Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 3 (2023) 226-235

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Natural Fibres as Pavement Construction Materials: A Review

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DOI: https://doi.org/10.30880/rtcebe.2023.04.03.024
Received 06 January 2022; Accepted 15 May 2023; Available online 31 December 2023

Abstract: The rapid urbanisation happening nowadays has increase the demand and usage of pavement over the years. As the increasement of traffic happens, the loads that pavement need to withstand also increases. The number of axles and high tyre pressure from vehicles resulted in traffic-related pavement distresses and failure causing the asphalt surface to lose its original shape and evolves, resulting in materials stress which causes cracking, potholes, rutting, ravelling and depressions towards the pavement. In order to overcome this issue, engineers have found that natural fibres could be the solution. The main goal of this research is to study the suitability of natural fibres according to the types of natural fibres which are jute, coir and hemp fibre, the physical, mechanical and chemical properties of each fibres and the stance of natural fibres in asphalt pavement. In conclusion, this review paper can explore the potential of natural fibres in asphalt pavement when it is modified.

Keywords: Natural fibre, Asphalt Pavement, Fibre's Properties.

1. Introduction

Pavement have been serving as a dynamic role for human civilisation and transportation since it was first being constructed. The main function of a road is to connect between places in the use of travelling or visiting places and most importantly to make a contribution for economy growth and increase development. Along the years, pavement design and construction has been evolving towards a better performance following the present and future needs. As one of the main transportation systems, engineers have been experimenting on using different type of materials in the making of pavement to ensure it to be able to disperse loads given from moving vehicles at road surface to the sub base and subgrade soil without failure [1].

With the constant usage of the pavement, maintenance must be done occasionally to ensure that the it is giving its one hundred percent performance towards the road users. Common flexible pavement consists of aggregate, sand and binder made from bituminous material such as tar and asphalt [1]. The materials were widely used as the top layer of pavement because of the strong adhesive properties given

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by the binder that bind the materials together providing great stability and performances in the comfort of driving, durability, workability and water damage [2, 3].

Even though the properties of the flexible pavement are good, it can still be affected under great pressure. Nowadays the volume of heavy traffic has increase compared to before due to the increasement of vehicle on the road. This has tremendously reduced the pavement performance. In order to prevent the situation from happening, fibres were added in the mixture to increase the tensile properties and strength of pavement towards pavement deteriorations [4].

The objective of this research is to determine the suitability of natural fibre in asphalt pavement mixture materials and to promote sustainability method as materials for road construction. Natural fibres as one of the materials in pavement can help to enhance the properties of flexible pavement mixture. This will delay the time for maintenance of the pavement and decrease the cost for pavement fixtures. There are many types of natural fibres that can be used for the design making it easy to find the materials. The usage of natural fibres also has great potential because it is an environmental-friendly material, so environment can be conserved.

Natural fibres promote the sustainability of materials due to the lower cost of maintenance and reconstruction. Adding natural fibres in the materials help to increase the tensile strength of an asphalt pavement. The agricultural economy in the country can also be increased when using natural fibres that is plant based as a new raw material in pavement construction.

Peter Gallo in his paper mentioned that natural fibre is composed of cellulose that could help to increase the tensile strength, reduce severity, increase fatigue resistance, increase rutting resistance and increase the abrasion resistance of an asphalt pavement [5]. Due to its strength provided towards the pavement, it is considered as an excellent raw material in road construction in the mean to reduce usage of non-biodegradable materials that help to increase the physical properties of a pavement.

2. Assessment of Flexible Pavement

In general, there are two different type of pavement. The first one is called flexible pavement and the other is rigid pavement. In this review, only flexible pavement will be touched. Flexible pavement is those that are surfaced with bituminous or more known as asphalt materials. They are called “flexible” because of the ability to bends or deflects the total pavement structure causing from the traffic loads. A flexible pavement structure is usually made of several layers of materials which can accommodate the flexing mechanism. Flexible pavement uses more flexible surface course and can distribute loads over a smaller area. It mainly relies on a combination of layers for transmitting load to the subgrade. In flexible pavement, a typical cross-section is shown in figure 1.

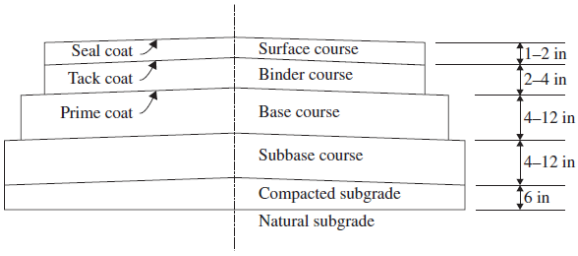

Figure 2: Standard cross-section of a flexible conventional pavement.

