Chapter

Polymer-Modified Bio-Asphalt: A Sustainable Panacea to Greenhouse Gas Emissions

Modupe Abayomi Emmanuel

Abstract

The asphalt industry has been perpetually challenged with its health hazardous emissions and global warming issues, especially when produced with or from derivatives of fossil fuels and together with the need for higher strength to meet the heavy truck axle loads on highways. In view of the steady increase in high traffic intensity of heavily loaded trucks and the increase in the overloading of truck axles together with the significant variation in daily and seasonal temperature due to climate change effects, it is essential to modify the conventional asphalt cement using a combination of modifiers to improve the engineering properties of mixes to meet the complexity of the factors for higher strength and the environment. Global warming has consequently contributed immensely to adverse climate change effects, environmental degradation and attendant human health problems. The challenges posed by global pollution and depletion of fossil fuels leading to high cost of bituminous binder derivatives such as bitumen have motivated the search for and development and utilization of alternative binders, amongst which are polymer-modified bitumen and bio-oils. Research in this direction is hoping to find a permanent replacement for bitumen, thereby reducing greenhouse gas emissions and attendant climate change effects.

Keywords: bio-oil, bio-asphalt, sustainable pavements, pavement engineering, polymer-modified bitumen, polymer bio-asphalt, greenhouse gases

1. Introduction

The dynamics of world resource management suggest that all industries, including the asphalt pavement industry, should be exploring the benefits of economic, social and environmental sustainability in all spheres and sectors of development [19]. Sustainability is a growing concept of the twenty-first century Millennium Development Goals (MDGs), and it refers to the utilization of the Earth's resources in such a way that they fulfill the demands of the present generation without impeding the needs of future generations [1]. Sustainable pavements minimize the use of natural resources, reduce energy consumption, reduce greenhouse gas emissions, limit pollution, improve health and safety and ensure a high level of comfort for users [2]. For instance, the current high pavement construction costs have encouraged the use of wastes and renewable resources in asphalt pavements, with the eventual belief that a reduction in binder consumption shall have corresponding reduction in the cost of pavement mixes for development and maintenance [3]. The binder, bitumen, a major component in pavement mixes can be sourced from many avenues, amongst which are natural sources (lake asphalts) and by extraction from tar sands. It is a product of the fractional distillation of crude oil and is currently very expensive because of the high demand to meet the modern-day flexible pavement development for the rising number of automobiles on the roads, in both urban and rural areas [4].

Moreover, in recent years, the total price of asphalt mixes has increased significantly, owing to an increase in the price of the major binder and industrial fuel source, which is crude oil. Asphalt mixes are the most common and widely utilized materials in the construction and maintenance of transportation infrastructures. For instance, a 53% increment in the price of asphalt was reported by [5] to have occurred between the year 2004 and 2007, specifically from $68 to $104 per ton, over a 3-year span. Consequently, the attention of many highway pavement experts has been drawn to seek more economically and environmentally sustainable ways through the investigation of the means of cutting down on bitumen consumption in the asphalt mixes with alternative binders [6]. Besides, for sustainable pavement works, this approach can also produce sustainable binders, for example, from biomass sources, that can reduce the viscosity; reduce the demand for and consumption of virgin bitumen; lower the mixing and compaction temperature of the asphalt mixtures, as an attempt to address the environmental hazards associated with bitumen; and also reduce the heat emissions that mainly comes from the asphalt industry, which is believed to be worsening the effects of global warming [7]. The demand for bio-based fuels is gaining popularity as it is not only sustainable; it also provides secure energy and a positive economic opportunity [8]. The blend of bitumen with the alternative binders (bio-oils), obtained from vegetative or ornamental plants, is expected to improve the performance of bitumen and, by extension, polymer bio-asphalt with the inclusion of specialized strength improvement modifiers called polymers.

The focus of this paper is to discuss the global warming threat posed by the continuous dependence on fossil sources of pavement binders and evaluate the potentials of alternative binders especially polymer bio-asphalt for sustainable pavement works including the possibility of developing a polymer bio-based economy for developing countries as practiced currently in some developed nations of the world.

2. The asphalt industry and global warming threat

The asphalt industry is constantly challenged by its health hazardous emissions and global warming issues, especially when produced from dependence on fossil fuel sources for energy, industrial, commercial and domestic uses, together with the need for higher strength to meet the heavier truck axle loads on highways. Global warming has consequently contributed immensely to adverse climate change effects, environmental degradations and attendant human health problems in some developing economies around the world [9]. These challenges posed by global pollution and depletion of fossil fuels leading to high cost of bituminous binder derivatives such as bitumen have motivated the search for and development and utilization of alternative binders, amongst which are polymer-modified bitumen and bio-oils [10], which are blended together to produce polymer bio-asphalt. To reduce this global threat to climate and human health coupled with the need to improve the engineering properties of fossil-based asphalt pavements, selected polymer modifiers which include waste thermoplastic polyurethane, waste polyethylene terephthalate (PET) and waste tyre rubber and so on and bio-oils are blended with bitumen to produce a new hybrid polymer bio-asphaltic concrete with necessary investigations on modification effect on its mechanical and durability properties.

