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Forming Process Analysis in Environmentally-Friendly Composite Production from Fibres of Oil Palm Empty Fruit Bunches

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ABSTRACT

The empty fruit bunch of oil palm (EFB) is the solid waste that is generated at palm oil mills. In 2012 only, it was available in large amounts by more than 50 million tons worldwide. Its utilisation for technical purposes is unfortunately very limited and so far, it is still less value-added. It would be interesting to discover the appropiate technology so that the biomass has an added-value such utilisation for technical and commercial products. Fibre from EFB can be processed to be environmentally-friendly composites by mixing the fibres with renewable binding agents based on starch such as potato starch. There are some options to forming the between product into a composite such as creating a dough base first that is then laminated and finally mixed (nonwoven). Experiments to produce possible composites can be done where the combination between product and technology matches so that the fibres are spread randomly and homogenously throughout the body of the composite. The variables for this option of producing a composite with a thickness of 2 mm are a temperature of 180°C, press duration of 5-15 min and pressure of about 10-30 bar where the modulus of elasticity is about 7 GPa.

Keywords: biomass, composite, empty fruit bunch, forming process, oil palm

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INTRODUCTION

In 2012, crude palm oil (CPO) was the most produced vegetable oil with a world production of about 53.3 million tons. Indonesia is the largest producer of CPO in the world, producing 26.9 million tons a year. The same amount of empty fruit bunches (EFB) was also produced i.e. about 53.3 million tons of EFB worldwide and

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26.9 million tons of EFB just from Indonesia in 2012 (Arya et al., 2015). The production of CPO is increasing from year to year, so that the amount of EFB produced every year is also increasing. EFB is an economical biomass. It can produce about 50-53% fibre, which is a potential industrial raw material (Arya et al., 2015). Scale enlargement of EFB fibre under the microscope and from using Structural Equation Modelling (SEM) it is known that fibre has a honey-comb structure, which is the basic structure for lightweight construction (Arya, 2005; Arya, 2015) as shown in Figure 1 below.

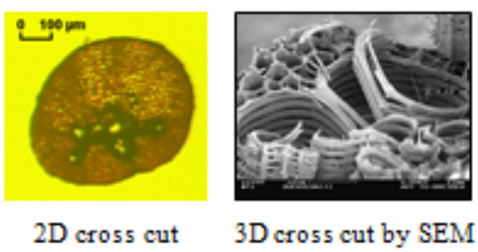


Figure 1. Structure of EFB fibre (Arya, 2005; Arya, 2015)

This research focussed on studying the structure of EFB fibre to consider its potential use as an industrial raw material especially for technical purposes as a composite.

Of the various types of waste (gas, liquid, solid) produced in the palm oil mill, the solid waste of EFB has the potential to be utilised as raw material for industrial use as a natural fibre that can be utilised to produce composites. Composites can be applied in various technical and commercial products. A composite material has a distinctive specification as a lightweight material with high strength. Thus, the basic ingredients of composite products can be further applied as an exterior component of automotive parts or bulletproof (hard plate) items. Hard plate today is produced from synthetic material such as aramid, HPPE, minerals (ceramic) or metals. Synthetic and mineral raw materials¬ are difficult to be composted without the help of sustainable chemical and mechanical processes but EFB fibre is a natural fibre that is renewable and biodegradable. In comparison with non-organic components such as minerals, aramid, which is made from a complex process and also through the addition of metals to achieve the desired strength so that in bulletproof items, five layers of composites are able to withstand the bullets of a certain calibre. The technology to produce the composites requires binding agents based on starch such as potato starch or protein such as casein to be added. This technology produces an environmentally-friendly composite that is biodegradable, possesses strong mechanical characteristics (a high mechanical strength) by more than 7 GPa, has good heat resistance up to 240°C, is resilient to electrical conductivity, has good thermal insulating and has sound-proofing characteristics. Composites made out of EFB are expected to have mechanical strength equal or equivalent to the mechanical strength of conventional materials.

Utilisation of natural fibres in composites for technical products has been carried out in Europe for about 15 to 20 years, especially for vehicle components. Used natural fibres that are available in Western Europe include fibres of flax and hemp, while natural fibres imported from India include fibres such as kenaf. Efforts to use natural fibres takes into account several factors that support the development of the automotive industry like global markets and the development and production of components that can use non-woven fibres. Generally, composites consist of two main components i.e. fibres as reinforcing material and fibres as fillers in the form of adhesive.

