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An Overview of Waste Materials for Sustainable Road Construction

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Abstract: Untreated soil typically has low shear strength, swelling behavior, high compressibility and its characteristics were highly dependent on the environment. In general, such problematic soil will lead to severe damages in road construction industry such as bearing capacity failure, slope instability, and excessive settlement. Agricultural waste, construction waste, and municipal waste have recently gained considerable attention as a sustainable material in road construction application due to its availability, environmental friendly and low-cost materials. Therefore in this review, randomly distributed fiber reinforced soil and oriented distributed fiber reinforced soil will be extensively discussed based on the emerging trend. It further reviewed the feasibility of using waste materials as a reinforcement material for the road construction industry. The review also attempts to evaluate and compare the engineering properties of soil and sustainable materials in order to enhance soil performance as well as help to improve the environment affected by growing waste materials.

Keywords: Engineering properties; soft soil; soil reinforcement; sustainable material

1. Introduction

Road construction was designed as accordance with the pavement system that was already well established since decades ago. However, each layer of pavement needs to be stabilized or improve in order to withstand a repeated or cyclic traffic loads that were tremendously increases day by day. The pavement system consists of surface layer (rigid slab), subbase layer (aggregate materials), and subgrade layer (existing soil) as illustrated in Figure 1(a) (Behiry, 2014; Saberian, Li, Nguyen & Wang, 2018). The pavement system must be able to withstand and absorb the stress that was produced from repeated traffic loads. Researchers have found that repeated traffic loading can cause the fine particles from subgrade layer migrate into the subbase layer, lead to the road settlement and be the reason of the bumpy road. Figure 1(b) shows the illustration of the migration of fine particles from the subgrade layer into the subbase layer (Kermani *et al.,* 2018).

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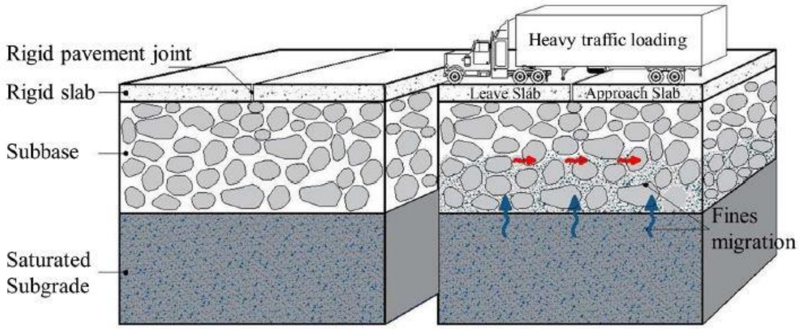


Fig. 1 - Pavement design (a) Pavement layer; (b) Fine particles migration from subgrade layer into subbase layer (Kermani *et al.*, 2018)

The characteristic of existing soil at the construction site is not always totally suitable in supporting structures especially when dealing with soft soil such as peat soil, clay soil and sandy soil. Such soils are problematic soil, with high moisture content, low bearing capacity, low shear strength, high compressibility and its characteristics are highly depend on the environment (Cai *et al.*, 2018) In the past few years, the construction activities under this kind of soil recorded a lot of geotechnical issues such as unsatisfactory bearing capacity, extra post construction settlement and instability. Zhu *et al.* (2019) claimed that the settlement of road was deflected from the construction of roads on the soft soil. Hayashi *et al.* (2016) and Wijeyesekera *et al.* (2016) also found that the road settlement failure was due to the construction on peaty soil. Figure 2 shows the example of roads failure on the peaty soil. Particularly, soft soil is not preferred as a foundation soil due to its limited geotechnical properties. However, the geotechnical proper-ties of the subgrade soil can be stabilized or improved by using various methods such as preloading, sand or stone column, pre-fabricated vertical drains, piles, fiber-reinforced and chemical stabilization.

