Jurnal
Teknologi

Full Paper

A Review of Utilization of Coconut Shell and Coconut Fiber in Road Construction

Article history
Received
30 April 2015
Received in revised form
6 August 2015
Accepted
1 September 2015

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Graphical abstract

Abstract

This paper provides a review of utilization coconut shell and coconut fiber in road construction. Coconut shell and coconut fiber are new waste materials used in highway industry. Some studies showed that coconut fiber can increase the stability, skid resistance and resilient modulus while coconut shell can improve the indirect tensile strength and static creep behavior of the modified asphalt pavement. In contrast, coconut fiber does not improve the fatigue life of the modified bituminous mixes. In general, the previous research illustrates that coconut shell and coconut fiber significantly improves the engineering properties of asphalt mixtures when mixed with modified bitumen.

Keywords: Coconut Shell, coconut fiber, skid resistance, waste material, asphalt pavement

1.0 INTRODUCTION

Coconut shell is one of the main polluter that contributes to the nation's pollution problem. It is a solid waste in form of shell with approximately 3.18 million tonnes produced annually [1]. The common waste materials that used to improve the quality of pavement construction are ash, scrap tire, iron and steel slag, fly ash and plastic waste[2]. Coconut shell (CS) and coconut fiber (CF) as shown in Figure 1 are known as new waste materials that used in highway industry. This is because coconut shell has good weather resistant thus it is suitable to use as construction materials. Besides, it has no economic value and its dispose process is costly and will cause environmental problem [3].

Figure 1 Coconut shell (left) and coconut fiber (right)

The chemical compositions of CS contains is 33.61% cellulose, 36.51% lignin, 29.27% pentosans and 0.61% ash [4]. CS has low ash content but high volatile matter, 65-75%[3]. While CF has the lowest cellulose content, 36 - 43% but with twice amount of lignin (41-

45%) compared to jute and sisal which makes it has greater resistance and hardness [5]. CF will act as stabilizing additives when added into the asphalt mix around 180°C [6].The water absorption of the CS is higher than conventional aggregate, which is 24% compared to 0.5 [1]. CS is also more resistance against impact, crushing and abrasion compared to others conventional crushed granite aggregate [4]. It can use to mix with asphalt mixture directly for the experiment except water absorption test [4,7]. This is because coconut shell has high water absorption capability and not suitable to use for mixing without treatment.

CF generates many advantages when react with asphalt mixture as it can reduce bleeding of the binder and advancing the macrotexture of the coating [8]. Besides, it can help to reform the mechanical characteristics and improve surface drainage pavement of tyres [9]. CF enable the use of discontinuous of grain size, which can increase the content of binder [10-11], hence the aggregates will coat with thicker film. This can reduce the oxidation of asphalt mixtures, moisture penetration and separation [10].

On the other hand, all asphalt applications has one problem, it will become brittle at low temperatures and soft at high temperatures [12].CF can increase the range of temperature of porous asphalt thus help to resist degradation. This function can reduce the drying and cracking that occur in conventional asphalt pavement when faces various climate [13]. At high mixing and compaction temperatures, CF also helps in reduce the flow of asphalt hence it can help to prevent bleeding and make sure the air void content is not clogged by asphalt binder [14]. The characteristics and properties of coconut fiber are given Table 1.

CF has outstanding moisture absorption because the irregular of crack in the cross section surface provides unique structure. The unique structure also results in better air permeability and moisture conductivity. In addition, the unique structure of the CF will improve the moisture susceptibility, viscoelasticity and rutting resistance as well as ameliorate low temperature anti-cracking properties, durability, material toughness, fatigue life and lowering reflective cracking of asphalt concrete mixtures and pavements [11,15].