A conventional flexible pavement is made up with a few different layers which stack on top of each other in the sequence of natural subgrade, compacted subgrade, subbase course, base course, binder course and surface course as shown in the figure. In between of the top three layers there are usually three kinds of coats that are needed in asphalt pavement construction such as seal coat, tack coat and prime coat. Seal coat is a thin asphalt surface treatment that is use to prevent water from penetrating

into the surface course. The tack coat, which is usually an asphalt emulsion diluted with water, helps to the cohesiveness between the underlying course and the surface above it. For prime coat, it is constructed of low-viscosity cutback asphalt to ensure a solid bond between the base course and binder course. Low viscosity cutback asphalt is also utilized as a prime coat material because of its property to easy absorption by the base layer. The design of flexible pavement typically consists of subgrade, subbase course, base course and surface course from the ground.

2.1 Subgrade

Subgrade is the part of embarkment or the natural soil under the subbase and road shoulder. This is the first part of the road construction prior to the other structure and can be identified as formation level. Formation level is the soil surface after the earthwork, consolidation, compaction and stabilization works were completed. The function of subgrade is to be a layer that sustain load from the top surfaces. It is very vital to select a suitable soil to be use as the formation layer in order to ensure a sturdy base. A good subgrade should be stable under the varieties of vehicle load and climatic condition, sustain its strength throughout their whole design period and most importantly have the ability to drain water.

2.2 Subbase course

Subbase course is the layer immediately above subgrade. The requirements for subbase course are usually in terms of their gradation, plastic characteristics and strength along with must drain readily. The functions of subbase are to sustain road base layer and distribute load from the vehicle, to act as a drainage layer, can be used as a temporary road during construction, to protect the subgrade from the failure due to climate effect and as a barrier layer to avoid the mixing of subgrade and road base materials.

2.3 Base course

Base course in the layer above subbase course. This layer must help to distribute the load for the flexible pavement. For this layer, the specifications is more strict than subbase materials especially in respect to their plasticity, gradation and strength. In order to be on par with the requirements, this course is made of granular materials consists of sand, crushed gravel, crushed stone or slag that are hard and durable. Other materials that does not follow the requirement can be used as long as they are properly stabilized by Portland cement, asphalt or lime.

2.4 Surface course

Surface course are the most top layer out of all the layers and immediate above base course. This layer is in direct contact with the vehicles loads therefore good quality aggregates and high-density asphalt are required to use in designing the layer. Surface course has the function to provide the pavement a skid resistant surface, friction and drainage. In order to preserve the surface's integrity and prevent humidity from accessing the inner structure, the pavement must be resistance to thermal and fatigue cracking. Typically, surface course has 25 to 50 mm thickness.

2.5 Pavement Materials

There are two main mixtures that is needed to make asphalt pavement which are aggregate and binder. Aggregate is a composition of rocks that has different and small in size which is used to make asphalt pavement meanwhile there are many types of binder that could be used in pavement making. One of it is tar or asphalt. Usually binder is used to bind the materials altogether making sure that there is no gap in between the aggregate so that no water leakage could enter into the layers of pavement.

3. Assessment of Natural Fibres

Natural fibres are fibres that are produced by animals, plant or natural geological process. They are widely used mainly because of the cost effective, ease of availability, light weight and environmental-friendly. It has a thread like structures that are thin, long and flexible that can be used for many different purposes such as textiles, clothes, geotextiles and for this paper it is being use as a material for pavement. This paper will be focusing on the plant-based type of natural fibres since it offers many advantages to the environment in the aspect of degradability and application of natural resources in pavement [6]. By using the materials from plant-based fibres as one of the materials for asphalt pavement, the amount of synthetic material or chemical used could be reduced and enhancing the pavement physical properties.

The plant-based natural fibres can be categorised according to its origin which are bast, leaf, seed or fruit fibres. Not only that, natural fibre composites are made out of cellulose, hemicelluloses, lignin, pectin and waxy substances. A cellulose fibres act as a stabilizing agent as it is the major component in fibres [7]. These compositions are the one that gives the fibre the reinforcement to make pavement the improvement of tensile strength. The fibres's advantages are it give out low cost, low density and have a good thermal property. Other than that, it is a biodegradability property.

