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Impact of Bitumen Binder: Scope of Bio-based Binder for Construction of Flexible Pavement

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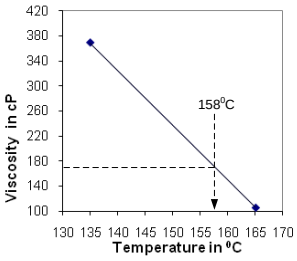
Graphical abstract



Abstract

Bitumen (asphalt) is a very complex material which is widely used as binder for flexible pavement but it is a hazardous material during production of Hot Mix Asphalt (HMA) with low dielectric constant (ε'). This paper provides a review about the bituminous material in the sector of construction of roads and highways. The behavior and adverse effects caused by bitumen binder to the environment as well as to the living being and need of alternative sources are discussed here. Statistics shows that a large number of workers are involved in the construction of flexible pavement around the world and they are exposed to the bituminous fume generated in the Hot-Mix Asphalt (HMA) process which causes severe damage to their health even cause cancer. When the bitumen spill exposed to the environment, bitumen fume and washed away particle mix with the environmental elements and cause pollution. To overcome this situation, world needs an alternative bio-based binder which will be efficient enough, cost effective and environment friendly.

Keywords: Bitumen; hazardous material; pollution; health hazard; industrial waste; bio-binder

1.0 INTRODUCTION

Transportation and highway is the engineering sector which includes planning, designing, construction, operation and maintenance of all kind of roads, tunnels and bridges to ensure safety and comfort for the transportation of people and goods. There are 15 types of pavement where flexible and rigid pavements are the most important [1]. Flexible pavement is widely used in all over the world. Where all the materials are 100% reusable due to this advantage 95% of world's highways are flexible pavement [2]. The basic difference between these two is the type of binder. In case of flexible pavement, bitumen is used as traditional binder whereas portland cement is used in rigid pavement as binder. Physically bitumen can be categorized as a viscoelastic and rheological material which is black or dark brown in color. Chemically bitumen is soluble in carbon di-sulphide (CS_2) to a great extent and having adhesive and water proofing qualities. This is a chemical compound of hydrocarbons where there is at least 80% of carbon and 15% of hydrogen and rests are oxygen, nitrogen, sulphur and metals. The reason of its use as binder in flexible pavement is its viscoelastic behavior. Bitumen binder is viscous so that it can hold all the aggregates altogether and it is elastic and can reform after deformation due to wheel loads. Basically source of bitumen is fossil fuel, the petroleum which is a natural resource. The volatility of the world's oil market has pushed oil prices to more than US $70 per barrel in the summer of 2008, this resulted in asphalt binder quickly spiking to more than US $400 per ton [3]. National Asphalt Pavement Association (NAPA) conducted study on warm mix asphalt under the contract of Federal Highway Administration (FHA). The result indicates that in the year 2012, total 1141 U.S asphalt plants queries produced 86.7 million tones warm mix asphalt. The reason of the application of Warm Mix Asphalt (WMA) in large scale is that it is produced at a lower temperature as a result the mixing process consumes less energy and reduces the emission of carbon. Overall process provide safer environment for workers. According to the Transport Research Board annual meeting in 2012, it is possible to save up to US $3.6 billion of money in energy cost by 2020 if warm mix asphalt (WMA) is used in the construction of roads and highways [4]. Bitumen is heated for workability in quarry, laying on roads and in the laboratory condition also. A huge fume emission during heating creates vigorous reaction, effect environment and hazardous to health and safety [5]. Because of the limitation of fossil fuel and huge

environmental impact the world needs an alternative binder for flexible pavement. The alternative source can be a bio-based, environment friendly economic material. Which will serve the purpose of bitumen efficiently.

2.0 BITUMEN

Bitumen can be defined as the amorphous, dark colored, viscoelastic material composed of heavy hydrocarbons and soluble in carbon disulfide. This is a lowloss material as loss tangent, tan δ (ε''/ε') <0.5 and its microwave permittivity (dielectric constant, ε') value ranges from 2 to 7 depending on grade of bitumen and asphaltenes content [6]. There are two sources of bitumen.

1. Natural asphalt (e.g. Pitch lake, Trinidad)
2. Petroleum asphalt

There is another form of asphalt which is called emulsified asphalt. This is the emulsion of asphalt and water in presence of emulsifying agent. In the emulsified asphalt, asphalt is in the form of minute globules in water as suspension. The mixture can be made and applied even without any application of heat. The application of asphalt emulsion requires a sufficient time to break and the water to evaporate so that the asphalt can stay and serve as binder. Inverted asphalt emulsions are seldom used in pavement applications [7].

