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FEA Technique for Design and Simulation of Sisal Decorticator Raspador

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ABSTRACT

Finite element analysis (FEA) is a computational technique used to provide the numeric solution of complex structures by dividing them into small elements using various partial differential equations. In agriculture, the numerical simulation based on the FEA technique allows the engineers to study the behavior of various input products to optimize the design of any machine without developing a prototype. The present study focused to design and simulates the sisal decorticator raspador by employing the FEA technique. For this purpose, a 3D-CAD model of sisal decorticator raspador was developed using the Creo Parametric design software and a static structural test using the FEA technique was performed in the ANSYS version 15.0 workbench software. To compute the force required to scrap the pulpy material of the leaves in the Universal Testing Machine, a special fixture has been developed. The simulated results predicted that maximum deformation was observed as $8.09e^{-7}$ m while maximum shear stress and Von-Mises equivalent stress were found to be $1.30e^{5}$ Pa and $2.48e^{5}$ Pa, respectively at 250 N scraping forces. It was also observed that stress values are within the yield strength of the material. Hence, FEA technique was found to be a scientific and very effective approach for design and simulating the sisal decorticator raspador.

Key Words: ANSYS, Total deformation, Von Mises equivalent stress and FEA.

INTRODUCTION

Sisal (*Agave sisalana*) is an important fibrous plant of Agavaceae family and belongs to the genus Agave. Sisal is originated from Mexico, later widely cultivated in Brazil, China, Kenya, Tanzania, Madagascar and Mozambique (FAO, 2013). In India, sisal plants are majorly cultivated on the bunds, embankments, and roadsides for serving the purpose of soil conservation and for the protection of main crop as hedge plantations (Saxena *et al*, 2011). In India, total area under sisal cultivation comes to approximately 0.007 Mha. The total production of sisal plants is approximately1000 tons with a productivity of around 145 kg/ha in 2017-18 (Naik and Baite, 2018). In India, sisal plants are majorly cultivated in the states of Orissa, Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Bihar, Jharkhand, Maharashtra, Karnataka, and Tamilnadu (Sinha *et al*, 2009) in which Orissa is having highest area and productivity followed by Andra Pradesh (Naik and Baite, 2018).

The sisal plant has a shallow root system and has a life of 7-10 years. Harvesting of sisal starts after 2.5 yr and is subsequently cut after 5-12 m (Ahmad *et al,* 2017). After harvesting, fibre must be extracted on the same day or within 48 hr to avoid deterioration (Ahmad *et al,* 2017). The conventional practice of fibre extraction involves scraping away the pulpy matter manually with a blunt knife. Besides, people of the sisal growing area also sometimes prefer thin ribbons and hot water boiling of sisal leaves to separate pith matter from fibre (Naik *et al*, 2013) which are then washed and dried. These methods are characterized as time-consuming, cumbersome, unhygienic, low production, low quality and not practical on a

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large scale (Naik *et al*, 2013). Moreover, the acidic sap released during manual decortication causes skin irritation and discomfort. To overcome these drawbacks, different companies have developed a mechanical sisal decorticator having a raspador type of cylinder to beat and scrap the leaves. However, the decortication cylinder is fabricated by assuming/selecting material available at a cheaper rate. The prototype of the cylinder might be a weak or heavy structure. Calculating maximum stress and optimum material consumption not only improves the efficiency of the machine, but also reduces the breakage and excess load on the prime mover.

Finite Element Analysis (FEA) or Finite Element Method (FEM) is a numerical technique that segregates complex structures into a number of small elements and approximate solutions to boundary value problems for algebraic equations (Zienkiewicz *et al,* 2013). The origin of FEA cannot be predicted accurately, but its gaining popularity nowadays due to advancements in computer technology. This technique works on the principle of formulating the hypothetical equations of the problem and solving them, distinct the domain area of the problem, and computing the variables of interest (Velloso *et al*, 2018). FEA allows the engineers or developers to investigate the behavior of various input materials before developing the mechanical prototypes, thus assisting both in the manufacturing process and in monitoring the feasibility of use and detecting possible usage or material failures. There are numerous software available in the market like AutoCAD, CREO, ANSYS, SolidWorks, CATIA etc. to design and simulate any mechanical component of the whole body. These have different functions that are used by specific fields for specific purposes. Out of these, ANSYS is the most powerful and popular software among the engineers' community, to perform the finite element analysis to get numerical solutions to a wide variety of mechanical problems. These problems include static/dynamic, structural analysis, heat transfer, and fluid problems, as well as acoustic and electromagnetic problems.

