A short review on the extraction of kenaf fibers and the mechanical properties of kenaf powder composites

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Abstract. Kenaf fibers are rapidly growing in the global market and currently being used as a composite to replace other expensive composite materials available in the market. Kenaf powder has the potential to replace other traditional fillers due to its low cost, eco-friendliness, and renewability. The aim of this paper is to review on the mechanical properties of Kenaf fibers, and its powder composites. This paper discusses on the Kenaf plants itself, extraction process, physical properties of kenaf fibers, and finally the mechanical properties of the kenaf powder composites. It can be concluded that Kenaf powder composite has more opportunity for further growth with new methods and technologies which keeps on evolving.

1. Introduction
Since ancient civilisation, natural composites had been used to build up structures or products. One such example, is the use of straws and clays to build up walls. However, the use of natural fiber started to decline when the age of industrialisation started replacing these natural composites with higher strength materials. The downside of these materials is that they are too expensive. Thus, researchers started to find other possibilities that could replace this type of material which could reduce the cost while still retaining the high strength [1–5]. One of the solutions is replacing with a natural fiber composites. Natural fiber composites does not only have the high strength to weight ratio property, it is also eco-friendly, renewable, and biodegradable. Out of all available natural composites, a lot of attention are being given to Kenaf composites due to its low cultivation needs with high amount of harvest within half a month.

Kenaf could grow as high as 6 meters within 6 to 8 months of plantation and produce around 6 to 10 tonnes of dry fiber each year. Kenaf markets are expanding rapidly locally and globally especially with the introduction of new technologies and applications that could potentially improve Kenaf fibers mechanical and chemical properties and replace other materials in the coming future [6]. This paper will be reviewing specifically on Kenaf extraction, its powdered form, and the mechanical properties of Kenaf powder composites.
2. Kenaf extraction

The extraction process of Kenaf fiber are essential to determine the quality of extracted fiber. The harvesting and extraction of Kenaf fibers has always depend on the location, equipment, method of processing and functions of the final products [7]. Mainly, there are two methods of harvesting fibers, which are hand harvesting, and using the whole stalk harvesters.

In hand harvesting, the process starts from harvesting manually by hand. The plant will be cut near the ground level with a sickle or a curved blade. This harvesting process has been used since 6000 years ago, and therefore it is the most traditional way of harvesting. This method requires human labour and time-consuming. The other method of harvesting and extraction is by using Kenaf Whole Stalk Harvesters. In this method, harvesting could be summarised into three steps which starts with pulling and windrowing, followed by retting, and finally balling parallel stalks. Currently, there are two type of harvesters available in the market which are the Sugarcane-type harvesters and forage-type harvesters. In both type of harvesters, researchers were focusing more on adapting with existing machines instead of innovating a new type of harvesters specifically for kenaf. Sugarcane-type harvesters are unmodified or slightly modified type of sugarcane harvesters. This harvester uses rotating blades or circular cutting blades to cut off the base of the kenaf stalks and also separate the low fiber from foliage and top portions of the plants. The long stalks will then laid down in a long windrow on the field to dry via the harvesting machine. Unlike Sugarcane-type harvesters which will harvest the long stalks vertically, forage-type harvesters will harvest kenaf by chopping the crops into small pieces. After that, a balling equipment will be used to turn the chopped kenaf into different sizes of square bales or large round bales.

After harvesting, it will undergoes retting process to extract the fibers. Currently, there are four types of retting process that has been used which are biological retting (dew retting, water retting, enzyme retting), mechanical retting (using decorticator), chemical retting, and physical retting [8].

In biological retting, the dew retting were carried out by spreading out the stalks on the field and expose them to the rain, sun and dew for several weeks until the stalks begin to separate from the fiber naturally [8]. Due to the long exposure to the natural conditions, fibers tends to lose its original colour and turns brown. Furthermore, this method reduces the fibers strength and quality. Water retting involves tying several bundles of stalks and immersed them in streams or water of at least 60 cm in depth. This process usually took around 2 weeks until the bast fibers naturally separates from the core fibers. These bundles were then taken out of the water and left to dry. Finally, enzyme retting the safest and fastest process of retting, where the core fibers can be taken out from the bast fibers after several hours. Some examples of enzymes that has been used are pectinase, and xylanase.