As the bitumen is derived from petroleum, the price of bitumen highly relies on the price of petroleum. In the world market the price of petroleum is increasing time to time. This is because the source of petroleum is limited but the demand is increasing every day. The price of petroleum crude oil was US $61.95 per barrel in 2008 but in 2013 the price increased to US $97.98 per barrel [8].

Bitumen can be classified by their penetration grade, performance grade and viscosity grade. Example of performance grade is PG 76 and example of penetration grade is 60-70 and 80-100. According to the experiments conducted by Aziz (2012) [9] the viscosity, blending temperature test and penetration test results of neat bitumen are given in the Table 1, Figure 1 and Table 2 respectively.

Table 1 Viscosity of 80-100, 60-70 and PG 76 graded neat asphalt binder [9]

Type of Asphalt	Viscosity, cP		Ratio of Viscosity $135^0C/165^0C$
	At 135^0C	At 165^0C	
80-100	368.7	106.	3.47
60-70	425.0	150.	2.83
PG 76	1600.	675.	2.37

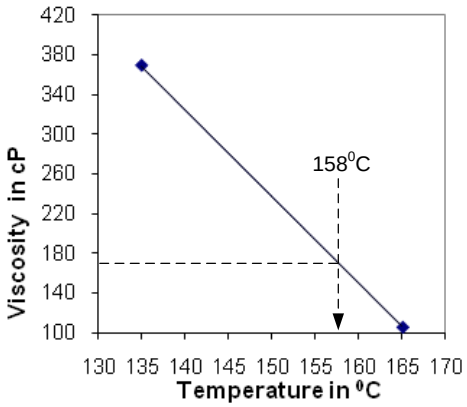
The result of viscosity test of bitumen binder shows that in lower temperature bitumen exhibit higher viscosity and PG 76 possess higher viscosity than 60-70 and 80-100.

Penetration test result shows that PG 76 possess comparatively lower penetration value compare to others that makes it more suitable for the construction of road in warmer region

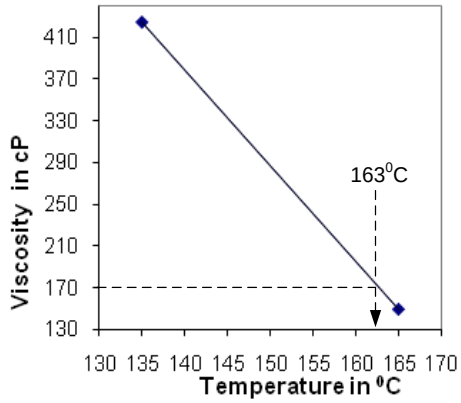
Table 2 Penetration Test Result of 80-100, 60-70 and PG 76 Graded Neat Asphalt Binder [9]

Sample No.	Type of Asphalt	Penetration test, units in 1/10 of mm				
		25°C	30°C	35°C	40°C	45°C
1.	80-100	81.33	119.67	210.33	263.33	324.00
2.	60-70	55.50	92.17	162.33	273.00	345.50
3.	PG 76	48.33	71.00	114.33	162.00	232.00

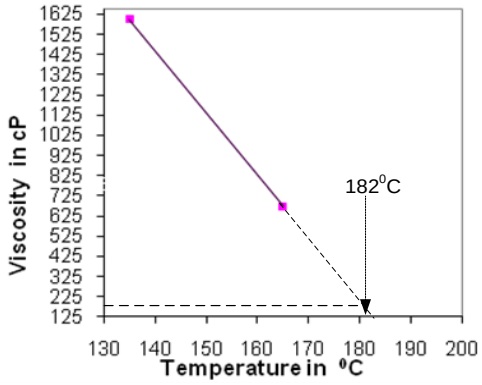
Blending temperature test shows that blending temperature of 80-100, 60-70 and PG 76 is 158°, 163° and 182° Celsius respectively at 170 cP. Where PG 76 needs the higher temperature that makes it stiff than 60-70 and 80-100.



(a) Blending temperature of 80-100 at 0.17Pa.s



(b) Blending temperature of 60-70 at 0.17Pa.s



(c) Blending temperature for PG 76 at 0.17Pa.s

Figure 1 Blending temperature for three grades of neat asphalt binder (a, b, c) [9]

3.0 IMPACT OF BITUMEN

Bitumen is a complex substance. It contains heavy hydrocarbons and heavy metals. It needs to be heated at 165°-200° Celsius temperature to get enough fluidity to coat all the aggregates in road construction. A vapor is released by the heating of bitumen in the time of construction of roads, later it condensates by cooling contains volatile components which is present in the bitumen. These components are chemically and potentially toxicologically distinct from bitumen. The vapor as the asphalt fume is cloud of micro and macro particles which is harmful enough to cause adverse impact on environment as well as in human [10].

