PROPERTIES OF WASTE POLYETHYLENE TERPHTHALATE (PET) TILE CONTAINING FLY ASH AND PALM OIL FUEL ASH AGGREGATES TOWARDS SUSTAINABLE CONSTRUCTION MATERIAL

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by

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DEDICATION

I dedicate this research study to the Almighty God; the creator of heaven and earth and also to my lovely husband and children; Mr. Omosebi Duyilemi A, Dr. Praise, Dr. Peace, Engr. Samuel, and Precious Omosebi.

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile-Butadiene-Styrene
Al	aluminum
Al_2O_3	aluminum oxide
BBA	Bisphenol
$CaOH_2$	calcium hydroxide
CCl_4	Carbon tetrachloride
CH3COO4	Acetic Acid
CO	carbon monoxide
CO_2	carbon dioxide
DTA	Differential thermal analysis
EPA	Environmental Protection Agency
EPS	Extruded Expandable Polystyrene
EU	European Union
FA	Fly ash
Ga	gallium
GAIA	global alliance for alternative incineration methods
Ge	germanium
GHGs	Green House Gases
H_2SO_4	sulfuric acid
HCl	Hydrochloric acid
HDPE	High-density polyethylene
HNO_3	Nitric acid
LCA	life-cycle assessment
LDPE	low-density polyethylene
Na_2CO_3	Benzene, Sodium carbonate
NaCl	Sodium chloride
NaOH	Acetone, Sodium hydroxide
OPC	Ordinary Portland Cement
PE	polyethylene
PET	polyethylene terephthalate
POFA	palm oil fuel ash
PP	polypropylene

PS	polystyrene
PVC	polyvinyl chloride
SEM	Scanning Electron Microscopy
SiO_2	crystalline silicon dioxide
TGA	Thermogravimetric analysis
Ti	titanium
V	vanadium
WRAP	Waste and Energy Action Program
XRD	X-ray diffraction

SIFAT-SIFAT JUBIN TERPHTHALATE POLYETHYLENE (PET) BUANGAN MENGANDUNGI BATU BAUR ABU TERBANG DAN ABU RELAU KELAPA SAWIT KE ARAH BAHAN BINAAN LESTARI

ABSTRAK

Perkembangan yang pesat di dalam sektor pembinaan global secara tidak langsung telah memberi kesan dan impak yang besar kepada perubahan kos bahan binaan dan juga sumber semula jadi yang digunakan di dalam pembuatannya serta kepada alam sekitar. Manakala pengurusan sisa plastik juga telah menjadi satu isu global di mana ia menjadi ancaman kepada kesihatan persekitaran disebabkan oleh kadar pembuatannya yang tinggi serta tidak boleh untuk menjalani proses biodegrasi. Oleh disebabkan itu, peluang untuk menukar sisa buangan plastik kepada bahan binaan yang baru dapat menjadi satu penemuan yang baik. Kajian ini dilakukan bagi tujuan menyelidik penggunaan bahan polyethylene terephtalate (PET) botol terpakai, pasir sungai, abu terbang dan abu relau kelapa sawit (POFA) di dalam penghasilan jubin. Ciri-ciri fizikal dan mekanikal seperti ketumpatan, permukaan liang, kadar penyerapan air, daya mampatan, kekuatan lenturan, kemudahbakaran, ketahanan lelasan, kestabilan haba, kadar toleransi terhadap bahan kimia ke atas pembuatan jubin Polymer serta pes PET selain interaksi antara struktur mikro pasir juga telah dianalisis. Bahan buangan PET telah digunakan dalam kuantiti yang berbeza (30%, 50%, 70%,

90% dan 100%) dalam pasir, abu terbang, dan POFA mengikut berat. Penilaian mekanikal dan ciri fizikal menunjukkan jubin yang mengandungi 30% PET berfungsi dengan lebih baik dari segi ketumpatan bahan, ketahanan, rintangan terhadap bahan api, kestabilan haba berbanding yang lain. Manakala kekuatan mampatan maksimum dengan nilai 19.71, 6.88 dan 8.37 MPa telah direkodkan dalam jubin Polymer yang diperbuat daripada pasir, abu terbang dan juga POFA. Selain itu, jubin Polymer juga

mencatat peratusan penyerapan air yang sangat minimal berbanding jubin seramik dan jubin simen. Peratusan penyerapan air yang direkodkan adalah di antara 0.1% - 1.91%. Manakala bagi pemeriksaan mikroskopik ke atas permukaan jubin pasir-Polymer telah menemukan kadar saiz lekatan antara plastik dan komponen pasir adalah kecil secara relatif. Saiznya juga direkodkan berkadar songsang dengan kandungan PET untuk sampel jubin. Jubin juga menunjukkan tahap toleransi yang kuat terhadap asid dan juga larutan asas yang berbeza. Botol terpakai PET sebagai bahan pengikat bersama pasir, abu terbang dan POFA terbukti boleh digunakan bagi menghasilkan jubin mesra alam di mana ia berfungsi lebih baik dari segi ketahanan dan kekuatan serta daya tahan hakisan juga baik berbanding jubin kawalan. Selain daripada boleh digunakan untuk kawasan kediaman dan komersial, ia juga dapat meningkatkan kemampanan alam sekitar di samping dapat menjadi usaha terbaik bagi menangani isu dalam pengurusan botol plastik, abu terbang dan juga sisa POFA.