The second major component of a composite that is available now is unfortunately based on non-renewable raw materials e.g. metals, minerals and polymers. Composites may be applied as industrial raw materials in manufacturing, in this case as a filler component, but the materials available are still based on non-biodegradable materials e.g. binding agent of latex, where latex is a derivative of natural rubber and used as an adhesive (Felegi, 1990). On the other hand, a combination of natural fibres and natural adhesives based on starch (potato) can produce composite materials that are renewable and environmentally-friendly.

In the palm oil industry, fresh fruit bunches (FFB) are the main raw material to produce crude palm oil (CPO), where FFB is harvested for palm oil and its derivatives. At the first stage of production, the FFB is sterilised (this is called the evaporation process), where steam at a temperature in the range of 130 to 140°C and by pressure of about 2.8-3.0 kg/cm^2 is channelled to a sterilisation tank. After the sterilisation process, the fruits in the FFB are easily separated in a thresher machine. After the fruits are separated from the bunch, what is left behind is the empty fruit bunch, EFB, or the bunch without fruits. This EFB is the biomass or solid waste produced from CPO production in a palm oil mill.

The oil palm fruit contains palm oil (CPO) in the palm fruit flesh (mesocarp) and its oil is has economic value. The EFBs are a solid waste that is burnt in an incinerator or used as compost instead of fertiliser for oil palm plantations. Both are no-added-value solutions. If the EFB can be utilised, it will be an added-value for the palm oil industry and other industrial sectors. EFB fibres are a potential renewable raw material for producing technical and commercial products. This solution can give added-value for this solid waste for instance if it is used as a component of exterior and interior parts of vehicles or as a bulletproof material. Fiberising EFB for technical and commercial use is done in a hot press at 180°C.

MATERIALS

The Fibres of Oil Palm Empty Fruit Bunch

The first step is the procurement of the main raw material, the EFB. This study traced the route of EFB that was transported from a palm oil mill in PTPN VIII, Kertajaya, located in Lebak, Banten, Malimping, West Java. The EFB is generated at the palm oil mill as biomass. Its availability is centralised;

this is a very good logistic factor. EFBs are generated after the separation process separates the fruits from their bunches in a thresher machine. The EFBs are transported in a truck with a load of about 4-7 tons. The EFB is fiberised manually. Some unused parts such as burnt fibres, thorns, leaves and dust are separated. Only good fibres are used as raw material for composite production.

After the raw material is obtained, the next stage is the process of fiberisation, where the bunches are made into fibre (this requires a duration of one month for 7 tons of EFB). This is followed by washing, drying, election, where brightly coloured fibres are separated from the brown, burnt ones during the sterilisation process in the palm oil mill and finally, packing the fibre. Fibre requires careful packaging as it needs to be properly stored. If possible, it should be supplied to purchasers immediately. Fibre packaging is a new process. It takes about six months for the whole process from washing to packaging to be completed.

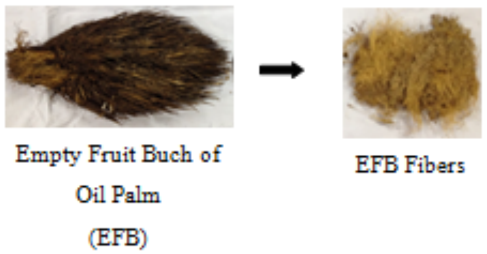


Figure 2. EFB and its fibres

Producing a Binding Agent from Potato Powder

Potato starch is used to make the binding agent. The potatoes are bought at traditional markets. Figure 3 shows how the binding agent from potato starch is produced.

