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

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Abstract: The function of pavement is to transfer weight from the base to the sub-base and underlying soil. The pavement in civil engineering must be durable, able to withstand geographic, climatic, and temperature changes, as well as traffic overloading. Rutting pavement failure is one of the major distresses in asphalt pavement that happens on Malaysia road. Rutting occurs due to longitudinal depression in wheel path or poor road construction work that can cause many negative impacts such as shear failure, lateral movement of the material, hydroplaning, and road users' safety issues. The increasing of vehicles in Malaysia is the main contribution to pavement damage. Hence, the explore of the potential of pineapple leaves fibre (PALF) as a modifier in asphalt mixture is important. The asphalt mixture modification with natural fibre helps provide good performance, service life, and road maintenance costs. However, only a few studies had been done in evaluating the benefits of PALF in asphalt mixture. Therefore, this study is significant in evaluating PALF potential in the asphalt mixture based on the PALF physical, mechanical, and chemical properties. From the previous study, the PALF act as a catalyst to improve the asphalt mixture's properties in terms of rutting and crack resistance in densely graded asphalt mixtures. Besides discussing the properties of PALF, the Marshall Stability of asphalt mixture's performance with PALF from the previous study was also studied. In conclusion, PALF in asphalt mixtures is important for improving performance and stabilising the binder during mixing and placement, and minimising pavement distress, especially rutting.

Keywords: Pineapple Leaves Fibre (PALF), Asphalt Mixture, Rutting, Natural Fibre

1. Introduction

Road pavement is the mixture of road material located directly above the subgrade and beneath any wearing surface. The purpose of the pavement is to transfer weight from the base to the sub-base and underlying soil. In civil engineering, the pavement must be durable, withstand geographic, climatic change, temperature variations, and traffic overloading. In Malaysia, rutting is one of the road pavement

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problems. The rate and depth of rutting are determined by both internal and exterior factors such as truckload and volume, tyre pressure, temperature, and construction methods, while internal considerations include pavement thickness, bitumen, aggregate, and mixing characteristics [1]. Besides, in Malaysia, the road's damage is generally caused by vehicle overloading and looping because of the increasing number of vehicles year by year. Moreover, the climatic effects, temperature variations, infiltration of rainwater, road drainage system, and groundwater because of nature capillary will also damage the road pavement. Then, agricultural waste has been increasing rapidly in Malaysia. Hence, to keep rutting within acceptable limits is to enhance the materials in various level of asphalt layer. It is important to accurately evaluate the rutting resistance of asphalt mixtures in pavement structure and material [2]. Asphalt pavement design is important since it contributes to the network's performance, service life, and cost efficiency [3]. The overall performance of the asphalt mixture depends on its composition, including properties, proportions, and ingredients distributions. Besides, for centuries, natural fibres had been utilised in construction field such as in building. This is because their presence has been shown to significantly improve the composite material's overall physical and mechanical characteristics [4]. Moreover, PALF has a great potential to use as reinforcement in asphalt mixture because fibres showed many advantages, including reducing degradation and significant improvements in the stabilization of asphalt mixture [5].

Therefore, this study seeks to evaluate of Pineapple Leaves Fibre (PALF) potential in the asphalt mixture and asphalt's physical and mechanical properties. Next, stability of asphalt mixture improves due to the extra resistance provided by the fibres, while flow reduces due to the fibre's resistance to deformation [6]. This is because PALF is a critical natural fibre with high specific strength, stiffness, flexural, torsional rigidity, and characteristics comparable to another natural fibre such as jute fibres [7]. Hence, by considering these unique characteristics of PALF, the industry may consider it a viable alternative raw material for reinforcing composite matrixes [8]. Thus, it is important to boost the resulting composite's performance and stabilise the binder during mixing and placement, reducing pavement distress, especially rutting by adding PALF in asphalt mixture. However, the study focus on the application of PALF in highway construction is very minimum. Therefore, this study is needed to summarise the benefit of the application of PALF in pavement materials.

2. Review Methodology

A review study was conducted to evaluate Pineapple Leaves Fibre (PALF) performance in asphalt mixture based on rutting to achieve this study's objectives. The Marshall Mix Design and Indirect Tensile Strength test specification are based on PALF from previous study reviewed in this study.

The first stage of the review is searching. The related articles have been carried out to enable the keywords to be formulated for review. The search databases were selected because they are the largest abstract and citation database of literature reviewed, such as academic journals, books, technical reports, and conference proceedings. Next, a systematic and extensive search conducted using the Boolean search technique and keywords under the "title/abstract/keyword" fields in the database. The search result saved in pdf format contains author, title, year of publication, abstract, and keywords to facilitate the reference analysis. Then, the information collected from previous research will be discussed and compared. Lastly, the conclusion would be made based on finding from the previous study.