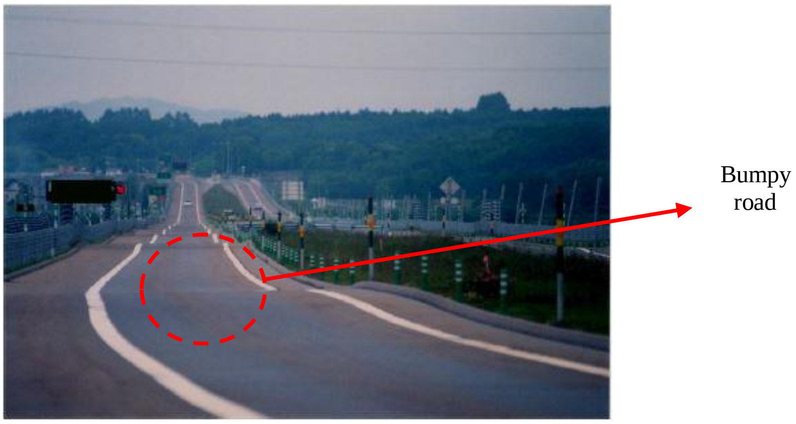


Fig. 2 - The road settlement failure due to the construction on peaty soil (Hayashi *et al.*, 2016)

Hejazi *et al.* (2012) summarized three different methods of soil reinforcement include of physical, chemical, and mechanical methods, as mentioned in Table 1. Based on Table 1, some methods may have drawbacks as they can contribute to the environmental issues. Moreover, the road construction by using physical method (vertical drain and piling) was very costly and can create noise. On the other hand, the steel mandrel and column that were used in the physical method were exposed to the corrosion and lead to the severe damage in the bridge construction (Giraldo & Rayhani, 2018). Besides, by using chemical methods, the additive materials such as lime, cement, and fly ash will lead to the ground contamination. The chemical reaction between the additive materials with soil can cause pollution and it will change the physical and mechanical properties of soil. For example, major chemical com-pound in lime is calcium carbonate ($CaCO_3$), where it can react with water and result in the formation of calcium hydroxide $Ca(OH)_2$. This situation has changed the geotechnical properties of soil. Thus, the mechanical method by using fiber reinforcement (randomly and oriented distributed fiber soil reinforcement) has shown the most promising method for the stabilization of soil. In contrast, by using the physical method, the durability of using synthetic and non-synthetic material were longer compared to the used of vertical drainage and piling techniques. In recent years, the consumption of various waste materials has been reported and highlighted by many researchers in improving the strength of soils (Xie *et al.*, 2016). At the same time, it also defined the sustainable development. Hence, this paper had outlined the current available literatures on the stabilization of soil by utilizing sustainable materials such as agricultural waste, construction waste, and municipal waste.

Agricultural waste such as rice husk ash, sugarcane bagasse ash, coconut fiber and palm fibers were widely used in geotechnical application due to its low-cost, lightweight and environmentally friendly (Hejazi *et al.,* 2012). On the other hand, the utilization of construction waste such as construction and demolition waste has helped to reduce the hazardous environment impacts of the waste and improve the geotechnical properties of soil. Lastly, using a municipal waste such as polymer is a versatile material because it is abundantly available all over the world. Reinforced technique applied to the soil by two methods which are randomly distributed fiber and oriented distributed fiber as noted in Table 1 were critically discussed in this paper.

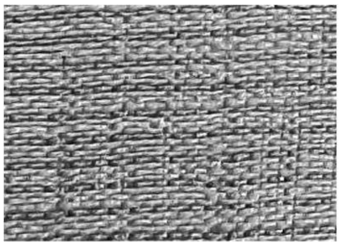
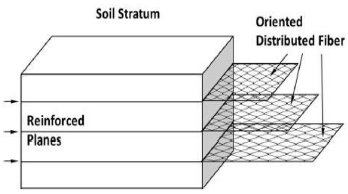
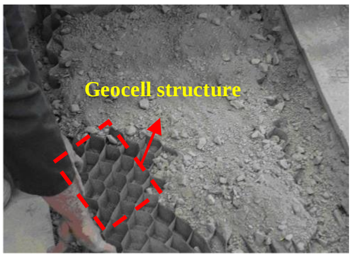
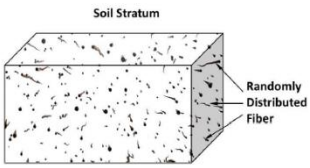
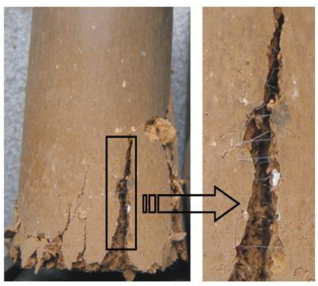
Table 1 - Various method of soil stabilization

