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A SHORT REVIEW OF WASTE OIL APPLICATION IN PAVEMENT MATERIALS

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Large amount of waste product from the automotive industry and by-product of frying can impose adverse impact if not disposed properly. Recycling of the waste product can be seen as sustainable options, which offers conservation of natural resources and economic benefits. The application of waste engine oil (WEO) and waste cooking oil (WCO) were contemplated in pavement materials as to reduce the stiffening effect of reclaimed asphalt pavement (RAP). This short review highlights on the application of waste oil in asphalt pavement and the effects of waste oil on binder and asphalt mixture performance.

Keywords: liquid waste; used engine oil; waste cooking oil; reclaimed asphalt pavement

Introduction

Waste oil which discarded into the landfill without any treatments prominently produced the adverse impact to the environment. The effect can be seen by eutrophication process. The thin layer of oil appears on the surface of river or lake can block the sunlight, the photosynthesis and also disrupting the oxygen supply to the aquatic life (El-Fadel and Khoury, 2001; Hamad et al., 2003). These processes lead to the excessive growth of micro-organism, phytoplankton and algea that use the waste oil as a food source. Lake or river quality was deteriorating and also disrupted the intrinsic equilibrium of aquatic ecosystem. The source of waste oil pollution to the river can be contributed by engine oil from automotive industry and also waste cooking oil from residential area. With the concern of high construction cost and natural resource conservation, waste oil recycling is becoming the viable alternative in mitigating these problems (El-Fadel and Khoury, 2001).

After years of exposure to traffic loads and climate change, the road will experience aging and reduction in binder performance. The pavement distinctive feature is that after the end its design life, the pavement surfaces can be milled and recycled which is known as reclaimed asphalt pavement (RAP) (Jamshidi et al., 2012; NAPA, 2009). This renewability process can be done through 'rejuvenation'. Usually, RAP was added in asphalt mixtures between 10% and 60% of the total mixture weight. Higher RAP content in the mixture can significantly increase the mixture's stiffness. However, too much RAP can reduce the mixtures performance. Therefore, through rejuvenation the properties of the old asphalt pavement particularly the binder properties can be improved to restore the original ratio of asphaltenes to maltenes and compensate this hardening effect (You et al., 2011; Garcia et al., 2011; Romera et al., 2006). This is to provide sufficient binder coating to new aggregates from the reclaimed asphalt mixture to produce pavement with consistent performance. Asphaltenes is a solid, hard brittle component and not affected by oxidation, whereas maltenes is a liquid one, oily and resinous in appearance (Brownridge, 2010). This paper presents a short review on the application of waste oil in asphalt pavement especially in term of binder modification.

Types of Waste Oil

Economic improvement has a direct impact on commercial activities and road network facilities in a country. This situation can lead to an increase in the number of vehicles on the road. In Malaysia, there are a total of 22 million registered vehicles which can contribute to the waste engine oil (WEO), that can lead to environmental pollution if not disposed of properly or recycled (Road Transport Department, 2012). Generally, engine oil also referred as oil lubricants, oil cylinder, crankcase oil and motor oil (Ssempebwa and Carpenter, 2009; Romera et al., 2006). Vehicle workshops and factories with heavy machinery are seen as primary sources that generate WEO. If the discharge of waste engine oil is not well managed or disposed, it will affect human health, aquatic life and ground pollution. According to previous studies, little waste engine oil is enough to ruin millions of gallons of fresh water (Moghaddam et al., 2011). Figure 1 shows the color difference between fresh oil and waste engine oil where fresh oil has a gold and translucent color and after the heating process of the engine, the oil turns black and opaque.

Figure 1: Different colour between fresh (left) and waste (right) engine oil

In addition to the engine oil, there are also many sources of cooking oil can be recycled, and has the potential to be used as an additive in asphalt mixtures. This oil is processed from sources that vary by geographic location such as soybean oil and salad oil in the United States, China's animal fat, soybean and canola oils in England, rapeseed oil and sunflower oil in Europe, palm oil in Malaysia and animal fats in Canada. Figure 2 shows the total production WCO by various countries. United States is the top producer of WCO with 10 million tonnes per year whereas Taiwan produces the lowest WCO with 70,000 tons per year. In Malaysia, palm oil is used as cooking oil due to its low processing cost and high availability of local resources compared with other countries. Waste cooking oil is a product of the frying activity at high temperatures that are usually available from the food industry, restaurants, hotels and residences (Zhang et al., 2012). These products are usually treated and discharged into the river.