2.1 Pineapple Leaves Fibre (PALF)

The pineapple or Ananas Comosus is a tropical plant from the Bromeliaceae family and monocotyledon plants introduced in Malaya in the 16th century by the Portuguese. Pineapples continue to grow and are one of the country's wealth in Malaysia's agricultural sector, and Malaysia also is one of the world's main producers of pineapples in the world. There are various methods to extract the PALF from the leaves of a pineapple. The scrapping method of extraction is one of the methods that widely used to extract PALF. A scrapping machine is used for scrapping the PALF [7]. This machine utilises three separate rollers, which are feed roller, leave scratching roller, and serrated roller [9]. The purpose of feed roller is to feed leaves into the machine. Once inside, the leaves will pass via the scratching roller, this rollers function to scratches the leave's top layer and removes the waxy coating on pineapple leaves. Then, the leaves will go to the attached blade serrated roller, which crushed the leaves and creates many breaks for the entry passage for the retting microbes [7]. The next method of extraction PALF is retting, which is the small bundles of scratched pineapple leaves are immersed in a water tank that contains substrate, which is liquor in 1:20 ratio, urea 0.5%, or diammonium phosphate (DAP) for fast retting reactions. Then, materials in the water tank are regularly checked to ensure fibre is loosened and can extract many chemical constituents. Then, fibres are segregated mechanically through a washing pond in pond water and dried in a hanging place by air [9]. Lastly, the PALF must be cleaned and cut into small pieces in length 2mm to 4mm to ensure proper mixing with the aggregates and binder during mixing in Marshall Mix Design.

Subsequently, the dry method and wet method are the two most often used for combining additives in bituminous mixture. The dry method is the most often used method fibres since it is the simplest to apply and can achieve the best distribution of fibre in the mixture and it is also widely used in fieldwork. For this reviewed study, the dry method was utilised. Firstly, the aggregates were heated to about 175^{o}C for approximately four hours. The aggregates were then combined for 90 seconds using an automated mixer, followed by the addition 0.3% of PALF fibre and another 90 seconds of mixing [10]. This was followed by the addition of an optimal bitumen concentration for a further 90 seconds at a temperature range 160^{o}C to 170^{o}C to ensure proper spread [11]. Finally, for another 90 seconds the mineral powder was mixed for another 90 seconds [12].

3. Results and Discussion

The application of Pineapple Leaves Fibre (PALF) in the engineering field is because of its attractiveness in terms of its physical, mechanical, and chemical properties compared to other natural fibres. Therefore, this chapter discussed the physical, mechanical and chemical properties of PALF from previous research. Lastly, applying this type of natural fibre in asphalt mixture based on the Marshall Stability test and Indirect Tensile Strength test from past researchers were also discussed in this chapter.

3.1 Physical and mechanical properties of PALF

PALF has superior physical and mechanical properties as reinforcement in the asphalt mixture. The physical and mechanical characteristics of PALF was discussed in Table 1, including its density, length, fibre diameter, tensile strength, Young's Modulus, and elongation of fibres, which all contribute to the fibres' overall qualities.

Table 1: Physical and mechanical properties of PALF

No.	Density (g/cm^3)	Length (mm)	Fibre diameter (µm)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at break (%)	Author
1.	-	-	50-91	210-695	15-53	-	[13]
2.	1.526	-	50	413	4.2	3.0-4.0	[14]
3.	1.5	6	5	165	7.25	13	[15]

The tensile strength values obtained from the past study are in the range 165MPa to 695 MPa, which shows the characteristics of the fibres that can withstand high stresses and enabling the PALF used as reinforcement in construction materials. Besides, Young's Modulus value showed that the minor strains at failure are explained by the fact that the fibres have an elastic behaviour. In addition, the higher the concentration of pineapple fibre leads to the higher the stress needed for the same deformation and results in higher Young's Modulus [16]. However, the moduli and tensile strength of the fibres are significantly different depending on the cultivars [13]. Next, this type of natural fibre also has the highest cellulosic content of almost 80% and the highest Young's Modulus and tensile strength of any natural fibre [7]. Moreover, Table 3.1 presented the elongation at break of PALF ranges 3% to 13%, compared to other natural fibre, it shows that the PALF has high strength and good elastic properties. Meanwhile, the mechanical properties coupled with thermogravimetric analysis indicated that the cultivars of PALF meet the requirement in a reasonable range to be used as fibrous reinforcement of possible composite application, especially if the properties of PALF compared with other natural fibre properties [13].