Categories	Ref.	Method	Descriptions	Discussions
Physical Method	Indraratna *et al.* (2012)	Vertical drain	The installation of vertical drain using steel mandrel ease the flowing of water, reduce the moisture content in soil and accelerate the consolidation process.	The main advantage of this method is no chemical residue will be left behind in the soil and no noise pollution compared to piling method.
	Collin *et al.* (2005)	Piling	The insertion of column in the soft soil reduces the settlement failure as the stress of traffic load was transferred to the vertical column.	
Chemical method	Kolias *et al.* (2005)	Cement	The addition of cement into the soil improves the strength of soil.	The stabilization of soil by using chemical method was widely used because of the strength of the soil has significantly increased. However, the chemical reactions in soil need to be monitor for a long-term application.
	Okagbue *et al.* (2000)	Lime	The addition of lime into the soil decreases the shrinkage properties of soil.	
Mechanical method	Avalle & Grounds (2004)	Rolling	This method was used for many decades. The rolling process reduces the permeability of soil.	The simplest method compared to physical and chemical methods.
Mechanical method	Mittal & Shukla (2018)	Fibre reinforced soil	(a) Oriented distributed fibre: The maximum dry density (MDD) of soil was improved after the inclusion of geotextile and geogrid. The California bearing ratio (CBR) and unconfined compressive strength (UCS) were improved up to 58% and 32%, respectively.	Two type of fibre materials such as synthetic and non-synthetic materials.
	Boz *et al.* (2018)		(b) Randomly distributed fibre: The addition of 6% of lime and 0.75% of fiber has increased the strength of soil to 1150 kPa. The fibres have more interfacial bond with soil.	

2. Fiber Reinforced Soil

Fiber reinforced soil can be classified into two types which are oriented distributed fiber reinforced soil and randomly distributed fiber reinforced soil as shown in Figure 3(a) and 3(b), respectively. In the oriented distributed fiber reinforced soil, the geosynthetic fiber was placed by using a planar system where the fiber will layer parallel to the subgrade soil in a vertical, horizontal or in both directions (Dash *et al.*, 2004). Latha & Somwanshi (2009) reported that the soil reinforced with planar system has been successfully utilized in geotechnical area. The geosynthetic fiber that commonly used in soil stabilization are geotextile, geogrid and geocell as shown in Table 2. Marto, Oghabi & Eisazadeh (2013) claimed that the utilization of geosynthetic fiber in the construction area had increased the bearing capacity of soil about 3% by the increasing layer of geosynthetic fiber. Table 2 illustrates the different structures of oriented (geosynthetic) and randomly distributed fiber reinforced soil. Geotextile fibers usually made from textiles such as silk, cotton, and wool (Brown, Kwan & Thom, 2007). On the other hand, geocell commonly looks like a honeycomb structure and it is usually made from high density polyethylene (HDPE) (Misnon *et al.,* 2014). Geogrid fiber was mainly fabricated from the polypropylene and they have found that the strength of soil has increased up to 50% (Basu *et al,* 2009). The bridging and interlocking of fiber in soil had stabilized the geotechnical properties of soil. Referring to Table 2, it can be concluded that the fiber reinforced soil is one of the promising methods that can be used to stabilize the soil in a pavement design. Moreover, these two types of reinforcement method were very suitable for country with the highest rainfall distribution because most of the synthetic fiber materials have high resistance to moisture and known as non-biodegradable materials.

Table 2 - Oriented and randomly distributed fiber reinforced soil

Categories	Ref.	Types of fibre	Remarks
		1. Geotextile	
	Mehrjardi, Tafreshi & Dawson (2012)		This type of geotextile fiber was suitable for reinforcing unpaved road with medium repeated traffic load. The soil has gain 73% of soil strength after the construction of 18 months.
		2. Geocell	
Oriented distributed fiber reinforced soil  Fig. 3(a) Illustration of oriented distributed fiber reinforced soil (Gowthaman *et al.*, 2018).	Krishnaswany *et al.* (2000); Alamshahi & Hataf (2009)		The three-dimensional reinforcement structure of geocell has increased the bearing capacity of soil.
		1. Geogrid	
	Zidan (2012); Tang *et al.* (2007)		Zidan (2012) have found that the bearing capacity of sandy soil have increased with the decreasing spacing between geogrid layer.
		2. Randomly distributed fiber	
Randomly distributed fiber reinforced soil  Fig. 3(b) Illustration of randomly distributed fiber reinforced soil (Gowthaman *et al.*, 2018).	Yetimoglu & Salbas (2003); Chen *et al.* (2015); Gowthaman *et al*, (2018)		The shear strength of the soil increased after the addition of 3% of polymer fiber. Meanwhile, the addition of lime, basalt, and PP reduced the mass loss. Mostly, sample with 0.5% polymer fibre has shown the decreasing in mass loss.