Each of the fibre has a complex, layered structure consisting of a thin primary wall that deposited during the cell growth surrounding a secondary wall. For secondary wall it is made up of three different layers while the centre layer determines the mechanical properties of the fibre. Therefore, with different type of fibre that have different property of the middle layer, it will give out a different type of fibre. Other than that, the size of diameter of the microfibrils angle is also varies from one another. Typically, a microfibrils angle would have a diameter of 10-30 nm that is made up to 30-100 cellulose molecules extending the chain and the strength of the fibre [8]. Due to their tight composition, it will manage to prevent draindown in between gaps, help to reduce noise and resist rutting on the pavement [5].

Although there are many different types of natural fibres, on this paper, only three of the fibres will be discussed on. The natural fibres are jute fibres, coconut or coir fibres and hemp fibre. Firstly, jute fibre is a long, soft and shiny type of bast fibre. It is a type of fibre that can be spun and made into a long, strong threads. It originates from a type of flowering plant which is a type of mallow family malvaceae. The cost of jute fibre can be considered as one of the cheaper among fibre category. Secondly is coconut or known as coir fibre. Coir is a natural fibre that came from the coconut. It is extracted from the outer of the coconut husk. Coir is very common to found in Malaysia and it has the property that a natural fibre had to be included into the pavement mixture. Lastly is hemp fibre. It is extracted from a plant family called Cannabis. The growth of a cannabis plant can take very quick that it is named one of the fastest growing plant on earth. This give an advantage to the resources because the production of hemp fibre will not take a long time.

4. Methodology

In order to achieve the objectives of review study, all the guideline and consideration were obtained from literature review through reading of journal, books, articles and other resources. The detailed review study will be conducted to investigate the performance of natural fibres in pavement and the significant of using it towards the environment. In this review study, a methodology flowchart was used as a guideline in accomplishing the objectives. Figure 2 shows the flowchart of the review study methodology.

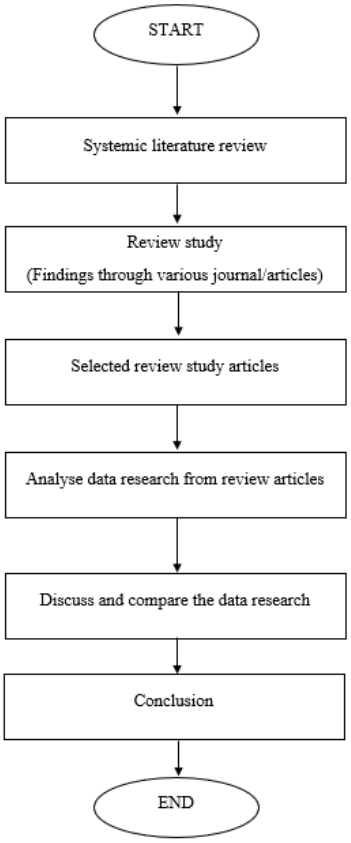

Figure 2: Review research methodology (Flowchart).

4.1 Systemic Literature Review

A systemic literature review is an identification and selection of research papers to be able to formulate answer for questions or problem statement of a research [9]. There are many ways to search for the academic papers. One of the routes is by searching at search databases that UTHM has provided such as “ScienceDirect”, “SpringerLink” and “Access Science”. There different type of article that can be taken for example, review articles, research articles, conference abstracts, book chapters, and journals.

In order to search through the many different type of articles, it is advice to use a few strategies to make it easier to find the correct one. Firstly, by typing in the correct keyword which is related to the topic. Secondly is to use BOOLEAN search which is to add AND/OR/NOT in the keyword typed in. Thirdly, usually online database will provide a database filtering that can be use to limit the outcome from the search. Lastly is to use truncation (*) and word phrase (“…”) to make the keyword searched more easily to be found.

4.2 Selected Review Study Articles

The amount of article found could be overwhelming but it can be reduced and screened to get the best data. There are many ways to select articles depending on the type of the specific view. Firstly, is to read through each piece of literature that come out in full but this method is very time consuming. Second method is to focus on the research method or findings of the paper. Third method is to review the abstract of each paper and determine whether it is the suitable article and read through it later. The method that was chosen was method two and method three [10].

Based on the literature review, the journal and articles found from the search database were about natural fibres, the type of fibres, properties of natural fibres and usage of natural fibres in pavement.

4.3 Analyse Data Research from Review Articles

After conducting the selection of literature review, analysis of the data research from the review articles comes next. It is the most crucial part in a research. By using the selected literature reviews, a systematic data presentation will be needed in order to show the idea and review of the collected data. Each data needs to be harmoniously within each other for it to be in flow with the topic [11].

