

Potential Use of Oil Palm Lignocellulosic Materials in Preparation of Stone Mastic Asphalt - A Short Review

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ABSTRAK

Bahan lignoselulosa daripada industri sawit seperti pelepah, batang sawit, tandan kosong dan fiber mempunyai banyak kegunaan. Selain daripada kegunaan di dalam industri kayu dan perabot, bahan tersebut dapat dimanfaatkan di dalam pembinaan jalan raya terutamanya untuk menghasilkan 'stone mastic asphalt (SMA)'.

ABSTRACT

Lignocellulosic materials from the oil palm industry such as frond, oil palm trunk, empty fruit bunch and fibre have many applications. Besides being used in the wood and furniture industries, the materials can be exploited in road construction particularly in producing stone mastic asphalt (SMA).

CELLULOSE

Cellulose is the most abundant naturally occurring organic substance, being found as the principal cell-wall constituent of higher plants in which it provides the main structural or skeletal element. Cellulose is distributed in all plants from highly developed trees to primitive living things such as seaweeds, flagellates and bacteria (*Table 1*). It is found in almost pure form in cotton fibres where it is present to about 98% on a dry-weight basis. Bast fibres such as flax (80%-90% cellulose), ramie (80%) and jute (60%-70%) are also good sources of this polysaccharide. Wood is a less abundant source (40%-50%) but provides the most important commercial source of cellulose.

Another important source of cellulosic materials is the oil palm industry. With an estimate of three million hectares of oil palm plantations in Malaysia by the year 2000, it is expected that the annual production of fibrous biomass will be around

TABLE 1. CELLULOSE CONTENT
FROM VARIOUS SOURCES

Source	Cellulose (% dry weight)
Cotton	95-99
Ramie	80-90
Bamboo	40-50
Wood	40-50
Bark	20-30
Mosses	25-30
Horse-tail	20-25
Bacteria	20-30
Oil palm	
Trunk	} 25-40
Frond	
Press fibre	
Empty fruit bunch	

20 to 25 million tonnes (Kamarudin *et al.*, 1997; Mohamad *et al.*, 1995; Ma and Zin, 1995). These include empty fruit bunches (EFB), palm press fibre (PPF), oil palm fronds (OPF) and oil palm trunks (OPT). All these are renewable natural sources of lignocellulosic materials.

As the major constituent of plant matter, billions of tonnes of cellulose are produced each

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year. The annual consumption of cellulose is about 500 million tonnes. They are used in various industrial and commercial applications such as wood, paper, cotton textiles, film, plastics, coatings and fuel. With further analytical, biotechnological, chemical and industrial developments, new applications of lignocellulosic materials are being actively investigated (Fengel and Wegener, 1983).

The 'ideal' cellulose is a linear polymer composed of individual anhydrogluco units (also known as glucopyranose units) linked at the one and four positions through glucosidic bonds with the beta configuration. Hence, the units are bound by β -(1 \rightarrow 4)-glycosidic linkages. Two adjacent glucose units are bonded by elimination of one molecule of water between their hydroxylic groups at carbon 1 and carbon 4. The β -position of the OH-group at C1 needs a turning of the following glucose unit around the C1-C4 axis of the pyranose ring. Strictly speaking, the repeating unit of the cellulose chain is a cellobiose unit with a length of 1.03 nm (*Figure 1a*).

Another feature of this polysaccharide is the presence of OH-groups at both ends of the cellulose chain. These OH-groups show a different behaviour. The C1-OH is an aldehyde hydrate group derived from the ring formation by an intramolecular hemiacetal linkage. This explains the situation why the OH-group at the C1-end has reducing properties, while the OH group at the C4-end of the cellulose chain is an alcoholic hydroxyl and therefore non-reducing (*Figure 1b*). The properties of cellulose are characterized by the nature of its solid state. It is neither completely crystalline like glucose, nor amorphous like a supercooled liquid but has some aspects of both states. Within cellulose fibre, there are areas of complete order, *ie.* crystalline areas, and also less ordered or amorphous regions. The degree of crystallinity within fibres varies with the source of the cellulose and the treatment to which it has been subjected. The crystallizing tendency inherent in such regular and highly polar units as the anhydroglucose rings is counteracted by the difficulty of getting the rings in regular crystalline array because they are parts of long, somewhat flexible, mutually entangled chains. Therefore, no two cellulose fibres have exactly the same internal structures; each reflects