3. Soil Stabilization using Waste Materials

Soil stabilization by using waste material had become a great attention to the researchers due to its outstanding properties such as high tensile strength and high resistance to chemical and weather (Poulikakos *et al.*, 2017). Soil stabilization can improve bearing capacity, compressibility, and shear strength of soil by the infusion of reinforcement and additive materials such as plastic and cement, respectively (Akbulut, Arasan & Kalkan 2007). In this section, three types of waste materials which are agricultural waste, construction waste, and municipal solid waste were further discussed. Such types of materials have been produced in large quantities every day worldwide and have a negative impact on the environment due to the potential of land contamination. Thus, it is necessary to reduce these materials by utilizing them in soil stabilization. Table 3 represents the engineering properties of sustainable materials for road construction application.

Table 3 – Engineering properties of sustainable reinforcement material for road construction

Categories	Materials	Ref.	Properties of material			Type of soil	Additive materials	Properties of reinforced soil			Research Findings
			Ratio (%)	Specific gravity	Strength (MPa)			OMC (%)	UCS (kPa)	CBR (%)	
Agricultural waste	Rice husk ash	Basha *et al.* (2005)	5.0	3.68			4.00% cement	30.00	1200	-	The addition of RHA has increased the shrinkage limit of clay. Then, the CBR of soil has shown the improvement after the addition of RHA due to the frictional resistance generated form RHA. The liquid limit and plastic limit were decreased significantly because RHA content high percentage of Silica and lead to the hydration. The UCS was increased by the increasing amount of RHA.
		Anupam, Kumar & Ransinchung (2013)	25.00	2.17	-	Clay	-	34.00	-	12 (28 curing day)	
		Muntohar (2004)	12.50	-	-	Clay		37.94	219	6.39	
			12.50	-	-	Clay	6.00% lime	32.50	369	16.30	
		Brooks (2009)	-	-	-	clay	25.00% fly ash	-	1150 (28 curing day)	9 (28 curing day)	
	Coconut husk fiber	Singh & Mittal (2014)	1.00	-	-	Clay	-	-	620.76	9.22	The addition of CHF has increased the OMC percentage. The UCS and CBR also increased by the increasing amount of CHF. The pavement thickness can also be decreased with the addition of CHF. The addition of CHF leads to the increasing permeability of soil.
		Anggraini *et al.* (2015)	2.00		100	Clay	5.00% lime	-	700	-	
		Tiwari & Mahiyar (2014)	1.00	-	-	Black cotton soil	20.00% fly ash and 5.00% crushed glass	-	-	5.2	
Construction	Concrete	Arulrajah *et al.* (2015)	100		5.35	-	-	-	-	-	The concrete waste was mainly use in subbase layer due to its high strength materials.
		Xuan, Molenaar & Houben (2015)	100		10.00	-	-	-	-	-	
Municipal solid waste	Plastic	Pekrioglu (2017)	0.50	-	-	Clay	-	-	345	-	The addition of PP fibre has improved the ductility of soil. Then, the hydraulic conductivity of soil increases with the increasing amount of PP. In fact, the damping ratio and UCS of soil has increased with the addition of 0.2% of PP. The increasing amount of PP fiber has increased the shear strength axial strain of soil.
		Anagnostopoulos, Tzetzis & Berketis (2013)	0.10	-	-	Clay	-	-	-	800 kPa (shear strength)	
		Ding *et al.* (2018)	0.25	-	-	Clay	-	-	790	-	
		Akbulut, Arasan & Kalkan (2007)	0.20	-		Clay	12.00% cement	-	1500	-	
		Pasetto & Baldo (2016)	0.20	-	-	Clay	-	-	200	-	

