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Systematic Review of Plastic Waste as Eco-Friendly Aggregate for Sustainable Construction

Okka Adiyanto[1,2], Effendi Mohamad[1*], Jeefferie Abd Razak[1]

[1]Fakulti Kejuruteraan Pembuatan,
Universiti Teknikal Malaysia Melaka, Jalan Hang Tuah Jaya durian Tunggal, Melaka, 76100, MALAYSIA

[2]Teknik Industri,
Universitas Ahmad Dahlan, Jalan Ringroad Selatan Kragilan, Yogyakarta, 55191, INDONESIA

*Corresponding Author

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Abstract: The advent of the COVID-19 pandemic has increased the amount of plastic waste. The demand for food and plastic-packaged foodstuffs has increased, and the use of disposable utensils has increased. The large usage of plastic packaging was the main factor which contributed to the plastic waste disposal. Since these plastic wastes are not easily degraded, it has led into massive environmental pollution. Transitioning towards eco-friendly materials for new sustainable technologies will be critical to combating future pandemics and reduce the plastic waste. Hence, recycling of plastic waste and its re-utilization as green and eco-friendly construction material could decrease the tendency of environmental pollution. In this review paper, we have presented an overview of the published articles which recycled plastic waste as an eco-friendly aggregate material for different construction-based applications before COVID 19 and during COVID 19. Furthermore, the processing methods which were suggested in the published articles for recycling plastic waste have been discussed. A few construction materials could be developed by utilizing the plastic wastes, including the polymer-modified asphalt mixes, eco-bricks, and construction and demolition materials. These products could be used as novel products for other sustainable applications and benefits of circular economy. According to several reports, polymeric based plastic wastes can be effectively used as a recycled material, decrease the demand for traditional materials and also tremendously reduce the construction costs.

Keywords: Plastic waste, Eco-friendly aggregate, Eco-brick, Covid-19, and material construction

1. Introduction

1.1 Plastic Waste Management

The COVID-19 coronavirus which was officially identified in December 2019. The emergence of the COVID-19 pandemic has increased the complexity of plastic waste management. In addition, national lockdowns and home quarantine orders have led to increased reliance on online delivery of food and other essential groceries which has led to an increase in the production of plastic packaging waste (Benson et al., 2021; Scaraboto et al., 2020). The temporary closure of restaurants and shops will change people's habits of life and consumption; this will create an accumulation of waste generation. Individual choices during the Lockdown period have also increased the demand for plastics. Packaged food and groceries delivered to homes accounted for an additional 1400 tonnes of plastic waste during Singapore's 8-week lockdown. The global plastic packaging market size is projected to grow from USD 909.2 billion in 2019 to 1012.6

*Corresponding author: effendi@utem.edu.my

billion in 2021, at a compound annual growth rate of 5.5%, mainly due to the pandemic response (Yudell et al., 2020).

Management of plastic waste is of major significant environmental issue in pandemic era This problem can negatively affect the global climate, which in turn, could severely affect the public health (Kholil & Jumhur, 2018).Several factors have been attributed to an increasing waste, i.e., population explosion, community-levelactivities, socio-economic practices, technological advancements and the community life-style pattern (Boysan et al., 2015; Setyowati & Mulasari, 2013). Due to the constant increase in the global population, there has been a significant increase in the generation and disposal of plastic waste (Budiyanto, et al., 2020). Different countries produce different types of plastic waste. As a result, a 3R (i.e., Reuse, Reduce, and Recycle) program was proposed for decreasing the waste products which affected the environment (Rehman et al., 2020). The amount of waste produced in a community can be effectively managed after converting it to many useful products which are economically sustainable and viable (Boysan et al., 2015).

Like other countries, Indonesia is also suffering from the arising issues due to the accumulation of plastic waste (Kholil & Jumhur, 2018). Furthermore, our fast-paced living have led to the massive utilisation and application of plastic packaging. The plastic packaging is very useful in day-to-day activities due to their lower production costs and high-performance features (Hasnat & Rahman, 2018; Liliani et al., 2020). The plastic material is produced using the principles of polymer chemistry and cannot be naturally decomposed if buried with the other waste (Wahid., 2015). A combination of several synthetic polymers (like polyamide, polystyrene, polyvinyl chloride, polyethylene, polyethylene terephthalate, and polypropylene) were used as packaging materials (Dixit & Yadav, 2019). Different polymeric wastes like plastic are produced after the consumption of packaging materials. These form a solid wastes which are not easily degraded and it was kept exponentially accumulated, thereby causing a huge environmental burden (X. Li et al., 2020). The primary and secondary carbon molecules present on the polymeric structures of the plastic materials were mainly responsible for their non-biodegradable properties (Arredondo-Orozco et al., 2019).

Even today, many illegal societies have collected the plastic waste from the residents and dispose it into landfills, rivers or other water-bodies, which finally transported to the ocean (Wulandari., 2017). One related study have stated that about ≈10 million tonnes of plastic waste has generally thrown to the sea, which then negatively affects marine life-forms (Mourshed et al., 2017). The most commonly used forms of plastic materials which are used for packaging and as bottles includes the Polyethylene Terephthalate (PET) High-Density Polyethylene (HDPE), and Low-Density Polyethylene (LDPE) (Intan & Santosa, 2019).

Recycling these plastic wastes could significantly decrease the problems related to the disposal in global communities. One such method used for recycling plastic waste was through converting it into some tangible products which have added value and properly reuse the plastic wastes (Deutz., 2010). Some techniques which are practiced for recycling the plastic wastes are through the production of bags, crafts, as plastic flowers, purses, etc. (Indrianti, 2016; Wulandari et al., 2017).

Along with these different domestic applications, plastic wastes are effectively used as an alternative ingredient in paving blocks, road construction, asphalt pavement, bricks and eco-bricks (Agyeman et al., 2019; Akinwumi et al., 2019; Appiah, Berko-Boateng, & Tagbor, 2017; Arul Arulrajah et al., 2020; Intan & Santosa, 2019; Köfteci, 2016; Limami et al., 2020; Movilla-Quesada et al., 2019; Taaffe et al., 2014). The recycling of plastic waste was an effective technology which helped in managing waste. It was usually implemented after the preventing action, minimizing and reusing waste have been applied (Bundhoo, 2018). The recycling process transforms the waste materials into different products which possessed an additional value with regards to their social, financial or environmental aspect (Afroz et al., 2017).

1.1 Classification on the Plastic Waste

Table 1 presents the different categories in which plastic wastes are classified. Product packaging is the main application of plastic materials and was accounted for 40% of total usage. Hence, the categorization of plastic wastes are based on the raw plastic used for packaging purposes and was classified based on their special numbers. Packaging based products includes plastic wraps were usually been discarded after used and need to be sorted out in accordance their respective numbers, for assisting the recycling process (Nandy et al., 2015).

Table 1 - Classification of plastic waste (Kumar et al., 2018)

S. No.	Source code	Name of plastics	Applications	Current generation rate (kg/tonne of MSW)
1	1	Polyethylene terephthalate (PET)	Drinking water bottles, soft drink bottles, food jars, jell and pickles jars, plastics films, sheets	7.702
2	2	High density polyethylene (HDPE),	Shopping bags, food containers, woven sacks, bottles, plastics toys, milk pouches, detergent bags, metalized pouches	30.650
3	3	Polyvinyl chloride (PVC)	Pipes, hoses, sheets, wire, cable insulations, multilayer tubes	0.506
4	4	Low density polyethylene (LDPE)	Plastic bags, various containers, dispensing bottles, wash bottles, tubing	9.948
5	5	Polypropylene (PP)	Disposable cups, bottle caps, straws	5.649
6	6	Polystyrene (PS)	Disposable cups, glasses, plates, spoons, trays, CD covers, cassette boxes, foams	1.084
7	7	Thermoset, polycarbonate (PC), Polyurethane (PU)	CD, melamine plates, helmets, shoe soles.	1.365
Total generation of plastic waste				56.904

In the study performed by Kumar et al {Formatting Citation} has classified the plastic users based on the types of users socio-economic, which mainly categorized into 3 different groups, i.e., Higher SocioEconomic Group (HSEG), Middle SocioEconomic Group (MSEG), and Lower SocioEconomic Group (LSEG). As shown in Fig. 1, HSEG is the major consumers of plastic materials, which accounted about 54%.