PROPERTIES OF WASTE POLYETHYLENE TERPHTHALATE (PET) TILE CONTAINING FLY ASH AND PALM OIL FUEL ASH AGGREGATES TOWARDS SUSTAINABLE CONSTRUCTION MATERIAL

ABSTRACT

The fast expansion of the global construction sector has a significant impact on the cost of building materials, and also the natural resources required for the materials' production and the environment**.** Plastic waste management on the other hand is a global issue that poses a threat to our environment's health because of its high manufacturing rate and inability to biodegrade. The opportunity to turn waste plastics into new construction materials would be a major gain. This study examines the application of polyethylene terephthalate (PET) waste bottles, river sand, fly ash, and palm oil fuel ash (POFA) to produce tiles. Physical and mechanical characteristics such as density, porosity, water absorption, compressive strength, flexural strength, flammability, wear-abrasion resistance, thermal stability, and chemical tolerance of the manufactured Polymer tiles and also the PET paste and sand microstructure interaction have been investigated. PET waste was utilized in varying quantities (30 %, 50%, 70%, 90%, and 100 %) of sand, fly ash, and POFA by weight. The evaluation of the mechanical and physical characteristics of the materials demonstrated that the tiles with a 30% PET content performed better in terms of material density, strength properties, flame resistance, and thermal stability than others. The maximum compressive strength values of 19.71, 6.88, and 8.37 MPa were found in the polymer tiles made of sand, fly ash, and POFA respectively, in this study, the highest compressive strength was greater than the control sample. Also, polymer tiles have a very miniature percentage of water absorption in comparison to ceramic and cement tiles. The percentage of water absorption is between 0.1% - 1.91%. Microscopic

examination of the sand-polymer tiles' interface zone, revealed adhesion between the plastic and sand components with relatively small voids in which the size is inversely proportional to the PET content in the sample's tiles. The tiles also demonstrated strong tolerance to different acids and basic solutions. In conclusion, waste PET bottles as a binder with sand, fly ash, and POFA can be used to manufacture eco- friendly tiles that performed better in terms of durability and strength, are strongly resistant to abrasion than the control tile, and can be used in both residential and commercial areas. In addition, this will enhance environmental sustainability while also serving as an effective method of managing plastic bottles, fly ash, and POFA.

CHAPTER 1

INTRODUCTION

1.1 Background of Research

The building industry is one of the important sectors of the world. In the past few decades, there have been rapid industrialization and urbanization which have resulted in global infrastructure developments. However, this equally led to an undesirable scarcity of building materials and a rise in waste generation (Foti, 2013). The global building industry is influenced by the cost of construction materials and the raw materials necessary to create them, as well as the supportive climate, which is rising at an unprecedented rate. Furthermore, the construction industry's raw material consumption is increasing day by day, resulting in natural resource depletion, increased environmental impacts, and carbon dioxide emissions all over the world (Kare & Lomite, 2009). Solid waste is becoming an issue in addition to the environmental damage produced by the rapid growth of the construction industry. The volume of solid waste is rapidly increasing. The rate of expansion is anticipated to double every year. Plastics have gotten a lot of attention among solid waste materials because they are not biodegradable (Parvesh, 2015).

Plastic wastes are solid wastes that are produced in vast amounts and pose a serious danger to our planet's sustainability. When plastic debris reaches the oceans, it has been reported that it harms the ecosystem, economy, and aesthetics (Jambeck et al., 2018). About 300 million metric tons of waste plastics are manufactured each year (Singh et al., 2017). Because of its widespread use, such as in automotive, manufacturing, packaging, and healthcare, large amounts of plastic waste are generated all over the world.

Global demand for plastics continues to rise with its related untenable waste generation. By 2030, it is anticipated that the amount of plastic used per year will have increased from 236 million tons to 417 million tons (Hundertmark et al., 2018). On the other side, to avoid accidental plastic disposal, it is necessary to recycle or intentionally release polymeric materials into the atmosphere, thereby reducing the environmental pollution. Just 16 % of the polymers in the stream was processed for recycling in 2016, with the remaining 40 % going to landfill and 25% being incinerated (Hundertmark et al., 2018). European countries have recently a stepped-up commitment to increasing % of waste recycled. Europe collected 2018 about 29.1 million tons of plastic post-consumer waste. Only about one-third of it has been recyclized, this has marked a two-fold rise in recycled materials and also decreased exports of waste plastics outside the European Union by thirty-nine % relative to that of 2006. Packaging accounted for most of the plastic flow 39.9 percent (Plastics Europe, 2019). Packaging recycling is also more commercially viable than other plastics industry segments because of Europe's high turnover of post-consumer waste, 42 percent of it is recycled, 40 percent of the waste is transferred to be recycled into energy, and 19 percent is disposed of in landfills (Plastics Europe, 2019). Plastics' ability to degrade is limited by their stability, a vital performance feature that encouraged their use. As a result, landfills are overburdened, and excess waste is released into the atmosphere (Brahney et al., 2020). Based on a finding by the Waste and Energy Action Program WRAP, (2007) in 2018, the United Kingdom generates forty-seven percent of its waste plastic packaging to be recycled, and just forty-three percent of it is converted into useful feed (Plastics Europe, 2019; Hundertmark et al., 2018). In 2017, Japan produced over 9 million tons of plastic waste, incineration with energy generation and heat recovery, fuel waste, and auxiliary fuels in cement kilns processed more than 50 % of plastic waste, while only

23 % of the waste was recovered through material recycling (figure 1.1) (Hundertmark et al., 2018).