3. Background on polymer bio-asphalt constituents

3.1 Bitumen

Bitumen is a very complex, viscoelastic, rheological and non-crystalline material (black or brown in color), which is substantially soluble in carbon disulphide (CS_2) and exhibits adhesive and waterproofing characteristics. It is composed of aromatic hydrocarbons and particularly includes 80% of carbons (C) approximately, 15% of hydrogen (H) and remnants such as oxygen, sulfur, nitrogen, metals, etc. [11]. Bitumen however causes severe impact on our environment as well as the health of pavement workers when processed by heat. This is because of the release of vapor when it is heated to a temperature of about 165–200°C, which reduces the viscosity to a concentration that can coat all the aggregates for the desired construction purposes. The vapor released condenses after it has cooled down. It contains greenhouse gases and volatile components which are toxically and chemically different from the origin material. The fumes of bitumen contain tiny particles which are created as condensation occurs from its gaseous state [12]. These particles in the form of vapor mix with the air consumed by construction workers as well as other environmental elements resulting in toxic pollution. Bitumen is also an important low-cost thermoplastic which finds many applications as a building and engineering material; however, it is challenged with poor mechanical properties as it is hard and brittle in cold environments and soft and fluid in hot environments [13].

3.2 Bio oil

Bio-oil is a dark brown liquid with a smoke-like odor, produced from fast pyrolysis of biomass. Unlike the derivatives of petroleum, it has a different composition. The distribution of the constituent compounds varies, depending on the type of biomass and the intensity of the heat applied in its processing. Bio oil has a major component which is water. The other compounds are hydroxyl aldehydes, hydroxyl ketones, sugars, carboxylic acids and phenols [14, 15] used swine manure to produce oil. They successfully converted swine manure to oil with 50% efficiency at 380°C and 40 MPa (around 400 atm) pressure. Zhang et al. [16] reported that bio-oil possesses similar components as asphalt binder derived from petroleum. The components can be classified into asphaltenes, polars, aromatics and saturates. Nevertheless, as a result of the higher content of oxygen in bio oil, its elemental components also differ significantly from conventional asphalt [17]. Fini [18] in his research produced bio-oil from swine manure and used it as a partial replacement of bitumen. Thermochemical liquefaction process was used to convert swine manure to bio oil, while the remaining heavy residue obtained in the process was used as an asphalt modifier. In a research carried out by Raouf and Williams [19] through which bio-oil was produced from three sources, viz., corn stover, switch grass and oakwood, the bio-oil was mixed with bitumen and also blended with a polymer modifier. Results show a great improvement on the temperature susceptibility of the resultant mix after testing.

3.2.1 Biomass sources for bio-oil production

Biomass is any living matter on earth in which solar energy is stored. By the process of photosynthesis, plants produce biomass continuously [20]. Bio-fuels which are classified as liquid or gaseous fuels are produced from plant matter and residues of agricultural crops, municipal wastes and agricultural and forestry by products [21]. According to [22], biomass resources can be divided into two broad categories, that is, natural and derived materials, and then subdivided into three categories:

1. Wastes from agricultural produce, agricultural processing wastes, wastes from crop residues, wastes from mill wood, urban wood and organic wastes.

2. Wastes generated from forest products such as trees, shrubs, wood residues, bark and sawdust.

3. Energy crops and energy crop wastes such as grasses, sugar crops, oilseed crops, starch crops and herbaceous woody crops.

Biomass is the major energy source in Nigeria, contributing nearly 78% of Nigerian primary energy supply [23]. Woody and herbaceous species, wood wastes, energy crops, bagasse, agriculture and industrial residues, waste paper, municipal solid waste, sawdust, bio solids, grass, waste from food processing, animal wastes, aquatic plants and algae, etc. are different kinds of biomass resources [24]. Specifically, in Nigeria, the following biomass resources are available: fuel wood, agricultural waste and crop residue, sawdust and wood shaving, animal dung/poultry droppings, industrial effluents and municipal solid wastes [26]. Others which have been recently discovered and reported to possess high potentials to be used as binders are *Jatropha curcas*, *cassava peels* and *sawdust*. **Table 1** shows the estimated biomass resources in Nigeria. Biomass resources are essentially composed of organic polymers such as cellulose, hemicellulose and lignin, and they include various natural and derived materials.