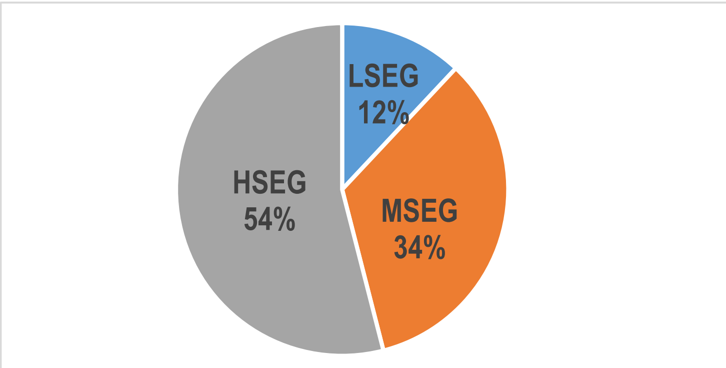

Fig. 1 - Distribution of the socioeconomic group with regards to the plastic waste management (Kumar et al., 2018)

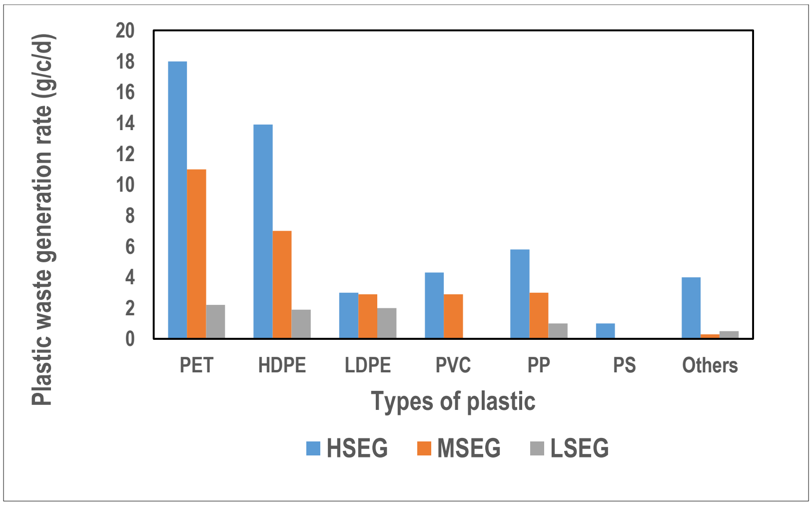

Fig. 2 - Rate of plastic waste generated by different socioeconomic groups (Kumar et al., 2018)

Plastic materials are generally consumed in the form of PET based products. As shown in Fig. **2**, the plastic waste produced from PET (which is used in different products like drinking bottles, food bottles, plastic films, soft drink bottles, and sheets) were generated consumed by the entire different social groups. Along with the PET-based products, the PP, HDPE, LDPE, and PVC wastes are also generated by different social groups. Since it was very difficult to review the problems related to all forms of plastic materials, the researchers have only focused on the management of plastic wastes that generated from PET, HDPE, LDPE, PVC and PP plastics. Different studies had stated that these materials could be effectively utilized as the building mix materials (Agyeman, Obeng-Ahenkora, et al., 2019; Akinwumi et al., 2019; Appiah et al., 2017; Arul Arulrajah et al., 2020; Intan & Santosa, 2019; Köfteci, 2016; Limami et al., 2020; Movilla-Quesada et al., 2019; Pereira & Lourenço, 2016; Taaffe et al., 2014). This application was attributed to the fact that plastics were of major types of polymeric material with varying chemical and technical specifications. Though, plastic wastes are non-degradable, they also can be used as raw materials for recovering energy (Vidales-Barriguete et al., 2020). High temperatures and ultraviolet radiation are used for breaking the polymeric structure and converting it first into smaller pieces and finally into microscopic granules which are mixed with other materials to form a novel and more durable product (Hasnat & Rahman, 2018).

One study has stated that a campaign was carried out for recycling plastic waste in Denmark. In many of the Denmark recycling centres, the plastic wastes were categorised into three categories, i.e., hard plastics, plastics films and PVC, as shown in Fig 3 (Faraca & Astrup, 2019; Kaliyavaradhan et al., 2019). Hard plastic are mainly consisted of PP. This material was mainly used for non-food related applications (42%), food packaging (20%) and in an automotive sector (16%). HDPE was used for non-food packaging applications like construction (18%) and plastic toys (10%). The plastic film waste was generated by five different types of plastics, i.e., LDPE (63%), PP (25%), HDPE (7%), PET (5%) and engineering polymers (0.2%). Plastic films were generally produced by using LDPE, PP, and PET based raw materials (Horodytska., 2018). Basically, in our daily lives, we used many types of plastics like PP, PET, HDPE, LDPE, and PVC.

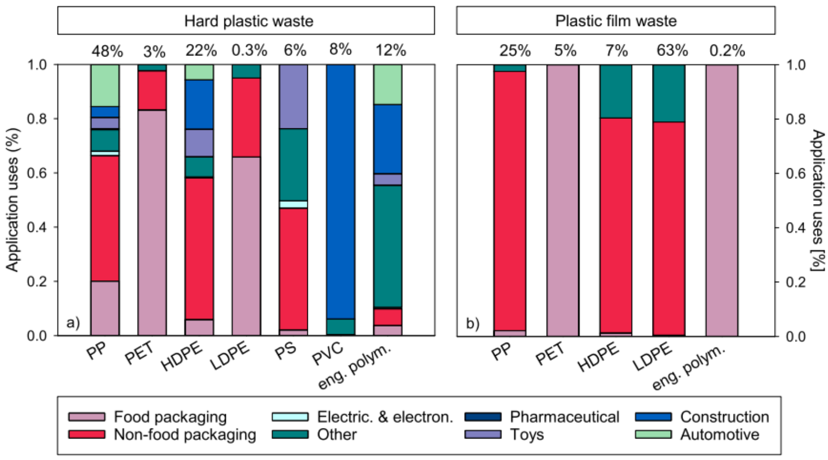

Fig 3 - Use of polymers in applications that generate hard and plastic film wastes (Faraca & Astrup, 2019)

2. Methodology

2.1. Application Screening Criteria

Two techniques were used for defining the screening criteria. In the first process, practical screening was determined by assessing the abstracts, publication content, and publication type and research background. In the second screening process, the quality of the methodology used in the paper would further narrow the process. In this review, the researchers have focused only on articles which discussed the use of plastic wastes for producing different end products. Here, we reviewed the articles which presented all the techniques for recycling plastic wastes and producing construction and building materials. The keywords used in this study are included '*plastic recycling*' and '*plastic waste*'.

2.2. Bibliography Analysis

The initial screening process that has been generated by 111 previous related studies were double-screened by using the second approach to finally yield into 105 refined high-impact articles. The publication date of these papers was restricted to those published between year 2008 and 2021. Among all, about 16 articles were related to plastic and polymeric recycling, which were published in 2021. The results was indicated that this research topic has garnered a lot of attention after year 2015. As a result, the number of articles which discussed this topic and were published after 2015 was very high and this trend has only increased in the last six years (Fig. 4). During the COVID-19 pandemic, there were more than 30 articles discussing plastic waste during the COVID-19 pandemic. Research on this topic has overwhelmingly increased because the society needs to become aware of environmental sustainability, particularly regarding the issues related to the recycling of plastic wastes and its benefit to circular economy.

