Mechanical Design and Evaluation of Kapok Fibre Seeds Separator

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Abstract. The demand on Kapok fibre-based products has currently shown an increase particularly those from small business traders in comparison to massive market sellers due to lower cost offered. However, the small business traders commonly use manual technique to separate the Kapok fibre from its seed before continuing to the next stages, thus, leading to labour-intensive work, longer processing time, and low output. The aim of the study was to design and develop a Kapok fibre seeds separator to efficiently perform the work. A number of idea generation and concept development phases were undertaken. The finalised concept was transformed into a three-dimensional (3-D) model using a computer-aided design (CAD) software. A computational 3-D finite element analysis (FEA) was conducted to evaluate the structural performance under simulated loadings. Also, the product prototype was built and its usability has been tested. The outcomes of 3-D FEA showed that the highest mechanical stress recorded within the structure was favourable with low tendency towards failure. Whilst, the results of usability testing demonstrated that the proposed product reported an increase of 52.8% in the amount of separated seeds. Thus, the new design of Kapok fibre seeds separator is found to be superior in solving the problems issued by the manual processing technique.

1. Introduction

Kapok or also known as cotton-like fluff plant can largely be found in Mexico, West Africa, Northern South America, and Southeast Asia, including Malaysia. Kapok tree is usually cultivated for its seeds and fibre which may also be referred as silk cotton, Java cotton, or ceiba. Hundreds of pods produced by a Kapok tree with each pod is generally 15-cm long. The pod contains seeds which surrounded by yellowish and fluffy fibre. The Kapok fibre is also light, resilient, resistant to water, and buoyant [1]. However, it is really flammable. The Kapok tree grows in sunny sites on the forest edges, along watercourses and in clearings in the primary forest.

Kapok fibre is processed to produce many types of daily-used product such as pillows, cushions, and hand-made mattresses. Besides, it has extensively been used in linen and fabric industries, life-saving equipment making, and walls construction. The Kapok fibre is biodegradable unlike polyester stuffing that offers similar roles [2]. Meanwhile, Kapok seeds are usually harvested for their oil. The oil smells good and it is in yellow colour, delicate, style, and not drying [3]. Harvesting the Kapok pod is considered as an intensive process. The ripe and unopened pods are picked up by knocking them off the tree. Whilst, those of ripe and opened commonly fall down to the ground or may also be harvested.
manually. They are collected at one place wherein the fibre and the seeds will then be removed from the pod and separated using bare hands.

On average, a fully mature Kapok tree yields about 15 units of fibre weight per year [2]. Small business traders of Kapok fibre still widely practices the separation of the seeds from the fibre through manual technique. The seeds are lie and loose within the fibre and fall down into the container with the aid of little shaking. This method preserves and secures high quality of the fibre as the fibre is inspected carefully. However, for a massive output production due to high demand, that could hardly be achieved because requiring high labour-intensive work, that leading to the increase in cost. Furthermore, it may result in a longer processing time as the manual separating method normally produces low-volume output which is about 1 kg per 2 hours. Safety is also another important element to be taken into account whereby the labours are highly exposed to the risk of back pain regardless of working time duration.

The present study, thus, places a major focus on the design and development of a Kapok fibre seeds separator for small business traders to overcome all the shortcomings given by the manual technique in producing high output volume. The proposed device is expected to be having an improved and effective separating mechanism, effortless skills, as well as ergonomic and safety features.

2. Materials and Methods

2.1. User Needs Determination

There were two main approaches of primary data collection implemented – interview and observation. The interview session had involved two small business traders. The outputs of the interview and observation indicated that the use of bamboo pole is still adopted to harvest the Kapok pods. Besides, the separating process was initially executed by drying the pod for approximately 3 to 4 hours, and then followed by extracting the fiber from the pod. Next, removing the seeds from the fibre using hands before storing the separated fibre in the container. No other methods used to separate the seeds owing to high cost to afford especially those of advanced machine-operated devices. In terms of operating time, the interviewees stated that the duration was about 5 to 10 minutes for one pod involving 2 to 3 labours, depending on the size of request. Also, the surrounding condition of the working area is vital which must be free from strong air movement as the fibre may easily be flown away. Mask should be worn for health safety precaution.

2.2. Product Design Specifications

After completing some assessments on the significant findings from the primary data collections, the following specifications have thus been determined: 1) operating system: motorized; 2) power source: electric; 3) separating mechanism: extracting the seeds from the fibre; 4) material: metal sheets; 5) dimension: 1000 (h) x 500 (w) x 800 mm (l); 6) weight: 100 kg; and 7) safety features: fully sealed. Then, functional analysis was performed by considering all these specifications which interpreted into a number of specific function groups through a morphological chart. Brainstorming was undertaken to develop several detailed ideas for each function [4-6,28]. As a result, a total of eight different classifications of function was established which are motor type, separating mechanism design and position, structure material, frame design, casing style, jointing type, and storing compartment design. Figure 1 shows three design concepts that were developed based on combination of different ideas for each function.

