Waste Plastic in Road Construction, Pathway to a Sustainable Circular Economy: A Review

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Abstract. Plastic waste is one among the numerous waste that is harmful to the environment and is been established to have a significant dominance among the industrial waste. A critical problem is in how to discard the waste plastic which is quite difficult because its non-biodegradability. Similarly, improving the sustainability of manufacturing industry and the overall circular economy remain a major challenge to the global economy. Thus, this study focused on the existing literatures on thedeployments of waste plastic in road construction. From the literature consulted, it was discovered that the incorporation of the waste plastics into the building materials like bitumen depends on the economical, ecological and technical requirements. However, adequate application of the waste plastics in road construction will provide roads and pavements with adequate rheological properties and reliability. Also, it will minimize the problem of dumping of waste plastics on the landfills that could pose threat to the environment. Thus, bringing a sustainable circular economy. This study provides a hub of information that will guide the government and other authorities on the need to develop policy that will guide the use of waste plastic in road construction without compromising the standard quality of road required.

Keyword: Waste plastics, road construction, circular economy, bitumen, asphalt, environment

1. Introduction

Plastics are materials which are not environmentally friendly and long lasting and appears eternal in the nature. It contains some chemical substance which increased its life span and repel degradation process. Currently, an average of 45 Kg of plastic is being used by a single person which culminate to about 360 million tons. The environmental problems caused by used plastics is highly colossal. It has some intrinsic properties that made it difficult for it to be disposed of easily because it has the capacity to stay for decades and discarding it into landfills, plastics will find its way via air or water into the environment. More so, it can be consumed by certain creatures which could result to poison and death if not well taken care of [1].

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Studies have established that waste plastics could be deployed into the construction industry such as road construction which represent a means of disposing them as waste, hence improving the recycling process as well as developing the circular economy. It was reported that it has the characteristic of improving the rheological properties of the road and is even economical and proficient as well. Road made from plastics have unique and quality characteristics than the one constructed using bitumen. Thus, it has the capacity to strengthen the road and thus, improving the durability as well as water resistant ability [2].

According to Abdy et al. [3], there are increasing pressure on the techniques of managing plastics waste and structures due to the need to improve on its sustainability in the aspect of recycling. One of the promising technologies for recycling plastics is the use of thermochemical technology which is the current method used to meet the European Union 2030 agenda especially for large scale pyrolysis. Based on this, the study focused on the application of pyrolysis to the large-scale recycling of polyolefin, high-density polyethylene, polypropylene and low density polyethylene with the aim of achieving the main wax product present. The out revealed that plastics from bitumen as a modifier could help in overcoming the limitations associated with modifiers of bitumen involving plastics. In a study by Parihar and Verma, [4], it was established that the western part of India is deserted and dominated by dune sand. The sand is known to be characterized by zero plasticity and cohesive force as well as low compressive strength. Admixture of this sand with plastic waste helps in the stabilization of the dune sand which made suitable for road constructions and other structures like helipads as well as in the construction of airfield.

In the same vein, it was established that management of plastics which formed a major municipal solid waste in Ghana is a major problem. Also, the roads in their major cities are characterized by potholes resulting from heavy traffic and weight of vehicles and their axles. To this end, Appiah et al. [5] examined the effect of blending polyethylene and polypropylene into a traditional AC-20 bitumen grade using varying compositions of the plastics. The experimental work involved the shredding of the plastics and blending with the bitumen using a mixer having the temperature range of between 160 to 170 degree Celsius. Further characterisations of rheological properties like penetration, ring and ball softening process as well as viscosity were carried out. While the varying changes in the bitumen was explored using FTIR spectroscopy. The result showed that there was a significant enhancement in the modified bitumen compared with the unmodified with decrease in the value of penetration for the increasing values in the ratio of the bitumen.