Subsequently, from the previous study, PALF can be used in concrete to increase its properties because the strong properties of PALF can increase compressive strength, tensile strength, and flexural strength compared to conventional concrete [15]. Furthermore, chemical changes, physical and mechanical characteristics, and hybrids of PALF demonstrate that it is appropriate for use as building and construction materials, automotive components, and furniture [7]. Hence, the extraordinary qualities of PALF from a previous study depicted in Table 3.1 can be used as a reinforcing composite matrix, and it can also promise the best result of an asphalt mixture modified with PALF according to the specification of mix design, which can reduce rutting problems on the pavement.

3.2 Chemical properties of PALF

PALF has extraordinary chemical characteristics such as cellulose, hemicellulose, lignin, pectin, fat, wax, and ash that enable it to be utilised to strengthen polymer composites. Furthermore, chemical properties in PALF play an important role to determine the performance of fibres. Table 2 summarises the chemical properties of PALF.

Table 2: Chemical properties of PALF

No.	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pectin (%)	Fat and Wax	Ash (%)	Author
1.	80.83	15-20	8-12	2-4	4-7	2-6	[17]
2.	81	-	12.7	-	-	-	[18]
3.	72.14	4.86	13.55	1.6	-	1.0	[19]

The cellulose is one of the components that can make the fibre of the non-wood materials stronger [20]. From Table 2, it can summarise that PALF contains 72.14% to 81% cellulose PALF with high cellulose content offers outstanding mechanical characteristics that can raise the strength of the fibre [21]. Moreover, the higher cellulose and hemicellulose content would increase the quality of the asphalt mixture with PALF that produced. Next, the range of lignin from the previous study is between 8% to 13.55%. Lower lignin content makes the fibre strength greater and harder to break [22]. Then, the percent of pectin contains in PALF is higher, which is 1.6% to 4% compared to other natural fibres such as jute with 0.2% of pectin value, ramie with 0.9% of pectin value, and hemp with 0.9% of pectin value [7]. Meanwhile, the PALF’s lignin content is between 8% to 13.55%, which provides an adhesive characteristic that helps strengthen the fibre's strength [19]. Therefore, lignin and pectin are important in fibre to provide an adhesive quality responsible for the strength and rigidity of cellulosic fibre [7]. Next, the chemical properties of PALF from the previous study are the critical factors to consider when considering the applicability of PALF in the asphalt mixture, which is a key to improve asphalt characteristics. Hence, using PALF in the asphalt mixture with stronger chemical qualities than other natural fibres can minimize rutting on the road pavement.

3.3 The application of PALF in asphalt mixture

Table 3 shows the application of PALF in asphalt mixture from the previous study. This study is important to evaluate the potential of PALF in asphalt mixture.

Table 3: The application of PALF in asphalt mixture

Proper-ties	Bitum-ent Conte-nt (%)	Bulk densi-ty (g/cm^3)	Vv (%)	VMA (%)	VFB (%)	Marsh-all Stabili-ty (KN)	Flow (mm)	OBC (%)	Author
With pineapple leaves fibre	5.5	2.211	6.84	17.24	-	6.24	2.72		[10]
	6.0	2.308	2.04	14.03	-	7.42	2.85		
	6.5	2.204	5.83	18.36	-	7.19	2.80		
	7.0	2.181	6.18	19.66	-	6.91	3.00	-	
Without pineapple leaves fibre	5.5	2.256	4.93	15.54	-	6.10	2.47		
	6.0	2.242	4.86	16.51	-	6.75	2.69		
	6.5	2.238	4.37	17.09	-	7.41	3.01		
	7.0	2.194	5.62	19.18	-	7.07	3.15		
With pineapple leaves fibre	5.5	2.301	6.04	18.44	67.27	12.32	4.71	6.70	[23]
	6.0	2.316	4.52	18.53	76.04	15.34	5.82		
	6.5	2.308	4.31	19.21	76.55	14.86	6.04		
	7.0	2.307	3.95	19.78	80.03	14.12	9.01		
With coir fibre	5.5	2.311	5.47	17.96	69.54	13.87	2.86	6.60	
	6.0	2.315	4.85	18.46	73.76	14.53	3.97		
	6.5	2.318	4.10	18.86	78.29	16.04	4.44		
	7.0	2.316	3.58	19.47	81.63	15.18	7.02		

The stability of the mixture increased when asphalt content increased up to a certain level of asphalt binder content, and then, the stability value would decrease. The overall result of Marshall Stability shows the Marshall Stability of the mix with PALF higher than the mix without PALF or other natural fibre. Hence, adding PALF in the asphalt mixture would increase the mixture's stability by functionally improving the mixture's toughness and improving the mixture's performance compared to the standard mixture. From Table 3, the bulk density of PALF slightly lower than the bulk density of asphalt without PALF. This is because, the asphalt content has to fill the air voids progressively. After all, the fibre or PALF is already filled up some air voids, decreasing when the asphalt increases as the asphalt would also fill the air voids. When the voids in the mineral aggregate are large, they are made up of asphalt that has not been absorbed into the aggregate and air voids [24]. The asphalt that has not been absorbed into the aggregate is then referred to as an effective asphalt binder. Next, the voids mineral aggregates for asphalt mixtures increased when the asphalt binder content increased. Therefore, the voids mineral aggregates value for asphalt mixture with natural fibre more than voids mineral aggregates value for asphalt mixture without natural fibre.