3.2.1.1 Jatropha curcas

Jatropha curcas (physic nut) belonging to the *Euphorbiaceous* family, a native of tropical America, has been introduced into Africa and Asia and is now cultivated worldwide over an area of approximately 1 million ha [27]. Studies and forecasts by the Global Social Investment Exchange indicated a strong expansion in the cultivation of this crop by up to 12.8 million ha in 2015 [28]. Another study by the International *Jatropha* Organization confirmed the trend, with a forecast of 160 million tons of seeds from 32.72 million ha cultivated worldwide in 2017. *Jatropha* is a genus of approximately 175–200 plants, shrubs and trees adapted to arid conditions, which can easily be propagated by cutting, and is extensively planted with a built-in capacity to combat desertification by restoring vegetative cover. Its seeds contain some proportion of crude oil, proteins, water, crude fibers, ash and carbohydrates. The plant is also relatively drought resistant and has potential for controlling soil erosion and increasing the habitat of wild animals. The plant does not require any particular soil type for growth, can flourish on almost any soil composition and can produce seeds containing up to 40% mass of oil [29]. Jatropha has become a very important crop to the developing world that is constantly challenged by the effects of climate change due to its ability to

Resources	Quantity (million tons)	Energy value ('000 MJ)
Fuel wood	39.1	531
Agro-waste	11.244	147.7
Sawdust	1.8	31.433
Municipal solid waste	4.075	—

Source: Kuye and Ede, 2013; [25].

Table 1.
Biomass resources and the estimated quantities in Nigeria in the year 2000.

grow on arid, waste or marginal lands, producing energy crops without displacing food crops. Its ability to reclaim problematic lands and restore eroded areas is added advantages. *Jatropha* plays an important role in keeping out cattle and protecting other valuable food crops or cash crops. *Jatropha* products from the fruit—the flesh, seed coat and seed—cake are rich in nitrogen, phosphorous and potassium and are fertilizers that improve soil. Biodiesel extracted from *Jatropha* can be used for rural electrification, transportation and in industries [30]. Thus, *Jatropha curcas* oil is considered a more sustainable feedstock for energy production than any other food-based crop, such as palm oil, rapeseed oil, soybean oil and sunflower oil [31].

Besides, the increasing emphasis on pavement sustainability and the promotion of the use of alternative resources as binder, coupled with the successes achieved in using waste engine oil (WEO) and waste cooking oil (WCO) in rejuvenating recycled asphalt pavements, has driven the idea of using *Jatropha curcas* oil (JCO), a nonedible oil as a result of the presence of anti-nutritional factors, such as phorbol esters as a bio-based rejuvenating agent for aged bitumen. This means that it possesses resistance to aging and has good storage stability, making it a focus of interest in this research in addition to its availability and low cost. Several vegetable oils have been used as raw materials for biodiesel production and in flexible pavement applications. Vegetable oils such as palm oil, soybean oil, sunflower oil, coconut oil, rapeseed oil, tung oil, groundnut and palm kernel oils which are classified as edible oil seeds have been used. Even the use of oils from algae, microalgae, bacteria and fungi has been investigated [32]. Some of these feedstocks are found in abundance in Nigeria. The nonedible ones that are most commonly found are *Jatropha curcas* (*Jatropha curcas* L.) and neem (*Azadirachta indica*), and very little or no research especially in flexible pavement applications has been carried out [29] investigated the feasibility of utilizing JCO as a bio-based recycling and rejuvenating agent through physical tests and storage stability properties of bitumen. The results showed that JCO was capable of rejuvenating and recycling aged bituminous mixtures as well as reducing construction and maintenance cost. This conclusion was derived from the positive test results on penetration index (PI) which is an indication of good resistance to low temperature cracking and storage stability and increase in softening point.

Consequent upon these exciting and inherent benefits of the utilization of *Jatropha* oil and because there has been no research until now that studies its modification of fresh bitumen, it is the interest of this study to investigate the applicability of utilizing it as partial replacement for bitumen in production of asphaltic concrete for sustainable pavement works.