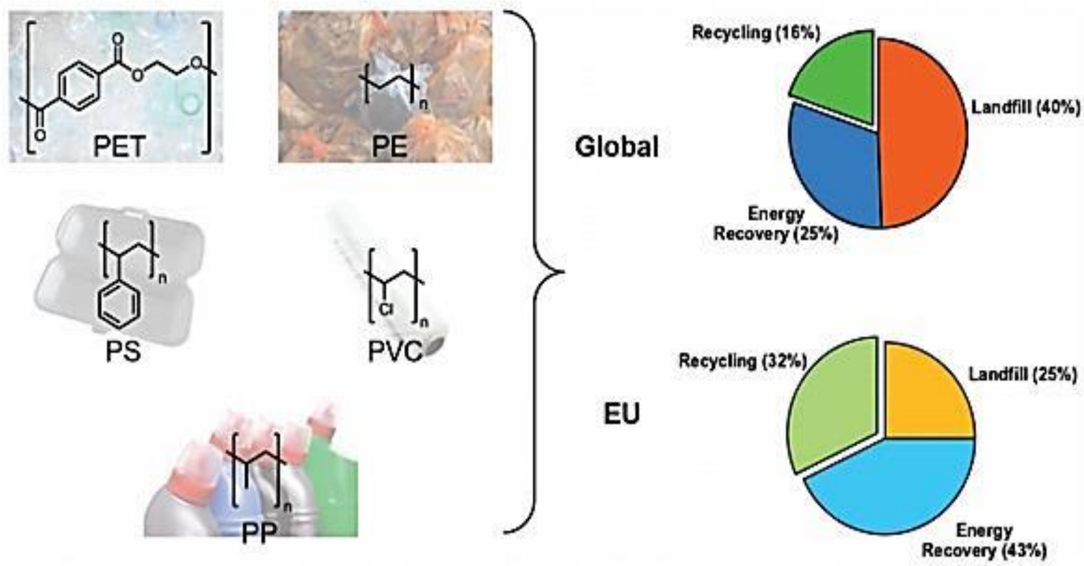

Figure 1.1 The primary packaging polymers are the current global and EU waste management percentage rates (Hundertmark et al., 2018; Tax, 2020).

Using the United Kingdom, for example, forty percent of obtained wastes in 2015–16 was polyethylene terephthalate (PET), and twenty-two percent polyethylene (PE), ten percent polypropylene (PP), polyvinyl chloride (PVC), and polystyrene (PS), which is two percent (WRAP, 2018). High-density polyethylene (HDPE) and PET bottles are used for packaging toiletries, food, also household cleaning items. The plastics industry in the world is essentially linear. Plastics are manufactured, used, and almost half of them are discarded without being retrieved (Hundertmark et al., 2018). To protect the environment while satisfying consumer needs, a global initiative must be made to turn the linear economy into a circular paradigm (Prata et al., 2020). The COVID-19 epidemic has shown that single-use plastics are required. Plastic use is on the increase because of emerging health risks and societal concerns about virus-infected goods generate consumer worries about re-use and lower recycling rates (Prata et al., 2020).

Plastic waste recycling is one approach for reducing its adverse environmental impacts and preventing depletion of resources, which can result in lower materials and energy consumption per unit of production and hence greater green building (Hamad et al., 2013; Singh et al., 2017). The ability to utilize these plastics waste for construction purposes not only conserves natural resources but also minimizes the total environmental harm that the generation of these plastics entails. Furthermore, the prospective use of waste plastics in construction applications will help the construction sector accomplish its sustainability objectives. Recycling plastic waste reduces energy consumption and carbon emissions by reducing the amount of new plastic processed and made (Awoyera & Adesina, 2020). Cement is also a prominent binder in the construction sector, but it is a costly substance (Konin, 2011). Owing to its high population growth and urbanization, to meet the demand for homes, various construction projects have been required, resulting in growing cement costs (Otuoze et al., 2012). As a result of this issue, several studies have concentrated on the use of different cost-effective materials for cost-effective construction (Ramaraj & Nagammal, 2014; Velumani, 2017). This has led to PET bottle usage as binders in the production of various construction goods, such as tiles. Shredded plastic waste is a recyclable material in the building industry that has attracted a great deal of attention.

There are several forms of plastic waste, with polyethylene and polyethylene terephthalate being the most common in waste streams (PET). Waste plastic bottles are the most common source of management of solid waste. Polyethylene Terephthalate (PET, PETE, or polyester) is a type of plastic used to make carbonated beverages and water bottles. It was an environmental concern because waste plastic materials are nonbiodegradable and require techniques other than recycling or reusing them (Frigione, 2010). Since plastic waste recycling has been proven to be effective, the packaging business has intensively researched various methods to recycle this waste; nevertheless, it is less commonly used in the building industry (Awoyera & Adesina, 2020). Thus, by molding plastic waste into tiles for building purposes, it is possible to recycle plastic waste in the most environmentally friendly way while also turning its major disadvantage into a benefit. The effect of different filler compositions is evaluated by determining the linear burning rate, assessing tensile strength, and testing chemical tolerance. The primary purpose of the project is to address the issue of plastic waste by recycling in a less capital-intensive manner, with the main goal of employing plastic waste bottles PET to manufacture plastic tiles, thereby resolving the problem of dumping this waste into landfills. Recently, many researchers have proposed the use of plastic waste in construction. Many researchers have shown the potential usefulness of plastic trash as construction materials; for example, Mehdi et al., (2017) found that roof tiles constructed from high-density polyethylene plastics and sand can be created. After investigation, the composite tiles made with 70% high-density polythene content exhibited improved quality and performance.

Similarly, a few studies on the usage of waste PET bottles as an alternative to natural aggregates in concrete have recently been published (Elshaday et al., 2019; Harini & Ramana, 2015; Mohan & Gayathri, 2019; Parvesh, 2015; Saxena et al., 2020) and in polymer concrete as resin (Niaki et al., 2018). Also, Akinwumi et al., (2019) reported the manufacturing of stabilized soil blocks from shredded plastic trash; the study approved the use of 1% finely shredded PET waste (size 6.3 microns) by weight for efficient block stabilization. Another study by Kumi-Larbi et al., (2018) reported effective manufacturing of sand blocks using plastic waste; the results of the study showed that solid and durable sand blocks can be generated without additional water using only waste plastic.

Sand is a granular material made up of mineral grains and finely distributed material that occurs naturally. Sand's composition varies based on local geological conditions and origins, but in non-tropical coastal locations and continental inland settings, crystalline silicon dioxide (SiO_2) is the most prominent ingredient. The other often used sand is calcium carbonate, e.g., aragonite, which has arisen over the previous half billion years predominantly by diverse life forms, including corals and shellfish, and can be found in a wide range of structures.

