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Overview of Potential Application of Pineapple Leaves Fibre (PALF) in Asphalt Mixture Focusing on Fatigue Resistance

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Abstract: Asphalt mixture has played an important role in the transportation system throughout the world. Even if asphalt mixture are well designed and constructed, they may require proper maintenance to avoid some typical of asphalt mixture distresses occur due to traffic loading, environment or climate influences and material quality problems. Fatigue cracking is one of the major modes of failures in asphalt pavement. Modifying asphalt mixture using fibres for superior performance is not a new phenomenon. PALF is one of the natural fibres which have good potential in asphalt pavement. However, study focus on pineapple leaves fibre (PALF) in highway engineering is very minimum. The main objective of this overview are to investigate fatigue resistance of asphalt pavement modified with fibres and their scopes of study. In addition, Marshall Stability and Indirect Tensile Strength test of asphalt mixture performance with PALF also studied from the previous study in order to achieve these review study objectives. PALF has the potential to be a new supply of raw materials for industry, as well as a potential alternative for costly and nonrenewable synthetic fibres. In conclusion, this review article has explored the basic information of PALF and compared the physical, chemical and mechanical properties with other natural fibres in modifying in asphalt mixture. In addition, future research towards the use of PALF experimental procedure in laboratory also needed in order to prove the potential of PALF in asphalt mixture and also to determine the optimum percentage of PALF to be apply in asphalt mixture is encouraged.

Keywords: Pineapple Leaves Fibre (PALF), Asphalt Mixture, Fatigue Cracking

1. Introduction

Asphalt mixture plays an important role by the connectivity of various places with adequate road network which contributes to the socioeconomic development of country. The purpose of an asphalt mixture is to transfer vehicle loads to the sub-grade by superimposing layers of processed materials above the natural soil sub-grade. Asphalt concrete is a mixture of aggregates, binder, and filler to construct and maintain the quality of asphalt mixtures. Aggregates are divided into two categories which

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is course aggregates and fine aggregates. According to [1], the characteristic of aggregates is the most effective parameters that cause pavement distress. From their studies, the aggregate size that conducted on Marshall test are 19 mm. For coarse aggregate, it shall be material substantially retained on 2.4 mm sieve opening and shall be crushed work or crushed gravel and free from foreign materials. While, material passing 2.4 mm filter opening is required for fine aggregates. Aggregates have qualities that allow them to endure the stress that is applied to road surfaces and sub-surface layers. Next, asphalt binder is an essential component of asphalt concrete where the function is to holds the aggregate together. The bitumen act as asphalt binder of grade 60/70 penetration was used in the preparation of mixtures since it is commonly used and acceptable for temperature condition in Malaysia [2]. In addition, Filler was derived from the crushing of rocks or can be manufactured as it is in the case of limestone dust, cement, fly ash or slag. The filler is used as a modification to improve the asphalt mixture temperature susceptibility and durability [3]. According to [2], filler shall meet the following grading requirements, as given in table 1.

Every layer's role is to serve the traffic load while also generating forces against the mixture. These forces include vertical force (due to vehicle load), horizontal style (due to shear or break of the vehicle's wheels), and vibration force (collision or blow wheel). Thus, as the basis of the multilayer asphalt mixture structure, it is essential to appropriately characterise the behaviour of subgrade soils and unbound aggregate layers [4]. Hot mix asphalt (HMA), cold mix asphalt (CMA), and warm mix asphalt (WMA) are examples of asphalt concrete mixtures that can be classified in a variety of ways which depend on various temperatures and conditions. In Malaysia, most of the major road network is flexible pavement and HMA are applied in asphalt pavement construction. On roadways and highways, HMA is often utilized. Due to the inconsistencies in our country climatic circumstances, the temperature in our nation influence the asphalt mixture condition which cause pavement structure serviceability to deteriorate.