Although the finite element method is popular in the mechanical design industry, its application in agricultural machinery design is yet to gain phase. Furthermore, the literature on FEM in the fibre extraction machinery is scarce. According to the review survey, only one researcher employed a FEM to hemp processing equipment for optimizing the parameters (Olan *et al*, 2020). Unlike other machinery, fibre processing machinery must be studied with FEA method to ensure optimum design. The present study aimed to design a 3D model of sisal decorticator raspador and simulate it using the FEA technique to investigate the suitability of the design for the development.

MATERIALS AND METHODS

A sisal decorticator was designed and simulated by employing the Creo Parametric (version 7.0) and ANSYS workbench (version 15.0) software and fabricated at ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata. The major components included prime mover (electric Motor), frame, feeding chute, raspador (cylinder) with blunt blades, conveying system and breastplate (cuttingplate). These components were fabricated using the mild steel (MS) because of its various physical and mechanical properties suited for design, cheap, and readily available everywhere.

Theoretical design of sisal decorticator raspador

The Raspador (Cylinder) is the most important component of the sisal decorticator. The main principle of operation of the raspador is to apply impact force on leaves and scrap the pulpy material from the sisal plants. When a sisal leaf is inserted between the raspador blades and concave through breastplate, then due to beating principle, the beater blades progressively crush the leaf at closely spaced intervals and chip off it against the breastplate until the leaf comes out the beating zone of raspador. Due to impact force of blades, the parenchyma cells and vascular tissues of the leaf becomes softened and finally, continuous beating action scraps away the pulpy material from leaves and reveals the fibrous material. The working principle of raspador is shown in Fig. 1. Therefore, for developing the actual prototype of raspador, a 3D CAD model has been designed and developed on the basis of theoretical calculation as described by below.

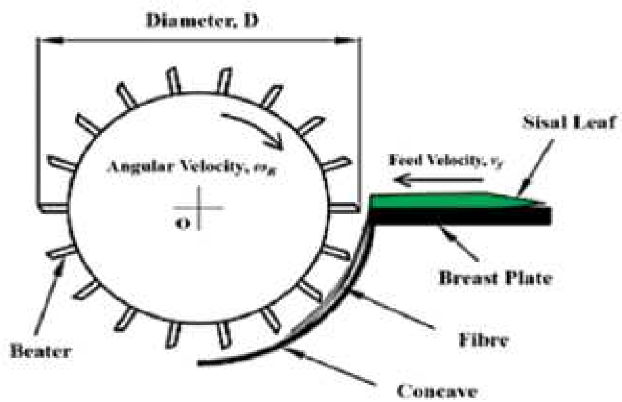

Figure 1. Principle of operation on sisal decorticator raspador (cylinder)

In order to get optimum scraping, it has to rotate with some standard rpm which develops angular momentum at tip of the blade. The angular momentum developed at the tip of the beating blade computed using the Equation 1as suggested by Ahmad *et al*., (2017)

Where, = angular momentum, kg.m^2/s, = linear velocity at the tip of blade, m/s, = Diameter of the raspador, m, and = unit mass of the raspador, kg

The quantity of the material scrapped off with raspador blades can be determined by pitch lengthrequired for decortication (Ahmad *et al*., 2017) by using the Equation.

Where, =pitch length required for decortication, mm, = feeding velocity of leaf, mm/s, = angular velocity of raspador, rad/s, and = number of blades on the periphery of raspador

The length of the raspador was calculated by using the Equation as described by the Varshney *et al.,*(2006).

Where,=Length of cylinder, (m), =Material feedrate; (kg/s),=Thickness of the plant mass layer at the entrance in meter, =Coefficient of cylinder length utilization (0.7-0.8),=Bulk density of plant mass entering and =Velocity of plant mass entering (1-2 m/s assumed).

After designing the decorticator raspador using the theoretical equations and CAD model was made in Creo Parametric 7.0 software as shown in Fig. 2. The raspador was designed by considering the decortication capacity of about 300 kg/h. The diameter of the raspador is 300 mm with raspador shaft of 30 mm. The overall length of the cylinder was 800 mm. The raspador has 20 beater blades on its periphery.