Cement is commonly utilized as a binder in the building sector; nevertheless, the exorbitant cost of cement has kept many people from taking advantage of this opportunity from constructing their homes and hampered the growth of the construction sector (Ramaraj & Nagammal, 2014; Srivastava & Singh, 2020; Velumani, 2017). Therefore, it is critical to find a suitable substitute for this costly and necessary material for construction (Harini & Ramana, 2015; Niaki et al., 2018). Structural and architectural items used for lining floors, roofs, and walls are tiles. In a number of places, most of them are seen, such as buildings floors, doors, warehouses and restaurants, art galleries, industrial garages, schools, and workshops. Tapestry, wood, stone, or cork are examples of non-ceramic surface content that can be generalized to incorporate tiles (Bhogayata & Arora, 2018).

Fly ash (FA) is a substance produced by coal combustion in power plants. The abundance of fly ash around the world presents an opportunity to use this by-product of coal combustion as a fine aggregate replacement in tiles production. Fly ash is a readily available raw material for geopolymer binders, although its application so far has been restricted. More specifically, the worldwide output of coal ash is anticipated to reach 390 million tons per year, with less than 15% usage (Malhotra et al., 2018).

Palm oil fuel ash (POFA) is another type of ash produced by the combustion of waste materials such as palm kernel shells and palm oil husks (Awal, 2011). POFA is usually disposed of in landfills, which results in an increased amount of Ash deposits every year and now has become a burden (Chindaprasirt and Homwuttiwong, 2007).Palm oil is mostly produced in Southeast Asian countries. Palm oil fuel ash (POFA) is an important by-product of the palm oil industry (Khankhaje et al., 2016; Tangchirapat et al., 2007),and it is produced by burning waste materials such as palm oil fiber, empty fruit bunches, kernels, and shells in power stations to produce electricity (Khankhaje et al., 2016).The amount of POFA produced grows over time as the amount of palm oil produced increases. Malaysia is a major exporter and producer of palm oil in the world (Yusoff, 2006). The annual POFA manufacture in Malaysia is expected to be over 10 million tons (Awal, 1997; Safiuddin et al., 2011). In Malaysia, about 1000 tons of POFA were thrown into lagoons and landfills, with little consideration given to the material's potential use in other industries (Awal, 2011). As a result, innovative approaches to using waste materials while avoiding potential dangers are required. Researchers in this field must focus on the utilization of alternate renewable resources, such as palm oil waste, which are being used in the construction industry to attain higher sustainability. In terms of cost savings, employing POFA as an aggregate in plastic tiles production will lower the cost of tiles manufacturing as well as mitigate and lower garbage in landfills, this will benefit the ecosystem.

Tiles are commonly used in a variety of places, including building floors, warehouses, and museums. Art galleries, building walls, commercial parking, a hall, and a factory are all examples of this. They are ornamental or structural elements that are used to cover floors, roofs, and walls. This could comprise small flat bits of non-ceramic surfacing material, such as carper, wood, stone, or cork (Ohijeagbon et al., 2012). According to the literature, there are few publications on the use of plastic wastes in tile manufacture, despite the fact that many studies have been published on the use of plastic wastes in concrete production. In addition, the mechanical properties of plastic waste-containing composites have been the subject of most literature studies, with little attention paid to the effects of such addition of plastic waste on the wear-abrasion resistance, flammability, and chemical resistance of such composites. This study, therefore, concentrated on the possibility of using river sand, POFA, fly ash, and PET plastic wastes as complete cement substitutes in the construction of tiles. For various properties (such as flammability, abrasion resistance, and chemical resistance) on the resulting interlocks, different PET waste contents (30 to 100 percent) by weight were examined; laboratory investigations were also conducted on the mechanical and physical characteristics of the resulting tiles, samples were also subject to microstructural studies. Therefore, applying these harmful and non-biodegradable wastes in various tiles, PET as a binding agent, and substitution of cement with river sand, fly ash, and POFA may be able to decrease environmental problems caused by improper waste disposal while also lowering the cost of building production (Elshaday Haile & Emer Tucay Quezon, 2019).

1.2 Problem Statement

This research identified the following problem statements that must be addressed.

1.2.1 The amount of Plastic waste in circulation

Global demand for plastics continues to rise with its related untenable waste generation. By 2030, it is anticipated that the amount of plastic used will have climbed from 236 million to 417 million tons per year (Hundertmark et al., 2018). Based on a finding by the Waste and Energy Action Program (WRAP) In 2018, the United Kingdom generated 47 percent of its waste plastic packaging to be recycled, and just 43 % of it is converted into useful feed (PlasticsEurope, 2019; Hundertmark et al., 2018). In 2017, Japan produced over 9 million tons of plastic waste. Plastics account for approximately 12.3% of total municipal solid waste. It is worth noting that the majority of plastics are drinking bottles made primarily of PET (Ramadevi & Manju, 2012). With an alarming pace of demand and supply for PET bottles, which come in the form of packaged water, soft drinks, cold drinks, and other beverages, there is a huge challenge ahead on what to do with used PET bottles once they have been dumped as waste (Angyal et al., 2010). By recycling this waste, solid waste management related to plastic waste in landfill or incinerators would be decreased. This study will also assist the government's effort to establish green building products in the market, giving construction professionals more options for choosing the most environmentally friendly and low-cost materials.

1.2.2 Recycled Plastic Used in Building and Construction

Every day, a massive number of plastic and polymer products are manufactured around the world. Although the majority of items are designed to be recycled, the reality is rather different. According to statistics, the percentage of recyclable plastic and polymer items that are actually recycled is quite small. The building and construction industry utilizes up to 20% of all manufactured plastic (Figure 1.2). As a result, they persist as possible contaminants in the environment. This research investigates the reusability of PET plastic bottle waste as a binder to manufacture tile for construction purposes in order to promote PET usage in building and construction, minimize environmental hazards, and properly reduce building production costs.