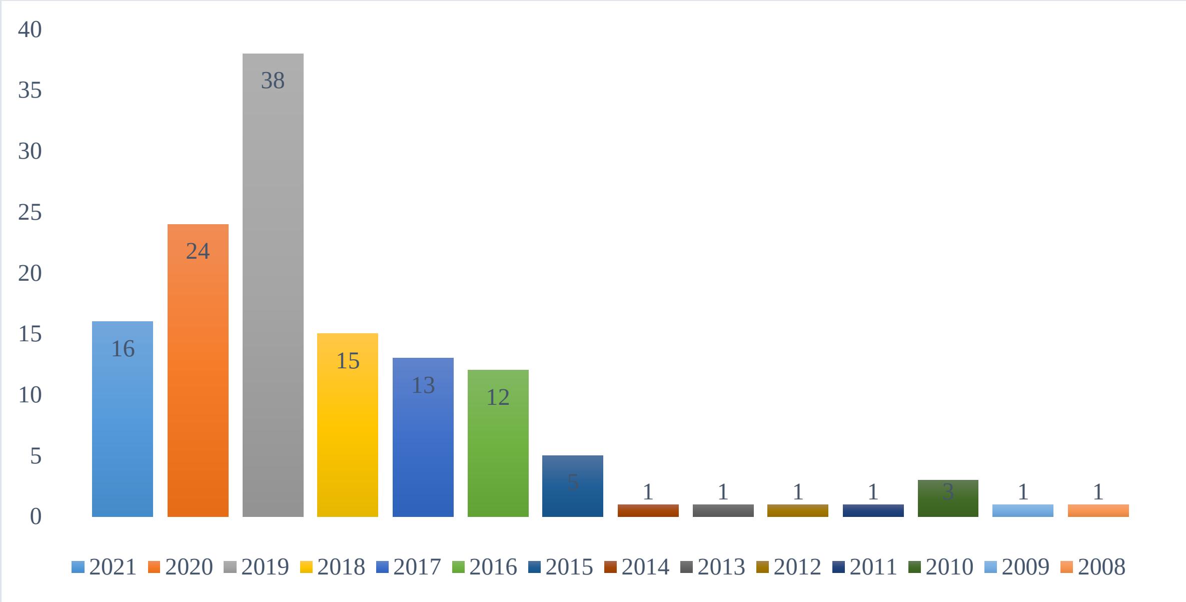

Fig. 4 - Number of publications

This review determined about four types of publications which published the majority of technical studies regarding on the recycling of plastic wastes. As shown in Fig. 5, these publications were classified into journal papers (89%), conference proceedings (6%), reports (3%) and books (2%). Since the majority of the articles were published in research journals, these publications were further classified into journals which possessed an impact factor and had a Quartile index by Scimago. Table 2 indicated that the majority of articles which were reviewed belonged to Q1, Q2, and Q3 categories.

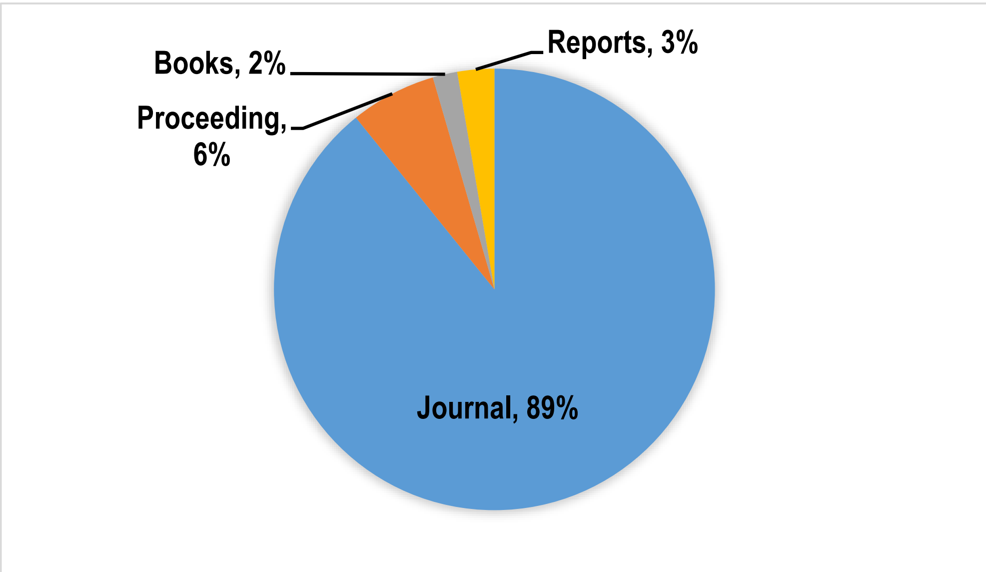

Fig. 4 - Types of Publication

Table 2 - Groups of publication

Search Screening	Number of articles
Q1	68
Q2	16
Q3	6
None from Scimago list	21

The different journals which published articles related to the recycling of plastic waste were further determined as shown in the following Fig 6. The results indicated that the *Journal of Waste Management* had published the maximal number of articles on this topic and provided maximal information regarding the waste management program. The *Journal of Construction and Building Materials* has also contributed and published many articles related to the topic of waste management and the use of recycled plastic as a building material.

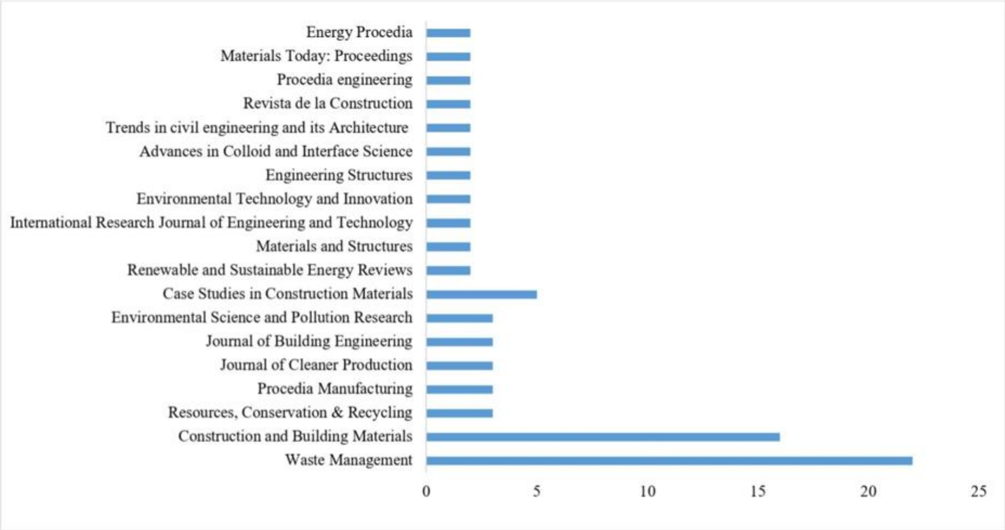

Fig. 6 - Number of publications published by different Journals

The data presented in Fig. 6 could be evaluated and categorised based on the type of plastic waste that was generally used in the society. This classification considered the type of product which was developed after recycling the different types of plastic materials. All these data are based on 11 articles which were assessed in this review and summarised in Table 3.