4.4 Discussion and Comparison

There are many ways for the final review article to be structured but a generalised article can be made [10]. Through the review articles sorted out, the information taken need to be describe transparently be it the process of analysing, synthesizing and reporting. By using the format, it will give the readers easier understanding and a better quality of work. The discussion and comparison can be simplified by using figures or tables that shows the data better towards reader. Furthermore, the writing needs to be authentic and every material used from other authors must be cited to acknowledge their hard work and diligent.

4.5 Conclusion

A conclusion is made for an end remark of any writing be it essay, article or report. It will be proposing the general idea that can be gathered from the whole writing that provide an answer for the question that were made in the beginning of the writing process. It clarifies on why the paper was written and offer a recommendation and a solution about the topic matter.

5. Results and Discussion

This section will discuss the physical and mechanical properties of natural fibres from previous researches. Three types of natural fibres that will be discussed are jute fibre, coconut or coir fibres and hemp fibres.

Testing the physical and mechanical properties of fibres is very important in order to know the strength and limits of that particular fibre as each type of fibres have their own composition and could vary over the species. The limitation of the material will help to design a suitable and sustainable for the roadwork usage. According to the IOWA State University, mechanical properties is tested by using the material's reaction towards load upon it that can be used to pinpoint what type of material that is. The properties that can be listed are such as hardness, strength, impact resistance and ductility [12].

Meanwhile for physical properties are the experiment that can be observed without replacing the characteristic of the materials. The properties that can be listed are colour, hardness and density [13].

5.1 Physical and Mechanical Properties of Natural Fibres

The first natural fibre to be discussed is jute fibre. Jute fibre are usually available in threads which are mechanically woven. According to Abiola et al, the result from a conducted research for jute fiber as an alternative to synthetic fibre in bituminous pavement, it shows that jute fibre can replace synthetic fibre but with the following limits. Jute fibre have permanent deformation resulting in a high tensile strength, higher than its predicted showing that the fibre's adhesion is great [7]. Table 1 shows the lists of physical and mechanical properties of jute fibre as reported by previous researches.

Table 1: Physical and Mechanical properties of jute fibre

Density (kg/m^3)	Moisture Content (%)	Tensile Strength (GPa)	Maximum Strain (%)	Diameter (μm)	References
1300-1500	12	200-450	2-3	15.9-20.7	[7]
1300-1490	-	393-800	1.16-1.5	25.0	[14]

The second fibre to be discussed is coir fibre. Coir fibre can easily be obtained from coconut barks. According to Sandra, Jose and Jesner, in order to get an ideal property for the coir fibre, the coconut barks must go through different processing steps to remove the unwanted particles and dried at room temperature. The coir fibre will only then be examined or used. It is also stated that the elongation at break for coir fibre is 23.9 to 51.4 percent along with modulus of elasticity of 2.8GPa [15].

According to Abiola et al, after a drain-down test result for coir fibre, the fibre can be a replacement for cellulose staple fibre that is use to stop drain-down during production [7]. Coir fibre has also shown that it can increased the fatigue life of bituminous mixes helps in stabilize the mixture [15].

Table 2 lists the physical and mechanical properties of coir fibre as reported by a couple of researches. According to the table, the physical and mechanical parameter were found to be in the following ranges, density of 1150 kg/m^3 to 1770 kg/m^3, and tensile strength of 95GPa to 175GPa.

Table 2: Physical and Mechanical properties of coir fibre

Density (kg/m^3)	Moisture Content (%)	Tensile Strength (GPa)	Maximum Strain (%)	Diameter (μm)	References
1770	-	95-118	-	-	[15]
1150-1250	13	106-175	15-40	16.2-19.5	[7]
1200	-	175	30	15.0-25.0	[14]

The third fibre to be discussed is hemp fibre. According to Abiola et al, hemp fibre can conduct heat and dries easily while having natural anti-bacterial properties. From the results obtain during investigation using fibre content and length of the material, it shows that there is a decrease of complex modulus increasing the fatigue life of the fibre especially with 5 cm length and percentage of 0.4% fibres [7].

Table 3 shows the physical and mechanical properties of hemp fibre. According to the table, the physical and mechanical parameters were found to be in following ranges.

Table 3: Physical and Mechanical properties of hemp fibre

Density (kg/m^3)	Moisture Content (%)	Tensile Strength (GPa)	Maximum Strain (%)	Diameter (μm)	References
1400-1500	12	310-750	2-4	17-23	[7]
1470	-	690	2-4	25	[14]

5.2 Chemical Composition of Natural Fibres

Different type of fibres has variety kind of chemical composition. The identification of composition will give advantage to researches in designing the pavement. In reference of Parul Sahu and MK Gupta,

for natural fibres that are lino-cellulose the main compositions are cellulose, wax, pectin, lignin and hemicellulose [14].

