



Review

An overview on alternative binders for flexible pavement

Md Maniruzzaman A. Aziz^{a,*}, Md Tareq Rahman^a, Mohd. Rosli Hainin^a, Wan Azelee Wan Abu Bakar^b^a Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia^b Department of Chemistry, Faculty of Science, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

HIGHLIGHTS

- We have provided information regarding bitumen and its adverse impact to the human life and environment.
- We present the prospect of alternative binders that can be used to reduce the use of bitumen.
- We have proved that, use of bio oil, polymer and waste cooking oil can be an effective alternative by literature review.
- We provide instructions about the criteria and experimental method to do further study for future research.

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ABSTRACT

Bitumen (asphalt) is viscoelastic, rheological and non-magnetic material composed of heavy hydrocarbons with low dielectric constant (ϵ'). It is a by-product of petroleum oil refinery. Though it is used as a binder for flexible pavement all over the world, it has severe environmental impacts. Bitumen is non-hazardous at room temperature but when heated at 165–200 °C, it becomes toxic. Consequences, such as environmental degradation, depleting petroleum reserves and price-spiking, led researchers to explore alternative sources of obtaining binder for pavement. This paper provides an overview of the probable materials that could be used as an alternative binder. The materials obtained from bio-based sources, such as bio-oil, polymer, plastic, rubber and waste cooking oil and retrieved from waste material show promise and discussed. Further research is needed to make them satisfactory replacement of bitumen on an industrial scale, and be a sustainable source of binder for flexible pavement.

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1. Introduction

'Sustainability' is an evolving concept of the 21st century millennium development goals (MDG), defined as using Earth's

resources in such a way that they fulfil the demand of the current generation without hampering the needs of future generations [1]. The increasing demand of Earth's finite resources have created a global and pressing issue of the modern era. Hence research for alternative source or bio renewable sources are given high priority so that the 'sustainability' can be ensured.

* Corresponding author.

E-mail address: mzaman@utm.my (M.M.A. Aziz).

Smalley, a Noble prize winner in 1996, enumerated top ten problems concerning humanity for the next 50 years, where 'Energy' and 'Environment' are amongst the most vital issues [2]. The world is now prodding to inaugurate an economy which is bio-based where energy generated from organic renewable sources rather than natural fossil fuel which will save the world from natural energy source depletion and provide safe environment [3]. Bio-based source of energy is renewable, efficient, cost effective and environment friendly which could be a great economical asset for any country. Organic plant matter and residues from agricultural and forestry sector for instance, crops, municipal waste etc. are used [3,4].

Road and highway network is the largest sector of the world in terms of asset management. Flexible and rigid pavements are the two most important roads among 15 types of pavements [5]. 95% of the whole world's highways are flexible pavement [6]. The basic difference between the two is the type of binder used. For flexible pavement, bitumen is used as traditional binder, while, Portland cement is utilized as binder in rigid pavement.

Bitumen is a very complex, viscoelastic, rheological and non-crystalline material (black or dark brown in color), which is substantially soluble in carbon disulfide (CS_2), and exhibits adhesive and water-proofing characteristics. Beside its physical and chemical properties it possesses a unique and fundamental microwave property (permittivity). It is a low loss material as loss tangent, $\tan \delta$ (ϵ''/ϵ') <0.5 and its microwave permittivity (dielectric constant, ϵ') value ranges from 2 to 7 depending on the grade of bitumen, asphaltenes content, temperature and microwave frequency [7]. 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. Bitumen is used in flexible pavement primarily due to its viscoelastic behavior. Since bitumen is a by-product of crude petroleum, the price of bitumen varies with the price of petroleum. In the world market the price of petroleum is constantly increasing as the consumption level spikes. The price of petroleum crude oil was \$61.95 per barrel in 2008 but in 2013 it had gone up to \$97.98 per barrel [8].