Table 3 - Usage of various plastic wastes in numerous end products

No	Plastic category	Product	Reference
1	HDPE and PP	Mix Asphalt	(Appiah et al., 2017)
2	HDPE	Mix Asphalt	(Köfteci, 2016)
3	PP	Paving Blocks	(Agyeman, Obeng-Ahenkora, et al., 2019)
4	PET, HDPE, PVC	Mix Asphalt	(Movilla-Quesada et al., 2019)
5	PET	Aerogel	(Le et al., 2019)
6	PET	Cement stabilized	(Arul Arulrajah et al., 2020)
7	HDPE and PET	Construction material	(Limami et al., 2020)
8	PET and LDPE	Brick	(Intan & Santosa, 2019)
9	PET	Brick	(Akinwumi et al., 2019)
10	PET	Eco-brick	(Taaffe et al., 2014)
11	PET	Construction material	(Perera et al., 2019)

3. Results and Discussion

3.1. Polymer Modified Asphalt Mixes

The plastic wastes can be effectively used as the reinforcement material and as an enhancer additive ingredient. These utilizations can provide alternative solutions for managing the plastic waste (Movilla-Quesada et al., 2019). The asphalt mixture contains asphalt and aggregate-binding compounds which are petroleum-based plastic materials (Lesueur, 2009). Many studies have been investigated the effects of recycled plastic wastes addition to the asphalt mixtures. It was seen that these plastic-based mixtures were similar to the modified binder materials (Polacco et al., 2015). Addition of plastic wastes to the asphalt had improved its durability which also led into the economic benefits (Landi et al., 2018). In an earlier study, the researchers used plastic waste mixtures as the substitute for partial binders in the production of asphalt (Movilla-Quesada et al., 2019). This was an efficient process as it did not require the separation of various polymeric constituents. All types of plastic wastes which originated from PVC, PET and HDPE were crushed to form into smaller chips. In the next step, i.e., at the solidification of the recycled aggregates, the wastes were crushed into a size which was similar to the natural aggregates (Jiang et al., 2019). Once it became flaky, the waste was melted at a temperature of 180°C so that the flakes could be binded together. Table 4 presents the different combinations of mixtures with varying volumes and percentages of ingredients or composition.

Table 4 - Bitumen and plastic scrap composition (Movilla-Quesada et al., 2019)

Series	Bitumen (%)	Plastic Scrap	
		Coarse (%)	Fine (%)
REF	100	-	-
REF$_1$	90	-	-
PF1	90	-	10
PG$_1$	90	10	-
PF$_2$	90	-	20
PG$_2$	90	20	-

The REFerence (REF) aggregate mixtures were mixed with bitumen for 3 mins. On the other hand, the polymeric mixture was mixed with the plastic pieces and aggregate and heated at 150°C (Fernandes et al., 2017; Lastra-González, Calzada-Pérez et al., 2016). A Wheel tracking test was carried out. The results indicated that the mixtures containing the plastic wastes has yielded better results in comparison to the REF. An increase in the concentration of the plastic wastes improved the settling of the materials, as shown in Fig. 7. The plastic wastes bind and tighten the mixture more firmly. They also display a better affinity with the aggregates so that it shows a lesser deformation (Movilla-Quesada et al., 2019).

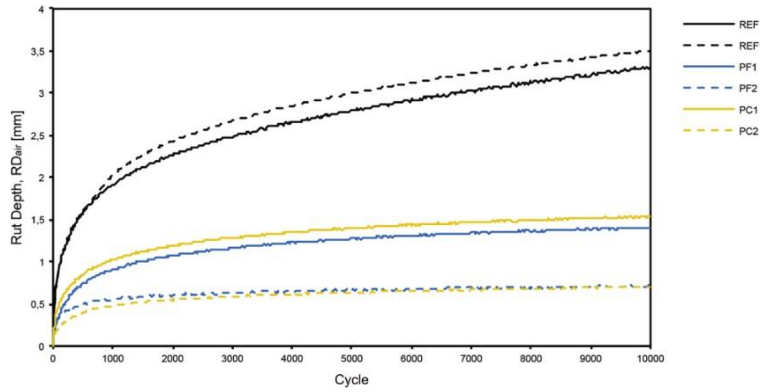

Fig.7 - Wheel tracking test (Movilla-Quesada et al., 2019)

This study indicated that the plastic waste material could be used as the binder for asphalt. The scrap plastic waste interacts with the aggregate material such that these plastic particles showed a size of ≤2.00 mm. This filled the air void within the asphalt. When the asphalt was mixed with plastic wastes, it increased the pressure because of better energy dissipation, which decreased its permanent deformation rate (Gautam et al., 2018; Mahdi et al., 2010; Movilla-Quesada et al., 2019). Another study investigated the benefits of using recycled plastic wastes for road construction in Ghana.

They focused on the HDPE and PP wastes mixed with asphalt (Appiah et al., 2017). In their study, the researchers has manually liquefied the plastic wastes at the temperatures ranging at between of 160° and 170°C. Thereafter, they analysed the mixture by determining the softening point (ASTM D-36), penetration (ASTM D-5), viscosity (ASTM D-4402), and the Fourier Transform Infra-Red (FTIR) analysis. The FTIR spectrophotometric analysis has indicated that the HDPE and PP polymers were properly mixed with the bitumen matrix, indicating that the PP and HDPE were effective bitumen mixture materials and could be used for highway repairs and construction. Based on the results of the mentioned tests, it was concluded that the PP and HDPE could be used for constructing roads (Appiah et al., 2017). In another study, Kofteci investigated the effect of mixing only the HDPE plastic waste with asphalt (Köfteci, 2016). The researchers aimed to assess the effect of using a single plastic waste on the performance of this asphalt mixture. They carried out the Indirect Tensile Test (ITT) for determining the water damage, flow value and stability of the mixtures. In their study, they has compared five difference treatment strategies. HMA-0 was used as the control, while HMA-1 contained 1% HDPE, HMA-2 contained 2% HDPE, HMA-3 was made by using 3% HDPE, and finally, HMA-4 contained of 4% HDPE. The results indicated that the asphalt mixtures with 2 and 4% of HDPE content, showed the best resistance characteristic. Furthermore, the HMA-4 mixture also showed higher stability and better resistance to water damage. Thus, the researchers has concluded that the HDPE was a more appropriate material which could be used for preparing the asphalt mixtures (Köfteci, 2016).

3.2. Construction and Demolition (C&D)

In a material construction field, PET can be mixed with cement and the construction materials or demolition waste (Arul Arulrajah et al., 2020). The Construction and Demolition (C&D) activities generated a lot of waste and rock particles in the urban areas, which was generally filled into landfills. For decreasing the quantity of disposed waste, this waste needs to be used for forming brick products (Ouda & Gharieb, 2020). The construction waste had severely affects the community and environment as the disposed waste was thrown into the landfills (Z. Li et al., 2020). Sustainability is regarded as the biggest priority in the construction industry. In the past few years, plastic was used as the aggregate material for managing strategically the uncontrolled disposal of plastic wastes (Jassim, 2017).