3.2.1.2 Cassava feedstock

Cassava, the third largest carbohydrate source in the world, is widely cultivated as an annual crop in tropical and subtropical regions. This is due to its starchy and edible tuberous root. It has heavy presence in countries like Thailand, Brazil and Nigeria and is a very promising feedstock for ethanol production [33]. Residues from cassava plantations include rhizome, stalk and peels. Nigeria is greatly endowed with fertile hectares of land that support the cultivation of agricultural biomass. Agricultural biomass is a relatively broad category of biomass that includes the food-based portion of crops and nonfood-based portion of crops, as seen in the energy crop presented above. The food-based portion of crops is the part of the plant that is either oil or simple sugars. Examples include rapeseed (used for canola oil), sunflower, soybeans, corn, sugarcane and sugar beets. Corn and sugar beets can be used for ethanol production through fermentation, while the oilseed crops can be used to produce biodiesel. On the other hand, the nonfood-based portion of crops is that part which is usually discarded as a residue. Crop residues are those residues that are associated with agriculture either as on-the-farm crop wastes, such as cornstalks or as processing wastes such as rice husk, corn shells, palm kernel shell, cassava peels, cassava rhizome, cassava stalk, etc. [34]. They are available in Nigeria in large quantities especially in the rural areas where crops are cultivated. From **Table 1**, the agro-waste (crop residues) in Nigeria was estimated in the year 2000 to be about 11.244 million tons of the entire biomass resources of that year, and this amounted to 147,700 MJ of energy [35]. These wastes are currently burned directly as a starter or supplement materials to fuelwood. They have a great potential for bio-fuel production. Recently, some of these biomasses have been used by different researchers to produce bio oil. These include rice husks and sawdust [30]and cassava plantation like cassava stalk and cassava rhizome [36] and cassava peels [37].

[37] reported in their experiment that bio-oil yield from fast pyrolysis of cassava peel ranged from about 38.7 to 51.2%. The maximum yield of bio-oil was obtained at temperature of 525°C. The main organic composition of bio-oil can be grouped into acids, esters, aldehydes, ketones, phenols, alcohols, hydrocarbons and other organic compounds and some un-identified organic compounds. The physicochemical properties of bio-oil produced from pyrolysis of cassava peels were comparable to the ASTM standard for bio-oil. However there has been no research until now that studies the applicability of utilizing bio oil from cassava feedstock as partial replacement for bitumen for sustainable pavement works.

3.2.1.3 Sawdust

Sawdust is a typical example of lignocellulosic biomass (biomass that is mostly plant cell walls which have high carbon content). It is readily available in Nigeria, as can be seen from **Table 1**. It is associated with the lumber industry and the main by-product of sawmill. The sawdust generated from sawmills are often discarded, burnt as wastes or used for cooking but may also constitute an environmental hazard if not properly used. However, as noted earlier, sawdust can also be converted to bio-oil. In the recent times, [38] investigated the use of sawdust in the production of bio oil. Also, [39] investigated fast pyrolysis of waste furniture sawdust in a fluidized bed. Specifically, large quantities of oxygenated compound are present in bio-oils produced from wood. In the bio-oils huge proportion of xylenols, eugenols, cresols and phenols are also found. It has been observed that the phenolic fraction has shown good performance as an adhesive for waterproof plywood as reported by [20]. Nigeria has a great potential for the various kinds of biomass, such as sawdust, agricultural residue, wood crop and municipal waste. Sawdust has been recognized as a biomass with the highest yield of bio oil according to [40]. This has prompted research into the sustainability potential of utilizing it as bio modifier for bitumen for use in flexible pavement, especially sustainable pavement construction.

3.2.2 Production of bio-oils by pyrolysis

Pyrolysis is a technology used to extract bio-oil from biomass. It produces three different products: syngas, biochar and bio oil. It is a process that has been found to be versatile, efficient and environmentally acceptable [30]. The conversion process from biomass to bio-oil is through fast pyrolysis, slow pyrolysis, carbonization, liquefaction or gasification. Fast pyrolysis is the technique most widely used because of its many advantages, such as high yield, simplicity and low cost [41]. In the absence of oxygen, biomass decomposes at a temperature of 400–600°C, and during this process, a high energy product known as bio-oil is produced which has the capacity to replace conventional fuels and can be applied in different ways, such as in boilers and turbines and high-power diesel motors. According to [20] three products are produced during pyrolysis, which is conducted in the absence of oxygen; they are a mixture of noncondensable gases (syngas), a charcoal coproduct and a condensable liquid (pyrolysis oil). He further revealed that through pyrolysis, a complex mixture of oxygenated compounds is formed by the conversion of the organic materials.