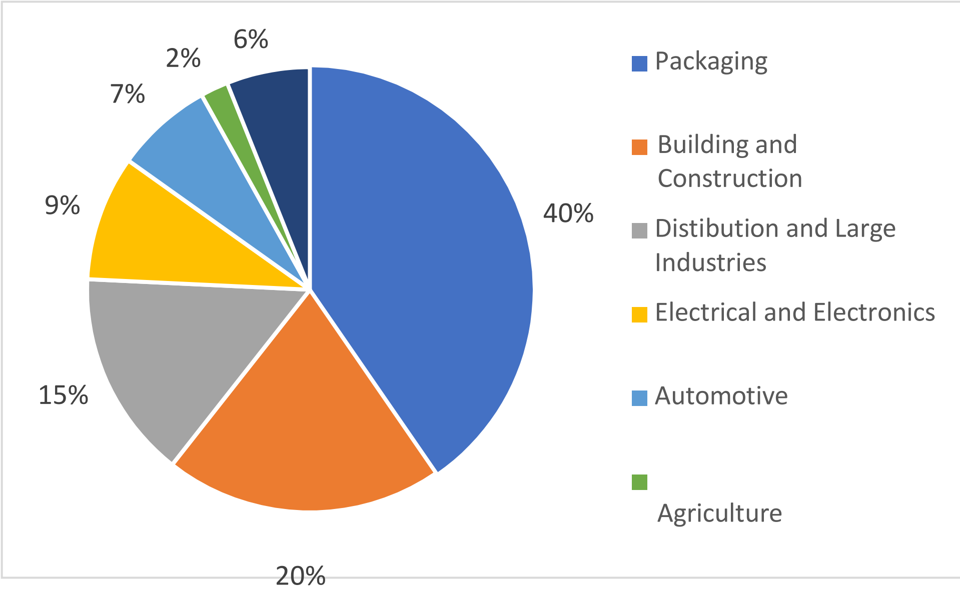

Figure 1.2 Recycled Plastic Material Used in Different Field (Zoorob & Suparma., 2000)

1.2.3 Health and environmental hazards from plastic waste

Plastics are convenient packaging materials and containers, but their waste is a major source of pollution in the environment; when incinerated, they generate harmful chemicals and are not biodegradable. When plastic waste is burned, poisonous gases such as Sulphur dioxide, phosgene, chlorine, nitrogen oxide, carbon monoxide, and other dangerous dioxins are released into the atmosphere. Plastics' ability to degrade is limited by their stability, a vital performance feature that encouraged their use. As a result, landfills are overburdened, and excess waste is released into the atmosphere (Brahney et al., 2020). Physical fragmentation, the introduction of micro-and nano-plastics in water sources, urban habitats, protected areas, and our food chain have all been compounded by the substance's ubiquity and the variability of its disposal (Brahney et al., 2020). However, to avoid accidental disposal of plastics, it is necessary to recycle or intentionally release polymeric materials into the atmosphere, thereby reducing the environmental pollution. This research is converting this hazardous waste into useful building material through recycling.

1.2.4 Low percentage of plastic waste recyclable

According to research published by the United States Environmental Protection Agency (US EPA, 2015), just 7 percent of the plastic waste produced yearly is recycled, with the other 8% being burnt. Consequently, due to the high price and energy required with the landfilling process, these wastes have ended up in bodies of water. Just 16 % of the polymers in the stream was processed for recycling in 2016, with the remaining 40% going to landfill and 25% being incinerated (Hundertmark et al., 2018). Europe collected 29.1 million tons of post-consumer waste made of plastic in 2018, and just about one-third of it has been recyclized, this has marked a two-fold rise in recycled materials also decreased exports of waste plastics outside the European Union by thirty-nine % relative to that of 2006. Waste and Energy Action Program (WRAP) in 2018 reported that the United Kingdom generates 47% of its waste plastic packaging to be recycled, and just 47% of it is converted into useful feed (Hundertmark et al., 2018; Plastics Europe, 2019). In 2017, Japan produced over 9 million tons of plastic waste. Incineration with energy generation and heat recovery, fuel waste, and auxiliary fuel in cement kilns processed more than 50% of plastic waste, while only 23% of the waste was recovered from material recycling (Figure1.2) (Hundertmark et al., 2018; Tax, 2020). Using PET plastic bottle waste to manufacture construction and building materials will be a great advantage and enhance its management and environmental sustainability.

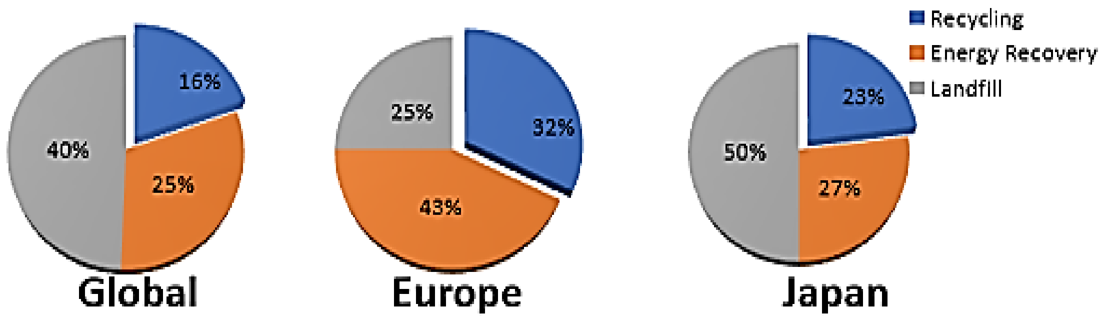

Figure 1.3 United States, Europe, and Japan's current plastic waste management rates (Hundertmark et al., 2018; Tax, 2020).