Asphalt mixture damage occurs as a result of a variety of circumstances, one of which has a significant impact is overload [5]. The most important factor influencing asphalt mixture performance is traffic loading where the loading magnitude, configuration and the number of load repetitions by heavy have the greatest impact on asphalt mixture performance [6]. In flexible pavements, fatigue cracking is a key cause of pavement failure. Figure 1 shows the deformation of fatigue cracking. The maximum tensile stress in asphalt pavement typically occurs on the lower face of the bottom layer bonded by bitumen, causing fatigue cracking to develop due to repetitive loading and proceeding from the bottom upwards [7]. When an asphalt mixture fails to meet climatic, traffic, or pavement structural requirements, one of the strategies to improve the asphalt mixture performance is to modify it [4]. The usage of fibres did help to delay and decrease cracking on the cracked and seated section [8]. This shows that fibres have high potential to resist asphalt pavement distresses that occur on a surface of asphalt pavement. Thus, in light of growing concerns about the environmental issue, the evolution of fibres from agricultural waste to use as alternative raw materials in asphalt mixture construction industries is a natural process of sustainable development.

The aim of this research is to explore the potential of PALF as modifier in asphalt mixtures. PALF is a natural fibre that enhance the physical properties of asphalt mixture. PALF has the highest potential for improving specific strength and stiffness due of its high cellulose content [9]. PALF has a high specific strength and stiffness due to its high cellulose content, which makes it hydrophilic in nature [10,11,12]. For the purpose of stabilization, cellulose and mineral fibres have been commonly used in asphalt mixture [13]. PALF has higher cellulosic contents compared to other natural fibres [14] where in the range of 67-82%. As a result, it is an excellent alternative raw material in the road construction industry to minimize asphalt pavement distresses such as fatigue cracking and extended the asphalt mixture service life.

Table 1: Filler for Bituminous Mix [2]

Sieve Opening	Percentage by weight passing
600 µm	100
150 µm	90 - 100
75 µm	70 - 100

Figure 1: Deformation of fatigue cracking [15]

Figure 2: Pineapple Leaves Fibre (PALF) [9]

2. PALF

Mechanical extraction produces good results in the fibre characteristic such as fibre strength and chemical content, because of the separation of the fibre from the original leaves with carefully. The machine used for scrapping method for scrapping PALF is scrapping machine [16]. The machine is made up of three rollers which are feed roller, leaf scratching roller and serrated roller. The feed roller is used to feed leaves into the machine; the leaves then pass through the scratching roller, which is the second roller. It removes the waxy covering from the upper layer of the leaf by scratching it. Finally, the leaves reach the densely attached blade serrated roller, which smashes the leaves and creates many breaks for the retting bacteria to enter [17]. In addition, for the retting process of PALF, [9] evaluated that for rapid retting reactions throughout the retting process, small bundles of scratched pineapple leaves are immersed in a water tank containing substrate liquor in a 1:20 ratio, urea 0.5%, or diammonium phosphate (DAP). After retting process, leaves were removed and washed mechanically by pond water retting after the retting procedure. Then, extracted fibres are dried in hanging position. According to [18], PALF may be extracted from chopped fresh pineapple leaf using both a ball mill and a disc mill. The procedures are not only simple, but it is also produce more fibre and smaller fibre than traditional ways.

3. Laboratory Test on Asphalt Mixture

There are few different type of test that conducted on the asphalt mixtures by previous researchers in order to evaluate the performance of the road pavement for fatigue damage. In this review studies, Marshall and Indirect Tensile Strength Test were conducted by previous researchers where PALF act as alternative raw materials in asphalt mixture modification.

3.1 Sample Preparation

According to [19], natural fibres were cut into small pieces and directly add to the aggregate samples. The aggregates with fibres and binders were kept at the specific temperature. Then, required quantity of binder was then added to the aggregates-fibre mixture, and the mixture was mixed until it was homogenous or uniform. Afterwards, the mixture was poured into Marshall moulds. and the specimens were kept overnight in room temperature. Then, the samples are test according to the standard testing procedure.

Marshall Mix Design method was used to determine the Optimum Binder Content (OBC) and evaluate the stability and resistance deformation of the mixtures. The most suitable composition such as OBC, optimum fibres content and optimum length of fibres in asphalt mixes was selected from the results of Marshall Test. According to [20], the Marshall Stability will load before failure occur at a constant deformation rate of 5 mm per minute. Then, the total duration between removing the specimen from bath and completing the test should not exceed 30 seconds. Table 3 shows the requirements in asphaltic concrete mix design according to [2]. The stability value, flow value and voids filled with bitumen value are checked in Table 3, as mixes with very high stability value and less flow value are highly tendency to form cracks due to the repeated traffic loads.