Table 1 Characteristics and properties of the coconut fiber [14]

Characteristics of granulated	Results
Average length of the granulated one	10-20mm
Average thickness	0.1mm
Amount (percentile in weight)	0.5-0.7%
Ph	5.4
Electric Conductivity	1.8dS/m
Capacity of cationic exchange	92
Relation C/N	132
Specific mass	70g/L
Water retention	538ml/L
Capacity of aeration	45.5%
Porosity	95.6%

2.0 RESEARCH FINDING

Abiola *et al*. [16] reported that there have two methods to mix fiber into bitumen modification. The wet process blends the fibers with asphalt binder prior to incorporating the binder into the mixture while the dry process mix the fiber with aggregate before adding asphalt. From the experiment result, Abtahi *et al*. [17] stated that there is no difference in the Marshall properties between the dry process and wet process. However, the dry process is easier to carry out and better distribute the fiber in the mixture. Besides that, there is no advantages carry out wet process since fibers would not melt in the asphalt and the field work normally used dry process. Do Vale *et al*. [14] have applied the coconut fiber on Stone Matrix Asphalt (SMA) using two different methods which are Marshall[18]and Superpave [19]. The Marshall method controls the void during the compaction of the mixtures with different blows adopted for each face. The samples in Superpave were compacted in 100mm cylinder with 100 turns for the sample without fiber and with fiber of cellulose while 160 turn for samples with fiber of coconut to reach 4% of air void content.

The samples from Superpave and Marshall had been used for indirect tensile strength[20], drain down test [21], resilient modulus [20], moisture susceptibility and fatigue life [22]. The results show that tensile strength and resilient modulus of SMA CAP 50/70 with coconut fiber was higher by using Superpave method and it was the highest among three different condition of samples: without fiber, with coconut fiber and with cellulose fiber [23]. The coconut fibers are used to prevent flow of asphalt at high compaction and mixing temperatures. The percentages of fiber used are 0.1 to 0.7 and they were heated up separately with aggregate at 175°C before mixing with asphalt binder. Do Vale el al. [14] presented the result that 0.5% of coconut staple fiber is workable in mixtures of types SMA with CAP 50/70 can prevent the flow parameter. The length of coconut fiber should not be more than 20 mm. Table 2 summarize the results of Marshall Flow with different CF in asphalt mix.

Table 2 Flow of asphalt mixture incorporating coconut fiber [14]

Fiber	Fiber content (%)	Flow parameter (%)	
		T= 165°C	T= 180°C
Without fibers	0.0	1.06	0.70
Coconut	0.5	0.08	0.25
	0.7	0.04	0.09
Cellulose	0.3	0.01	0.03
	0.5	0.01	0.02

Figure 2 show that coconut fiber does not improve the fatigue resistance of SMA mixtures. However, coconut fiber was reported that it can improve the fatigue resistance of bituminous mixes [24]. On the other hand, Thulasirajan and Narasimha [25] conducted a study on flow, stability and volumetric properties of the modified fiber with coconut fiber by varying binder content, fiber content and fiber length. A 5.72% of bitumen content with 0.52% of 15mm of fiber content shows good stability and volumetric properties. The research can conclude that coconut fiber can improve the structural resistance to traffic loads in flexible pavement.