1.2.5 Non-biodegradability of plastic waste

Thermoplastics get a large market worldwide because of their low manufacturing costs, strength, chemical resistance, and durability. However, the same features that make those plastics appealing equally make them a danger to life on Earth. These plastics are chemically non-biodegradable and can pollute the land and oceans; due to these reasons, their disposal was a major issue (Li et al., 2018; Ryan, 1988; Thompson et al., 2009). Plastic's poor biodegradability severely limits its recyclability and environmental disposal. As a result, using these toxic and non-biodegradable wastes in the manufacture of plastic tiles as a complete replacement for cement may be able to mitigate environmental issues caused by improper disposal of plastic waste bottles.

1.2.6 POFA and FLY ASH generation and their environmental hazard

Palm oil production accounts for the majority of global vegetable oil output, which totaled more than 60 million tons in 2012, with palm oil accounting for more than 35% of overall vegetable oil production in the same year (Chiew & Shimada, 2013; Hansen et al., 2015). Malaysia and Indonesia produce the most palm oil production in the world, accounting for greater than 80% of total output. In 2011, Indonesia produced 48 percent of all palm oil, Malaysia 38 percent, and Thailand 3 percent (Awalludin et al., 2015; M. Gatto, 2015; Sulaiman et al., 2012). Increased production of palm oil results in a large number of waste materials, such as POFA, which have a high silica concentration and have major environmental consequences if not employed in other industries. Malaysia's yearly production of POFA is estimated to exceed 10 million tons (Abdul Awal & Warid Hussin, 2011). Over 1000 tons of POFA have been thrown into Malaysian lagoons and landfills, with little consideration being given to the material's potential use in other industries. Palm oil fuel ash (POFA) accounts for around 5% of solid waste weight created following steam boiler combustion (Sata et al., 2004). The ash is light and tiny, so it is readily blown out by the wind, causing haze on a humid day. Smog makes it difficult to see and poses a traffic risk, in addition to creating a health concern by triggering bronchial and lung diseases.

Also, it is estimated that 360 million tons of fly ash are stockpiled around the world. Electrical energy is generated in thermal power stations that use coal, particularly in Turkey. There are over 15 million tons of fly ashes that are produced at the end of coal-based energy production. Because this form of industrial waste is held on plant grounds, it is unavoidable that it causes air pollution, visual pollution, and soil contamination as a result of meteorological conditions such as wind and rain. In this regard, coal fly ash causes significant storage and environmental issues, it is critical that fly ashes contribute to the economy by being recycled in industries such as chemicals, ceramics, glass, and buildings, rather than being stored on plant grounds (Cheng & Chen, 2004; Derun et al., 2010; Erol et al., 2008; Fernández-Pereira et al., 2011; Ghorab et al., 2007; Haiying et al., 2011; Joseph & Ramamurthy, 2009; Nochaiya et al., 2010). In terms of cost savings, employing POFA and Fly ash as aggregate in plastic tiles production will lower the cost of tiles manufacturing as well as mitigating and lowering garbage in landfills, this will benefit the ecosystem**.**

1.2.7 High cost of building materials

The construction industry is one of the largest consumers of natural resources (Al-fakih et al., 2019). The construction sector is a vital part of the global economy. Many infrastructural expansions are occurring as a result of growing industrialization and urbanization, resulting in a severe shortage of construction materials (Foti, 2013). The demand for housing, infrastructure facilities, and other concrete building increase according to the increment of the world population. As a result of this, the production of concrete has rapidly increased virtually in all countries. Concrete is currently the second most widely used building material after water, with a global consumption percentage of approximately 25 X 109 tons yearly (Celik et al., 2015). Cement is the most widely used binder material in concrete structures, accounting for approximately 3.3 billion tons of cement usage per year (Embong et al., 2016). Cement production is an energy-intensive process that consumes approximately 4 GJ (a gigajoule = one thousand million joules) of energy per ton of cement produced. Besides that, during fuel combustion and limestone calcination, 622 kg of CO_2 per ton of cement is produced, as well as other hazardous greenhouse gases (Al-fakih et al., 2019). The global production of ordinary Portland cement (OPC) rises by 9% per year, posing a critical environmental issue because it emits a significant amount of CO_2 into the atmosphere (Joseph & Mathew, 2012). Ordinary Portland cement production, in particular, emits approximately 1.5 billion tons of greenhouse gases per year, accounting for 6% of total emissions from various industries globally (Joseph & Mathew, 2012; Shobhakar Dhakal, 2009). However, integrating PET plastic bottle waste as a total cement replacement in the product reduces the amount of cement usage; as a result, this environmentally friendly construction material reduces greenhouse gas emissions, saves energy, reduces energy consumption, and protects natural resources (Albitar et al., 2015).

1.2.8 Sustainable Construction Materials

The development of sustainable building materials has the potential to prevent and manage pollution and environmental damage, which is one of Malaysia's Green Strategies (Department of Environment, 2010). According to Zhang et al., (2021), producing 1kg of Ordinary Portland Cement (OPC) takes around 1.5kWh of energy and emits roughly 1kg of CO_2 into the atmosphere. The production of polymer tiles from plastic bottle wastes as building materials, for example, reduction in production and energy costs, and also a reduction in carbon dioxide emissions.

1.3 Research Gap

In current history, scientists have concentrated their efforts on developing cost-effective and ecologically friendly technologies for recycling and reusing plastic waste. Many viable recycling solutions have been developed. Researchers have devised strategies for using plastic waste as a fine aggregate in concrete mixtures to produce a product with excellent flexural and compressive strength as well as mechanical resistance compared to traditional concrete products (Bhogayata & Arora,
2018; Saikai & De Brito, 2016). However, based on literature many studies have been published on the usage of plastic wastes in concrete production, but there are few reports on the use of plastic wastes in tile production and there was no literature that use the three waste Fly ash, POFA, sand with PET to produce tiles.