In addition, [21] stated the properties that are include in Marshall Mix Design method are theoretical specific gravity G_t, the bulk specific gravity of the mix G_m , percent air voids V_v , percent volume of bitumen V_b , percent void in mixed aggregate VMA and percent voids filled with bitumen VFB. The gradation limit of the aggregate used in Marshall mix design is shown in table 2 as referred to [2].

Optimum binder content (OBC) was found by Marshall Test. In order to attain strength and durability, HMA must be designed with an ideal bitumen content. Previous researchers suggested by taking three average value of binder content correspond to maximum stability, binder content correspond to G_m and binder content correspond to V_v in the total mix, the optimum binder content for the mix design can be determined in order to reach optimum OBC level.

Table 2: Gradation limit of aggregates [2]

Mix type	Wearing Course	Binder Course
Mix designation	ACW 14	ACB 28
B.S. Sieve Size (mm)	% Passing by weight	
20.0	100	72 - 93
14.0	90 - 100	58 - 82
10.0	76 - 86	50 - 75
5.0	50 - 62	36 - 58
3.35	40 - 54	30 - 52
1.18	18 - 34	18 - 38
0.425	12 - 24	11 - 25
0.150	6 - 14	5 - 14
0.075	4 - 8	3 - 8

Table 3: Asphaltic concrete mix design [2]

Quality	Wearing course	Binder course
Stability (kg)	Not less than 500	Not less than 500
Flow (1/100 cm)	20 - 40	20 - 40
Void in the total mix (%)	3 - 5	3 - 7
Void filled with bitumen (%)	75 - 82	65 - 75
Residual Stability (immersed) (%)	Not less than 75	Not less than 75

3.2 Indirect Tensile Strength Test

Indirect Tensile Strength Test is used to determine the indirect tensile strength of asphalt mixes [22]. Fatigue failures occur in regions where large tensile stresses and strains are present. The ITS Test is often used to assess pavement distress. It is used to obtain the tensile characteristics of a material. According to [23], this test was performed by using cylindrical specimen from the Marshall sample was loaded vertical diametrical plane between two loading strips where tensile strength of the material indicates the maximum indirect tensile strength and strain which material can withstand before failing.

4. Results and Discussion

Previous researchers have found the effect of fibres on asphalt mixtures, while PALF have been overlooked.

4.1 Effect of Cross-Sectional Diameter and Length of Fibres on Mechanical Properties of PALF

The impact of fibre size on asphalt mixtures has been noticed, and some relevant research has been undertaken, where the size mainly included the diameter and length of fibres. Researchers had studied the mechanical properties from the extraction of PALF with respect to fibre cross-sectional diameter and fibre length. The strength of the fibres may vary depending on their diameter and length [24]. A list of fibre diameter from previous research are depicted in table 4. It was observed from the results, due to the tensile concentrating defects, the mechanical properties of the fibres decreased as the diameter of the fibres increased. Thus, in order to increase the mechanical properties of PALF, the cross-sectional fibre diameter should be reduced. Moreover, [25] observed that there were changes in tensile properties with fibre length of PALF. Based on table 5, it shows the effect of fibre length on the properties on PALF from previous researchers. They discovered that as the length of fibre is increase, the tensile strength of PALF is also increase. According to [26], long PALF delivered highest tensile strength and flexural strength than short PALF.

Besides, short fibres are noted for being difficult to manage their orientation and for acting in a brittle manner. However, too long fibre might cause a balling problem, in which some fibres gather together and make it difficult to obtain a good blend in asphalt concrete, whereas too short fibre cannot offer a good reinforcing effect in the mix [27]. Moreover, according to [28], fibres with excessively long length may experience a negative impact on stability and reinforcing compared to the shorter length of fibres. Thus, it summarizes that length of PALF influence the tensile strength in mixture properties of asphalt mixture in order to mitigate the fatigue resistance.