According to Merchanet al. [7], the production of plastic has grown tremendously due to the increasing demand by industries like medicals, pharmaceuticals and packaging industries. Thus, the reason behind the massive plastic waste generation could then be attributed to the following:

- Increase in world production of plastic if 200 fold which commenced from 1950 to 2014. This is expected to double by the year 2050 if certain measure to control it is not taken
- Inadequate and consistent recycling techniques, thus, causing excessive landfills with plastics
- Short term utilization of the plastics

Based on these problems, the study investigated the possibility of linking the economic and environmental benefits of waste plastics to the construction industry via effective valorization methods so as to have an inclusive circular economy. The results showed that

the adoption of the circular economy would help to make plastic waste ecofriendly as well as sustainable green building materials, hence this aligns with sustainable development goal number 11 where building sustainable cities and infrastructures as well as resilience and safety were encouraged. Figure described the various standard recycling codes world wide and their mode of applications. They are divided into thermoplastics and has the capacity to melt during application of heat as well as hardened after cooling and thermoset which have variation in chemical composition after heating. Figure 2 also display the annual production of plastic from 1959 to 2020. The increasing rise in urbanization, population and increase in consumption habit resulted to the rise as shown in Figure 2. Unfortunately, plastic is non-biodegradable and can last for hundreds of decades.

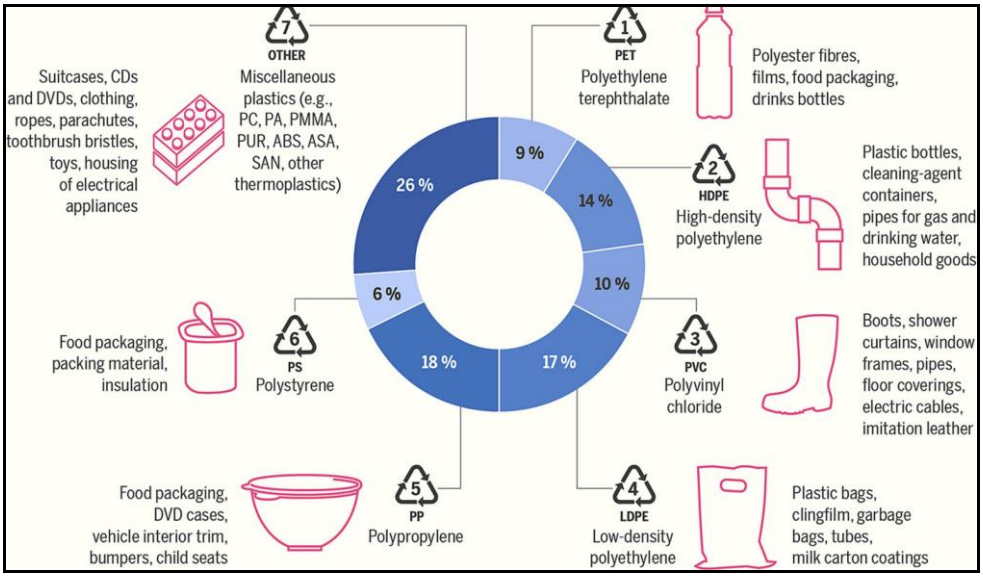

Figure 1: Standard Recycling Codes for Plastic Wastes Source: [7]