4.0 IMPACT ON ENVIRONMENT

The exposure of bitumen to the environment is undeniable as bitumen and bitumen fume transported to air, water and soil hence affects the habitants and pollute water and air. Cooper *et al*. [11] determined the components of runoff from asphalt pavement in fish (rainbow trout Oncorhynchus mykiss, brown trout Salmo trutta, and Paiute sculpin Cottus beldingi) and invertebrates from streams in California, USA. Asphalt fractions consists of polars, saturates and aromatics which are characterized in airborne particles and air samples which are termed as airborne particles. In a study in Denmark air sample was collected from 2.0 to 83.6 m of highway and in organic samples (grass, leaves etc.) collected 2.0-10.0 m from the highway [12]. After analysis it was found that the percentage of asphalt was 1.61-11.02% in these airborne particles. The concentrations of asphalt fractions in the sample collected are shown in Table 3.

Table 3 Concentration of asphalt fraction in sample [10]

Sample type	Concentration		
	Polar	**Aromatic**	**Saturates**
Air	0.54-3.96 x 10^{-3} mg/m^3	1.77-9.50 x 10^{-4} mg/m^3	0.21-1.23 x 10^{-4} mg/m^3
Plant	0.96 mg/g	0.89 mg/g	0.37 mg/g
Grass	0.93 mg/g	3.07 mg/g	2.91 mg/g
Leaves	3.89 mg/g	1.28 mg/g	1.53 mg/g
Wheat straw (at 5m)	1.19 mg/g	0.29 mg/g	1.38 mg/g
Wheat straw (at 10m)	1.30 mg/g	0.63 mg/g	0.56 mg/g

According to the study conducted by Kriech *et al*. (2002) [13] paving samples contained detectable amounts of naphthalene and phenanthrene. Though the levels were well below drinking-water limits (0.015 mg/litre) in the USA. Still the amount of contamination can be vary from place to place and it becomes vulnerable for health.

5.0 IMPACT ON HUMAN

Impact of bitumen in human specially the workers who exposed to the bitumen fume directly is adverse. A survey was conducted in USA about the number of workers involved in mixing of asphalt which shows that around 300,000 workers are working in HMA asphalt facilities [14]. Among them 50,000 workers are working in the operation of asphalt roofing and approximately 1,500-2,000 workers are employed in around 100 of roofing manufacturing plants [15].

Statistics from Western Europe says that as at least 5-10 workers are employed in every single asphalt mixing and processing plant where the total number of mixing plant is around 4000. Approximately the number of pavers is 100,000 who lay the asphalt mix to the roads [16]. The chronic effects of exposure to asphalt and asphaltic contents among workers in every sector of the asphalt industry (HMA plants, construction work, roofing, paving etc.) includes the following symptoms as basic.

i. Irritation of serous membranes of conjunctivae.

ii. Unpleasant feeling in the mucous membranes of the upper respiratory tract.

iii. Coughing.

These kinds of health effects appear to be mild and temporary. There are some additional symptoms like pruritus, nausea, skin irritation, stomachache, headache, fatigue, rashes, skin disease, itching which are reported by the pavers and the workers involved in asphalt industry. World Health Organization (WHO) found that some workers also suffer from lower respiratory tract manifestations like coughing, asthma, wheezing etc. and even bronchitis. The minimum range of trigger point (TP) exposure is 0.02 mg/m^3 cause respiratory tract symptoms [10].
Several studies has been conducted to determine the possibility of cancer because of the exposure of the fume to the pavers a summary of the study is illustrated on Table 4.

6.0 BIO BINDER

Due to the price hike, limitation of the natural resources and the severe adverse environmental impact of bitumen the world needs an alternative binder for flexible pavement. Bio binder is the concept of bio based alternative for traditional bitumen. The advantage of bio-binder in the case of applying is that it can be applied in three different ways, so that the demand of fossil fuel based conventional bitumen binder can be decreased. There are:

i. Complete replacement of bitumen (100% replacement)

ii. Partial replacement as a bitumen extender (25%-75% replacement of bitumen)

iii. Bitumen modifier (1-10% replacement of bitumen) [22]. Currently the use of modifiers are in practice where modifiers are mostly bio-based or the recycled waste. The more modifiers are used the percentage of petroleum based bitumen decreases thus as well as the level of pollution. This helps the environment, reduces the price and improve performance of the road. Research is going on to produce alternative bitumen for road construction. Few probable sources has been found by researchers, those are bio based source and from waste materials. Bio-base sources are mainly bio-oil like palm oil, cooking oil, vegetable oil, biomass, swine manure etc. Waste materials like waste polymer, peanut oil waste, coconut oil waste, waste engine oil, waste crumb rubber, dried sewerage effluent etc. [23], [24], [25], [26], [27].