Notes: OMC (Optimum moisture content), UCS (Unconfined compressive strength), and CBR (California bearing ratio)

3.1. Agricultural Waste

Recently, agricultural waste such as coconut husk fiber, rice husk ash, palm oil fuel ash, and sugarcane bagasse ash widely used as a reinforcement material because it can abundantly found in nature and its physical properties were suitable in geotechnical application (Yusoff, 2016). On the other hand, agricultural waste can also be assumed as cost effective materials as these non-renewable resources only filling up in our landfill lead to the cause of pollution (Sarki *et al.*, 2011).

In the last few years, many researchers investigated the effectiveness of agricultural waste as reinforcement materials in order to diminish the pollution and reduce the production cost (Vishnudas, 2006). In this section, the list of literature about the utilization of agricultural wastes were discussed and emphasized.

3.1.1. Coconut Husk Fiber

Coconut husk fiber (CHF) is mainly obtained from the husk of the coconut fruit surround the shell. The CHF can be classified according to its thickness, length, and color (Harish, 2009). Sivakumar & Vasudevan (2008) claimed that the high tensile strength of husk fiber makes it very suitable to be applied in geotechnical area.

Peter *et al.* (2016) have utilized coir waste, coir pith and coir fiber to investigate the feasibility of using the CHF as marine clay stabilizer. They have found the addition of 0.2% of CHF increased the value of OMC. The percentage of CBR was increased due to the frictional properties of CHF (Peter *et al.*, 2016). Chauhan, Mittal & Mohnty (2008) have utilized fly ash and fiber to stabilize the silty sand. They claimed that the optimum moisture content (OMC) increases and the maximum dry density (MDD) decreased with increasing percentage of fly ash and CHF. They also reported that the addition of 0.75% CHF has increased the unconfined compressive strength (UCS) value. It can be concluded that the CHF fiber can stabilized the soft soil due to its high tensile strength.

3.1.2. Rice Husk Ash

Rice husk are the shells that were produced during the de-husking of rice from paddy. Generally, rice husk contributes up to 23% weightage of paddy (Liu *et al.*, 2016). The world production of rice in 2002 was approximately 576 million tonnes. According to Kumar *et al.* (2015), Malaysia had produced about 2.1 million tonnes of rice every year. Rice husk was considered as a waste material and generally was disposed by dumping or burning it. In actual fact, the farmer had burned the rice husk in the paddy field and this problem can cause an environmental pollution (Pode, 2016). The ashes that were produced from the burning of rice husk were contain high percentage of biomass silica. The utilization of this biomass silica had improved the geotechnical properties of soil and minimize the utilization of natural material such as clayey soil. On the other hand, rice husk ash (RHA) also defined as a pozzolanic material due to its high amorphous silica content (Fernandes *et al.,* 2016). Table 4 represents the chemical and physical properties of RHA.

Table 4 – Chemical and physical properties of RHA (Kumar *et al.*, 2015)

Chemical composition		**Values (%)**
Calcium oxide	CaO	2.4
Silica	SiO_2	91.3
Alumina	Al_2O_3	1.4
Iron oxide	Fe_2O_3	0.6
Magnesia	MgO	2.1
Sodium oxide	Na_2O	0.3
Potassium oxide	K_2O	1.9
Physical properties		
Specific gravity	G_s	1.98
Maximum dry density	MDD	0.879

Table 4 shows that the silica is a highest chemical compound pre-sent in the rice husk ash and it has low optimum moisture content. Phanikumar & Nagaraju (2018) have utilized the rice husk ash in order to stabilize the expansive clay. They have found that the unconfined compressive stress of clay reinforced with rice husk ash was in-crease 340 kPa after 28 days curing time. They also claimed that the MDD of the reinforced soil decreased to 13.2 with the addition of 30% of rice husk ash. Furthermore, the swelling pressure of the soil was decreased to 75% (Phanikumar & Nagaraju *et al.,* 2018). Eberemu, Omajali & Abdulhamid (2016) reported that the 16% of the addition of rice husk ash into the tropical black clay after 56 curing day decreased the swell index. Moreover, the compressibility index of the soil has decreased with the increasing amount of rice husk ash.