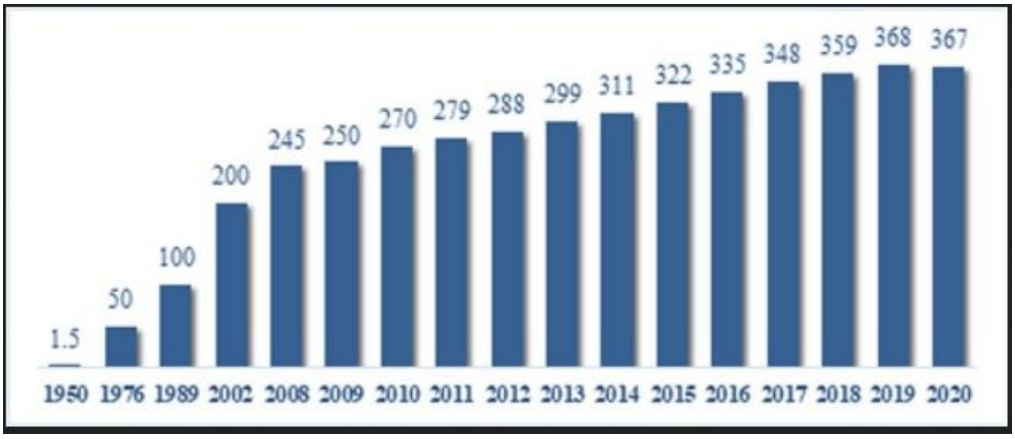

Figure 2: Annual Production of Plastics (1950-2020) Source: [7]

2. Waste Plastic Processing for Road Construction

In a study by Lu et al. [7], it was reported that the consistent transportation requirements and disposal of municipal solid waste caused consistent increase in the road network degradation as well as reducing the structural integrity of the soil. Hence, improving the standard quality of the road network is an essential need. For instance, the pavement quality depends on the mechanical properties of the soil which include permeability, resistance to erosion, compressibility and stiffness as well as strength etc. situation where low strength, increase permeability as well as consistent road swelling are signs of evidence of poor mechanical quality of the soil. Thus, a method of averting this problem lies in the stabilization of the soil quality using plastic wastes.

In the same vein, [8] established that the danger caused by waste plastic has great impact the ecological system and the inhabitants as well, especially the maritime environment. the uncoordinated disposal of plastics which eventually finds its way to the marine environment in which most times consumed by the marine animals eventually have effect on the human body in the form of poison. Hence, there is need to determine the most efficient methods of managing the plastics in a way to improve the sustainability of the ecosystem. Thus, consistent recycling of plastic waste and its deployment into road construction is an excellent way of improving the sustainability of the plastic waste. The technology for processing the waste plastics will have to involve adequate qualitative methods for different waste plastics and the most important feature that will be beneficial to the environment would be termed sustainable [9].

Innovation methods to remove waste plastics from the landfills is very important. It was established that plastic can be deployed as a single material or in combinations of additives in varying percentages to produce building materials ranging from asphalt, bitumen, insulation materials and door panels. Thus, reducing the pressure on transportation and storage of building materials as well as reducing the atmospheric pollution. However, commercialization of the recycling process whereby new technologies are applied in the recycling of waste plastic remain a major issue. Hence, there is need for adequate assessment of the recycling with strong emphasis on the regulations is critical to validating the sustainability of the waste management [10]. According to Suchithra et al. [11], formation of paver blocks by combining trashed plastics and debris of demolition materials with the aim of reducing cost of making paver blocks compared to the traditional paver blocks yielded a good result as the result of the mechanical strength and compressive strength as well as durability test revealed that both materials showed an ecofriendly behavior. Similarly, utilization of waste plastics in the formation of plastic wastes in the construction of road will help in reducing the issues associated with waste plastics [12].

Beyene et al. [13] reported that using expansive soil as a subgrade of pavement is always difficult because of the inadequate workability of the material and its insufficient capability to withstand the cyclic loading imposed by heavy traffic. Thus, for the pavement to perform well, there is a need to improve on the properties of the subgrade. A better means of achieving the solution to this problem is in leveraging on the abundant waste which are usually in large quantities. These wastes help in alleviating the instability in subgrades. Thus, the study focused on the stabilization potentials of the natural lime and ceramic dust in the modification of the geotechnical characteristics of the subgrade plastic material.

The separate and combined effect of the stabilizing materials with high regard to the needed parameters for adequate road construction were considered using the Ethiopian

road construction standard. The percentage of natural lime was given to be 6 while that of ceramic dust was 20 % for the safe road subgrades. Also, it was reported that the natural lime was observed to be stronger than the waste ceramic dust. The overall result revealed that there was an improvement of parameters in the combine case compared to the individual application of the additives.

