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ALTERNATIVE BINDERS FOR FLEXIBLE PAVEMENT

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ABSTRACT

Bitumen (asphalt) is a petroleum based material which is used as binder in flexible pavement and bitumen has severe adverse impact on environment as well as in living being. Due to the limitation of petroleum, increased price and the impact on the environment, research is going on to find an efficient, cost effective and environment friendly alternative binder to replace the bitumen. This paper provides a review about the probable materials that can be used as an alternative binder where most of them are bio-based material and waste materials like bio-oil, plastic, polymer, waste cooking oil, waste tire rubber etc. Researchers have found some positive result with these materials. Further research is needed to make these satisfactory replacement of bitumen in industrial scale which will lead to a sustainable source of binder for flexible pavement.

Keywords: Bitumen, bio-oil, waste material, sustainability, bio-binder

INTRODUCTION

The world is now taking actions to set up an economy which is bio-based and where renewable organic matter is the source of energy rather than natural fossil [1]. Bio-based source of energy is renewable, efficient, cost effective and environment friendly which can be a great economical asset to any country. Generally these are produced from organic waste, residues and plant matters such as waste from agriculture and municipal, agricultural crop and by product from forestry [1, 2].

Bitumen is a viscoelastic material composed of heavy hydrocarbons and soluble in carbon disulfide which is a lowloss material as loss tangent, $\tan \delta (\epsilon''/\epsilon')$ <0.5 and its microwave permittivity (dielectric constant, ϵ') value ranges from 2 to 7 depending on grade of bitumen and asphaltenes content which is derived from petroleum [3]. Recent research shows that the price of petroleum is increasing time to time and bitumen cause severe impact on environment and the pavement workers. It needs to be heated at 165°-200° Celsius (C) temperature to get enough liquidity to coat all the aggregates in road construction. Bitumen fume consists of minute hazardous particles which is formed by the condensation from the vapor stage after volatilization of bitumen [4]. This vapor mixes with the air consumed by the pavers and at the same time it mixes with the other environmental elements and pollute them.

Therefore, to save the world from the depletion of natural petroleum source, to save the environment from the pollution by bitumen and bitumen fume, to save the living being from the exposure of bitumen and to develop a bio-based renewable economy for sustainable living introduction of an alternative source of binder for flexible pavement is necessary.

BIO-BINDER

Bio binder is an alternative binder which is completely or partially derived from bio based material

which makes it renewable and environmental friendly. There are three ways to use bio-binders to reduce the demand of fossil fuel based traditional binder.

- i. Direct alternative (100% replacement of bitumen)
 - ii. Bitumen extender (25%-75% replacement of bitumen)
 - iii. Bitumen modifier (0%-10% replacement of bitumen)
- [5].

Bio fuels are classified in two forms, gaseous and liquid fuels. The sources are from municipal waste, agricultural and forestry by products, plant matter and residue [1, 2]. Additives are the emulsions, resin, polymer, crumb rubber etc. Waste materials like waste cooking oil, waste engine oil etc. can be an effective alternative.

Bio-oil

Recently the demand of bio-based fuel is gaining the popularity in developing a sustainable environment because there are many benefits over natural fossil fuel because they are environmental friendly, renewable, provide secured energy and a great opportunity in the economic sector. The sources of bio-fuels are biomass (residue and plant matter) e.g. agricultural crop, manure from livestock, waste from municipal dump, co-products from forestry and agriculture [1, 2, 6].

Rauf and Williams (2010) have conducted study at Iowa State University in bio oil. They have produced different bio-oils from different sources e.g. Oakwood, switch grass and corn Stover [5]. Finally they concluded that bio oil based binders have similar behavior to the bitumen binders because of its behavior such as with the increase of temperature, viscosity decreases.

Fini *et al* (2010) produced a bio oil from swine manure and used it as a partial replacement of bitumen [6]. The process associated with the conversion of swine manure to bio-oil was thermochemical and utilizes the heavy residue remaining in this process as an asphalt modifier. The percentages of saturates, aromatics, resins and asphaltenes (SARA) components of bio-binder were



determined using the solvent separation procedure and the chemical composition of oil is shown in Table 1 [6].

Table 1. Comparison of chemical composition of bio-binder and bitumen [6]

Components (%wt)	Bio-Binder	Bitumen (AAD-1, USA)
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	-

PLASTIC, POLYMER AND RUBBER

Bitumen is a viscoelastic material, because of bitumen pavement possess the flexibility and plays a very important role in pavement performance [7]. Use of plastic waste and crumb rubber which is obtained from waste tire rubber from vehicles in the construction of flexible pavement is gaining importance [8]. Since 1843 polymers are being used in bitumen as modifier. In the year 1950, North America and Europe started to use latex rubber where the research started in 1930. Because of high expense of

polymer, USA was limited to use Polymer Modified Rubber (PMA) in the end of 1970 [9, 10].