3.2.3 Physical and rheological properties of bio-oils

The capability of bio-oil utilization as bio-binders, including its reliability, has been discovered to be properly investigated through physical property measurements as chemical analysis has proven to be very difficult in terms of performance characterization. According to a report by [42], the following is the description of the physical state of bio-oils: "Bio-oils' multiphase complex structure is accounted for by the presence of aqueous droplets with different natures, waxy materials, char particles, and micelles formed from heavy molecular compounds in a matrix of hollo cellulose-derived compounds and water". During transportation, and sometimes when stored or processed, bio-oil constituent compounds such as ketones, aldehydes and others can react through condensations to form larger molecules [21]. Therefore, these reactions lead to the undesirable changes in physical properties. For example, viscosity and water content can increase, whereas the volatility will decrease [43]. As reported by [44], this is analogous to the behaviour of asphaltenes contained in petroleum by some means. The following are the summarized physical properties of bio-oils: (1) a density of 1200 kg/m^3 higher than the original biomass; (2) a viscosity that ranges from 25 cPoise to 1000 vis-à-vis moisture content, the amount of light compounds and the aging [20]; and (3) a water content which ranges between 14 and 33% by weight. Williams et al. [45, 46]opined that the rheological properties play a significant role in describing the behaviour of bio-oils. Measuring the rheological properties is useful to determine behavioral and predictive information for bio-oils as well as knowledge of the effect of processing, formulation changes and aging phenomena.

3.2.4 Chemical properties of bio-oils

Bio-oils generally possess a complex chemical nature, thus making it difficult to conduct a complete chemical characterization, and sometimes it is almost impossible to do so. According to the findings by [43], the complexity of chemical analysis usually results from the presence of high molecular weight of phenolic species from the decomposition of lignin. Besides, different numbers of carboxylic and phenolic acids, hydroxyl groups and aldehydes exist alongside the fragmented oligomeric products, including alcohol and ether functions. Thus, phenolic species exist as different hydrogen-bonded aggregates, micelles, droplets and gels. Due to the complexity of the chemical structure and the broadness of chemical properties of bio-oils, the few chemical indices that are commonly investigated are corrosiveness, distillation, homogeneity, water content, molecular weight, oxidation and aging and phase stability.

3.3 Polymer modifiers

3.3.1 Definition of polymer

Polymer is a combination of two classical Greek words poly and meres which literally means "many" and "parts" [47]. It is a molecule with a long chain, consisting of many repeating units that are identical in structure. Polymers can be classified in so many ways, according to their origin (whether they are natural or synthetic (man-made)). The natural polymers such as cellulose, hemicellulose and lignin are found in nature; while the synthetic polymers are man-made polymers that are formed through synthetic routes, such as waste plastics (polyethylene) and crumb rubber (CR) (vulcanized rubber or scrap tyres), to mention a few. Plastics are low-cost, low-density (or light-weight), formable and durable materials which, due to their properties, are extensively used in many areas, sectors and industries. Plastics are of seven types: PET, high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS) and other types of plastics [48].

3.3.2 Significance of polymer modifiers

To obtain a bio-binder with suitable and similar binding characteristics for use as substitute for conventional bitumen, there is a need for the upgrading of the bio-oil produced from fast pyrolysis of biomass. According to previous studies, the bio-oil by itself possesses very good characteristics, like asphalt, at high and medium temperatures [19]. However, the performance at low temperatures was not acceptable for use in most of the USA, as they were too stiff at low temperatures and susceptible to low-temperature cracking. The approach used to solve this issue was to react a polymer with the bio-oil. A bitumen additive should improve binder properties at both low and high in-service temperatures [49]. Consequently, at high temperatures, it should be durable enough to resist loads from traffic, which may result into rutting or permanent deformation; and also at low pavement temperatures, it is expected to be flexible enough to avoid excessive thermal stresses. It also needs to be able to endure the thermal cycling of service without cracking or deforming. Furthermore, a modifying agent of bitumen should be easily incorporated to yield a highly viscous mixture at in-service temperatures which remains homogenous on storage and should have a viscosity which permits its use in standard material manufacturing and paving equipment. Besides, it should be highly resistant to ultraviolet light, thermal action and water, not leach deleterious substances into the environment, and be readily available [42].