Table 4: Effect of fibre diameter on properties of individual PALF

Fibre Diameter (μm)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)	References
20.0 - 80.0	413.0 - 1627	34.5 - 82.5	1.6	[29]
30.0 - 60.0	413.0	6.5	1.6	[30]
50.0 - 91.0	210.0 - 695.0	15.0 - 53.0	-	[31]
105.0 - 300.0	293.08	18.93	1.41	[32]

Table 5: Effect of fibre length on properties of individual PALF [25]

Fibre Diameter (mm)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)
5.0	15.6	815	3.0
10.0	35.0	1870	3.0
20.0	39.2	1990	3.0
30.0	52.9	2290	3.6

4.2 Effect of Fibre Loading on the Physical and Mechanical Properties of PALF

Fibres have a high tensile strength and can influence the tensile strength of asphalt mixtures while also minimising fracture propagation. According to [33], as the number of fibres in a composite increases, the density of the composite increases. They found that the density of the PALF increased as the weight percentage of fibre loading increased. Besides, [25] discovered that the tensile properties of PALF is changed with fibres loading. Table 6 shows the comparison of the tensile properties with the effect of fibre loading. Based on table 3, by addition of 40 wt % of fibres increased the tensile strength which is 63.3MPa compared to 0 wt % of fibre content, the tensile strength is lesser which is 20.6 MPa. This shows that by small amount of fibres acts as flaw in asphalt mixture.

However, due to its hydrophilic nature, natural fibre has a disadvantage in achieving good adhesion between fibres and matrix where the higher the presence of natural fibres in the composition, moisture content will be increase. Moreover, the stiffness of the asphalt mxiture might be increased excessively if the fibre content is higher. [34] discovered that an increase in the fibre content may cause the asphalt mixture to become more brittle, which is what causes most types of asphalt mixtures to crack. This shows that the fibres content in asphalt mixture influence the performance of asphalt mixtures. From this review study, higher fibre loading results in higher moisture content, which affects the interface between the fibres and the matrix. Therefore, it is important to consider the suitable amount of fibres loading to prevent the degradation of the properties of asphalt pavement.

Table 6: Effect of fibre loading on tensile properties of PALF [25]

Fibre Content (wt %)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)
0	20.6	580	1.6
10	17.1	1770	1.3
20	40.0	1830	3.0
30	52.9	2290	3.6
40	63.3	2520	5.0

4.3 Investigation on the Tensile Properties based on Marshall Stability and Indirect Tensile Strength Test

The fibres are mixed into the asphalt mixture to behave as its reinforcement, introduce absorption, dispersion and stability and also improve viscosity, which enable to boost the asphalt mixture in engineering properties. Besides, [35] studied the performance of fibre-reinforced asphalt mixes as the surface pavement material. The findings revealed that the fibres reinforcement can strengthen the resistance to the permanent distresses such as fatigue cracking. In addition, [36] examined the influence of fibres reinforcement in asphalt mixture based on the result of Marshall Stability and Indirect Tensile Strength test are presented on table 7 and table 8.

Table 7: Marshall Stability result [36]

	AC 60/70	AC 60/70 + Fibres
Mix from Laboratory (kN)	11.5	12.1
Mix from Plant (kN)	11.8	13.9

Table 8: Indirect Tensile Strength Test result [36]

	AC 60/70	AC 60/70 + Fibres
Mix from Laboratory (kN)	409.3	435.3
Mix from Plant (kN)	411.2	489.3

Based on the findings above, [36] observed the performance of AC 60/70 mixture provides high tendency to reduce the pavement distresses especially fatigue resistance. They discovered that the plant mixed AC 60/70 with fibres had higher stability value which is 13.9 kN compared to the laboratory mixed specimen which is 12.1 as depicted in table 7. On the hand, refer to table 8, AC 60/70 with fibre specimen exhibit the higher value of ITS which is 489.3 kPa compared to the laboratory mixed specimens which is 435.3 kPa. The mixing quality in the plant and the laboratory is nearly same and can be used directly to assess the HMA pavement performance. Besides, it can be seen that the ITS and Marshall Stability are increases due to the additional of fibres which gives an excellent engineering properties to endure fatigue resistance in asphalt mixture. Therefore, the higher the tensile strength of asphalt mixture, it contributes to the high resistance to crack propagation of asphalt mixture. However, findings on PALF as an additive in asphalt mixtures is not studied in detail, but another fibres had been discovered by previous researchers. Based on the findings previous researchers, it shows that the application of fibres in asphalt mixture modifies enhance the potential to mitigate asphalt pavement distresses such as fatigue resistance.