Table 4 Epidemiological studies of asphalt exposure: cohort studies of diseases in pavers [10]

Author, country and occupation	Numbers of study subject	Dates of case ascertainment	Type or site of condition	Number of deaths or case	Risk ratio	95% CI or *P* value
Hansen (1989) [17], Denmark, mastic Asphalt workers[b]	679	1959-1986	All cancers	74	SIR 1.95[c]	1.53-2.44
			Lung cancer	27	SIR 3.44[d]	2.27-5.01
			Mouth	2	SIR 11.11[d]	1.35-40.14
			Oesophagus	3	SIR 6.98[d]	1.44-20.39
			Rectum	7	SIR 3.18[d]	1.28-6.56
Hansen (1991) [18], Denmark, mastic asphalt workers[e]	679	1959-1986	All causes	148	SMR 1.57[d]	1.34-1.85
			All cancers	62	SMR 2.29[d]	1.75-2.93
			Lung cancer	25	SMR 2.90[d]	1.88-4.29
			Non-lung cancer	37	SMR 2.00[d]	1.41-2.76
			Bronchitis, emphysema, asthma	9	SMR 2.07[d]	0.95-3.93
Engholm, Englund, and Linder (1991) [19], Sweden, pavers[f]	2572	1971-1985	All causes	96	SMR 0.69	NR
			All cancers	47	SIR 0.86	NR
			Stomach cancer	5	SMR 2.01	NR
			Stomach cancer	6	SIR 2.07	NR
			Lung cancer	7	SMR 1.10	NR
			Lung cancer	8	SIR 1.24	NR
Bender *et al*. (1989) [20], USA, highway maintenance workers[g,h]	4849	1945-1984	All causes	1530	SMR 0.9	0.86-0.96
			All causes	274	SMR 0.89	0.73-0.94
			Lung cancer	57	SMR 0.69	0.52-0.90
			Mouth, pharyngeal cancer	2[i]	SMR 11.10	1.30-40.10
			Gastrointestinal cancer	3[j]	SMR5.82	1.20-17.00
			Prostate cancer			
			Kidney, bladder, other urinary organ cancer	11[k]	SMR 2.98	$P < 0.01$
			Leukemia	7[l]	SMR 2.92	10.17-6.02
				8[m]	SMR 4.49	1.94-8.84
Partanen *et al*. (1997) [21], Finland, road pavers (males only)			Lung cancer	NR	SMR 1.5	1.2-1.9
			Lung cancer	NR	SIR 1.4[n]	0.9-1.9

a Abbreviations: CI = confidence interval; NR = not reported; SIR = standardized incidence ratio; SMR = standardized mortality ratio.
b Possible exposure to coal tar pitch. Author concluded that smoking unlikely to account for 3-fold excess of cancer; exposure data limited to comparison population were based on Danish general population.
c All mastic asphalt workers (n = 679).
d Mastic asphalt workers aged 40–89 years (n = 547).
e Follow-up of Hansen (1989a); limitations the same as in previous analysis.
f Median follow-up for cohort 11.5 years; median age of cohort 42 years. No exposure assessment. Comparison populations for mortality and incidence studies were based on Swedish general population. Mortality and incidence studies did not control for smoking.
g Follow-up case–control study found RR = 3 for lung cancer after adjusting for smoking, but limited by small number of cases.
h Reference group was male population of Minnesota; quantitative exposure data limited. Highway maintenance workers employed as pavers,
landscapers, mowers, garage workers, and office workers. No adjustment for smoking.
i Employed ≥40 years.
j Urban workers with 40–49 years of latency.
k Started working 1955–1964.
l Workers with 40–49 years of latency.
m Employed 30–39 years.
n Asphalt exposure

■7.0 RECOMMENDATION

The world needs a sustainable source of energy to help the future generation from not facing the deficiency of petroleum and ensure a pollution free environment. To achieve this target alternative bio-based source is a must. The industries have to move forward to implement the use of bio-binder in construction sector. The use of modifiers are becoming a very popular because it saves the environment, cost and petroleum reserve. Studies are going on to find the efficient sustainable source for binder so that it can be applied as the complete replacement of bitumen.

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