3.3.3 Modification of bituminous mixes by crumb rubber and plastic wastes (PET)

Polymer modifiers have been reported to possess the capacity to improve the properties of bitumen and thus the overall properties of hot-mix asphalt (HMA) used in flexible pavement works [50]. Since the early 1970s, the utilization of petroleum-derived polymers has been well developed to be blended with conventional bituminous binders to modify the performance and rheological properties by decreasing temperature susceptibility and increasing cohesion as reported by [51]. In other words, practical experience has shown that the blending of bitumen binders with polymer modifiers (e.g. polyethylene and crumb rubber) has many advantages that include but are not limited to enhanced fatigue resistance, improved thermal stress cracking, decrease in temperature susceptibility and reduction of rutting [52]. Polymers that have been commonly used to modify bitumen include styrene-butadiene-styrene (SBS) copolymer, styrene-butadiene rubber (SBR), ethylene-vinyl acetate (EVA), polyethylene terephthalate (i.e. LDPE, HDPE, etc.) and waste polymers (plastic from agriculture, crumb tyre rubber, etc.) [53]. For such polymers, the mixing process may have a significant effect on the technical properties of the resulting blend, as well as on the costs of the whole operation [48]. Thus, to bring down the differences in viscosity between bitumen and polymer and to obtain suitable dispersions of polymer, high shear and processing temperatures (170–180°C) are necessary. Therefore, the final binder may undergo a "primary" aging, mainly due to the oxidation of maltene compounds and polymer degradation, leading to a decrease in the expected mechanical performance of bituminous binders [45]. Moreover, the use of high-molecular-weight polymers may yield thermodynamically unstable modified bitumen, and phase separation readily occurs during their storage at higher temperatures [42]. Besides, using PET-derived products as a performance-enhancing additive for asphalt can be one of the alternatives to recycle and reuse this waste material. Similarly, disposal of waste vehicle tyres is also a challenging environmental problem. Research has shown that the use of crumb rubber from waste tyres in asphalt helps improve some of its rheological properties but is often plagued with other concerns such as low storage stability. Leng et al. [28] in their research found out that the incorporation of PET-based additives to CRMA improved the storage stability, rutting and fatigue resistances and increased the rotational viscosity (RV) of the modified binders.

Generally, tyre rubber comprises of natural, synthetic rubbers, carbon black and other mineral fillers. Crumb rubber-modified asphalt can be divided into two categories, the wet and dry processes. The wet process is the most efficient in improving properties of an asphalt mixture [54]. Crumb rubber is known to absorb liquids and swell, depending on the temperature and viscosity of the liquids it is absorbing. Crumb rubber is a general term used to describe a granular rubber from waste tyres. At high temperatures, the asphalt binder tends to flow easier due to the natural decrease of viscosity associated with high temperatures. This condition creates a softer asphalt mixture, which is prone to rutting. The addition of crumb rubber to the HMA provides extra viscosity, thus stiffening the HMA at the high temperatures [54].

4. Conclusion

Modification of base bitumen with polymer and bio-oil blends or polymer bio-asphalt, to enhance the main engineering properties of base bitumen such as viscosity, penetration, softening point, flashpoint, fire point, density, specific gravity and so on, including Marshall properties of resultant polymer bio-asphalt concrete, can be a sustainable way out of the global warming crises and climate change experienced all over the world; therefore, it should be tenaciously promoted given its outstanding developmental and economic benefits. Furthermore, it is recommended that optimum combination proportions of both bio-oil from cassava peel and crumb rubber be investigated. The use of bitumen modified with bio-oil and crumb rubber for use in the construction of flexible pavements is recommended to reduce agricultural wastes and other environmental pollution issues as well as reduce road construction costs.

Acknowledgements

The author appreciates the Almighty God and the support of colleagues.

Conflicts of interest

Author declares no conflict of interest.

Funding

This work has not received funding from any source whatsoever.

Author details

Modupe Abayomi Emmanuel
Department of Civil Engineering, Highway and Transportation Engineering Research Group, Landmark University, Nigeria

*Address all correspondence to: modupe.abayomi@lmu.edu.ng

References

[1] Aziz MA, Rahman T, Rosli M, Azelee W, Abu W. An overview on alternative binders for flexible pavement. Construction and Building Materials. 2015;**84**:315-319

[2] Indexed S, Olumoyewa D, Aran O. Development and performance evaluation of crumb rubber—Bio-oil modified hot mix asphalt for sustainable highway pavements. International Journal of Civil Engineering and Technology. 2019;**10**(2):273-287

[3] Modupe AE, Atoyebi OD, Oluwatuyi OE, Aladegboye OJ, Busari AA, Basorun AO. Dataset of mechanical, marshall and rheological properties of crumb rubber—Bio-oil modified hot mix asphalt for sustainable pavement works. Data Brief. 2018;**21**:63-70

[4] Williams RC, Cascione AA, Cochran EW. Development of Bio-Based Polymers for Use in Asphalt; 2014

[5] Jamshidi A, Othman M, You Z. Performance of warm mix asphalt containing sasobit Ò: State-of-the-art. Construction and Building Materials. 2013;**38**:530-553

[6] Poh CC, Hassan NA, Azah N, Raman A. Effect of Fast Pyrolysis Bio-Oil from Palm Oil Empty Fruit Bunch on Bitumen Properties; 2018

[7] Williams RC, Rover M, Brown RC. Utilization of Fractionated Bio-Oil in Asphalt; 2011