its individual history. The differences between cellulosic pulps from different sources may be due to differences in the structure of the cellulose present, but it appears more probable that these differences are due largely to differences in the non-cellulosic components, in the degree of polymerization of the cellulose, and in the physical structure of the individual fibres. Fibres from different sources have markedly different structures. This internal structure is important, since it profoundly affects both the useful strength properties of the fibres and the rate and degree of reaction to which the cellulose in them reacts with chemicals, reagents or enzymes. The chemical reactions are controlled by limiting the access of reagents to the cellulose molecules in the solid. Due to differences in accessibility, many reactions that proceed quickly with glucose do not occur to a measurable extent with cellulose under similar treatments.

The molecular weight of cellulose varies widely (50 000-2.5 million) depending on the origin of the sample. As cellulose is a linear polymer with uniform units and bonds, the size of the chain molecule is usually defined as degree of polymerization (DP):

$$DP = \frac{\text{Molecular weight of the cellulose}}{\text{Molecular weight of one glucose unit}}$$

In general, cellulose is a material of special interest due to its widespread natural occurrence, and its past, present and future commercial and industrial applications. Scientific study and technological development have led to a great deal of knowledge about cellulose.

STONE MASTIC ASPHALT (SMA)

Stone mastic asphalt, which is also known as stone matrix asphalt, is basically a hot asphalt mixture for surface paving of different thickness. SMA is flexible and stable as well as durable, proving to be the most cost effective material for road surface construction and paving composition. Technically, it consists of coarse gap graded aggregate (70%-80% retained on a No. 8 sieve) and a high bitumen binder content of around 6% to 7% with cellulose fibres as additive. It was initially developed in 1968 in Germany to reduce the problem of highway wearing caused by studded tyres.

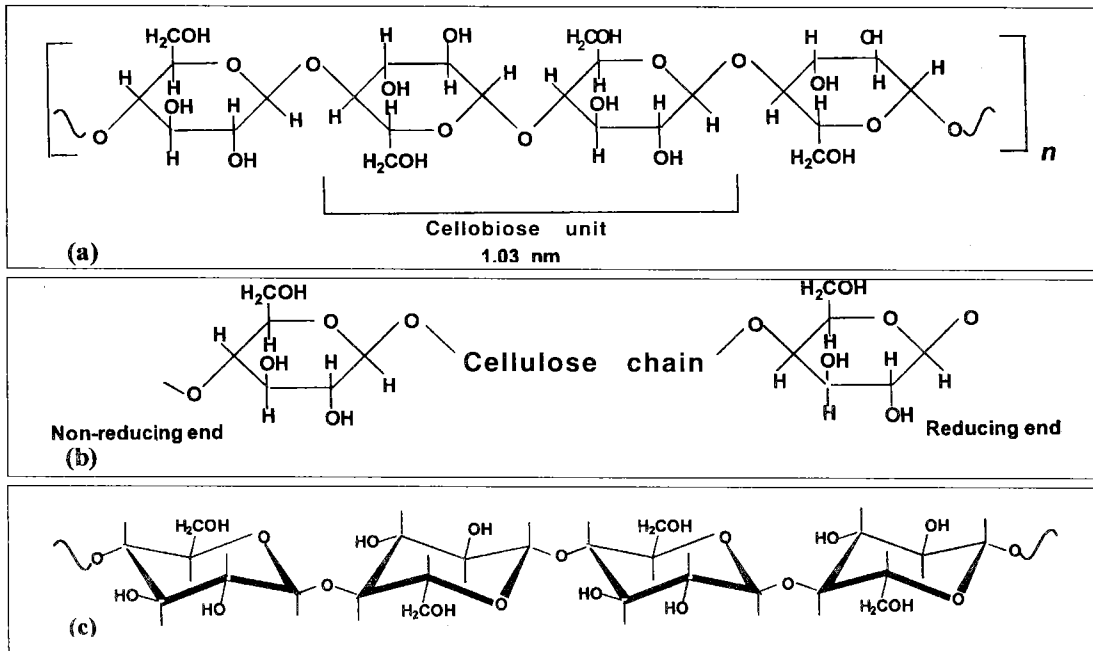


Figure 1. Formula of cellulose (a) Central part of the molecular chain, (b) Reducing and non-reducing end group of the molecule, and (c) Stereo-chemical formula of cellulose.