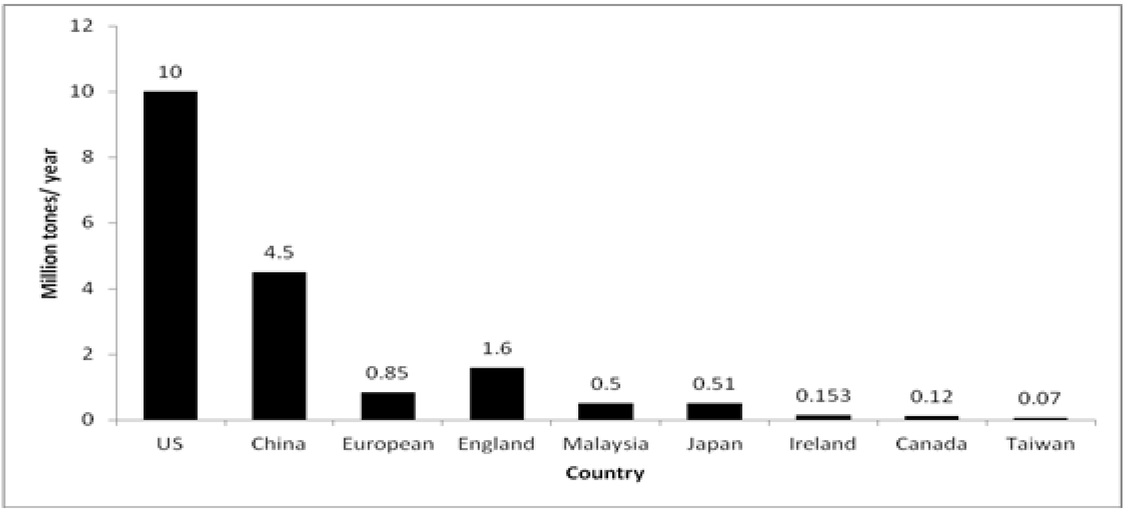

Figure 2: Quantity of WCO generated by various countries (Kulkarni and Dalai, 2006; Gui et al., 2008; Yaakob et al., 2012)

Properties of Waste Oil

The properties of WEO is depend on the combustion process, operation temperature, contaminant sources such as moisture, soot, diluents, rust, detergents and engine wear metal particles (Al-Ghouti& Al-Atoum, 2009; Bamiro and Osibanjo, 2004; Yang, 2008). According to El-Fadel and Khoury (2001), the source of heavy metals presence in the waste engine oil is due to the engine or metal wear and high quantities of lead. This constituent becomes the concern due to the hazardous characteristic. Table 1 presents the quantity of metals present in the waste engine oil and the maximum level permitted by the United State Environmental Protection Agency (EPA) and the Malaysian Department of Environment (DOE). The metal levels in the waste oil are acceptable and suitable to re-use as rejuvenator for the RAP mixture.

Table 13: Chemical properties in waste engine oil

Constituent	Symbol	Results (You	US Maximum Allowable Level	Malaysia Standard Maximum Allowable Level

		et al., 2011)	(You et al., 2011)	(DOE, 2010)
Arsenic	Zn	< 1.0 ppm	5 ppm	5 ppm
Ash	-	0.66%	NA	NA
Cadmium	Pb	0.28 ppm	2 ppm	2 ppm
Chromium	Mn	< 4.0 ppm	10 ppm	10 ppm
Lead	Cu	14.0 ppm	100 ppm	100 ppm
Sulfur	S	0.19%	NA	NA
Total Halogen	-	396 ppm	4000 ppm	1000 ppm

- NA – Not Available

Meanwhile, the chemical properties in waste cooking oil are listed in Table 2. According to US Patent no 20120167802 A1 (Huh, 2012), the organic acid composition in WCO are included in groups of cohesive agents. The main function of cohesive agents is to reduce the high viscosity of aged asphalt binders in RAP and thus produce the homogenous mixing when integrated with new pavement materials. The reduction viscosity of binder leads to the decreasing surface tension of the aggregate and coated binder. As a result, this process will easily expel the air curtain around aggregate particles to assist the cohesion. Therefore, it is interesting to note that WCO is a good rejuvenating agent where it can promote the good coating of the aged binder.