Bituminous mixture is stable which one of the most important properties of bitumen is. The optimum stability is the design stability which can withstand the traffic condition as required. If the stability is not enough it will cause striping, shoving and higher flow of the road surface [11]. To prevent the pavement from these kinds of failure there must be low flow. Flow is the property which is responsible in reducing stability [12]. There is a relation between hot climate rutting and cold climate cracking because of the sensitive response of bitumen due to temperature variation and imposed traffic load. [13]. To improve the performance and the quality of the asphalt addition of polymers is a very effective way [7]. The very first company which started to use polyphosphoric (PPA) as a modifier in bitumen without the blowing of air is TOSCO (The Oil Shale Company). There are some virgin polymers that can be classified into 5 groups. Table 2 shows the summary of these polymers and their advantages and disadvantages along with the current use as bitumen modifiers [7].

Table 2. Characteristics of polymers used to modify bitumen [7]

Polymer	Advantages	Disadvantages	Uses
Polyethylene (PE)	High temperature resistance Aging resistance High modulus Low cost	Hard to disperse in the bitumen Instability problems High polymer contents are required to achieve better properties No elastic recovery	Industrial uses Few road applications
Polypropylene (PP)	No important viscosity increase even though high amount of polymer are necessary (ease of handling and layout) High RandB Low penetration Widens the plasticity range and improves the binder's load resistance	Separation problems No improvement in elasticity or mechanical properties Low thermal fatigue cracking resistance	Isotactic PP is not commercially applied Atactic PP is used for roofing
Polyvinylchloride (PVC)	Lower cracking PVC disposal	Acts mostly as filler	Not commercially applied



Styrene-butadiene block copolymer (SBS)	Higher flexibility at low temperatures Better flow and deformation resistance at high temperatures Strength and very good elasticity Increase in rutting resistance	High cost Reduced penetration resistance High viscosity at layout temperatures Resistance to heat and to oxidation is lower than that of polyolefins (due to the presence of double bonds in the main chain)	Paving and roofing
Styrene-isoprene block copolymer (SIS)	Higher aging resistance Better asphalt-aggregate adhesivity Good blend stability, when used in low proportion	Asphalts suitable for SBS blends, need an asphalt with a high aromatic and a low asphaltene content	

Justo *et al.* (2002), conducted study on the possible use of processed plastic bag as an additive to use as modifier in bitumen at the Center for Transportation Engineering of Bangalore University [14]. The properties of the modified bitumen were compared with ordinary bitumen. After the experiment results shows that the ductility and penetration values of modified bitumen decreased with the increase in the percentage of added plastic modifier up to 12% by weight.

Shankar *et al.* (2009), used crumb rubber to modify bitumen. Crumb rubber was blended in and mixed with bitumen later on Marshall's mix design was carried out by replacing modified bitumen content at a fixed optimum effective rubber content [15].

Waste cooking oil

The U.S. Environmental Protection Agency conducted a survey which proves that around three billion gallons of waste cooking oil are collected from restaurants each year in USA [16]. Wen *et al.* (2013) conducted a study to evaluate the laboratory performance of waste cooking oil-based bio-binder in Hot Mix Asphalt (HMA) which includes fatigue, rutting, thermal cracking, and moisture susceptibility [17]. The outcome of that study was promising. Further modification and research is needed to get more efficient result.

RECOMMENDATION

Researchers have done several studies regarding the production of a bio-binder which can replace a significant percentage of traditional bitumen binder for a sustainable environment where the outcome is very positive. With the increase in the percentage of bio-based material in the mixture the percentage of bitumen decreases. Use of these bio-based and waste materials can be an effective alternative of bitumen with the help of more research and study with some additives. Among all the researches the usage of bio-oil and waste cooking oil can bring a breakthrough result in the field of roads and

highway construction material. The results exhibit very close similarity as bitumen in mixture. More research is needed to find the efficient percentage of the bio-based material, proper modification and mixing process to get the optimum result which will be effective enough in road construction and possible for industrial production for large scale. This will help in slowing down the depletion of petroleum, provide a pollution free environment, proper reuse of waste materials and will help the national economy.

ACKNOWLEDGEMENT

The support provided by Malaysian Ministry of Higher Education and Universiti Teknologi Malaysia (UTM) in the form of a research grant (Vote No. 09H33) and Shell Singapore by providing bitumen for this study is very much appreciated.

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