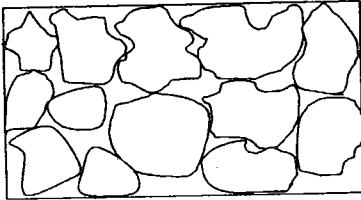
Typical climatic conditions in European countries resulted in the use of studded snow tyres, particularly during winter seasons. These tyres caused high wearing on the pavements and highways. Hence, between 1960 and 1968, the German authorities was searched for a formulation for paving composition to solve the problem of rutting caused by the use of studded tyres. Initially they applied a mastic formulation consisting of sand (40%-50%), filler (30%-35%) and asphalt cement (25%). The mastic was prepared in a mixing plant at 250°C and then delivered to the site by specially designed trucks. The hot mastic was manually transferred onto the rutted pavement, and finally the hot chipping components of grade 5 to 8 mm were distributed onto the hot surface before being pressed down by a roller. Despite this treatment resulting in a high wearing resistance, it had a few drawbacks, particularly the requirement for manual operation, limited capacity, high cost and in some cases, the road surface was not homogenous. Consequently, the asphalt industry looked for an alternative method to produce a similar product in standard plants. They found that using fibres as a stabilizing additive in a mix of 75% stones (5 mm-8 mm), 15% sand (0 mm-2 mm), 10% filler and 7% bitumen, which was eventually known as SMA, gave excellent results.

The success of SMA technology in highway engineering has been extended to other developed countries particularly Japan, USA and almost all European countries. SMA has also been introduced in countries with tropical and subtropical climates, especially Indonesia and Thailand. With further improvement to the cellulose fibres produced and by using the cheapest available lignocellulosic materials, SMA technology is becoming the most economical solution for road maintenance. Many studies have been made in the development of SMA technology due to variation of materials and natural resources available at different locations. This aspect is vital in order to reduce the cost as much as possible without jeopardizing the quality and performance of the product.

USE OF CELLULOSE FIBRE IN SMA

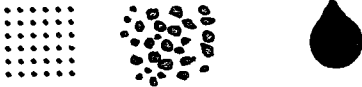
SMA comprises an optimum mix of coarse gap aggregate with sand, filler, cellulose fibre and bitumen binder as illustrated in Figure 2. This formulation is applied to the surface layers of all types of highways from high traffic, high speed highways to heavy load intersections and even bicycle paths and side walks. The higher propor-

SMA with cellulose fibres

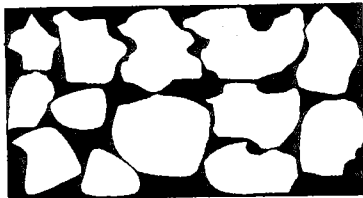


Stone skeleton

Filler + Sand + Bitumen



+ Cellulose fibres



Stone skeleton filled with mastic

Stones

+ Mastic

= Stones mastic asphalt

Figure 2. Formulation of stone mastic asphalt.

tion of crushed coarse aggregate provides a closed and interlocked skeletal structure which facilitates the dissipation of impact to the underground. This feature explains the strength of and resistance of SMA to be resistant wear and permanent deformation. Moreover, the three dimensional structure of the cellulose fibres helps the bitumen binder to maintain a high viscosity, avoiding drainage of binder during storage, transportation and laying of the SMA as well as allowing for a higher bitumen content in the mix which generates a thicker layer around each stone, inhibiting oxidation, moisture penetration and the stripping and cracking of the aggregate. This extra feature of protection offered by SMA provides a longer lasting surface.

Another advantage of using cellulosic materials in the bitumen binder is the stability of SMA under extreme range of temperatures. The fibre reinforcement and the natural polarity and lipophilic characteristics of cellulose (due to the multiple hydroxyl groups present in carbohydrates) as well as its frost resistance enable the formulation to withstand extreme range of temperatures without affecting its efficiency or suffering from deterioration.

With the present production of palm oil, it is expected that an annual potential of up to approximately 30 million tonnes of fibrous biomass (dry weight) can be generated in the form of EFB, PPF, fronds, trunks and palm kernel shell (PKS).