Table 14: Chemical properties of waste cooking oil (Asli et al., 2012)

Type of Free Fatty Acid	% Waste Cooking Oil
Oleic acid	43.67
Palmitic acid	38.35
Linoleic acid	11.39
Stearic acid	4.33
Myristic acid	1.03
ɣ - Linolenic acid	0.37
Lauric acid	0.34
Linolenic acid	0.29

Cis-11-Eicosenoic acid	0.16
Heneicosanoic acid	0.08
TOTAL	100

Method of Incorporating Waste Oil into Pavement Material

The use of residual oil in the pavement can be used directly in liquid form and capsules. Table 3 shows the mixing temperature range between residual oil and asphalt mixture as suggested by previous researchers. The oil is mixed with a binder to modify the binding characteristics. Usually waste oil is mixed with the binder prior mixing it with asphalt mixture. There is also a method in which the oil is poured directly into the RAP to improve the characteristics of the asphalt mixture (Bailey and Phillips, 2010; Tran et al, 2012). In order to assess the effect of waste oil in binder, the aging properties of the mix at certain temperatures has been studied.

Table 3: Mixing process of waste oil in asphalt

Author	Type of Oil	Mixing Temperature, (°C)	Time of Mixing, hour	Mixing speed, rpm
Dedene et al. (2011)	WEO	150	NA	NA
Borhan et al. (2009)	WEO	NA	NA	NA
A Zamhari et al. (2009)	WEO	NA	1 hour / cycle	NA
Villanueva et al. (2008)	WEO	160	1	500
Asli et al. (2012)	WCO	130	0.5	200
Zargar et al. (2012)	WCO	160	0.5	200

- NA – Not Available

Meanwhile, the capsule form is a new innovation in order to mitigate the reduction of skid resistance by the application of rejuvenators (García et al., 2011). The capsule was fabricated with shell as the outer layer and the inner is porous core where the rejuvenators were embedded. The shell is hard but impermeable. The shell is made from particles of cement Type I 52.5R bonded by a liquid epoxy resin (StruersEpofix resin, bisphenol A-epichlorohydrin) and hardener (triethyenetetramine) in a 10.7% weight proportion (García et al., 2011). Figure 3 shows the mechanism of the capsule that contained the aromatic and dense oil when subjected to the traffic load.

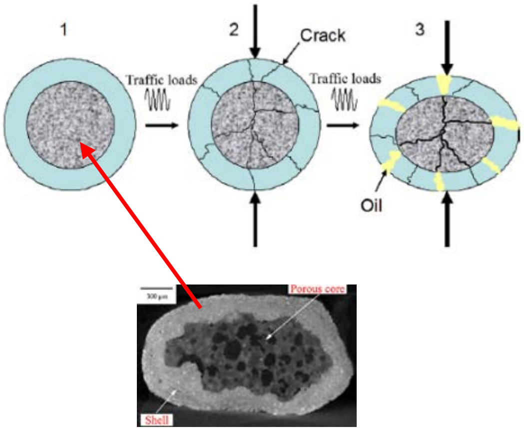

Figure 3: Mechanism of capsule form rejuvenator (García et al., 2011)

Previous Evaluation on Binder Performance

Waste oil prominently affects the properties of binder. Penetration, softening point, viscosity and dynamic shear rheometer test is frequently used for binder evaluation. Penetration and softening point measure the hardness and softness a binder. In this test, a 1 mm diameter needle was loaded with a weight of 100 g and the distance it drops in 5 s into a bitumen sample that maintained at a temperature of 25◦C. According to Read and Whiteoak (2003) the maximum difference between the highest and the lowest reading for the penetration group of 50–149 should be 4. Meanwhile, for softening point should not differ by more than 1°C otherwise the test should be repeated. These tests were significant to classify the bitumen grade based on penetration ranges.