The second type of retting process is mechanical retting which uses Kenaf Decorticators [8]. A decorticator is basically a machine which could separate the bast and core fibers for further processing. It could ensure that the fiber will not be damage while being extracted. Some of the component of this machines are the frame (to hold all the components), knife (to cut the stalks), knife plate (to hold the knife in place), feeding mouth and security cover (to place the stalks into the machine with safety), and much more. This decorticator machine could reduce the amount of labor needed while still maintaining harvest at a faster rate. In the latest research made by Makanjuola et al., they evaluated the performance of a Kenaf decorticator [9]. The decorticator machine works by feeding the stalks into feeding mouth, then the stalks will be sent to the beaters to be crushed. The crushed stalk that contain both bast fiber and core fiber will be pushed into the delivery plate. Finally, the bast fiber will be separated from the crushed core fiber manually.

The third process which is chemical retting is a process where the stalks were treated with acid and alkalis to remove the core fibers easily from the bast fibers [8]. In these method, the stalks are boiled.
with chemicals such as sodium hydroxide, sodium benzoate, and hydrogen peroxide, at a specific temperature for several hours, and then washed with clean water. The fibers obtained from this method usually felt coarser and rough compared to other methods.

The last process for fiber extraction is Physical retting \[8\]. This process involves two steps which starts with modifying the surface/volume ratio of fibers through chemical pre-treatment. Then, the stalks will be subjected to steam explosion where the fibers will be blown apart and separated. In this method, the water will be vaporized completely and increased in volume and it requires small amount of processing time. However, this method could only produce short fibers.

Generally, the fibers extracted from these harvesting methods will result with properties as shown in Table 1, and the range of each properties could vary depending on the method used to harvest and extract the fibers.

\begin{table}  
\centering  
\caption{Properties and cost of synthetic and natural fibers \[10, 11\].}  
\begin{tabular}{|c|c|c|c|c|c|c|}  
\hline  Fibers & Density \( (g/cm^3) \) & Tensile Strength \( (MPa) \) & Young’s Modulus \( (GPa) \) & Elongation to failure \( (%) \) & Moisitue Content \( (%) \) & Cost \( (RM/kg) \) \\
\hline  Carbon & 1.40 & 400 & 230 – 240 & 1.4 – 1.8 & - & 33.48 – 58.60 \\
E-Glass & 2.55 & 3.0 – 3.5 & 63 – 67 & 2.5 & - & 8.37 \\
S-Glass & 2.50 & 2000 – 3500 & 70 – 73 & 1.8 – 3.2 & - & 8.37 \\
Aramid & 1.44 & 3000 & 124 & 2.5 & - & - \\
Kenaf & 1.45 & 284 – 930 & 21 – 60 & 1.6 & 6.2 – 20 & 1.58 \\
Hemp & 1.48 & 550 – 900 & 70 & 1.6 – 4.0 & 8 & 6.49 \\
Flax & 1.40 & 800 – 1500 & 60 – 80 & 1.2 – 1.6 & 7 & 13.02 \\
Jute & 1.30 – 1.48 & 493 – 800 & 13 – 26.5 & 1.16 – 1.8 & 12 & 3.88 \\
\hline  
\end{tabular}  
\end{table}

In comparison, the density of synthetic fibers and natural fibers listed in Table 1 are almost the same. E-glass fiber possesses the highest density while Jute having the lowest, whereas Kenaf fibers is in the middle range density. The density of these materials will determine how light the final product will be and especially important when making sports equipment that involves speed. Table 1 also shows that the tensile strength of natural fibers are comparable with synthetic fiber with the exception of S-Glass fiber and Aramid fiber which have an extremely high tensile strength which is 2000-3500 MPa and 3000 MPa respectively. As for Kenaf fibers, it could reach as high as 930 MPa, which suggests it as a medium strength fibres compared to other fibers. Natural fibers stiffness could only reach as high as 80 GPa whereas synthetic fibers could reach as high as 240 GPa. The elongation to failure of natural fibers are also comparable to synthetic fibers, which lies between 1.2-2.5 %, with Kenaf fiber having 1.6% of elongation of failure. Unlike synthetic fibers, natural fibers has higher moisture content, which is one of its drawbacks, with Kenaf fiber within the range of high moisture content. Finally, the cost of natural fiber are extremely low in comparison with synthetic fibers. Kenaf has the lowest raw material cost leading to the production of low cost composite \[10\].

Kenaf fiber has the potential to replace synthetic fibers due to its low density, medium range tensile strength and stiffness, and extremely low cost of raw materials \[12\]. After the fibers has been extracted and separated, Kenaf powder was processed from the inner fiber (core) of the Kenaf stalk. The core fiber will be machined or crushed until it turns into a powder form as shown in Figure 3. This form were usually used as fillers when making a composite and has the highest possibility of replacing the traditional fillers such as talc and calcium carbonate.