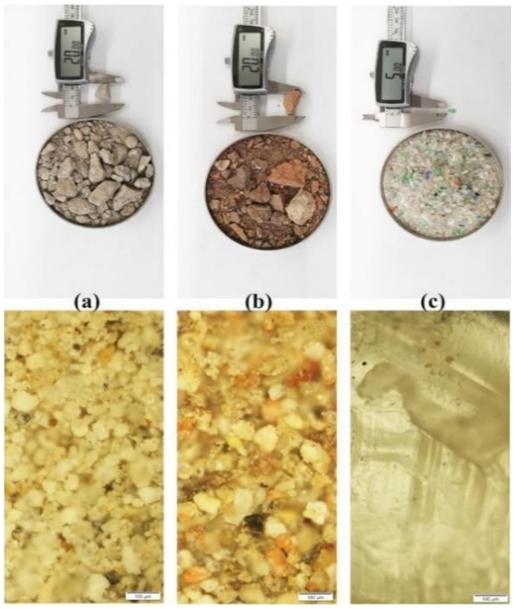

Fig. 8 - Physical appearance and microscopic structure of different materials; (a) RCA, (b) CB and (c) PET (Arul Arulrajah et al., 2020)

In their study, Mukherjee et al. (Mukherjee et al., 2020) noted that PET could be used for stabilising the cement and C&D mixture to yield the Recycled Concrete Aggregate (RCA) and Crushed Bricks (CB). The C&D wastes were described as a material which was often generated while demolishing a building or structure (A. Arulrajah et al., 2012). They conducted some characteristic tests using three types of materials, i.e., PET, RCA and CB. The PET material used in the study was crushed by using a chopper machine to produce a particle size of 5.00 mm (Yaghoubi et al., 2017). Fig. 8 describes the physical appearance and the microscopic structure of the materials that were used in the study. Table 5 depicts the different compositions of RCA, CB and PET used in the formulations.

Table 5 - Composition of PET blends (Arul Arulrajah et al., 2020)

Materials			**Blend Name**
RCA (%)	**CB (%)**	**PET (%)**	
100	0	0	100%RCA (control)
97	0	3	3%PET + 97%RCA
95	0	5	5%PET + 95%RCA
0	100	0	100%CB (control)
0	97	3	3%PET + 97%CB
0	95	5	5%PET + 95%CB

The researchers carried out some laboratory tests on the PET particles and determined the size distribution, water absorption, organic matter content, abrasion, particle density, crust index, and Unconfined Compression Stress (UCS) values. Fig 9. presents the particle size distribution curve for the different materials used in the study. The results indicated that the PET particles lay within the gradation curve limits that were described for the Registration of Crushed Rock Mixes (VicRoad).

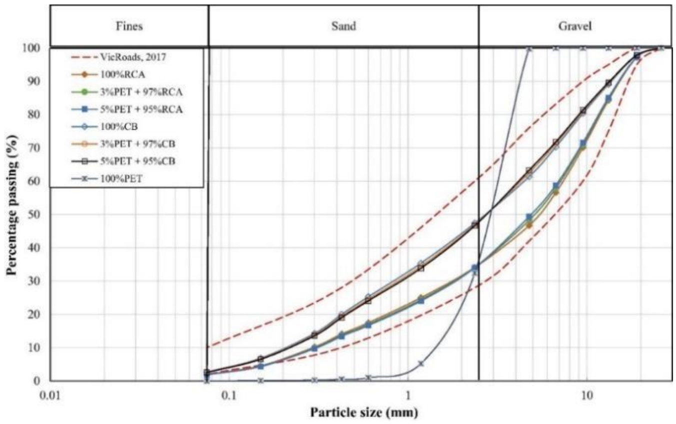

Fig. 9 - Distribution of the size particle curve (Arul Arulrajah et al., 2020)

The figure showed that the higher PET content decreased the modulus of rupture and the flexural modulus values for the RCA and CB. Many researchers recommended the use of different PET blends for constructing the pavement structures (Di Maria et al., 2016; Mahdi et al., 2010; Xiao et al., 2019). The researchers also assessed the geotechnical properties of these PET mixtures based on the California Bearing Ratio (CBR). The test results indicated that the PET mixtures with CB and RCA satisfied the CBR and RLT (Repeated Load Triaxial) requirements (Z. Li et al., 2020).

Table 6 - Test results for concrete paving blocks (Agyeman, Obeng-ahenkora, Assiamah, & Twumasi, 2019)

Specimen	Sample ID	Mix Ratio	Compressive Strength (N/mm^2)			Average Density (kg/m^3) and Porosity (%)		Water Absorption at 72 hrs (%)
			7 days	14 days	21 days	Density	Porosity	
Control	CB-001	1:1:2	3.81	4.23	5.56	1688.00		4.6
	CB-002		6.02	6.42	6.58	1738.50		5.2
Average			4.92	5.33	6.07	1713.25	35.35	4.9
Less in Plastic	LP-003	1:1:2	5.88	6.61	7.01	2052.50		2.9
	LP-004		6.04	7.26	7.61	2229.00		2.5
Average			5.96	6.94	7.31	2140.75	19.22	2.7
High in plastic	Hp-005	1:05:1	9.51	9.53	7.06	2287.50		0.44
	HP-006		7.26	7.29	9.99	2285.50		0.56
Average			8.39	8.41	8.53	2286.50	13.72	0.50

The plastic wastes are mixed with different aggregates and used as building materials and also pavement blocks (Agyeman et al., 2019). PET, LPDE and HDPE are the common types of plastics which are used for making pavement blocks. They are added to sand and cement in a fixed formulation ratio. Different tests were conducted for determining the porosity, average density, compressive strength and the water absorption capacity of these mixtures (Agyeman, Obeng-Ahenkora, et al., 2019; Thanyavinichakul & Thanyavinichakul, 2018). Table 6 summarises the test results, the table presented that the control sample (no plastic) showed a low compressive strength in comparison to the pavement blocks which were mixed using plastic as a binding material. Thus, the compressive strength of these blocks could be increased when the plastic wastes were used as a replacement for cement as the binding material. This was indicated as an increase in the adhesive strength and surface area between the plastic wastes and aggregates (Agyeman, Obeng-Ahenkora, et al., 2019). The higher contact area could further increase the strength of the material (Huang et al., 2019). The researchers also determined the water absorption capacity of different samples (Sharma & Sharma, 2017). The concrete paving blocks showed a higher water absorption capacity than the RPW (Recycled Plastic Waste) paving blocks (Table 6). In their study, Constantin et al. (Constantin et al., 2019) noted similar results since the porosity of the concrete paving blocks was higher in comparison to the RPW paving blocks. This was attributed to the fact that the hydrophobicity absorption decreased by 0.00 -1.00% when the blocks were immersed in water for a period ranging between 6 hrs and 1 week (Frigione, 2010; Thanyavinichakul & Thanyavinichakul, 2018). Thus, it could be concluded that the paving blocks could be used for constructing structures with a lower load like footpaths, walkways and pedestrian plazas.

Bricks are used in constructing buildings and other structures since the early civilisation period (Afzal et al., 2020). A majority of the conventional bricks are made using sand and clay, mixed in a proportion based on the binder materials used (Murmu & Patel, 2018). One approach that is applied for conserving energy and promoting green ecology included the creation of permeable bricks. The permeable bricks effectively decreased the heat effect, absorbed noise and showed a higher anti-skid performance (Smith et al., 2001). These permeable bricks could be made by adding plastic wastes, which made these bricks very eco-friendly (Zhou, 2018). Many different plastic wastes are used as a binding material for manufacturing permeable bricks. The addition of plastic waste increases the durability and compressive strength of the waste bricks (Amir & Yusof, 2018; Limami et al., 2020; Paihte, Lalngaihawma, & Saini, 2019). The results indicated that the PET-based bricks were more porous in comparison to those produced using LDPE and HDPE since they showed a higher Melt Flow Rate (MFR) (Wu, Lin, Huang, & Chen, 2016). Furthermore, LDPE and HDPE showed a higher density in comparison to PET (Intan & Santosa, 2019; Limami et al., 2020). These results led to the conclusion that plastic wastes like PET, HDPE and LDPE can be effectively used for manufacturing bricks (Akinwumi et al., 2019; Bhushaiah et al.,, 2008; Intan & Santosa, 2019; Limami et al., 2020; Sellakutty, 2016).