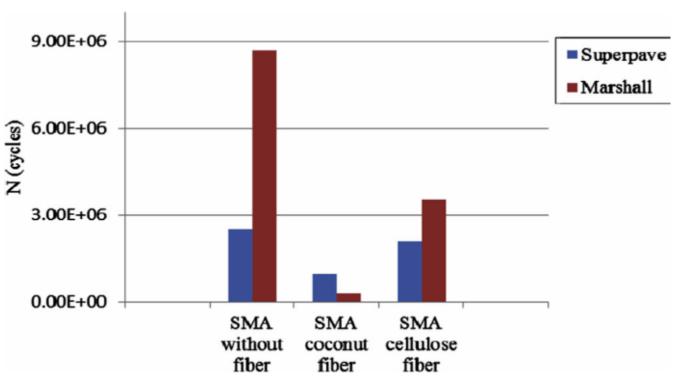

Figure 2 Fatigue of SMA mixture at different type coconut

Hadiwardoyo [26] has investigated the contribution of short coconut fiber to pavement skid resistance and the results are presented in Figures 3 and 4. The length of coconut fibers used was 0.5-1.25 cm and mixed with pen 60/70 asphalt and the percentages of fiber contents used were 0%, 0.75% and 1.5%. The modified asphalt mixtures mixed with course aggregate then mold and compacted with wheel tracking compactor by using an 8.16 ton of standard vehicle axle load. Skid resistance was tested by using British pendulum tester [27] at temperature of 26°C, 30°C, 35°C, 40°C, 45°C and 50°C. The samples were cut into 120 mm x 50 mm x 50 mm for skid resistance test to get the British pendulum number. Figure 3 shows that the modified asphalt with 0.75% of coconut fiber has higher skid number when compared to others two specimens. However, the skid number has decreased when temperature reached above 30°C. Meanwhile, skid number for modified asphalt with 0.75% and 1.5% of coconut fiber has after 2520 load passes has decreased after 30°C. The skid number has decreased for three different specimens, however, the modified asphalt with 0.75% of coconut fiber still has higher skid number when compared to others two specimens. It is concluded that modified asphalt with 0.75% of coconut fiber improved skid resistance but did not increase the resistance of the asphalt and temperatures changes.

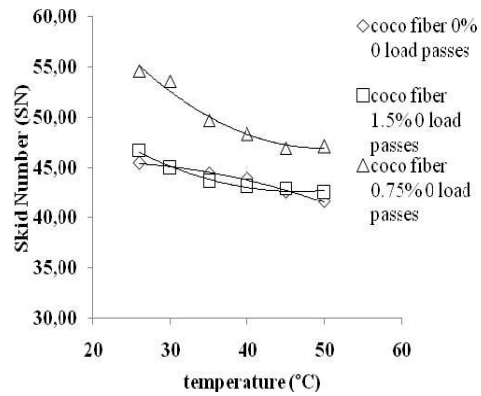

Figure 3 Relationships between skid number and temperature after zero load passes [28]

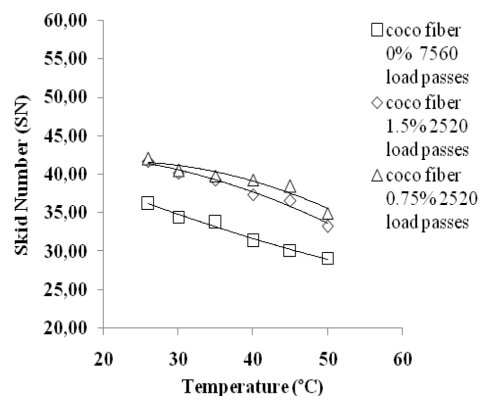

Figure 4 Relationships between skid number and temperature after 2,520 load passes [28]

Al-Mansob[28] has investigated the modified asphalt with palm oil shells (POS) and coconut shells (CS) as additives. Both additives are added by using 4.75 mm with various percentages (0, 5, 10, 15 and 20%) of the total weight of size 4.75 mm of the aggregate. The modified asphalt samples were compacted by Superpave method[29-30] and tested the modulus, static and dynamic creep tests by using IPC Global Universal Testing Machine. Besides that, the POS and CS had been tested for their density, relative density and absorption according to ASTM C 127 and ASTM C 128[31-

32].Table 3 shows the specific gravity of the aggregated and additives that used. The result shows that Gsg of CS is much lower than conventional aggregate which is 0.94 and 2.63 accordingly.

Table 3 Specific gravity of raw materials used [30]

Sieve size (mm)	Specific gravity, G_{sg}
9.50	2.63
4.75	2.63
2.36	2.64
0.30	2.65
0.075	2.64
Pan	2.65
4.75mm (Palm oil shells)	1.16
4.75mm(Coconut shells)	0.94
Asphalt Cement	1.03

Table 4 shows that optimum asphalt content (OAC) at 4% air void decreased as the percentage of CS added increased. This is because of the ability of CS to absorb the asphalt. However, modified asphalt for 15% and 20% CS added do not meet the specification required of National Asphalt Pavement Association (NAPA).