It can be concluded that the RHA increases the compressive strength of soil. On the other hand, the MDD and OMC of the soil reinforced with RHA decreases with the increasing of RHA content. Hence, it can be deduced that the RHA can be used as a soil stabilizer.

3.1.3. Palm Oil Fuel Ash

Palm oil fuel ash (POFA) is a by-product from the extraction process of palm oil combustion. Thomas, Kumar & Arel (2017) reported that 4 kg of biomass ashes were generated from 1 kg of palm oil. Malaysia is one of the biggest palm oil manufacturers in Asia. The residues from palm oil were collected after the extraction of oil and it was pyrolyzed at suitable temperature to produce biomass silica (Borhan, Ismail & Rahmat, 2010). Table 5 shows the chemical and physical properties of POFA.

Table 5 - Chemical and physical properties of POFA (Mujah *et al.*, 2015)

Chemical composition		Values (%)
Calcium oxide	CaO	7.16
Silica	SiO_2	63.72
Alumina	Al_2O_3	2.47
Iron oxide	Fe_2O_3	1.39
Magnesia	MgO	3.19
Sodium oxide	Na_2O	0.77
Potassium oxide	K_2O	6.20
Loss on ignition		12.56
Physical properties		
Specific gravity		2.35

Daud, Muhammed & Kundiri (2017) had investigated the performance of POFA in the granite residual soil. They found the addition of POFA improve the plasticity characteristics of soil. Then, the MDD and OMC decreased by the increasing of POFA content. Mujah *et al.,* (2015) claimed that the shear strength of soft soil was increased up to 50% after the addition of POFA. On the other hand, the addition of 16% of POFA has reduced the settlement value of soil. They also found that the utilization of POFA in a soft soil such as peaty soil was reliable in the road construction industry.

3.1.4. Sugarcane Bagasse Ash

Bagasse is a fibrous material that was remained after the extraction of sugarcane juice. Similar with RHA and POFA, bagasse needs to undergo a pyrolysis process in order to extract a biomass silica from its fibrous material. Generally, 1 tonne of sugarcane were producing around 280 kg of bagasse (Varma & Mondal, 2017). The improper disposal of this waste material can create an environmental pollution around the sugar production plant. Moreover, the leftover of sucrose in the bagasse after the extraction of it juice can generated smelly odor around the production plant or dumping area. Table 6 shows the chemical and physical properties of sugarcane bagasse ash (SBA) (Alavez-Ramirez *et al.,* 2012).

Table 6 - Chemical and physical properties of sugarcane bagasse ash (Alavez-Ramirez *et al.*, 2012)

Chemical composition		Values (%)
Calcium oxide	CaO	2.59
Silica	SiO_2	51.66
Alumina	Al_2O_3	9.92
Iron oxide	Fe_2O_3	2.32
Magnesia	MgO	1.44
Sodium oxide	Na_2O	1.23
Potassium oxide	K_2O	2.10
Loss on ignition	-	24.15
Physical properties		
Density	(kN/m^3)	21.48

Amu *et al.* (2011) have improved the geotechnical properties of lateritic soil by using sugarcane straw ash. They have found that the MDD and OMC of soil decreased by the increasing of sugarcane ash. On the other hand, the CBR of the soil reinforced lateritic soil increased up to 23.3%. Besides, the UCS increased up to 284.66 kPa.

As a conclusion, the agricultural waste such as RHA, POFA, and SBA have significantly increased the strength of the soil. Furthermore, the increasing amount of these agricultural wastes can cause the decreasing amount of MDD and OMC. This is due to the pozzolan activity of the agricultural waste.

3.2. Construction Waste

Construction waste is defined as wastes that unused from construction activities, such as pre-construction, construction and post construction. Rapid urbanization in metropolitan area led to the demolition of old civil engineering structures. Besides, the construction and demolition wastes were generated from the natural disasters such as earthquakes, tornadoes, and floodwater. Huang reported that over 30 million ton of wastes were produced after the earthquakes (Huang *et al.,* 2002). Generally, the construction waste consists of stones, steel, blocks, and concrete. The improper dumping of construction wastes on a landfill will lead to the serious environmental effect (Ozalp *et al*., 2016). The most effective way to diminish the construction wastes was to reuse and recycle the construction wastes (Gomathi & Pradeep, 2017). On the other hand, the cement kiln dust (CKD) also can be used to increase the geotechnical properties of soil.