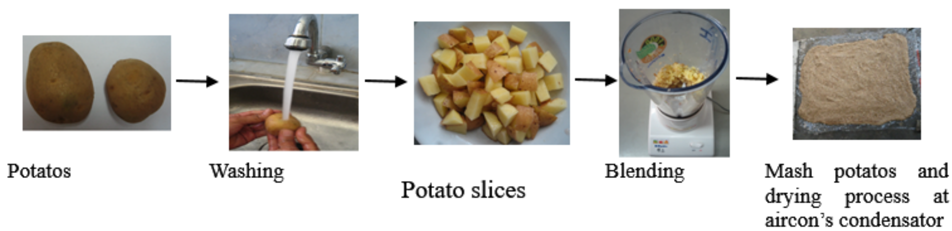


Figure 3. Production of binding agent raw material from potatoes

First, the potatoes are washed. Then they are cut into slices. The slices are blended in a blender and end up as mashed potato. The mash is air dried at about 40-60 0C. The drying process takes about 12 hours. The dried mash is crushed manually or in a blender to form a powder. This powder is the raw material for the binding agent. The powder is mixed in warm water and stirred slowly and consistently by hand. A gel-like substance is produced; this is the binding agent for the composite. The composite must have a viscosity η of 487 mPa s and a surface tension γ of 97 mN/m.

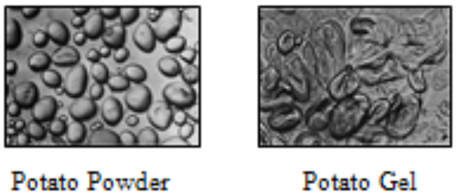


Figure 4. The powder and gelatinised powder of potato starch (Kohler, 1971)

METHODOLOGY

The production process of industrial raw materials (fibres) of the solid waste of palm bunches begins with the process of packaging and storing the industrial raw materials. The solid waste is supplied from palm oil mills. Next, the fibre is carried manually to reduce the possibility of damage to it. The fibre is collected and packed into a box that is then transported and stored in a humidity-controlled room. Figure 5 illustrates the forming process where the raw materials are mixed and formed before being turned into the end product (Arya, 2015).

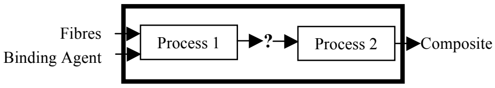


Figure 5. Process stages of end product forming

The question mark (?) in Figure 5 indicates the between product. The composite may take three forms, namely dough, laminate (fibres in row) and mixture (Arya, 2015), as explained below:

Option 1: Dough

According to Tsiapouris (Felegi et al., 1990), enthalpy bilance plays a big role in the process by when the option of dough is selected.

Accumulation of enthalpy = Temperature flows from hot plates – steam is given out, as shown by the formula below.

$$c_p M \frac{dT}{dt} = \alpha_e A[T_w(t) - T(t)] - \dot{M}_v (r_w + c_w T) \qquad (1)$$

Hot-pressing to form a dough as the between-product in producing the composite, unfortunately, did not yield a good result as the fibre was not homogenous throughout the composite. Figure 6 shows that the fibre did not spread out homogenously throughout the composite.

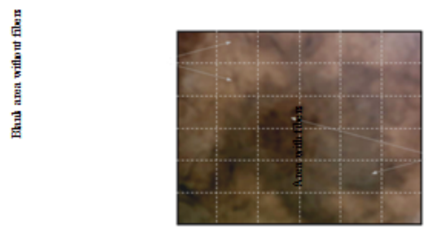


Figure 6. Expasion type of the fibres in composite (Felegi et al., 1990)

Option 2: Laminate

In lamination, the fibre is aligned in rows and coloums. The hole room of the positioned fibre is filled with binding agent so that the fibre is filled out with binding agent. This is the structure of built composite (see Figure 7).

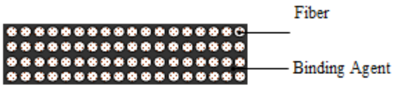


Figure 7. Composite built by fibres and binding agent (Felegi et al., 1990)

According to Föll (2003), all the fibre are straight and in parallel position throughout the matrix so that the composite material possesses elasticity as a mechanical property (fibres and matrix). An ideal composite material of fibre modulus of elasticity is greater than the matrix modulus (EF > EM) of hard fibre in a soft matrix. According to Hooke's law, the relationship between direct stress (σ in N/mm2), direct strain (ε) and modulus of elasticity (E in MPa) is formulated as follows (Köhler, 1971):

$$\sigma = E \cdot \varepsilon \tag{2}$$

Direct strain ε is the relative change in length (Köhler, 1971):

$$\varepsilon = \Delta l / l_0 \tag{3}$$

where

Δl: Change of measuring length

lo: initial length

l = lo +Δ l

The load on the fibre position (parallel or perpendicular) to produce direct stress σ on the composite body also depends on the position of the fibre, as shown in Figure 8 and Figure 9.