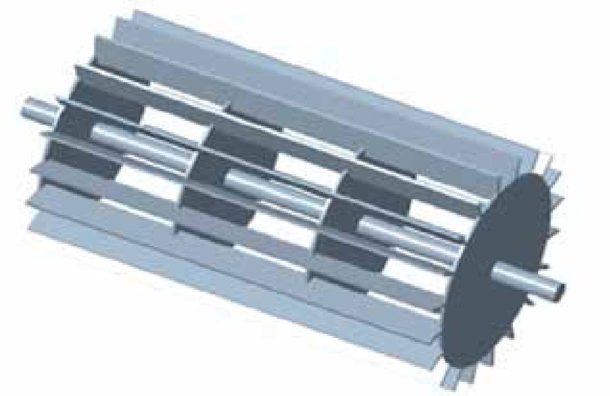

Figure2. 3D CAD model of the sisal decorticator raspador

Measurement of tensile force required to scrap a sisal leaf using UTM

The tensile test to measure the force required to scrap the pulpy material from the sisal leaves for simulation of a 3D model of raspador (cylinder) was performed in the Universal Testing Machine (INSTRON 4411).Before tests, according to the distribution of venations, different pieces of sisal leaves were cut from the middle portion of leaves into rectangle shapes of 150 mm × 50 mm and the thickness was measured by a vernier caliper. To prevent the samples from damaging in the universal testing machine, a pair of rubber fixtures was fixed on the clamps. After that tensile force was exerted to the samples along the direction of venation growth and the test was repeated on 30 samples. The mean of samples was calculated and recorded. In these

Table 1. Mechanical Properties of Mild steel.

Sr. No	Property	Value	Reference
1	Elastic modulus	210 GPa	Kreith, 1999
2	Poisson's Ratio	0.3	Norton, 2006
3	Density	7850 kg/m^3	Kreith, 1999
4	Tensile Yield strength	320 Mpa	Chapman, 1972
5	Tensile ultimate strength	400 MPa	Chapman, 1972

tests, the velocity for applying the tensile force was maintained as 6 mm/min (Read and Sanson2003), and the resulted stress versus strain results was recorded using the Bluehill® Universal software. Then the ultimate strength of each sample was computed by the using the given Equation (Wang *et al,* 2010)

Where,= ultimate strength, N/mm^2= maximum pulling force, N and = cross-sectional area of sample (leaf), mm2

Finite Element Analysis of the raspador

The main user interface shows wide range of analytical system after launching ANSYS Workbench. Since, main objective of this study was to examine the structural stress analysis of the raspador (cylinder), therefore Static Structural Analysis (SSA) tool was selected. The material used for construction of cylinder is MS and properties of MS not available in the existing library. Therefore, it is essential to create a new material library with isotropic elasticity and density options. The properties of MS used in the analysis are shown in Table 1. The next important step of FEM is to define the geometry, for this previously developed CAD model was imported through design modeler which is a parametric geometry modeler. The main advantage of design modeler is easy manipulation of existing geometry. After that meshing was done to perform the accurate simulation using FEA. A mesh was created using the elements which contain the various nodes (coordinate locations in space that can vary by element type) that represent the shape of the geometry. The default meshing option was opted. The boundary conditions of the model need to be carefully applied on to model in analysis setting. The force required to scrap the pulpy material from the sisal leaves were measured and found to be 250 N for three leaves. Two sides of the cylinder were selected as a fixed support and load was applied on the raspador of the cylinder vertically. After applying the boundary conditions, static structural simulation was carried for selected parameters like total deformation, equivalent stress, principal stress, shear stress.

RESULTS AND DISCUSSION

Total deformation

Total deformation of the model indicates the portion where maximum force and bends occur. It also includes that how much reaction force required to bend a material. Furthermore, it is used to obtain the displacement from applied stress. Summation of square of all the directional *i.e*., x, y and z gives the total deformation of the model. The colour red and blue indicates maximum (8.09 e^{-7} m) and minimum (0 m) deformation (Fig. 3). It was evident from the results that maximum deformation was observed in centre where the leaves undergo beating and scrapping. The analysis showed that maximum deformation is at centre of raspador model. The raspador model made of mild steel has less deformation than the yield point of the material (Khurmi and Gupta, 2005)

Maximum Shear Stress

The breakdown of material depends on the maximum shear stress of the product. The colour chart of the model indicates maximum and minimum shear stress. The maximum shear stress was found