In the same vein, Genet et al. [14] investigated the effect of modifying asphalt mix by reducing the quantity of bitumen and enhancing the mixture using waste LDPE plastic. The experimental approach involved four different mix ratios of bitumen varying from 4,6,8 and 10 % of plastic waste using varying mixing temperature of 160, 170 and 180 degree Celsius and mixing time of 1, 1.5 and 2 hours respectively to be able to determine the softening point, ductility as well as penetration point. The result revealed that at 170^{o} C and mixing time of 1.5 hours, a homogenous mx was achieved for the bitumen and LDPE plastic waste. compared to the other temperatures. Furthermore, the result of the optimal bitumen content using Marshall Test Method revealed that the optimum bitumen content was observed to be 5.16 % by weight of the total mixture, however, for the that of the LDPE modified with bitumen content was observed to be 6.5 % by weight. Subsequently, the sample of asphalt modified with 6.5 % of waste plastic had 33.67 % stability value when compared with the non-modified asphalt mix.

In an attempt to understand the proficient technology for processing and managing waste plastics Kalali et al [15] observed that the thermal processing of waste plastics involves plastic melting at elevated temperature, followed by casting using the mould to form the end product. It is worth noting that these plastics waste have varying commercial codes which include; 1,2,3,4,5,6, and 7 which represent polyethlene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP) and polystyrene (PS). Figure 3 showed the mechanical and chemical methods of sorting and recycling of plastic wastes. Also, it was reported that PET showed the lowest recyclability, while polyethylene and polypropylene have the highest energy consumption as well as management of the waste.

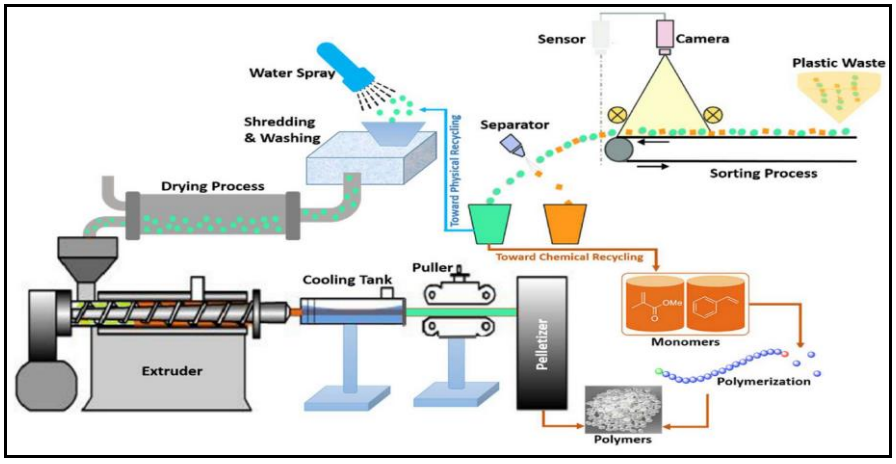

Figure 3: Mechanical and Chemical techniques of plastic waste recycling Source: [15]

Some of the technologies for converting plastics waste into useful products include; hydrothermal treatment, pyrolysis, incineration and mechanical recycling method. However, the cost of all these processes is quite high, hence the need to look at lower cost

technology and the one that will improve revenue generation. Hence, deploying the circular economy approach whereby conversion of waste plastic products is done in a way to optimize the increase in energy and convert the waste to energy [16]. In a study by Yao et al. [17], it was that there are great benefits of waste plastic recycling into the road construction as a reinforcement, however, only few studies have tried to exploit these benefits. To this end, the study examined the economic feasibility of using polyethylene terephthalate (PET) in modified asphalt used in the maintenance of pavement as well as road rehabilitation. The study also carried out the life cycle assessment as well as the life cycle cost analysis to understand the economic and the environmental impact. The results revealed that the incorporation of waste PET plastics and RAP into the pavement caused a reduction in the life cycle costs and greenhouse gas emissions. [18] established that natural aggregates are reducing due to the increasing demand in the road and building construction. Thus, the study investigated the use of pulverized palm-kernel shell as a replacement for the aggregates as well as waste plastics as the binder. Marshall Method was used to determine the physical and volumetric properties of the difference asphalt mix. The result revealed that stability value of the Marshall method increased from 9.8 to 12.1 KN while the flow value increased from 3.0 to 3.7 mm