3.2.1. Concrete Waste

Generally, concrete wastes were widely used in the subbase layer of pavement system due to high strength and high adsorption and low specific gravity compared to conventional mineral aggregate (Pourtahmasb & Karim, 2014). Table 7 shows the general properties of concrete waste (Kumar, 2017).

Table 7 - The general properties of concrete waste (Kumar, 2017)

Parameter	Value
Specific gravity	2.45
Aggregate crushing value (%)	30.7
Bulk density (kg/m^3)	1520
Water absorption (%)	4.23
Impact value (%)	18.5-21.1

Oikonomou (2005) reported that 40% of concrete wastes were generated from the demolition waste. Hence, it is necessary to utilize the concrete waste in the development of sustainable road construction. In fact, the concrete waste has been widely used in the geotechnical application such as in soil stabilization and the improvement of subbase. The researcher also reported that the concrete contains harmful elements that can cause pollution. Table 8 shows the harmful elements in concrete waste. Thus, the utilization of concrete waste in road construction industries become a great strategy to ensure the pollution from the concrete wastes is at a manageable level.

Conventionally, concrete wastes mostly used in subbase layer due to its structures. According to Vegas *et al.* (2008), the CBR of the recycled concrete aggregates were in between 82% to 107% and it is non-plastic material. They have found that the recycled concrete aggregates were suitable for the subbase layer in a pavement system because it is granular materials. A group of researchers have found that the utilization of 100% of recycled concrete aggregates have increased the subbase layer up to 375.9 MPa. They also claimed that the recycled concrete waste was a cost-effective material for road construction industry (Bennert *et al.,* 2000).

Table 8 - The harmful elements in concrete waste (Oikonomou, 2005)

Heavy metal		Limit (μg/l)
Arsenic	As	50
Lead	Pb	100
Cadmium	Cd	5
Copper	Cu	200
Nickel	Ni	100
Chromium	Cr	100

3.2.2. Cement Kiln Dust

Cement manufacturing industry was considered very crucial throughout the world and result in the production of high percentage of cement kiln dust. Cement kiln dust (CKD) were generated in the kiln during the production of cement clinker (Miller & Azad, 2000). Table 9 indicates the chemical composition of CKD (Ahmed, Shehata & Easa, 2009).

Based on Table 9, the major chemical composition in CKD was calcium oxide. Previously, the CKD was used as a stabilizing agent for the road work application. They have found that the CKD with the highest amount of calcium oxide (CaO) has increased the strength of soil to 2500kPa (Pheethamparan, Olek & Lovell, 2008). Jimoh, Amadi & Ogunbode (2018) have studied the influence of the CKD waste on the geotechnical properties of soil. They claimed that 25% of CKD in soil have increased the UCS up to 350 kPa. The increase of UCS value up to five times was found in the black cotton soil by 16% of CKD (Arulrajah *et al.,* 2017). It was found that the CKD was very reliable for the geotechnical application due to its CaO content. Moreover, by utilizing this waste material, the consumption of natural material such as limestone can be reduced.

Table 9 - The chemical compositions of CKD (Ahmed, Shehata & Easa, 2009)

Oxide compounds		Values (%)
Calcium oxide	CaO	60.98
Silica	SiO_2	19.30
Alumina	Al_2O_3	5.02
Iron oxide	Fe_2O_3	2.58
Magnesia	MgO	2.64
Sodium oxide	Na_2O	0.30
Potassium oxide	K_2O	1.18
Loss on ignition	-	3.10

3.3. Municipal Solid Waste (MSW)

Municipal solid waste normally sorted into four different types of recyclable materials, toxic substances, composable organic matter and soiled waste. However, in this paper, only two types of recyclable materials which are the glass and plastic were reviewed. Researchers claimed that the glass and plastic wastes were very suitable for road construction instead of other MSW such as paper and wood (Sharholy *et al.*, 2008; Poulikakos *et al.*, 2017). Generally, the MSW has increased year by year depending on the standard of living and human activities (Mohajerani *et al.*, 2017).