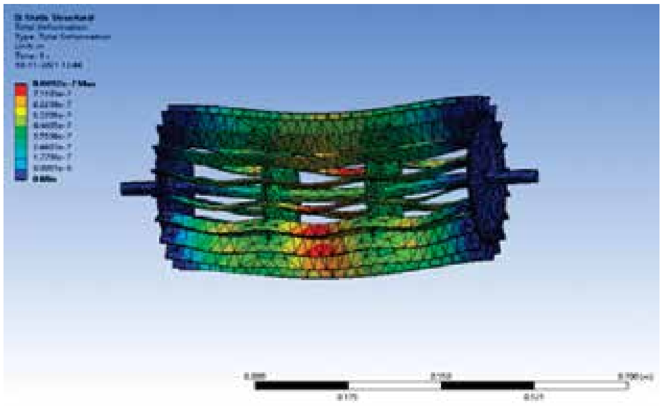

Figure3. Total deformation of the model

to be 1.30 e^5 pa while minimum as 0.02 pa (Fig. 4). The maximum shear stress of model is lower than its shear stress (200-300 MPa) (Khurmi and Gupta, 2005) which shows that deformation does not cause much failure on the raspador.

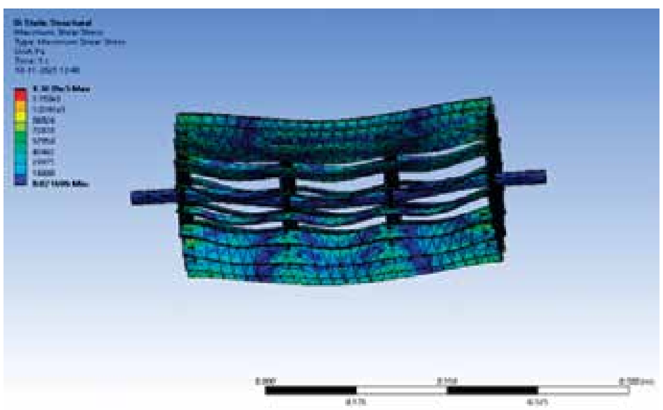

Figure4. Maximum Shear Stress

Equivalent stress (Von Mises)

Equivalent stress is computed to estimate yield failure criteria in ductile materials as shown in Fig. 5. The maximum equivalent stress was found to be 2.48 e^5 Pa whereas the minimum was found as 0.03 Pa. Jakasania *et al* (2016) conducted the similar study and suggested that, in designing model, working stress should take the lower than the maximum or ultimate stress at which failure of the material take place. The maximum value of the equivalent stress is within the limit, so model is safe (olan *et al*, 2020).

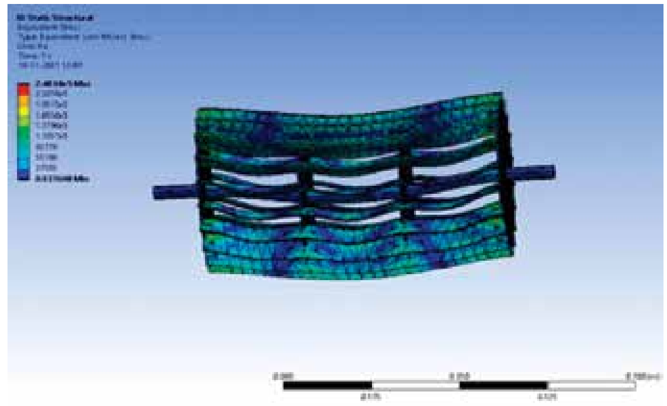

Figure5. Von Mises equivalent stress

CONCLUSION

To Design and Simulation of Sisal Decorticator Raspador, a 3D CAD model was designed in the Creo Parametric design software and static structural analysis was carried out in the ANSYS version 15.0 workbench software. To compute the force required to scrap the pulpy material of the leaves in Universal Testing Machine, a special fixture has been developed. The simulated results predicted that maximum deformation was observed as 8.09e^{-7} m while maximum shear stress and Von-Mises equivalent stress were found to be 1.30e^5 Pa and 2.48e^5 Pa respectively at 250 N scraping force. It was also observed that stress values are within the yield strength of the material. Hence, FEA technique was found to be a scientific and very effective approach to design and simulate the sisal decorticator raspador and on the basis of that a prototype of sisal leaf decorticator can be developed.

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