-910.

[32] Devasahayam, S., Raman, R. K., Chennakesavulu, K., & Bhattacharya, S. 2019. Plastics—Villain or Hero? Polymers and Recycled Polymers in Mineral and Metallurgical Processing—A Review. *Journal of Materials*. 12(4): 655.

[33] Jeske, H., Schirp, A., & Cornelius, F. 2012. Thermochimica Acta Development of a Thermogravimetric Analysis (TGA) Method for Quantitative Analysis of Wood Flour and Polypropylene in Wood Plastic Composites (WPC). *Journal of Thermochimica Acta*. 543: 165-171.

[34] Mubarak, Y. A., & Abdulsamad, R. T. 2019. Thermal Properties and Degradability of Low-Density Polyethylene Microcrystalline Cellulose Composites. *Journal of Thermoplastic Composite Materials*. 32(4): 487-500.

[35] Todica, M., Kovacs-Krauss, Z., Niculaescu, C., & Mureşan-Pop, M. 2019. XRD Investigation of Thermal Degradation of Some Gamma-Irradiated Polyethylene Terephthalate Samples. *Journal of Modern Physics B*. 33(12): 1950111.

[36] Sabiri, N. E., Caylet, A., Montillet, A., Le Coq, L., & Durkheim, Y. 2017. Performance of Nonwoven Geotextiles on Soil Drainage and Filtration. *European Journal of Environmental and Civil Engineering*. 1-19.

[37] Puppala, A. J., Ruttanaporamakul, P., & Congress, S. S. C. 2019. Design and Construction of Lightweight EPS Geofoam Embedded Geomaterial Embankment System for Control of Settlements. *Journal of Geotextiles and Geomembranes*. 47(3): 295-305.

[38] Tanchaisawat, T., Bergado, D. T., Voottipruex, P., & Shehzad, K. 2010. Interaction Between Geogrid Reinforcement and Tire Chip–Sand Lightweight Backfills. *Journal of Geotextiles and Geomembranes*. *28*(1): 119-127.

[39] Singh, M., Trivedi, A., & Shukla, S. K. 2019. Strength Enhancement of The Subgrade Soil of Unpaved Road with Geosynthetic Reinforcement Layers. *Journal of Transportation Geotechnics*.19: 54-60.