3.3. Use of Plastic Waste for Producing eco-Brick

Bricks are used as a construction material for building of many structures. The conventional bricks are made using clay. Continued usage of clay could deplete the topsoil which could cause soil infertility. Furthermore, these bricks have to be burned, which increases the greenhouse effect (Paihte et al., 2019). To decrease this effect, cheap, environment-friendly and light-weight construction materials need to be used (Kognole, Shipkule, & Survase, 2019; Wahid et al., 2015). Three different cost-effective construction materials can be used i.e., tetra pack chip panels, wood plastic composite, and PET eco-bricks (Arredondo-Orozco et al., 2019). Another eco-friendly alternative included the use of PET based plastic bricks (Jayaprakash et al., 2016). PET plastic bottles are used for producing environmentally-friendly bricks or eco-bricks. These eco-bricks were used as an effective alternative for construction materials (Antico, Wiener, Araya-Letelier, & Retamal, 2017; Safinia & Alkalbani, 2016; Singhal & Netula, 2017; Wahid et al., 2015). Making ecobricks during the CoVid-19 pandemic is a way for citizens and governments to reduce the spread of the SARS-CoV-2 virus. Ecobricking activities can help prevent virus transmission in disposable utensils (Alliance, 2020). Washing and drying the plastic packaging that we use can prevent the plastic from transmitting the virus. Packing clean and dry plastic into bottles and making ecobrick virus contamination can be minimized. In addition, making ecobricks using used plastic will help in assisting waste management in urban areas. The plastics display corrosion-resisting and long-lasting properties. They are also economical, light-weight and save energy (Jassim, 2017). Reuse of PET plastic bottles as construction materials saves energy and decreases CO_2 emissions (Jayaprakash et al., 2016).

Furthermore, the performance of the eco-bricks as effective construction materials is based on the material that is used for filling these bottles. Fig. 10 presents one example of eco-brick. The Rohingya refugees in Bangladesh have used eco-bricks as construction materials for building their houses (Antico et al., 2017; Haque, 2019).

Fig. 10 - One example of an eco-brick

PET plastic bottles contain a harmful chemical called Bisphenol-A (BPA) which causes environmental pollution when it is not properly recycled (Rehse, Kloas, & Zarfl, 2018). Eco-bricks make use of the PET plastic bottles which are filled using plastic wastes and are arranged to form an environmentally-friendly structure (Paihte et al., 2019). This plastic waste is filled into the bottles manually using sticks. For making eco-bricks, plastic scraps are inserted into the PET bottles using a stick. Tests need to be carried out for determining the strength, compressive force and radial deformation of these eco-bricks (Antico et al., 2017; Dominguez et al., 2017; Taaffe et al., 2014).

Taaffe et al. (Taaffe et al., 2014) tested 10 different samples of eco-bricks which were formed by using different plastic fillers and their results are summarised in Table 7. In their study, they used the PET bottles which were available in the market and weighed between 24 into 27 g per brick. These PET bottles were filled with plastic wastes and the final weight of these bottles ranged between 245 into 260 g. The results of the compressive test indicated that the bottles with the highest weight showed the maximal compression force, i.e., 40 kN. This indicated that the filler material in the bottle has affected the strength of these eco-bricks. The researchers also studied the relationship between the compressive strength of these eco-bricks and the density of the filler materials (Table 8). The results indicated that as the weight and density of the filler materials increased, the strength and compressive force values of the eco-bricks also increased.

Table 7 - Compressive force of specimens (Taaffe et al., 2014)

	Bottle weight (g)	Brick weight (g)	Compressive force (kN)
Specimen 1	26	250	35.1
Specimen 2	25	247	34.6
Specimen 3	26	258	39.3
Specimen 4	27	260	40.1
Specimen 5	25	251	35.3
Specimen 6	27	254	38.9
Specimen 7	24	245	34.5
Specimen 8	26	249	36.1
Specimen 9	25	252	36.3
Specimen 10	25	257	38.0

Table 8 - The resulted strength of each specimen (Taaffe et al., 2014)

	Compressive force (kN)	Area (m^2)	Strength (MPa)
Specimen 1	35.1	0.0136	2.59
Specimen 2	34.6	0.0136	2.55
Specimen 3	39.3	0.0136	2.90
Specimen 4	40.1	0.0136	2.96
Specimen 5	35.3	0.0136	2.60

Specimen 6	38.9	0.0136	2.87
Specimen 7	34.5	0.0136	2.55
Specimen 8	36.1	0.0136	2.66
Specimen 9	36.3	0.0136	2.68
Specimen 10	38.0	0.0136	2.80

Radial deformation was noted when the convergent temperature changes affected the filler materials used in the eco brick. Some factors like thermal shrinkage, density and elastic modulus were dependent on the filler content of the eco-bricks. Furthermore, the elastic-plastic behaviour of the eco-bricks was dependent on the load that was received by these eco-bricks. They also prevent the development of cracks owing to a higher thermal deformation (Taaffe et al., 2014). Antico et al. (Antico et al., 2017) stated that the eco-bricks showed an elastic behaviour when they were subjected to a specific load (i.e., h_{max} ranging from 4 and 8 mm). Thus, the test results indicated that the effectiveness of these eco-bricks was based on the filler materials used in the PET bottles

4. Conclusions

This review has successfully evaluated the potential of using plastic wastes as eco-friendly aggregate materials for building and construction purposes before pandemic Covid 19 and during Covid 19. Many past studies have been reviewed and it was found that the wastes generated by different plastics like PET, LDPE, HDPE, PP and PVC were added to the conventional building materials. These plastic wastes were added to asphalt, eco-bricks and other building materials. In general, plastic waste was recycled by breaking it into smaller pieces which were easily mixed into the mixtures. These plastic wastes could tighten the mixture and showed a higher affinity to the aggregate, which decreased the deformation rate. These alternative materials need to be applied in real applications for decreasing the plastic waste generated worldwide. Hence, it is important to assess the feasibility of the integration of plastic wastes to such applications

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References

Afroz, R., Rahman, A., Masud, M. M., & Akhtar, R. (2017). The knowledge, awareness, attitude and motivational analysis of plastic waste and household perspective in Malaysia. *Environmental Science and Pollution Research*, *24*(3), 2304–2315.

Afzal, Q., Abbas, S., Abbass, W., Ahmed, A., Azam, R., & Rizwan Riaz, M. (2020). Characterization of sustainable interlocking burnt clay brick wall panels: An alternative to conventional bricks. *Construction and Building Materials*, *231*, 117190.

Agyeman, S., Obeng-ahenkora, N. K., Assiamah, S., & Twumasi, G. (2019). Exploiting recycled plastic waste as an alternative binder for paving blocks production. *Case Studies in Construction Materials*, *11*, e00246.

Akinwumi, I. I., Domo-Spiff, A. H., & Salami, A. (2019). Marine plastic pollution and affordable housing challenge: Shredded waste plastic stabilized soil for producing compressed earth bricks. *Case Studies in Construction Materials*, *11*, e00241.

Alliance, G. E. (2020). *Preventing the Spread of SARS-CoV-2 on Single-Use Plastics through Enhanced Ecobricking*. Amir, S. N., & Yusof, N. zulaikha. (2018). Plastic in Brick Application. *Trends in Civil Engineering and Its Architecture*,*3*(1), 341–344.

Antico, F. C., Wiener, M. J., Araya-Letelier, G., & Retamal, R. G. (2017). Eco-bricks: A sustainable substitute for construction materials. *Revista de La Construccion*, *16*(3), 518–526.

Appiah, J. K., Berko-Boateng, V. N., & Tagbor, T. A. (2017). Use of waste plastic materials for road construction in Ghana. *Case Studies in Construction Materials*, *6*, 1–7.