Bailey and Philips (2010) have patented for asphalt rejuvenation using waste vegetable oil. The researcher claimed that the waste vegetable oil have the greatest effect to the penetration and softening point value when added to the heated RAP. About 9 -11% waste vegetable oil was recognized to rejuvenate aged samples from field to the targeted 40/60 penetration grade binder. Asli et al. (2012) introduced the environmental friendliness usage of WCO from palm oil sources for binder stage evaluation. Binder grade 80/100 was heated in the oven to get the aged samples. The aged binder of bitumen group 50/60 needed 1%, group 40/50 needed 3- 4% and group 30/40 needed 4 – 5% as the optimum WCO to achieve the original penetration value 80/100. Zargar et al. (2012) conducted the continuous heating of bitumen 80/100 and produced aged binder with penetration value about 45 dmm. This binder need the rejuvenator of WCO as 3% - 4% to meet the properties comparable with the original 80/100 bitumen. Meanwhile, the penetration value of aged sample from a motorway with 6.3 dmm, need about 20% of WEO to satisfactory to target grade 60/70 bitumen (Romera et al.,2006). Zamhari et al. (2009) revealed that the addition of 10% WEO to the artificial aged bitumen with penetration value 31 dmm have facilitated to achieve the target penetration grade 80/100. Here, obviously shows that the range of rejuvenator used to compensate the aging effect is depend on the hardness of aged binder and the target binder. The lower penetration value, need the higher amount of waste oil to achieve the target binder. Generally, the range 1 – 10% of WEO needed to rejuvenate the artificial aging binder and 10 % - 25% for aged sample from field.

Viscosity test is conducted to determine the ability for pumping, coating and placing the asphalt binder. Temperature for mixing and compaction can be obtained from viscosity graph. The unit of viscosity is Pascal seconds (Pa.s). The viscosity reading was taken at one-minute intervals for the total of three minutes. Zargar et al. (2012) conducted the viscosity test according to ASTM D4402 and used the temperature 135□C as the measuring workability. Various percentages of WCO added into penetration grade binder 40/50, which is compared to the original bitumen pen-grade 80/100. The aged bitumen has a higher viscosity value, while the addition of 4% WCO into the aged bitumen penetration group of 40/50 achieves almost the same viscosity as the original bitumen. As stated in literature, a rejuvenator must have the lower viscosity to ensure the sufficient coating of aged binder to aggregates and enhanced the workability. The results by Bailey and Phillips (2010) has proven this statement as shown in Table 5. The increasing of oil content and temperature has decreased the viscosity of the samples.

Table 5: Value of viscosity from different temperature (Bailey and Phillips, 2010)

Oil Content (%)	Viscosity (Pa.s)		
	120°C	150°C	180°C
0	1.074	0.231	0.074
2	0.844	0.200	0.064
4	0.723	0.172	0.060
6	0.607	0.151	0.053
8	0.504	0.131	0.046
10	0.429	0.117	0.044