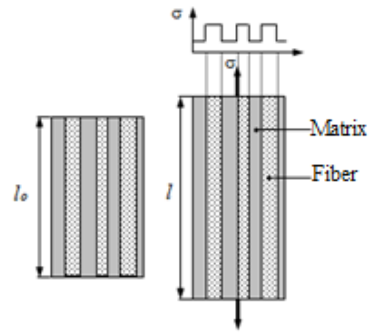


Figure 8. Tensile test parallel to the fibre position

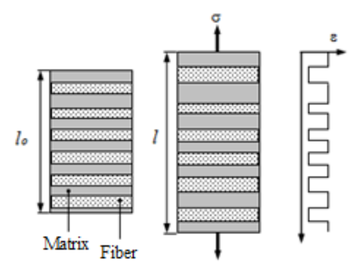


Figure 9. Tensile test perpendicular to fibre position

The modulus of elasticity of the composite by tensile test is found to be parallel to fibre position. In order to stretch the fibre to ε more power must be applied to the cross-sectional area of the fibre than to an equally large area of the matrix (Tsiapouris, 2000).

$$\sigma VB = \varepsilon \, [E_F \cdot V_F + EM \cdot (1 - V_F)] \tag{4}$$

or

$$Ep = E_F \, . \, V_F + E_M \cdot (1 - V_F) \tag{5}$$

The modulus of elasticity of the composite by tensile test is found to be perpendicular to fibre position. Here, the fibre is less stretched than the matrix (Föll, 2003).

$$\varepsilon = \sigma\left(\frac{V_F}{E_F} + \frac{1 - V_F}{E_M}\right) \quad (6)$$

or

$$E_s = \frac{1}{\frac{V_F}{E_F} + \frac{1 - V_F}{E_M}} \quad (7)$$

where

Ep: Modulus of elasticity of composite by tensile test parallel to fibre position

Es: Modulus of elasticity of composite by tensile test perpendicular to fibre position

σ_{VB}: Tension on cross-sectional area of the composite material

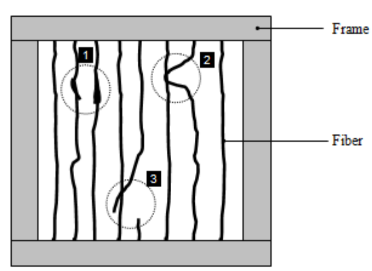
V_F: Volume fraction of the fibre

E_F: Fibre modulus of elasticity

E_M : Binding agent or matrix modulus of elasticity

According to Arya (2005), the production of a laminate of oil palm fibre produced in relation to the manufacture of fibreglass indicates the following (see Figure 10):

- Oil palm fibre is a corrugated fibre (wave type) and has non-uniform fibre thickness that ensures that parallel fibre order cannot be realised
- Fibre breaks indicate that the fibre laminate has not formed well because the fibre strands are no longer parallel to one another.
- Where fibre strands overlap between the upper and lower strands, no fibre bonding through the binding agent takes place and that location is a weak spot in the composite.
- EFB fibre is not an endless fibre; the dimensions of the sample will depend on the maximum fibre length of this natural fibre and the preparation process (shredding/crushing the EFB).
- A problem during gluing occurred where the gelantinised binding agent derived from potato starch dried out under normal weather conditions and shrank by about 80%, rendering the laminate option inappropriate for use in forming a composite.



. .: Fibre thickening and corrugated (wave)

. .: Fibre overlap

. .: Fibre fracture

Figure 10. Experimental equipment for laminate specimen production (Arya, 2005)

The laminate option was also problematic as the binding agent lost volume and would not dry as did the synthetic binding agents. Figure 11 shows how the binding agent of potato will lose volume after some days and weeks.