Apart from Bamigboye et al. (2019), Diptikar Behera (2018), Elshaday Haile and Emer Tucay Quezon (2019), Pagar et al. (2018), Mohan and Gayathri (2019), Dhawan et al. (2019), and few others utilized PET waste as a binder in replacement of cement. Most researchers carried out experiments using PET waste as an aggregate replacement for concrete production such as Iucolano et al. (2013), Akçaözoğlu et al. (2013), Saikai and De Brito (2016), Fraternali et al. (2013), Saikia and De Brito, (2014), Saxena et al. (2020), Borg et al. (2016) to mention but few, they evaluate the competency of plastic waste bottles can be used to partially substitute fine and coarse materials in concrete manufacturing. Using it as a binder as a full replacement of cement to produce a sustainable construction and eco-friendly component such as plastic tiles is very rare. Additionally, the mechanical properties of composites containing plastic waste were determined by most researchers, with little attention paid to the effects on thermal stability, flammability, abrasion, and chemical resistance of such composites.

Consumption of plastic materials increased rapidly, in 1964, annual plastic output amounted to only 15 million metric tons, but by 2018, it had increased to 360 million metric tons (Neufeld, Stassen, Gilman, 2016; Plastics Europe, 2019). Around 8660 million metric tons of virgin plastic have been generated globally by 2018. This has resulted in huge waste being injected into the production volume. By 2015, the projected global plastic trash was over 6300 million metric tons, of which only 9 percent had been recycled, 12 percent had been burnt, and 79 percent had been deposited in landfills or the natural environment (Geyer et al., 2017). Because of its wide range of applications, such as in automotive, industrial, packaging, and healthcare, plastic waste is generated all over the world. According to research published by the United States Environmental Protection Agency (US EPA, 2015), just 7% of the plastic waste produced annually gets recycled, 8% is burnt, and the rest is landfilled. However, due to the high expense and energy connected with landfilling, these wastes have been placed in bodies of water. Furthermore, plastic's poor biodegradability limits its recycling rate and disposal in the environment significantly. As a result, converting this trash into tiles will not only reduce pollution but also enhance the sustainable environment.

The cost of construction materials and the required raw materials to produce them within the enabling environment is having an impact on the global construction industry, which is growing at an alarming rate. In addition, plastics wastes are becoming a threat to the environment because of its presence in the large amount due to their increased usage, the disposal is either in landfills or incineration which caused environmental pollution due to their non-biodegradability nature and poisonous gas emission through incineration. Recycling these wastes into different tiles such as roof, floor, and interlocking tiles will be a great advantage.

Also, looking to the high cost of cement, which is generally accepted as a binder in concrete production, many people could not afford personal building, especially urban dwellers (Velumani, 2017).This calls for alternative materials which are economical and can serve the same purpose in replacement of cement. The utilization of PET waste as a binding agent is a good alternative and very economical. Applying PET wastes which are harmful and non-biodegradable wastes as a binder in various tiles production, in replacement of cement could able to alleviate the environmental issues caused by improper waste plastic bottle disposal and over- mining of natural clay for cement production since cement contain 70% of clay and another ingredient.

Fly ash is a substance produced by the burning of coal in power plants. The abundance of fly ash around the world presents an opportunity to use this byproduct of coal combustion as a fine aggregate replacement in tiles production. It is a readily available raw material for geopolymer binders. More specifically, the estimated global coal ash output exceeds 390 million tons yearly, while its utilization is estimated to be less than 15% (Malhotra et al., 2018). Likewise, increased palm oil production generates a large number of waste products like POFA, that contain a high silica concentration and have major environmental consequences if not employed in other industries (Hamada et al., 2018).

Cement, the most often used binder in the construction sector, is very expensive (Mehdi et al., 2017). This is really a direct outcome of rapid population growth and urbanization, which has increased the appeal of cement for a variety of development goals, including the requirement to build a large number of structures. As a result of the requirement to bridge the gap between demand and high cost, researchers are investigating the use of less expensive alternative sources, such as Polyethylene Terephthalate (PET) wastes, as cement replacement to produce construction material.

1.4 Research of Objectives

The main objective of this project was to examine the possibility of using PET waste (plastic bottles wastes) with river sand, fly ash, and POFA to produce polymer tiles as a constructional material. This is intended to mitigate the environmental pollution caused by PET plastic waste disposal and minimize the cost of building products.

1.4.1 Specific Objectives

The specific objectives are to:

i. To evaluate the microstructural analysis of the polymer tiles produced from PET waste as a binder and river sand.
ii. To evaluate the mechanical properties of the polymer tiles produced from PET waste, fly ash, POFA, and river sand in terms of compressive strength and flexural strength.
iii. To evaluate the durability of the polymer tiles produced from PET waste, fly ash, POFA, and river sand in terms of water absorption, porosity, and chemical tolerance.
iv. To examine the polymer tiles produced from PET waste and river sand in terms of Abrasion/wear resistance, flammability resistance, and thermal stability compared to the control tile or pure PET tile.

1.5 Research Questions

According to prior studies, PET waste aggregate has the potential to produce tiles depending on % PET composition. This study wishes to investigate the appropriate percentage of PET composition that could produce strong, durable, and eco-friendly tiles.

Therefore, the following research questions have been designed for this study in order to obtain substantial answers to the above statement:

i. What is the correct PET waste content required to produce tile of equal or higher strength than the conventional or cement tile?

ii. Which of the aggregates, sand, fly ash, and POFA, provided the strongest polymer tiles?

iii. What is the percentage of water absorption of each Polymer PET tile?

iv. What is the chemical resistance capacity of the Polymer PET tiles with respect to strong Acid and Alkaline solutions?

v. How is Polymer PET tile superior to traditional or ceramic tile in terms of wear-abrasion, flammability, and thermal stability?