Arredondo-Orozco, C., Luna-Delrisco, M., Villegas-Moncada, S., Gonzalez-Palacio, M., Arrieta-Gonzalez, C., Cuatindioy-Imbachi, J., … Quintero-Suarez, F. (2019). A novel energy-efficient machine to compress inorganic residues in eco-bricks as a sustainable construction strategy for low-cost housing. *Iberian Conference on Information Systems and Technologies, CISTI*, *2019-June*(June), 19–22.

Arulrajah, A., Piratheepan, J., Bo, M. W., & Sivakugan, N. (2012). Geotechnical characteristics of recycled crushed brick blends for pavement sub-base applications. *Canadian Geotechnical Journal*, *49*(7), 796–811.

Arulrajah, Arul, Perera, S., Wong, Y. C., Horpibulsuk, S., & Maghool, F. (2020). Stiffness and flexural strength evaluation of cement stabilized PET blends with demolition wastes. *Construction and Building Materials*, *239*, 117819.

Benson, N. U., Bassey, D. E., & Palanisami, T. (2021). COVID pollution: impact of COVID-19 pandemic on global

plastic waste footprint. *Heliyon*, *7*(2), e06343.
Bhushaiah, R., Mohammad, S., & Rao, D. S. (2008). Study of Plastic Bricks Made From Waste Plastic. *International Research Journal of Engineering and Technology*, 1122.
Boysan, F., Özer, Ç., Has, M., & Murat, M. (2015). Project on Solid Waste Recycling Plant in Sakarya University Campus. *Procedia Earth and Planetary Science*, *15*, 590–595.
Bundhoo, Z. M. A. (2018). Solid waste management in least developed countries: current status and challenges faced. *Journal of Material Cycles and Waste Management*, *20*(3), 1867–1877.
Budiyanto, Tri, Reni Dwi Astuti, and Annie Purwani. 2020. "Pelatihan Dan Pendampingan Pengolahan Sampah Menjadi Produk Bernilai Ekonomi Pada Bank Sampah Bersih Bersama Karanganom, Sitimulyo, Piyungan, Bantul." *SPEKTA (Jurnal Pengabdian Kepada Masyarakat : Teknologi dan Aplikasi)* 1(2): 49.
Constantin, J. T. Y., Shitote, S. M., Abiero Gariy, Z. C., & Ronoh, E. K. (2019). Influence of coarse aggregate on the physical and mechanical performance of paving blocks made using waste plastic. *International Journal of Engineering Research and Technology*, *12*(6), 912–916.
Deutz, P., Neighbour, G., & McGuire, M. (2010). Integrating sustainable waste management into product design: Sustainability as a functional requirement. *Sustainable Development*, *18*(4), 229–239.
Di Maria, F., Bianconi, F., Micale, C., Baglioni, S., & Marionni, M. (2016). Quality assessment for recycling aggregates from construction and demolition waste: An image-based approach for particle size estimation. *Waste Management*, *48*, 344–352.
Dixit, S., & Yadav, V. L. (2019). Optimization of polyethylene/polypropylene/alkali modified wheat straw composites for packaging application using RSM. *Journal of Cleaner Production*, *240*, 118228.
Dominguez, D., Muñoz, V. P., & Muñoz, V. L. (2017). Impact of Using Lightweight Eco-bricks as Enclosures for Individual Houses of One Story on Zones of High Seismicity. *Materiales de Construccion*, *67*(328), 133.
Faraca, G., & Astrup, T. (2019). Plastic waste from recycling centres: Characterisation and evaluation of plastic recyclability. *Waste Management*, *95*, 388–398.
Fernandes, S., Costa, L., Silva, H., & Oliveira, J. (2017). Effect of incorporating different waste materials in bitumen. *Ciencia e Tecnologia Dos Materiais*, *29*(1), e204–e209.
Frigione, M. (2010). Recycling of PET bottles as fine aggregate in concrete. *Waste Management*, *30*(6), 1101–1106. Gautam, P. K., Kalla, P., Jethoo, A. S., Agrawal, R., & Singh, H. (2018). Sustainable use of waste in flexible pavement:
A review. *Construction and Building Materials*, *180*, 239–253.
Haque, M. S. (2019). Sustainable use of plastic brick from waste PET plastic bottle as building block in Rohingya refugee camp: a review. *Environmental Science and Pollution Research*.
Hasnat, M. A., & Rahman, M. A. (2018). A review paper on the hazardous effect of plastic debris on marine biodiversity with some possible remedies. *Asian Journal of Medical and Biological Research*, *4*(3), 233–241.
Horodytska, O., Valdés, F. J., & Fullana, A. (2018). Plastic flexible films waste management – A state of art review.
Waste Management, *77*, 413–425.
Huang, H., Yuan, Q., Deng, D., Peng, J., & Huang, Y. (2019). Effects of chemical and mineral admixtures on the foam indexes of cement-based materials. *Case Studies in Construction Materials*, *11*, e00232.
Indrianti, N. (2016). Community-based Solid Waste Bank Model for Sustainable Education. *Procedia - Social and Behavioral Sciences*, *224*(August 2015), 158–166.
Intan, S. K., & Santosa, S. (2019). Utilization of PTE and LDPE plastic waste and building material waste as bricks.
Korean Journal of Materials Research, *29*(10), 603–608.
Jassim, A. K. (2017). Recycling of Polyethylene Waste to Produce Plastic Cement. *Procedia Manufacturing*, *8*(October 2016), 635–642.
Jayaprakash, M. ., Deeksha, I., & Soumya, M. (2016). PET Bottles for Eco-friendly Building in Sustainable Development. *International Journal of Current Trends in Engineering & Research*, *2*(5).
Jiang, T., Wang, X. M., Chen, G. M., Zhang, J. J., & Zhang, W. P. (2019). Behavior of recycled brick block concrete-filled FRP tubes under axial compression. *Engineering Structures*, *198*(July), 109498.
Kaliyavaradhan, S. K., Ling, T. C., Guo, M. Z., & Mo, K. H. (2019). Waste resources recycling in controlled low-strength material (CLSM): A critical review on plastic properties. *Journal of Environmental Management*, *241*(February), 383–396.
Kholil, A., & Jumhur, A. A. (2018). *Waste Management Based on 3R in Mutiara Waste Banks Bekasi City Indonesia*. *8*(3), 71–76.
Köfteci, S. (2016). Effect of HDPE Based Wastes on the Performance of Modified Asphalt Mixtures. *Procedia Engineering*, *161*, 1268–1274.
Kognole, R. S., Shipkule, K., & Survase, K. S. | M. P. | L. P. | U. (2019). Utilization of Plastic waste for Making Plastic Bricks. *International Journal of Trend in Scientific Research and Development*, *Volume-3*(Issue-4), 878–880.
Kumar, A., Samadder, S. R., Kumar, N., & Singh, C. (2018). Estimation of the generation rate of different types of plastic wastes and possible revenue recovery from informal recycling. *Waste Management*, *79*, 781–790.
Landi, D., Gigli, S., Germani, M., & Marconi, M. (2018). Investigating the feasibility of a reuse scenario for textile fibres

recovered from end-of-life tyres. *Waste Management*, *75*, 187–204.

Lastra-González, P., Calzada-Pérez, M. A., Castro-Fresno, D., Vega-Zamanillo, Á., & Indacoechea-Vega, I. (2016). Comparative analysis of the performance of asphalt concretes modified by dry way with polymeric waste. *Construction and Building Materials*, *112*(March 2018), 1133–1140.

Le, D. K., Leung, R. I. H., Er, A. S. R., Zhang, X., Tay, X. J., Thai, Q. B., … Duong, H. M. (2019). Applications of functionalized polyethylene terephthalate aerogels from plastic bottle waste. *Waste Management*, *100*, 296–305.