	Filling the potato binding agent into the box eith fibers
	Drying process of the potato binding agent after 5 days where it loses its volume
	Drying process of the potato binding agent after 1 week where it loses more its volume

Figure 11. Drying process of potato binding agent

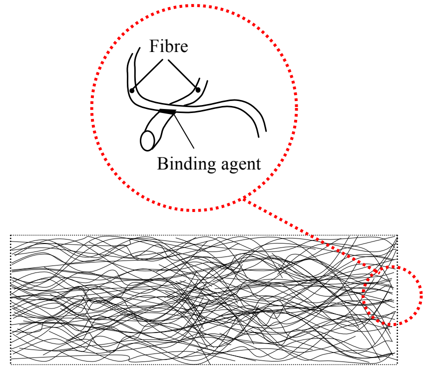


Figure 12. Mixture (non-woven) of EFB fibres (Arya, 2005)

Figure 12 shows that the EFB fibre with length of more than 1 cm (long fibre) is positioned in random direction. The fibre have a wave structure that naturally provides support, giving strength to the composite. If bent, the strands of fibre will be bent but they will not break, as shown in Figure 13 below.

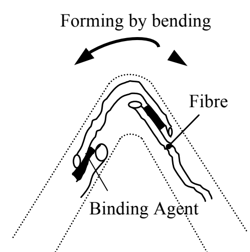


Figure 13. Composite flexibility through fibre flexibility (Arya, 2005)

Option 3: Mixture (Nonwoven)

The EFB fibre strands are first mixed with the binding agent and then dosed in unorientated/random fashion in a matrix box. The fibre strands are compressed to a certain thickness and dried, leading to the naming of this option as mixture or non-woven.

The long fibres of EFB ensure flexibility of the composite. The binding agent is carried in steam (moisture content) in soft condition and remains deformed after the steam leaves the body of the composite. This option was chosen for the development of a production process for this research. With EFB fibres, unfortunately the modulus of elasticity calculation, according to Föll, cannot be produced. Due to non-orientated fibre positioning, uneven fibre length and thickness of the EFB fibre strands and the extreme reduction in volume of the binding agent after drying, laminating was considered an inappropriate option for forming a composite. Where the structure of the processing goods (fibre and binding agent) and adhesive strength may have influence on product specificcation, a different approach can be taken for the calculation of composite strength such as through the three-point bending test (bending modulus), where the flexural modulus of elasticity is the relationship between the increasing surface stress of a rod with increasing outer fibre strain and unhindered cross-sectional deformation (Blumenauer, 1994).

In the production process using this mixture option the variables and parameter are 120-180°C hot pressing temperature, pressure at 10-30 bar, pressing duration of 15-30 minutes (Arya, 2015) to gain strength. Another matter that needs to be considered is the humidity of the materials (ϕm); the value of moisture affects the hot-press process duration. In the pressing process, heat is delivered from the top plate and the bottom plate, both of which must reach the same temperature so that the body of the composite receives the same amount of heat and is therefore, homogeneous. Figure 12 below shows the effect of input material humidity (in %) on the hot-press process duration where the body of the composite is homogenous in terms of temperature.

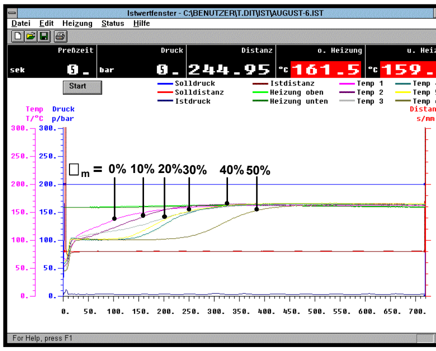


Figure 14. Composite flexibility through fibre flexibility (Arya, 2005)

Figure 14 shows the composite in the hot-press process receiving equitable distribution of heat throughout its body.

Figure 15. Environmentally-friendly composite from EFB fibres and binding agent from potato)

CONCLUSION

The following are the conclusions of this study.

- Paying attention to the uniform distribution of the EFB fibre strands in the composite body established a match for the option of mixture (non-woven) in forming the between product for a composite for this research.
- The option of lamination was discarded because of the reduction in volume (shrinkage) of the binding agent of about 80% that was produced using this option.
- The option of lamination required each strand of fibre to be tied to the frame. This difficulty was another reason for discarding this option.
- The environmentally-friendly composite that was produced can be used in manufacturing automotive (interior or exterior as well) parts and bulletproof material, among other uses.

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