Furthermore, bitumen causes severe impact on our environment as well as the health of pavement workers. It needs to be heated at 165–200° Celsius temperature to lower down the viscosity in order to coat all the aggregates for road work. During this process, vapor is released and when the vapor cools down, it condenses. These vapors contain greenhouse gases and volatile components which are chemically and toxically different from origin material. Bitumen fume contains tiny particles created by condensation from gaseous state [8]. This vapor mixes with the air consumed by workers as well as with other environmental elements resulting in pollution. Developing a bio-based renewable economy for sustainable living, it is necessary to look for an alternative source of binder for flexible pavement.

2. Alternative binder

Alternative binder for flexible pavement is derived from sources other than crude petroleum. The binder is completely or partially derived from bio-based material. There are three ways in which bio-based alternative binder decreases the use of natural fossil fuel based bitumen (shown in percentage) [9].

- i. Direct alternative (75–100% bitumen replacement).
- ii. Bitumen extender (10–75% bitumen replacement).
- iii. Bitumen modifier (<10% bitumen replacement).

Use of modifiers in conventional bitumen binder has been utilized in almost all road construction. Research is being done

on bitumen extender as 100% replacement of bitumen in an effort to decrease the demand of petroleum based bitumen. The probable materials that can be used as the alternative for bitumen or can decrease the proportion of bitumen in the binder mixture are bio-oils, additives, waste materials etc. Bio-fuels can be in gaseous or liquid form as they are extracted from organic plant matter and residue, e.g., crops, municipal waste, byproduct of forestry and agriculture [3,4]. Additives are the emulsions, resin, polymer, crumb rubber etc. Waste materials like waste cooking oil, waste engine oil etc., may be the promising alternatives. The prospect of bio-oil, polymer and waste cooking oil is discussed here. The more modifiers are used the percentage of petroleum based bitumen decreases along with pollution. As a result, it helps the environment, reduces the price, and improves performance of the road [10].

3. Bio oil

The demand of bio-based fuel is gaining popularity as it is not only sustainable, it also provides secure energy and a positive economic opportunity [3,11–13].

Manure management is an important issue related to swine production [14,15]. Appel and his team used swine manure to produce oil [16]. They successfully converted swine manure to oil with 50% efficiency at 380° C and 40 MPa (around 400 atm) pressure [16]. Fini produced a bio-oil from swine manure and used it as a partial replacement of bitumen [17]. Thermo-chemical liquefaction process is used to convert swine manure to bio-oil while the remaining heavy residue obtained in this process, to be used as an asphalt modifier. The percentage of saturates, aromatics, resins and asphaltenes (SARA) components of bio-binder were determined using the solvent separation procedure and the chemical composition of binders as in Table 1 [17].

According to Fini, this bio-binder can be an effective material when added to bitumen binder due to its ability to improve some of the asphalt binder properties (low-temperature properties and wettability) while also providing economic and environmental benefits [17]. Raouf and Williams conducted a study on bio-oil in Iowa State University, U.S.A. They produced different bio-oils from various sources e.g., Oakwood, switch grass and corn Stover [9]. In the research bio-oil was mixed with polymer modifier and bitumen, and the temperature susceptibility of the mixture was checked afterward. Finally they concluded that bio-oil based binders behave much like bitumen binders. Their behavior changes when temperature increases, and viscosity begins to decrease making bio-oils more vulnerable to temperature than bitumen binders. Further research is needed to standardize them by rheological testing and simulative aging prior to usage in the pavement industry.

Scientific interest in the extraction of lipid from microalgae for the production of biodiesel, has grown in the last decade. Microalgae presents many advantages compared to other energy crops, namely, high growth rate, high biomass production and non-competition with human food production. To realize the concept of

Table 1
Comparison of chemical composition of bio-binder and bitumen [17].

Components	Bio-binder (%wt)	Bitumen (AAD-1, USA) (%wt)
Carbon (C)	72.58	81.6
Hydrogen (H)	9.76	10.8
Nitrogen (N)	4.47	0.77
Oxygen (O)	13.19	0.9
Water content	2.37	–
Ash content	0.13	–

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