Lesueur, D. (2009). The colloidal structure of bitumen: Consequences on the rheology and on the mechanisms of bitumen modification. *Advances in Colloid and Interface Science*, *145*(1–2), 42–82.

Li, X., Ling, T. C., & Hung Mo, K. (2020). Functions and impacts of plastic/rubber wastes as eco-friendly aggregate in concrete – A review. *Construction and Building Materials*, *240*, 117869.

Li, Z., Zhang, T., Wang, Y., Yue, X., Yang, D., & Qiu, F. (2020). Waste-to-resource strategy to fabricate functionalized material from waste brick. *Science of the Total Environment*, *703*, 135032.

Liliani, Tjahjono, B., & Cao, D. (2020). Advancing bioplastic packaging products through co-innovation: A conceptual framework for supplier-customer collaboration. *Journal of Cleaner Production*, *252*, 119861.

Limami, H., Manssouri, I., Cherkaoui, K., & Khaldoun, A. (2020). Study of the suitability of unfired clay bricks with polymeric HDPE & PET wastes additives as a construction material. *Journal of Building Engineering*, *27*(June 2019), 100956.

Mahdi, F., Abbas, H., & Khan, A. A. (2010). Strength characteristics of polymer mortar and concrete using different compositions of resins derived from post-consumer PET bottles. *Construction and Building Materials*, *24*(1), 25–36.

Mourshed, M., Masud, M. H., Rashid, F., & Joardder, M. U. H. (2017). Towards the effective plastic waste management in Bangladesh: a review. *Environmental Science and Pollution Research*, *24*(35), 27021–27046.

Movilla-Quesada, D., Raposeiras, A. C., Silva-Klein, L. T., Lastra-González, P., & Castro-Fresno, D. (2019). Use of plastic scrap in asphalt mixtures added by dry method as a partial substitute for bitumen. *Waste Management*, *87*, 751–760.

Mukherjee, C., Denney, J., Mbonimpa, E. G., Slagley, J., & Bhowmik, R. (2020). A review on municipal solid waste-to-energy trends in the USA. *Renewable and Sustainable Energy Reviews*, *119*(March 2019), 109512.

Murmu, A. L., & Patel, A. (2018). Towards sustainable bricks production: An overview. *Construction and Building Materials*, *165*, 112–125.

Nandy, B., Sharma, G., Garg, S., Kumari, S., George, T., Sunanda, Y., & Sinha, B. (2015). Recovery of consumer waste in India - A mass flow analysis for paper, plastic and glass and the contribution of households and the informal sector. *Resources, Conservation and Recycling*, *101*, 167–181.

Ouda, A. S., & Gharieb, M. (2020). Development the properties of brick geopolymer pastes using concrete waste incorporating dolomite aggregate. *Journal of Building Engineering*, *27*(May 2019), 100919.

Paihte, P. L., Lalngaihawma, A. C., & Saini, G. (2019). Recycled Aggregate filled waste plastic bottles as a replacement of bricks. *Materials Today: Proceedings*, *15*, 663–668.

Pereira, J. M., & Lourenço, P. B. (2016). Experimental bond behaviour of GFRP and masonry bricks under impulsive loading. *Materials and Structures*, *49*(11), 4799–4811.

Perera, S., Arulrajah, A., Wong, Y. C., Horpibulsuk, S., & Maghool, F. (2019). Utilizing recycled PET blends with demolition wastes as construction materials. *Construction and Building Materials*, *221*, 200–209.

Polacco, G., Filippi, S., Merusi, F., & Stastna, G. (2015). A review of the fundamentals of polymer-modified asphalts: Asphalt/polymer interactions and principles of compatibility. *Advances in Colloid and Interface Science*, *224*, 72–112.

Rehman, M. U., Ahmad, M., & Rashid, K. (2020). Influence of fluxing oxides from waste on the production and physico-mechanical properties of fired clay brick: A review. *Journal of Building Engineering*, *27*(July 2019), 100965.

Rehse, S., Kloas, W., & Zarfl, C. (2018). Microplastics Reduce Short-Term Effects of Environmental Contaminants . Part I: Effects of Bisphenol A on Freshwater Zooplankton Are Lower in Presence of Polyamide Particles. *International Journal of Environmental Research and Publication Health*, *15*.

Safinia, S., & Alkalbani, A. (2016). Use of Recycled Plastic Water Bottles in Concrete Blocks. *Procedia Engineering*, *164*(June), 214–221.

Scaraboto, D., Joubert, A. M., & Gonzalez-Arcos, C. (2020). Using lots of plastic packaging during the coronavirus crisis? You're not alone.

Sellakutty, D. (2016). Utilisation of Waste Plastic in Manufacturing of Bricks and Paver Blocks. *International Journal of Applied Engineering Research*, *11*(3), 364–368.

Setyowati, R., & Mulasari, S. A. (2013). Pengetahuan dan Perilaku Ibu Rumah Tangga dalam Pengelolaan Sampah Plastik. *Kesmas: National Public Health Journal*, *7*(12), 562.

Sharma, P., & Sharma, M. (2017). *Utilization of Quarry Dust in Cement Concrete Paver Blocks for Rural Roads*. *2*(1), 118–124.

Singhal, A., & Netula, O. (2017). Utilization of Plastic Waste in Foundry Sand Bricks. *International Journal for Research in Applied Science and Engineering Technology*, *V*(IV), 977–982.

Smith, T., Tighe, S., & Fung, R. (2001). Concrete Pavements In Canada : A Review Of Their Usage And Performance. *2001 Annual Conference and Exhibition of The Transportation Association Of Canada, September 16-19, 2001, Halifax, Nova Scotia: Partnering For Success In Transportation*.

Taaffe, J., O'Sullivan, S., Rahman, M. E., & Pakrashi, V. (2014). Experimental characterisation of Polyethylene Terephthalate (PET) bottle Eco-bricks. *Materials and Design*, *60*, 50–56.

Thanyavinichakul, S., & Thanyavinichakul, A. (2018). The brick pavement production using waste plastic as ingredients together. *2018 22nd International Computer Science and Engineering Conference, ICSEC 2018*, 1–4.

Vidales-Barriguete, A., Atanes-Sánchez, E., del Río-Merino, M., & Piña-Ramírez, C. (2020). Analysis of the improved water-resistant properties of plaster compounds with the addition of plastic waste. *Construction and Building Materials*, *230*, 116956.

Wahid, S. A., Rawi, S. M. R., & Desa, N. M. (2015). Utilization of Plastic Waste in Foundry Sand Bricks. *Journal of Basic and Applied Scientific Research*, *5*(1), 35–44.

Wu, M. H., Lin, C. L., Huang, W. C., & Chen, J. W. (2016). Characteristics of pervious concrete using incineration bottom ash in place of sandstone graded material. *Construction and Building Materials*, *111*, 618–624.

Wulandari, D., Hadi Utomo, S., & Narmaditya, B. S. (2017). Waste bank: waste management model in improving local economy. *International Journal of Energy Economics and Policy*, *7*(3), 36–41.

Xiao, W., Yang, J., Fang, H., Zhuang, J., & Ku, Y. (2019). A robust classification algorithm for separation of construction waste using NIR hyperspectral system. *Waste Management*, *90*, 1–9.

Yaghoubi, E., Arulrajah, A., Wong, Y. C., & Horpibulsuk, S. (2017). Stiffness properties of recycled concrete aggregate with polyethylene plastic granules in unbound pavement applications. *Journal of Materials in Civil Engineering*, *29*(4).

Yudell, M., Roberts, D., DeSalle, R., & Tishkoff, S. (2020). Accumulation of plastic waste during COVID-19. *Science*, *369*(6509), 1314–1315.

Zhou, C. (2018). Production of eco-friendly permeable brick from debris. *Construction and Building Materials*, *188*, 850–859.