Concept A is built by steel sheets and square-shape bars as its main material and having a general dimension of 600 (w) x 400 (h) x 400 mm (l). Vacuum suction pressure is used to separate the seeds from the fibre in which the seeds will be falling down through a series of filters placed parallelly in the chamber. The operation is completely automatic with overall estimated weight of the device is 7 kg. Meanwhile, concept B focuses on the use of plastic and steel bars for the body and frame, respectively. The device is 1000 mm in the height, 500 mm in the width, 500 mm in the length, and 3 kg in the weight. It has semi-automatic operation with a support of battery. A rotating vertical barrel completed with filters is suggested for the separation purpose. Concept C is represented by a vertical chamber that made
of aluminium with approximated weight of 5 kg. The dimension of the device is 800 (h) x 400 (w) x 500 mm (l) and it is semi-automatic. The seeds are separated from the fibre by a rotating motion of rod shaft that attached with blades. Through screening and scoring evaluations, concept C recorded the highest score and it was selected for further modifications.

Figure 1. Three different design concepts of Kapok fibre seeds separator, (a) concept A, (b) concept B, and (c) concept C.

2.3. Three-Dimensional Modelling and Prototype Construction

Some significant revisions were imposed on concept C to improve its features. The enhanced concept was further transformed into a three-dimensional (3-D) model using a computer-aided design (CAD) software, SolidWorks. As a result, the final design comprises eight major parts which are frame structure, motor, seeds chamber, front cover, back cover, chamber door, filters, and separating blades. Aluminium has been chosen as the main material that constituting chamber and body casing (front and back covers), whilst other parts such as frame structure, blades, and filters are made of mild steel. The Kapok fibres are loaded into the machine through a protruded vertical open channel. The motor-operated blades will rotate and separate the fibre from the seeds. Then, the extracted seeds are filtered and directed into a chamber at the bottom side and the fibres are ready to be collected. The machine is 780, 420, and 335 mm in the length, width, and height, respectively.

A series of fabrication processes involved in producing the product prototype. Steel bars were measured and cut in appropriate size before being welded at related joints to build the main frame. Aluminium sheets were then installed onto the frame using rivets with suitable size. Large rivets may induce high force resulting in considerable indentation on the aluminium surfaces, hence, they were avoided. Last phase was the finishing wherein the aluminium surfaces were thoroughly cleaned and coated with coloured spray. Figure 2 illustrates the 3-D model and prototype of the product.
2.4. Computational Analysis Pre-Processing Settings

A prediction on the structural performance of the main frame was performed via computational analysis using finite element method. Finite element analysis (FEA) promotes a promising role in solving mathematical modelling problems in numerous areas of technology, science, and industry [7-31]. All CAD files of the product were exported into a FEA software in ACIS file format (.sat). The elastic modulus and Poisson’s ratio of mild steel with the value of 300 GPa and 0.3 [32,33], respectively, were assigned to the model and assumed as homogenous, linearly elastic, and isotropic. A pressure magnitude of $6.08 \times 10^{-4}$ N/mm$^2$ in downwards direction ($y$-axis) was applied onto the flat surface of the frame indicating the weight of two electric motors and full loading of the fibres. Meanwhile, for the boundary condition, the bottom surface of all six frame legs was fixedly constrained. All part models were meshed with four-node solid tetrahedral elements with the size of 11.0 mm. Accordingly, the total number of node and element are 23,563 and 12,253, respectively.

3. Results and Discussions

3.1. Equivalent von Mises Stress Results

Two main approaches used to present the results of equivalent von Mises stress which are magnitude and distribution (colour spectrum scale). High stress value is represented by grey colour band, whilst low stress value is represented by the one of blue colour. The findings demonstrated that the maximum level of stress was 0.3 MPa, generated within one of the frame legs specifically at the connecting part. This could be due to the location of the leg that close to the main region of the loading when compared to other parts. Besides, the adjacent distance among the four legs supporting the weight as well as large surface area have also led to the high stress concentration. Minimal stress magnitude in the opposite side could be explained by the adequate yet sufficient surface regions for the mechanical stresses to be dissipated. This is also substantiated by those regions depicted bluer colour than the greatly-stressed locations. Figure 3 illustrates the highest magnitude of equivalent von Mises stress and its corresponding location recorded within the frame model.
Figure 3. The maximum value of von Mises stress of 0.3 MPa located at the connecting joint of the frame leg.

It is important to note that the maximum stress (0.3 MPa) in the frame was considerably lower than the yield (250 MPa) and ultimate tensile (841 MPa) strength values of mild steel [32,34] approximately 99.88 and 99.96%, respectively. This determines that the proposed design of Kapok fibre seeds separator does not prone to failure under the application of such loading. The connecting joints or junctions of the leg with high stress intensity, nevertheless, can be reduced by adding fillet features.

3.2. Usability Testing Results

The actual testing on the usability of the prototype was conducted to compare the amount of Kapok fibre seeds collected within a certain period of time between the proposed product and the manual separating technique. The results showed that the proposed separator recorded a greater amount of the seeds (36) being about 52.8% increase than the existing manual approach (17) in 3 minutes of working operation. Furthermore, the increase in working time operation has increased the number of the pods to be processed accordingly. Our findings evidenced that in 15, 40, and 80 s, there were 1, 2, and 3 pods, respectively, have successfully been processed.

4. Conclusions

The results of this study support the following conclusions. The proposed Kapok fibre seeds separator was observed to be favourable in separating the seeds from its fibre as compared to the traditional method. The highest mechanical stress level of 0.3 MPa generated within the main frame seemed to result in low tendency towards failure. Moreover, the amount of the extracted seeds was evident to significantly be improved for about 52.8% by the use of new Kapok fibre seeds separator. Therefore, this separator is realised to be able to eliminate the limitations of the existing manual separating technique.

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