3. Challenges Associated with Plastic Management

The recycling of plastic waste has great negative impact in the environment such as the water, air and pollutions of the land [19]. A study established that dumping and incineration are not environmentally friendly, also, the conventional recycling of plastic waste poses a serious threat to the ozone layer as greenhouse gas emission now increase with the recycling process [20]. Also, sorting of plastic waste is very crucial when using mechanical and chemical methods. However, use of pyrolysis and liquefaction methods have been considered to be the best, but very expensive. This is due to its operating procedure [21]. The best method of decomposing plastic is oxo-biodegradation. However, this is considered very easy at the laboratory scale, but have certain issues at the industrial scale [22]. To ensure the quality of process viability, it is important to regulate the process variables which include catalyst, temperature and reactor [23]. Also, to develop solutions capable of maintaining the values of the plastic, there is a need to understand the lifecycle of the plastic waste. however, both the chemical and mechanical method are good processes of improving the circular economy especially in the industrial process [24]. Meanwhile, the inefficiency in the recycling procedures can be managed using the plastic garbage while sorting and segregating plastic waste are crucial methods that could also improve the recycling process [25-27].

Although, roads modified with plastics provide a promising solution to the reduction of landfills and improvement of the circular economy, pavement performance improvement. [28] developed a new method of quantifying the release of microplastic from the recycled plastic incorporated with modified asphalt using different environment. the study focused on using a wet track abrasion machine to simulate the road in real life while a microplastic extraction method was deployed to extract the microplastic. The result showed that the incorporation of the waste plastic after recycling it caused an initial release of microplastics compared to its addition as a synthetic aggregate in the asphalt. This result provides a better information for the government and local authorities on the assessment of quality procedures that will drive the sustainability of recycled plastic that is suitable for road construction.

In the study of Arulrajah et al. [29], it was reported that polyethylene terephthalate plastic contributes a substantial amount of the annual landfilling composition of the entire world. Thus, using the plastic waste as a substitute to the traditional construction material will provide a sustainable solution for the environmental problems associated with landfilling. Hence, bringing a total reduction in the demand for the natural quarry materials.

4. Conclusion

Isolation of waste plastic is the most important step in the accomplishment of waste management in any society. Adequate separation of plastic waste involves some difficulties due to the variations in the different available plastics especially in the urban population. This is one reason among others why waste plastics have been left in the landfills without exploiting its potentials. In this study, it was established that plastic wastes have several advantages in the construction of roads and other building structures which have brought about the sustainability in the circular economy of most developed countries. Some of the highlighted advantages of roads constructed by using waste plastics as additives include;

- Roads constructed with waste plastics are stronger and durable
- It gives the best protection to road due to the prevention of stagnant water on the road
- Plastic roads do not have potholes or strip on it
- The roads constructed with plastics have adequate binding and excellent bonding compared to the conventional road with normal asphalt roads
- There is a reduction in the pores of the aggregates which reduces rutting as well as raveling
- There are no radiating effect has strong reliability in terms of strength

Subsequently, it was also discovered from literature study that the integration of plastic waste particles as a modifier to the asphalt and bitumen was observed to provide better result in the road construction. Thus, with the clamour for a sustainable circular economy, there is a critical need to assess the environmental impact of these waste plastics before the regulating agencies can develop policies relevant to its utilization. However, it was confirmed based on the relevant literatures consulted that several advantages are associated with the use of plastic waste in road construction.

Acknowledgment

The author hereby acknowledged the financial support by Afe Babalola University in publication of this paper.

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