Hence these fibres can be exploited in civil engineering works particularly in all types of road engineering, besides providing a renewable natural resource for wood-based industry. The use of lignocellulosic components from the oil palm industry will definitely help the industry to reduce the environmental problems caused by accumulation of these wastes as well as bring extra revenue to the milling and plantation sectors by selling these waste materials to industrial sectors.

METHODOLOGY

To understand the characteristics of lignocellulosic materials from the oil palm industry, one has to understand the chemical components of the material concerned, as illustrated in *Figure 3*. Here, a distinction must be made between the main macromolecular cell wall components cellulose, polyoses (hemicelluloses) and lignin which are present in all woods, and the minor low-molecular-weight components (extractives and mineral substances), which are normally related to the types and species of woods.

PREPARATION OF CELLULOSE

The preliminary stage of cellulose preparation from woody material involves the removal of the extractives. Extractive-free oil palm lignocellulosic materials may be prepared by several methods; however successive extraction with ethanol-benzene (1:2 v/v) and 95% ethanol following hot

water treatment is by far the most common method applied. This method, when a final water rinse is omitted, is also applicable to determine and quantify the minor components present in the sample particularly the fats, resins, tannins and other phenolic compounds.

The inorganic part of oil palm lignocellulosic material is determined as ash by incineration of the organic oil palm residues at 600°C-800°C. The amount of ash is between 0.2% and 0.5% in the case woods from temperate zones but often much higher in oil palm residues (from 1.2% to 5.6%), as reported by Kamarudin *et al.* (1997). The main ash components of oil palm residues are potassium, chlorine, silica and calcium.

Lignin is another macromolecular wood component. The molecules of lignin are built quite differently from those of polysaccharides, as they consist of an aromatic system composed of phenylpropane units. The standard method for lignin determination requires samples of 1g or 2g of material (TAPPI Standard, 1983).

Delignification, also known as the preparation of holocellulose is another step in the preparation of cellulose. Ideally, delignification should result in the complete removal of lignin without chemical modification or reaction with the polysaccharides, but there is no delignification procedure which completely satisfies this requirement. Three important criteria can be defined for

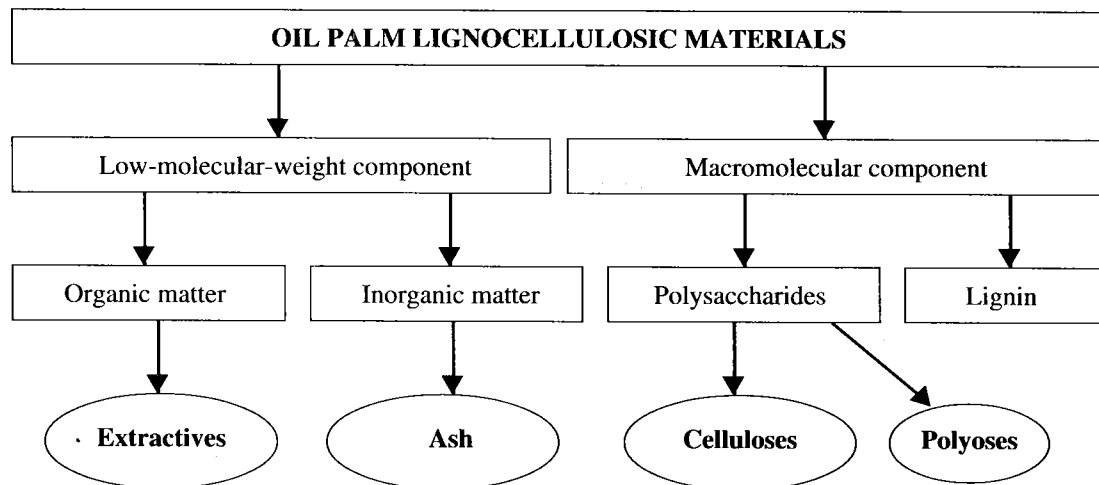


Figure 3. General scheme of the oil palm wood components.

holocelluloses:

- Low residual lignin;
- Minimal loss of polysaccharide; and
- Minimal oxidative and hydrolytic degradation of cellulose.