[8] Yang X, You Z. High temperature performance evaluation of bio-oil modified asphalt binders using the DSR and MSCR tests. Construction and Building Materials. 2015;**76**:380-387

[9] Owamah HI, Izinyon OC. Bioresource technology development of simple-to-apply biogas kinetic models for the co-digestion of food waste and maize husk. Bioresource Technology. 2015;**194**:83-90

[10] Abdel M, Mohamed R. Development of Non-petroleum Binders Derived from Fast Pyrolysis Bio-Oils for Use in Flexible Pavement; 2010

[11] Raman NAA et al. A review on the application of bio-oil as an additive for asphalt. Jurnal Teknologi. 2015;**72**(5):2017

[12] Poh CC, Hassan NA. The Effect of Oil Palm Waste Pyrolysis Bio-Oil on Modified Bitumen Properties

[13] McNally T editor. Polymer modified bitumen: Properties and characterization. Elsevier; 2011

[14] Gobinath R, Ganapathy GP, Akinwumi II, Kovendiran S, Hema S, Thangaraj M. Plasticity, strength, permeability and compressibility characteristics of black cotton soil stabilized with precipitated silica. Journal of Central South University. 2016;23(10):2688-2694

[15] Jensen EA, Mousavi M, Pahlavan F. Multiscale investigation of a bioresidue as a novel intercalant for sodium montmorillonite. The Journal of Physical Chemistry C. 2017;**121**(3):1794-1802

[16] Zhang R et al. Thermal storage stability of bio-oil modified asphalt. Journal of Materials in Civil Engineering. 2018;**30**(4):1-9

[17] Zhang R, Wang H, Gao J, You Z, Yang X. High temperature performance of SBS modified bio-asphalt. Construction and Building Materials. 2017;**144**:99-105

[18] Fini EH et al. Source dependency of rheological and surface characteristics of bio-modified asphalts. Road

Materials and Pavement Design. 2016;**18**:408-424

[19] Raouf MA, Williams RC. Temperature and shear susceptibility of a nonpetroleum binder as a pavement material. Transportation Research Record. 2010;**2180**(1):9-18

[20] Demirbas MF. Recent advances on the production and utilization trends of bio-fuels: A global perspective. Energy Conversion and Management. 2006;**47**:2371-2381

[21] Mohan D, Pittman CU, Steele PH. Pyrolysis of wood/biomass for bio-oil: A critical review. Energy & Fuels. 2006;**20**(3):848-889

[22] Goyal HB, Seal D, Saxena RCÃ. Bio-fuels from thermochemical conversion of renewable resources: A review. Renewable and Sustainable Energy Reviews. 2008;**12**:504-517

[23] Agbro EB, Ogie NA, Rjeas R. A comprehensive review of biomass resources and biofuel production potential in Nigeria. Research Journal in Engineering and Applied Sciences. 2012;**1**(3):149-155

[24] Yaman S. Pyrolysis of biomass to produce fuels and chemical feedstocks. Energy Conversion and Management. 2004;**45**:651-671

[25] Kuye AO, Edeh I. Production of bio-oil from biomass using fast pyrolysis: A critical review. Journal of Minerals Research. 2013;**1**(1):1-19

[26] Sambo BAS. Strategic developments in renewable energy in Nigeria. International Association for Energy Economics. 2009;**16**(3):15-19

[27] Simón D, Borreguero AM, De Lucas A, Gutiérrez C, Rodríguez JF. Sustainable polyurethanes: Chemical recycling to get it. In: Environment, Energy and Climate Change I. Springer, Cham; 2014;229-260

[28] Leng Z, Padhan RK, Sreeram A. Production of a sustainable paving material through chemical recycling of waste PET into crumb rubber modified asphalt. Journal of Cleaner Production. 2018;**180**:682-688

[29] Ahmad KA, Abdullah ME, Hassan NA. Investigating the Feasibility of Using *Jatropha curcas* Oil (JCO) as Bio Based Rejuvenator in Reclaimed Asphalt Pavement (RAP)2017. p. 09013

[30] Zhu J et al. GC – MS and FT-IR analysis of the bio-oil with addition of ethyl acetate during storage. Construction and Building Materials. 2014;**2**(2):53-60

[31] Subroto E, Manurung R, Heeres HJ, Broekhuis AA. Mechanical extraction of oil from *Jatropha curcas* L. kernel: Effect of processing parameters. Industrial Crops and Products. 2015;**63**:303-310

[32] Aransiola EF, Daramola MO, Ojumu TV, Aremu MO, Layokun S, Solomon BO. Nigerian *Jatropha curcas* Oil Seeds: Prospect for Biodiesel Production in Nigeria. Vol. 2; 2012