4.4 Potentiality of PALF as Reinforcement in Asphalt Mixtures

PALF is more compactible natural fibres resources [9]. Compared to other green fibres such as kenaf, sisal fibres and PALF, PALF reveals excellent mechanical properties, and has good tensile and flexural properties. It can be seen from table 9 where PALF can be a potential natural fibres reinforced composite for various application. It is proven that the PALF has higher tensile strength compared to the kenaf and sisal fibres. Besides than physical properties, the quality of the natural fibres also depend on chemical properties such as cellulose, hemicellulose and holocellulose content. [37] studied the chemical composition of PALF, corn stalk and napier grass. They found that PALF contains high holocellulose content (85.7%) compared to corn stalk (82.1%) and napier grass (80.4%). Besides, PALF also contains high cellulose content (66.2%) compared to corn stalk (39.2%) and napier grass (12.4%). From their study, they found that higher cellulose content in PALF will give better quality of products and also provide stronger fibres compared to other natural fibres. From the observation made, it can be concluded that the properties of PALF is better compared to other natural fibres. Thus, PALF are recommended in mix composition of asphalt mixture where it shows a good indication to prevent the fatigue cracking in the asphalt mixture.

Table 9: Physical Properties of Natural Fibres

Fibres	Tensile Strength (MPa)	Tensile Modulus (GPa)	Sources
PALF	413.0-1627.0	34.0-82.5	[24]
Kenaf	223.0-624.0	11.0-14.5	[38]
Sisal	80.0	1.46-15.8	[17,39]

4.5 Challenges for PALF as an Additive Alternative Raw Material

PALF is one of the natural fibres with the highest cellulosic content nearly 80%. When compared to other natural fibres, PALF has the highest tensile strength. Specific strength of natural fibres improves the physical and mechanical strength of polymer matrix without any additional processing required [9]. However, natural fibres have several drawbacks, such as a low resistance to moisture content due to the seasons of growth. It can produce swelling or dimensional defeat, which can influence the physical and mechanical properties of the finished product in construction inductries. Therefore, before utilizing the fibres as a compound material, the interfacial interaction between the matrix and the fibres can be enrich by natural fibres modified.

Most of the chemical treatments improved the strength, and adhesion of natural fibres reinforced asphalt composites. Chemical treatment of the fibres has been discovered as a way to overcome these drawbacks [40]. By chemically treated, there is changes the synergetic interaction between the natural fibres and the matrix. Due to their hydroxyl groups, hydrophilic fibres have been treated to achieve hydrophobic properties have less water absorption. Moreover, chemical treatment may reduce the amount of hemicellulose, lignin, pectin and natural oils covering the surface of the fibres where it will change the behaviour and roughness of the natural fibres [41,42]. Thus, depending on the availability, different researchers employ different modifications. Based on the researcher's point of view, there were no specialised chemicals for treating specific fibres types. Various strategies have been used to improve the mechanical properties of various natural fibres. Therefore, surface modification using appropriate chemicals is required to improve the adhesion property of fibres.

5. Conclusion

The creation of new technologies, which makes possible the construction of highways with a longer useful life and reduce in the frequency of maintenance activities. From the socio economic prospective, pineapple leaves fibre (PALF) as an additive material in industry has the potential to replace costly and non-renewable synthetic fibres. This paper reviewed the potential of utilization of fibres in asphalt mixtures. As stated in the corresponding fibre type in this paper, the use of fibres has significantly enhanced the performance of asphalt mixtures such as fatigue cracking. However, due to the drawbacks in the properties of fibres, their performance in asphalt mixtures is inconsistent. Therefore, the evaluation of fibres is required to improve the adhesion property of fibres. Thus, it is important to understand the fibres reinforcement in asphalt mixtures. Next, PALF fibres have outstanding features in terms of cellulose content, economic effectiveness, environmental friendliness, and fibre strength. Moreover, fibres length, fibres diameter and fibres content are the keys to mixture performance, according to natural fibres researchers. From this review, it is clear PALF has the highest tensile strength range, which indicates that it has a high tendency to improve the properties and performance of the asphalt mixture in order to prevent pavement distresses such as fatigue cracking. In the near future, the use of PALF in composite materials opens up a new world of materials that are both cost-effective and environmentally beneficial. Therefore, future research towards the use of PALF in the modification of asphalt mixture is encouraged.

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