Rheological characteristic is prominently determined by dynamic shear rheometer (DSR) test in order to verify any changes in the behavior of the binders or the shear resistance at temperatures which rutting and fatigue occur due to addition of waste oil. The rheology equipment consists of a fixed lower plate and oscillating upper plate through which shear force is applied to the specimen. The unaged and short term aging specimen is loaded with gap 1 mm, meanwhile the sample long term aging used gap of 2 mm. The rheology in binder closely related to viscous and elastic behavior. These two parameters are important to able for a binder to stand firm of permanent deformation and fatigue cracking. DSR measures the complex shear modulus, G* and phase angle, □ of asphalt binders for unaged, short term aging using Roll Thin Film Oven (RTFO) and long term aging using Pressure Aging Vessel (PAV). G* is divided sin □ or G*/sin□ as indicator of rutting potential at high temperature and G*sin □ as to predict fatigue cracking at intermediate temperature. The compliance of rutting parameter, G*/sin (δ) equal to 1 kpa for un-aged and 2.2 kpa for aged binders after RTFO.Meanwhile, fatigue parameter, G*sin (δ) for 5 MPa, stiffness and m-value of the blend after RTFO + PAV aging (Shen and Ohne, 2002; Romera et al., 2006; Shen et al., 2007). The rutting parameter, G*/sin δ was observed to decreased with the addition of oil (Dedene et al., 2011). Rheological properties also can be represented either by master curve or isochronal curve. Master curve is the variation of complex modulus in shear mode, G* as a function of frequency at a reference temperature. Meanwhile, isochronal curve is the variation in G* and phase angle, δ with temperature at a selected frequency or loading time (Kim, 2006). Zargar et al. (2012) focused on isochronal plot, where phase angle was plotted versus temperature for each sample modified with 0, 1, 2, 3 and 4% waste cooking oil. As the temperature increased from 30□C to 80□C, the complex shear modulus was decreased. Bitumen aging also implies a complex shear modulus, G*, increase and a phase angle δ decrease, providing more resistance to deformation. Dedene et al. (2011) conducted a preliminary study of recovered asphalt binder blended with waste engine oil. The concentration used as 4% and 8% by weight of the total mix. The test involved viscosity test and dynamic shear rheometer (DSR). However, this effect was counteracting by the addition of waste oil.

Previous Evaluation on Performance of Asphalt Mixture Modified with Waste Oil

Oil has the ability to reduce the bitumen viscosity and soften the bitumen. Rutting is a problem that mainly occurred on the soft mixture. Higher rutting potential is when the large amount of permanent deformation was observed (Borhan et al., 2007). Creep test is one of the tests that can be used to assess the permanent deformation of asphalt mixtures and it can be conducted either in static or dynamic loading. Borhan et al. (2007) conducted laboratory evaluation of low cost cold mix asphalt which modified with 0, 20, 25 and 30% of used cylinder oil by weight of binder content. As the amount of used cylinder oil increased, the creep stiffness decreased. The oil weakens the bonding between the binder and aggregate within the cold mix. The addition of used engine oil to the cold asphalt mixture made asphalt pavement become susceptible against permanent deformation. The stiffness also was reduced about 28% compared to the control mixtures (without waste engine oil) at the temperature of 40□C. This is due to the lower viscosity offered by the waste engine oil deteriorating the mastic bonding.

Stiffness, rutting resistance and cracking resistance are significant properties of bituminous pavement (Widyatmoko, 2008). Higher application of RAP materials, cause higher materials stiffness. Bailey and Philips (2010) reported that the used of vegetable oil decreases the stiffness of the aging mixture. The oil was introduced to the mixture at the stage of hot mix recycling. Dedene (2011) conducted the rutting resistance test using APA machine at the temperature 58□C. The sample consist 25% RAP and two amount of WEO (4% and 8%). The sample with WEO showed the increased rutting compare to control. Tran et al. (2012) revealed the application of emulsion manufactured from a naphthenic crude stock (Cyclogen® L) to the 50% RAP, increases the mixture resistance against low temperature cracking. By adding 50% RAP with 12% Cyclogen® L, the mixture exhibits lower critical failure temperature compared to control mixture. This findings show that the application of waste oil will be effective if used with the high RAP percentage.

Conclusions

The effects of WEO and WCO are commonly produced both of the adverse and good effects to the pavement. The appropriate amount of waste oil depends on the constituent of aged mixture material. The high stiffness of mixture also require high amount of waste oil. In cold mix, it was reported that the performance was affected such as stability, strength and weakening the bonding between aggregate and binder. However, in hot mix asphalt where the oil was integrated into the RAP, it offered the stiffness reduction and therefore improved resistance to cracking. The temperature, amount of waste oil and RAP are notable to give significant influence on the performance properties. Therefore, these factors are an intriguing which could be usefully explored in further sustainable research.

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