[33] Nigeria to Produce Bioethanol from Cassava; Biofuels International Magazine

[34] Edhirej A, Sapuan SM, Jawaid M, Zahari NI. Cassava: Its polymer, fiber, composite, and application. Polymer Composites. 2017;**38**(3):555-570

[35] Raman NAA, Hainin MR, Hassan NA, Ani FN. A review on the application of bio-oil as an additive for asphalt. Jurnal Teknologi. 2015;**72**(5)

[36] Pattiya A, Titiloye JO, Bridgwater AV. Catalytic Pyrolysis of Cassava Rhizome. Table 2 Characteristics of Selected Catalyst Samples. Vol. 202006. pp. 1-6

[37] Ismadji S, Ju Y, Xiang C, Kurniawan A, Lu O. Bio-Oil from Cassava Peel:

Potential Renewable Energy Source; 2012

[38] Chang S et al. Bioresource technology effect of hydrothermal pretreatment on properties of bio-oil produced from fast pyrolysis of eucalyptus wood in a fluidized bed reactor. Bioresource Technology. 2013;**138**:321-328

[39] Su H et al. Bioresource technology bio-oil production from fast pyrolysis of waste furniture sawdust in a fluidized bed. Bioresource Technology. 2010;**101**(1):S91-S96

[40] Wei L, Cheng S, Zhao X, Huang Y, Yu Y. Exploration of Lignocellulosic Biomass Precision Pyrolysis for Advanced Biofuel Production. In 2015 ASABE Annual International Meeting American Society of Agricultural and Biological Engineers. 2015. p. 1

[41] Carpenter D, Westover TL, Czernik, S, Jablonski W. Biomass feedstocks for renewable fuel production: A review of the impacts of feedstock and pretreatment on the yield and product distribution of fast pyrolysis bio-oils and vapors. Green Chemistry. 2014;**16**(2):384-406

[42] Garcia-Perez M et al. Fast pyrolysis of oil mallee woody biomass: Effect of temperature on the yield and quality of pyrolysis products. Industrial and Engineering Chemistry Research. 2008;**47**(6):1846-1854

[43] Nanda S, Mohanty P, Kozinski JA, Dalai AK. Physico-chemical properties of bio-oils from pyrolysis of lignocellulosic biomass with high and slow heating rate. Energy and Environment Research. 2014;**4**(3):21-32

[44] Czernik S, Bridgwater AV. Overview of applications of biomass fast pyrolysis oil. Energy & Fuels. 2004;**18**(2):590-598

[45] Raouf MA, Engineering T, Williams RC. Determination of Pre-Treatment Procedure Required for Developing Bio-Binders from Bio-Oils; 2009

[46] Raouf MA, Williams CR. General rheological properties of fractionated switchgrass bio-oil as a pavement material. Road Materials and Pavement Design. 2011;**11**(sup1):325-353

[47] Fried JR, Hu N. The molecular basis of CO_2 interaction with polymers containing fluorinated groups: Computational chemistry of model compounds and molecular simulation of poly [bis(2,2,2-trifluoroethoxy) phosphazene]. Polymer. 2003;**44**: 4363-4372

[48] Habib NZ, Kamaruddin I, Napiah M, Tan IM. Rheological properties of polyethylene and polypropylene modified bitumen. International Journal of Civil and Environmental Engineering. 2010;**4**(12):381-385

[49] Polacco G, Vacin OJ, Biondi D, Stastna J, Zanzotto L. Dynamic master curves of polymer modified asphalt from three different geometries. Applied Rheology. 2003;**13**(3):118-124

[50] Köfteci S, Ahmedzade P, Kultayev B. Performance evaluation of bitumen modified by various types of waste plastics. Construction and Building Materials. 2014;**73**:592-602

[51] Aisien FA, Hymore FK, Ebewele RO. Application of ground scrap Tyre rubbers in asphalt concrete pavements. International Journal of Materials Science and Engineering. 2006;**13**:333-338

[52] Totry E, González C, Llorca J. Mechanisms of shear deformation in fiber-reinforced polymers: Experiments and simulations. International Journal of Fracture. 2009;**158**(2):197-209

[53] El-ghaffar MAA, Youssef EAM. Maleic acid/phenylene diamine adducts as new antioxidant amide

polymers for rubber (NR and SBR) vulcanizates. Polymer Degradation and Stability. 2003;**82**:47-57

[54] Panda M, Mazumdar M. Utilization of reclaimed polyethylene in bituminous paving mixes. Journal of Materials in Civil Engineering. 2002;**14**(6):527-530