![Kenaf Core Fiber](image1.png) ![Kenaf Core Powder](image2.png)

\textbf{Figure 3.} The core fiber (a) will be crushed and machined into powder form (b) Kenaf core powder

### 3. Mechanical properties of Kenaf powder composite
Composites are materials made up of reinforcements (fibers) and matrix (thermosets, thermoplastics, etc.) [13]. Composites which are made from a powdered form usually have lower tensile strength although it has lighter weight. Sometimes, in order to increase the strength of the composite, most fibers will be treated chemically. The chemical treatment can enhance the interfacial bonding, thus reduce the tendency of fibre pull out within the composites, which leads to failure [14–16]. The mechanical properties of kenaf powder composites vary depending on the type of treatment, fiber loading, and types of hybrids being used. Table 2 shows the mechanical properties of several types of Kenaf powder composites (KCP) reported previously.

Each of the work involved the use of varied amount of fibers starting from 0% up to 20-30%. The addition of Kenaf powder decreases the strength, but increases the stiffness of the composites [14–18]. Abdul Majid et al had conducted two experimental studies in 2016 [15] and 2018 [14]. Both of these experiments had used 70% Polyvinyl Chloride (PVC) and 30% Epoxidised natural rubber (ENR) with different Kenaf fiber loadings (0% - 20%). Both studies differ in terms of chemical treatment used which is Benzoyl Chloride (BC) [14] and Sodium dodecyl sulphate (SDS) [15]. From their research, it was found that the experiment used SDS has higher tensile strength compared from using BC which is 4 MPa and 3.5 MPa respectively.

Another research conducted by Mustaffa et al [16] also added the fiber loading from 0% up to 20% with 70% Polypropylene (PP) and 30% Virgin Acrylonitrile Butadiene Rubber (vNBR). When compared to Alias and Ismail’s research [17], the tensile strength and Young’s modulus of the composites had decreased significantly probably due to low percentage of PP. They also compared with presence of BC treatment. After being treated with BC, it was found that the tensile strength and Young’s modulus had shown an increment. Alias and Ismail [17] conducted the experiment using 90% Polylactic Acid (PLA) and 10% Natural rubber (NR) with different fiber loadings. It was found that the higher the amount of fiber loading, the lower the tensile strength of the composite. When the fiber loading was the highest (20%) the tensile strength had been reduced from 41.39 MPa (0% KCP) to 34.21 MPa (20% KCP). However, the Young’s Modulus increased from 1.459 GPa (0% KCP) to 2.578 GPa (20% KCP).

In different studies, Pang and Ismail [18] used 70% PP and 30% Waste tire dust (WTD) with variation in the amount of fiber loading and the form of Kenaf fibre. Similar with the previous researches, the higher the amount of fiber loading, the lower the tensile strength of the composite whereas the composite’s Young’s modulus kept increasing. It can also be seen that different kenaf form will give different results. In this case, the composite using short fibers will have better tensile strength and Young’s Modulus compared to composites using powder form.

| Composites                                  | Tensile Strength (MPa) | Young’s Modulus (GPa) | References |
|---------------------------------------------|------------------------|-----------------------|------------|
| 20% KCP + 70% PVC + 30% ENR + BC            | 3.50                   | 0.013                 | [14]       |
| 20% KCP + 70% PVC + 30% ENR + SDS           | 4.00                   | 0.010                 | [15]       |
| 30% KCP + 70% PP + 30% vNBR + BC            | 8.00                   | 0.450                 | [16]       |
| 20% KCP + 90% PLA + 10% NR                  | 34.21                  | 2.578                 | [17]       |
| 20% KCP (powder) + 70% PP + 30% WTD         | 10.00                  | 0.750                 | [18]       |

### 4. Conclusion

The global market of Kenaf are expanding rapidly over the past several years. Currently, industries are manufacturing more products by using Kenaf composites. By comparing several other fibers (carbon, glass, Kevlar, hemp, jute, flax) with kenaf, it was found that Kenaf fibers are cheaper and better strength among other natural fibers. Kenaf fibers can be extracted using three different methods which is hand harvest and retting, using decorticator machine, and whole stalks harvesters. In order to get kenaf powder, the core fiber of kenaf will be crushed completely into powder form. Several researches had been done in order to develop a composite using kenaf powder. The mechanical strength of kenaf powder composite are commonly enhanced using chemical treatments. Thus, with the rapid growth of research being carried out, it can be predicted that these kenaf powder composites could be strengthen to resemble a carbon fiber composite and act as a replacement.
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