3.3.1. Plastics Waste

Plastics such as expanded polystyrene (EPS) (Pourtahmasb & Karim, 2014), high density polyethylene (HDPE) (Kumar, 2017), geocomposite cellular mat by recycle polypropylene (Ismail *et al.*, 2014; Ismail, 2017), and scrap tires (Rao *et al.*, 2014) have been used in road construction for many years. However, polypropylene has gained great attention from researchers due to its high resistance to chemical and weather. Furthermore, plastics were widely used in geotechnical application because it is lightweight material (Noor Hasanah *et al*., 2014).

Polypropylene is the world's second most widely produced synthetic plastic, after polyethylene. The latest report of the market research company expects the demand for this type of plastics to grow by, on average 3% per year until 2024. In order to decrease this type of fiber waste, it can be utilized for various engineering applications such as in soil stabilization. Polypropylene fibers are one of the most promising synthetic materials used for reinforcing soil due to its nontoxicity, high chemical resistance, and high tensile strength (Rana, 2018).

Kumar, Rabindra & Kar (2012) have utilized clay and polypropylene fiber (PP) to stabilize the soil and they have reported that the strength of soil had increased after the addition of 0.6% of PP fibers. They also claimed that the ductility of soil was increased. Ple & Le (2012) have improved the shear strength of soil by the inclusion of 20mm length of fiber. A group of researchers also found that the lithormargic soil was increased after the addition of 3% PP (Boz & Sezer, 2016). Previously, the mass loss of kaolin clay was decreased with the addition of 0.5% PP, lime and basalt (Rao *et al*., 2018). It can be concluded that the addition of polypropylene into the soil was improved the strength characteristic of soil. This method also reduces the brittleness and it is more durable in soil (Marandi *et al.*, 2008).

3.3.2. Glass

Rapid development in infrastructure for improvement of standard living has increase the municipal waste such as glass. The United Nation claimed that almost 200 million tons of glass waste was generated. Table 10 shows the physical properties of glass waste aggregate (Cabrere *et al.,* 2016).

Table 10 - The physical properties of glass waste aggregate (Cabrera *et al.*, 2016)

Physical properties	Value
Shape	Elongated
Specific gravity	2.5
Impact value (%)	22
Crushing value (%)	31
Elongation index (%)	42

Amlashi *et al.* (2018) have utilized limestone and recycled glass for the application of roadworks. They have found that the shear strength of the sample was decreased with the increasing amount of recycled glass. It was found that the optimum content of recycled aggregates that can be used to stabilize the pavement layer were 25 %. Alhassan, Yunusa & Sanusi, (2018) have mixed the cullet glass from waste glass bottle to improve the asphalt layer. They claimed that the fine sized glass bottle has shown similar properties with sand and crushed rock. On the other hand, they also reported that the bulk density of 8% of glass with asphalt have approximately similar with their specified asphalt value.

4. Conclusions

This paper intends to contribute to the understanding of waste materials consumption in road construction in pursuing strategies for sustainable development. Hence, agricultural waste, construction waste and municipal solid waste evidently significant have a huge potential in road construction applications and it have been critically reviewed in this paper. The findings of this review are summarized as follows:

a) The various soil stabilization method such as physical, chemical, and mechanical methods have its own pros and cons. However, the fiber reinforced soil methods which were randomly and oriented distributed fiber reinforced have become a great attention to researchers due to its cost-effective method compared to the others.
b) The agricultural waste materials including coconut husk fiber, rice husk ash, sugarcane bagasse ash, and palm oil fuel ash was very reliable to be used in the road construction industry. The high biomass silica content in these materials has increased the pozzolan reaction with soil. The pozzolanic additives have increased the geotechnical properties of soil. However, the durability of biomass silica in the soil was limited. Thus, it is crucial to introduce other non-biodegradable materials into the soil.
c) The construction waste such as concrete waste was very suit-able to be used in subbase layer of pavement system. The utilization of aggregate waste in subbase layer can reduce the us-age of natural material such as aggregate and rock.
d) The utilization of plastics waste such as polypropylene fiber has increased the strength and durability of soil. The outstanding properties of polypropylene such as non-biodegradable and high ductility make it feasible for the application in sub-grade soil of pavement system.

In conclusion, it is beneficial to use the outlined stabilization agents in this review as they are low-cost, environmental friendly and effective to soil stabilization, particularly the agriculture waste and municipal solid waste, as it has the added advantage of solving the environmental problem.

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