Delignification with acidified sodium chloride is usually carried out by the method of Wise *et al.* (1946). This standard procedure comprises the treatment of pre-extracted oil palm residues with an acidified sodium chloride solution (pH 4) at 70°C-80°C for 3-5 hr. The chlorous acid procedure is relatively easier to perform but its two drawbacks are some slight oxidative degradation of carbohydrate and incomplete delignification. In theory, the total sum of holocellulose and lignin should equal 100%, but in practice the values vary, usually in the range of 97%-102%, and occasionally may be 94%-105%.

PREPARATION OF SMA

The asphalt mixture is composed of aggregate(s), mineral filler and bitumen, plus required additives and combined as necessary to suit the needs of the project requirements and specifications (NAPA, 1994). The SMA preparation consists of selecting the material and proportioning the mix, choosing the thickness of the layer (between 1.5 cm and 5.0 cm), and the steps required for laying the SMA. The aggregates have to be selected from the available raw materials. The composition of the mix is as follow: 60%-80% aggregates (5 mm-8 mm), 15% sand, 10% filler and 7% bitumen. The amount of cellulose fibres to be added, is between 0.3% and 1.5% by weight of the total mix. The cellulose fibres used in this preparation are subjected to the following tests to examine the fibre properties:

- Sieve analysis;
- Ash content;
- pH;
- Oil absorption; and
- Moisture content.

The SMA samples prepared in the laboratory are normally subjected to a few tests such as Schellenberg Binder Drainage Test (to check the degree of drainage of asphalt cement from the mixture), Stability, Voids in Total Mix and other

relevant analyses. Later on, trial section(s) will be constructed (at least 150 m length) off site to examine the mixing plant process control, placement procedures, SMA surface appearance, compaction patterns and to calibrate the nuclear density device. SMA can be batch mixed in a pugmill or continuously produced in a drum mixer. The production of the mix is one of the most important elements in the construction of an SMA pavement. It is produced in a similar form to the method used with asphalt concrete with the exception that special attention needs to be given to the correct aggregate fractionating and the mixing times with the addition of the cellulose fibre. A constant quality product is vital to provide a homogenous, long lasting and problem free surface.

CONCLUSION

The SMA technology has been tested in many European countries, USA, Japan and Indonesia for being the most economical solution for road maintenance. The technology also offers other advantages such as high resistance against rutting (high temperature heavy traffic), high flexibility, good wearing resistance (studded tyres), no water-stripping, watertightness, good wearing resistance, high durability and low noise. Furthermore, the use of local cellulose fibres particularly those derived from oil palm lignocellulosic materials will definitely boost other secondary and tertiary industries as well as bring extra revenue to the oil palm industry.

REFERENCES

- FENGEL, D and WEGENER, G (1983). *Wood: Chemistry, Ultrastructure, Reactions*, Walter de Gruyter, Berlin, Germany, p. 1-556.
- KAMARUDIN HASSAN; MOHD BASRI WAHID; MOHD NASIR HJ AMIRUDIN; JALANI SUKAIMI; ARRIFIN DARUS and RIDZUAN RAMLI (1997). TT No. 47: pulp and paper from oil palm fibre. *Proceedings of the 1997 PORIM Technology Transfer Seminar*, PORIM, Bangi. p. 40-49.
- MA AH NGAN and ZIN ZAWAWI ZAKARIA (1995). Management of wastes of palm oil mills -

towards zero waste (Jalani, B S *et al.* eds.). *Proceedings of the 1995 PORIM National Oil Palm Conference*, PORIM, Bangi. p. 208-216

MOHAMAD HUSIN; JALANI SUKAIMI and ARIFFIN DARUS (1995). *Proceedings of the 1995 PORIM National Oil Palm Conference*, PORIM, Bangi. p. 171-187.

NATIONAL ASPHALT PAVEMENT ASSOCIATION (1994). Oil palm biomass utilization in wood-based industries (Jalani, B S *et al.* eds). *Guidelines for Materials, Production and Place-*

ment of Stone Matrix Asphalt (SMA), National Asphalt Pavement Association (NAPA), Lanham, USA, p. 1-18.

TAPPI STANDARD T 222 OM-83 (1983). Acid-insoluble lignin in wood and pulp. p. 207-208.

WISE, L E; MURPHY, M and D'ADDIECO, A A (1946), Chlorite holocellulose, its fractionation and bearing on summative wood analysis and on studies on the hemicellulose. *Paper Trade J.*, 122 No. 2: 35-430.