1.6 Significant of Research

From the environmental perspective, the utilization of plastic wastes like polyethylene terephthalate (PET) bottle wastes as a replacement for cement, fly ash, and POFA in the production of strong and durable tiles will reduce the dependency on cement and as a result, will decrease the carbon footprint as well as lessen the energy consumed for the production of cement. PET plastic, fly ash, and POFA wastes utilization will reduce the negative impact of landfill and incineration due to the disposal of PET plastic waste. Additionally, using PET plastic bottle wastes, fly ash, or POFA, in producing tiles is more cost-effective especially when time, cost, and quality became a major concern for industry players. Considering the numerous industrial and municipal solid wastes generated globally, this research study is being carried out in order to collect experimental information regarding the physical and mechanical properties of tiles made from PET plastic, fly ash, and POFA waste in the laboratory**.** It also investigates the durability, flammability, thermal, abrasion, and chemical resistance of the tiles produced**.**

Theoretically, extensive research was conducted on the use of PET plastic bottle wastes as a partial alternative for cement in concrete production and complete replacement in tiles production, yet some limitations on materials testing and characterization such as flammability, abrasion, thermal stability, and chemical resistance assessment are not well recorded**.** In addition, combining PET waste with fly ash and, in particular, POFA in the production of tiles has received little attention.

Also, since PET has poor resistance to flame, mixing it with fly ash which is rich in SiO_2 will reduce the burning rate of the plastic and make it more durable. Those metal oxides prevent polymer carbonization, resulting in a more long-lasting and effective char layer that serves as a buffer between surface undecomposed and burning materials. The use of fly ash improves the flammability resistance of plastic tiles.

The research will aid in reducing the volume of plastic waste, fly ash, and POFA dumps in cities and towns, resulting in a less unattractive landscape, flooding due to blockage of water flow channels, and disease outbreaks with environmental degradation and the outrageous cost of building materials are reduced. In view of this, using PET waste as full cement replacement in the production of tiles will enhance the following**:**

The perspective on sustainable /green building materials is based on the design ecologically correct by using internal recycling, renewable energy sources, and recyclable materials without the need of sacrificing or depending on natural resources**.** This novel product has the potential to compete with other similar products if properly designed. The study's findings will herald a new attempt to develop a novel sustainable construction material with sufficient strength and durability, as well as a focus on the practicability of sustainable/green building materials**.**

1.7 Scope and Limitation

In terms of context, the research focused on the process of producing polymer tiles from PET wastes with river sand, fly ash, and POFA and river sand**.**

In this research washed shredded PET waste bottles were used of varying proportions; 100%, 90%, 70%, 50%, and 30%, these were melted and mixed with river sand aggregate (<0.6mm size), fly ash, and POFA to produce thirty samples per mix for testing.

This is to supplement current research and acquire a thorough view of the expanding amount of study on polymer tiles**,** established fundamental and empirical laboratory tests such as flexural strength, compressive strength, water absorption, and effect of acids and alkaline on the mechanical properties were employed. Polyethylene Terephthalate (PET) which is of interest in this study, was processed into aggregates and used in place of cement as a binder for manufactured tiles. Laboratory studies were conducted to determine the suitability of the polymer tiles as a construction material by comparing them with conventional tiles. This research is not intended to investigate and compare theories in polymer tiles but to embrace the application of this far- fetching technology by taking cognizance of subsequent developments and the menace of waste plastic.

Summarily, the center focus of this research includes the following:

a. The production of tiles from fly ash, POFA, river sand, and PET wastes (plastic bottle wastes) as a binder in complete replacement of cement.
b. To investigate the durability and mechanical properties of the PET polymer tiles produced.

c. Examine the thermal stability and microstructural analysis of the PET polymer tiles produced.

d. Lastly, an assessment of the best percentage composition of the PET waste content that could produce high strength and durable tiles when compare with the control tile.

Hence, the following are the study's limitations:

i. The contents of PET wastes used in this experiment are 30%, 50%, 70%, 90%, and 100% while the river sand, fly ash, and POFA contents are 70%, 50%, 30%, and 10% only.

ii. The samples were cooled at room temperature for 24 hours before testing, because there was no cement in the mixture, no curing was performed.

iii. The recycling method used is mechanical recycling techniques.

iv. The mixing was done manually.

All of the tile samples were evaluated solely for their mechanical properties and durability, with the exception of the sand-polymer tile, which was subjected to additional tests such as abrasion, SEM, TGA, and thermal conductivity testing. Due to a lack of funds and the testing machines in my school (Housing, Building, and Planning), I was unable to conduct additional tests on the Fly ash and POFA samples. The gap could be filled by a future researcher.

1.8 Outline of Thesis

The thesis comprises six chapters: Chapter 1 highlights the background of the study, problem statement, research gap, research question, research aim and objectives, and scope, and significance of the study.

Chapter 2 examines the previous literature concerning the topic of plastic waste recycling into plastic tiles. Analysis of the previous studies was rigorously carried out in this chapter. The historical background of plastic and PET waste, types of plastic, method of recycling, and its application in building.

Chapter 3 explained in detail the methodology involved in this research, including the experimental program and material characteristics, also the substantial criterion for examination or exploration program are detailed.

Chapter 4 elaborate on the physical properties of the river sand, the characteristic strength, and fluid transport properties of the PET plastic tiles and pavers produced in term of density, compressive strength, flexural strength, porosity, water absorption, and chemical resistance of all sample.

Chapter 5 present a detailed assessment of material characteristics and flammability resistances of the polymer tiles and paver compared to other conventional tiles. Aside from this, the thermal stability of the study samples was also analyzed**.**

Chapter 6 which is the last chapter of this thesis provides a concise summary of the experimental work's conclusion reports. It also contains implementation recommendations and future research possibilities**.**