Table 4 shows the list of chemical composition for jute fibre, coir fibre and hemp fibre. From the table, the average chemical composition for jute fibre cellulose is in between of 61% to 71%, hemicellulose is in between of 12% to 20.4%, pectin is 0.2, wax is 0.5% and lignin is 11.8% to 13%. The average of chemical composition for coir fibre cellulose is in between of 32% to 43%, hemicellulose is in between of 0.15% to 0.25%, pectin is in between 3% to 4% and lignin is 40% to 45% meanwhile the average of chemical composition for hemp fibre cellulose is in between of 70.2% to 74.4%, hemicellulose is in between of 17.9% to 22.4%, pectin is 0.9%, wax is 0.8% and lignin is 3.7% to 5.7%.

Table 4: Chemical Composition of Jute, Coir and Hemp fibres.

Type of fibre	Cellulose (%)	Hemicellulose (%)	Pectin (%)	Wax (%)	Lignin (%)	Reference
Jute	61.0-71.5	13.6-20.4	0.2	0.5	12.0-13.0	[7]
	61.0-71.5	13.6-20.4	-	0.5	12.0-13.0	[16]
	61.0-71.5	12.0-20.4	0.2	0.5	11.8-13.0	[14]
Coir	36.0-43.0	0.15-0.25	-	-	41.0-45.0	[16]
	32.0-43.0	0.15-0.25	3.0-4.0	-	40.0-45.0	[14]
Hemp	70.2-74.4	17.9-22.4	0.9	0.8	3.7-5.7	[7]
	70.2-74.4	17.9-22.4	-	0.8	3.7-5.7	[16]
	70.2-74.4	17.9-22.4	0.9	0.8	3.7-5.7	[14]

5.3 Discussion

It is very important to understand the physical, mechanical and chemical properties of each type of natural fibres in order to use it in the pavement mixtures as pavements see larger volumes of traffic and increased loads particularly from heavy trucks. The usage of fibres creates a need to improve the tensile strength and flexibility of the mixture to prevent failure such as deformations from plastic and forming rutting forms or cracks all over the pavement after construction has finished [7]. The addition of fibre to the mixture, can bring huge improvement the engineering properties [17].

From natural fibres past researchers, the key for a stable mixture performance include uniform distribution, proportion, fibre length and the orientation of the fibre. It is recommended that the orientation of fibres through the mixes to be examined using optical or scanning or scanning using electron microscopy to get a better look to the mechanical properties.

6. Conclusion

Natural fibres such as jute fibre, coir fibre and hemp fibre can be use as one of the pavement material filler because of the composition that can help improve the elasticity of the pavement reducing bleeding in the asphalt mixture. Natural fibres can be found in the nature vastly all around the world therefore the process of making the fibre is rather easier in comparison to synthetic fibre that uses harmful substances. The use of natural fibres as a pavement material can also help reduce the amount of natural waste in plantation making it environmental-friendly, recyclable and cost-effective.

The advantages and the unique quality of natural fibres, it made them having the potential to be a better substitute for synthetic fibres. It is a source of reinforcement to be added in the mixture of pavement or other civil engineering construction that can be found at low cost and easy access.

The disadvantage of using natural fibre is that such materials must be handle delicately coming from the limitations of natural fibre composites such as weak fibre-matrix interfacial adhesion, inherent high moisture absorption and frail interfacial contact between the polymer and the fibre and the natural fibres' hydrophilic nature. Different techniques can be explored to enhance the properties using chemical treatments that would achieve to improve the liability of the natural fibre's adhesion in the mixture. The design lifetime is also not very long lasting because it can be decomposable which need to be in consideration during designing process.

The apprehension of reinforcement materials can be enhanced to the maximum when proper research was conducted accordingly towards each type of natural fibres that are included into the pavement mixture. The surrounding area of the construction site must also be taken to calculation in order to optimize the usage of natural fibre.

It is necessary to associated the research with failure so alteration can be made. This should be aim to be for the best condition performance for pavement that are sustainable for a long time with low maintenance cost along this. Natural fibre as a pavement material is a very nifty idea but it needed further research in the form of how to lengthen the design lifetime in order for it to be more sustainable and needed less maintenance.

Acknowledgement

The authors would also like to thank the Faculty of Civil Engineering and Built, Universiti Tun Hussein Onn Malaysia for its support.

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