Table 4 Optimum bitumen content for cs mixes [28]

Properties	Asphalt content (%)				
Percentage of agg. (4.75 mm)	0%	5%	10%	15%	20%
Resilient modulus (MPa)	4.70	4.90	4.85	4.75	4.6
VMA (%)	4.50	5.55	5.35	5.55	5.5
Va(%)	5.80	5.80	5.60	5.05	5.1
U.W (g/cm^3)	5.00	5.70	5.45	5.75	5.7
VFA (%)	5.05	5.48	5.29	5.30	5.3
OAC	5.00	5.49	5.31	5.28	5.3

Figure 5 shows the resilient modulus for POS, CS and control mixes. Resilient modulus is most significant in the mechanistic design of pavement structure. The result shows that resilient modulus has increased as the percentage of CS mixtures increased. This shows that CS can increase the resilient modulus of the asphalt pavement.

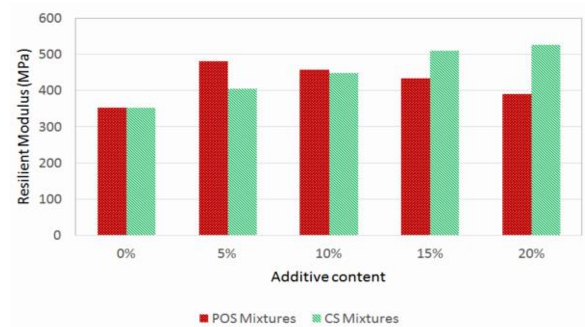

Figure 5 Resilient modulus for POS, CS and control mixes [28]

Static creep test is used to delve into the asphalt mixtures permanent deformation. A 5% of CS mixes showed higher performance than others CS and also the control mixes as illustrated in Figure 6. However, a 10% of CS mixes is accepted and reliable because it is quite nearly with the control mixes.

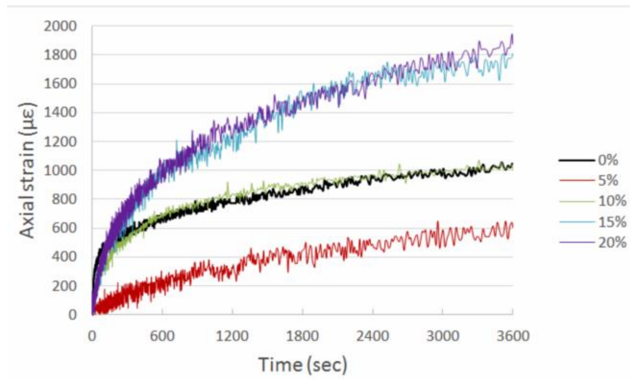

Figure 6 Comparison of static creep behavior and CS mixes[28]

Dynamic creep test is used to verify the robustness of bituminous mixtures to plastic deformation. Table 5 shows that the CS mixes lower the increment of the creep resistance as the plastic and cohesive properties of the modified asphalt are lost. CS mixes do not improve the modified asphalt concrete performance which is also found by Do Vale *et al*. [14]

Table 5 Dynamic creep behavior of CS mixes[14]

CS additives (%)	Maximum permanent deformation (mm)
0	0.247655
5	0.101954
10	0.399878
15	0.496093
20	0.641636

3.0 DISCUSSION

Detailed investigated should be done on the CS and CF like reinforcing mechanisms as well as optimum fiber and shell content. The various properties of CS and CF like fiber and shell content, fiber length, shell's size, shell's shape and orientation of fibers should be focus in the asphalt pavement in the future research. In addition, field performance of shell and fiber modified asphalt pavement should be determine the boundary effects on the test results. New research field can be conducting such as investigate modeling of mechanical properties of CS and CF modified asphalt pavement by using composite science principles.

Acknowledgement

The support provided by Malaysian Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia (UTM) in the form of a research grant number Q.J130000.2622.09J75 for this study is very much appreciated.

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