Moreover, establishing an adequate amount of voids in a mineral aggregate mix during the Marshall Mix Design helped establish film thickness by minimize the risk of excessive asphalt bleeding and flushing. Asphalt film thickness describes the dimension of the asphalt binder coating of the aggregates particles [25]. If the coating on the aggregates particles is thin, it could cause the premature ageing of the binder. Meanwhile, the ability of an asphalt mixture to react to incremental settlements and motions without cracking is referred to as flow. The flow of the mixture would increase if the bitumen content increased. However, when the bitumen content increased, the binder properties dominate, making the fibres clump together and reduced the stability of the mixture [26]. Hence, the lower the bitumen content, the more the fibres would fill the voids, contributing to the mixture's homogeneity. Therefore, the applicability of the mixture increased as the flow value increases while deformation resistance decreases. Additionally, asphalt mixture's mechanical properties improve, PALF and other natural fibre minimize drain down and increased the stability of the mixture [23]. Hence, from previous study results, PALF has shown excellent additives in asphalt mixture to boost asphalt properties in strengthening dense-graded asphalt mixes to resist rutting and crack [27].

3.4 Investigation on the tensile properties based on Indirect Tensile Strength test

Previous researchers conducted an Indirect Tensile Strength test to determine the optimal quantity of fibre in asphalt mixture to provide a high tendency by reducing the pavement distress, especially rutting problems. Hence, the finding from the Indirect Tensile Strength test on the performances of polyolefin and aramid fibre is presented in Table 4.

Table 4: The result of the Indirect Tensile Strength test on the performances of polyolefin and aramid fibre [28]

Mix from laboratory		Mix from plant	
AC 60/70 (kPa)	AC 60/70 adding fibre (kPa)	AC 60/70 (kPa)	AC 60/70 adding fibre (kPa)
11.5	12.1	11.8	13.9

As shown in Table 4, the value of asphalt concrete adding with 0.05% fibre is slightly higher than common asphalt concrete for both types of mixed methods, which are laboratory and plant. The Indirect Tensile Strength test is related to the percentage of air voids. Particularly, when the Indirect Tensile Strength value increased, the void would percentage decreased. This relation could be explained by the different densification of the mixes [29]. Thus, the Indirect Tensile Strength data was evident to the strength contribution of fibres because the presence of fibres had affected the tensile and volumetric properties of asphalt mixtures [30].

The outstanding result of fibres in Table 3.4 had proof that fibres could improve the rutting resistance of asphalt mixtures. Next, raw materials are used as filler in asphalt mixtures, the Indirect Tensile Strength value increases by 7% compared to a conventional mixture [29]. However, the finding of PALF as an additive in asphalt mixture is not studied in detail, but previous researchers discovered another fibres. According to the result of the Indirect Tensile Strength test from previous researchers, it was observed that this types of test increases due to the addition of fibre which gives excellent engineering properties to endure rutting resistance in asphalt mixture.

4. Conclusion

Malaysia has received more significant attention from government agencies, private organizations, and the public for almost a decade to apply natural fibres for reinforcing asphalt pavement and be a vision for using renewable natural materials in the construction industry to achieve a sustainable environment. Additionally, the growing amount of traffic year after year, the need for improved durability, sustainable growth, and the need for a lower cost of asphalt mixture are the primary reasons for exploring and discovering new solutions. This review study found that materials extracted from renewable energy sources can reduce the rutting problem in asphalt pavement. Moreover, there are methods that reviewed in this review study are Marshall Stability test and Indirect Tensile Strength test to introduce the potential of fibres in asphalt mixture. Next, this review study could lead to a better understanding and knowledge of the fibres' physical, mechanical and chemical compositions. Therefore, the modification of PALF as a modifier for asphalt mixture predestined to find more and more applications in the future, especially in Malaysia. As a result, the civil engineer can use the findings of this study to conduct future applied research on pavement that can minimize pavement distress which can be beneficial not only to the road user but to the government. On the whole, the objectives of this review study had been achieved because the results from the previous study and Marshall Stability analysis from the past study showed the addition of natural fibre, specifically PALF, would be beneficial in improving some of the main properties of the pavement and minimize rutting resistance.

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